Station

CO-2081 (OW) = C-1103

MC-5002

MC-5001

CO-2317 = W-16884

APT SITE NAME SCCWPT

COLLIER COUNTY PUBLIC WORKS SOUTHERN REVERSE OSMOSIS WELLFIELD STUDY COLLIER COUNTY, FLORIDA

Prepared for:

Board of County Commissioners
Collier County Government
3301 E. Tamiami Trail
Naples, Florida 34113

October, 2000

by:

CDM/Missimer International Inc.
8140 College Parkway, Suite 202
Fort Myers, Florida 33919

Project No: FH8-812/9086-28655-DN.FWF

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October , 2000

Mr. Mohan Thampi, P.E.
Collier County Public Works
Public Works Engineering Dept., Bldg. D
3301 East Tamiami Trail
Naples, FL 34113

Re: Collier County SCRWTP Expansion
Southern Reverse Osmosis Wellfield

Dear Mr. Thampi:

Enclosed please find 5 copies of the report entitled "Collier County Public Works, Southern Reverse Osmosis Wellfield Study." The report documents the results of the hydrogeologic investigation that was conducted as part of the SCRWTP expansion project. Results of the investigation indicate that a substantial supply of brackish water is available beneath the study area to meet the raw water supply needs of the proposed reverse osmosis plant addition to the SCRWTP for many years. An optimum brackish water wellfield design is given for an 8 MGD finished water plant capacity. Raw data as well as analyses are also provided within the two volumes.

We appreciate the opportunity to provide assistance on this project and look forward to working with the County toward implementation of the report recommendations.

Sincerely,

W. Kirk Martin, P.G.
Vice President
Hydrology Services

WKM:lk

TABLE OF CONTENTS

TABLE OF CONTENTS – Continued:

LIST OF FIGURES

TABLE OF CONTENTS – Continued:

LIST OF FIGURES – Continued:

LIST OF FIGURES – Continued:

LIST OF TABLES

EXECUTIVE SUMMARY

The demand for potable water within the Collier County Utility service area is increasing rapidly due to population growth. Additional water supplies need to be developed in order to meet the increase in demands. Large-scale development of fresh groundwater sources from the shallow aquifer system near the major population centers is no longer feasible due to competing uses, the potential for saline water intrusion problems, and perceived impacts to wetlands or other environmentally sensitive areas. The Collier County Board of Commissioners and the County Public Works staff recognized the need for additional water and authorized a project to expand the capacity of the South County Regional Water Treatment Plant (SCRWTP). Reverse osmosis treatment of brackish groundwater sources will be required because of the restrictions on available freshwater supplies. The treatment plant expansion project includes three major components. A reverse osmosis treatment facility, a concentrate disposal system, and the raw water supply wellfield. This report addresses the testing and evaluations conducted in order to design the raw water supply wellfield.

Brackish water is known to occur in aquifers at depths of 250 feet below land surface and greater in the vicinity of the SCRWTP based on the results of previous hydrogeologic investigations conducted in the area. A detailed program of testing and analyses was developed to: identify one or more sources of brackish water suitable for reverse osmosis treatment; assess the quantity of water available for public supply use; estimate the pumpage induced, long-term changes in water quality with time; and to collect sufficient data to insure the long-term viability of the water source(s) and obtain a water use permit from the South Florida Water Management District. The investigation included the drilling of several test wells at three separate sites, collection of aquifer yield and water quality data, computer modeling to evaluate the impacts of the proposed pumpage, and development of wellfield design scenarios.

Two aquifers suitable for use as raw water supply sources for a reverse osmosis treatment facility were identified based on the results of the hydrogeologic investigation. The

Hawthorn Zone I Aquifer occurs between the approximate depths of 300 and 450 feet below land surface near the SCRWTP and is considered the primary source of feedwater for the proposed reverse osmosis treatment facility. The Lower Hawthorn Aquifer occurs between roughly 650 and 800 feet below land surface and can also be utilized as a raw water source. These two sources combined have the ability to yield adequate brackish feedwater within a two-mile radius of the SCRWTP to supply a reverse osmosis treatment plant with a finished water capacity of 8 MGD. These aquifer sources may be capable of yielding sufficient raw water from the study area to meet the demands of a 12 MGD treatment facility. However, expansion of the test program beyond the current test area is recommended to obtain additional data needed to fully evaluate the feasibility of developing raw water supplies in excess of that required for the 8 MGD finished water plant capacity.

1.0 CONCLUSIONS AND RECOMMENDATIONS

A hydrogeologic investigation and evaluation of brackish groundwater resources in the vicinity of the Collier South County Regional Water Treatment Plant (SCRWTP) was conducted in order to determine the availability of feedwater for a proposed reverse osmosis (R.O.) water treatment facility. The conclusions and recommendations presented below are based on the results of the study conducted.

1.1 Conclusions

- Brackish groundwater resources in the vicinity of the SCRWTP were evaluated to a depth of approximately 1600 feet below land surface as part of a hydrogeologic study of raw water supplies available for reverse osmosis treatment. The two sources most feasible for use are the Hawthorn Zone I Aquifer and the Lower Hawthorn Aquifer.

- A total of **10 test wells** were completed within the two aquifers and numerous tests were conducted to evaluate aquifer yield and water quality conditions. The Hawthorn Zone I aquifer was selected as the primary source of raw water for the proposed R.O. plant based on the generally higher well yields encountered within this unit. The Lower Hawthorn Aquifer is also a viable source of raw water based on the study results.

- Testing and analysis of the Hawthorn Zone I Aquifer indicate that the unit consists primarily of porous limestone. The aquifer occurs between the depths of approximately 300 and 450 feet below land surface in the study area and ranges in thickness between 100 to 150 feet. Dissolved chloride concentrations of water within the aquifer range from approximately 1800 mg/l to approximately 2800 mg/l in the vicinity of the SCRWTP. The aquifer transmissivity ranges from approximately 20,000 gpd/ft to approximately 100,000 gpd/ft. Storativity ranges from 1×10^{-4} to 4×10^{-4}. The leakance is estimated to be approximately 3×10^{-4} gpd/ft^3.

- Testing and analysis of the Lower Hawthorn Aquifer indicate that the unit consists primarily of porous limestones and dolomites. The aquifer occurs between the approximate depths of 650 and 800 feet below land surface in the study area and it is approximately 150 feet thick. Dissolved chloride concentrations of water within the aquifer range from approximately 1500 mg/l to approximately 3000 mg/l in the study area. Average dissolved chloride concentration near the SCRWTP is approximately 2000 mg/l. Aquifer transmissivity is highly variable and ranges from approximately 10,000 gpd/ft to approximately 260,000 gpd/ft. The storativity is approximately 1×10^{-4}. The leakance is estimated to be approximately 1×10^{-3} gpd/ft^3.

- Potentiometric levels in both aquifers range from approximately 35 to 45 feet NGVD or 20 to 25 feet above land surface in the study area. Water levels in the Lower Hawthorn Aquifer are approximately 1 to 4 feet higher than the Hawthorn Zone I water levels measured in the test wells. Wells tapping both units flow freely due to natural artesian pressure.

- Hydraulic and solute transport computer models of the Hawthorn Zone I and Lower Hawthorn Aquifer Systems were developed to simulate aquifer response in terms of drawdown and water quality changes that may result due to the proposed raw water withdrawal rates. Pumpage at 11.0 MGD from the two aquifers near the SCRWTP and raw water pumpage at a rate of 11.0 MGD from the existing Lower Hawthorn Aquifer wellfield that supplies the north reverse osmosis plant was simulated. A proposed design for the southern reverse osmosis wellfield was evaluated using these computer models to estimate the amount of drawdown that would occur in the aquifers due to the proposed withdrawals and the associated salinity changes over a 20-year period. Maximum drawdowns of 50 feet in the Hawthorn Zone I Aquifer and 40 feet in the Lower Hawthorn Aquifer are anticipated based on the model results. The solute modeling indicates that dissolved chloride concentrations from the southern wellfield may increase from an average initial value of 2600 mg/l up to 4500 mg/l due to the proposed pumpage.

1.2 Recommendations

- A total of 14 production wells should be utilized to meet the raw water demands of the proposed reverse osmosis plant (finished water capacity of 8 MGD). This includes 11 primary and 3 backup wells with an average production rate of 1 MGD per well. The wells should tap both the Hawthorn Zone I (10 wells) and Lower Hawthorn aquifers (4 wells). The three test/production wells tapping the Hawthorn Zone I Aquifer constructed as part of this investigation have adequate yield for use as permanent production wells and should be utilized, if feasible.

- The proposed Hawthorn Zone I Aquifer production wells should be constructed with 16-inch diameter PVC casings extending to a depth of approximately 300 feet below land surface. A hydrogeologist should supervise construction of the wells and recommend final cased and total depths for each well based on lithologic analysis of formation samples obtained during drilling and the correlation of units with the previously drilled test wells. Open hole sections of the wells should be drilled to a depth of approximately 420 feet below land surface with the reverse air drilling technique. No drilling fluid, other than clean water, should be used in the production zone. The production wells should be thoroughly developed with compressed air to remove all drill cuttings and sediment from the open boreholes.

- The proposed Lower Hawthorn Aquifer production wells should be constructed with fiberglass (FRP) or PVC casings extending to a depth of approximately 650 feet below land surface. The casings should be 12-inch diameter with the upper 120 feet increased to 16-inch diameter to allow for adequate pump sizing. The wells should be drilled to a total depth of approximately 800 feet below land surface. The drilling and development techniques should be similar to those utilized during the construction of the Hawthorn Zone I Aquifer wells.

- Step-drawdown pump tests should be conducted on the production wells. Pumping rates during the tests may range from 300 to 1500 gpm or more. Specific capacity values calculated based on the test results can be used to assess individual well yields and confirm the proposed pump setting depths and withdrawal rates. All of the production wells should be disinfected following development and pump testing. Submersible pumps equipped with electric motors should be installed in the wells with the intakes set at depths determined based on the specific capacity test results. It is estimated that motor horsepowers within the range of 40 to 75 hp will be required. Intake setting depths of 60 to 120 feet below land surface are anticipated. Recommended withdrawal rates for the wells when the R.O plant is in operation may range from 0.5 to 1.5 MGD and can be varied to meet the treatment plant demands.

- Water level and water quality data should be collected from the reverse osmosis test wells on a periodic basis. Monitoring of the test wells should be initiated soon to obtain background data before the wellfield is put into operation.

- Areas for future wellfield expansion should be selected based on site availability, proximity to existing pipeline infrastructure, and with consideration given to how the additional pumpage will affect aquifer drawdown and water quality degradation. The hydraulic and solute transport models of the aquifer system developed as part of this investigation should be used to evaluate any proposed wellfield expansion scenarios. The construction of wells to the east of Section 25 or south of I-75 are considered the most likely scenarios for wellfield expansion based on the available data.

