VOLUME I. ENGINEERING REPORT

DRILLING AND TESTING OF THE DEEP INJECTION WELL SYSTEM AT NORTH PORT, FLORIDA

Prepared for
GENERAL DEVELOPMENT UTILITIES, INC.
Miami, Florida

TM

Prepared by

CH2M HILL

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GDU Work Release No. 1538

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EXECUTIVE SUMMARY

GDU has successfully completed the drilling and testing of the North Port DIW system in accordance with TAC recommendations and the FDER permit requirements (Settlement Agreement). Construction of the DIW system began January 1987 and was completed by January 1988. Operational testing of the facility has been ongoing since January 1988.

The DIW system consists of a 14-inch DIW, a 6-inch dual-zone onsite monitor well, and a regional monitor well. A total of 1,105 feet of 14-inch seamless steel casing was installed at the DIW with an open hole from 1,105 feet to 3,200 feet. The dual-zone onsite monitor well consisted of 6-inch FRP to 730 feet with an open hole to 750 feet, and an open annulus from 551 to 600 feet. This well is located approximately 80 feet from the DIW. A regional monitor well was constructed approximately 4,150 feet from the DIW and consist of 1,100 feet of 6-inch FRP casing with an open hole to 1150 feet.

Hydrogeologic formations penetrated while constructing the DIW indicated that this zone would be suitable for deep well injection. A good confining layer was found separating a very productive injection zone from overlying sources of drinking water (TDS $\leq$ 10,000 mg/l). The major injection zone penetrated extended from approximately 1,120 feet to 1,640 feet in depth.

Water quality results from reverse-air drilling, hydraulic testing, and straddle packer testing suggest that this location is suitable for the disposal of secondary treated effluent. The 10,000-mg/l TDS interface is estimated to occur between 551 and 600 feet in depth. Water quality deteriorated rapidly with depth below this point, with the injection zone having a TDS concentration ranging from 25,000 to 36,000 mg/l. The TDS concentration of seawater is approximately 35,000 mg/l.

Coring and straddle packer tests conducted during the testing program show that good confinement exist between the 10,000-mg/l TDS interface and the top of the injection zone. The composite vertical permeability, using the Sinclair (1974) method, is estimated to be 0.058 ft/day. This value is low and is indicative of a good confining unit, and within the range of values reported for the Ocala Group at other locations.

Vertical travel time has been calculated to estimate the time required for injected fluids to reach the 10,000-mg/l TDS interface using data collected during the drilling and testing phase. It is estimated that it will take 347 years for the injected fluid to travel vertically and reach the 10,000-mg/l TDS interface.

Two separate mechanical integrity tests were performed to confirm the integrity of the DIW construction. The internal mechanical integrity was tested using a casing pressure test. This test was successfully conducted by pressurizing the 14-inch casing and monitoring for pressure drops. The DIW was able to hold a constant pressure for one hour without any pressure drop. A radioactive tracer survey was also conducted to check the external mechanical integrity of the cement seal around the outside of the bottom of the casing. A radioactive tracer was released at the bottom of the casing and a gamma ray tool monitored the movement of the tracer as fresh water was injected in the DIW. There was no vertical movement detected throughout this test. The external mechanical integrity was determined to be in good condition.

A 24-hour pumping test was conducted at the DIW using the RMW as a monitor well to measure water levels. Results from this pumping test show that very productive zones were penetrated at the injection well. These zones have an estimated transmissivity of 1,900,000 gpd/ft. This shows that the injection zone can receive high flows at relatively low injection pressures making deep well injection suitable for this area. The high transmissivity value estimated from the 24-hour pumping test is similar to the transmissivity values estimated from several other single well pumping tests conducted during the construction of the DIW.

Modeling was performed to estimate the movement of the injected fluids in the surrounding areas, especially Warm Mineral Springs. Two alternatives were modeled: one with an average injection rate of 2.3 mgd and one with an injection rate of 4.76 mgd, which is equivalent to the maximum injection rate permitted for a 14-inch casing. The minimal effects shown in the 2.3-mgd run, coupled with the fact that no apparent hydraulic connection was detected between Warm Mineral Springs and the injection zone during this study, suggest that the effluent in the injection zone would simply move downgradient with the regional flow. The second scenario predicts that the injected fluids may reach the area of concerns after continuous pumping at 4.76 mgd. It is very unlikely that the well will be operating at 4.76 mgd since the WWTP capacity is much less. The model assumes that Warm Mineral Springs originated from the same zone as the DIW.

Monitoring at Warm Mineral Springs during operational testing of the DIW system has not shown any impact on the Springs from the DIW. Temperature, conductivity, and water levels were measured continuously throughout the drilling and testing of the DIW system. Monthly sulfate and chloride water samples were also collected. Results of the monitoring showed that there has been no apparent impact on Warm Mineral Springs. Only the pumping test conducted while testing the DIW from 560 to 854 feet showed a slight hydraulic effect at the spring. The effects from this test were minimal and no other impact was noticed while testing below this depth. The DIW is cased to 1,105 feet, far below this depth.

Operational testing of the North Port DIW system began in January 1988 and has continued through the present. The system appears to be operating as planned and no significant problems have developed as a result of injection. Average injection rates have been approximately 382 gpm at injection pressures of approximately 14.6 psi. No significant increases in injection pressures, monitor well pressures, or flows at Warm Mineral Springs have occurred as a result of injection at the DIW.

CH2M HILL's recommendations regarding the operation of the North Port DIW system follow. These recommendations have been proposed after careful review of the drilling and testing data, including operational testing data.

1. Continue operation of the North Port DIW permanently in accordance with the proposed monitoring schedule.

2. Monitor the DIW for the following parameters:

   - Injection wellhead pressure (psi)/continuously
   - Daily flow rate (gpm)/continuously
   - Total flow volume (gallons)/daily

3. Monitor the OMW shallow and deep zones and the RMW for the following parameters:

   - Wellhead pressure (psi)/continuously
   - Conductance (μmhos/cm)/monthly
   - Total dissolved solids (mg/l)/monthly
   - Chloride (mg/l)/monthly
   - Sulfate (mg/l)/monthly
   - Fecal coliform (#/100 ml)/monthly
   - Complete primary and secondary drinking water standards/annual

4. Monitor the WWTP effluent for the following parameters:

   - pH/weekly average
   - BOD5/weekly average
   - Suspended solids/weekly average

5. Monitor Warm Mineral Springs for the following parameters:

- Temperature (°C)/continuously
- Conductance (μmhos/cm)/continuously
- Spring pool water level/continuously
- Stream gaging/quarterly
- Chlorides (mg/l)/monthly
- Sulfate (mg/l)/monthly
- Rainfall (inches)/daily at Warm Mineral Springs

CONTENTS

CONTENTS, Continued

TABLES

TABLES, Continued

FIGURES

FIGURES, Continued

ACKNOWLEDGEMENTS

The Florida Department of Environmental Regulation (FDER) Technical Advisory Committee (TAC), comprising representatives of the FDER, U. S. Environmental Protection Agency (EPA), Southwest Florida Water Management District (SWFWMD), and the United States Geological Survey (USGS), reviewed the work performed and provided technical interpretation of the settlement agreement throughout all phases of the project. The following people played key roles in the execution of the project:

- Dr. Richard Garrity, Mr. Gardner Strasser, and Mr. Joe Haberfeld, FDER
- Mr. Craig Hutchinson, USGS
- Mr. Gene Coker and Mr. John Mason, EPA
- Mr. David Slonena and Mr. Eric Eshom, SWFWMD
- Mr. Clark Niewendorp and Mr. Rick Steele, Sarasota County
- Mr. Jay Landers, Esq., Landers, Parsons & Uhfelder
- Mr. Sam H. Herron, Jr., Warm Mineral Springs
- Mr. Russell J. Kerrn, Mr. Brent Collins, and Mr. Hubert Pippin, and drilling crew of Alsay, Inc.
- Mr. Steve Uhrick, Mr. F. Ray Bailey, Mr. Dave Waldie, Mr. Chris Livolsi, and Mr. Bob Proctor, General Development Utilities

Section 1
INTRODUCTION

1.1 PROJECT DESCRIPTION

General Development Utilities, Inc. (GDU), owns and operates the North Port Wastewater Treatment Plant (WWTP), which serves the community of North Port in Sarasota County, Florida. The WWTP consists of two contact stabilization process trains operated in parallel, referred to as Plant 1 and Plant 2. Both plants have common units such as chlorination, effluent storage, effluent pumping, and sludge dewatering. Each plant operates in the contact stabilization mode of the activated sludge process and has separate units for the influent pumping, chlorine contact, clarification, stabilization, and aerobic digestion. The total present capacity of the WWTP, as permitted by Florida Department of Environmental Regulation (FDER), is 0.95 million gallons per day (mgd).

The secondary treated effluent was historically disposed by land application, using both overland flow with eventual discharge to surface waters and spray irrigation. Secondary treated effluent that could not be spray irrigated was trucked to a nearby WWTP for disposal. At that time, a deep injection well (DIW) at North Port was being tested for supplementary disposal of the treated effluent as recommended in the report entitled <u>Engineering Study of the Wastewater Treatment and Effluent Disposal at the North Port Wastewater Treatment Plant</u> (CH2M HILL, March 1985). Irrigation on adjacent golf courses was the preferred option.

This report presents the results of the drilling, testing, and associated environmental monitoring of the North Port DIW system, including the data collected before and during operational testing of the DIW system. A 14-inch-diameter DIW, a 6-inch-diameter dual-zone onsite monitor well (OMW), and a 6-inch-diameter regional monitor well (RMW) were constructed and tested as part of the DIW system. All of these wells are located in Sarasota County.

The RMW was constructed in response to concerns regarding an environmentally sensitive area, Warm Mineral Springs, which is located approximately three miles from the DIW site. The proximity of Warm Mineral Springs to the DIW prompted Sarasota County, Warm Mineral Springs, Inc., and others to file a petition against the planned construction of the DIW. An out-of-court settlement agreement was reached and a modified program proceeded.

Construction of the North Port DIW system began in January 1987 and was completed in January 1988. Operational testing was authorized by FDER upon completion of the drilling and testing; operational testing began on January 21, 1988.

Copies of the construction permit including the settlement agreement and the authorization to commence operational testing are included in Appendixes A and B, respectively. The following sections of this report describe the results of drilling and testing program for the North Port DIW system.

1.2 INVOLVEMENT OF REGULATORY AGENCIES

Regulatory agencies play a key role in the drilling and testing of any deep injection well. In the case of the North Port DIW, the agencies' role was even more involved because of the provisions of the settlement agreement. The settlement agreement included many criteria requiring concurrence from a Technical Advisory Committee (TAC). The TAC is a group of representatives from regulatory agencies that provides advice and assistance on technical aspects of the DIW system to FDER, the permitting agency. The TAC includes representatives from the following agencies:

- FDER Tampa Office
- FDER Headquarters, Tallahassee
- Environmental Protection Agency (EPA), Region IV, Atlanta
- Southwest Florida Water Management District (SWFWMD), Brooksville
- United States Geological Survey (USGS), Tampa

Following the out-of-court settlement, FDER issued a permit on January 15, 1987 (Permit No. UC58-110617) to construct a Class 1 test/injection well. FDER issued authorization to begin operational testing on January 19, 1988.

CH2M HILL kept members of the TAC informed of drilling and testing activities through the duration of this project by periodic meetings, weekly progress reports during construction, and monthly transfer of data collected during operational testing.

Section 2
CONSTRUCTION AND TESTING ACTIVITIES

2.1 SITE DESCRIPTION

The North Port DIW and the OMW are located just west of Campbell Street in Sarasota County in the northeast corner of Section 12, Township 40 South, and Range 20 East. The DIW is located at latitude 27°00'57" and longitude 82°15'26", while the OMW is located at latitude 27°00'58" and 82°15'26". The RMW is located in Section 1 of the same township and range at latitude 27°01'39" and longitude 82°15'20". The locations of the DIW, OMW, and RMW are shown in Figure 2-1.

A 16-inch-diameter pipeline connects the DIW with the North Port WWTP, which is approximately two and one-half miles from the DIW site. Warm Mineral Springs is located approximately three miles from the DIW site.

A major consideration in locating the DIW was the proximity of a borrow pit containing brackish water, where water produced during drilling and testing activities could be discharged. Water produced during drilling and testing went through a series of settling basins to control turbidity before discharge into the borrow pit. A silt curtain was also installed around the discharge point as a precaution to keep suspended solids discharge to a minimum. With open circulation drilling and testing of the DIW and OMW, CH2M HILL was able to collect more representative water quality data since native water is not recirculated within the borehole as is done with closed circulation. These techniques also allowed for a more quantitative hydraulic testing program than could be accomplished under a closed circulation drilling program.

As requested by TAC, the OMW is located within 100 feet of the DIW. It is situated approximately 80 feet north and on the same drilling pad with the DIW, as shown in Figure 2-2. The OMW is used to monitor for any vertical movement of the injected fluids through the overlying confining beds.

The RMW was constructed to monitor the regional movement of injected fluids in the injection zone between Warm Mineral Springs and the DIW. CH2M HILL suggested the well be located midway between the DIW and Warm Mineral Springs, near the old effluent disposal facility, which is connected to the WWTP. This location was conducive to open circulation drilling during construction and provided an available disposal point during future water sampling. The TAC requested that the well be located closer to the DIW to provide earlier detection of horizontal movement of injected

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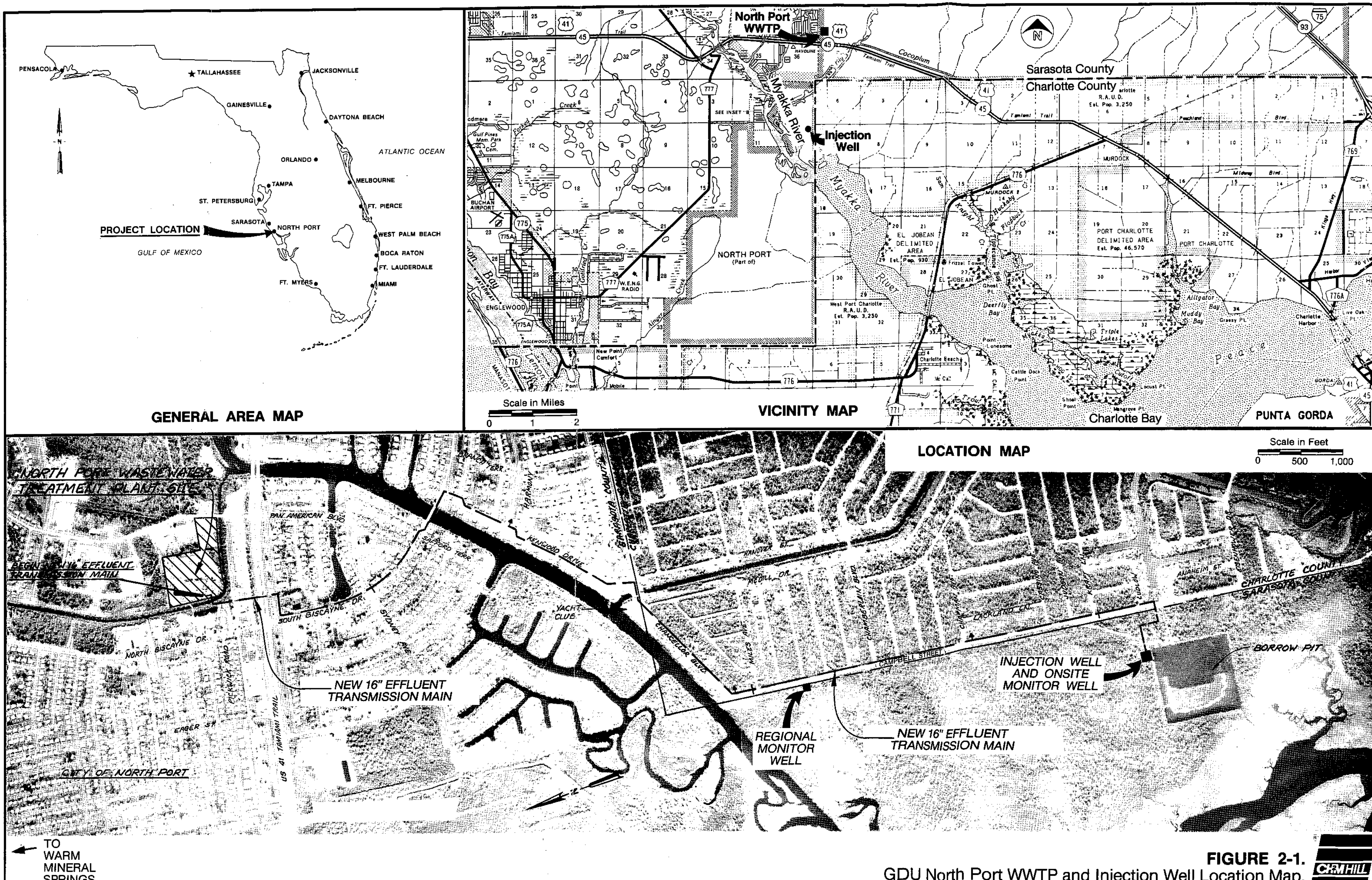

FIGURE 2-1.
GDU North Port WWTP and Injection Well Location Map.

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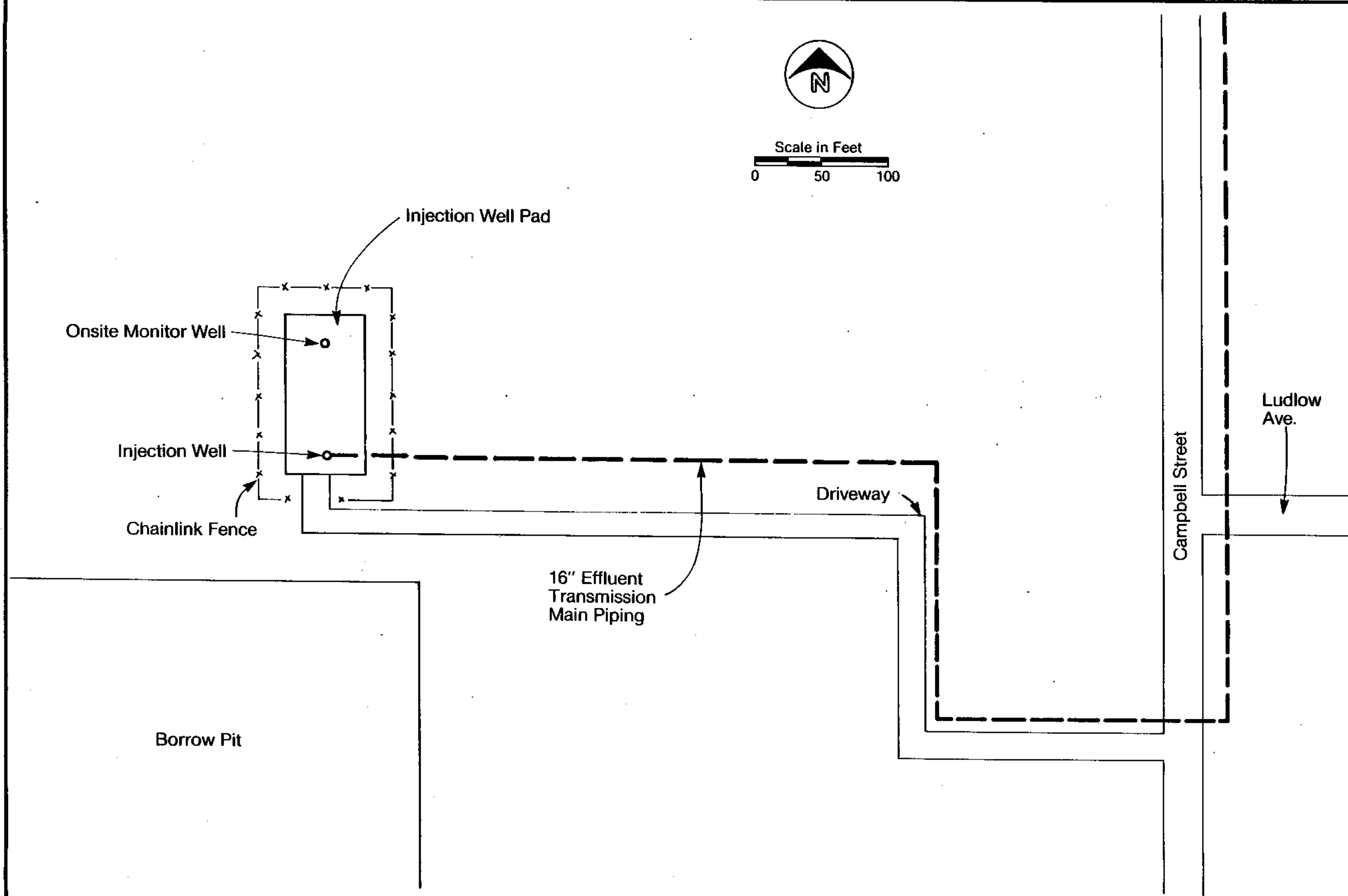

FIGURE 2-2.
North Port Injection Well Site Layout.

fluids toward Warm Mineral Springs if such movement were to occur. Accordingly, the well was constructed on GDU property approximately 4,150 feet north of the DIW. The final location of the RMW was approved by the TAC.

2.2 DEEP INJECTION WELL

The test/injection well was constructed approximately two and one-half miles south of the North Port WWTP to investigate the feasibility of disposal of secondary treated effluent by deep injection wells. A 3,200-foot DIW with 1,105 feet of 14-inch-diameter final casing string was constructed and tested in accordance with Chapter 17-28 Florida Administrative Code (FAC), the settlement agreement, and directions issued by the TAC. In response to concerns about potential environmental impacts, an extensive monitoring system was established. This system consists of a dual-zone OMW adjacent to the DIW and a RMW between the DIW and Warm Mineral Springs. Monitoring is also conducted at Warm Mineral Springs.

GDU awarded the drilling contract to Alsay Inc. from Fort Pierce, Florida; this firm constructed all three wells. CH2M HILL designed the wells and provided resident observation and services during construction and testing activities. Construction activities began in January 1987 and were completed, except for operational testing, in December 1987. Data gathering from the operational testing is expected to last a minimum of 6 months.

Construction and testing of the DIW was performed in several stages as discussed below. Details of the lithology and the testing are presented in Section 3. A chronological schedule of the drilling and testing activities of the North Port DIW system is shown in Table 2-1.

Alsay received notice to proceed on the North Port DIW system on January 28, 1987. Shortly thereafter, the site was cleared and an access road to the DIW site was constructed. Surface casings for the DIW and the OMW were installed by vibrating the casing into the first competent geologic formation. Approximately 26 feet of 42-inch-diameter and 27 feet of 36-inch-diameter surface casings were installed at the DIW and OMW, respectively. Copies of casing mills certificates are included in Appendix C. An 80-foot by 120-foot concrete drilling pad was poured on February 21, 1987, to support the loads anticipated during drilling and to contain any spillage of fluids that might occur during drilling and testing activities.

Two shallow water table wells were installed near the northwest and southeast corners of the drilling pad. These wells were constructed to monitor potential water quality

Table 2-1
NORTH PORT DIW SYSTEM CONSTRUCTION AND TESTING SCHEDULE

Construction Activity	Date
FDER construction permit issued	January 15, 1987
Award of construction contract/notice to proceed submitted to drilling contractor (start date of 1/28/87)	January 21, 1987
Official project start date; Alsay, Inc., mobilized for the DIW	January 28, 1987
SWFWMD construction permit issued	February 5, 1987
Set 42" diameter surface casing (26')	February 10, 1987
Poured concrete drilling pad DIW	February 21, 1987
Completed 12" diameter exploratory hole to 598'	March 19, 1987
Reamed exploratory hole to 560' (42" dia)	April 7, 1987
Set and cemented 34" casing (560')	April 7, 1987
Conducted hydraulic test 560-850'	April 14, 1987
Conducted hydraulic test 560-1,100'	April 19, 1987
Conducted hydraulic test 560-1,200'	April 22, 1987
Ran packer tests	April 23-26, 1987
Conducted hydraulic test 560-1,600'	May 5, 1987
Set and cemented 24" casing (1,100')	May 13-15, 1987
Conducted hydraulic test 1,100-2,000'	May 26, 1987
Drilled and cored to 3,200'	May 27-June 4, 1987
Conducted hydraulic test 1,100-3,200'	June 5, 1987
Awaited TAC decision on depth of 14-inch casing	June 8-30, 1987
Set and cemented 14" casing (1,105')	August 4, 1987
Mobilized on OMW	July 10, 1987

Table 2-1
(continued)

Construction Activity	Date
Set and cemented 12" casing OMW (551')	July 17, 1987
Set and cemented 6" casing OMW (730')	August 26, 1987
Located RMW	July 29, 1987
Completed OMW	August 29, 1987
Awaited permit on RMW	September 3-16, 1987
TAC meeting	October 8, 1987
Poured concrete drilling pad at RMW	October 13, 1987
Set and cemented 16" casing RMW (560')	October 29, 1987
Set and cemented 6" casing RMW (1,100')	November 8, 1987
Completed RMW	November 12, 1987
Conducted 24-hour pumping test	November 23, 1987
Conducted radioactive tracer survey	December 7, 1987
Completed DIW	December 8, 1987
TAC meeting	December 17, 1987
FDER authorized operational testing	January 19, 1988
Conducted short-term injection test	January 21, 1988
Began operational testing data gathering	January 22, 1988
End of operational testing data gathering for engineering report	July 21, 1988

changes in the water table aquifer resulting from the drilling activities. Details of these wells are presented in Section 2.5.

Monitoring of Warm Mineral Springs began in March 1987 in accordance with the final settlement agreement and as directed by the TAC. Flow, conductivity, and temperature were measured continuously, while chlorides and sulfates were recorded monthly.

Drilling at the DIW began with a nominal 12-inch-diameter exploratory hole drilled using mud circulation drilling methods to approximately 598 feet below land surface (bls). Representative formation samples were collected at 5-foot intervals during drilling to identify the lithology encountered. Gamma ray, caliper, and LSN geophysical logs were run to a depth of about 570 feet on March 20, 1987. A summary of all the geophysical logs run at the DIW is shown in Table 2-2.

After logging, the 12-inch exploratory hole was reamed to 42 inches to an approximate depth of 560 feet. A total 560 feet of 34-inch diameter steel casing was then installed and cemented in place. Cementing of the casing was accomplished by pressure-grouting from the base of the casing to pad surface. This process required a total of 946 sacks of 4-percent bentonite cement followed with 274 sacks of neat cement. The cement was placed in a single stage with cement returns at pad surface. The casing was shut-in for 24 hours to allow the cement to set. A summary of the casing and cement schedule is presented in Table 2-3.

Drilling methods were changed from closed circulation drilling with mud to reverse-air open circulation below 560 feet. A pumping test was conducted when the exploratory hole was approximately 850 feet deep. Caliper, fluid resistivity, fluid velocity, and temperature geophysical logs were run.

The exploratory hole was then extended to 1,100 feet, and another pumping test was conducted. Again, caliper, fluid resistivity, fluid velocity, and temperature geophysical logs were run. Five 4-inch-diameter rock cores were collected while drilling between 850 and 1,030 feet.

Five additional rock cores were collected as the exploratory hole was extended to 1,200 feet in depth and another pumping test was performed. Caliper, fluid resistivity, fluid velocity, temperature, and gamma ray geophysical logs were run at this depth. A color television survey was also run to help select intervals for packer testing.

Two straddle packer tests were conducted between the intervals of 1,020-1,030 feet and 1,054-1,064 feet. Additional

Table 2-2
Geophysical Logging Schedule for the North Port DIW

Date	Interval (feet)	Casing or Borehole Diameter (inches)	Geophysical Log	Remarks
3/20/87	0-300 300-570	17-1/4 12-1/4	gamma ray caliper LSN	Mudded hole
4/14/87	0-560 560-850	33 ID 12-1/4	caliper fluid resistivity (p) fluid velocity (p) temperature (p)	Pump Test No. 1
4/19/87	0-560 560-1100	33 ID 12-1/4	caliper fluid resistivity (p) fluid velocity (p) temperature (p)	Pump Test No. 2
4/22/87	0-560 560-1200	33 ID 12-1/4	caliper fluid resistivity (p) fluid velocity (p) temperature (p)	Pump Test No. 3
5/5/87	0-560 0-1600	33 ID 12-1/4	caliper fluid resistivity (p) fluid velocity (p) temperature (p)	Pump Test No. 4
5/26/87	1-1100 1100-1600 1600-2000	23 ID 17-1/4 12-1/4	caliper fluid resistivity (p) fluid velocity (p) temperature (p)	Pump Test No. 5
6/4-5/87	0-1100 1100-1600 1600-3200	23 ID 17-1/4 12-1/4	caliper fluid resistivity (p) fluid velocity (p) temperature (p) gamma ray LSN induction electric(*) compensated acoustic velocity(*)	Pump Test No. 6
8/10/87	0-1105	13 ID	temperature	Cement Final Casing
8/24/87	0-1105	13 ID	cement bond log (*)	
11/30-12/1/87	1105-3200	12	caliper fluid resistivity (p) fluid velocity (p) temperature (p) gamma ray LSN	Pump Test No. 7
12/1/87	0-1105 1105-3200	13 ID 12	black and white TV survey	
12/7/87	0-1105	13 ID	radioactive tracer survey(**)	
1/17-1/18/88	1105-3200	12	temperature fluid velocity	Static
1/21/88	1105-3200	12	fluid velocity (p) fluid resistivity (p) temperature (p)	24-hr pump test

(*) geophysical log performed by Schlumberger
(**) geophysical log performed by Haliburton/Welex
(p) geophysical log run under pumping/flowing conditions.

Table 2-3
North Port DIW Casing and Cement Schedule

Casing Purpose	Casing Material	Outside Diameter (inches)	Inside Diameter (inches)	Thickness (inches)	Casing Depth (feet)	Cement Stage	Type of Cement	Quantity of Cement (sacks)	Remarks
Surface	Steel	42.000	41.250	0.375	26	N/A	N/A	N/A	Casing installed by Vibrating 2/10/87
Outer	Steel	34.000	33.000	0.500	560	1st	4% gel Neat	946 274	Stage placed by pressure-grouting lead cement - 946 sacks 4% gel, 274 sacks neat cement, placed 4/7/87
Middle	Steel	24.000	23.000	0.500	1100	1st	Neat	510	Stage placed by pressure-grouting 510 sacks neat cement 5/14/87
						2nd	Neat	150	Stage 2 placed with tremie pipe, annulus was left open from 880' to pad surface 5/15/87
						3rd	4%	400	Stage placed with tremie pipe on 7/1/88
						4th	4%	400	Stage placed with tremie pipe on 7/2/88
						5th	4%	400	Stage placed with tremie pipe on 7/2/87
						6th	12%	200	Stage placed with tremie pipe on 7/3/87
						7th	12%	200	Stage placed with tremie pipe on 7/3/87
						8th	12%	200	Stage placed with tremie pipe on 7/3/87
						9th	12%	200	Stage placed with tremie pipe on 7/4/87
						10th	12%	112	Stage placed with tremie pipe on 7/4/87

Table 2-3
(Continued)

Casing Purpose	Casing Material	Outside Diameter (inches)	Inside Diameter (inches)	Thickness (inches)	Casing Depth (feet)	Cement Stage	Type of Cement	Quantity of Cement (sacks)	Remarks
Final	Steel Seamless	14.000	13.000	0.500	1105	1st	4%	455	Stage 1 placed by pressure-grouting lead 455 sacks 4% gel cement
							Neat	338	338 sacks neat cement placed 8/8/87
						2nd	4%	697	Stage 2 placed with tremie pipe 8/9/87

Note: Gel = Bentonite

packer tests could not be conducted because of the physical condition of the borehole. A ledge of hard dolomite occurred between 780 to 800 feet in depth, with a "wash out" area below it with a diameter too large to set packers.

Water-producing zones were encountered between the approximate depths of 1,140 and 1,180 feet. Because of this condition, CH2M HILL and GDU decided to extend the exploratory hole to the next testing point (1,600 feet) before setting the 24-inch-diameter intermediate casing.

On May 5, 1987, after the exploratory hole reached 1,600 feet in depth the well was allowed to flow and caliper, fluid resistivity, fluid velocity, and temperature geophysical logs were run. Upon completion of the test, a casing depth of 1,100 feet was selected for the 24-inch-diameter casing from water quality and lithologic data. A bridge plug was set at approximately 1,110 feet to make casing setting easier.

The exploratory hole was reamed to a nominal 34-inch-diameter hole, and 1,100 feet of 24-inch-diameter intermediate casing was cemented in place with two stages of neat cement. Five hundred and ten sacks of neat cement were pressure-grouted on the first stage and 150 sacks of neat cement were placed using tremie pipe during the second stage. The annulus opening from 880 feet up to the pad surface was left uncemented at this time pending the results of the complete testing program.

A 17¼-inch-diameter bit was used to drill out the bridge plug and to a depth of 1,600 feet because the 17¼-inch bit had better dredging characteristics than the 12¼-inch bit. Drilling using the 12¼-inch bit continued to a depth of 2,000 feet, at which time an additional pumping test was conducted. Caliper, fluid resistivity, fluid velocity, and temperature geophysical logs were run.

Exploratory hole drilling continued to a total depth of approximately 3,200 feet with several coring attempts made during drilling to 2,700 feet. The hole was extended to 3,200 feet in search of a fractured and highly permeable zone, which was reported at approximately 3,000 feet at a nearby well to the south (Gulf Vanderbilt Well No. 1). Such a zone was not encountered at this well. A pumping test and caliper, fluid resistivity, fluid velocity, temperature, gamma ray and temperature geophysical logs were then run. Schumberger Well Services ran an induction electric log and a compensated acoustic velocity log. A color television survey was run, although the survey reached only about 3,100 feet because the light on the camera failed. Several unsuccessful attempts were made to televise the bottom 100 feet of borehole. However, the high temperature (111°F) of the water at that depth caused the camera lamp bulb to fail on each attempt.

Drilling and testing activities were suspended from June 7, 1987, to June 30, 1987, while TAC decided on the final design of the North Port DIW system. Final agreement for the completion of the North Port DIW system was reached by TAC near the end of June 1987. A decision was made to eliminate annular monitoring at the DIW and to cement the 24-inch casing up to the pad surface. A total of 1,105 feet of seamless 14-inch steel casing was to be set at the DIW and the borehole was to be left open to a total depth of 3,200 feet. The TAC also decided to require construction of a dual zone OMW and a RMW.

Another bridge plug was set at approximately 1,100 feet bls, and the drilling contractor began mobilizing for the OMW. Activities resumed on June 30, 1987, with cementing of the 24-inch casing up to the pad surface. The casing was cemented using tremie pipe in eight stages with 4-percent and 12-percent bentonite cement. Tremie pipe was used and a total of 1,200 sacks of 4-percent bentonite cement and 912 sacks of 12-percent bentonite cement was placed by pressure grouting.

A total of 1,105 feet of 14-inch-diameter seamless steel casing was set at the DIW. This final casing string was cemented in two stages: the first, pressure-grouted and the second, by tremie pipe. The first stage consisted of 455 sacks of 4-percent bentonite cement followed by 338 sacks of neat tail end cement. The second stage consisted of 697 sacks of 4-percent bentonite cement. A cement bond log was run at the DIW on August 24, 1987.

After allowing the cement to set for 48 hours, a pressure test was run on the casing on August 11, 1987, to confirm mechanical integrity. The casing was pressurized to 115 psi and shut in for one hour. No pressure loss was observed during this time.

The DIW was then drilled out to the selected total depth of 3,200 feet and background water samples were collected from the DIW.