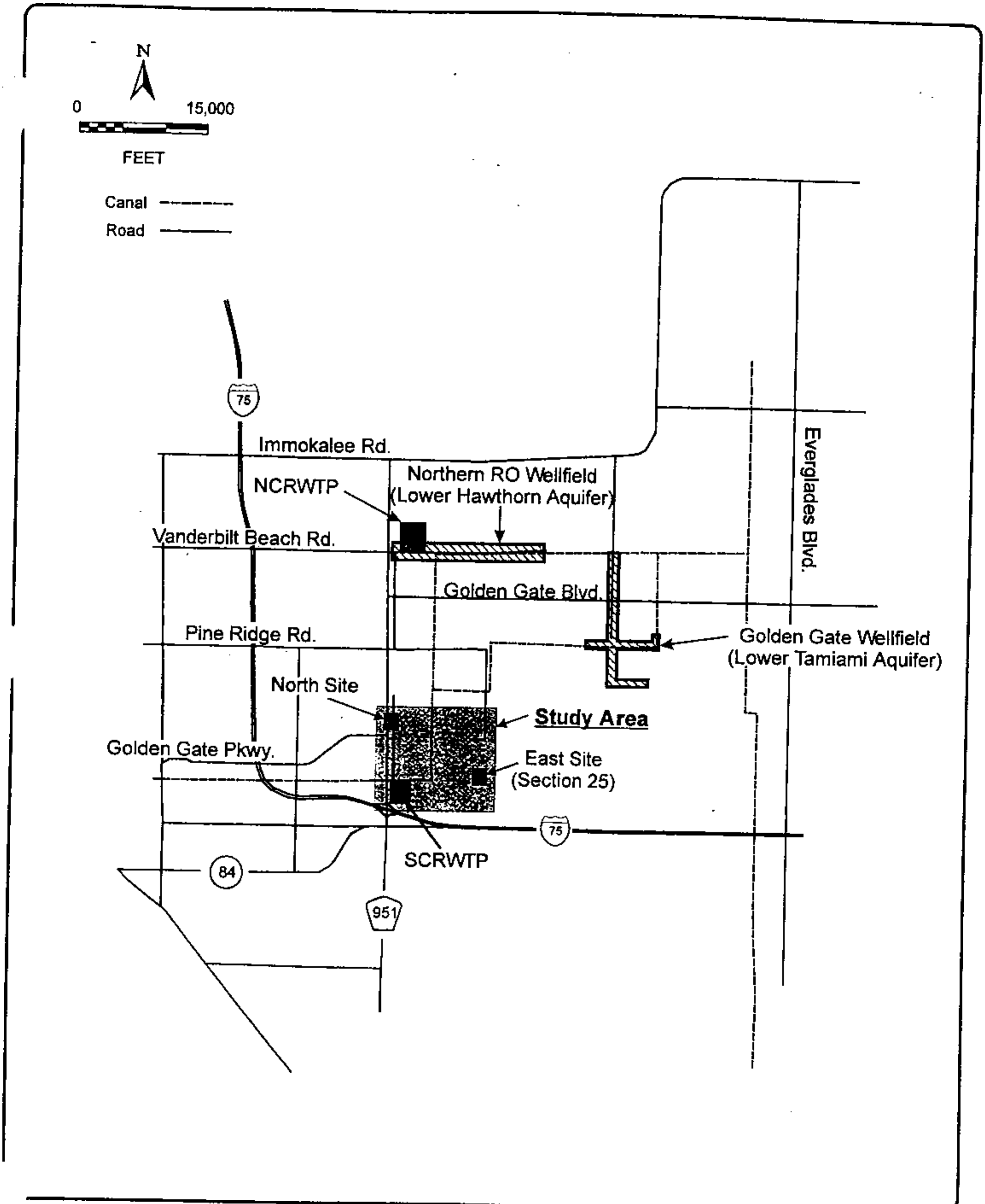
- An application should be submitted to the SFWMD for modification/renewal of the County water use permit No. 11-01447-W for withdrawals from the Hawthorn Aquifer system. The permit modification will include the addition of the proposed Hawthorn Zone I and Lower Hawthorn Aquifer production wells and a concomitant increase in average and maximum daily water use allocations. Data collected during this investigation should be used in support of the application for permit modification.

2.0 INTRODUCTION

2.1 Background

The Collier County Water Department needs to develop additional water supplies to meet the rapidly increasing demand for potable water within the County service area. The County currently operates two water treatment facilities with a combined capacity of 32 MGD. The North County Regional Water Treatment Plant (NCRWTP) utilizes both membrane softening (12 MGD) and reverse osmosis (8 MGD) treatment methods to produce potable water. The South County Regional Water Treatment Plant (SCRWTP) has a capacity of 12 MGD and utilizes the lime softening treatment process. A wellfield tapping the Lower Hawthorn Aquifer supplies brackish raw water to the reverse osmosis membranes at the NCRWTP. A freshwater wellfield tapping the Lower Tamiami Aquifer supplies both the SCRWTP and the membrane softening units at the NCRWTP.

Increased withdrawals from the Lower Tamiami Aquifer are not feasible due to regulatory concerns over potential adverse impacts to the environment, domestic wells, or other permitted users. Deeper aquifer sources that contain more mineralized water need to be considered for future water supply development. A preliminary investigation of the deep aquifer system to identify potential brackish raw water supply sources and zones suitable for aquifer storage and recovery in southwest Collier County was conducted previously (Missimer & Associates, Inc., 1991). The results of that investigation indicated that potential raw water sources were available within the intermediate and Upper Floridan Aquifer system. This additional, more detailed hydrogeologic investigation was conducted in the vicinity of the SCRWTP in order to more fully evaluate brackish groundwater sources in the area suitable for reverse osmosis treatment. The study area is shown in Figure 2-1. Two raw water sources, the Hawthorn Zone I and Lower Hawthorn aquifers, were identified as a result of the investigation. This report has been prepared to document the methods and procedures used during the investigation and the results obtained. A discussion of the project work scope follows.



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Pr. Name: SCRWTP RO EXPANSION	
Pr. No. FH8-812	Date: 7/20/00
DWG No.	Rev. No.

GROUNDWATER
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ENVIRONMENTAL SERVICES

FIGURE 2-1. SITE MAP

2.2 Work Scope

The scope of the project included: 1) a compilation and review of available geologic, hydraulic, and water quality data collected during previous hydrogeologic investigations, 2) construction of test wells tapping the Hawthorn Zone I and Lower Hawthorn aquifers in the vicinity of the SCRWTP and adjacent areas, 3) collection and analysis of lithologic, geophysical, and water quality data during well construction and testing, 4) aquifer performance testing to determine pertinent aquifer hydraulic characteristics for both the Hawthorn Zone I and Lower Hawthorn aquifers, 5) development of hydraulic and solute transport computer models to evaluate various wellfield scenarios and estimate water level and water quality changes that may result due to raw water pumpage at rates of up to 11 MGD, and 6) preparation of this report summarizing the results of the investigation. Additional tasks that remain to be completed for wellfield development as part of the overall water treatment plant expansion project include: preparation of technical specifications for construction of the reverse osmosis production wells and assistance in the bid process; modifying Collier County water use permit No. 11-01447-W to authorize increased pumpage from the Hawthorn Aquifer system; provision of observation services during production well construction; perform step-drawdown tests to evaluate individual well yield and; start up services for the raw water supply wellfield.

The drilling and testing procedures used during the investigation are presented in the following section of this report. A discussion of the hydrogeology of the study area and how it affects water supply development is also provided along with descriptions of how the computer models were constructed and used to evaluate the potential for water level and water quality changes due to pumpage. Water quality data obtained by sampling the test wells constructed for the study and other existing water quality data were used for solute transport modeling and by the engineers responsible for the membrane process design. The MODFLOW computer code developed by the United States Geological Survey was used to construct the hydraulic flow model of the aquifer system. Aquifer parameters utilized in the model were determined from the results of aquifer performance testing conducted near the SCRWTP and the surrounding area as part of this and previous hydrogeologic investigations. Solute transport modeling was accomplished using the SEAWAT computer code developed by CDM/Missimer International, Inc. staff.

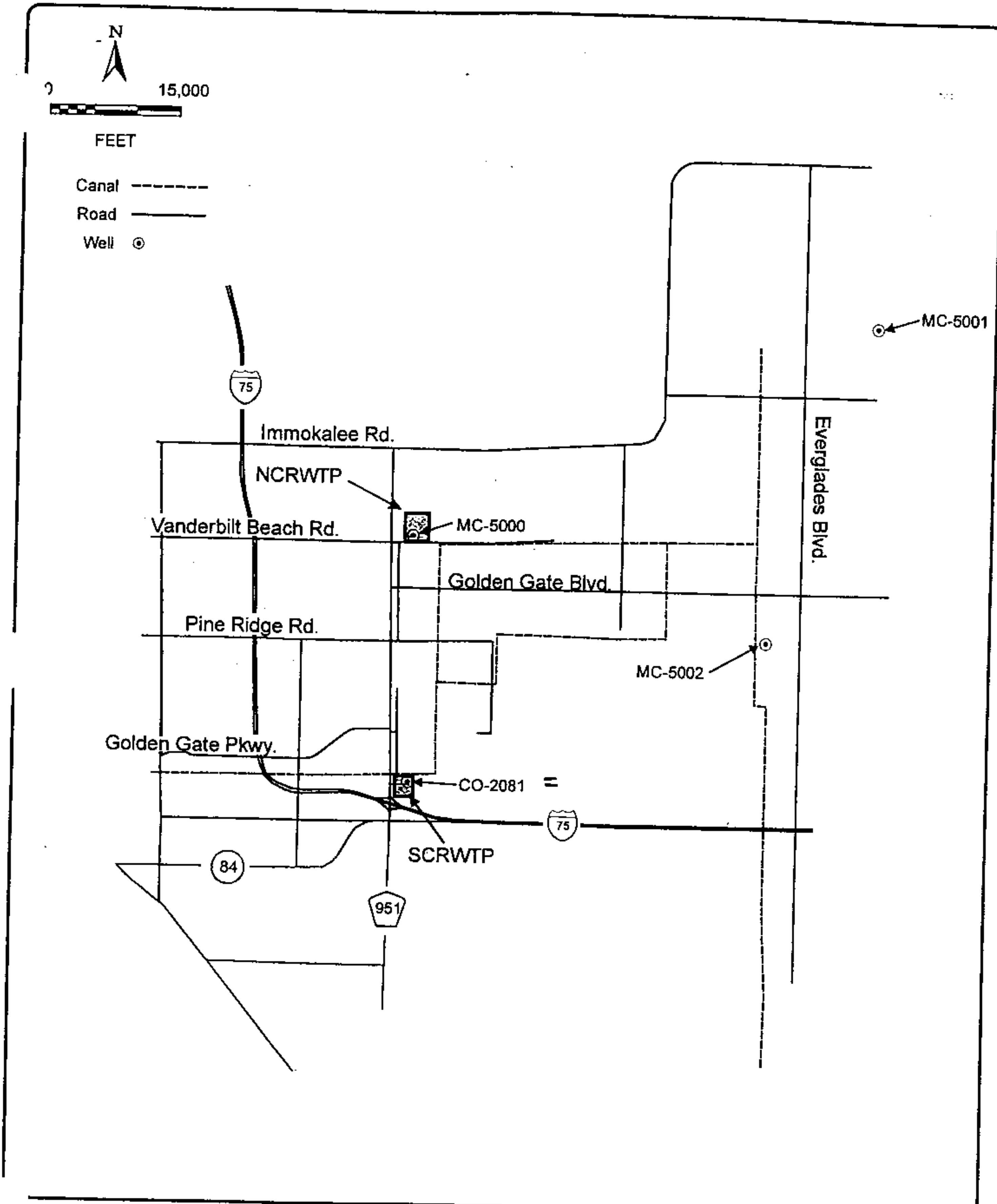
3.0 METHODS OF INVESTIGATION

3.1 Existing Data Compilation and Review

Geologic and hydrologic data available in western Collier County were compiled and evaluated as a preliminary assessment of the brackish groundwater sources suitable for reverse osmosis treatment in the area near the SCRWTP. The data sources included: the Missimer International, Inc. in-house hydrogeological data base, information gathered during the North County Regional Water Treatment Plant (NCRWTP) RO Expansion, the United States Geological Survey (USGS) and Florida Geological Survey publications, the Bureau of Oil and Gas files, South Florida Water Management District (SFWMD) files, and university files and theses. A partial list of the references utilized is provided at the end of this report.

A study of brackish water sources was conducted previously (Missimer & Associates, Inc., 1991) to identify deep aquifers suitable for either reverse osmosis raw water supply or for aquifer storage and recovery (ASR) of excess water available during the wet season months. Well CO-2081 was drilled to a depth of 1600 feet during December 1990 at the SCRWTP as part of that study. Hydraulic test data, geophysical logs and water quality data from well CO-2081 were reviewed to help select potential brackish water supply zones.

The locations of the wells used in the preliminary evaluation of the regional hydrogeology are shown in Figure 3-1. The information obtained from these wells was used to identify potential production aquifers. The initial data review revealed that two aquifer units (Hawthorn Zone I and Lower Hawthorn) within the Hawthorn Group merited further investigation as potential brackish water supply sources.



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Pr. No. FH8-812	Date: 7/20/00
DWG No.	Rev. No.

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FIGURE 3-1. LOCATION OF WELLS USED IN THE PRELIMINARY INVESTIGATION FOR THE SCRWTP RO EXPANSION.

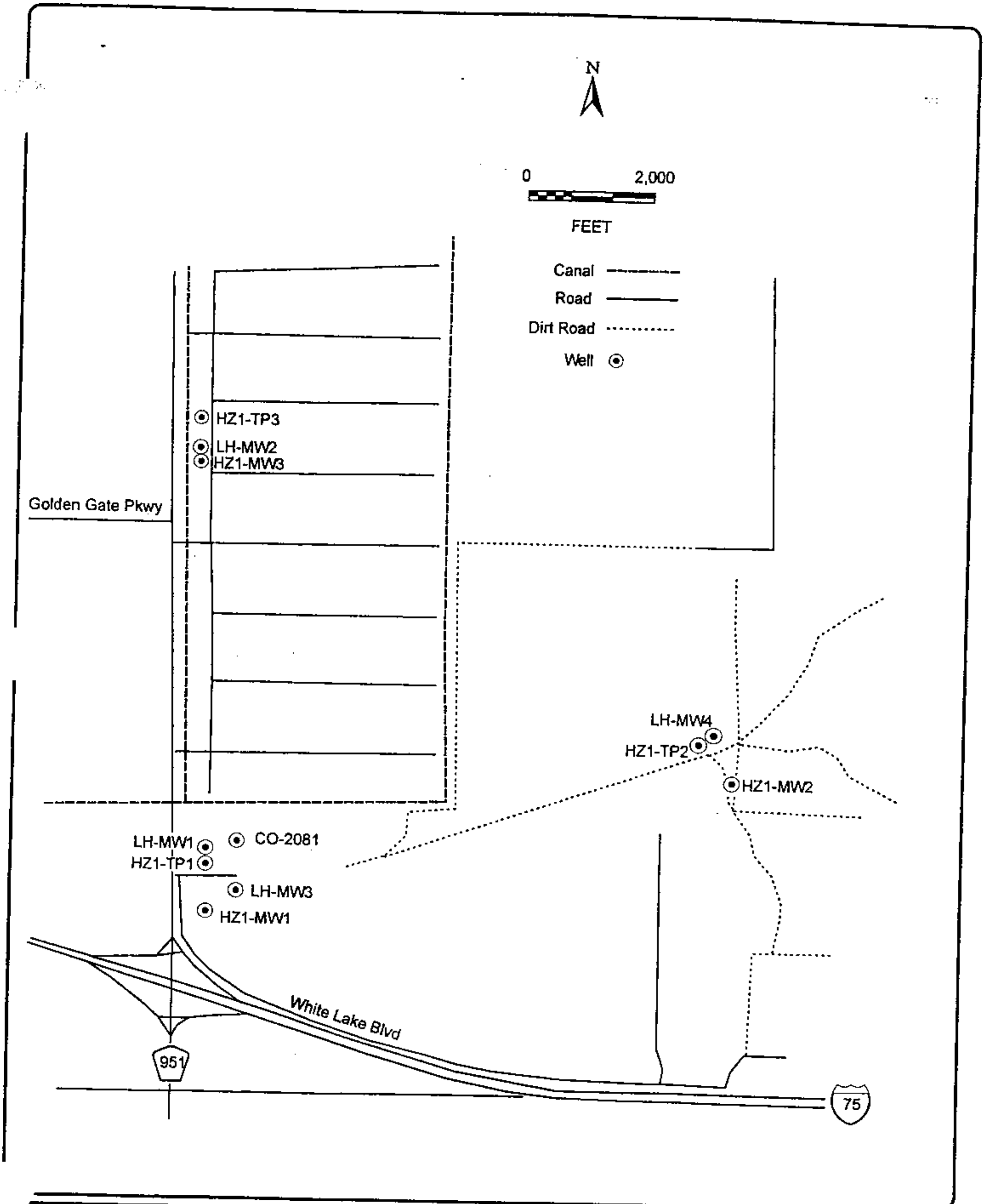
3.2 Test Drilling

3.2.1 Hawthorn Zone I Aquifer Wells

Three 12-inch diameter test/production wells, HZ1-TP1 (MC-5055), HZ1-TP2 (MC-5057), and HZ1-TP3 (MC-5065), were installed from January, 2000 to June, 2000 by West Coast Drilling, under Missimer International, Inc. supervision. Well HZ1-TP1 is located on the grounds of the SCRWTP, well HZ1-TP2 is located in the woods east of the water plant and north of the landfill (Section 25, T49S, R26E), and well HZ1-TP3 is located north of the water plant near C.R. 951. These wells penetrate the Hawthorn Zone I Aquifer and were constructed so that testing of the aquifer could be performed and water quality data could be collected. Three monitor wells tapping the Hawthorn Zone I Aquifer were also installed. The monitor wells were installed to serve as observation wells for water level measurement during aquifer performance testing. Monitor well HZ1-MW1 (MC-5054) is located on the grounds of the SCRWTP. Monitor well HZ1-MW2 (MC-5056) is located in the woods near HZ1-TP2 (Section 25, T49S, R26E), and monitor well HZ1-MW3 (MC-5069) is located north of the plant along C.R. 951 near HZ1-TP3.

Formation samples in the form of drill cuttings were collected by an on-site hydrogeologist and observed by hand lens to assess lithology, color, hardness, and apparent porosity and permeability. Geologist's logs of the sediments encountered during drilling are included in the appendix of this report. Locations of the test/production and monitor wells are given in Figure 3-2. General well construction details of the Hawthorn Zone I Aquifer test/production and monitor wells are provided in Figures 3-3 and 3-4, respectively.

Similar drilling techniques were used for all of the wells with minor alterations to accommodate the different well sizes and site specific conditions. For the test/production wells, 20-inch diameter Schedule 40 PVC surface casings were installed to depths ranging from approximately 10 to 20 feet below land surface (bls) at each site.



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Pr. No. FH8-812 Date: 7/20/00

DWG No. Rev. No.

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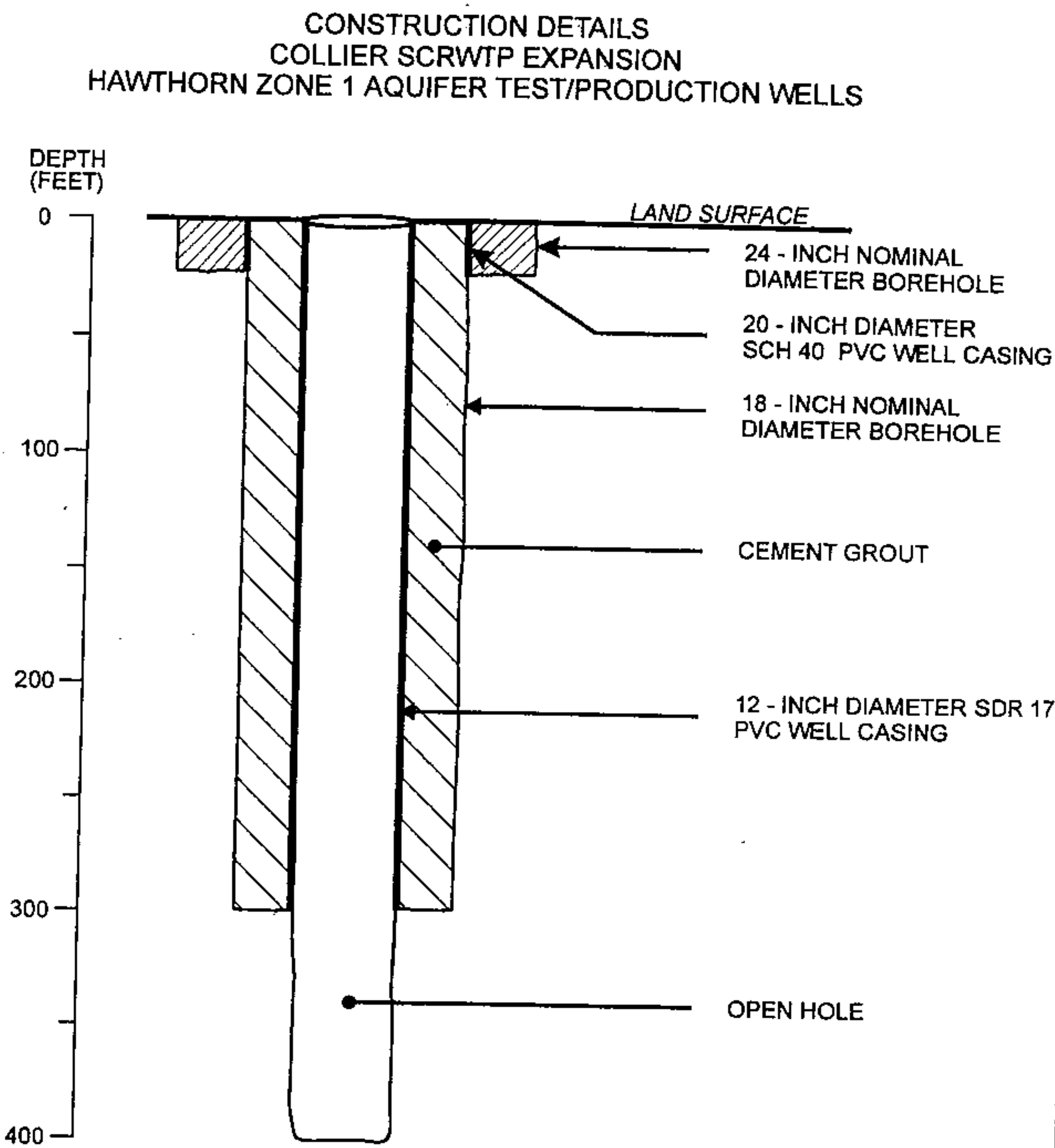
FIGURE 3-2. TEST WELL LOCATIONS



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	Pr. No. FH8-812	Date: 7/20/2000	
	DWG No.	Rev. No.	

FIGURE 3-3. SCHEMATIC DIAGRAM SHOWING GENERAL CONSTRUCTION DETAILS FOR THE SCRWTP REVERSE OSMOSIS HAWTHORN ZONE 1 AQUIFER TEST/PRODUCTION WELLS. ACTUAL CASED AND TOTAL WELL DEPTHS VARY.

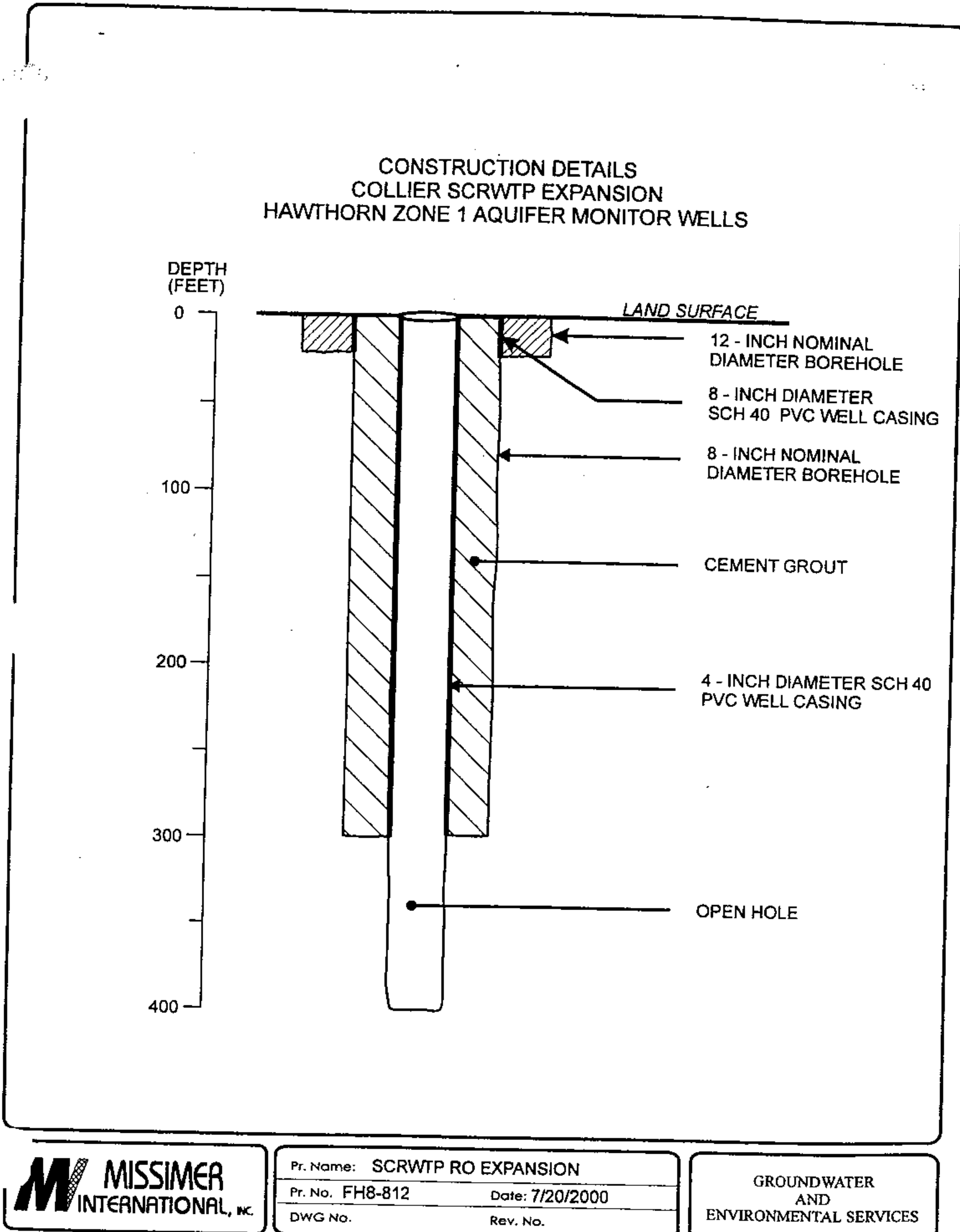


FIGURE 3-4. SCHEMATIC DIAGRAM SHOWING GENERAL CONSTRUCTION DETAILS FOR THE SCRWTP REVERSE OSMOSIS HAWTHORN ZONE 1 AQUIFER MONITOR WELLS. ACTUAL CASED AND TOTAL DEPTHS VARY.