A 24-hour pumping test was conducted after completion of the OMW and RMW. Five days of background water levels were collected at the DIW, OMW, and RMW beginning on November 18, 1987. Pumping began on November 23, 1987, at 10:30 a.m. and ended at 10:30 a.m. on November 24, 1987. Twenty-four hours of recovery data was also collected. Geophysical logs were run on November 30, 1987. Caliper, fluid resistivity, fluid velocity, temperature, gamma ray, and LSN geophysical logs were run. A black-and-white television survey of the completed well was also run.

A successful radioactive tracer survey test was run on December 7, 1987, as an additional measure to confirm the external mechanical integrity of the cement around the casing. Alsay contracted Haliburton and Welex to perform this test.

A completion diagram of the North Port DIW is shown in Figure 2-3. The wellhead at the DIW was completed as shown in Figure 2-4. A survey was performed to establish elevations of a reference point at the DIW, OMW, and RMW to correlate water levels (pressures) to national geodetic vertical datum (NGVD).

2.3 ONSITE MONITOR WELL

Construction of the OMW began in July 1987 after the TAC agreed upon a monitoring plan. A dual-zone OMW was chosen to detect upward migration of injected fluid toward the 10,000-mg/l interface (established at 551 to 600 feet) by monitoring the first two permeable zones overlying the confining units. The lower interval is used to monitor a zone from approximately 730 to 750 feet (the first permeable zone above the confining units), and the upper interval is used to monitor a zone from 551 to 600 feet (the location of 10,000-mg/l TDS interface).

Surface casing consisting of 27 feet of 36-inch-diameter casing was vibrated in place during construction of the drilling pad. A nominal 22-inch hole was then drilled using mud circulation to approximately 560 feet, and caliper, gamma ray, and LSN geophysical logs were run. The lithology of this well was described by inspecting cuttings collected at 5-foot intervals during drilling.

After logging the well, 551 feet of 12-inch-diameter intermediate casing was set and cemented in two stages. The first stage was pressure-grouted with 464 sacks of 4-percent bentonite cement followed by 333 sacks of neat cement. A second stage, consisting of 160 sacks of 4-percent bentonite cement, was placed using tremie pipe.

A nominal 11-inch-diameter hole was drilled using reverse-air open circulation to about 735 feet and caliper, fluid resistivity, temperature, gamma ray, and LSN geophysical logs were run on August 24, 1987.

A total of 730 feet of 6-inch-diameter FRP casing was set; the bottom 130 feet (600 to 730 feet) was cemented in two stages with neat cement. The first stage was placed by pressure-grouting 75 sacks of neat cement. A tremie pipe was used to place 29 sacks of neat cement for the second stage. An open-hole annular space from approximately

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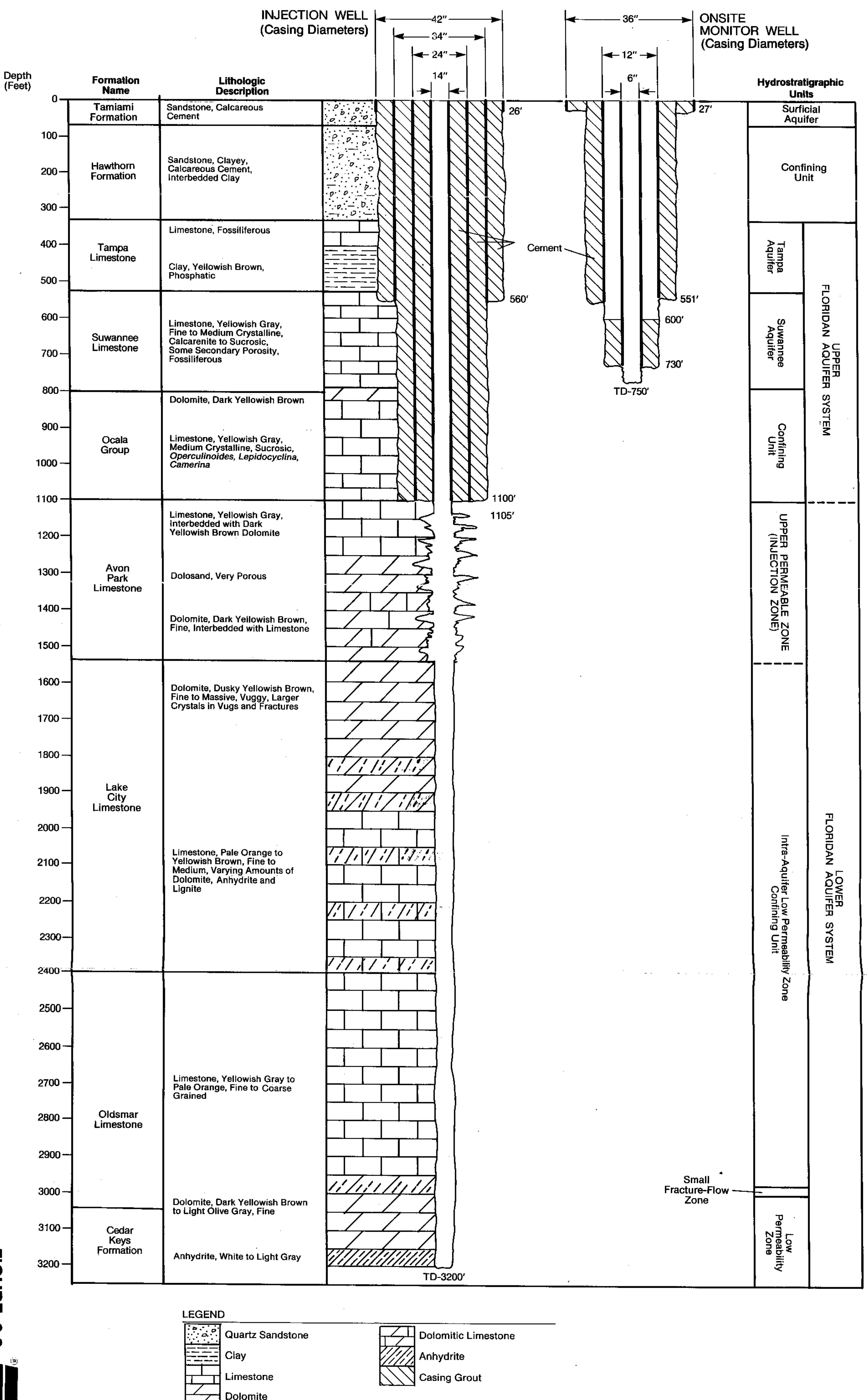

FIGURE 2-3.
DIW and OMW Construction Summary.

CH2MHILL

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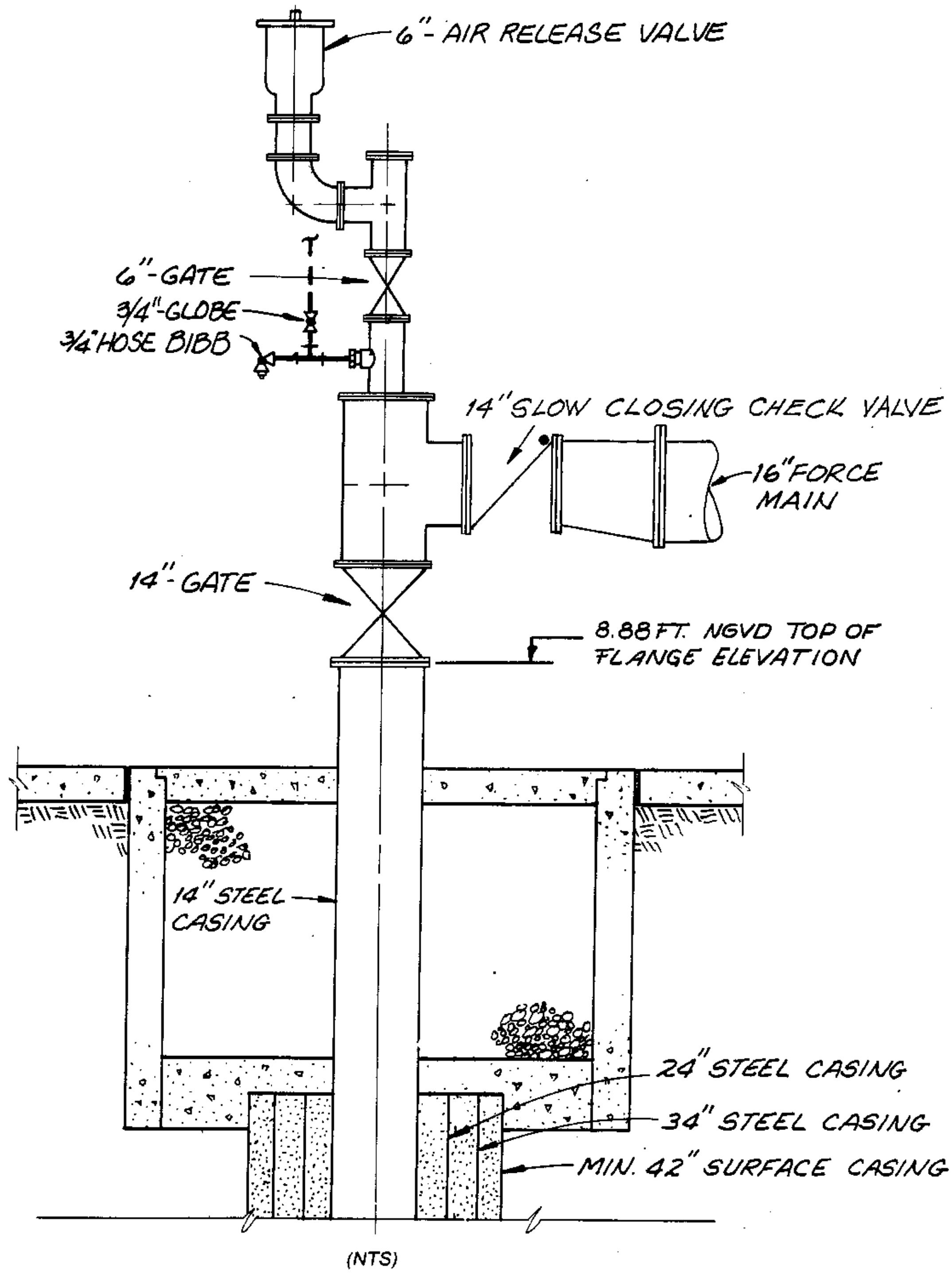

FIGURE 2-4.
GDU North Port Injection Wellhead Record Drawing.

600 feet up to the bottom of the 12-inch casing at 551 feet was left uncemented for use as a monitoring zone. TAC and CH2M HILL agreed to leave the entire annular space open for monitoring instead of placing small-diameter monitor tubes, which could easily plug with time. Provisions were made at the wellhead for sampling and water level measurement in this zone.

The OMW was completed by drilling a nominal 5½-inch-diameter open hole down to 750 feet and running final geophysical logs. On September 9, 1987, caliper, fluid resistivity, temperature, gamma ray, and LSN geophysical logs were run. Construction details of the OMW are shown in Figures 2-3 and 2-5. A summary of geophysical logging and cementing activities is shown in Tables 2-4 and 2-5.

2.4 REGIONAL MONITOR WELL

At TAC's request, an RMW designed to penetrate the upper 50 feet (1,100-1,150 feet) of the injection zone was constructed to monitor the regional movement of injected fluids over time. At the TAC's request, only the upper 50 feet was penetrated to detect the injected fluids, since they would tend to float on the denser native seawater. CH2M HILL and GDU recommended that the RMW be located midway (approximately 8,000 feet) between Warm Mineral Springs and the DIW site near the old effluent disposal facility. This location was recommended because, being midway between Warm Mineral Springs and the DIW, this well would be more effective as a "regional" monitor well. Another reason the site was recommended is the existing pipeline connecting this site to the WWTP. Water from the RMW drilling operations could thus be easily disposed of during sampling. The TAC preferred a location closer to the DIW since this would allow quicker detection of injected fluid movement towards Warm Mineral Springs if this movement were to occur. At the TAC's direction, the RMW was constructed approximately 4,150 feet from the DIW.

After several weeks of permitting, construction of the RMW began in late September 1987. Permits to construct an access road and to clear the RMW site was obtained from the City of North Port on September 17, 1987. Shortly thereafter, 42 feet of 24-inch-diameter surface casing was vibrated in place and a 40-foot by 60-foot concrete drilling pad was poured.

A nominal 23-inch-diameter hole was then drilled using mud circulation to approximately 560 feet bls. Formation samples were collected every 5 feet during the drilling of this well to identify the lithology encountered. Caliper, gamma ray, and LSN geophysical logs were run on the mudded

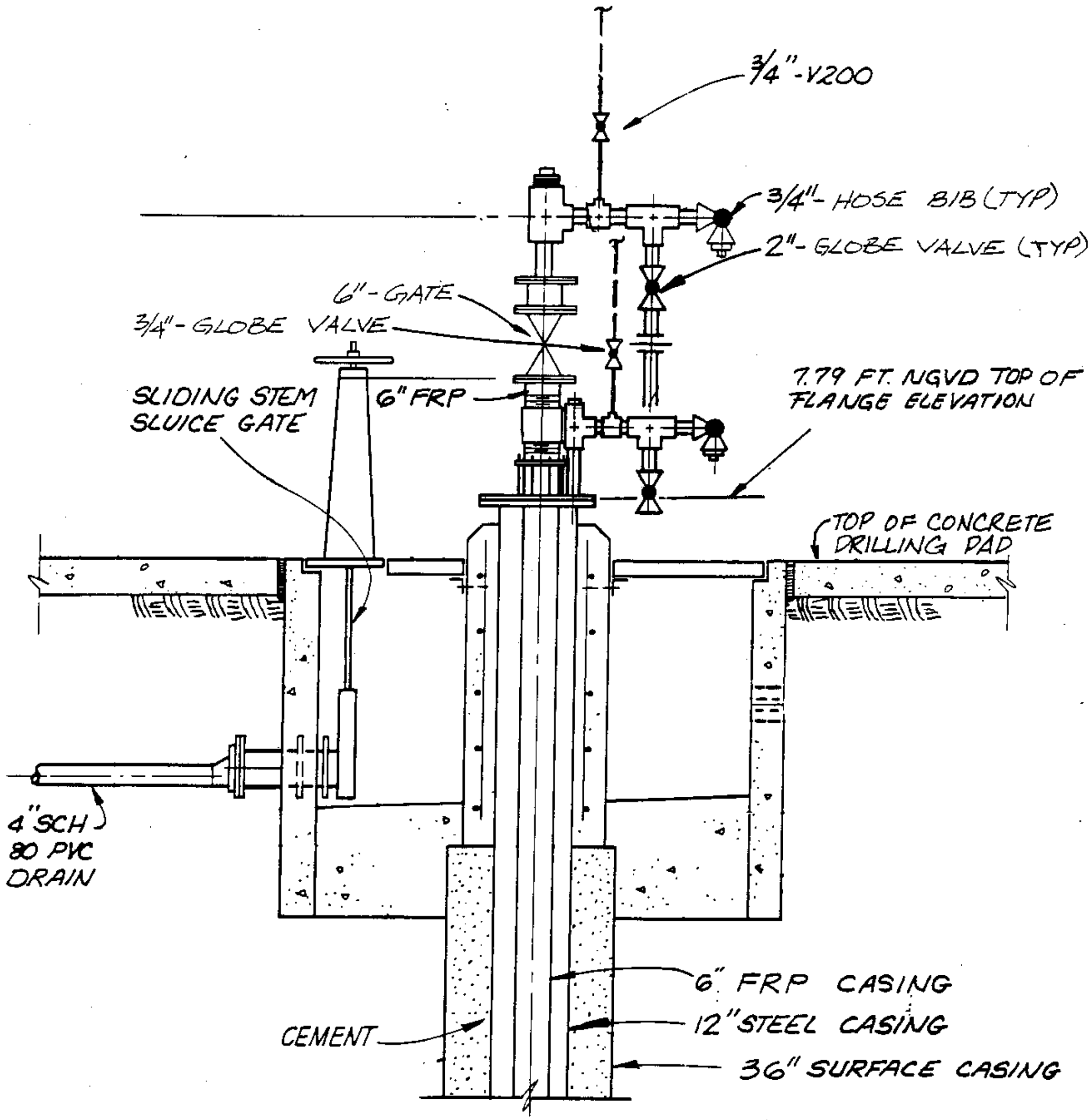

FIGURE 2-5.
GDU North Port Onsite Monitor Wellhead Record Drawing.

Table 2-4
GEOPHYSICAL LOGGING SCHEDULE FOR THE NORTH PORT OMW

Date	Interval (feet bls)	Casing or Borehole Diameter (inches)	Geophysical Log	Remarks
7/16/87	0-27 27-560	35 (ID) 22	gamma ray caliper LSN	mudded hole
8/24/87	0-551	11 (ID)	caliper	set 12-inch casing
	551-730	12¼	fluid resistivity* gamma ray temperature* LSN	
8/27/87	0-551	11 (ID)	temperature	cement 12-inch casing
9/9/87	0-730 730-750	6 (ID) open hole	caliper fluid resistivity* LSN temperature* gamma ray	open hole

*Geophysical log run under pumping/flowing conditions.

Table 2-5
North Port OMW Casing and Cement Schedule

Casing Purpose	Casing Material	Outside Diameter (inches)	Inside Diameter (inches)	Thickness (inches)	Casing Depth (feet)	Cement Stage	Type Of Cement	Quantity Of Cement (sacks)	Remarks
Surface	Steel	36.000	35.250	0.375	27	N/A	N/A	N/A	Casing installed by vibrating 2/10/87
Middle	Steel	12.000	11.000	0.500	551	1st	4% Gel Neat	464 333	Stage placed by pressure-grouting lead cement: 464 sks 4% gel and 333 sks neat cement. Placed 7/18/87
						2nd	4%	160	Stage placed with tremie pipe 7/20/87
Final	FRP	6.625	5.625	0.500	730	1st	Neat	75	Stage placed by pressure-grouting 75 sacks neat cement 8/26/87
						2nd	Neat	29	Stage placed with tremie pipe 8/27/87
									Casing cemented from 730' up to 600'. Interval from 560-600 left uncemented and used as a monitor zone.

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hole and 560 feet of 16-inch-diameter intermediate casing was installed. This casing was cemented in one stage using 325 sacks of 4-percent bentonite cement followed by 275 sacks of neat cement. Summaries of the geophysical logging, casing, and cement schedules for the RMW are shown in Tables 2-6 and 2-7, respectively.

Reverse-air closed circulation drilling methods were then used to drill a nominal 15-inch-diameter hole to approximately 1,100 feet bls. On November 5, 1987, caliper, fluid resistivity, gamma ray, and LSN geophysical logs were run before 1,100 feet of nominal 6-inch-diameter FRP casing were set. The final casing string was cemented in four stages, as shown in Table 2-7. A mechanical integrity test was run on the FRP casing after cementing by pressurizing the casing up to 70 psi, locking in the well, and checking for pressure drops for 1.5 hours. No loss in pressure was observed.

The TAC required the RMW to be completed by drilling a nominal 5-inch-diameter open hole to 1,150 feet bls to easily identify the presence of treated effluent, which may be more buoyant than the native saltwater. CH2M HILL had recommended completing the RMW similar to the DIW, with an open hole to 3,200 feet so that it would penetrate the same zones as the DIW. Caliper, fluid resistivity, temperature, gamma ray and LSN geophysical logs were then run. Diagrams of the completed RMW are shown in Figures 2-6 and 2-7.

2.5 DRILLING PAD SHALLOW WELLS

Two shallow monitor wells (SMW-1 and SMW-2) were constructed on the east and west sides of the drilling pad at the DIW/OMW site, and as shown in Figure 2-8. Both shallow wells were constructed before drilling operations began at the DIW and the monitor wells. The shallow monitor wells were designed to determine if any changes in the surficial aquifer water quality would occur as a result of any overflow during drilling or testing. No changes in surficial water quality were detected throughout the entire drilling and testing period.

Both shallow monitor wells are 2-inch-diameter PVC wells with 5 feet of PVC screen from 15 to 20 feet in depth. Each well is also equipped with a steel sleeve at land surface.

Table 2-6
GEOPHYSICAL LOGGING SCHEDULE FOR THE NORTH PORT RMW

Date	Interval (feet bls)	Casing or Borehole Diameter (inches)	Geophysical Log	Remarks
10/28/87	0-42 42-565	23 (ID) 20	gamma ray caliper LSN	mudded hole
11/5/87	0-560	11	caliper	set 16-inch casing
	560-1,100	12	fluid resistivity gamma ray LSN temperature	
11/9/87	0-1,035	6	temperature	cement 6-inch casing
11/12/87	0-1,100 1,100-1,150	6 open hole	caliper fluid resistivity LSN temperature gamma ray	open hole

Table 2-7
North Port RMW Casing and Cement Schedule

Casing Purpose	Casing Material	Outside Diameter (inches)	Inside Diameter (inches)	Thickness (inches)	Casing Depth (feet)	Cement Stage	Type Of Cement	Quantity Of Cement (sacks)	Remarks
Surface	Steel	24.000	23.000	0.500	42	N/A	N/A	N/A	Casing installed by vibrating 9/25/87
Middle	Steel	16.000	15.000	0.500	560	1st	4% Gel Neat	325 275	Stage placed by pressure-grouting lead cement, 325 sks 4% gel, and 275 sks neat cement. Placed 10/29/87
Final	FRP	6.625	5.625	0.500	1100	1st	4% Gel Neat	150 200	Stage placed by pressure-grouting lead cement, 150 sks 4% gel, and 200 sks neat cement. Placed 11/7/87
						2nd	4% Gel	150	Stage placed with tremie pipe 11/8/87
						3rd	4% Gel	300	Stage placed with tremie pipe 11/8/87
						4th	4% Gel	25	Stage placed with tremie pipe 11/9/87

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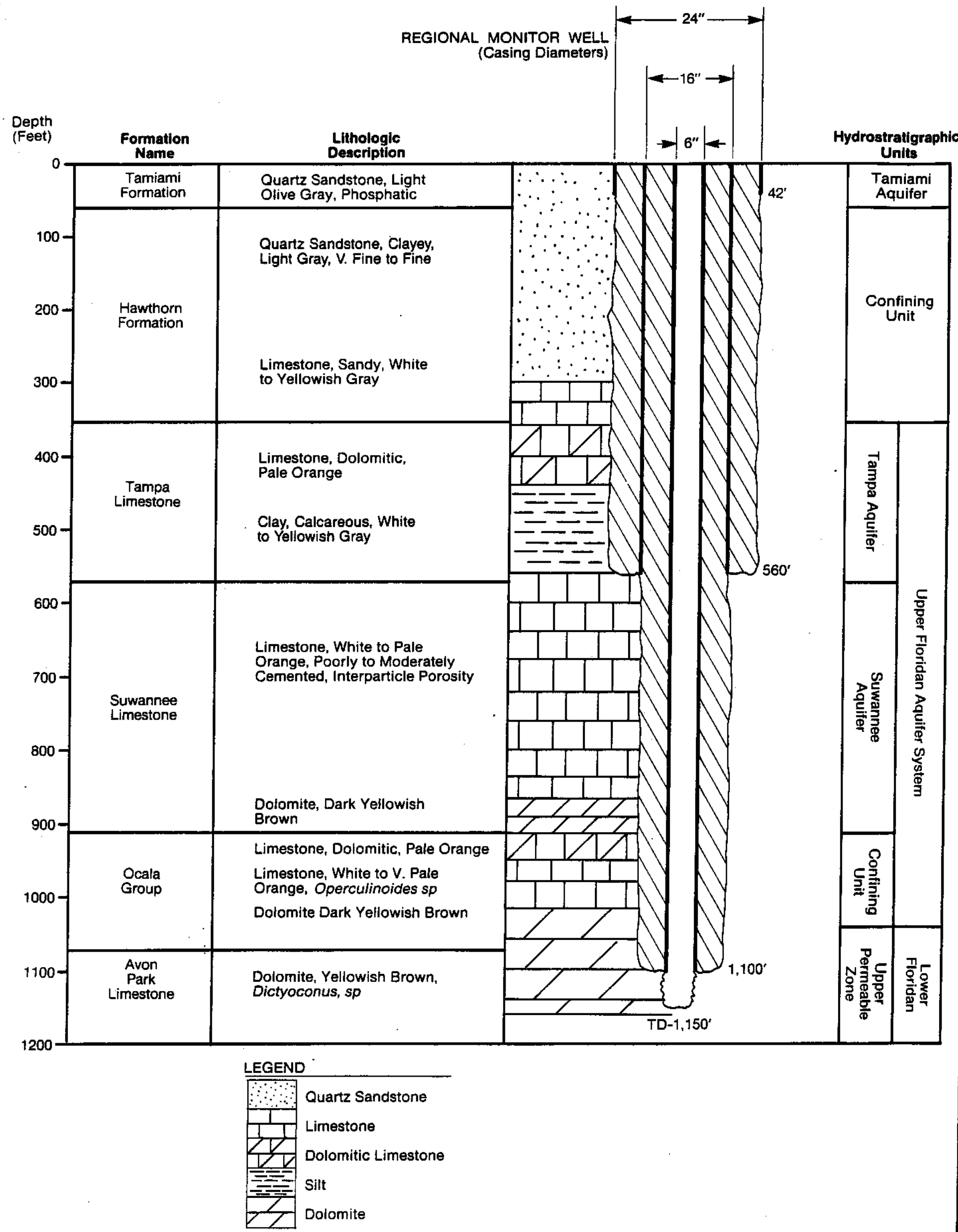

FIGURE 2-6.
RMW Lithology and Construction Diagram.

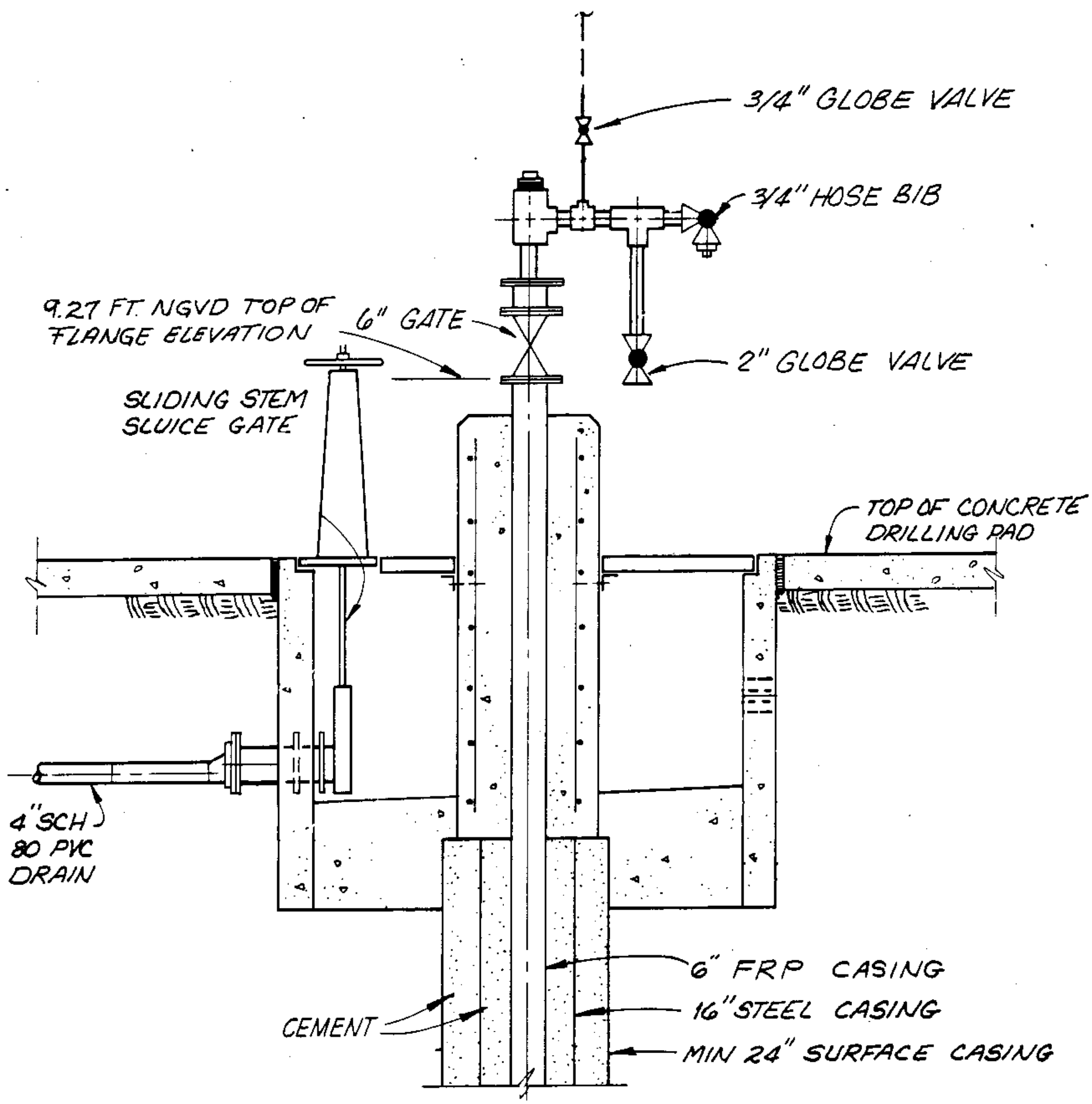

FIGURE 2-7.
GDU North Port Regional Monitor Wellhead Record Drawing.

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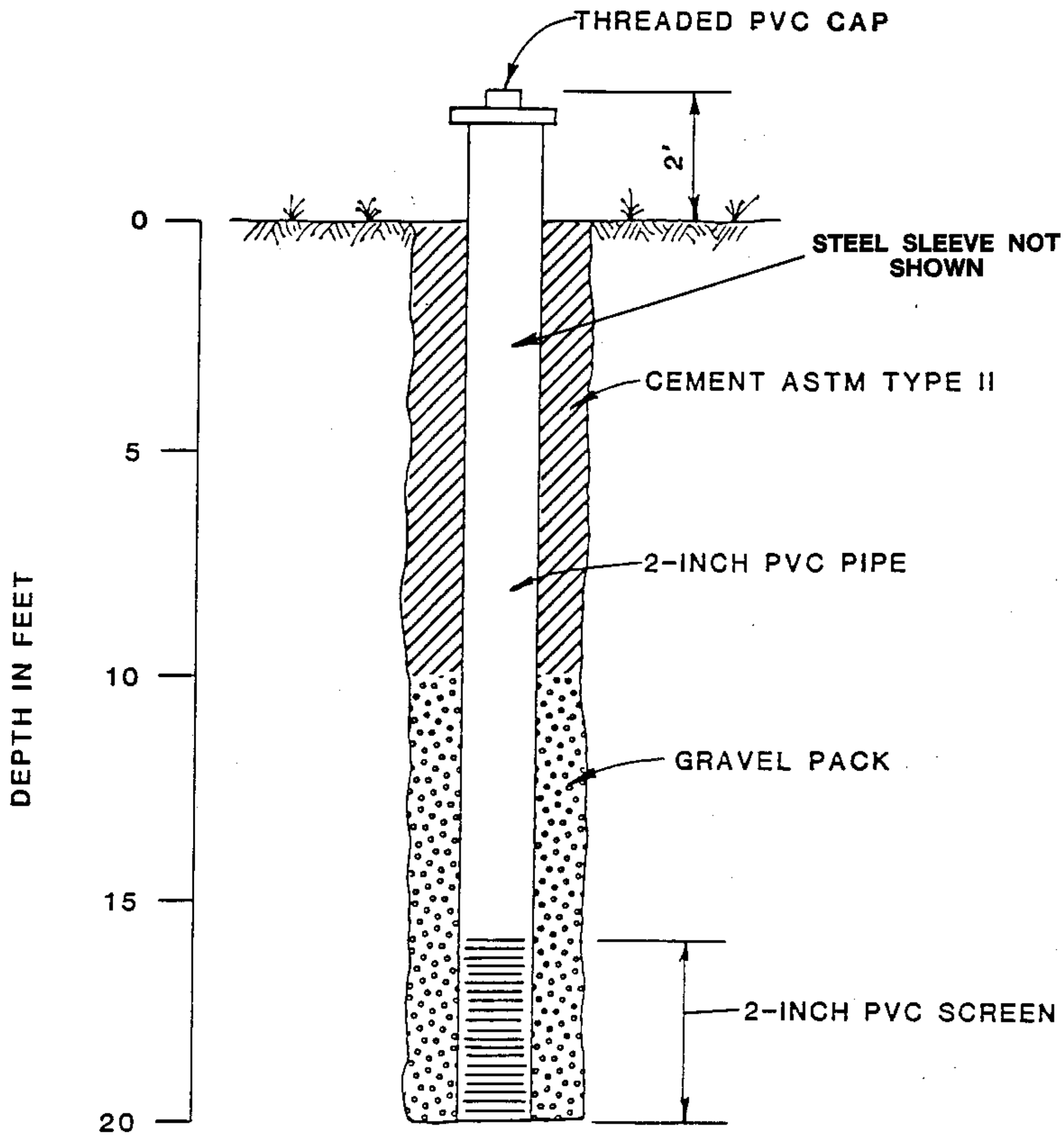

FIGURE 2-8.
General Shallow Monitor Well Record Drawing.

CH2M HILL

Section 3
HYDROGEOLOGIC DATA

3.1 SCOPE OF TESTING

The testing program for this system has been one of the most extensive efforts for this type of installation in Florida. This testing and monitoring effort was necessary because of the proximity of Warm Mineral Springs, an environmentally sensitive area. The central focus of the testing was the confirmation of the presence of adequate injection and suitable confinement zones at North Port.

Initial work on the feasibility assessment showed that a potential injection zone existed in the dolomitic limestone of the Floridan aquifer system. This zone seemed to be confined from overlying water sources by low-permeability intervals within the lower Floridan and the Ocala Limestone.

The system was hydraulically tested to determine the injection potential of the North Port site. The onsite hydrogeological testing and data collection work for the North Port DIW project began in January 1987, and the short-term injection testing was completed in January 1988. Pumping tests on the DIW were run as the DIW exploratory hole was advanced. Six short-term pumping step tests were run during well construction. A final 24-hour pumping test was run after the completion of all well construction, including the OMW and RMW. Geophysical logging during the pump testing allowed additional identification of hydraulically significant zones as well as provided a quantification of the relative productivity of the aquifers encountered. Data from the final pump test gathered in the RMW were used to analyze the regional aquifer hydraulic parameters of the injection zone.

Identification of zones of very low vertical permeability in the confining material was fundamental to the feasibility of DIW usage at North Port. Two potential pathways of effluent movement from the injection zone were investigated during the course of the DIW design and construction. The first of the two is the possible pathway of effluent out of the injection zone through a potential vertical fracture that could breach the confining beds overlying the injection zone. The second potential pathway of migration investigated was a direct flow of effluent from the injection zone to overlying formations through the confining beds.

Investigation of the vertical fracture pathway was conducted using both remote sensing and direct measurement techniques. The initial DIW site was evaluated with an aerial photo mosaic by photolineament interpretation to identify a possible direct connection between the site and Warm Mineral Springs, which is a fracture-related hydrogeologic feature. Other photo lineaments in the area were also mapped during this initial work. CH2M HILL carefully monitored Warm Mineral Springs during construction and pump testing of the DIW to try to determine whether a vertical fracture pathway existed between the injection zone and overlying aquifers. No direct pathways were identified.

The possible pathway of direct movement of the effluent through the confining zone was investigated by hydraulic testing of the confining material both in situ and in the laboratory. The geologic materials encountered were carefully examined to establish a lithologic log correlating to field conditions. This geologic description was initially used to identify zones of interest for testing. As confining zones above the expected injection zone were penetrated, barrel cores of the geologic material were taken for permeability and compressibility testing. Straddle packer tests were run to investigate in situ permeability and water quality of selected zones representing the confining bed.