A nominal 18-inch diameter borehole was then drilled into the top of the first limestone unit within the Hawthorn Group, which occurs at approximately 285-290 feet below land surface in the vicinity of the SCRWTP. The boreholes were drilled 5 to 10 feet into the limestone to ensure the integrity of the casing seat. A 12-inch diameter, SDR-17 PVC casing string was then installed and grouted in place using neat Portland Type II cement for the bottom 100 feet, and 5 % bentonite combined with the Portland Type II cement for the remainder of the grouting. The initial cement stage was installed by pressure grouting using a 1-inch PVC line that was run through the well casing, while the remaining annular space was grouted in stages using a tremie pipe.

The open hole sections of the test/production wells were drilled with a 10.5-inch diameter tri-cone bit using the reverse-air drilling method. The reverse air method allows the collection of clean drill cuttings and water samples with depth during drilling. Groundwater samples were collected at intervals of approximately 10 feet during reverse-air drilling. The Hawthorn Zone I Aquifer wells were drilled to total depths ranging from 400 to 420 feet bls depending on local site conditions. Final well depth was determined by the on-site, MI hydrogeologist based on lithology, water quality, and total well yield. After reaching total depths, the wells were air developed for several hours from within the casing. Another water sample was collected after development of the wells was completed. The three Hawthorn Zone I Aquifer monitor wells were constructed in a similar fashion.

3.2.2 Lower Hawthorn Aquifer Wells

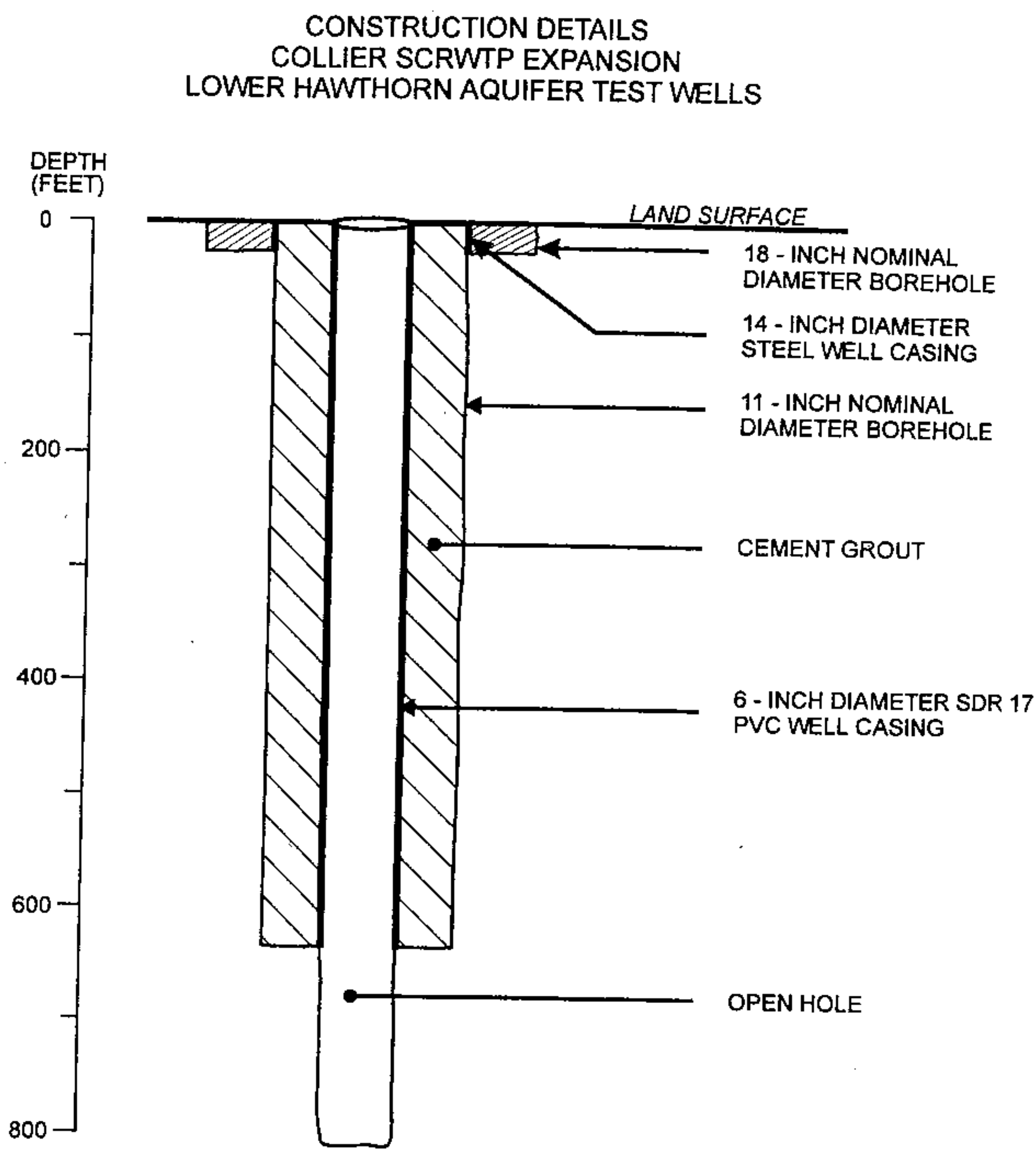
Four Lower Hawthorn Aquifer test wells, LH-MW1 (MC-5060), LH-MW2 (MC-5066), LH-MW3 (MC-5067), and LH-MW4 (MC-5068) were installed from March, 2000 to August, 2000 by West Coast Drilling, under Missimer International, Inc. supervision. Wells LH-MW1 and LH-MW3 are located on the grounds of the SCRWTP. Well LH-MW4 is located in the woods east of the water plant and north of the landfill (Section 25, T49S, R26E), and well LH-MW2 is located approximately 1 ½-miles north of the water plant near C.R. 951. These wells were drilled so that hydraulic testing of the Lower

Hawthorn Aquifer could be performed and water quality data could be collected. An on-site hydrogeologist collected cuttings samples and selected casing setting depths based on site specific lithologic conditions. Locations of the Lower Hawthorn Aquifer test wells are shown on the well location map (Figure 3-2). General well construction diagrams for the Lower Hawthorn Aquifer test wells are provided as Figures 3-5 and 3-6.

Construction of each Lower Hawthorn Aquifer test well followed similar methodologies with minor alterations to accommodate the different well sizes and site specific conditions. The 14-inch diameter steel surface casings (10-inch PVC for LH-MW3) were installed to depths of approximately 15 to 20 feet bls in 18-inch nominal diameter boreholes (15-inch for LH-MW3) that were drilled using the hydraulic rotary mud method. The annular spaces between the borehole walls and casings were filled with neat ASTM Type II (high sulfate resistance) Portland cement grout.

After the surface casings had been installed, the Lower Hawthorn Aquifer test wells LH-MW1, LH-MW2, and LH-MW4 were drilled using the mud-rotary method by advancing a 12-inch diameter bit to the top of the Lower Hawthorn Aquifer, which occurs at approximately 640 feet bls in the vicinity of the SCRWTP. The boreholes were drilled 5 to 10 feet into the limestone formation to ensure the integrity of the casing seat. The 6-inch diameter, SDR 17 PVC casing strings were then installed and grouted in place using neat Portland Type II cement for the bottom 100 feet and 5 % bentonite combined with Portland Type II cement for the remainder of the annulus. The initial grout stage was installed by pressure grouting through the well casing, while the remaining annular space was grouted in stages using a tremie pipe. The other Lower Hawthorn Aquifer well, LH-MW3 was constructed in similar fashion but with a 9-inch diameter bit and a 4 ½-inch diameter SDR-17 PVC casing.

The three larger Lower Hawthorn Aquifer wells were deepened using a 5-inch diameter tri-cone bit, while LH-MW3 was deepened with a 4-inch diameter tri-cone bit. The reverse-air drilling method was used to drill the open hole section in all of the wells. The reverse air method allows the collection of clean drill cuttings and water samples



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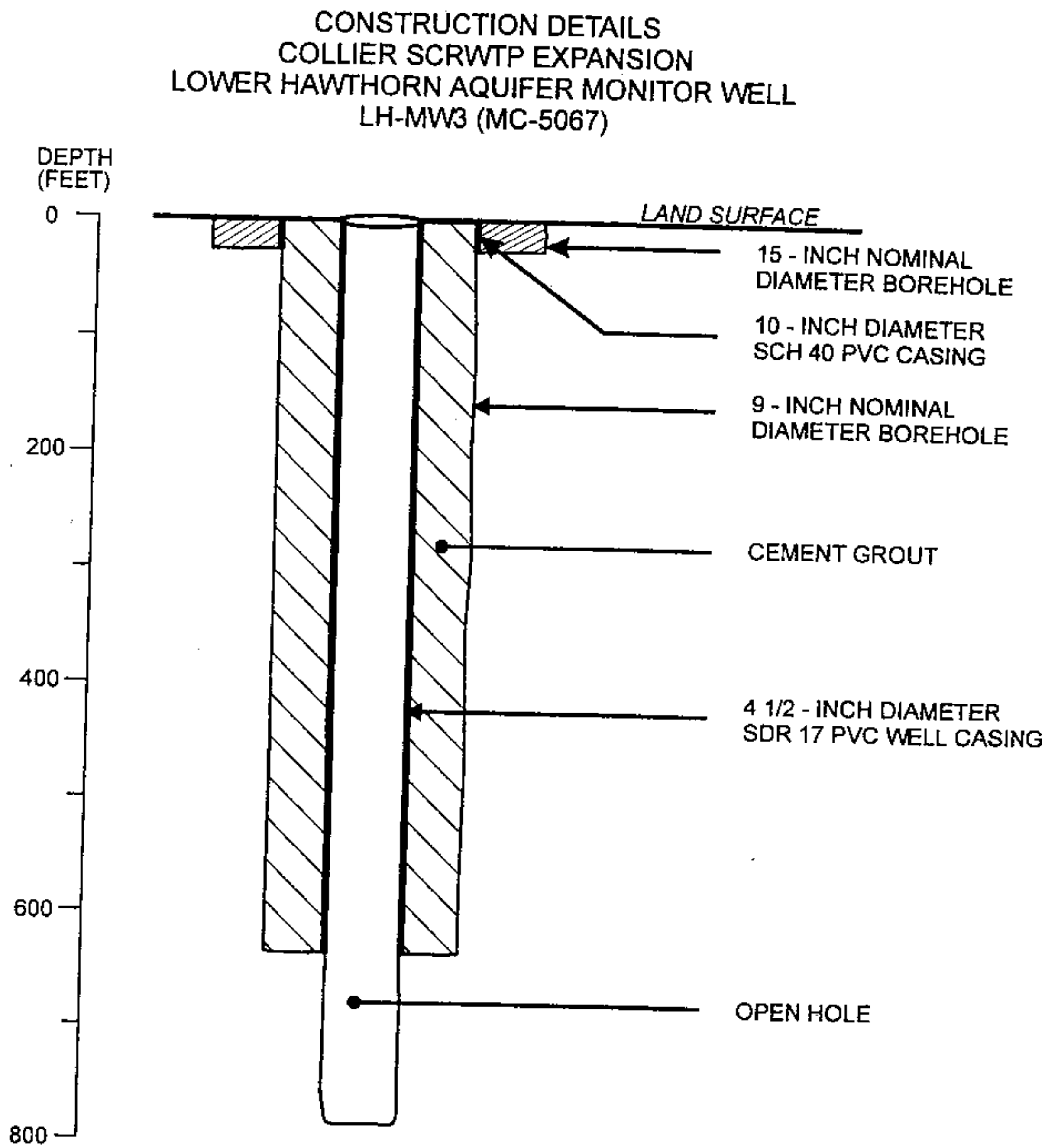
Pr. No. FH8-812	Date: 7/20/2000	
DWG No.	Rev. No.	