The mechanical integrity of the well was confirmed during construction of the well. This assessment included a casing pressure test and, following construction, a radioactive tracer survey.

The final testing associated with construction was a short-term injection test with effluent to determine the injection capacity of the DIW.

3.2 LINEAMENT STUDY

As a condition of the settlement agreement and the DIW construction permit, a fracture trace photolineament study of the DIW site and surrounding area was conducted. The investigation, which CH2M HILL conducted before the start of test drilling, included the use of aerial photographs and photomosaics and satellite imagery to detect surface expressions of fracture patterns. The detected surface patterns were subsequently used to evaluate the probability of a subsurface direct connection between the proposed DIW location and Warm Mineral Springs.

In the study area, the top bedrock is the Tampa Formation, 50 to 100 feet bls. Large solution features (caverns) from groundwater flow would be expected to occur along fractures in the upper part of this stratum and their effects should be detected at the surface. It is not known, however, whether or not the fractures in the bedrock surface extend to the depths of the proposed injection, or if the lineations mapped relate to groundwater circulation at these greater depths.

Lineament mapping was done primarily on the black-and-white photographs of the site area taken before development (1950's). False-color infrared photography and Earth Resources Technology-1 (ERT-1) satellite imagery were less useful than the photographs. Lineaments were mapped by placing a photographic mosaic under study on a table and rotating them through 360 degrees while viewing from an angle of 20 to 30 degrees above the horizon. A detected lineament, mutually agreed upon by two observers, was viewed vertically for confirmation as a non-anthropogenic feature before marking.

Results of the study showed two complementary sets of lineaments. The sets have a NE/SW and NW/SE orientation, consistent with orientations seen in previous regional patterns mapped by the Florida Department of Transportation (FDOT) on ERTS imagery. Lineament lengths mapped range from 3 miles to more than 30 miles; shorter lineaments could not be reliably mapped.

Both Warm Mineral Springs and Little Salt Spring lie along the NE/SW orientation of one set of lineaments. Warm Mineral Springs lies within 500 feet of a lineament bearing N45E, and Little Salt Spring lies about 2,000 feet southeast of the same lineament. Other than their locations, there is no evidence that either spring is directly associated with the mapped lineament.

The injection well site lies between two parallel lineaments bearing approximately N25°E. The nearest lineament is about 0.5 mile southeast of the site. A shorter parallel lineament segment would, if extended, pass about 1,000 feet northwest of the site.

While some of the lineaments mapped during this study may extend to the depth of the proposed injection, the effects most probably extend to a depth of no more than 200 to 300 feet into the bedrock. None of the photo lineaments mapped during the study suggest a direct connection between the injection site and Warm Mineral Spring or Little Salt Spring.

The lineament study summary report is included in Appendix D. CH2M HILL will keep the original marked photography, displayed in the FDER Tampa office before test drilling, for one year after project completion. Black-and-white photographs of the marked photo lineaments have been provided to each member of the TAC.

3.3 HYDROGEOLOGIC FRAMEWORK

The hydrogeologic framework section is divided into two parts: a lithostratigraphic description and a hydrogeologic description.

3.3.1 LITHOSTRATIGRAPHIC DESCRIPTION

The lithostratigraphic description is based on a comparative analysis between the described geology at the DIW site with other geologic publications describing the geologically distinct units representing periods in geologic time. The comparative analysis is used to date the DIW geologic material and to distinguish the different units as they relate to the unit type area as described by others. Once determined, the lithostratigraphy of the site can be related to the hydrogeology of other sites by comparing like formations. The lithostratigraghic description of the North Port DIW site is presented from the oldest formations to the youngest. The description is based on a physical description of the geologic material made by CH2M HILL hydrogeologists, the occurrence of fossil assemblages, and geophysical logs (e.g., gamma and electric) run during the construction of the well. Lithologic logs are presented in Appendix E.

Paleocene Series

Cedar Keys Formation. The Cedar Keys Formation is the oldest formation encountered and appears at an approximate depth of 3040 feet. Chen (1965) characterized the Cedar Keys as conformable with the overlying Oldsmar Limestone, with a distinct change in lithology marking the top of the bed. The formation top is identified by a gray, slightly calcitic, microcrystalline dolomite that is not usually fossiliferous. The top is slightly to moderately gypsiferous and has a relatively low resistivity curve on electric logs (Chen, 1965). Chen (1965) shows the top of the Cedar Keys Formation at a 3,400-foot depth on a regional map.

The deep injection well at the site penetrated the Cedar Keys Formation at a depth of 3,040 feet. The natural gamma ray log shows a strong deflection to the left at that depth, which is indicative of anhydrite (Keys and MacCary, 1971). The electric log shows a strong overall deflection to the right beginning at 3,030 feet in depth, which also indicates evaporites. The lithologic description shows a formation change over the interval from 3,030 to 3,070 feet bls, as the dolomite changes from a dark yellowish brown to a light olive gray, and the evaporite content approaches 40 percent of the sample. The Cedar Keys Formation extends to the total depth of the hole (3,200 feet). The anhydrite content increases with depth, as reflected by the decreasing gamma ray counts.

Eocene Series

Ocala Group. The Upper Eocene Ocala Group occurs unconformably with the older Avon Park Limestone and unconformably below the younger Suwannee Limestone in southwest Florida. It is a highly fossiliferous limestone characterized by the large distinctive foraminifera *Lepidocyclina* sp. and *Operculinoides* sp. (Chen, 1965).

The Ocala Group occurs between 800 and 1,090 feet bls at the DIW and between 910 and 1,070 feet at the RMW. Its presence is indicated by the appearance of the characteristic foraminifera, and a low count on the natural gamma ray log. Excellent correlation between the natural gamma ray logs for these two wells exists, supporting the 100-foot difference in depths for the formation top. The formation is predominantly a fossiliferous, calcilutitic limestone with numerous echinoid spines, bryozoan fragments, *Lepidocyclina* sp., and *Operculinoides* sp. The base of the Ocala Group is a thin layer of fine-grained sediments. In the DIW this layer is described as a light greenish-gray clay that is sticky and stiff. In the RMW, this layer is described as a dark yellowish-brown dolosilt that is soft and plastic. This bed occurs at the 1,090- to 1,100-foot level in the DIW and at the 1,060- to 1,080-foot level in the RMW. Both wells show an increase on gamma radiation logs associated with this clay-dolosilt.

Avon Park Limestone. The Avon Park Limestone, of late Middle Eocene age, is similar to the underlying Lake City Limestone, an interbedded limestone and dolomite formation. Limestone constitutes the majority of the formation and dolomite occurs near the base of the formation. The top is marked by a brown fossiliferous limestone of brown fine crystalline dolomite, and is overlain unconformably by the Ocala Group (Chen, 1965). Evaporites and carbonaceous material occur sporadically throughout the formation. The base, conformable with the Lake City Limestone, is typically a thick, non-fossiliferous crystalline dolomite (Chen, 1965).

The Avon Park Limestone occurs in the interval from 1,090 to 1,540 feet bls at the DIW, and was first noted at 1,070 feet in depth at the RMW. The formation is characterized by a yellowish-gray, calcarenitic limestone with numerous foraminifera and echinoid particles, interbedded with yellowish brown, fine-grained crystalline dolomite with well-developed moldic and intercrystalline porosity. The Avon Park Limestone at the North Port site is distinctive in that large cavities were encountered. The borehole-compensated sonic log shows the erratic cycle skipping characteristic of cavities. The caliper log shows the interbedded nature of this formation with a washed out, overgauge hole with peaks indicative of cavities superimposed on the overgauge trace. The cavity development was so extensive in this formation that considerable dredging occurred with drilling, and multiple coring runs were made to obtain the minimum core recovery.

Lake City Limestone. Chen (1965) characterizes the Lake City, of Middle Eocene age, as interbedded highly fossiliferous limestone and brown to dark brown dolomite, with a thick basal sequence of dark brown, finely crystalline dolomite. The first appearance of Dictyoconus americanus has commonly been used to mark the top of this formation. Thin laminae of peat and impregnation with anhydrite and gypsum are also common (Stringfield, 1966). The existence of an unconformity between the overlying Avon Park and the Lake City is uncertain, while the base is conformable with the Oldsmar (Chen, 1965). Puri and Winston (1974) identify the Lake City in the Gulf Vanderbilt #1 well (Sec. 35 T41 R21E) in the approximate interval from 1,700 to 2,500 feet.

At the North Port site, the Lake City Limestone is identified in the DIW from 1,540 to 2,400 feet bls. Dictyoconus sp. were first noted at 1,540 feet bls. A massive sequence of dense dolomite with very few cavities persists from the top of the Lake City to approximately 1,970 feet bls, with some possible cavity development at the 1,800-foot zone. The higher resistivities of the dense dolomites are well illustrated on the dual induction log, while the lack of cavities in this interval (except for the 1,800-foot zone) is shown by the lack of cycle skipping on the borehole compensated sonic log. The smooth trace of the sonic log varying little in amplitude for the next 600 feet in depth indicates the uniform character and porosity of the calcarenitic limestone. The consistent nature of this interval is occasionally broken by thin dolomite and lignite stringers. Minor amounts of gypsum and anhydrite occur in the lower portion of the formation.

Oldsmar Limestone. The Oldsmar Limestone may be characterized as predominantly limestone and dolomite, with minor components of chert, gypsum, and peat. The formation is described as a biostratigraphic unit with four distinct faunal zones. The literature includes conflicting options on whether the formation is conformable with the underlying and overlying formations.

Chen (1965) describes the limestone as "usually light brown to chalky white, rather pure, porous, and fossiliferous," while the interbedded dolomites are typically "brown to dark brown, rather porous, fine to coarse crystalline, commonly saccharoidal textured." Chen shows the top of the Oldsmar Formation at 2,400 feet bls near the site.

The top of the Oldsmar Limestone was encountered at 2,410 feet bls at the North Port site. Lithologic and paleontologic indications of a formation change include a reduction in gamma ray counts on the natural gamma ray log at 2,400 feet in depth, and an absence of Dictyoconus sp. below that depth. The upper part of the Oldsmar Limestone is a pale orange, moderately soft to moderately hard calcarentiem with minor amounts of lignite and anhydrite. A formation change is also indicated on the dual-induction log at approximately 2,400 feet, which shows a more uniform resistivity trace beginning at that depth. A thick sequence of limestone (calcarenite) with a few stringers of dolomite persists until 2,960 feet bls. The moderately soft nature of this limestone is evidenced by the caliper log, which shows a borehole size averaging 16 inches in diameter over this interval.

Below this depth, the Oldsmar grades into a fine-grained sucrosic dolomite which predominates to the top of the Cedar Keys Formation. From approximately 2,990 feet bls to the base of the Oldsmar Formation, the borehole compensated sonic log shows cycle skipping and the dual-induction log shows highly variable resistivities, which are both indicative of cavernous fractured dolomites; however, the caliper log did not indicate fracturing.

Oligocene Series

Suwannee Limestone. Johnson (1984) describes the Suwannee Limestone of Oligocene age as a somewhat argillaceous and arenaceous, coquinoid to chalky limestone with some dolomite and dolomitic limestone. He indicates that, in southwest Florida where the Suwannee is typically developed to a 300- to 400-foot thickness, it may be divided into two distinct natural gamma ray zones.

The Suwannee Limestone is present in the DIW from 525 to 800 feet bls, in the OMW from 520 feet to the total depth of the hole (750 feet), and from 570 to 910 feet in the RMW. The gamma ray intensities are lower in the Suwannee Limestone than in the overlying Tampa Limestone; the two zones Johnson (1984) described are easily discernible. The lower zone of higher gamma ray counts occurs between 700 and 800 feet bls at the DIW, and between 790 to 910 feet at the RMW. The 100 feet of difference in the Oligocene-Upper Eocene interface in the 4,150-horizontal foot distance between the DIW and the RMW is attributed to erosional relief at the non-conformable boundary. Puri and Winston (1974) state that the Oligocene-Upper Eocene boundary is unconformable and can show up to 200 feet of relief locally in southwest Florida. This is substantiated by other works showing an erosional boundary with significant relief in western Charlotte County.

The Suwannee Limestone at the site is a pale orange, granular calcilutite to calcarenite that is essentially devoid of foraminifera. However, it contains numerous echinoid spines, bryozoan fragments, and gastropod molds.

Miocene Series

Hawthorn Formation. The Hawthorn Formation is variable in lithology and generally consists of interbedded sand, silt, clay, dolostone, and limestone, with a characteristically high phosphate content (Johnson, 1984). At the North Port site, the Hawthorn Formation is between 70 and 330 feet at the DIW, between 70 and 370 feet at the OMW, and between 60 and 350 feet at the RMW. Characteristic high gamma counts, reflecting the phosphatic content, are found on the natural gamma ray logs run at these wells.

The Hawthorn Formation at the site is typically a silty quartz sandstone, with a calcareous cement. Phosphate grains constitute up to 15 percent of the sample, and individual grains range in size from silt to small pebbles.

Tampa Limestone. The early Miocene Tampa Limestone is a slightly phosphatic limestone and dolostone, with some clay and chert, with appreciably less phosphate than the overlying Hawthorn Formation (Johnson, 1984). The Tampa Limestone reaches a 250- to 300-foot thickness in Manatee, Sarasota, and Charlotte counties.

At the North Port site, the Tampa Limestone occurs between 330 and 525 feet bls at the DIW, between 370 and 520 feet at the OMW, and between 350 and 570 feet at the RMW. The formation consists of a phosphatic quartz sandstone, and a silty phosphatic clay at the DIW. At the RMW, the Tampa Limestone is a sandy, dolomitic limestone, slightly phosphatic, and a calcareous silt.

Pliocene/Pleistocene Series

Pleistocene Series. Phosphatic sandstone occurring in the upper 20 or 30 feet at the site may possibly be the Fort Thompson Formation.

Tamiami Formation. The Tamiami Formation of Pliocene Age occurs at the site approximately 20 or 30 feet bls, to a depth of 70 feet. The formation is predominantly a silty quartz sandstone with very fine phosphate grains and few shell fragments.

3.3.2 HYDROGEOLOGIC DESCRIPTION

The hydrogeologic description of the site is based on the occurrence of hydraulically significant zones in the subsurface as well as the geologic position of these zones. A hydrogeologic framework for the system can be described by integrating the hydrologic information with the lithostratigraphy. This description starts with the upper strata and proceeds to the deeper strata. The description is based on the lithostratigraphy, flow measurements with the geophysical logger, and pump testing, all done during DIW construction.

The hydrogeology of the North Port site is characterized as a complex series of water-producing intervals with varying degrees of hydraulic interconnection. The most significant of these zones occur in the upper and lower sections of the Floridan aquifer system. These two sections of the aquifer and the intervening confining unit were the primary focus of the hydrogeologic investigation and testing.

Mud rotary drilling was used during construction of the DIW to the upper Floridan aquifer system. This drilling technique prevented hydraulic testing of the material above the 560-foot depth. The limited investigation of the aquifers above 560 feet does not allow detailed characterization of the hydrogeology of those zones. However, the lithologic description and geophysical logs allow a limited discussion of the hydrogeology.

The hydrogeologic information gathered during construction and testing is compiled in Figure 3-1, a hydrogeologic cross section from the DIW to the RMW. A description of the hydrogeologically significant zones identified in Figure 3-1 follows.

Surficial Aquifer

The surficial aquifer is generally defined in this area of Florida as the water-bearing zones above the Hawthorn Formation. At the North Port site, this aquifer consists of a poorly sorted quartz sandstone with calcareous cement. The aquifer extends to about 70 feet bls at the DIW site where the clayey beds of the Hawthorn Formation are encountered. Groundwater in this aquifer is under nonartesian conditions with recharge primarily by infiltration of rainfall to the water table.

Groundwater flow in the surficial aquifer in this area is generally west/southwesterly, toward the Myakka River and Charlotte Harbor. The production potential in this area is not known since no tests involving this aquifer were conducted. But the lithology indicates that the permeability is limited by the poorly sorted, fine sand matrix.

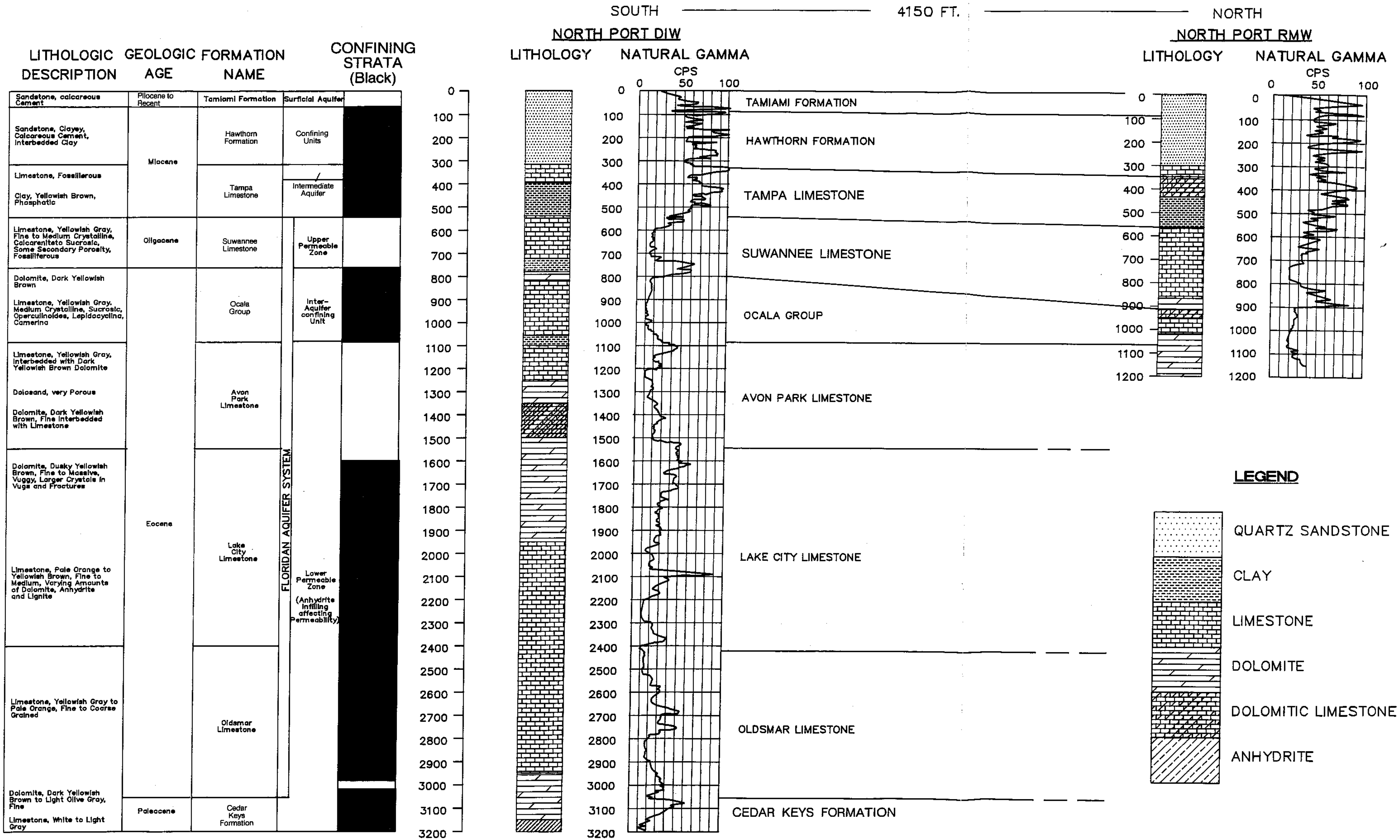

FIGURE 3-1.
North Port Hydrogeologic Cross Section.

The surficial aquifer is separated from deeper producing zones by approximately 250 feet of clayey quartz sandstone of the Hawthorne Formation.

Intermediate Aquifer, Tampa Limestone

The intermediate aquifer is composed primarily of the Tampa Limestone, a local producing zone in the vicinity of North Port. The Tampa Limestone occurs from about 320 feet to 520 feet bls at the DIW. No testing of the zone was possible during construction since the zone was penetrated during the mud rotary phase of the drilling.

The lithology of the zone shows the occurrence of a distinct limestone occurring from 320 feet to 390 feet bls. This limestone probably represents the portion of the Tampa limestone in the section that could be a potential production zone. From the bottom of the limestone section to 520 feet bls, the formation is typically a yellowish-gray clay with a limited amount of limestone, which probably represents confining material. The Tampa Limestone is shown as a continuous confining unit in Figure 3-1 because of the marginal water-bearing capacities of the formation found in other areas.

Upper Floridan Aquifer System, Upper Permeable Zone

Suwannee Limestone. The Suwannee Limestone represents the upper part of the Floridan aquifer system in the North Port area. This zone is of significant use farther inland where the zone contains freshwater. The Suwannee Limestone at the North Port site is largely a yellowish-gray moderately hard limestone, showing a consistent lithology over the formation thickness.

Three pumping tests of the DIW, discussed in detail in Section 3.6, were run while the Suwannee Formation was open to the borehole. Test 1, open hole 560 feet to 854 feet bls, was the most deterministic test of the Suwannee run during construction. Inspection of the flowmeter, caliper, temperature, and fluid resistivity logs characterized the flow zone occurrence and relative contribution during the pump test. The major flow zone in the Suwannee Formation at the DIW site is from about 620 feet to 710 feet bls. The caliper log shows a jagged borehole that is at a diameter maximum at the 675-foot depth level, which corresponds to a significant increase in flow on the flowmeter log. By analyzing the flowmeter log and the caliper log concurrently, CH2M HILL calculates the contribution of total flow from the 620 to 710 foot zone as being between 80 and 90 percent of the total flow when the open-hole section between 560 and 854 feet was pumped. The temperature log from the pumping test shows about a 3/4-degree F increase from 620 feet to 710 feet; more importantly, however, the temperature is very unsteady in the zone. Shifts showing a ½-degree cooling in the temperature profile probably represent cooler water coming into the borehole from several flow zones within the 90-foot section. Noticeable temperature shifts occur at 620 feet, 670 feet, and 710 feet. A zone from 740 to 760 feet in depth produced most of the remaining 10 to 20 percent of water from the tested interval.

Groundwater elevations mapped in the area (Mills et al., 1975) show a gradient in the upper permeable zone from the east/northeast to the west/southwest.

Ocala Group. The Ocala group is not a significant water production zone in the North Port area. The zone is basically a confining bed between the upper and lower parts of the Floridan aquifer system. The Ocala group occurs from 800 feet to 1,090 feet bls in the DIW. The lithology is a fairly consistent yellowish-gray limestone that is moderately soft and fossiliferous.

The Ocala Group was open to the DIW well bore during the construction pump test from 560 feet to 1,100 feet bls. Inspection of the flowmeter, caliper, and temperature logs run during that pump test shows that production from the Ocala is limited to about 20 percent of the total pump test production of 900 gpm. That production occurs as diffuse contributions from 820 feet to 920 feet bls. A shift on the temperature log at 825 feet may correspond to the zone that contributes the majority of the flow from the Ocala. The section below 920 feet appears to have very few fractures as indicated by the caliper log. The temperature log shows a steady increase corresponding to the same section of borehole. No temperature deflections from inflow are apparent. The flowmeter log shows an insignificant contribution from this section of the lower Ocala Group.

The confirmation of the Ocala group as an effective competent confining unit is necessary for adequate confinement of effluent in the lower zone of the Floridan aquifer system. Additional testing beyond pump testing was done on this zone to determine confining zone hydraulic. This testing included barrel coring to obtain samples for permeability testing and testing in situ permeability of the zone using straddle packer tests. This testing is reported in Sections 3.7 and 3.8.

Floridan Aquifer System, Lower Permeable Zone

Avon Park Limestone. The Avon Park Limestone is the most permeable of all zones penetrated during the drilling at North Port. The zone is predominantly limestone with a significant dolomite portion. The highest production appears to be from cavities associated with dolomite layering. The Avon Park Limestone is present from 1,090 feet to 1,540 feet bls at the DIW site.

Water-producing zones in the Avon Park Limestone were tested during the construction pump test run on the open hole from 1,100 feet to 2,000 feet bls. The geophysical logs run during this test are used to define the flow zones in the Avon Park. The geophysical logs run during the construction pump test on the Avon Park Limestone section (Pumping Test 5) and the hydrogeologic interpretation of the logs from the test are presented in Figure 3-2.

Two significant flow sections were noted during the testing of the Avon Park. The uppermost zone starts starting at the first cavity encountered (1,120 feet) and remains highly productive to about 1,220 feet bls. The production appears to be associated with the numerous cavities in the dolomite in this section. This upper section contributed about 46 percent of the total flow seen on the flowmeter log during the test, which was run at 4,500 gpm.

The second major production zone in the Avon Park occurs from about 1,450 feet to slightly more than 1,600 feet bls. This zone contributed approximately 38 percent of the flow to the well bore during the pump test according to the flowmeter log. This lower section also includes the upper 100 feet of the Lake City Limestone. Production from the Lake City Limestone is from small fractures in the dolomite.

Other minor production was noted in the very cavernous section of the Avon Park between 1,220 feet and 1,450 feet bls. Production from the layer between the two major zones appears to be 10 percent of the test total pumpage.

<u>Lake City Limestone</u>. Significant water production in the Lake City Limestone is not apparent below the first 100 feet of the formation. The formation consists of dolomite from 1,540 feet bls to a depth of 2,000 feet where the pale yellowish-brown limestone of the Oldsmar occurs. Gypsum and anhydrite begin to occur in the Lake City in small amounts at 1,900 feet. The content increases to 5 to 10 percent in deeper parts of the formation.

Two construction pumping tests were run with the Lake City Limestone section open to the borehole. The 1,100-foot to 2,000-foot depth test previously described for the Avon Park was open to the upper 460 feet of the formation. The last test run during construction, 1,100-foot to 3,200-foot depth, was open to the entire Lake City Limestone section. Examination of the geophysical logs from both tests show that there is limited water production below a small cavity shown on the caliper log at 1,810 feet. Analysis of the

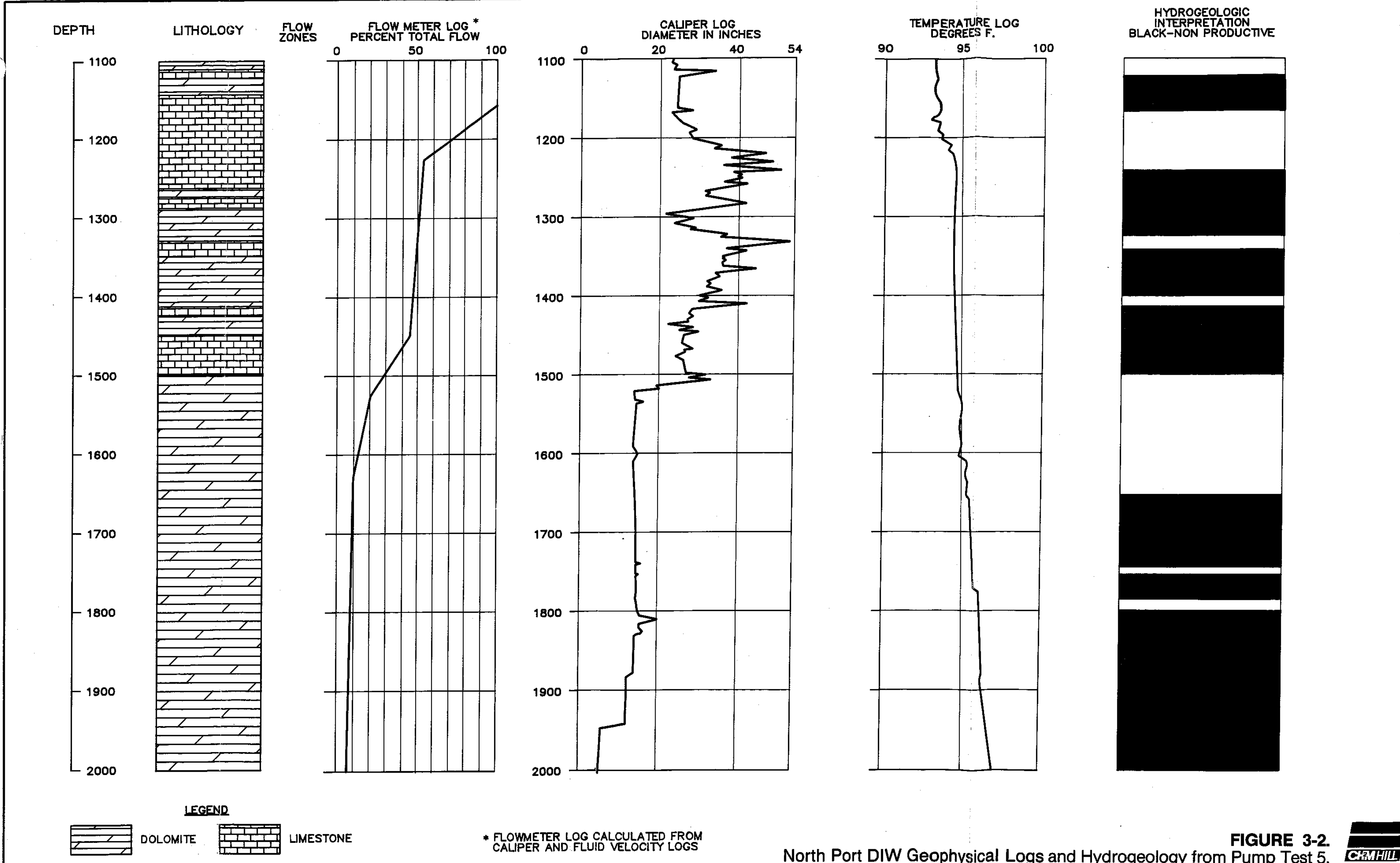

FIGURE 3-2.
North Port DIW Geophysical Logs and Hydrogeology from Pump Test 5.

flowmeter log produced from the caliper and fluid velocity logs shows that only 12 to 15 percent of the water produced during the construction test came from below 1,640 feet. About half of the 15 percent can be accounted for from a small fracture at 3,000 feet. This very limited production potential in the Lake City Limestone below 1,800 feet can be correlated to the occurrence of anhydrite and gypsum in the formation matrix, which begins about 1,900 feet bls.

The borehole television surveys show what appears to be both cavity infilling from the anhydrite and gypsum and inclusion of this material in the rock matrix. The mechanisms which contribute to the precipitation of anhydrite and gypsum, as opposed to the typical dissolution of carbonates is discussed by Vernon (1970). He cites the solubility curves produced by Runnells (1969) to point out that dissolution of rock matrix is thought to occur in zones of mixing along the contact of fresh- and saltwater with the solution becoming undersaturated with some constituents and supersaturated with others.

Oldsmar Limestone and Cedar Keys Formation. These two formations appear to have very little hydrogeologic significance in the North Port well. The occurrence of anhydrite and gypsum in various levels of these formations appears to have had the same effect on the limiting of production zone formation as seen in the Lake City Limestone. One small cavity appears on the caliper log from the 1,100-foot to 3,200-foot depth test. This cavity occurs at about 3,000 feet and contributes only about 8 percent of the flow recorded during the test.

3.3.3 ASSESSMENT OF SITE HYDROGEOLOGY

The hydrogeology of the material penetrated at the North Port site is such that large-scale injection of effluent below the depth of about 1,640 feet appears not to be feasible because of the lack of an adequate receptor zone. But an injection zone extending from about 1,110 feet to 1,640 feet bls has the capacity to accept effluent injection.

Two major water-producing zones were identified in this area. The uppermost, a dolomite and limestone sequence from about 1,100 feet to 1,220 feet bls is probably hydraulically connected with the lower zone, the limestone-dolomite interface between the Avon Park and Lake City Limestones at depths 1,460 feet to 1,640 feet. A summary of the flowmeter logs run during construction tests on the DIW showing the location of the major producing zones is shown in Figure 3-3. The entire zone from 1,100 to 1,640 feet appears to be well suited for large-scale injection.

The degree of confinement of the strata that separates these flow zones from the overlying aquifers and the hydraulic

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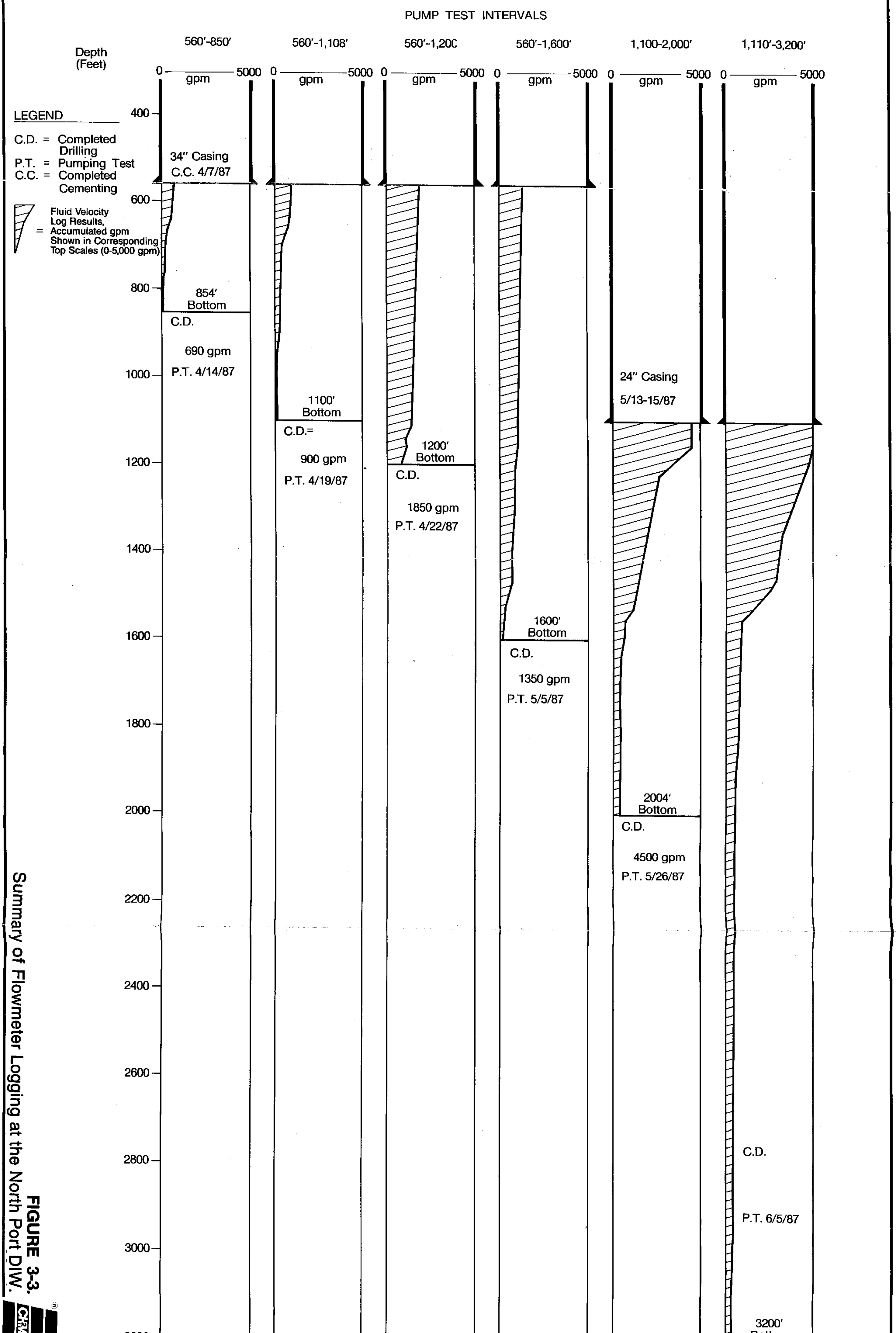

Note: Flowmeter log is calculated from caliper, temperature, and fluid velocity logs.