FIGURE 3-5. SCHEMATIC DIAGRAM SHOWING GENERAL CONSTRUCTION DETAILS FOR THE SCRWTP REVERSE OSMOSIS TEST WELLS IN THE LOWER HAWTHORN AQUIFER (EXCLUDING LH-MW3).



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Pr. No. FH8-812	Date: 8/2/2000	
DWG No.	Rev. No.	

FIGURE 3-6. SCHEMATIC DIAGRAM SHOWING CONSTRUCTION DETAILS FOR THE SCRWTP REVERSE OSMOSIS MONITOR WELL LH-MW3 (MC-5067) IN THE LOWER HAWTHORN AQUIFER.

with depth during drilling. Groundwater samples were collected at intervals of approximately 10 feet during reverse-air drilling. The wells were drilled to total depths ranging from 760 to 810 feet bls depending on local site conditions. Final well depth was determined by the on-site hydrogeologist based on lithology, water quality, and well yield. After reaching total depths, the wells were air developed for several hours from within the casing. An additional water sample was collected after development was complete. Construction details of the test wells installed for this investigation are given in Table 3-1.

Table 3-1. Test Well Construction Details

Well	Site	Casing Diameter (in)	Cased Depth (ft bls)*	Total Depth (ft bls)*	Aquifer	Use	Completion Date
HZ1-TP1	WTP	12	295	400	Hawthorn Zone 1	Test Production	1/11/00
HZ1-TP2	EAST	12	299	399	Hawthorn Zone 1	Test Production	2/11/00
HZ1-TP3	NORTH (951)	12	296	420	Hawthorn Zone 1	Test Production	6/22/00
HZ1-MW1	WTP	4	290	417	Hawthorn Zone 1	Monitor	12/17/99
HZ1-MW2	EAST	4	302	406	Hawthorn Zone 1	Monitor	1/25/00
HZ1-MW3	NORTH (951)	4	300	400	Hawthorn Zone 1	Monitor	8/7/00
LH-MW1	WTP	6	650	762	Lower Hawthorn	Test	3/9/00
LH-MW2	NORTH (951)	6	640	810	Lower Hawthorn	Test	7/6/00
LH-MW3	WTP	4.5	647	780	Lower Hawthorn	Monitor	7/26/00
LH-MW4	EAST	6	635	760	Lower Hawthorn	Test	8/18/00

*Feet below land surface (ft bls)

3.3 Geophysical Logging

MV Geophysical, Inc. ran wireline geophysical logs, under Missimer International supervision on selected wells to provide additional hydrogeologic data. Geophysical logs were run prior to setting the final casing on wells HZ1-MW1, HZ1-TP2, and LH-MW1 including; gamma ray, dual induction, and caliper logs. Logs were run after well completion on HZ1-TP1 and LH-MW2 including gamma ray, caliper, flowmeter, and fluid resistivity logs. Detailed logging information is given in Table 3-2 below.

Table 3-2. Geophysical Logs (Depth Logged in Feet)

Well	Mudded Hole			Open Hole				
	X-Y Caliper	Gamma	Dual Induction	X-Y Caliper	Gamma	Dual Induction	Flow-meter	Fluid Resist.
HZ1-MW1	0-300	0-300	0-300					
HZ1-TP1				295-400	0-400	265-400	265-400	265-400
HZ1-TP2	0-300	0-300	0-300					
LH-MW1	0-655	0-655	0-655					
LH-MW2				650-705	0-705			

3.4 Water Chemistry

Groundwater samples were collected at intervals of approximately 10 feet during reverse-air drilling and analyzed for specific conductance (conductivity) and dissolved chloride concentration. Conductivity was measured in the field using a YSI Model 3000 T-L-C Meter or a YSI Model 30 S-C-T Meter. Eight-ounce samples were also retained to conduct laboratory analysis for dissolved chloride concentration. Dissolved chloride and conductivity measurements were also made during aquifer performance testing and additional samples were collected from several of the wells and sent to state certified laboratories for analysis of chemical parameters critical to reverse osmosis treatment design for both the Hawthorn Zone I and Lower Hawthorn aquifers. Results of the chemical analyses are given in Section 4.0 and in the appendix.

3.5 Aquifer Hydraulic Testing

3.5.1 Step-Drawdown Testing

Step-drawdown tests were performed on the three Hawthorn Zone I Aquifer test/ production wells and on Lower Hawthorn Aquifer wells LH-MW1 and LH-MW2. The wells were pumped at separate steady rates (steps) using centrifugal pumps with suction and discharge ports ranging from 3-inch to 6-inch diameter depending on the estimated maximum pumping rate for each well. The three Hawthorn Zone I Aquifer test/production wells were pumped at higher rates than the two Lower Hawthorn Aquifer wells because the larger casing diameter allowed use of a larger pump. The pumping rate was measured using a 6-inch diameter orifice plate (with a manometer tube) attached to the end of a 10-inch diameter PVC discharge pipe for the larger pumping rates, and a 4-inch orifice attached to a 6-inch diameter discharge pipe was used for the lower rates. Static water levels in the wells were measured prior to the tests with a pressure transducer. The static water level in all of the wells exceeds 20 feet above land surface and the wells flow freely due to natural artesian pressure. Pumping water levels were measured using the wetted tape method. Each step lasted approximately 1 hour or until water levels in the wells stabilized. The step-drawdown tests were performed to obtain aquifer and well yield information and to aid in selecting appropriate pumping rates for the aquifer performance tests.

3.5.2 Constant Rate Aquifer Performance Tests

Constant rate aquifer performance tests (APTs) were conducted to determine aquifer hydraulic coefficients for both the Hawthorn Zone I and Lower Hawthorn aquifers. Two types of APTs were performed. For the first type, the test/production wells tapping the Hawthorn Zone I Aquifer and the 6-inch Lower Hawthorn well LH-MW1 at the SCRWTP were separately pumped at continuous rates while drawdowns were recorded at specified time intervals in one or more nearby monitor wells. In some of the APT tests, the wells were allowed to flow due to natural artesian pressure, for the others, a centrifugal pump was used to stress the aquifer. Time and potentiometric water level data from the observation wells were measured and recorded using pressure transducers coupled to an electronic data logger. Prior to conducting the APT's, background water level data were recorded in order to measure natural fluctuations of potentiometric pressures. The period and magnitude of the background water level changes suggest the fluctuations are due to tidal influences. At the water treatment plant site, two wells were available to monitor water levels in the Hawthorn Zone I Aquifer because of the existing test well CO-2081. This dual zone monitor well includes an interval open to the confining unit between the Hawthorn Zone I and Lower Hawthorn aquifers which was monitored during the APT test of the Hawthorn Zone I Aquifer at the SCRWTP.

The second type of APT was a single well recovery test that was utilized for wells LH-MW2 and LH-MW4 where monitor wells open to the same aquifer were not available for water level measurement. In this type of test, the well is allowed to flow for a period of time at a constant rate and then the well is shut-in and water levels are measured for several hours. Potentiometric water levels are measured with a pressure transducer coupled to an electronic data logger. The pressure transducer in this case is mounted on the wellhead of the stressed well.

3.5.2.1 Hawthorn Zone I Aquifer APT

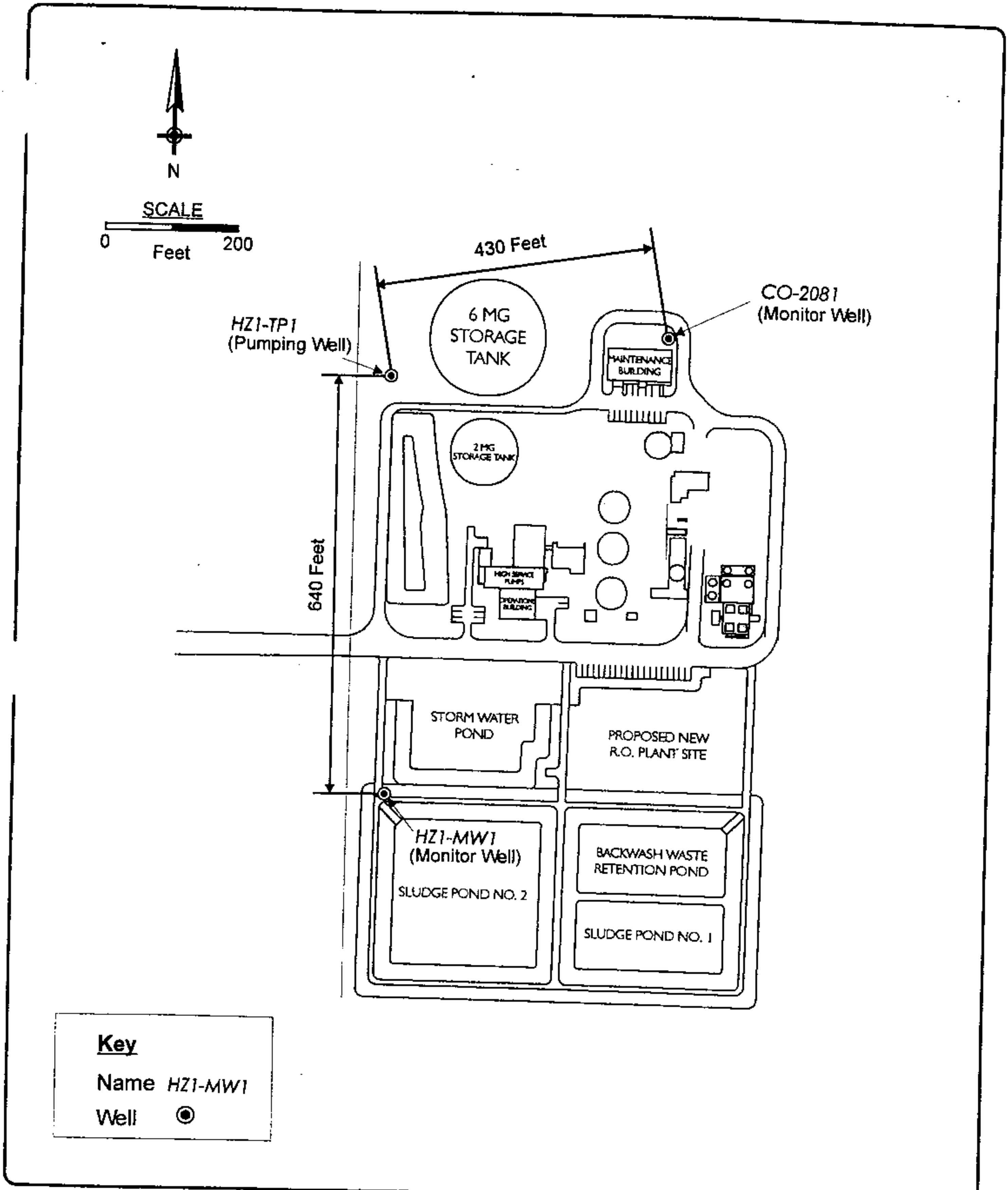
Test/production well HZ1-TP1 at the SCRWTP was pumped at a constant rate of 775 gpm for a period of 77 hours. The well was pumped using a trailer-mounted centrifugal pump with 6-inch diameter suction and discharge ports. The discharge rate was measured using a 6-inch by 10-inch orifice weir. Drawdowns of potentiometric pressures for both the Hawthorn Zone I Aquifer and the confining layer below it were recorded by means of the dual zone observation well (CO-2081) located 430 feet away from the pumped well. Drawdown was also measured in Hawthorn Zone I Aquifer monitor well HZ1-MW1, located 640 feet to the south of the pumped well. Recovery of potentiometric levels was monitored for 24 hours following termination of pumpage. All aquifer test data were transferred to a computer for plotting and analysis. A schematic diagram showing the test set up is provided in Figure 3-7.

An additional APT of the Hawthorn Zone I Aquifer was performed at the SCRWTP using HZ1-TP1 as the test/production well. For this APT, the well was allowed to flow under artesian pressure at a rate of 433 gpm for a period of 70 hours. The discharge rate was measured with an orifice weir and manometer, and the drawdowns were measured in the dual zone well CO-2081 and in well HZ1-MW1 as before. Recovery of potentiometric levels was monitored for 24 hours after the completion of the flow test. Comparisons of the pumped APT and the flow APT results were favorable. The flow APT method was therefore used at the other test sites.

A flow APT was conducted at the east test site using HZ1-TP2 as the test/production well with a flow rate of 370 gpm for a period of 96 hours. The discharge rate was measured using a 6-inch by 10-inch orifice weir. Drawdowns of potentiometric pressure in the Hawthorn Zone I Aquifer were measured in monitor well HZ1-MW2 located 735 feet away from the pumping well. A flow APT was also performed at the North test site using HZ1-TP3 as the test/production well with a flow rate of 380 gpm for a period of 72 hours. The discharge rate was measured using a 6-inch by 10-inch orifice weir and drawdowns in the Hawthorn Zone I Aquifer were measured in the monitor well HZ1-MW3 located 405 feet away from the pumping well. Schematic diagrams showing the test set up of the east and north site Hawthorn Zone I Aquifer APT's are provided in Figures 3-8 and 3-9.

3.5.2.2 Lower Hawthorn Aquifer APT

An APT of the Lower Hawthorn Aquifer at the SCRWTP was started at 9:00 a.m. on July 26, 2000. Lower Hawthorn Aquifer well LH-MW1 was pumped at a constant rate of 320 gpm for 96 hours. The pumping rate was measured with a 4-inch by 6-inch orifice weir and manometer tube. Water level drawdowns in the Lower Hawthorn Aquifer were recorded in monitor well LH-MW3 located 807 feet away. The pressure response in the



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Pr. No. FH8-812	Date: 8/1/00
DWG No.	Rev. No.

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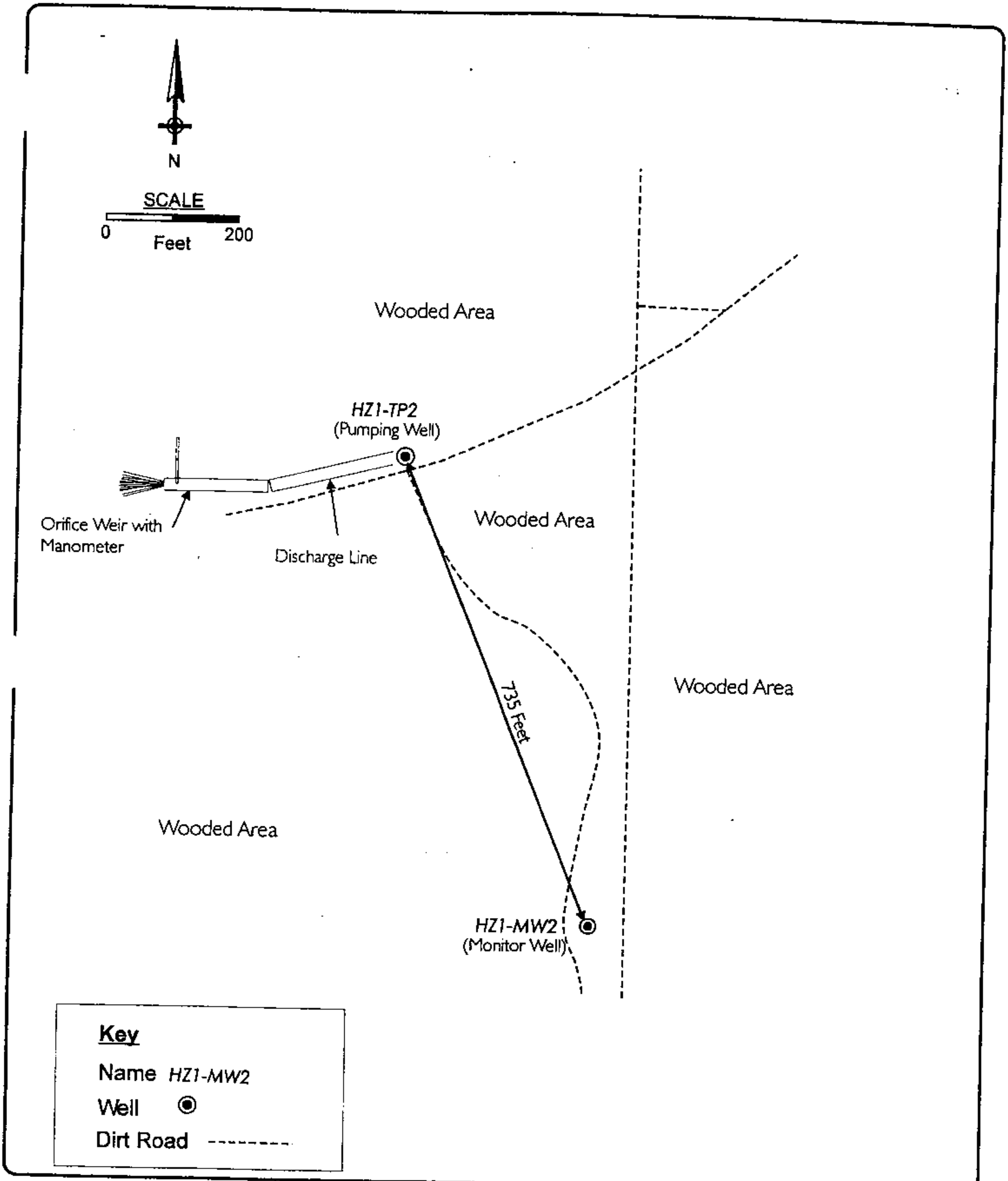
ENVIRONMENTAL SERVICES

FIGURE 3-7. SCHEMATIC OF THE AQUIFER PERFORMANCE TEST ON THE HAWTHORN ZONE 1 AQUIFER AT THE SCRWTP (SEE FIGURE 3-2 FOR GENERAL LOCATION).



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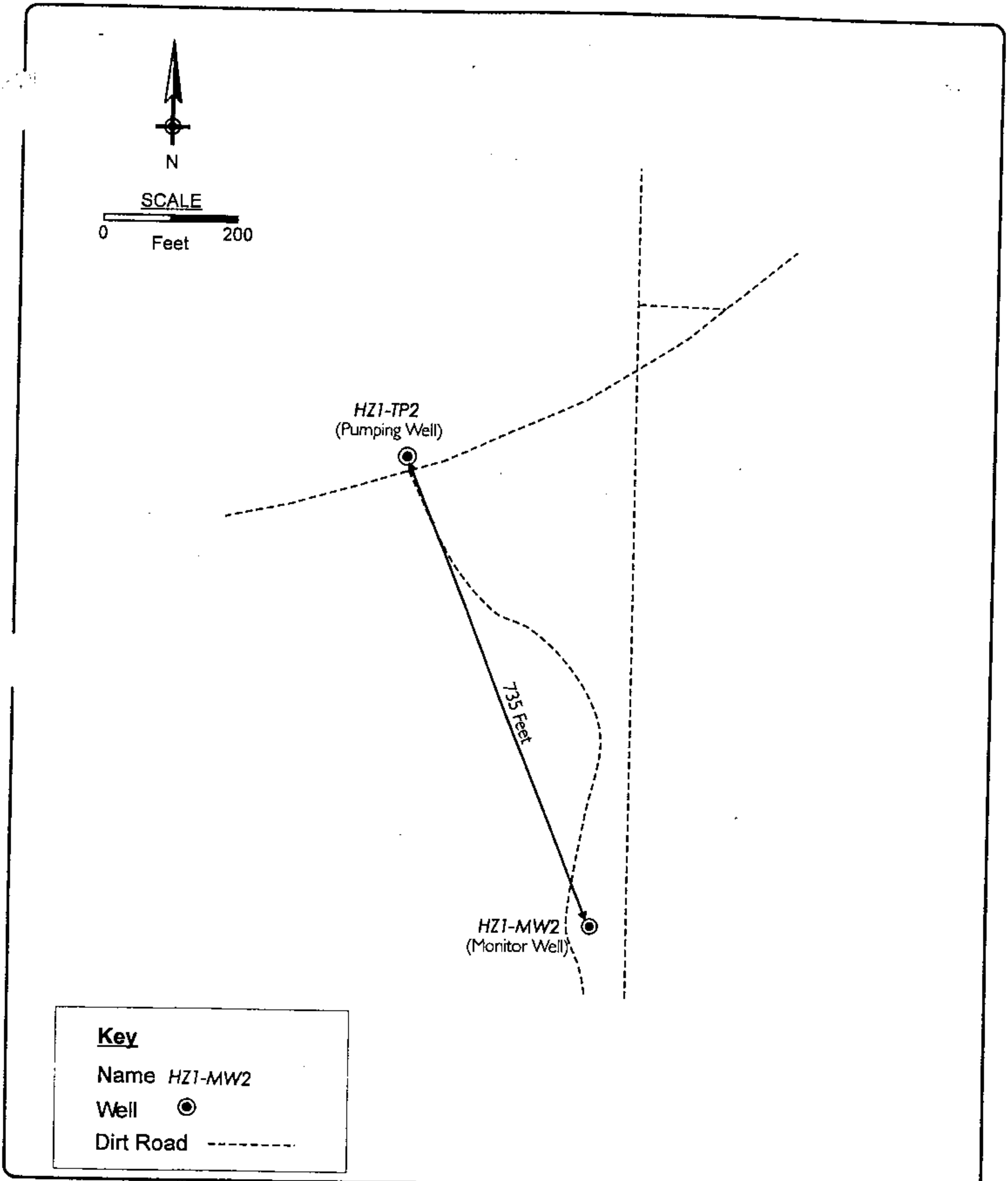
DWG No. SCRWTP3	Rev. No.	

FIGURE 3-8. SCHEMATIC OF THE AQUIFER PERFORMANCE TEST ON THE HAWTHORN ZONE 1 AQUIFER AT THE EAST TEST SITE (SEE FIGURE 3-2 FOR GENERAL LOCATION).



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DWG No. SCRWTP3	Rev. No.	

FIGURE 3-8. SCHEMATIC OF THE AQUIFER PERFORMANCE TEST ON THE HAWTHORN ZONE 1 AQUIFER AT THE EAST TEST SITE (SEE FIGURE 3-2 FOR GENERAL LOCATION).