FIGURE 3-3.
Summary of Flowmeter Logging at the North Port DIW.

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parameters associated with this injection zone were extensively tested and analyzed. These results are presented later in this section.

3.4 WATER QUALITY

This section summarizes the methodology and results of sampling conducted during the construction and testing of the North Port DIW. The first purpose of the sampling was to determine the water quality of the hydrogeologic zones penetrated during the installation of the injection system. The sampling also established a water quality baseline for comparison to monitoring data to be obtained during system operation. The water quality data for the DIW and the OMW during construction is representative since these wells were drilled free-flowing after setting casing to the top of the Floridan aquifer system. Therefore, water quality samples could be taken without interference from drilling fluids. However, no representative water quality data were obtained from the RMW until after setting the casing at 1,100 feet since this well had to be drilled closed circulation because of environmental restrictions.

The water quality samples obtained are grouped as follows:

- o Samples collected during the drilling of the DIW:
  - Chlorides
  - Electric conductance
  - Total dissolved solids (TDS)
- o Samples collected during pump and packer tests on the DIW
  - Physical parameter analysis
  - Discharge samples--physical analysis
  - Depth samples--chloride, electrical conductance, and TDS
- o Samples collected during construction and testing of the OMW
- o Background Samples
  - Backround samples on the DIW, OMW, and RMW
  - Discharge samples collected during the 24-hour pumping test
- o Samples collected during the injection test

A summary of each of the different groups of samples collected and a discussion of the analysis results follows.

Water quality analyses not summarized in the data tables of this section are contained in Appendix F.

3.4.1 SAMPLES COLLECTED DURING DIW DRILLING

Samples were collected from the start of reverse-air drilling after setting the casing at 560 feet to the end of drilling at 3,200 feet bls. Samples collected taken at every rod change (30 to 32 feet).

The water samples were marked as to time and date collected. Field measurements of temperature, conductivity, and chloride concentration were made at the time of collection whenever possible. A duplicate sample for each depth was chilled and then sent to CH2M HILL's laboratory in Gainesville, Florida, for analysis of conductivity and TDS.

Results of the analysis of reverse-air samples during drilling do not necessarily reflect exact water quality conditions at the listed depth indicated by the sample. Because the drill rod acts as a pump during reverse-air drilling, the water collected represents a mix of borehole waters reaching the drill stem. The reverse-air samples are therefore only indicators of significant water quality changes.

The water quality determinations made on the reverse-air samples collected during exploratory hole drilling for the North Port DIW are compiled in Table 3-1. Plots of depth vs. water quality have been constructed from the exploratory hole data to illustrate the water quality changes with depth observed during the drilling at North Port. The increase in chloride, conductivity, and TDS with respect to depth in the DIW is shown in Figures 3-4, 3-5, and 3-6.

The water quality data indicates that the 10,000-mg/l TDS interface occurs in the Suwannee Limestone very near the top of the zone where reverse-air drilling began. As shown in Table 3-1, the first sample collected (825 feet) had a TDS concentration of 13,220 mg/l and a conductivity of 20,700 μmhos/cm, giving a ratio of 0.64. By applying this ratio to reverse-air samples taken from the first few rods, CH2M HILL determined the the 10,000-mg/l TDS interface apparently occurs between the 632-foot and 662-foot levels.

The most significant water quality shift observed in the pilot hole while drilling was at the 1,100- to 1,200-foot depth range. As shown in Figure 3-5, the conductivity shifts from the 21,000 μmhos/cm range to the 40,000 μmhos/cm range at approximately 1,200 feet, and remains above 30,000 μmhos/cm to the total depth of the well. This shift is also shown by the chloride levels in Figure 3-4 and TDS levels shown in Figure 3-6. This shift in water quality corresponds to the penetration of the Avon Park production zone by

Table 3-1
NORTH PORT DIW WATER QUALITY DATA FROM REVERSE-AIR SAMPLES FROM PILOT HOLE DRILLING

Date	Time	Depth (feet)	Field Data[a] Temperature (C°)	Field Data[a] Conductivity (umhos/cm)	Field Data[a] Chloride (mg/1)	Wet Laboratory[b] Conductivity (umhos/cm)	Wet Laboratory[b] Total Dissolved Solids (mg/1)
4/12/87	0730	604	20	11,800	3,877	----	----
4/12/87	0830	632	20	14,800	5,578	----	----
4/12/87	1030	662	20	16,600	6,428	----	----
4/12/87	1230	692	10[c]	17,200	6,603	----	----
4/12/87	1400	724	10[c]	16,200	6,403	----	----
4/12/87	1500	754	10[c]	20,200	7,470	----	----
4/13/87	0730	793	10[c]	21,100	7,804	----	----
4/13/87	1103	825	10[c]	21,000	7,954	20,700	13,220
4/13/87	1630	854	10[c]	20,500	8,154	19,700	13,640
4/15/87	----	884	24	21,100	8,297	22,300	14,458
4/15/87	0940	917	26	22,000	7,847	22,900	15,502
4/16/87	1645	960	21	21,300	8,097	23,000	14,836
4/16/87	1022	990	21	20,000	7,397	22,000	14,150
4/17/87	0030	1,013	21	20,000	6,797	21,600	13,988
4/17/87	1047	1,043	25	20,900	8,597	22,000	14,252
4/18/87	0852	1,074	21	21,100	8,897	22,100	14,480
4/20/87	0600	1,110	25	18,600	7,197	21,600	14,434
4/20/87	2100	1,138	30	25,400	8,497	24,600	16,249
4/20/87	0715	1,169	30	17,100	8,704	25,800	17,112
4/21/87	1515	1,200	30	21,900	10,406	33,600	23,070
4/27/87	1055	1,235	26	32,000	13,395	41,900	34,000
4/28/87	1730	1,268	26	29,000	12,896	36,800	26,600
4/29/87	1730	1,296	26	28,000	14,895	39,000	27,600
4/29/87	1030	1,329	13[c]	29,000	15,695	38,300	27,000
4/30/87	1130	1,363	17[c]	20,000	13,495	39,000	28,500
5/01/87	0823	1,396	27	30,000	15,895	46,100	28,200
5/01/87	2321	1,425	32	36,000	15,995	47,600	35,500
5/02/87	1745	1,460	21	27,000	15,195	47,900	35,800
5/03/87	0415	1,489	29	31,000	16,095	47,600	34,800
5/03/87	1111	1,522	30	32,200	15,695	48,900	42,400
5/03/87	1930	1,555	24	30,000	14,495	47,500	36,200
5/04/87	0950	1,587	33	28,000	15,365	34,600	25,400
5/19/87	0920	1,620	33	34,000	15,708	41,400	30,800
5/19/87	2300	1,650	33	38,800	16,708	46,500	34,150
5/20/87	1030	1,680	33	36,500	16,308	46,200	35,000
5/21/87	1500	1,718	33	37,500	15,908	45,800	34,900
5/22/87	0400	1,749	33	37,000	16,509	41,900	31,000
5/22/87	1130	1,782	33	33,500	15,109	43,000	32,000

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Table 3-1 (Continued)

Date	Time	Depth (feet)	Field Data[a] Temperature (C°)	Field Data[a] Conductivity (umhos/cm)	Field Data[a] Chloride (mg/l)	Wet Laboratory[b] Conductivity (umhos/cm)	Wet Laboratory[b] Total Dissolved Solids (mg/l)
5/22/87	1820	1,810	33	35,000	16,209	44,400	32,500
5/22/87	1842	1,846	33	33,000	16,409	46,100	34,400
5/23/87	0015	1,870	33	36,000	16,509	40,600	29,700
5/23/87	1030	1,910	33	31,500	15,009	42,000	30,500
5/23/87	1600	1,941	33	32,000	14,707	42,500	34,900
5/23/87	1852	1,974	33	32,500	15,809	46,200	35,300
5/23/87	1950	2,004	33	35,000	17,800	45.900	34,000
5/27/87	1915	2,036	25	36,000	16,194	41,600	34,400
5/29/87	----	2,067	25	35,000	15,995	44,200	34,300
5/29/87	0848	2,100	30	37,000	15,595	42,800	33,900
5/29/87	2320	2,164	30	37,900	13,995	40,100	30,600
5/30/87	0500	2,195	34	35,000	13,795	40,600	39,800
5/30/87	0800	2,227	35	36,000	15,195	43,000	35,400
5/30/87	0925	2,258	36	40,000	15,795	41,600	35,000
5/30/87	1201	2,291	36	39,000	15,995	43,400	35,100
5/30/87	1615	2,323	35	36,000	15,495	42,600	35,200
5/30/87	1824	2,355	23	30,000	14,995	43,300	35,600
5/30/87	2300	2,385	24	29,500	14,695	44,500	34,600
5/31/87	0030	2,420	24	30,000	14,695	44,100	34,100
5/31/87	0145	2,456	24	29,500	14,495	43,500	34,100
5/31/87	0330	2,488	24	29,000	14,295	44,000	33,400
5/31/87	0540	2,520	24	29,500	14,195	41,100	30,800
5/31/87	0719	2,551	29	33,000	14,195	44,900	34,000
5/31/87	1400	2,584	23	34,000	15,495	42,900	32,800
6/01/87	0830	2,615	35	40,000	14,195	43,500	34,300
6/02/87	0115	2,656	24	31,000	14,595	43,600	34,200
6/02/87	0430	2,683	25	31,000	14,195	43,300	33,800
6/02/87	0710	2,712	26	38,000	14,595	43,900	33,900
6/02/87	0900	2,744	26	38,500	14,195	43,700	34,800
6/02/87	1006	2,777	31	35,500	14,095	43,600	34,100
6/02/87	1130	2,810	34	37,000	14,885	43,700	34,300
6/02/87	1435	2,842	36	39,000	13,795	43,400	34,400
6/02/87	1455	2,875	36	38,000	14,795	42,800	34,000
6/02/87	1600	2,906	31	36,500	14,195	43,900	33,600
6/02/87	1725	2,938	33	36,500	14,095	44,500	34,500
6/02/87	1930	2,971	27	30,000	14,085	45,600	33,900
6/02/87	2317	3,004	27	30,000	15,895	46,000	35,600
6/03/87	0603	3,034	28.5	33,000	14,095	43,500	35,600
6/03/87	1020	3,065	38	43,000	16,494	45,500	35,400
6/03/87	1600	3,095	32	35,500	14,895	45,300	35,400
6/03/87	2230	3,132	27	33,500	14,195	45,000	36,800
6/04/87	0532	3,157	28	33,000	14,895	45,900	35,500
6/04/87	1225	3,188	34.5	37,000	14,695	46,300	36,500
6/04/87	1450	3,200	32.5	33,000	17,110	45,700	36,800

[a] CH2M HILL field trailer.
[b] CH2M HILL laboratory.
[c] Sample was chilled prior to reading.

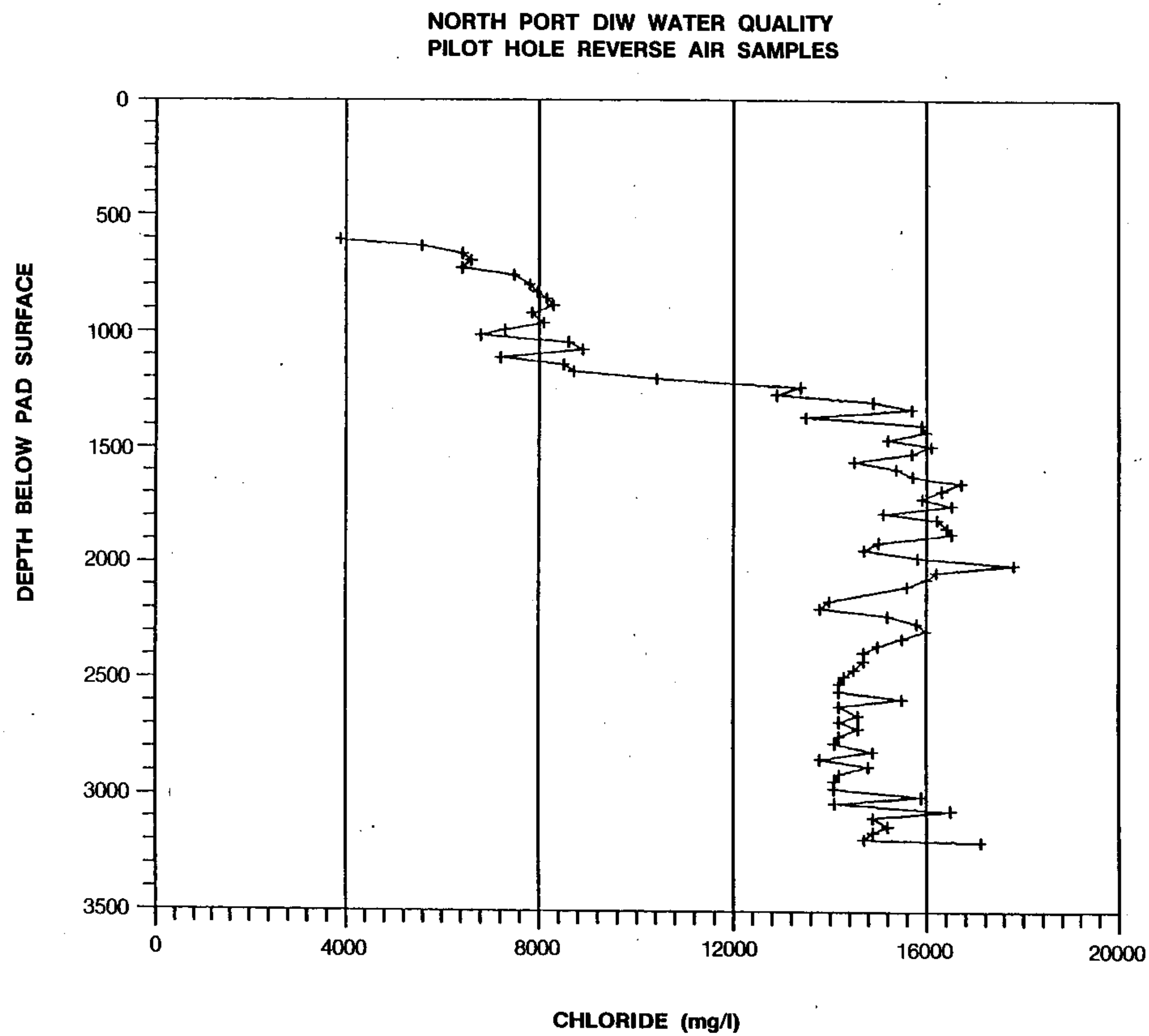

FIGURE 3-4.
Plot of Field Lab Chloride Data from Pilot Hole Drilling of the North Port DIW.

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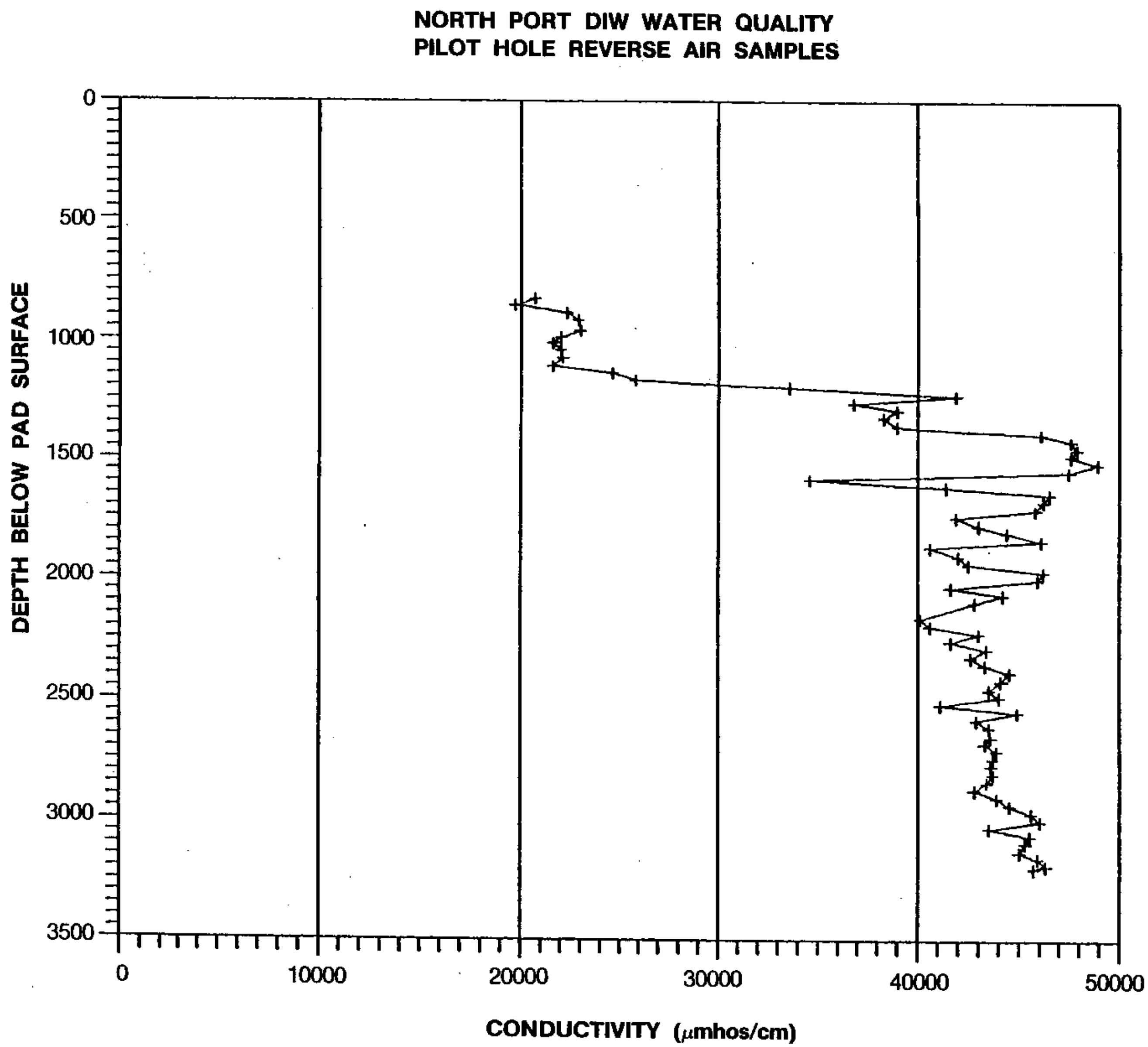

FIGURE 3-5.
Plot of Wet Lab Conductivity Data from Pilot Hole Drilling of the North Port DIW.

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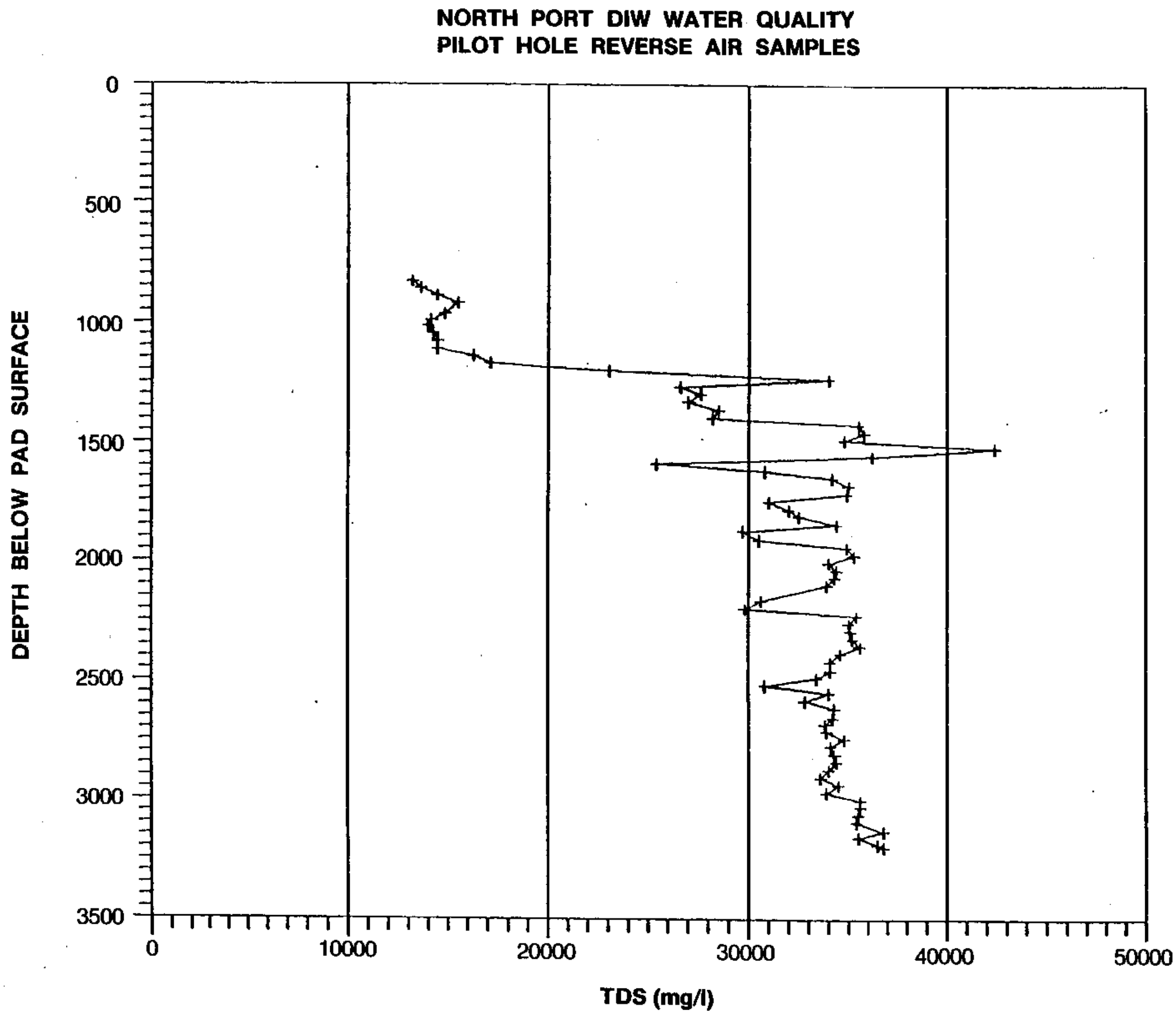

FIGURE 3-6.
Plot of Wet Lab TDS Data from Pilot Hole Drilling of the North Port DIW.

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the exploratory hole. The occurrence of the more highly mineralized water in the lower part of the Floridan aquifer may be indicative of good hydraulic separation between the upper and lower parts of the Floridan aquifer system at this site. The water in the lower Floridan probably represents older, more highly mineralized water associated with a less active recharge system than the upper Floridan.

3.4.2 SAMPLES COLLECTED DURING PUMP AND PACKER TEST FROM THE DIW

Water quality data from samples collected during hydraulic and packer testing on the DIW during construction are compiled in Table 3-2. Depth samples were collected from the test well during each of the six hydraulic tests to characterize the water quality of zones of interest detected during drilling and from the geophysical logs, which were run before depth sampling. Depth samples were generally collected above and below major producing zones in the tested section to give an indication of the general water quality being contributed by the zone of interest. Water samples collected with the depth sampler were immediately measured for conductivity, chloride, and temperature in the field. Duplicate samples were chilled and sent to CH2M HILL's Gainesville lab for conductivity and TDS analysis. Certain samples were analyzed for a more thorough list of constituents; these samples are indicated in Table 3-2.

The depth samples show the same basic water quality trends as the exploratory hole reverse-air samples. Above 1,100 feet, conductivities were in the 20,000 µmhos/cm range. Below 1,100 feet water quality deteriorates rapidly, with the 1,175-foot depth sample having a conductance of 35,200 µmhos/cm (Table 3-2).

The bottom hole depth sample taken at 3,000 feet shows a TDS content of 51,600 mg/l. This level is considerably higher than the concentration in the 3,200-foot reverse-air sample, probably reflecting mixing in the reverse air sample.

Packer test samples were collected at the end of both tests run on the DIW. Sample handling was the same as the depth samples. The results of the analysis for the packer test samples are shown at the bottom of Table 3-2.

The packer test samples represent the water quality in the discrete zone packed off during the test. Both packer tests (discussed later in this section) were run in the Ocala formation where a smooth borehole wall allowed packer setting. Water quality was similar between tests with TDS levels between 22,000 and 24,000 mg/l.

Table 3-2
NORTH PORT DIW WATER QUALITY DATA FROM HYDRAULIC TESTING

Date	Time	Type Test	Field Data[a] Temperature (C°)	Field Data[a] Conductivity (umhos/cm)	Field Data[a] Chloride (mg/l)	Wet Laboratory[b] Conductivity (umhos/cm)	Wet Laboratory[b] Total Dissolved Solids (mg/l)	Sample Description
5/14/87	1600	Pump Test 854 ft	25	20,600	7,397	20,300	13,940	Pumped Discharge
5/14/87	1400	Pump Test 854 ft	25	21,000	8,397	20,600	14,920	580 ft Depth Sample
5/14/87	1400	Pump Test 854 ft	25	21,000	11,696	20,100	15,190	605 ft Depth Sample
5/14/87	1500	Pump Test 854 ft	25	21,900	10,796	20,600	15,780	632 ft Depth Sample
5/14/87	1520	Pump Test 854 ft	25	21,800	10,946	21,000	12,330	700 ft Depth Sample
5/14/87	1545	Pump Test 854 ft	25	21,200	9,896	17,200	11,950	780 ft Depth Sample
5/19/87	1315	Pump Test 1,100 ft	26	21,500	11,496	21,800	14,026	Pumped Discharge
5/19/87	1320	Pump Test 1,100 ft	27	15,000	5,498	15,100	9,107	900 ft Depth Sample
5/19/87	1340	Pump Test 1,100 ft	26	16,100	6,298	17,200	10,850	1090 ft Depth Sample
5/22/87	1600	Pump Test 1,200 ft	30	24,000	11,406	31,600	21,350	Pumped Discharge[c]
5/22/87	1420	Pump Test 1,200 ft	30	22,100	20,905	32,400	22,076	1118 ft Depth Sample[c]
5/22/87	1430	Pump Test 1,200 ft	30	24,100	13,006	35,200	24,900	1175 ft Depth Sample[c]
4/05/87	1800	Pump Test 1,600 ft	30	32,000	14,007	33,800	27,400	Pumped Discharge
4/05/87	1814	Pump Test 1,600 ft	30	25,000	15,208	47,700	36,500	1260 ft Depth Sample[c]
4/05/87	1850	Pump Test 1,600 ft	30	25,000	16,909	40,400	33,700	1540 ft Depth Sample[c]
5/27/87	0030	Pump Test 2,000 ft	--	----	----	41,600	31,600	Pumped Discharge[c]
5/27/87	0030	Pump Test 2,000 ft	--	----	----	45,900	34,000	1790 ft Depth Sample
6/05/87	1300	Pump Test 3,200 ft	33	34,500	16,670	45,800	32,300	Pumped Discharge (early)
6/05/87	1700	Pump Test 3,200 ft	33	35,200	15,710	44,900	31,900	Pumped Discharge (late)
6/06/87	0030	Pump Test 3,200 ft	33	50,500	25,314	66,800	51,600	3000 ft Depth Sample[c]
5/24/87	1840	Packer 1,020-1,032	29.5	25,300	13,107	33,800	23,842	1020-1032 ft Packer Test
5/25/87	1500	Packer 1,054-1,066	29	24,200	12,806	33,400	22,076	1054-1066 ft Packer Test

[a]Samples analyzed at field laboratory in onsite trailer
[b]Samples analyzed at CH2M HILL lab in Gainesville, Florida
[c]Sample analyzed for additional selected constituents

3.4.3 SAMPLES COLLECTED DURING CONSTRUCTION AND TESTING OF THE OMW

The water quality data obtained during the construction and testing of the OMW are summarized in Table 3-3. Reverse-air samples were collected at each rod change (30 to 32 feet) below the 551-foot casing setting depth. These samples were sent to the CH2M HILL Gainesville laboratory for analysis. During logging of the OMW, the well was free-flowing and depth samples were obtained.

The 10,000-mg/l TDS interface apparently occurs between the 629-foot and the 660-foot level as indicated by the reverse-air sample. This corresponds well with the location of the 10,000-mg/l TDS interface in the DIW.

3.4.4 BACKGROUND SAMPLES

In the October 8, 1987 meeting, the TAC outlined the background data required by FDER for the North Port system to satisfy permit requirements before effluent testing. These requirements are shown in Tables 3-4 and 3-5. Table 3-4 is a list of cations, anions, and physical properties analysis for each well. Table 3-5 is a list of primary and secondary standard constituents analyzed in each well.

Each well was sampled twice to provide a check for the analysis performed. Sampling was performed on November 6, 1987, and November 27, 1987, for the listed parameters in the DIW and OMW construction permits. Sampling took place on November 13 and 27 for the RMW.

A summary of the analysis results, showing constituents of interest, from the background water quality sampling is presented in Table 3-6. Table 3-6 does not list any of the organics, pesticides, herbicides, or heavy metals sampled for in the wells, since the only constituent of this nature above the method detection limit was toluene. Toluene appeared in the 1-2 parts per billion (ppb) range in several of the samples. This was likely to be bottle contamination and not a groundwater contaminant as explained by a memo attached to the sample analysis sheets in Appendix F.

During the 24-hour pump test of the DIW (discussed later in this section), water samples were collected from the well for analysis by the USGS and FDER. A 5-gallon sample was sent to Joe Haberfeld at the FDER Tallahassee office. A 1-gallon sample was sent to Craig Hutchinson with the USGS Tampa office.

Table 3-3
NORTH PORT OMW WATER QUALITY DURING CONSTRUCTION AND TESTING

Date	Time	Field Data Activity	Wet Lab[a] Cond. (umhos/cm)	Wet Lab[a] Chloride (mg/l)	Cond.[b] (umhos/cm)	TDS[b] (mg/l)	Sample Description
22-Jul-87	1200	Pilot Hole Drilling	8,000	1,999	9,700	5,820	551 to 561-Ft. Reverse Air
22-Jul-87	1515	Pilot Hole Drilling	11,000	3,099	12,600	7,820	597-Ft. Reverse Air
22-Jul-87	1605	Pilot Hole Drilling	13,900	4,398	15,400	9,470	629-Ft. Reverse Air
22-Jul-87	1705	Pilot Hole Drilling	15,000	4,898	17,100	10,700	660-Ft. Reverse Air
22-Jul-87	1740	Pilot Hole Drilling	17,200	6,497	22,000	13,300	690-Ft. Reverse Air
22-Jul-87	1820	Pilot Hole Drilling	18,000	6,298	21,900	14,100	720-Ft. Reverse Air
22-Jul-87	1940	Pilot Hole Drilling	18,800	6,398	23,500	14,700	735-Ft. Reverse Air
							Open Hole 560-735
24-Aug-87	----	Logging	----	----	23,600	14,200	560-Ft. Depth Sample
24-Aug-87	----	Logging	----	----	22,800	14,500	600-Ft. Depth Sample
24-Aug-87	----	Logging	----	----	24,200	15,100	730-Ft. Depth Sample
							Open Hole 735-755
09-Sep-87	1228	Logging	----	----	21,400	13,860	730-Ft. Depth Sample
09-Sep-87	1455	Logging	----	----	19,700	13,580	755-Ft. Depth Sample

Notes:

[a]Samples analyzed at field laboratory in onsite trailer.

[b]Samples analyzed at CH2M HILL lab in Gainesville, Florida

Table 3-4
NORTH PORT DIW BACKGROUND WATER QUALITY PARAMETERS:
CATIONS, ANIONS, AND PHYSICAL PROPERTIES

Cations and Anions	Physical Properties
Chloride	Total Dissolved Solids
Fluoride	Conductivity
Sulfate	Turbidity
Carbonates	PH
Bicarbonates	PHs
Calcium	Saturation Index
Magnesium	Odor
Sodium	Total Hardness
Iron	Carbonate Hardness
Potassium	Noncarbonate Hardness
Phosphorus	Alkalinity
Nitrogen Series	Density

Notes:

1. Samples to be collected during the final pump-out test on the DIW, the RMW, and the two OMW zones.

2. A 5-gallon sample of non-acidized water was collected and sent to the DER.

3. A 1-gallon sample of water was collected from the DIW and sent to the Tampa office of the USGS.

Table 3-5
NORTH PORT DIW BACKGROUND WATER QUALITY PARAMETERS: PRIMARY AND SECONDARY STANDARDS

PRIMARY STANDARDS

Inorganics

Arsenic
Barium
Cadmium
Chromium
Lead
Mercury
Nitrate (as N)

Organic

Pesticides
Endrin
Lindane
Methoxychlor
Toxaphene
2, 4-D
2, 4, 5-TP Silvex

Volatile Organics

Trihalomethanes (total)
Trichloroethylene
Tetrachloroethylene
Carbon Tetrachloride
Vinyl Chloride
1, 1, 1-Trichloroethane
1, 2-Dichloroethane
Benzene
Ethylene Dibromide

Other

Turbidity
Microbiological
Radium-226 and -228
Gross Alpha

Parameters Added by Oct 8 TAC

Potassium
Phosphate
Nitrate Series
Density

SECONDARY STANDARDS

Inorganic

Iron
Copper
Manganese
Zinc
Sulfate
Total Dissolved Solids

Other

PH
Color
Corrosivity
Foaming Agents
Odor

Table 3-5
(Continued)

SEWAGE EFFLUENT--GROUNDWATER MONITORING PARAMETERS

Inorganic

Sulfide (field)
Soluble Orthophosphate
Ammonium
Organic Nitrogen

Pesticides

Aldrin
Dieldrin

Acid Extractables

Phenol
2, 4, 6-trichlorophenol
2-chlorophenol

Metals

Antimony

Volatile Organics

Toluene
1, 2 dichlorobenzene
1, 2 dichloroethylene
Chloroethane

Base/Neutral Organics

Diethylphthallate
Dimethylphthallate
Butylbenzylphthallate
Naphthalene
Anthracene
Phenathrene

Table 3-6
NORTH PORT DIW
SUMMARY OF BACKGROUND WATER QUALITY RESULTS

Parameter	DIW		RMW		OMW (Shallow) (550-600 ft bls)		OMW (Deep) (730-750 ft bls)	
	6-Nov-87	13-Nov-87	27-Nov-87	13-Nov-87	6-Nov-87	13-Nov-87	6-Nov-87	13-Nov-87
General								
Ph	7.35	7.15	7.00	7.15	7.55	7.30	7.50	7.25
Color	--	0	--	0	--	0	--	0
Conductivity	37,900	41,800	35,800	----	15,200	16,500	20,700	22,500
Calcium Hardness (as CaCO3)	5,200	3,800	4,200	3,700	2,700	2,500	3,200	2,300
Specific Gravity GM/CC	1.01	1.02	1.02	1.01	1.00	1.01	1.01	1.00
Turbidity	0.57	0.45	0.79	0.16	2.30	0.28	1.0	0.22
Solids								
Total Dissolved Solids	29,300	32,800	25,200	22,100	9,680	10,900	13,700	15,000
Anions								
Chloride	17,000	16,600	13,200	11,800	5,400	5,400	7,900	7,910
Flouride	1.40	1.30	0.96	----	1.24	1.18	1.38	1.30
Sulfate	2,960	3,060	1,920	1,810	1,930	975	1,420	1,450
Metals								
Calcium	2,080	1,520	1,680	----	1,080	1,000	1,280	920
Iron	0.39	0.32	1.73	0.23	0.33	0.15	0.17	0.13
Magnesium	408	720	360	----	168	72	96	720
Potassium	290	315	235	201	61.9	68.2	111	126
Sodium	9,870	8,700	6,800	----	3,490	2,500	4,780	3,500
Copper	0.03	0.03	----	0.07	<.02	----	<.02	----
Nutrients								
Ammonia (asN)	0.98	1.14	0.19	0.30	0.44	0.41	0.38	0.46
Nitrate & Nitrite (as N)	21.0	19.40	0.05	<.02	9.2	9.00	12.9	11.30
Kjeldahl Nitrogen (as N)	1.09	1.17	0.40	0.52	0.82	0.73	0.64	0.52
Total Nitrogen (as N)	22.1	20.60	0.45	0.52	10.0	9.73	13.5	11.80
Total Phosphorus (as P)	0.12	0.02	<.01	0.02	0.02	0.02	0.03	0.03

Notes:
---- Indicates sample not run
≦ - Indicates less tha listed value

3.4.5 SAMPLES COLLECTED DURING OPERATIONAL TESTING

Samples taken during the operational testing data collecting period consisted of weekly and 3-month samples at each of the monitoring points, and a 6-month sampling from the monitoring points and WWTP influent and effluent. The analysis results of the weekly sampling program are included in Appendix L. The 3-month sampling (March 20, 1988) consisted of analyzing for primary inorganic metals and some secondary inorganic metals. Analytical results from the 3-month sampling are also included in Appendix L. A 6-month sampling (July 6, 1988) was collected and analyzed for the parameters listed in Tables 3-4 and 3-5. The complete analytical results from this sampling effort are shown in Appendix L.