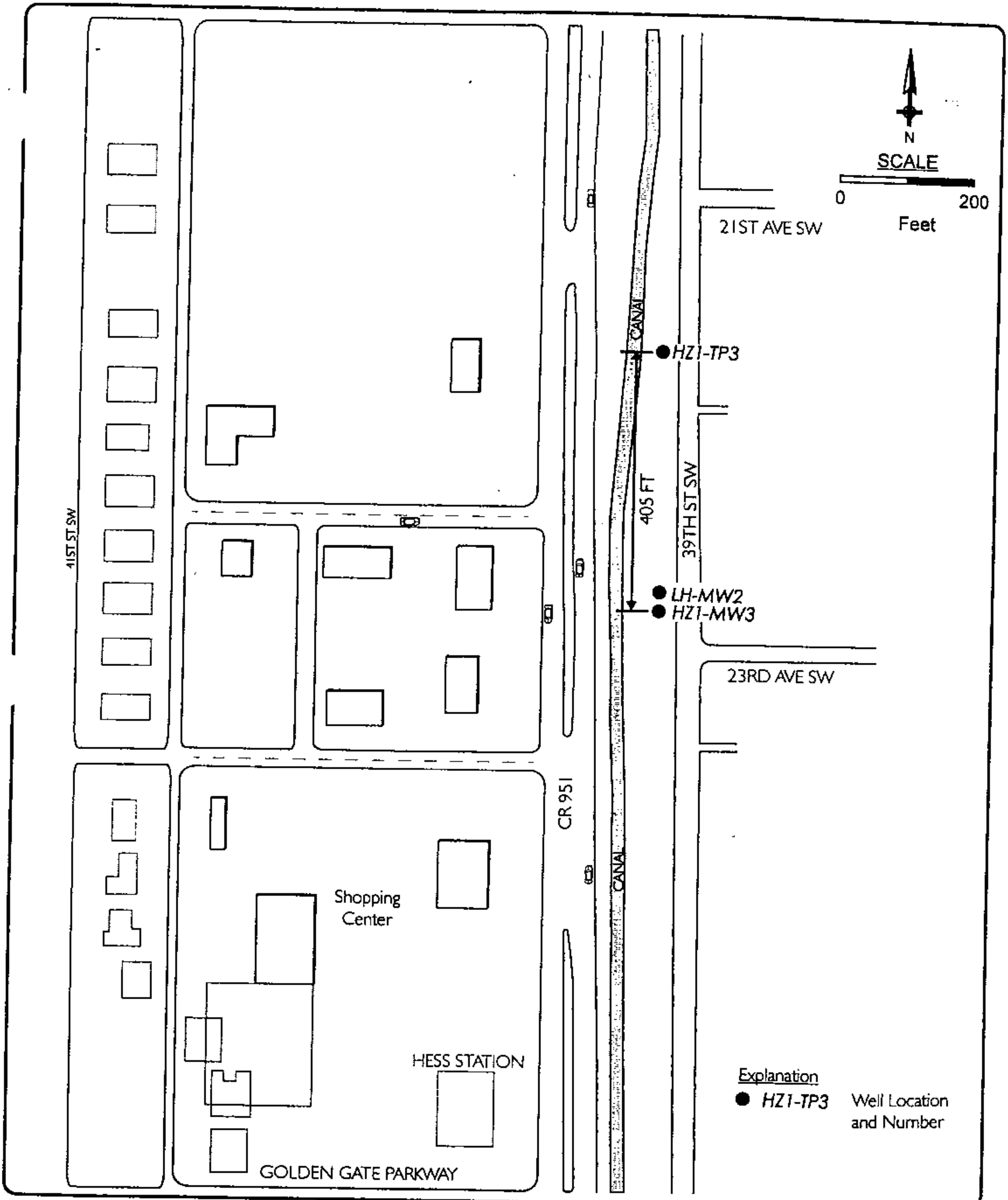

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FIGURE 3-9. SCHEMATIC OF THE AQUIFER PERFORMANCE TEST ON THE HAWTHORN ZONE 1 AQUIFER AT THE NORTH TEST SITE (SEE FIGURE 3-2 FOR GENERAL LOCATION).

Hawthorn Zone I Aquifer was monitored in well HZ1-TP1 approximately 50 feet from the pumped well. A schematic diagram showing the test set up is provided in Figure 3-10.

Additionally, single well APT tests were conducted on Lower Hawthorn Aquifer wells LH-MW2 and LH-MW4 at the north and east test sites, respectively. The APT on LH-MW2 was started on July 11, 2000 at a flow rate of 113 gpm. After 68 hours, flow was terminated and recovery of the potentiometric pressure in the well was monitored for 300 minutes. The APT on LH-MW4 was conducted on August 21, 2000 at a flow rate of 560 gpm. After 21 hours, flow was terminated and recovery of the potentiometric pressure in the well was monitored for 100 minutes.

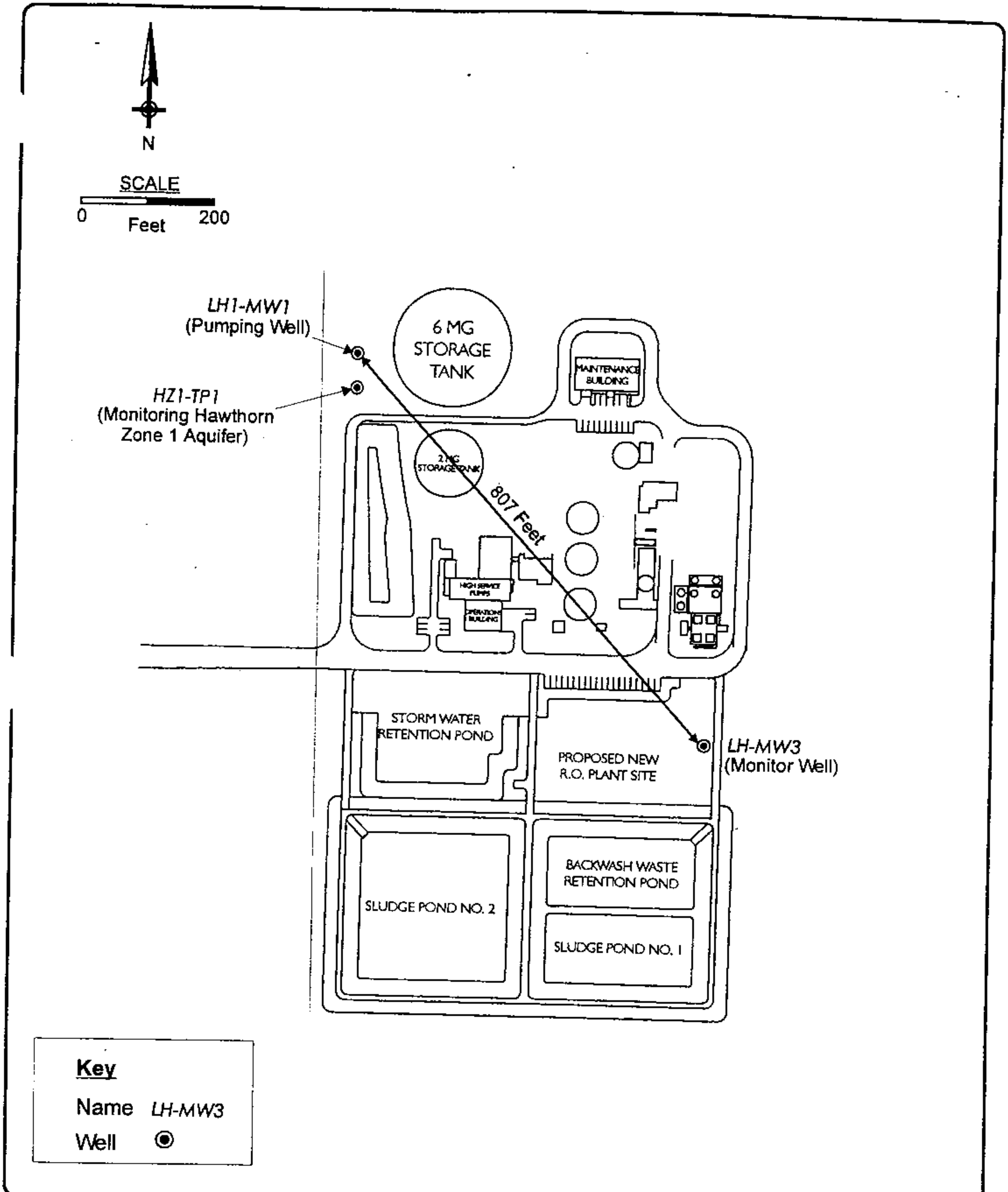

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FIGURE 3-10. SCHEMATIC OF THE AQUIFER PERFORMANCE TEST OF THE LOWER HAWTHORN AQUIFER AT THE SCRWTP (SEE FIGURE 3-2 FOR GENERAL LOCATION).

4.0 INVESTIGATION RESULTS

4.1 Geology

The geology and hydrogeology of Collier County have been described in a number of investigations conducted by the U.S. Geological Survey, the South Florida Water Management District, academicians, and various consultants including CDM/Missimer International, Inc. A partial bibliography is given at the end of this report. The descriptions provided below are based on a combination of the above sources and the analysis of drill cuttings collected during drilling at the three test sites located near the SCRWTP. The classification scheme of Dunham (1962) was used to describe the cuttings recovered from the test wells constructed as part of the SCRWTP expansion investigation. The stratigraphic and hydrogeologic terminology used in this report conforms to that recommended by the Florida Geological Survey Special Publication 28 and Bulletin 59, Scott (1988).

A description of the geologic formations, aquifers, and confining beds encountered during the drilling of the test wells is provided below. The geologic and hydrogeologic units are described from youngest to oldest (Figure 4-1). The SCRWTP is underlain by a series of interbedded siliciclastics, limestones and dolomites of recent to Miocene age, and limestones and dolomites of Oligocene to Eocene age. The uppermost formation encountered at the project site is the Pamlico Sand.

<u>Pamlico Sand</u>

In southwestern Florida, the late Pleistocene-aged, Pamlico Sand is predominantly composed of medium to fine grained quartz sand with varying amounts of shell, detrital clays, and organic constituents. These sediments are commonly clayey and the development of soil horizons within the unit is common. Permeability is generally medium to low (10 to 100 ft/day) depending on the quantity of secondary constituents. At the SCRWTP site, the Pamlico Sand is less than five feet thick and consists predominantly of a subrounded to well rounded, well-sorted, fine-grained quartz sand.

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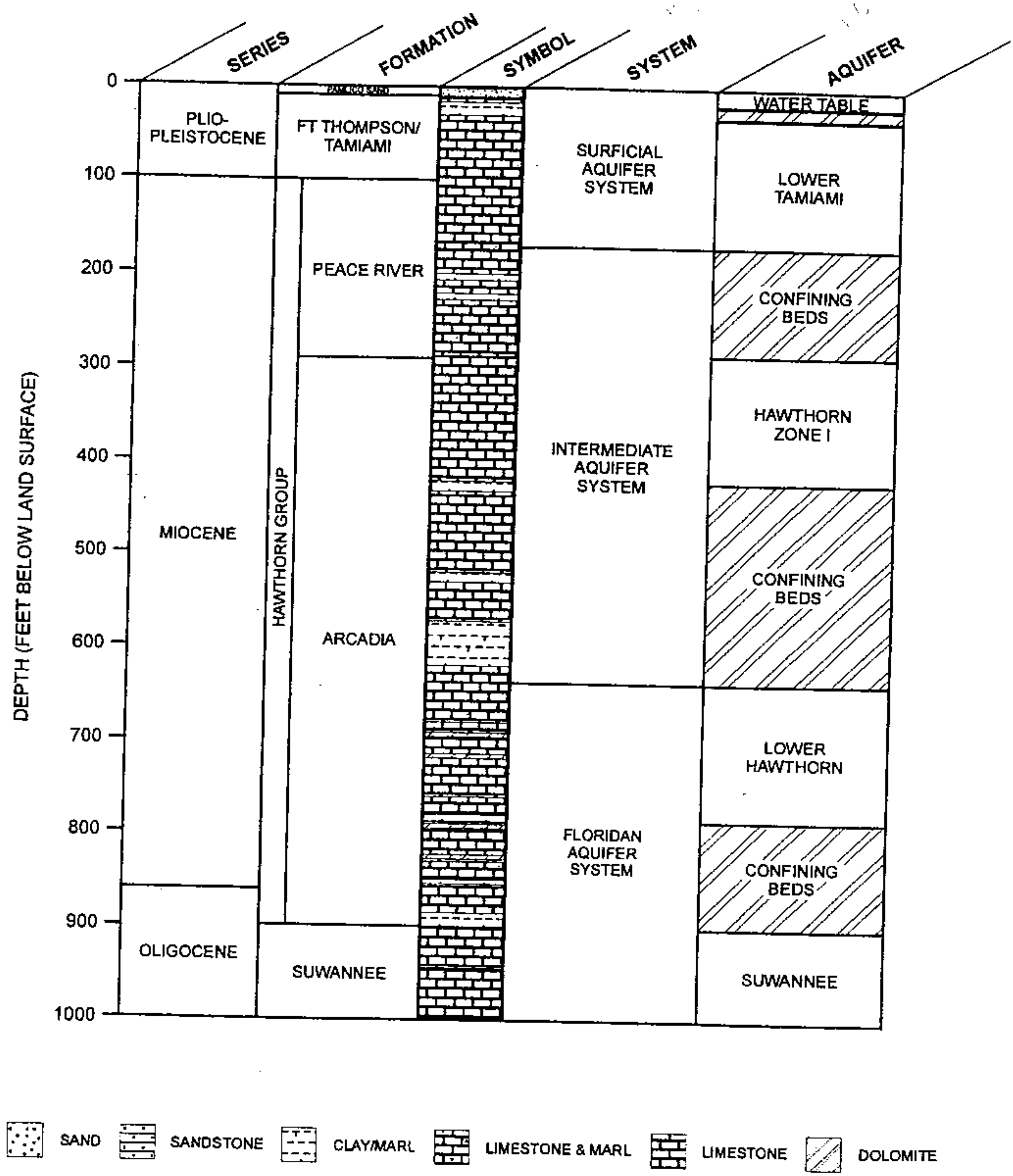

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GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 4-1. GENERALIZED HYDROGEOLOGY BENEATH THE SCRWTP.