3.5 GEOPHYSICAL LOGGING

Geophysical logging provided the basic hydrogeologic data for characterizing the geology and hydrogeologic zonation encountered during the test drilling. The logs were also used to guide construction of the DIW, especially in setting casings and other downhole operations.

Logging was done at the completion of each stage of the exploratory hole drilling concurrently with aquifer hydraulic testing in the DIW. Logging was also done during the construction and testing of the OMW and the RMW.

A CH2M HILL logger performed the caliper, long and short normal electrical resistivity, natural gamma ray, flowmeter, temperature, and fluid resistivity logging surveys. Specialized logging services were provided by Schlumberger well services and by Deep Venture Diving, Inc.

Schlumberger well services performed the cement bond with variable density log, used to evaluate the cement seal surrounding the casing. The variable density log is used to provide information about the quality of the cement-to-formation bonding. The cement bond log run on the 14-inch DIW final casing gives little indication of cement bonding to the casing. Very strong physical evidence was presented to the October 8, 1987, meeting of TAC that good cement placement had taken place in the annular space between the intermediate 24-inch casing and the final 14-inch casing (see Appendix H). The lack of bond signal was probably the result of a micro-annulus between the cement and the 14-inch casing as a result of slight cement shrinkage during curing. The external mechanical integrity was demonstrated by a radioactive tracer survey.

Schlumberger also performed the borehole-compensated sonic log to evaluate the amount of intergranular porosity in the formation.

Deep Venture Diving, Inc., provided the video surveys conducted on the injection well. Video surveys were used to evaluate the formation material and casing condition. The video survey was used as the final casing inspection after the cementing of the injection casing was completed.

The geophysical logs run during and after construction of the North Port DIW System are listed in Section 2. Table 2-2 summarizes the geophysical logging for the DIW. Tables 2-4 and 2-6 summarize the geophysical logging for the DMW and RMW, respectively. Copies of these logs are included in Volume III along with TV survey summaries.

3.6 AQUIFER WITHDRAWAL TESTS

Six short-term tests were run during the construction of the DIW to characterize the hydraulics of the producing zones penetrated by the pilot hole. The open hole depth range of each test and the hydrogeologic formation/formations tested are presented in Table 3-7.

Each test was run under artesian head conditions of varying height above land surface. Each test was designed to accommodate the differing head conditions.

Tests 1 and 2 in the upper Floridan aquifer were run by installing a vertical turbine test pump in the well at the level of the rig floor (13.05 feet above pad), discharge piping with a discharge measurement orifice, and a series of settling tanks that discharged to the adjacent borrow pit.

The artesian head in the upper Floridan aquifer allowed the well to flow over the stand pipe prior to pumping on these first two tests. Since this condition could not be corrected without considerable expense, Tests 1 and 2 were started from a flowing condition. The flow rates were allowed to stabilize before the start of the test. After drilling was completed, a header was installed on the well and the well was allowed to stabilize. A static head measurement was then taken with a pressure gauge to provide a starting point measurement for the test. Recovery data could not be taken for Tests 1 and 2.

Upon penetration of the highly productive zones of the lower Floridan aquifer (i.e., Avon Park), the well flowed at a rate of over 1,800 gpm. Therefore, Tests 3 and 4 were run as flowing artesian tests so that drawdown and recovery data could be taken.

When Tests 3 and 4 were run, the exploratory hole was open to both the upper and lower Floridan aquifer. During both tests, the artesian head equilibrium was in continuous flux

Table 3-7
RESULTS OF SHORT-TERM AQUIFER WITHDRAWAL TESTS FOR THE NORTH PORT DIW

Test Number	Depth Range (feet bls)	Flow Rate (gpm)	Formation(s)
1	560-854	690	Suwannee, Ocala (part.)
2	560-1,100	900	Suwannee, Ocala
3	560-1,200	1,865	Suwannee, Ocala, Avon Park (part.)
4	560-1,600	1,300	Suwannee, Ocala, Avon Park, Lake City (part.)
5	1,100-2,000	4,500	Avon Park, Lake City (part.)
6	1,100-3,200	5,000	Avon Park, Lake City, Oldsmar, Cedar Key (part.)

because of the density difference between water in the two zones. When shut in under these conditions the head in the well would rise to near the upper Floridan head. As the well was allowed to flow the denser water from the lower Floridan tended to "kill" the head in the upper Floridan, thus decreasing flow rate. The testing results from these two tests do not give valid hydraulic parameters for either the upper or lower Floridan aquifer.

Tests 5 and 6 were run under lower head conditions and with a relatively uniform density gradient, since the borehole was open only to the lower Floridan aquifer. The lower head allowed the ordinary setup of a vertical turbine test pump with discharge piping and an orifice discharging to the borrow pit.

During each test, the water level recorder at Warm Mineral Springs was carefully checked for proper operation before and after the testing to assure detection of any hydraulic effects on the spring flow from the testing.

A summary of the results of hydraulic testing during construction of the DIW is provided in Table 3-8. The test data from each of the tests is in Appendix I. A time vs. drawdown plot for each test is included with the pump test data. A recovery plot is also provided where recovery data were taken.

The purpose of running each of the pump tests and the hydraulic parameters derived from the analysis of the data (where possible) are described in the following subsections.

3.6.1 PUMP TEST 1

This test was conducted on the open hole from 560 to 854 feet bls. This test was run to characterize the hydraulics of the productive portions of the upper Floridan aquifer monitor zone. The 12-inch-diameter pilot hole was open to the Suwannee Limestone and the top of the Ocala Group.

Test 1, a step drawdown test, started from a flowing condition. Three flow rate steps were run, a flow measurement step of 51 gpm, and pumping steps of 550 and 690 gallons per minute (gpm). The first pumping step was run for 35 minutes with the last step run for 300 minutes while geophysical logging was proceeding. Discharge was measured using a 6-inch x 5-inch orifice plate. Water level measurements were made from the top of the rotary table using a chalked steel tape and also with a bubbler tube pressurized by the rig air supply with measurements taken with a Heise 0 to 60 psi pressure gauge calibrated in 0.1-psi increments.

Table 3-8
SUMMARY OF HYDRAULIC TESTING DATA FOR THE NORTH PORT DIW

Well	Test Type	Test No.	Date	Open Hole Interval	Step No.	Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)	Friction Losses	Corrected Specific Capacity	Calc. Transmis.[b]	Estimated Transmis. 2000 x SC (gpd/ft)
DIW	Pumped	1	4/14/87	560-854	1	51	1.76	29.0	--	--	--	57,955
					2	550	19.05	28.9	--	--	--	57,743
					3	690	23.55	29.3	--	--	--	58,599
DIW	Pumped	2	4/19/87	560-1100	1	600	18.04	33.3	--	--	--	66,519
					2	750	21.51	34.9	--	--	--	69,735
					3	900	29.36	30.7	--	--	108,000	61,308
DIW	Flowing[a]	3	4/22/87	560-1200	1	1060	1.45	731.0	--	--	--	1,462,069
					2	1284	2.51	511.6	--	--	--	1,023,108
					3	1865	4.58	407.2	--	--	794,100	814,410
					Recovery	0	--	--			214,000	--
DIW	Flowing[a]	4	5/5/87	560-1600	1	1300	4.82	269.7	--	--	1,716,000	539,419
					Recovery	0	--	--	--	--	300,000	--
DIW	Pumped	5	5/26/87	1100-2000	1	3000	4.71	636.9	0.79	765.3	--	1,530,612
					2	3500	5.29	661.6	1.02	819.7	--	1,639,344
					3	4000	5.95	672.3	1.30	860.2	--	1,720,430
					4	4500	6.86	656.0	1.63	860.4	--	1,720,841
					Recovery	0	--	--	--	--	1,450,000	--
DIW	Pumped	6	6/5/87	1100-3200	1	2320	4.52	513.3	0.52	580.0	--	1,160,000
					2	4000	6.15	650.4	1.30	824.7	--	1,649,485
					3	4500	6.21	724.6	1.63	982.5	--	1,965,066
					4	5000	7.17	697.4	1.97	961.5	--	1,923,077
					Recovery	0	--	--	--	--	1,400,000	--
DIW	Pumped	7	11/23/87	1105-3200[c]	1	2200	11.5	191.3	6.60	449.0	--	897,959
					Recovery	0	--	--	--	--	1,056,000	--
RMW	Observ. DIW Pumped	7	11/23/87	1100-1150	1	0	--	--	--	--	1,940,000	--
					Recovery	0	--	--	--	--	2,765,000	--

Notes:

[a]Test results affected by density stratification in borehole.

[b]Transmissivity calculated by Jacob Straight line.

[c]Test run with 14-inch casing installed.

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The resulting specific capacities for these three steps were 29.0, 28.9, and 29.3 gpm/ft, respectively.

A static head measurement was obtained after testing by welding a header to the well casing and making a static head measurement with a 12-inch Heise gauge after allowing the well to completely recover. The static head was measured at 23.85 feet NGVD.

No calculation of aquifer parameters could be made for the Test 1 data because of the lack of recovery data. However, estimates of the transmissivity could be estimated from observing the relationship between transmissivity and specific capacity described by Driscoll (1986). The transmissivity is estimated by taking a factor of 2,000 times the specific capacity in gpm/ft. For the specific capacity values obtained from Test 1, a transmissivity ranging from 57,000 to 59,000 gpm/ft was estimated.

Review of the water level chart from the recorder set at Warm Mineral Springs showed that this test had a perceptible effect on the spring. The effect was very close to the minimum detectable range of the recording equipment, being less than one hundredth of a foot. This was, however, the only test that showed an apparent effect on the water level of the Springs. As discussed in the hydrogeology section for the Suwannee zone, the geophysical logs indicated that most of water produced was from the 620- to 710-foot zones. One of the source zones of the spring may be from this identified production zone or the equivalent at the spring subsurface.

3.6.2 PUMP TEST 2

This test was conducted on the open hole from 560 to 1,100 feet for the same general purpose as Test 1: to characterize the hydraulic production of the upper permeable zone. Test 2 differed from Test 1 by having the pilot hole open to the entire thickness of the Ocala Group as well as the Suwannee Limestone.

Test 2 started from a flowing condition and included three steps: 600, 750, and 900 gpm. Discharge was measured with a 6-inch x 5-inch orifice plate and water levels were measured by both steel tape and the 12-inch Heise gauge (bubbler tube). The respective specific capacities for the three pumping rates were 33.3, 34.9, and 30.7 gpm/foot of drawdown. These capacities showed a slight increase over the capacities observed in Test 1. The increase may be due to the penetration of the small production zone at the top of the Ocala Group or the increased development of the exploratory hole in the Suwannee production zone with continued pumping or both. In any case, the increase in the estimated transmissivity was nominal, with the transmissivities estimated from Test 2 ranging from 61,000 to 69,000 gallons per day per foot (gpd/ft).

The static head measurement made after pump test recovery was 16.66 feet NGVD. Time drawdown plot for Test 2 is shown in Figure 3-7. This plot is the best available representation of the response of the upper Floridan aquifer to pumping stresses at the North Port site. The water level recorder chart at Warm Mineral Springs showed no perceptible response during of Test 2.

3.6.3 FLOWING TESTS 3 AND 4

Tests 3 and 4 were conducted on open-hole ranges of 560-1,200 feet and 560-1,600 feet, respectively. The results from both of these tests, as mentioned previously, were significantly affected by changes in the density of the water produced during the test.

Because of these conditions, hydraulic parameters should not be interpreted from these two tests. The parameters for the upper and lower Floridan aquifers could be determined from results of discrete tests of either the upper or lower Floridan aquifer production zones, which are similar in water quality and hydraulics. The parameters are shown in Table 3-8 and represent a significant increase over the previous tests.

Geophysical logging was done at the time of both tests. These logs allowed definition of the high transmissivity target zones for well construction and subsequent testing. The logs also were used to identify possible monitoring intervals and to obtain water quality data. The tests also allowed the team to investigate the possible effects on Warm Mineral Springs of having the entire Floridan aquifer system open to the borehole. No effects on the spring were observed in either test.

3.6.4 PUMP TEST 5

Test 5 was conducted on the open hole from 1,100 to 2,000 feet to evaluate the hydraulic characteristics of the Avon Park and the upper part of the Lake City Limestone. A high-rate step test was run to stress the section as much as possible, not only to evaluate the production zone but also to evaluate any hydraulic connection with Warm Mineral Spring. A vertical turbine pump was set in the DIW and discharge piping was routed directly to the borrow pit through a 16-inch x 12.5-inch orifice for flow measurement. Water level measurements were made in the DIW with wetted tape and an in situ pressure transducer. The test was run at four rates: 3,000 gpm, 3,500 gpm, 4,000 gpm, and

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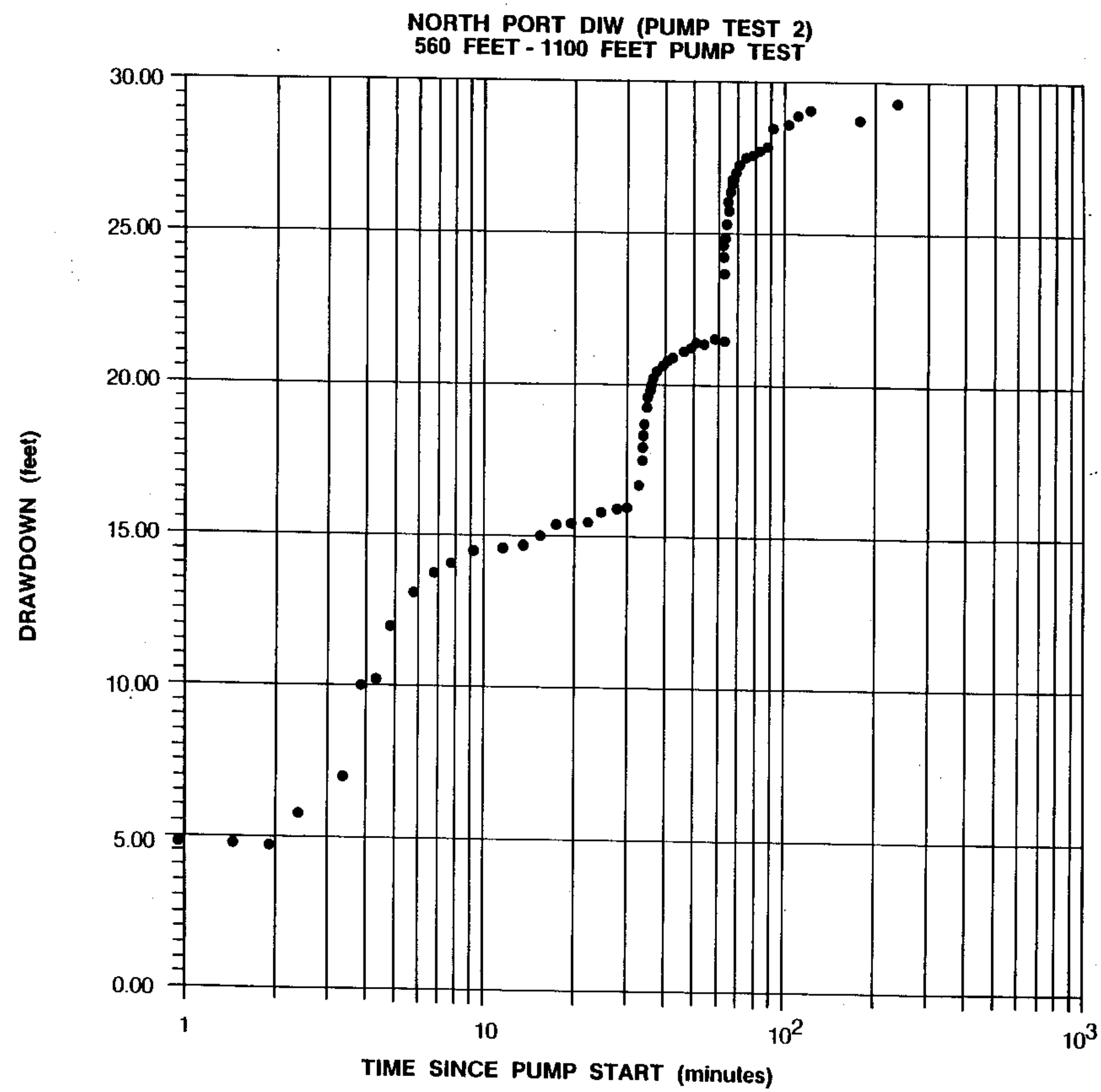

FIGURE 3-7.
North Port DIW Pump Test 2 Drawdown.

CH2M HILL

4,500 gpm. The well was pumped for 30 minutes for the first three rates and 240 minutes for the final rate. Recovery data were taken for an additional 173 minutes after pumping stopped.

The recovery data were analyzed with a method developed by Harrin (1970) for determining transmissivity from step drawdown test recovery data. Using this method, CH2M HILL calculated a transmissivity of 1,450,000 gpd/ft. This analysis is shown in Figure 3-8. Transmissivity estimated from the corrected specific capacity data ranged from 1,500,000 gpd/ft to 1,700,000 gpd/ft, as shown in Table 3-8.

The pumping during Test 5 had no observable effects on the level of Warm Mineral Springs.

3.6.5 PUMP TEST 6

This test was run on the open hole from 1,100 to 3,200 feet to characterize the hydraulic characteristics of the entire open-hole section of the lower part of the Floridan aquifer system. This test was a step test identical to Test 5. The test was run at 2,320 gpm, 4,000 gpm, 4,500 gpm, and 5,000 gpm. The test was run for 30 minutes per pumping step for the first three rates and 476 minutes for the final rate. Recovery data were taken for 714 minutes after pumping stopped.

The recovery data were analyzed with the Harrin (1970) method and a transmissivity of 1,400,000 gpd/ft calculated. A higher specific capacity was observed in the later steps of the test than was observed in Test 5. This increase in specific capacity is probably the result of borehole development during pumping since little production was indicated from the logs of the section of borehole deeper than 1,640 feet. Transmissivities estimated from corrected specific capacity ranged from 1,100,000 gpd/ft to 1,900,000 gpd/ft, as shown in Table 3-8.

Changes in the density of produced water were apparent during this test. The relatively long open-hole section (1,100-3,200 feet bls) had water quality in the 36,000-mg/l TDS range at the bottom of the borehole and water with a 15,000- to 20,000-mg/l TDS range in the upper part of the bore hole. The effect is most noticeable is the apparent decrease in transmissivity from those calculated from the recovery data in Test 5. The recovery for this test probably provides a less accurate picture of the true transmissivity than the value calculated from the Test 5 data because of density stratification.

The pumping during Test 6 had no observable effects on Warm Mineral Springs.

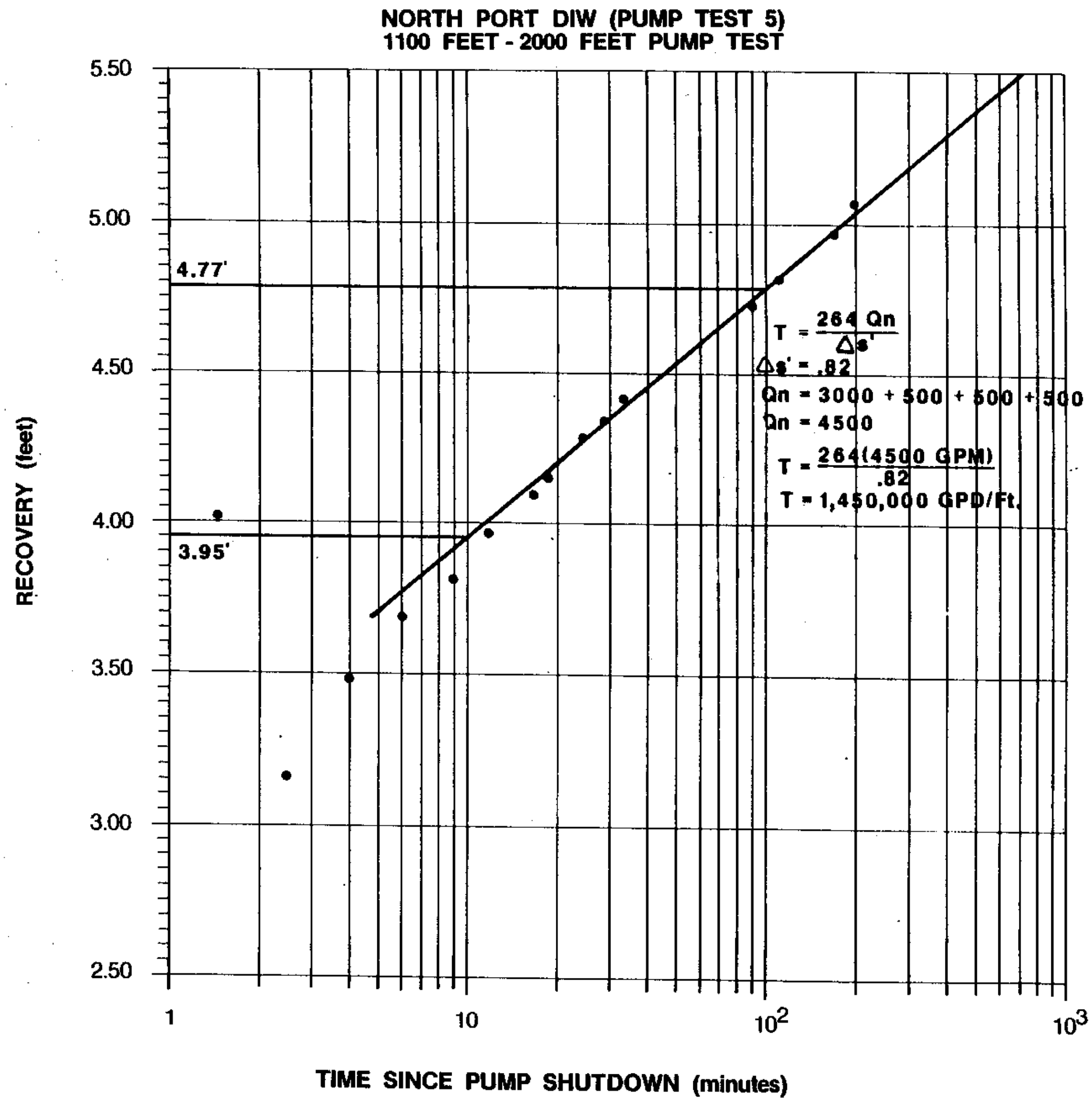

FIGURE 3-8.
North Port DIW Recovery Analysis of Pump Test 5.

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3.7 CORING

During the drilling of the 12¼-inch pilot hole, 10 limestone and dolomite rock cores were obtained from selected sections of the borehole. A total of 29 coring runs were made. Most of the missed cores occurred in the poorly consolidated formations between 1,200 feet and 1,750 feet bls.

The cores were retrieved with a 10-foot, 4-inch inside diameter core barrel tipped with either a tungsten carbide bit or diamond impregnated bit, depending on the hardness and texture of the material to be cored. A summary of the coring activity during the construction of the North Port DIW is presented in Table 3-9.

Sections of each core from the zones characterized hydrogeologically as confining units were sent to the Tuscaloosa Testing Lab (TTL) in Tuscaloosa, Alabama, for permeability, compressibility, and porosity testing. A summary of the TTL's analysis results is shown in Table 3-10.

The vertical permeability data from the test results from the cores were used to estimate the confinement of the injection zone from the overlying aquifers. The methodology applied is based on the method Sinclair (1974) used to estimate confining bed permeability above the Floridan aquifer in Hillsborough County, Florida. The method allows determination of the resultant vertical permeability of a confining unit by compositing the permeabilities and thicknesses of multiple zones within the confining unit. The compositing is done as follows:

$$Pv = M/(m1/p1+m2/p2+....mn/pn)$$

where:

Pv = the composite coefficient of vertical permeability for confining unit

M = the total thickness of all confining layers

m = the thickness of individual confining units

p = is the coefficient of vertical permeability in each layer

The thickness of zones that corresponded to specific core permeablity data was determined on the basis of similar lithology. The confining material from the bottom of the final injection casing at 1,105 feet to the bottom of the lower zone of the OMW monitoring well at 750 feet was used in the compositing. The resulting vertical permeability estimate for the 355 feet of material was 0.058 feet/day.

Table 3-9
SUMMARY OF THE NORTH PORT DIW CORING ACTIVITY

Core Run No.	Depth Ft. Bps	Formation Material	Percent Recovery	Acceptance[a]	Testing
1	854-864	LS	45	Yes	X-862[b]
2	892-902	LS	0	No	
3	904-914	LS	50	Yes	X-914
4	914-924	LS	80	Yes	X-916
5	941-951	LS	80	Yes	X-947
6	1020-1030	LS	90	Yes	X-1020, 1024
7	1060-1070	LS	0	No	
8	1071-1081	LS	90	Yes	X-1072
9	1100-1110	DOL & LS	80	Yes	X-1105
10	1138-1148	DOL & LS	90	Yes	X-1143
11	1170-1180	LS	20	No	
12	1180-1190	LS	40	Yes	X-1185
13	1220-1230	LS	0	No	
14	1268-1278	DOL & LS	0	No	
15	1279-1289	DOL	0	No	
16	1296-1306	DOL	5	No	
17	1308-1318	DOL	0	No	
18	1347-1357	LS	2	No	
19	1363-1373	DOL	4	No	
20	1448-1458	LS	60	Yes[c]	
21	1458-1468	LS	0	No	
22	1489-1499	DOL & LS	0	No	
23	1555-1565	DOL	0	No	
24	1738-1748	DOL	0	No	
25	2036-2046	LS	100	Yes[c]	
26	2051-2061	LS	0	No	
27	2069-2079	DOL & LS	100	Yes[c]	
28	2143-2153	LS	70	Yes[c]	
29	2565-2575	LS	0	No	
30	2631-2641	LS	0	No	

Notes:

[a]Acceptance based on recovery of 30 percent and an undisturbed section at least 6 inches long.

[b]X-862 indicates that the sample was sent to Tuscaloosa Testing Lab for permeability and porosity analysis. The number indicates the sample approximate depth.

[c]No testing was performed on these cores because they were already in the injection zone.

Table 3-10
SUMMARY OF CORE ANALYSES OF SAMPLES COLLECTED AT THE NORTH PORT DIW

Sample No.	Sample Depth (feet)	Effective Porosity (percent)	Vertical Permeability (feet/day)[a]	Horizontal Permeability (feet/day)[a]	Ultimate Load (lbs)	Corrected Unit Load (psi)
1	854-862 (862)	37	0.567	0.567	2300	851
2	903-913 (913)	37	2.268	1.134	1500	574
3	914-924 (916)	37	0.283	0.567	1400	530
4	941-951 (947)	31	0.085	0.142	1600	665
5	1020-1030 (1020)	24	0.057	0.085	4200	1607
5	1020-1030 (1029)	22	0.057	0.057	3000	1247
6	1071-1081 (1072)	22	0.026	0.057	4950	2058
6	1071-1081 (1074)	22	0.023	0.023	5550	2123
7	1100-1110 (1105)	27	0.006	0.011	3450	1334

[a] 20,000 ppm NaCl Solution used as permeant Analysis by Tuscaloosa Testing Lab, Tuscaloosa, Alabama

3.8 STRADDLE PACKER TESTS

Two straddle packer tests were run during the construction of the DIW to test the horizontal permeability of the confinement material and to obtain water quality samples from a discrete zone in the confinement.

The packer service company TAM International was hired by the contractor to build, deliver, and operate the straddle packer used to conduct both tests. The packer was a nominal 11-inch-diameter heavy vinyl face expansion packer, inflated with fluid. The separation between the two packer faces used was a nominal 12 feet. The packer was operated by placing the packer on the drill rod, lowering to the selected test internal face and inflating through the drill pipe. The packer elements were sealed after inflation above and below the section to be tested, and ports in the packer mandrel were opened to provide access to the packed-off formation.

The two zones that were packer-tested were 1,020 feet to 1,032 feet bls and 1,054 feet to 1,066 feet bls. These depths were chosen for two reasons:

1. The zones were in the lower, confining portion of the Ocala Group where testing would yield information on confining bed permeability.

2. The borehole at these locations showed a smooth face for packer sealing (both on caliper and video survey).

The following general procedure for running the packer tests was used: A submersible pump was set inside of the drill string at a depth of 90 to 100 feet below the rotary table. A pressure recorder was set up, with a transducer set just above pump depth for recording water levels. A bubbler tube attached to the Heise gauge was set up for backup water level measurements, and a constant-rate test was run. Typical pumping rate was less than 5 gpm. Pumping continued until the water level drew down to pump level and pumping had to stop. The final step was to take recovery data for 5 to 6 hours after pumping stopped.

Recovery data from the tests were used to calculate the transmissivity of the interval, which was converted to permeability by dividing by the interval thickness as shown in Figure 3-9 (the 1,020- to 1,032-foot depth interval test). The resulting calculated horizontal permeabilities for the two zones were: 1,020 to 1,032 feet, k = 0.19 feet/day and 1,054 to 1,066 feet, k = 0.52 feet/day. The permeability value for the 1,020- to 1,032-foot test was similar to the horizontal permeability found from the

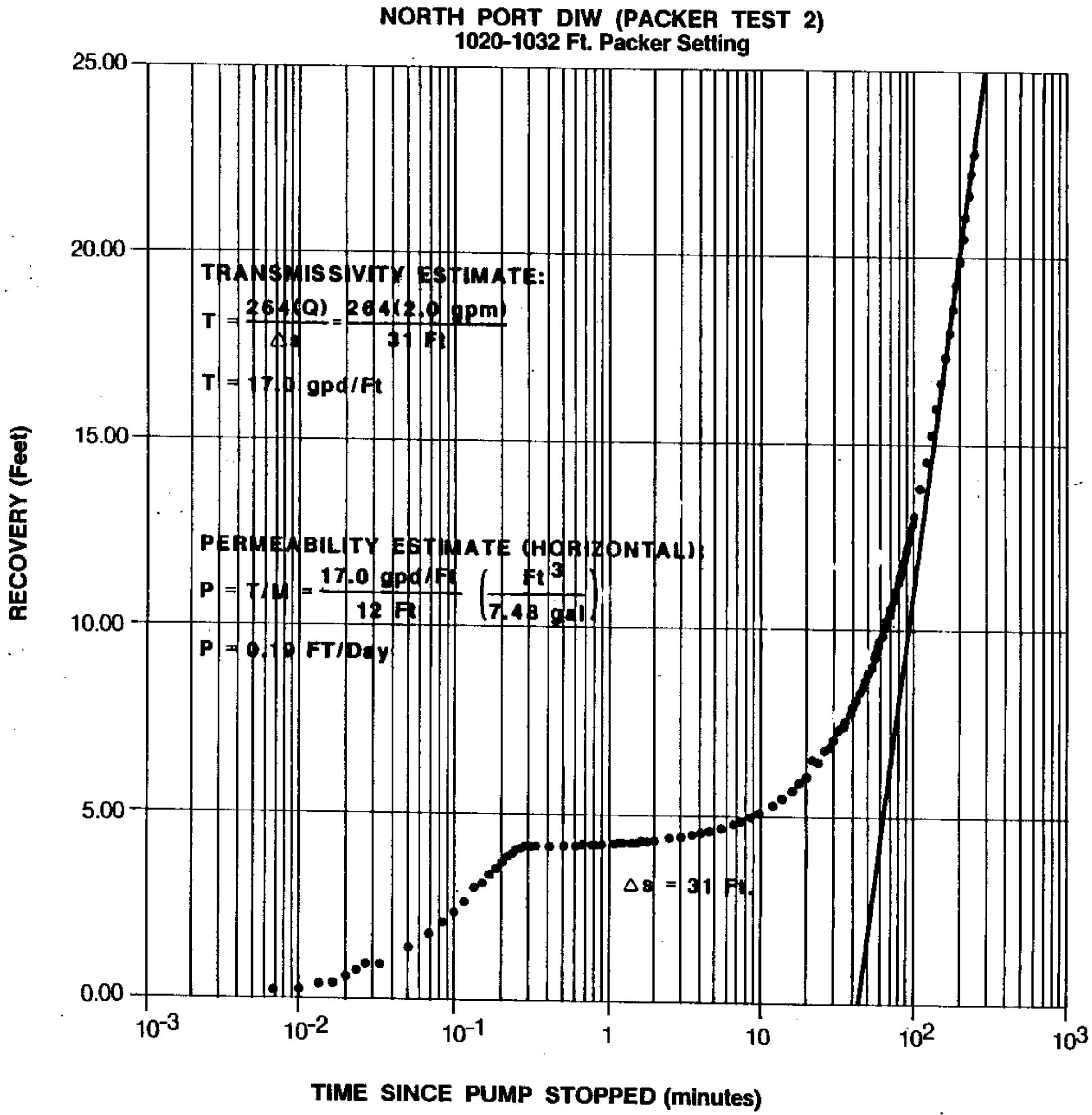

FIGURE 3-9.
North Port DIW Recovery Analysis of 1,020- to 1,032-foot Packer Test.

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corresponding core for the zone (0.085 feet/day). The permeability calculated for the 1,054- to 1,066-foot test is an order of magnitude higher than the 1,070-foot core, which gave a horizontal permeability of 0.057 feet/day. Several reasons may be theorized about why the two values differ. One reason is packer leakage, and another is that the packer tests a longer rock section, accessing more bed-oriented permeability within the confinement. However, the vertical permeability data from the core data would not be expected to show a similar behavior since vertical permeability is perpendicular to bedding planes. The leak mechanism may be that the boreholes are not smooth and obtaining a perfect hydraulic seal is difficult. Hydraulic test data from the two tests, including drawdown and recovery plots for each test, are included in Appendix G.

Water quality data from the two tests are shown in Table 3-2. The water quality for the two tests was similar. TDS was 23,842 mg/l in the 1,020- to 1,032-foot test and 22,076 mg/l in the 1,054- to 1,066-foot test.

3.9 NEUMAN-WITHERSPOON TEST FEASIBILITY STUDY

Phase II of the DER permit for construction of the North Port DIW (UC58-110617) mandated the need to use the Neuman-Witherspoon (1972) method to determine the properties of the confining zone, if this test method was determined feasible for the site. CH2M HILL investigated the feasibility of the success of the methodology in defining the characteristics of the confinement.

The feasibility study was based on the generation of synthetic responses calculated for the injection and confining zone with the analytical methodologies outlined in the Neuman-Witherspoon paper (1972). The analyses were performed for three different transmissivities and three different flow rates to determine a range of possible responses for the system. The calculations showed that, with the expected transmissivity of the DIW system at 2,000,000 gpd/ft, the drawdowns in the overlying confining layer would be small, since drawdowns in the aquifer were small at proposed testing rates. Problems occur with the accurate measurement of small drawdowns in the confinement, because of the effects of heterogeneities in the system and tidal influences. Therefore, more accurate confinement data could be obtained from the Neuman-Witherspoon method than those obtained from core and packer tests. The conclusions of the feasibility study were that the test was of marginal practical usefulness despite being theoretically appropriate and, if run, the monitoring should be done as close to the DIW as possible because of the high transmissivity of the injection zone.

The feasibility study was presented to the TAC at the June 11, 1987 meeting for review. The TAC decided during the next meeting on June 30, 1987, that, although being a good theoretical approach, the Neuman-Witherspoon was not a practical application at North Port. Several instances of practical shortcomings of the method in Florida applications were noted during the discussions. The TAC concurred with the CH2M HILL recommendation that the 24-hour pump test of the injection zone with monitoring of the OMW and the RMW be a more appropriate would substitute for the Neuman-Witherspoon testing.

The complete Neuman-Witherspoon feasibility study is included in Appendix J.

3.10 24-HOUR PUMP TEST

A final pump-out test on the North Port DIW was run on November 23, 1987, to comply with the TAC decision to test the proposed injection system to try to quantify the hydraulic parameters of the injection zone. A description of the methodology used in gathering the pump test data and the results of the data analysis follows.

3.10.1 TEST DESIGN AND MONITORING

At the October 8, 1987, TAC meeting, a 24-hour constant discharge pump test was agreed upon as the preferred test type and length for determining injection zone parameters useful in quantifying the hydraulic effects of the proposed effluent injection on the Avon Park/Lake City injection zone. The RMW, completed in the injection zone at a radius of 4,150 feet from the DIW, was planned to provide drawdown and recovery data useful in the estimating the hydraulic parameters of transmissivity (T), storage (S), and leakance coefficient (L) for the injection zone.

The test was designed to be run in three phases over 7 days as follows:

- <u>Background Data Collection</u>. Background data were collected for 5 days before the testing period. The data were collected to provide trend correction information for the testing period.

- <u>Pumping Data Collection</u>. Potentiometric data from all monitored zones were collected on a continuous basis for the 24 hours of constant discharge pumping.

- <u>Recovery Data Collection</u>. The potentiometric surface recovery data for all monitored zones were collected for 24 hours after pumping stopped.

3.10.2 OTHER MONITORING

During the background and testing period, the continuous stage recorder at Warm Mineral Springs was operating and spot checks were made to check the equipment. Water quality observations of the spring were also continued and barometric pressure and rainfall were recorded during the testing.

3.10.3 BACKGROUND DATA COLLECTION

In addition to the above monitoring at Warm Mineral Springs, four points were monitored during the collection of the background data: the DIW, the RMW, and both zones of the OMW.

The DIW and the OMW zones were monitored with 0- to 15-psi pressure transducers linked to a central data collection unit. The central unit was an Enviro Labs EL-200/System 17 groundwater monitoring system. The data collection time interval was set at 15 minutes during the background period.

The RMW was monitored with a Stevens Type-F recorder set on a stand pipe. An 8-day time scale was used with a 1:1 gear ratio between the float and recorder drum.

The elevation of each wellhead was established by a registered surveyor. These wellhead elevations were used to establish the elevation of the instrument recording heights. The background data were taken from the recording instruments, tabulated, and plotted as elevations. This information is included in Appendix I.

Potentiometric surfaces for all points appear to have a definite tidal fluctuation pattern of about 0.1 foot in magnitude, twice daily. The wells also show some fluctuations not tidally influenced. One noteworthy fluctuation occurred in the DIW. Before installation and testing of the pump on November 22, the potentiometric surface elevation of the DIW was between 12 and 13 feet NGVD. After installing the pump and pump column, and conducting a short preliminary test to check equipment, the potentiometric surface elevation stabilized between 14 and 15 feet NGVD. The reason for this shift in elevation was not readily apparent, but is probably a result of flushing a denser water from the well casing and replacing the water with less dense, but still salty water (greater than 10,000 mg/l TDS) from a formation higher in the open hole section of the DIW.

The RMW showed a long-term downward trend over the background recording period. The magnitude of the trend was small, several tenths of a foot per week, and appeared to be stabilized by the start of the pumping test.

3.10.4 PUMPING TEST DATA COLLECTION

The 24-hour pumping test of the North Port DIW started at 10:30 a.m. on November 23, 1987, and ended at 10:30 a.m. on November 24. The well was pumped at a constant rate of 2,200 gpm throughout the test.

Monitoring of the DIW and both OMW zones was performed with the Enviro Labs EL-200/System 17. The sampling intervals for pressure recordings from the well were set as follows:

30-second intervals: 0 through 10 minutes
1-minute intervals: 10 through 40 minutes
2-minute intervals: 40 through 100 minutes
15-minute intervals: 100 through 1440 minutes

Because the large amount of data gathered during testing was difficult to manage, the Enviro Labs system was interfaced with the onsite microcomputer for data management and compilation.

The Stevens recorder on the RMW was set to a 12-hour time scale during pumping and recovery testing to allow detailed time drawdown resolution in the RMW. Float-to-drum-turn ratio was kept at 1:1 during both the drawdown and recovery periods.

The drawdown data from the recording instruments were taken and compiled on the pump test forms in Appendix I. Plots of the corrected drawdown (see Section 3.10.6) in the DIW and RMW were made. Elevation data from the OMW zones were plotted for the same time period. The plots of the data are also included in Appendix I.

3.10.5 RECOVERY DATA COLLECTION

Recovery data were collected immediately following pump shutdown for 24 hours, ending at 10:30 a.m. November 25, 1987. The DIW was not disturbed during the recovery period.

Data were collected by the same method and frequency used for the drawdown data. Compilation of the data was in the same format as the drawdown data. The recovery data are included in Appendix I along with plots of the recoveries in the DIW and RMW and elevation plots of the OMW data.

3.10.6 ANALYSIS OF PUMPING AND RECOVERY DATA

The data from the RMW and the DIW were used to calculate aquifer parameters. Data from the RMW, however, were preferred data since analytical limitations allowed only transmissivity to be calculated from the DIW data.

Before the RMW data could be used, tidal correction was required. The tidal correction was made by appending the tidal fluctuations for the two days before the start of pumping to the data collected during the pumping and recovery phases of the test. The correction was made by normalizing the drawdown and recovery data to a central line that would have occurred if no tidal fluctuation had taken place. The actual tidal correction value used is shown on the pump test form for the RMW.

The DIW data were also influenced by the tidal fluctuation, but the magnitude of the fluctuation compared to pump fluctuations during the pumping and density stratification during recovery make the correction insignificant. A friction loss correction was necessary for the drawdown data from the DIW. A calculation of friction loss in the well casing was made using the Hazen and Williams formula (Cameron Hydraulic Data). The calculation of friction loss in the casing (Appendix I) gave a loss of 6.6 feet, which was used to correct the drawdown data.

The corrected RMW data were plotted on fully logarithmic paper (see Figure 3-10) and used with the graphical curve matching method for determining the aquifer parameters as developed by Hantush and Jacob in 1955 (Lohman, 1979). The method was developed for analyzing leaky artesian aquifers under constant discharge conditions. The best match obtained followed the nonleaky, or Theis, portion of the L(u,v) versus the 1/u curve for the duration of the collected data. Since the data curve did not show the tendency to follow any of the leaky-type curves the calculation of leakance would have been an extrapolation of injection zone behavior beyond the limits of the data collected. Leakance was therefore not extrapolated from the RMW data. Values of leakance for the confinement are calculated from the core testing data (see Section 5.2).

Once the graphical match of the data to the type curve was established, calculations of the aquifer parameters were made using the match points. The transmissivity calculated from the RMW data was 1,940,000 gpd/foot; storage was 0.0018.

Recovery data from both the DIW and the RMW were plotted on semi-logarithmic paper using the Jacob straight-line method for recovery data analysis (Lohman, 1979). The RMW data analysis gave a transmissivity of 2,765,000 gpd/foot and a storage coefficient of 0.0010. The DIW recovery data gave a transmissivity of 1,056,000 gpd/foot. Storage cannot be calculated at the pumping well. The DIW calculation is considered less reliable than the RMW-derived value because of the density changes in the well water during recovery. A plot of the recovery data from the RMW with the calculations

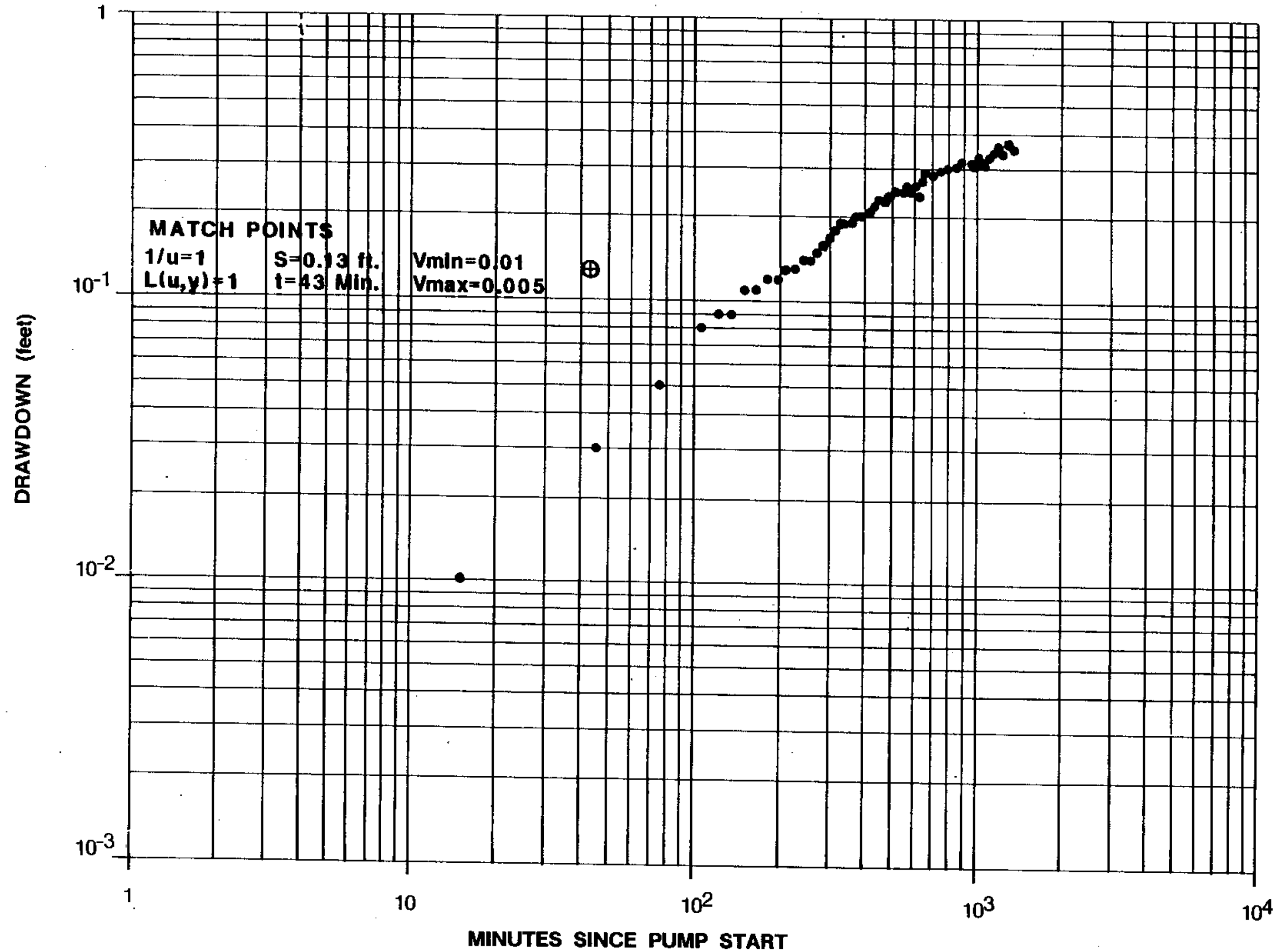

FIGURE 3-10.
North Port DIW Log-Log Plot of Regional Monitor Well Drawdown Data.

for transmissivity and storage is presented in Figure 3-11. Recovery data are compiled along with plots of drawdown and water level elevation for the wells in Appendix I.

3.10.7 SUMMARY OF PUMPING TEST RESULTS

The transmissivity of the injection zone as calculated with the RMW data appears to be similar to the transmissivities estimated from the hydraulic testing of the DIW during construction. A summary of the results of the hydraulic testing of the DIW is shown in Table 3-8. As discussed in Section 3.6, the test best showing the hydraulic characteristics of the injection zone during construction testing was Test 5. The transmissivity calculated from Test 5 recovery was 1,450,000 gpd/ft. Estimated transmissivity from Test 5 based on specific capacity data ranged from 1,500,000 gpd/ft to 1,700,000 gpd/ft. These transmissivity values show a strong correlation to analysis results from the RMW during the 24-hour pumping test, 1,900,000 gpd/ft. This strong correlation suggests that the injection zone is continuous in the area, and has fairly uniform areal hydraulic characteristics. A transmissivity value of 1,900,000 gpd/ft will be used for subsequent calculations. The storage coefficient for the system is probably in the range of 1×10^{-3} to 2×10^{-3}.

The leakance of the beds confining the injection zone could not be calculated from the RMW data since the data did not exhibit leaky characteristics during the test period. The vertical permeability of the confining material for the system, defined with core and straddle packer tests, will be used to estimate vertical travel time and leakance.

No unusual boundary-type effects were observed during the testing. However, apparent density stratification in the DIW produced some unaccountable changes in the potentiometric surface at the DIW. No apparent water level changes were noticed on the recorder data from Warm Mineral Springs.

3.11 MECHANICAL INTEGRITY TESTING

Tests were run on the DIW during and after construction to establish that the well has mechanical integrity and was free of problems not readily detectable during normal construction activities.

Two types of tests were run on the well to establish mechanical integrity. A casing pressure test of the final injection string was run before construction was completed. Also, a radioactive tracer survey was conducted to detect upward flow outside the final casing after construction was complete. A discussion of each test follows.

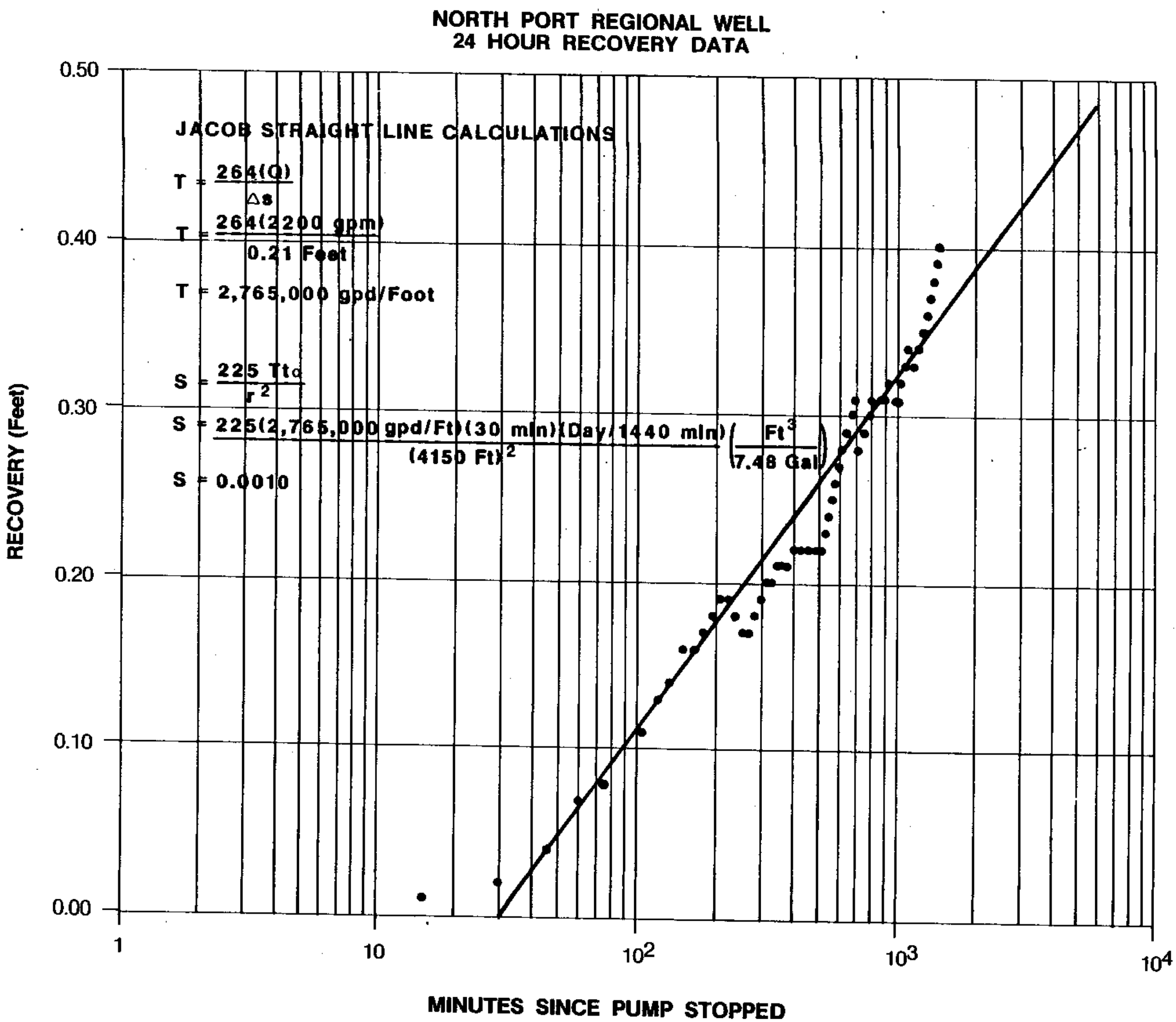

FIGURE 3-11.
North Port DIW Semi-Log Plot of Regional Monitor Well Recovery Data.

3.11.1 CASING PRESSURE TEST

The casing pressure tests provides a simple measure of a possible leak in the final injection casing string. After the 14-inch final casing was installed the cement was allowed to set for about 24 hours. The casing was then flushed with water to promote temperature stabilization between the setting cement and borehole fluid. A pressure header was welded on the casing and the casing was fluid pressurized to 115 psi. The pressure was monitored for a period of one hour for pressure change. No pressure changes were detected during the monitoring period. The pressure test for the final casing was run on August 11, 1987, and the record of the test is in the weekly summary that includes that date in Appendix K.

3.11.2 RADIOACTIVE TRACER SURVEY

TAC required a radioactive tracer study to determine the external mechanical integrity of the injection casing and cemented annulus before a test injection permit for effluent testing could be granted (October 8, 1987, TAC).

The drilling contractor, Alsay Inc., contracted with the well service companies Halliburton and Welex to provide this survey, which was run on December 7, 1987, and witnessed by representatives from CH2M HILL, FDER, and SWFWMD. A description of the testing procedure is shown in the CH2M HILL daily report for December 7, 1987, in Appendix K. A summary of the testing procedure and results follows:

- A casing header was installed to control the well artesian head. A 20-gpm injection rate was established with freshwater and the radioactive tracer was then released.
- The release of the tracer was confirmed by lowering a gamma ray tool below the casing. This tool was pulled back to monitor for tracer movement up and around the casing.
- Freshwater injection continued at 20 gpm for duration of test.
- Monitoring continued for 11 hours and no upward leakage was indicated.

Following the testing, Welex conducted a geiger survey of the area before demobilizing. No radiation was detected in the work area. The well was shut in after work completion. The log from the radioactive tracer survey is included in Volume III.

3.12 INJECTION TEST

A single step short-term injection test was run on the North Port DIW on January 21, 1988, to determine the injection capacity of the well.

The test was run with secondarily treated effluent from the North Port WWTP. The secondarily treated effluent was delivered to the well by the pumps and pipeline designed and constructed for the North Port system.

Monitoring of the plant flows to the well, pressure in the DIW, and pressure in the monitor wells was continuously recorded by the permanent system monitoring equipment. Wellhead pressure was monitored at the DIW with a 12-inch Heise gauge calibrated from 0 to 100 psi with 0.1-psi graduation.

Two 1,500-gpm vertical turbine primary pumps were used to deliver a 3,300-gpm continuous rate throughout the injection test (well pressures were slightly lower than design pressures). When the test was started at 10:00 a.m., the initial pressure at the wellhead was 9.90 psi. The injection test was run for 8 hours, 15 minutes and was stopped at 6:15 p.m. The final injection pressure at the DIW, recorded before test shut down, was 18.25 psi.

Long-term effluent testing of the system with ongoing monitoring started immediately upon the completion of the short-term testing.

Water quality samples of the effluent were taken during the testing. These samples were analyzed for conductivity, chloride, and TDS.

The pressure readings taken at the DIW and the recorder charts documenting flow rate and total flow from the test are included in Appendix L. Water quality analyses from the samples taken during the injection testing are also included in Appendix L.

Section 4
DIW MONITORING SYSTEM

4.1 MONITORING AT WARM MINERAL SPRINGS

Extensive monitoring was performed at Warm Mineral Springs during the drilling and testing of the North Port DIW. As required per the settlement agreement (Appendix A), continuous monitoring of flow, temperature, and specific conductance was performed. In addition to the continuous monitoring, monthly analyses for chlorides and sulfates was required.

Continuous discharge measurement from Warm Mineral Springs was obtained by maintaining a continuous stage recorder in the spring and measuring the discharge of the spring periodically for correlation. A Stevens Type-A water level recorder was installed on the northern edge of the spring lake. The recorder was placed in a protective, weatherproof box secured to a concrete block retaining wall. The recorder float was positioned in an 8-inch PVC stand pipe, immersed 1½ to 2 feet with several ¼-inch holes drilled below water level. The Stevens Type-A recorder is sensitive to water level changes of less than one-hundredth of a foot in the spring.

Periodic discharge measurement of the spring flow, for correlation with stage data, was done with flowmetering equipment. A uniform section of the discharge stream from the spring 10 feet downstream from old bridge abutment was chosen for stream flow measurement. This section was evaluated in 11 segments. Flow of the discharge was calculated by measuring the average flow velocity in each section, calculating the flow in each section, then summing sectional flow to find the total flow. A total of eight flow measurements were made during the North Port DIW construction. The average flow rate from stream discharge measurements was 8.99 cubic feet per second (cfs) (4,034 gpm or 5.8 mgd). The data will provide a basis for evaluating future changes in spring flow if they occur. The stream discharge measurement record sheets including correlation curves between discharge and stage height are included in Appendix M.

Water levels throughout the entire testing varied very little, as shown in the charts in Appendix M. Only water level charts from critical days, such as during pumping tests, are included in this report because of the volume of data associated with the strip chart recorders. The original strip chart is on file at the FDER Tampa office. In general, no apparent change was noticed from the pumping tests or injection testing of the North Port DIW at Warm

Mineral Springs. Small increases in water levels were noticed during rainfall events; however, the water levels remain fairly constant as a general trend. Rainfall was monitored at Warm Mineral Springs during the testing of the DIW system (see Appendix M).

Temperature and specific conductance was measured on a continuous basis with a self-contained underwater instrument YSI SCT Meter, Model 33. This instrument was attached to the water level recorder stand and data was recorded on an hourly basis. The hourly readings are included in Appendix M.

Both temperature and conductivity appear to be stable except for seasonal changes affecting the temperature and for periods of heavy rainfall that cause a temperature freshening of the waters (lower conductivity) from runoff from adjacent lands when deviations are noticed. Daily averages of the temperature and conductivity measured during the drilling and testing of the North Port DIW are shown in Figures 4-1 and 4-2.

Water samples were collected at the discharge point of Warm Mineral Springs and analyzed for chloride and sulfate on a monthly basis. Results of these analyses are shown in Appendix M. Plots of these parameters are shown in Figures 4-3 and 4-4 to show trends during the construction and operation of the DIW system. The figures show no apparent variations related to the drilling and testing of the DIW. Chloride concentrations appear to remain consistently around 10,000 mg/l. These data will need to be recorded over a longer period of time for a better definition of possible trends. The monthly sulfate data collected has also been consistent with concentrations ranging from 1,500 to 1,800 mg/l. Again, a longer recording period will be necessary to document possible changes from injection at the North Port DIW.

4.2 MONITORING DURING OPERATIONAL TESTING

On January 19, 1988, FDER issued a letter authorizing operational testing of the North Port DIW system with secondary treated wastewater effluent. A copy of this letter is included in Appendix B. This letter includes a strict monitoring program that must be observed throughout the initial operational testing period (approximately six months). Monitoring at the DIW includes reporting of the following:

Measurement	Frequency
Average Injection Pressure (psi)	Weekly
Maximum Injection Pressure (psi)	Weekly

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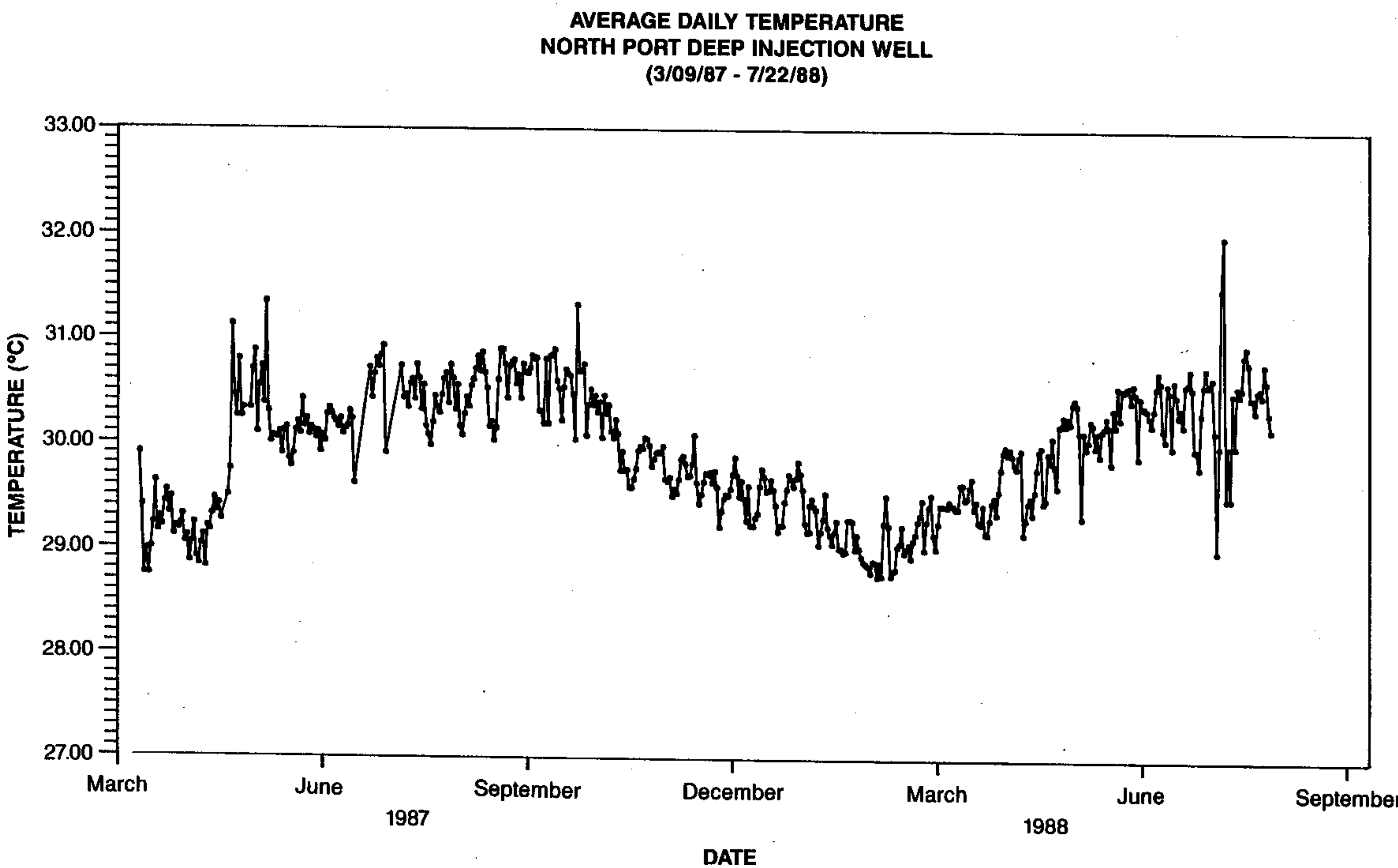

FIGURE 4-1.
Average Daily Temperature of Warm Mineral Springs.

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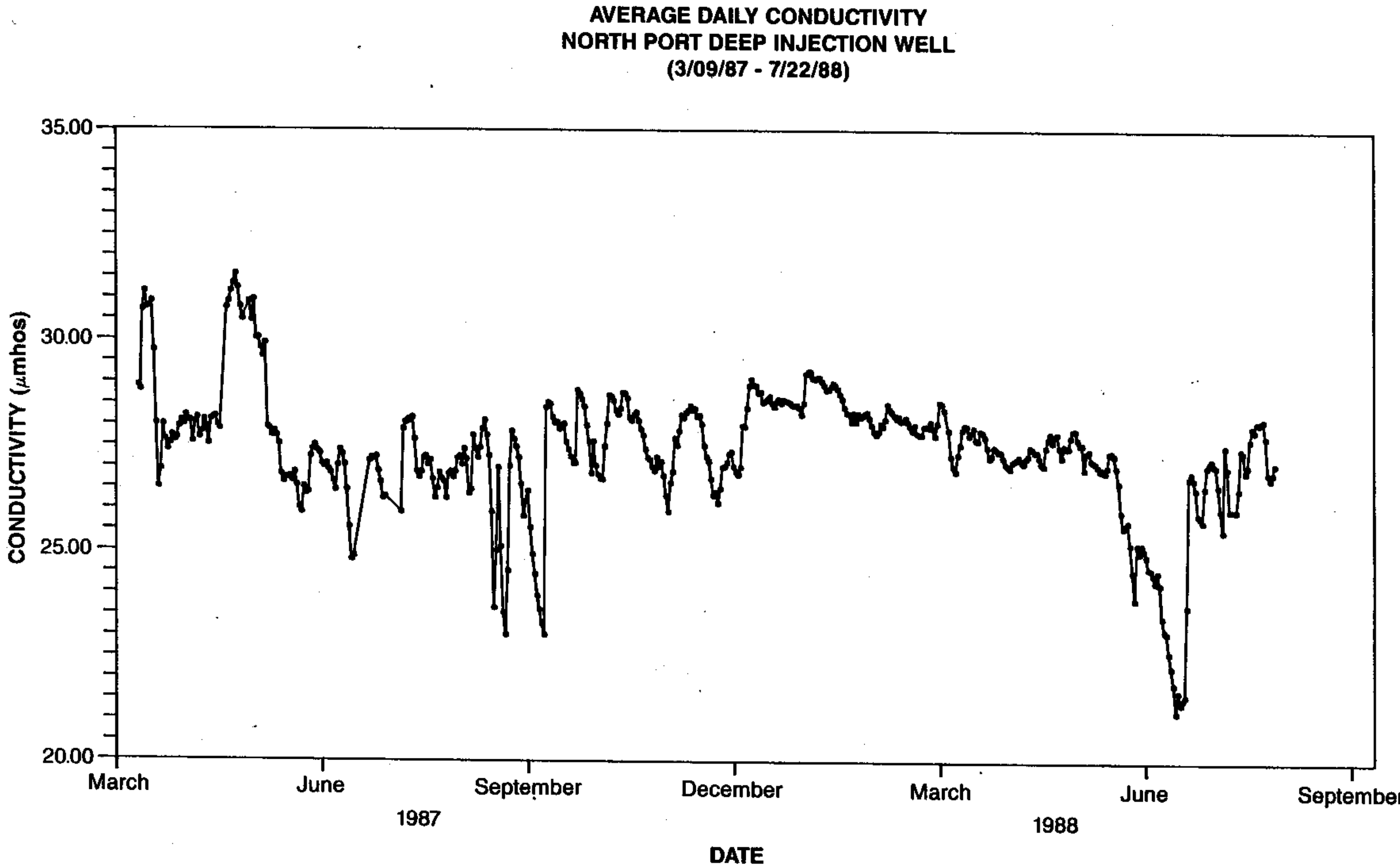

FIGURE 4-2.
Average Daily Conductivity of Warm Mineral Springs.

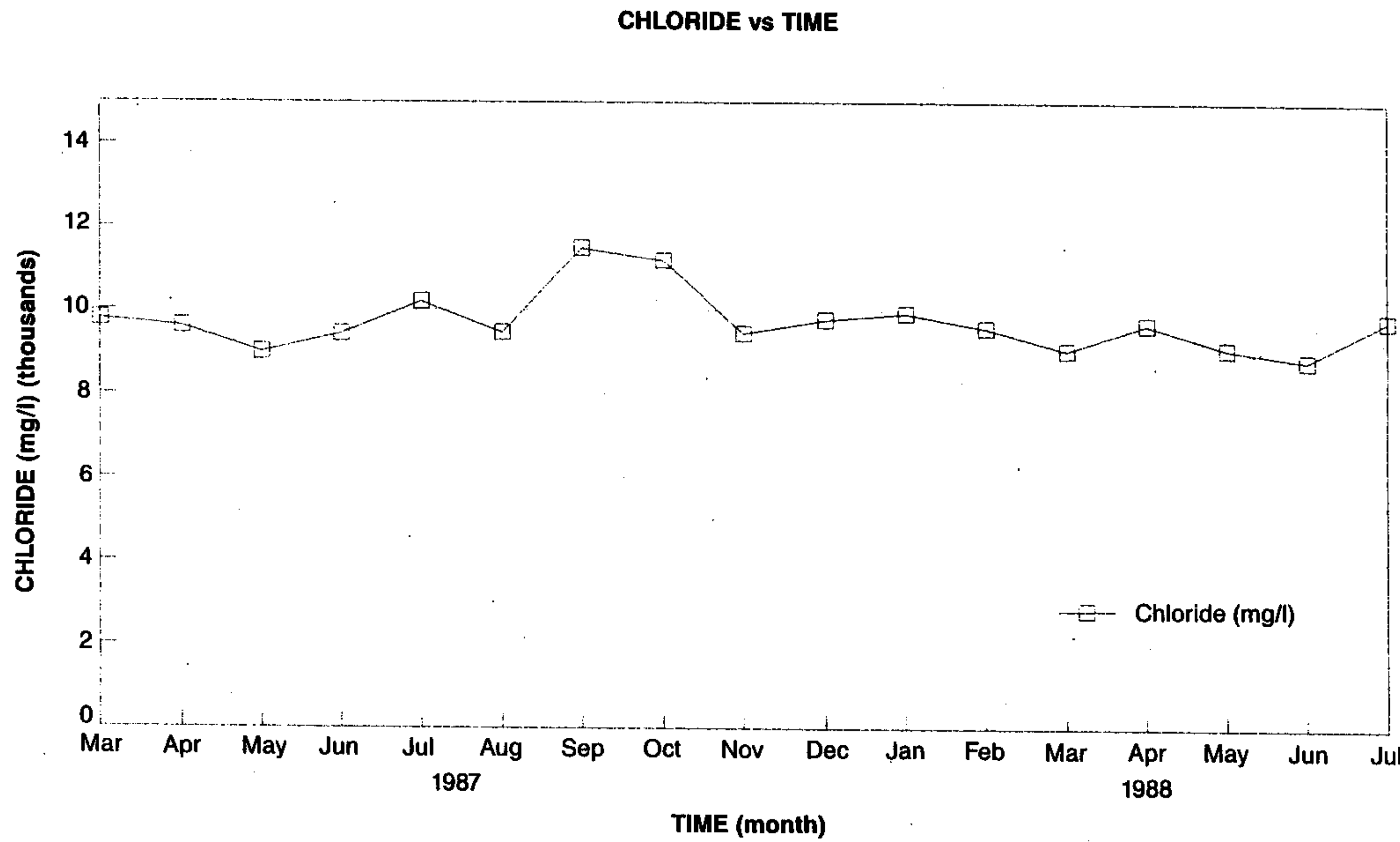

FIGURE 4-3.
Monthly Chloride Readings at Warm Mineral Springs.

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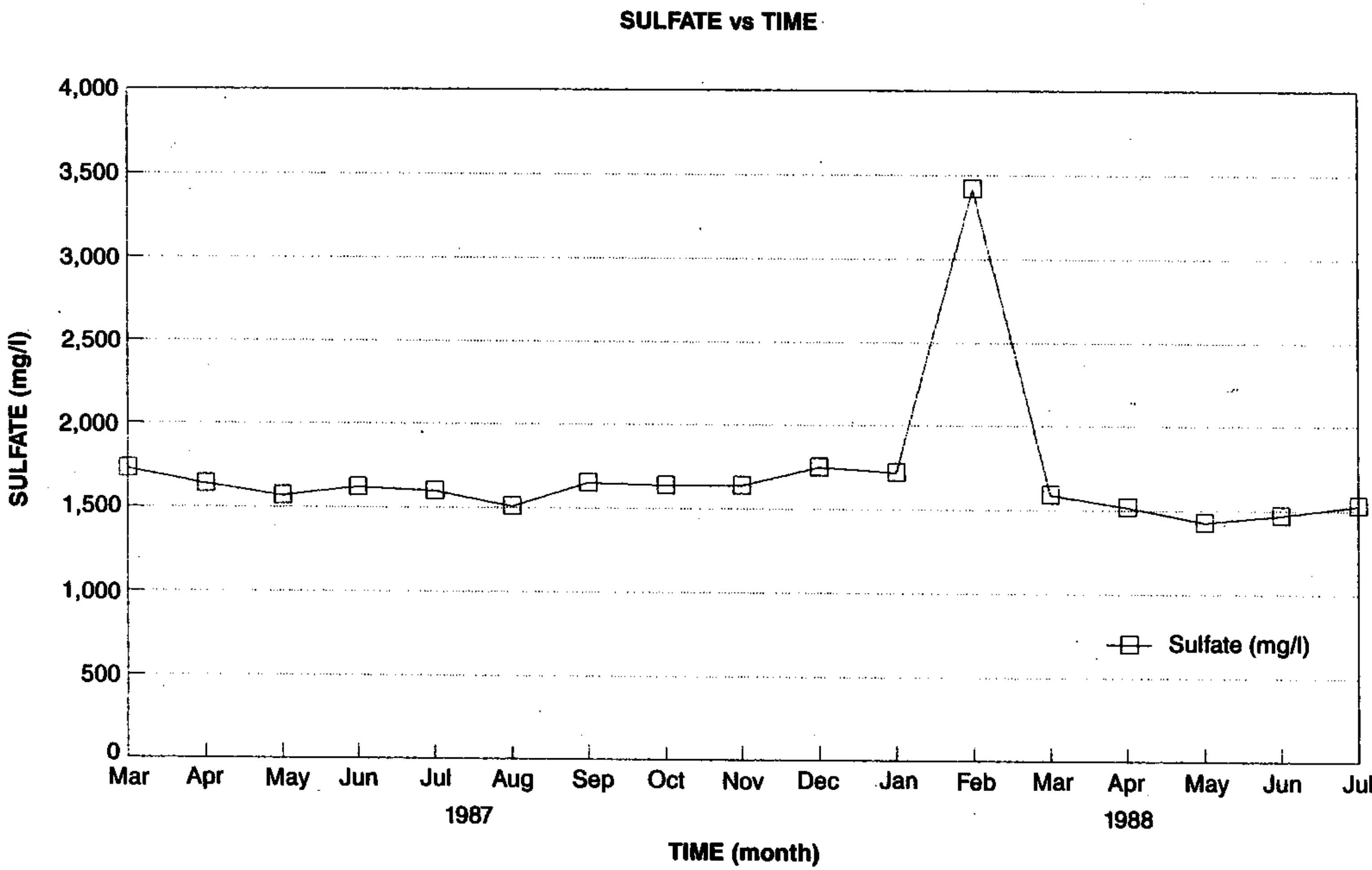

FIGURE 4-4.
Monthly Sulfate Readings at Warm Mineral Springs.

Measurement	Frequency
Minimum Injection Pressure (psi)	Weekly
Average Flow Rate (gpm)	Weekly
Maximum Flow Rate (gpm)	Weekly
Daily Average Injection Pressure (psi)	Continuously
Daily Maximum Injection Pressure (psi)	Continuously
Daily Minimum Injection Pressure (psi)	Continuously
Daily Average Flow Rate (gpm)	Continuously
Daily Maximum Flow Rate (gpm)	Continuously
Total Volume injected (gal)	Weekly
Total Volume Injected (gal)	Daily

Monitoring at the DIW is being accomplished with continuous recording instruments at the wellhead and at the pump station. A continuous pressure recorder is set up at the wellhead to record pressures in psi. The measuring point elevation of the recorder is 11.38 feet NGVD based on an elevation of the top of the bottom 14-inch flange at the DIW of 8.88 feet NGVD. Continuous flow rates are being recorded and totalized at the pump station.

Three depth intervals are being monitored during this period at the OMW and RMW. Monitoring includes both the shallow (551-600 feet) and deep intervals (730-750 feet) of the OMW in addition to monitoring of the RMW (1,100-1,150 feet). The following parameters are reported at these wells:

Hydraulic Parameters	Frequency
Weekly Average Pressure/Water Levels (psi/NGVD)	Weekly
Weekly Maximum Pressure/Water Levels (psi/NGVD)	Weekly
Weekly Minimum Pressure/Water Levels (psi/NGVD)	Weekly
Daily Average Pressure/Water Levels (psi/NGVD)	Continuously
Daily Maximum Pressure/Water Levels (psi/NGVD)	Continuously
Daily Minimum Pressure/Water Levels (psi/NGVD)	Continuously
Water Quality Parameters	
Specific Conductance (μmhos/cm)	Weekly
Chloride (mg/l)	Weekly
Total Dissolved Solids (mg/l)	Weekly

Sulfate (mg/l)	Weekly
pH (standard units)	Weekly
Nitrate (mg/l)	Weekly
Fecal Coliform (#/100 ml)	Weekly
BOD5 (mg/l)	Weekly
Total Kjeldahl Nitrogen (mg/l)	Weekly
Sodium (mg/l)	Weekly
Calcium (mg/l)	Weekly
Phosphorus (mg/l)	Weekly

In addition to the above, the monitor wells were also sampled for the parameters listed in the primary drinking water standards (FAC 17-22.210) and iron, copper, manganese, and zinc. This sampling effort was conducted after 3 months of operational testing. Another round of sampling was performed at the end of the 6-month operational testing period for the parameters listed in Tables 3-4 and 3-5. Monitoring at Warm Mineral Springs continued as described in Section 4.1 with continuous monitoring of flow, temperature, and specific conductance. Monthly chloride and sulfate sampling and analysis was also continued.

Specific injectivity testing of the DIW is performed monthly to establish an injectivity index. This index is reported in gpm/psi and generally indicates the performance of the DIW. Injectivity indexes which decrease rapidly over a short period of time may indicate potential problems (i.e., plugging at the borehole face) with the well.

All the above data has been summarized in monthly progress reports which were submitted to TAC near the 15th of each month. A copy of these summaries including tabulation of hydraulic data, recorder charts, and laboratory analytical results are included in Appendix L.

Daily average injection well pressures, recorded at the injection wellhead, have been approximately 14.6 psi throughout the operational period. Average flow rate during operational testing have been around 382 gpm with total daily flows of approximately 550,000 gallons. A summary of weekly average injection wellhead pressures, flow rates, and total weekly flows is shown in Figure 4-5. This figure shows that there is little variation in the weekly averages, although there has been a small decrease in flows since April which coincides with the end of the tourist season. Flows are expected to increase again in the winter.

Water levels recorded at each of the monitoring stations have shown no indication injected fluids migration vertically to the OMW or horizontally to the RMW. Average weekly pressures from each of the monitoring stations are presented in Figure 4-6. Pressures at the OMW shallow and deep zones are fairly consistent with little fluctuation of

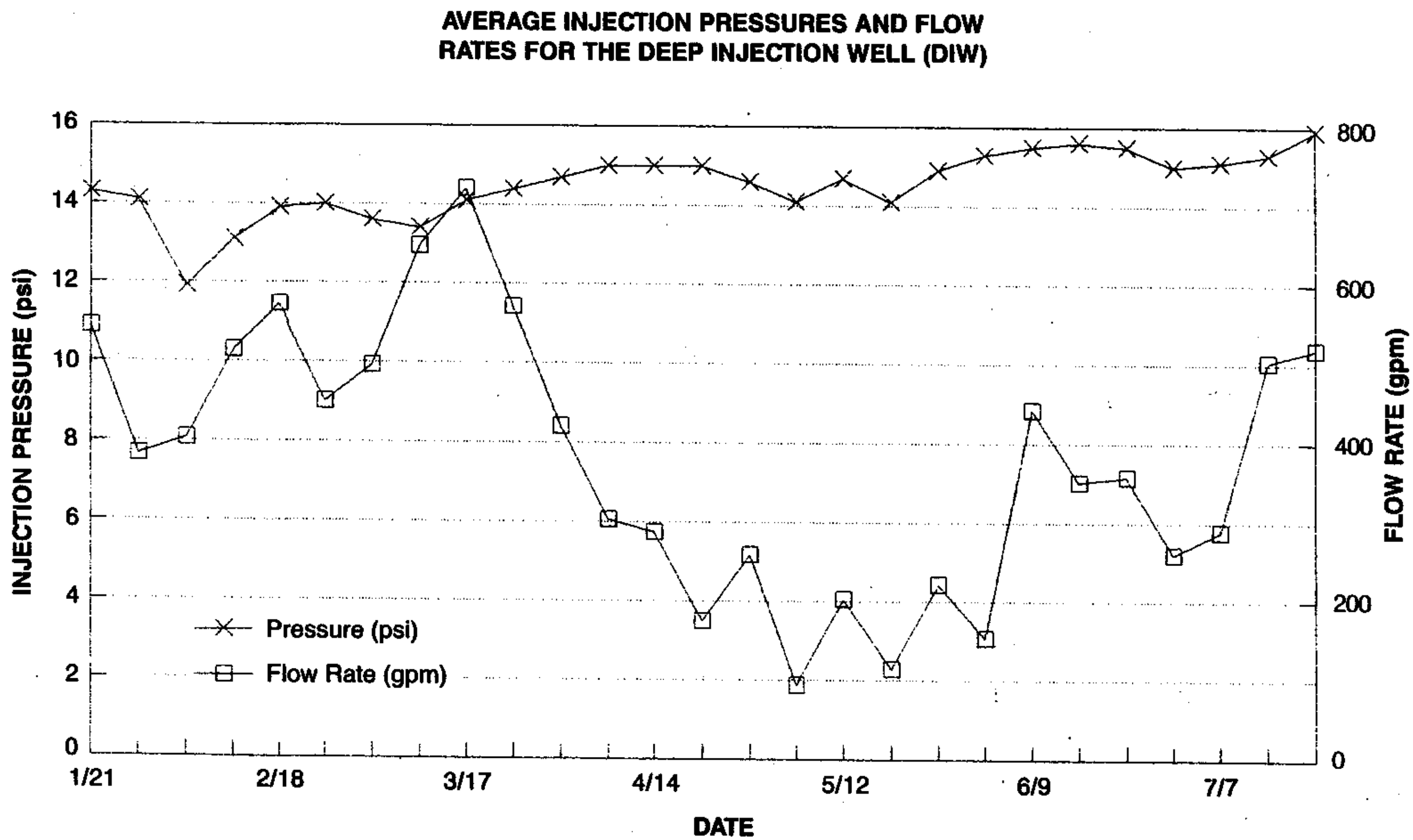

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FIGURE 4-5.
North Port DIW Operational Testing.

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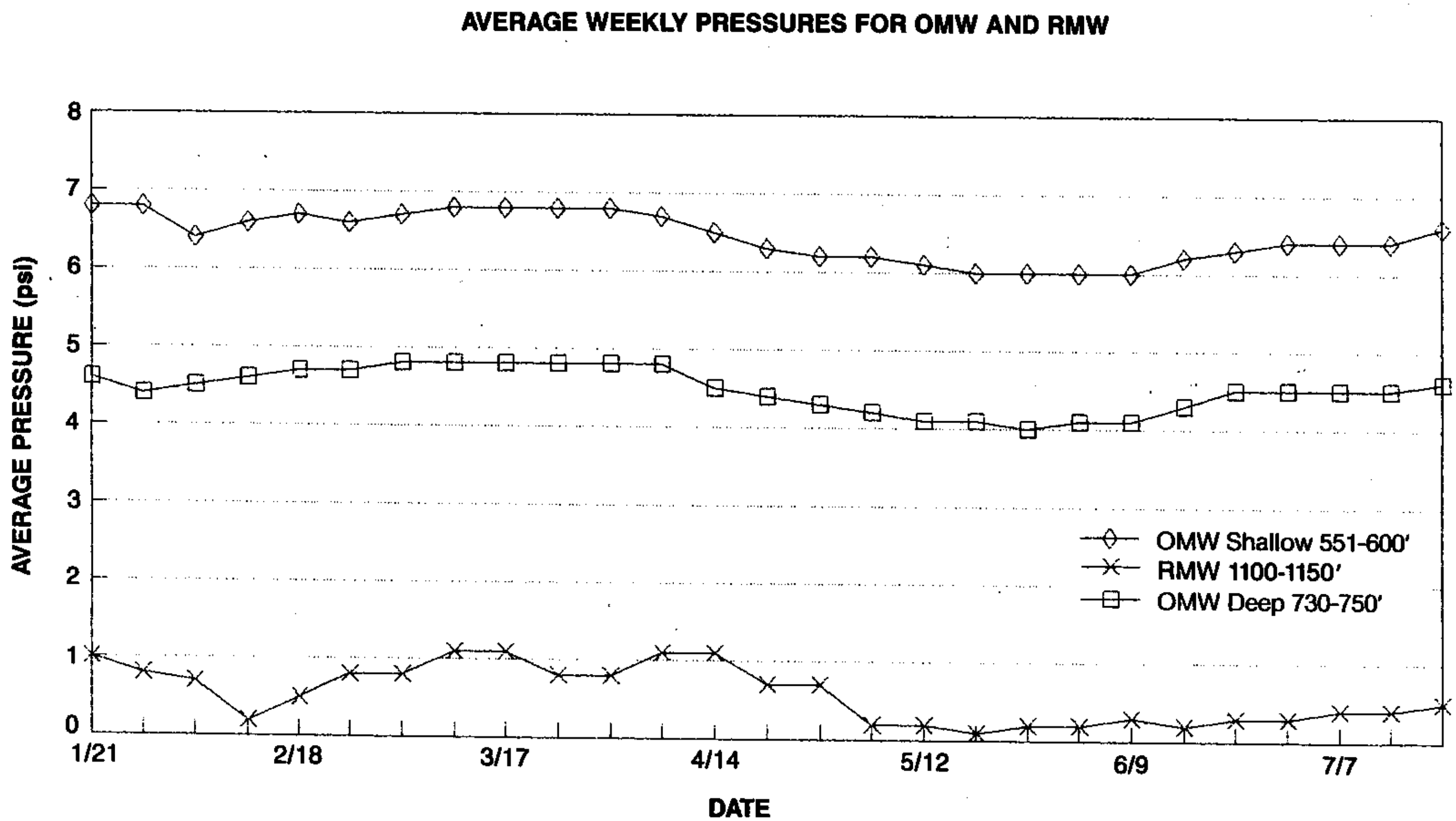

(1/21/88 - 7/21/88)

FIGURE 4-6.
North Port OMW and RMW Operational Testing.

pressures. Changes in pressures at the RMW appear to be the effects of barometric and tidal influences.

Results of the water sampling at the monitor wells also show no noticeable variations that could be caused by the injection of secondarily treated effluent. Plots of the weekly samples have been prepared to easily detect potential changes in water quality should there be any. Plots of the weekly TDS and chloride concentrations reported for the OMW shallow, OMW deep, and RMW, are shown in Figures 4-7, 4-8, and 4-9, respectively. A comparison of water quality collected before injection and results of samples collected during operational testing shows no evidence of "freshening" by the injection at the North Port DIW. Future monitoring of the DIW system should include tracking of these specific parameters to evaluate the operation of the system.

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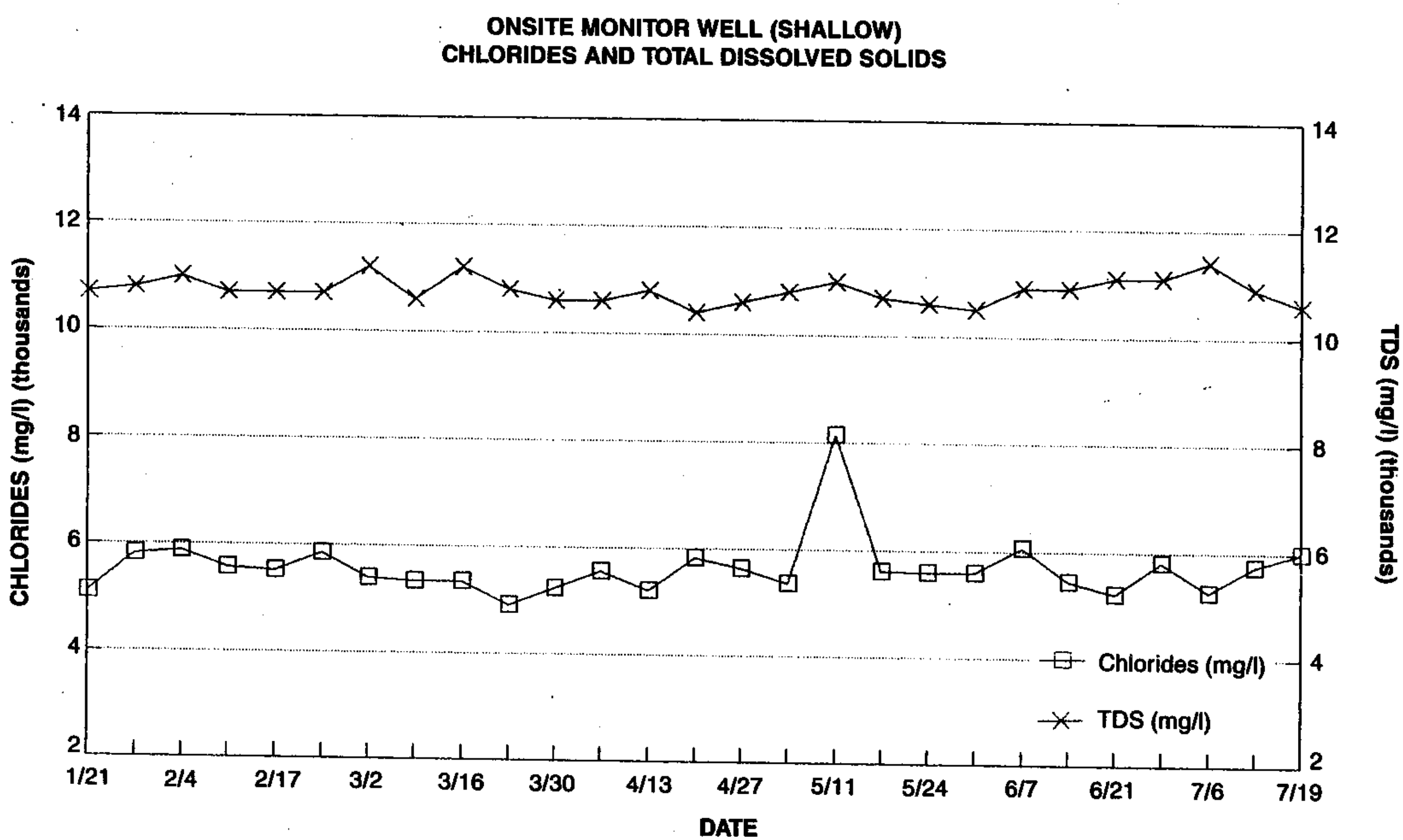

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FIGURE 4-7.
North Port Shallow OMW Operational Testing.

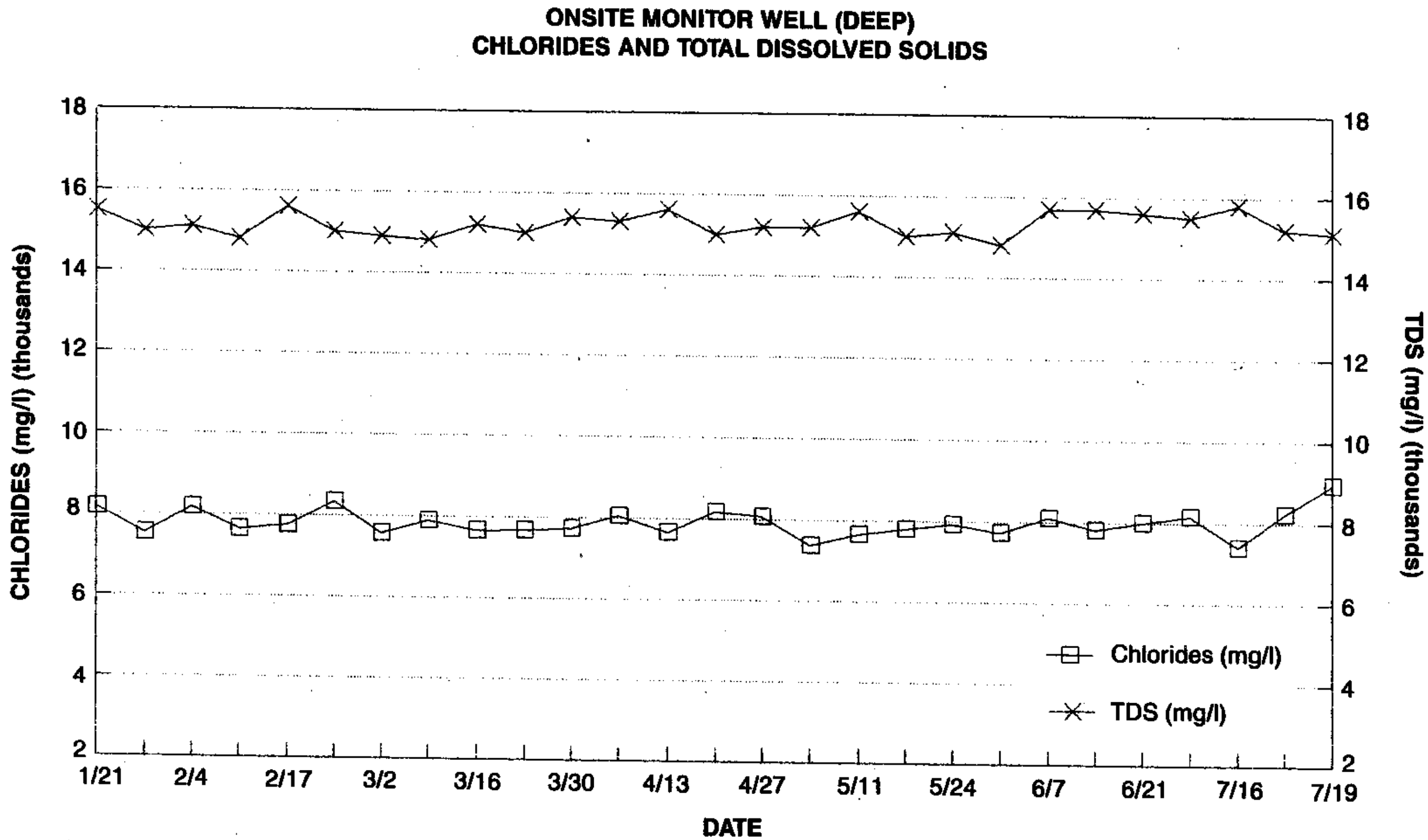

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FIGURE 4-8.
North Port Deep OMW Operational Testing.

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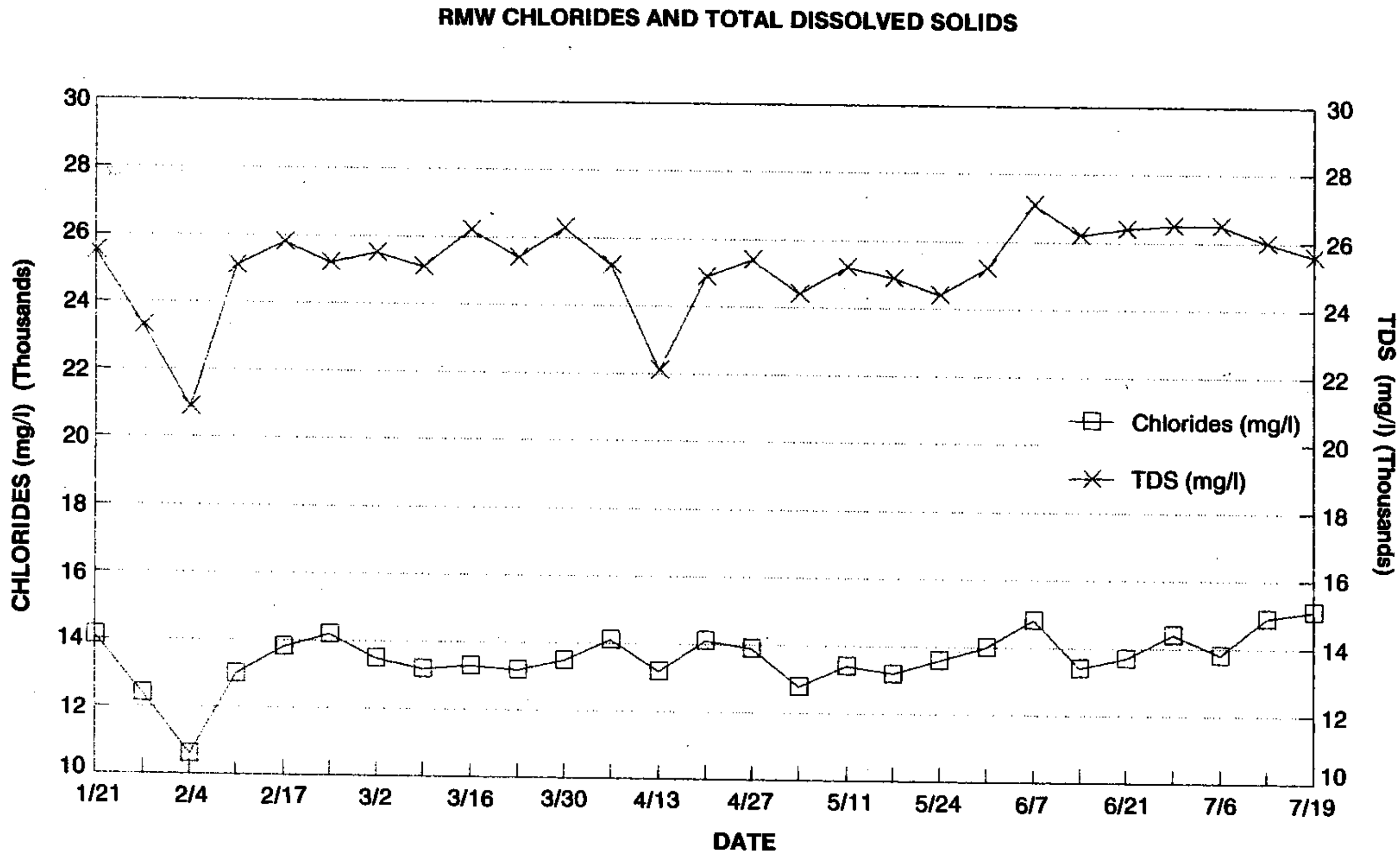

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FIGURE 4-9.
North Port RMW Operational Testing.

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Section 5
GROUNDWATER MODELING

5.1 ANALYTICAL MODELING

The injection well construction permit stipulated the following specific conditions:

> "All data obtained by the permittee at the conclusion of the thirty (30) day test shall be used by the permittee to prepare an analytical model to predict the ultimate disposition of effluent injected into the well, and the effects of injection on Warm Mineral Springs."

At the October 8, 1987, meeting, the TAC decided to substitute a 24-hour pump test for the 30-day test (the Neuman-Witherspoon testing). The data from the 24-hour pump test was collected as described in Section 3. The information from the injection zone gathered during the pilot hole testing was compiled along with the 24-hour test data for the analytical modeling work described herein. The analytical approach to satisfying the permit condition is a two-part effort described as follows:

1. A steady state solution for predicting head change in the injection zone (Hantush Steady State) as a result of the applied injection stress was used to predict the head change at Warm Mineral Springs.

2. A semi-analytical method combining uniform flow, point sources and sinks, and computer methods (the RESSQ model) was used to examine the flow field generated by the injection and to track the effluent front with a regional gradient imposed. These are referred to as the streamline and transport models.

The combination of the results of the two methods was used to determine the possible effects that the effluent injection may have on the injection zone and on Warm Mineral Springs if the Springs were directly connected to the injection zone.

Prediction of the effects of injection are limited in accuracy to the level of correlation that the local hydrogeologic data collected during the North Port work has with the true areal hydrogeology and the accuracy of assumptions about the origin of Warm Mineral Springs. Both analytical methods used to investigate the effects of effluent injection on Warm Mineral Springs are limited to solving in two dimensions under the assumption that the aquifer is uniform in hydraulic nature and infinite in areal extent.

These assumptions are generally common to analytical methods. The system being modeled by analytical methods must be transformed into a conceptual system that satisfies the analytical assumptions to make analytical predictions. The following major assumptions were used in the modeling at North Port.

- The injection zone is homogeneous, isotropic, and infinite in areal extent.

- The source of Warm Mineral Springs discharges are exclusively from the injection zone (i.e., they are directly connected, although they do not appear to be).

- For purposes the Hantush steady state prediction, injection zone transmissivity is 1,900,000 gpd/ft, aquitard thickness is 355 feet, and aquitard permeability is 0.434 gpd/sq. ft. (0.058 ft/d from core testing).

- For the streamline and transport model (RESSQ), the injection zone was assumed to have an effective porosity of 20 percent. The thickness of the aquifer was assumed to be 50 feet for this analysis. This thickness is a conservative estimate made to represent the freshwater effluent moving in the upper part of the aquifer rather than mixing throughout the aquifer. The effluent was assumed to be non-reactive and nondispersing.

- For the streamline and transport model (RESSQ) a regional gradient was applied to the solution, the gradient used for the injection zone (lower Floridan aquifer) was assumed to be the same as those mapped for the upper Floridan aquifer in the same area.

- A flow rate of 2.3 mgd (ultimate average rate) was used to predict head changes and the fate of the effluent over the life of the well. A flow rate of 4.76 mgd (ultimate maximum rated capacity) was also used for comparison.

Of the assumptions made for use of analytical methods to predict the effects of the effluent injection, the most significant and conservative assumption is that the origin of the flow at Warm Mineral Springs is the injection zone. This assumption allows the flux of the Spring to be placed in the same two dimensional planes as the North Port DIW. However, information collected during testing of the North Port DIW indicates that they are not connected. Section 3.6 discusses the absence of apparent hydraulic effects on the

Springs from test pumping at North Port DIW with the exception of the 560- to 864-foot pumping test. Should no direct hydraulic connection between the spring and the injection zone exist, the assumption that the spring source is in the injection zone would produce conservative predictions on the fate of the effluent and the effects of injection on the Springs.

5.1.1 STEADY STATE HEAD PREDICTION

The term "steady state" refers to a system that is in equilibrium with flux in equal to flux out. Applied to the North Port DIW, this state would be achieved when the amount of effluent pumped into the injection zone was in hydraulic equilibrium with discharges from the zone (not necessarily effluent discharges). The analytical equation developed by Hantush (Walton, 1970) to solve for the head changes that occur at steady state in a leaky aquifer was used to create the head increase vs. distance graph shown in Figure 5-1. The plot was created using the hydraulic data assumptions stated previously. Head changes were calculated for injection rates of 2.3 mgd and 4.76 mgd. Example calculations using the Hantush method can be seen in Appendix J. The computer spreadsheet used to calculate the steady state drawdowns is included with the modeling information in Appendix N.

At the radius of Warm Mineral Springs (16,000 feet) from the DIW, the predicted head build up from the hydraulic effects of effluent injection are less than 0.5 feet for both injection rates. The predicted effects on the spring are based on the previously stated assumptions about the direct interconnection of the Warm Mineral Springs hydrogeologic system. Since the Springs are a discharging point for the conceptualized hydrogeologic system, the predicted increase in head will probably be translated into an increase in spring flow.

5.1.2 STREAMLINE AND TRANSPORT MODEL

A semi-analytical approach was taken to predict the fate of the effluent and the effect on Warm Mineral Springs. The semi-analytical methods are based on the same general assumptions as pure analytical methods but allow more flexibility in the treatment of the number of sources, sinks, and boundary conditions.

The semi-analytical method used to predict the effects of the effluent at North Port is described in Javandel *et al.* (1984). They describe the solution procedure of the method as follows:

1. Identify simple flow components of the system such as uniform regional flow, point sources representing

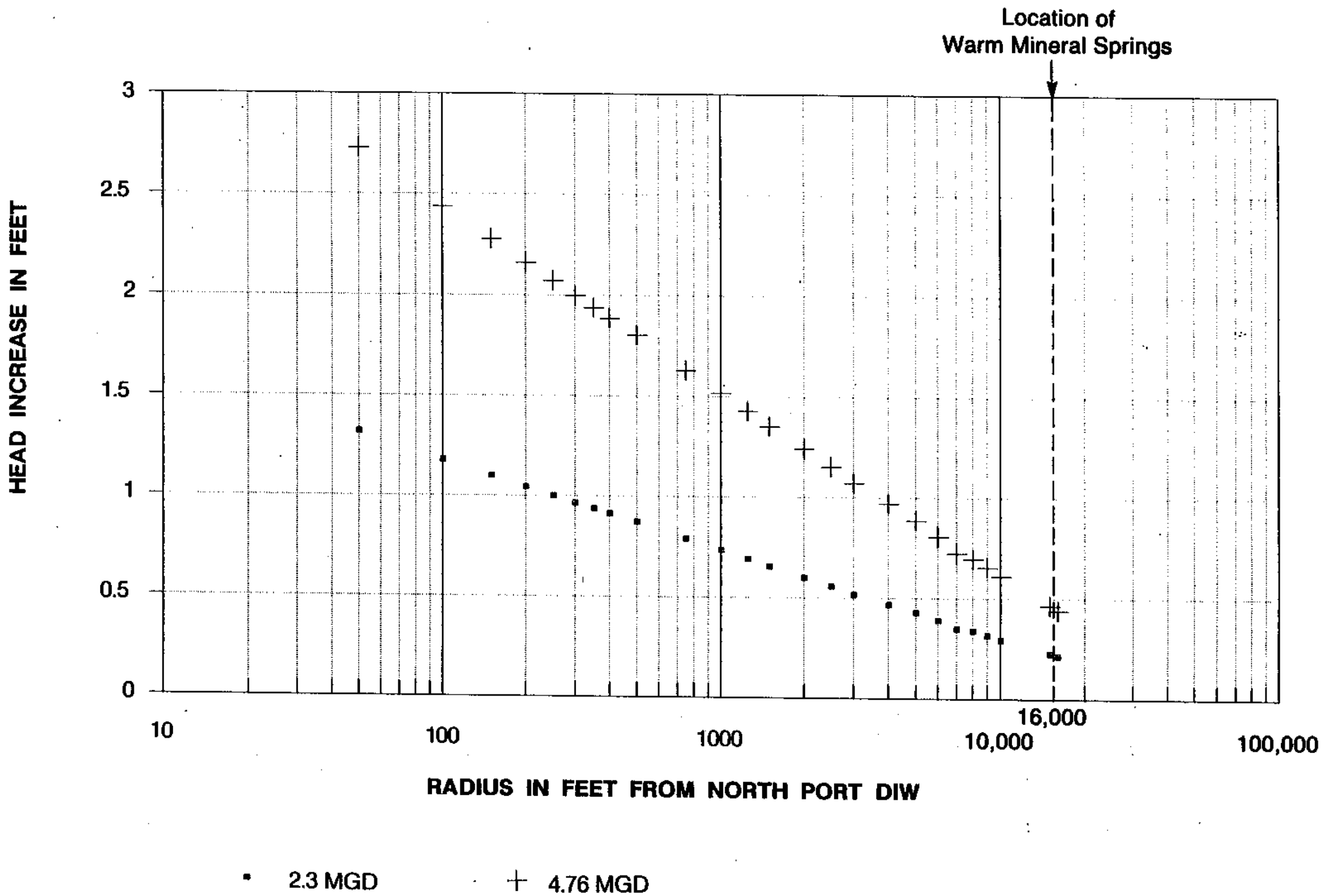

FIGURE 5-1.
Predicted Head Increase from Effluent Injection.

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recharge wells, point sinks representing discharge wells, and finite radius circular sources representing storage ponds.

2. Combine the expressions for each identified simple flow components to obtain the overall complex velocity potential of the system, satisfying the appropriate boundary conditions.

3. Construct the expressions for the velocity potential and stream function of the system.

4. Calculate the velocity field by taking the derivative of the velocity potential.

5. Construct flow patterns and identify locations of any treated effluent fronts for various values of time.

6. Using the stream function of the system, calculate the time variation of the rate at which contaminants reach any desired flow boundary.

In their description of the theory of the method, Javandel et al. (1984) state that the analytical function $W = \phi + i\Psi$ is the complex velocity potential. The functions ϕ and ψ are the velocity potential and stream functions, respectively. The curves of velocity potentials (ϕ) and streamlines (Ψ) intersect each other at right angles. By general relationships, Javandel et al. find that the stream function of a flow system with a known velocity potential can be obtained by using the Cauchy-Reimann equations which hold because of the properties of ϕ and Ψ. This yields the following relationships:

$$\frac{\partial \phi}{\partial x} = \frac{\partial \psi}{\partial y}$$

$$\frac{\partial \phi}{\partial y} = - \frac{\partial \psi}{\partial x}$$

Javandel et al. (1984) expand in their description of the development of the uniform flow theory and the addition of point and finite radius sources and sinks.

The computer program for the solution of the uniform flow theory as described by Javandel et al. (1984) was developed at the Lawrence Berkeley Laboratory from a solution procedure used by Gringarten and Sauty (1975). The program, called RESSQ by the authors, calculates two-dimensional contaminant transport by advection and adsorption (no dispersion or diffusion) in a homogeneous, isotropic confined aquifer of uniform thickness when regional flow, sources, and sinks create a steady state flow field. The program calculates the streamline pattern in the aquifer, the location of contaminant fronts around sources at various times, and the variation of contaminant concentration with time at sinks.

The theoretical development of the semi-analytical approach and the users guide to the computer program is included in Appendix N, which also includes the information from Javandel et al. (1984). The RESSQ program is available for users through the American Geophysical Union.

Model Setup

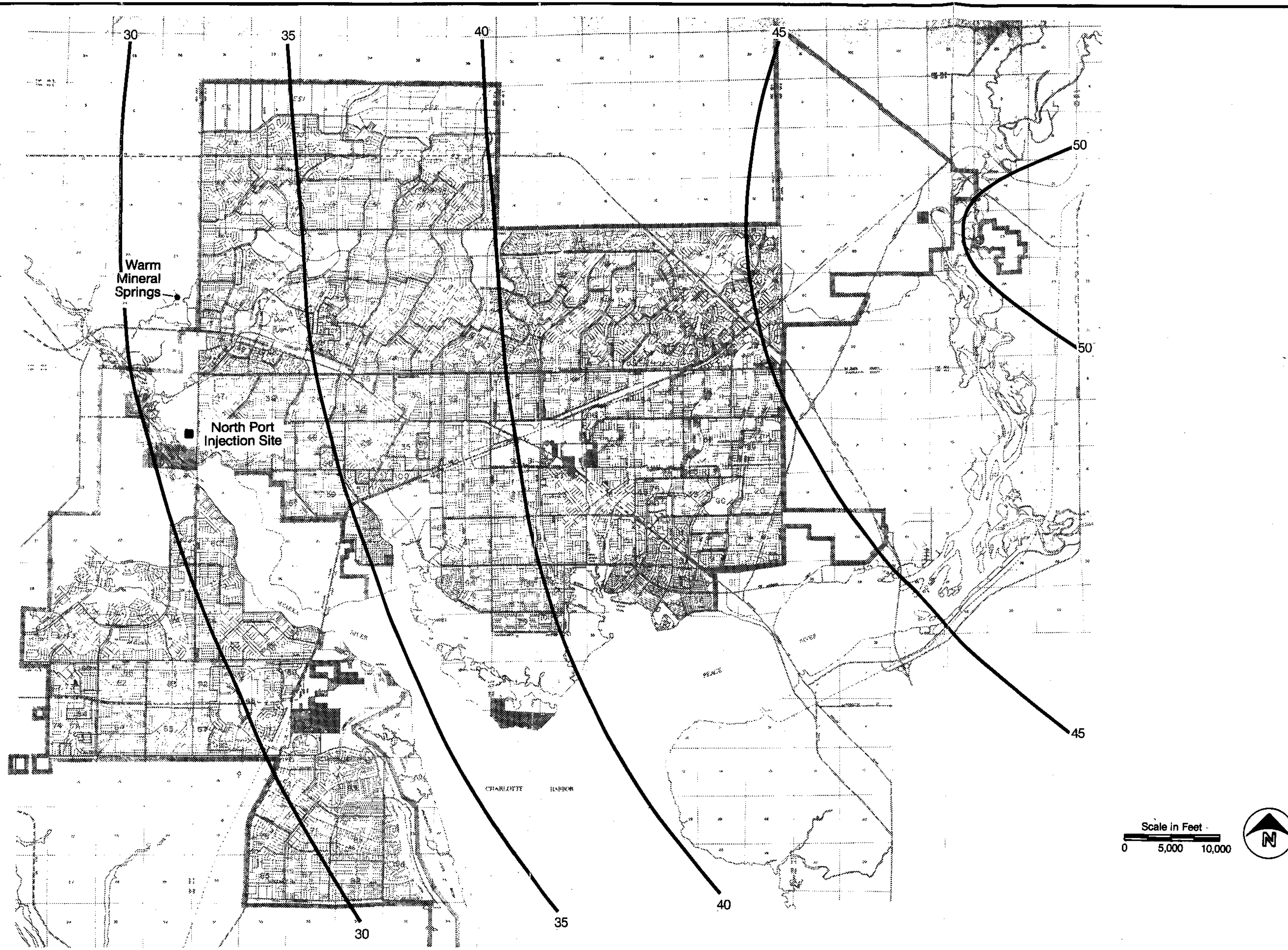
The RESSQ program was used to examine the fate of the effluent injected at the North Port DIW under the following conditions and assumptions:

1. One source (the North Port DIW) and one sink (Warm Mineral Springs) were set in the same two-dimensional hydraulic plane.

2. A regional gradient based on the potentiometric surface of the upper Floridan aquifer was assigned to the injection zone and incorporated into the program. A regional gradient in the injection zone, similar to the gradient in the upper Floridan aquifer, is thought and expected to occur, but little supporting data exist. For the purpose of examining the probable fate of the injected effluent from the North Port DIW, the gradient of the upper Floridan aquifer, as mapped by Mills, Laughlin, and Parsons (1975), was assumed to be the potentiometric surface of the lower Floridan (injection zone). The potentiometric surface used to impose a regional gradient on the model is shown in Figure 5-2. The gradient is imposed on the RESSQ model as a groundwater velocity with a single direction of flow. The groundwater velocity was calculated using the gradient across the area of interest 0.0003 ft/ft (I), an injection zone permeability of 508 ft^2/day (K), and an injection zone porosity of 20 percent (n). The groundwater velocity was calculated as $v = KI/n$. The velocity calculated and input into the RESSQ model was 0.76 ft/day. The direction of flow of the groundwater was input as 191 degrees counter-clockwise from the positive X axis (i.e., towards the southwest).

3. A 2.3-mgd injection rate was assigned to the DIW to represent the average injection rate planned over the life of the well. The maximum injection rate for the well of 4.76 mgd was used for an additional run for comparison to the planned well usage.

4. A discharge rate of 5.81 mgd was assigned to Warm Mineral Springs, all of the flow coming from the same



SOURCE: Mills, Laughlin and Parsons, 1975.

FIGURE 5-2.
Original Piezometric Surface of the Floridan Aquifer System.

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hydraulic plane as the DIW. The value 5.81 mgd was the average spring discharge rate measured during the monitoring program.

5. Eight to twelve streamlines were assigned to the DIW injection to allow tracking of the flow destination and effluent front. The calculation of the effluent front was for 5, 10, 20, 30, and 40 years. Total simulation time was set at 200 years.

6. As stated previously, an injection zone porosity of 20 percent and effective thickness of 50 feet were used for the program. These values are conservative estimates based on the values derived from the North Port testing and the behavior of injected effluent observed in other areas of this injection zone in Florida.

Model Runs

The results of the RESSQ model runs were interpreted from the configuration of the streamlines and effluent fronts through time. The model tracks the movement of the effluent front at user-specified times. The model also calculated the arrival time of each streamline at a discharge point, if the streamline ends at such a point in the modeled area.

The arrival time of a streamline to a discharge point may reflect a different travel time than the arrival of the effluent front at the same discharge point. The effluent front is determined by the displacement of the native fluid in the injection zone and not the movement of a single streamline. The position of the effluent front can be behind the arrival of a particular streamline at the discharge point.

The first model run presented is for the injection rate of 2.3 mgd, which is considered the average flow rate for the life of the well. Figure 5-3 shows the projected streamlines and effluent front in the North Port vicinity. As shown in the projected flow lines from the DIW, one of the twelve flow paths from the DIW reaches the spring discharge. The program shows the arrival of this streamline occurring at 70.6 years after the start of injection. The effects of this flow on the spring, if the hydraulics occurred as modeled, could be calculated by adding 1/12 of the injected fluid to the flow of the spring (i.e., 1/12 x 2.3 mgd = 0.19 mgd or about 135 gpm). This would increase spring flow by about 3 percent. Any concentration change at the spring could be calculated with the same approach.

According to the program results, the remaining 11/12 of the injected fluid would be carried with the natural flow downgradient to an ultimate discharge point not identified by

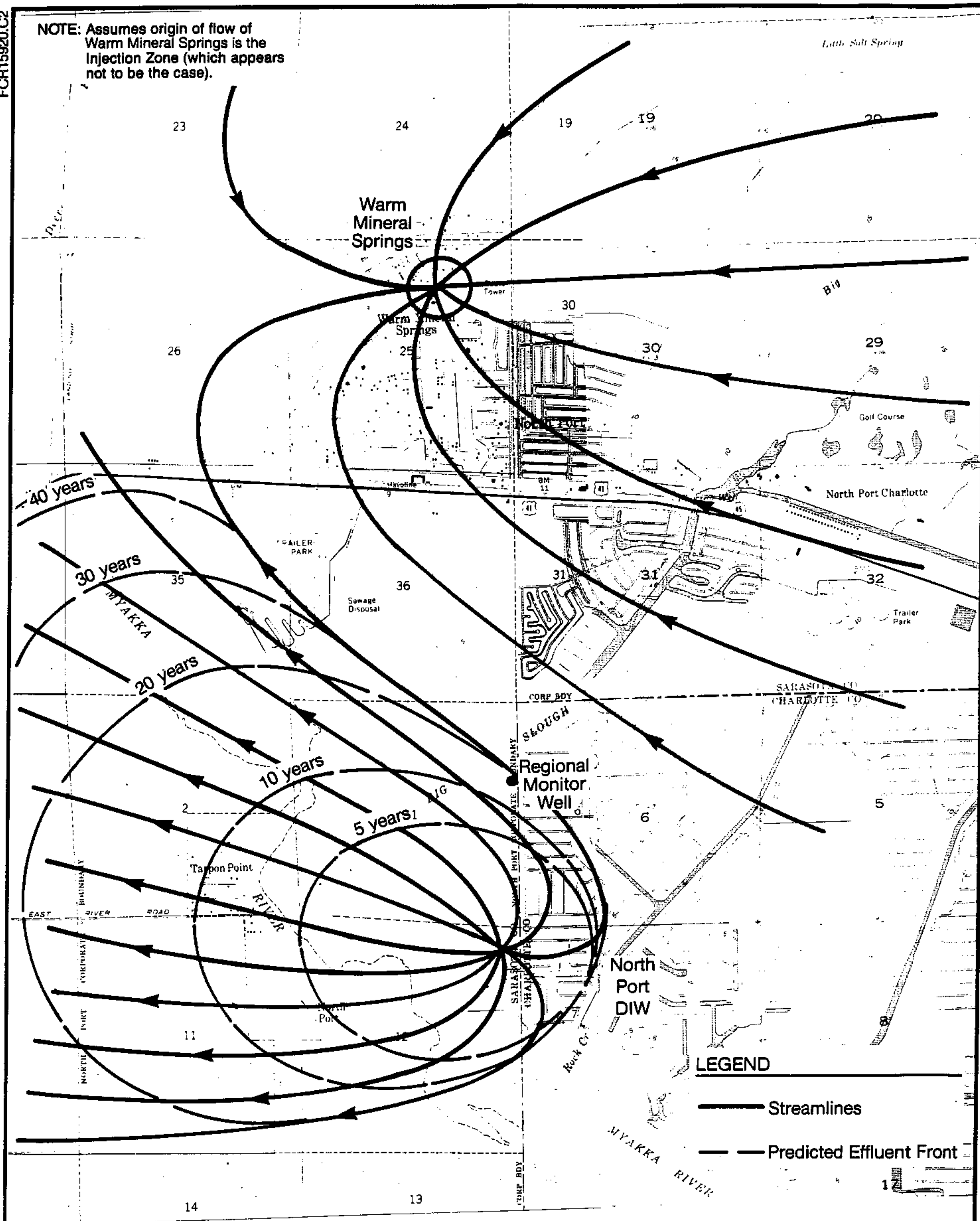

FIGURE 5-3.
Modeled Streamlines and Effluent Front for 2.3-mgd Injection with Regional Gradient Effects.

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this study. The model run results are displayed in Appendix N.

The second model run presented was done for a comparison with the first run. In the second run, the only change was to increase the injection rate for the DIW from 2.3 mgd to 4.76 mgd, which represents the maximum rated capacity of the well (at a fluid velocity adhering to FDER regulations). Also, only eight streamlines were used to track the effluent in this run. Figure 5-4 shows the projected streamlines and effluent front in the North Port vicinity. The projected flow lines at 4.76 mgd reach the spring at 33.4 and 39.6 years, respectively. This would theoretically add 1/4 of the DIW flow to the spring flow after both flow lines arrived at the Springs.

A comparison of the two runs showed that the predicted effluent time and volume of the spring changed with an increase in injection rate. The projected arrival time was 33 years at maximum injection rate and 70.6 years with the actual expected injection rate. The flow contribution to the spring approximately doubled with higher injection rate.

Discussion of Model Results

Interpretation of the results from the analytical modeling must be done with caution because of a number of unproven assumptions necessary to perform the modeling. Inaccurate assumptions may simply cause inaccurate predictions.

Predictions of streamlines and effluent fronts made with the RESSQ model are considered a first step in predicting effluent fate in a complex hydrogeologic setting such as that found in the injection horizons underlying the North Port site. The understanding of the fate of effluent injected into the high-capacity zones of the lower Floridan aquifer is hampered by the difficulty and expense of obtaining data. The modeling presented in this report recognizes these limitations and is a simplified approach to using the data at hand to provide the most meaningful prediction now possible. The regulatory agencies seem to share this view and have required the analytical approach to modeling the fate of injected effluent at this site rather than suggesting more complex modeling techniques for which data are lacking. The modeling results presented should therefore not be used for interpretation beyond the stated limitations.

CH2M HILL believes that the modeling results of greatest interest in the understanding of the fate of effluent injected at the North Port DIW are probably those shown in Figure 5-3, which was prepared to show the assumption that the Springs would be in direct connection with the injection, although this appears not to be the case. The injection

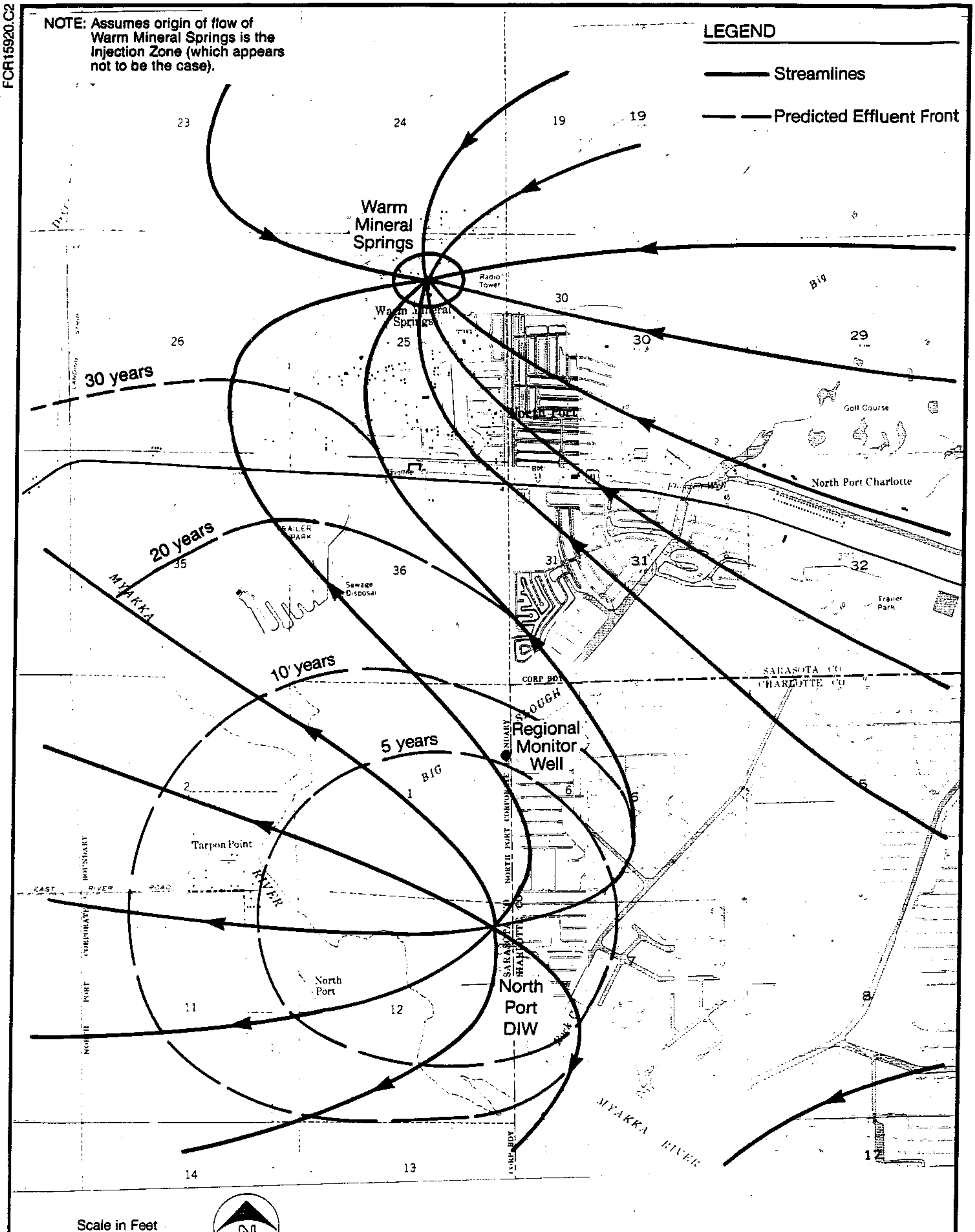

FIGURE 5-4.
Modeled Streamlines and Effluent Front for 4.76-mgd Injection with Regional Gradient Effects.

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rate of 2.3 mgd into the injection zone with an estimated regional groundwater velocity of 0.76 ft/day is probably the best representation of the injection effects on the system, as the system is now understood. The results of that run show a minimal effect of injection on Warm Mineral Springs, with only one of the twelve flow lines emanating from the injection well reaching the spring (at 70.6 years). The minimal effects shown in the 2.3-mgd run, coupled with the fact that no apparent hydraulic connection was detected between Warm Mineral Springs and the injection zone during this study, suggest that the effluent in the injection zone might simply move downgradient with the regional flow.

The ultimate fate of the effluent in the injection zone that does not reach the Springs under this assumption would be to flow into the Gulf of Mexico many miles from shore and hundreds, if not thousands, of years in the future. No other downgradient discharge points have been identified by this study. Degradation and mixing would be expected as the effluent moves downgradient in the injection zone with the regional flow.

As more monitoring data on the hydraulic conditions and chemical transport mechanisms in the injection zone become available, CH2M HILL strongly suggests that the injection system be further modeled to the fullest extent of the data available at that time. Groundwater modeling data are presented in Appendix N.

5.2 VERTICAL TRAVEL TIME ESTIMATE

Vertical travel time from the top of the injection zone to the 10,000-mg/l TDS interface was estimated using data collected during the drilling and testing of the DIW. The bottom of the 14-inch-diameter final casing string (1,105 feet bls) was used as the top of the injection zone. The top of confinement was selected to occur at 750 feet bls.

Results from the testing of the core samples was used to estimate the vertical permeability of the zones encountered. The methodology described in the report by Sinclair (1974) was used in estimating vertical permeability. This method consists of determining the resultant vertical permeability of a confining bed by compositing the tested permeabilities and thickness of multiple interzonal layers. The following equation was used in these calculations:

$$Pv = \frac{M}{m1/p1 + m2/p2 + \ldots mn/pn}$$

where

Pv = the composite coefficient of vertical permeability for all the confining layers

M = is the total thickness of all confining layers

m = is the thickness of each discrete confining layer

p = is the coefficient of permeability in each discrete confining layer

The thickness of each confining layer is shown in Table 5-1, along with the corresponding vertical permeability either from the core data or estimated where no core data were available. Confining unit thicknesses were selected according to similarity in lithology and correlation of similar lithology using geophysical logs. An average apparent porosity of 28.8 percent was used in the analysis.

A detailed summary of the vertical travel time estimate is presented in Table 5-2, which shows that the average vertical permeability is 0.058 feet/day for the zone considered. Vertical velocity was calculated to be approximately 0.028 feet/day. A vertical travel time was estimated to be 347 years based on the above assumption from the top of the injection zone to the 10,000-mg/l TDS interface. Actual travel times will probably be longer since actual injection rates at the DIW will probably be much less than those predicted under maximum injection rate conditions.

Table 5-1
NORTH PORT DIW CONFINING UNIT PERMEABILITIES

Interval (feet)	Thickness, m (feet)	Vertical Permeability, p (feet/day)	m/p (day)	Lithology
1,105-1,090	15	0.0057	2,632	Dolomite and clay
1,090-1,050	40	0.0235	1,702	Limestone, yellowish gray, mod. soft
1,050-1,020	30	0.0567	529	Limestone, yellowish gray, mod. hard
1,020-930	90	0.0850	1,058	Limestone, yellowish gray, mod. hard to soft
930-860	70	1.2760	55	Limestone, yellowish gray, mod. soft
860-750	110	0.5670	194	Limestone, yellowish gray, some clay and dolomite from 780-800'

Total Thickness = 355 feet

$$Pv = \frac{355 \text{ ft}}{(2632 + 1702 + 529 + 1058 + 55 + 194) \text{ day}}$$

Pv = 0.058 ft/day

where:

Pv = the vertical permeability in feet/day

Table 5-2
SUMMARY OF CALCULATIONS TO ESTIMATE VERTICAL TRAVEL TIME

1. Use average vertical permeability and apparent porosity from the core data.

   Pv = 0.058 feet/day
   $\emptyset$ = 0.288

2. Assume the following:

   - Estimated height of injected fluid column is 50 feet
   - Specific gravity of native water is approx. 1.025
   - Specific gravity of injected fluid is approx. 1.00

3. Calculate pressure increase near injection well considering buoyancy and using steady state leaky aquifer equations.

   - Density of injected fluid
     Yi = 62.4 lb/ft3 x 1.00 = 62.4 lb/ft3

   - Density of native water
     Yn = 62.4 lb/ft3 x 1.025 = 63.96 lb/ft3

   - Buoyancy force
     Fb = (Yn (h) - Yi (h))A where A = area
     Pb = Fb/A = (Yn - Yi)h
     Pb = (63.96 - 62.4)lb/ft3 x 50 ft
     Pb = 78 lb/ft2

     Convert to feet by dividing by 62.4 lb/ft3
     Hb = (78 lb/ft2)/(62.4 lb/ft3)
     Hb = 1.25 ft

4. Calculate injection well pressure increase using steady state leaky aquifer conditions at a radius of 10 ft.

   Q = 3200 gpm
   r = 10 ft
   T = 1,900,000 gpd/ft
   Hh = 3.75 ft

5. Calculate total upward pressure head

   Ht = Hb + Hh
   = 1.25 ft + 3.75 ft
   = 5.00 ft

Table 5-2
(Continued)

6. Calculate vertical velocity

$$V = \frac{(Pv) \times (I)}{\emptyset}$$

where:

I = the hydraulic gradient
I = Ht/m
= (5.00 ft)/(355 ft)
= 0.0141 ft/ft

$$V = \frac{(0.058 \text{ ft/day}) \times (0.0141 \text{ ft/ft})}{0.288} = 0.0028 \text{ ft/day}$$

7. Calculate vertical travel time

$$\text{Time} = \frac{m}{\bar{v}}$$

$$\text{Time} = \frac{355 \text{ ft}}{0.0028 \text{ ft/day}}$$

Time = 126,785 days

or

Time = 347 years (estimated)

Section 6
SUMMARY AND RECOMMENDATIONS

GDU has successfully completed the drilling and testing of the North Port DIW system in accordance with TAC recommendations and the FDER permit requirements (Settlement Agreement). Construction of the DIW system began January 1987 and was completed by January 1988. Operational testing of the facility has been ongoing since January 1988.

The DIW system consists of a 14-inch DIW, a 6-inch dual-zone OMW, and a RMW. A total of 1,105 feet of 14-inch seamless steel casing was installed at the DIW with an open hole from 1,105 feet to 3,200 feet. The dual-zone OMW consisted of 6-inch FRP to 730 feet with an open hole to 750 feet, and an open annulus from 551 to 600 feet. This well is located approximately 80 feet from the DIW. A RMW was constructed approximately 4,150 feet from the DIW and consist of 1,100 feet of 6-inch FRP casing with an open hole to 1150 feet.

Hydrogeologic formations penetrated while constructing the DIW indicated that this zone would be suitable for deep well injection. A good confining layer was found separating a very productive injection zone from overlying sources of drinking water (TDS $\leq$ 10,000 mg/l). The major injection zone penetrated extended from approximately 1,120 feet to 1,640 feet in depth.

Water quality results from reverse-air drilling, hydraulic testing, and straddle packer testing suggest that this location is suitable for the disposal of secondary treated effluent. The 10,000-mg/l TDS interface is estimated to occur between 551 and 600 feet in depth. Water quality deteriorated rapidly with depth below this point, with the injection zone having a TDS concentration ranging from 25,000 to 36,000 mg/l. The TDS concentration of seawater is approximately 35,000 mg/l.

Coring and straddle packer tests conducted during the testing program show that good confinement exist between the 10,000-mg/l TDS interface and the top of the injection zone. The composite vertical permeability, using the Sinclair (1974) method, is estimated to be 0.058 ft/day. This value is low and is indicative of a good confining unit, and within the range of values reported for the Ocala Group at other locations.

Vertical travel time has been calculated to estimate the time required for injected fluids to reach the 10,000-mg/l TDS interface using data collected during the drilling and testing phase. It is estimated that it will take 347 years for the injected fluid to travel vertically and reach the 10,000-mg/l TDS interface.

Two separate mechanical integrity tests were performed to confirm the integrity of the DIW construction. The internal mechanical integrity was tested using a casing pressure test. This test was successfully conducted by pressurizing the 14-inch casing and monitoring for pressure drops. The DIW was able to hold a constant pressure for one hour without any pressure drop. A radioactive tracer survey was also conducted to check the external mechanical integrity of the cement seal around the outside of the bottom of the casing. A radioactive tracer was released at the bottom of the casing and a gamma ray tool monitored the movement of the tracer as fresh water was injected in the DIW. There was no vertical movement detected throughout this test. The external mechanical integrity was determined to be in good condition.

A 24-hour pumping test was conducted at the DIW using the RMW as a monitor well to measure water levels. Results from this pumping test show that very productive zones were penetrated at the injection well. These zones have an estimated transmissivity of 1,900,000 gpd/ft. This shows that the injection zone can receive high flows at relatively low injection pressures making deep well injection suitable for this area. The high transmissivity value estimated from the 24-hour pumping test is similar to the transmissivity values estimated from several other single well pumping tests conducted during the construction of the DIW.

Modeling was performed to estimate the movement of the injected fluids in the surrounding areas, especially Warm Mineral Springs. Two alternatives were modeled: one with an average injection rate of 2.3 mgd and one with an injection rate of 4.76 mgd, which is equivalent to the maximum injection rate permitted for a 14-inch casing. The minimal effects shown in the 2.3-mgd run, coupled with the fact that no apparent hydraulic connection was detected between Warm Mineral Springs and the injection zone during this study, suggest that the effluent in the injection zone would simply move downgradient with the regional flow. The second scenario predicts that the injected fluids may reach the area of concerns after continuous pumping at 4.76 mgd. It is very unlikely that the well will be operating at 4.76 mgd since the WWTP capacity is much less. The model assumes that Warm Mineral Springs originated from the same zone as the DIW.

Monitoring at Warm Mineral Springs throughout this project has shown that the DIW has no apparent impact on the springs. Temperature, conductivity, and water levels were measured continuously throughout the drilling and testing of the DIW system. Monthly sulfate and chloride water samples were also collected. Results of the monitoring showed that there has been no apparent impact on Warm Mineral Springs. Only the pumping test conducted while testing the DIW from 560 to 854 feet showed a slight hydraulic effect at the spring. The effects from this test were minimal and no other impact was noticed while testing below this depth. The DIW is cased to 1,105 feet, far below this depth.

Operational testing of the North Port DIW system began in January 1988 and has continued through the present. The system appears to be operating as planned and no significant problems have developed as a result of injection. Average injection rates have been approximately 382 gpm at injection pressures of approximately 14.6 psi. No significant increases in injection pressures, monitor well pressures, or flows at Warm Mineral Springs have occurred as a result of injection at the DIW.

CH2M HILL's recommendations regarding the operation of the North Port DIW system follow. These recommendations have been proposed after careful review of the drilling and testing data, including operational testing data.

1. Continue operation of the North Port DIW permanently in accordance with the proposed monitoring schedule.

2. Monitor the DIW for the following parameters:

   - Injection wellhead pressure (psi)/continuously
   - Daily flow rate (gpm)/continuously
   - Total flow volume (gallons)/daily

3. Monitor the OMW shallow and deep zones and the RMW for the following parameters:

   - Wellhead pressure (psi)/continuously
   - Conductance (μmhos/cm)/monthly
   - Total dissolved solids (mg/l)/monthly
   - Chloride (mg/l)/monthly
   - Sulfate (mg/l)/monthly
   - Fecal coliform (#/100 ml)/monthly
   - Complete primary and secondary drinking water standards/annual

4. Monitor the WWTP effluent for the following parameters:

   - pH/weekly average
   - BOD5/weekly average
   - Suspended solids/weekly average

5. Monitor Warm Mineral Springs for the following parameters:

- o Temperature (°C)/continuously
- o Conductance (μmhos/cm)/continuously
- o Spring pool water level/continuously
- o Stream gaging/quarterly
- o Chlorides (mg/l)/monthly
- o Sulfate (mg/l)/monthly
- o Rainfall (inches)/daily at Warm Mineral Springs

Section 7
REFERENCES

CH2M HILL. Engineering Study of the Wastewater Treatment and Effluent Disposal at the North Port WWTP. Deerfield Beach, Florida. March 1985.

Chen, C. S. The Regional Lithostratigraphic Analysis of Paleocene and Eocene Rocks of Florida. Florida Geological Survey Bulletin No. 45. 1965.

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

Gringarten, A. C. and J. P. Sauty. A Theoretical Study of Heat Extraction from Aquifers with Uniform Regional Flow. Journal of Geophysical Research. Volume 80, No. 35. 1975. pp. 4956-4962.

Harrin, J. R. Determining Transmissivity from Water-Level Recovery of a Step Drawdown Test. U.S. Geological Survey. Professional Paper 700-C. 1970.

Ingersol-Rand. Cameron Hydraulic Data. Ingersol-Rand Co. Sixth Edition. 1981.

Javandel, I., C. Doughty, and C. F. Tsang. Groundwater Transport: Handbook of Mathematical Models. Water Resources Monograph Series 10. American Geophysical Union. Washington, D.C. pp. 35-182. 1984.

Johnson, Richard A. Stratigraphic Analysis of Geophysical Logs from Water Wells in Peninsular Florida. St. Johns River Water Management District Technical Publication SJ84-16. 1984.

Keys, W. S., and L. M. MacCary. Application of Borehole Geophysics to Water-Resources Investigations. Techniques of Water-Resources Investigations of the United States Geological Survey Book 2, Chapter E1. 1971.

Lohman, S. W. Ground-Water Hydraulics. U.S. Geological Survey. Professional Paper 708. 1979.

Mills, L. R., C. P. Laughlin, and D. C. Parsons. Potentiometric Survace of Floridan Aquifer. Southwest Florida Water Management District. SWFWMD FL 76003. September 1975.

Neuman, S. P. and P. A. Witherspoon. Field Determinations of the Hydraulic Properties of Leaky Multiple Aquifer

Systems. Water Resources Research. Volume 8, Number 5. 1972.

Puri, H. S., and G. O. Winston. Geologic Framework of the High Transmissivity Zones in South Florida. Florida Geological Survey Special Publication No. 20. 1974.

Runnells, Donald D. Diagenesis, Chemical Sediments, and the Mixing of Natural Waters. Journal of Sedimentary Petrology, Vol. 39, No. 3. pp. 1188-1201. 1969.

Sinclair, W. C. Hydrogeologic Characteristics of the Surficial Aquifer in Northwest Hillsborough County, Florida. Florida Bureau of Geology. Information Circular No. 86. 1974.

Stringfield, Victor T. Artesian Water and Tiertiary Limestone in the Southeastern States. U.S. Geological Survey Professional Paper 517. Washington, D.C. 1966.

Vernon, R. O. The Beneficial Uses of Zones of High Transmissivities in the Florida Subsurface for Water Storage and Waste Disposal. Florida Bureau of Geology Information Circular No. 70. 1970.

Walton, W.C. Groundwater Resources Evaluation. McGraw Hill Publishing Co. pp. 143-147. 1970.