Ft. Thompson/Tamiami Formation (Undifferentiated)

The Pamlico Sand is underlain by the Pleistocene-age, Fort Thompson Formation and the Pliocene-age, Tamiami Formation in southwestern Florida. The lithology of the Fort Thompson Formation is highly variable and includes freshwater, marine, and brackish water limestones, marls, sands, and shells. The Pliocene-aged Tamiami Formation, which lies unconformably below the Fort Thompson Formation, is also lithologically highly variable. At least nine mappable members or facies have been identified in the Tamiami Formation in southwestern Florida, which include such diverse lithologies as marls, sands and sandstones, dolosilt, and limestone (Missimer, 1992). Differentiation of the various members and facies of the Fort Thompson Formation and Tamiami Formation is not always possible, particularly from well cuttings.

The limestones present down to approximately 20 ft bls in the study area are likely part of the upper Tamiami Formation. If the marl/clay bed encountered in the test wells from approximately 15 to 35 ft bls is part of the Bonita Spring Marl Member of the Tamiami Formation, then the overlying fossiliferous limestone is part of the "Unnamed Limestone Member" described by Missimer (1992). Otherwise the entire limestone sequence between the Pamlico Sand and the Hawthorn Group may be part of the Ochopee Member of the Tamiami Formation.

The Ochopee Limestone Member of the Tamiami Formation is present from about 30 feet (or possibly higher, see above) to 100 ft bls in the study area. The Ochopee Limestone Member of the Tamiami Formation was named by Mansfield (1939) for the light gray to white sandy fossiliferous limestone that crops out near the town of Ochopee in Collier County (Hunter, 1968). According to Hunter (1968), the Ochopee Member typically is light gray to white calcarenite that has an extensive development of secondary porosity formed by the dissolution of the aragonitic shells of mollusks. Well-preserved pectens, oysters, barnacles, and echinoids are also present. The large interconnected molds give the unit a very high permeability.

Hawthorn Group

The mostly Miocene-age Hawthorn Group lies unconformably beneath the Tamiami Formation. The Hawthorn Group is regionally extensive and underlies most of Florida and parts of Georgia and South Carolina. It is a lithologically diverse unit that contains limestone, dolomite, sand, sandstone, marl, clay, and phosphate. The commonly high phosphate concentration of numerous beds within the Hawthorn Group results in these beds having a distinctive high gamma ray log response. In southern Florida, the Hawthorn Group is subdivided into two formations: the Peace River Formation and the underlying Arcadia Formation.

The contact between the Tamiami Formation and the Peace River Formation occurs at approximately 100 feet bls at the SCRWTP and is marked by a lithological transition downward from fossiliferous limestone to fossiliferous, fine-grained, sandy limestones that are finely phosphatic. The upper Peace River Formation sandy limestone interval is approximately 70 feet thick in the study area. The middle and lower parts of the Peace River Formation consist predominantly of olive gray and greenish-gray dolomitic and phosphatic marls and clays with subsidiary limestone beds. The marls and clays are soft (plastically deformable) and have very low permeabilities. The Peace River Formation is approximately 190 feet thick at the SCRWTP.

The boundary between the Peace River Formation and the underlying Arcadia Formation occurs at approximately 290 ft bls. The formation boundary is marked in western Collier County by a sharp downward lithological change from dark greenish-gray phosphatic clay to very light gray to yellowish-gray fossiliferous limestone. The Arcadia Formation contains a complex assemblage of carbonate and siliciclastic units including light-colored fossiliferous limestones, clay and marl beds, and olive gray and yellowish brown dolomite beds. The limestones consist mostly of fossiliferous mudstones to packstones, in which mollusks are the most abundant fossil types. Cemented carbonate sands (grainstones) are absent or rare. The dolomite in the Arcadia Formation is mostly finely crystalline and very hard. Dolomite beds in the Arcadia Formation may have very high permeabilities due to the presence of fractures. The Arcadia Formation is approximately 600 feet thick at the SCRWTP.

4.2 Hydrogeology

The hydrogeology of western Collier County is characterized by three major aquifer systems that extend from the water-table, located near land surface, to approximately 3370 feet bls (Missimer International, 1996). They are, in descending order, the Surficial Aquifer System, the Intermediate Aquifer System, and the Floridan Aquifer System (see Figure 4-1). The three principal aquifer systems contain numerous individual aquifers that are typically separated by intervening low permeability confining units. The Surficial Aquifer System has been described in detail in Missimer & Associates, Inc. (1986), and is given only cursory attention in this report.

The test/production wells and monitor wells constructed as part of the test drilling program for the SCRWTP expansion project tap the Hawthorn Zone I and Lower Hawthorn aquifers, which are part of the Intermediate and Floridan aquifer systems. A description of the hydrogeology in the vicinity of the SCRWTP site is provided below.

Surficial Aquifer System

The Surficial Aquifer System (SAS) at the SCRWTP extends from the water-table aquifer to approximately 170 ft bls at the top of the uppermost, thick, continuous marl or clay bed in the upper Peace River Formation. The SAS thus includes the Pamlico Sand, undifferentiated Fort Thompson Formation and Tamiami Formation, and part of the Peace River Formation. Thin marl units form semi-confining beds at several horizons within the aquifer system. Domestic wells in western Collier County tap the upper part of the Surficial Aquifer System. The domestic wells generally have sufficient yields and relatively good water quality. The lower aquifer units of the SAS contain brackish water that is not potable without treatment. The Lower Tamiami Aquifer is currently used as a feedwater source for the lime softening facility at the SCRWTP and the membrane softening units at the NCRWTP. Both the water-table and Lower Tamiami aquifers of the SAS have significant regulatory restrictions on their use because of concerns over environmental degradation (wetlands hydroperiod issue). For this reason, brackish water resources are being sought for future expansions of the County water system.

Intermediate Aquifer System

The Intermediate Aquifer System (IAS) lies between the Surficial Aquifer System and the Floridan Aquifer System. At the SCRWTP site, the IAS extends from approximately 170 ft bls to 450 ft bls. The IAS contains several limestone aquifers separated by clay or marl confining units. The water in the Intermediate Aquifer System aquifers is brackish and requires desalination in order to be used as a potable water source. The primary aquifer (Hawthorn Zone I) identified as a potential raw water supply source for the proposed reverse osmosis treatment facility is within the intermediate aquifer system and discussed in more detail in following subsections of this report.

Floridan Aquifer System

The Floridan Aquifer System (FAS) is one of the most productive aquifers in the United States. It underlies all of Florida and parts of Georgia and South Carolina for a total area of about 100,000 square miles. The system, which includes the Suwannee Limestone, the Ocala Limestone, the Avon Park Formation, and the Oldsmar Formation, consists of an extensive sequence of thickly bedded Tertiary-aged limestones and, less abundantly, dolomites, which are connected to varying degrees. Permeable limestone intervals in the lower part of the Hawthorn Group (lower Arcadia Formation) are also included in the FAS. The base of the Floridan Aquifer System is generally placed at the top of the uppermost evaporite bed in the Cedar Keys Formation, which is expected to occur between 3370 ft and 3380 ft bls near the SCRWTP. The water in the Floridan Aquifer System in southern Florida is brackish to saline.

4.3 Hawthorn Zone I Aquifer

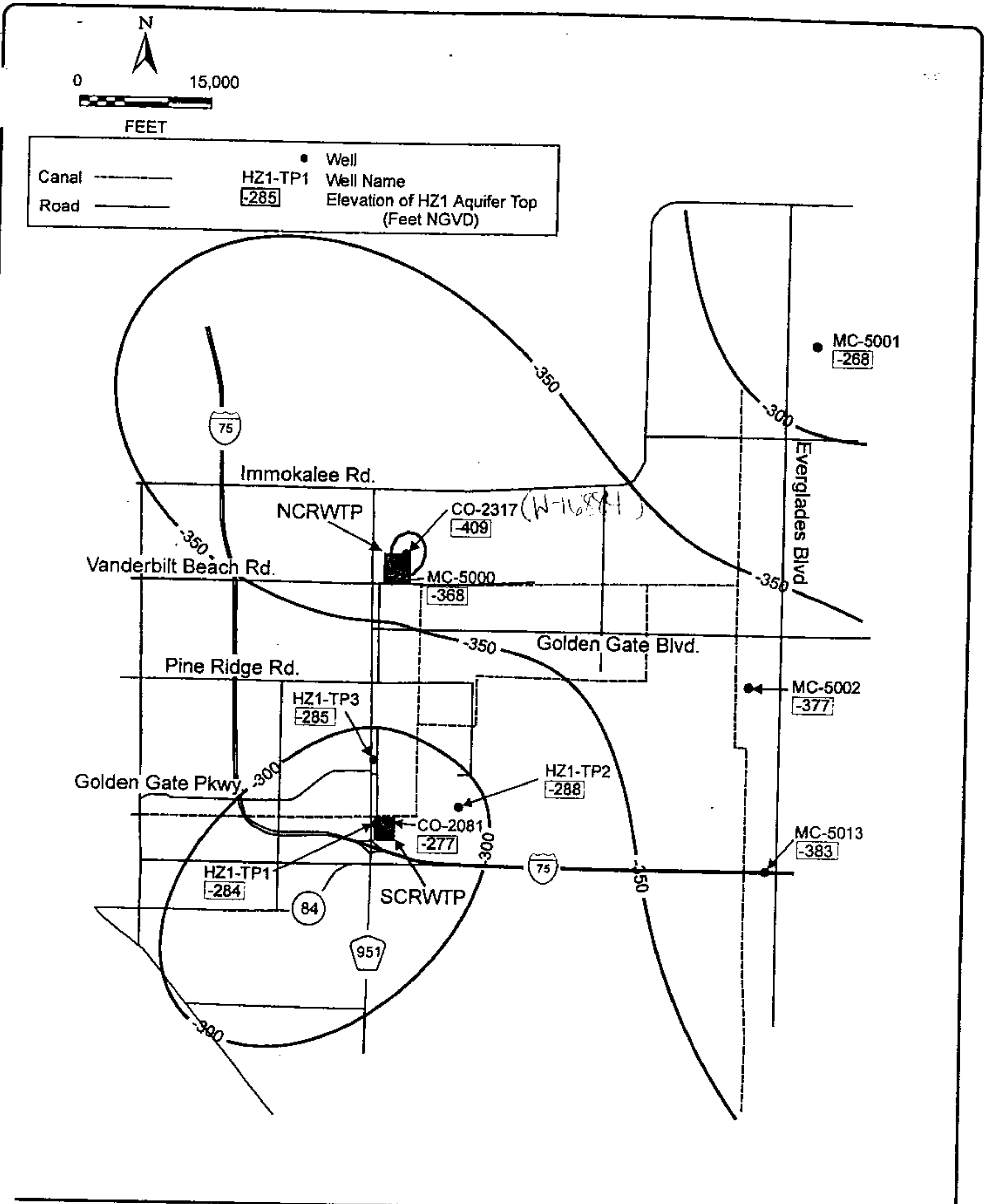
4.3.1 Aquifer Description

The Hawthorn Zone I Aquifer occurs within permeable limestone units that belong to the upper Arcadia Formation of the Hawthorn Group. The upper contact of the Hawthorn Zone I Aquifer is marked by a transition from the olive green gray clays of the overlying confining unit to a very light gray or yellowish gray limestone. The predominant lithology within the aquifer is limestone. The limestones consist mostly of fine-grained wackestones that are cemented to varying degrees. The limestones are moderately hard to hard, and usually have moderate to high porosity (both intergranular and moldic porosity).

The Hawthorn Zone I Aquifer occurs at depths of approximately 280 to 300 feet below land surface in the study area and ranges in thickness from approximately 100 to 150 feet. Figures 4-2 and 4-3 show the depths to and thickness of the Hawthorn Zone I Aquifer, respectively.

4.3.2 Water Levels

Potentiometric levels were measured in the test wells tapping the Hawthorn Zone I Aquifer that were constructed as part of this investigation. The levels were converted to an estimated NGVD reference based on land surface elevations obtained from USGS topographic maps. Water levels in the Hawthorn Zone I Aquifer near the SCRWTP range between 34 and 35 feet NGVD; however, the static water level in this aquifer for the eastern test wells MC5001 and MC5002 drilled for the NCRWTP RO Expansion, is significantly less (Figure 4-4). This apparently produces a west to east gradient in the aquifer.



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DWG No.	Rev. No.	

FIGURE 4-2. TOP OF THE HAWTHORN ZONE 1 AQUIFER IN FEET NGVD.

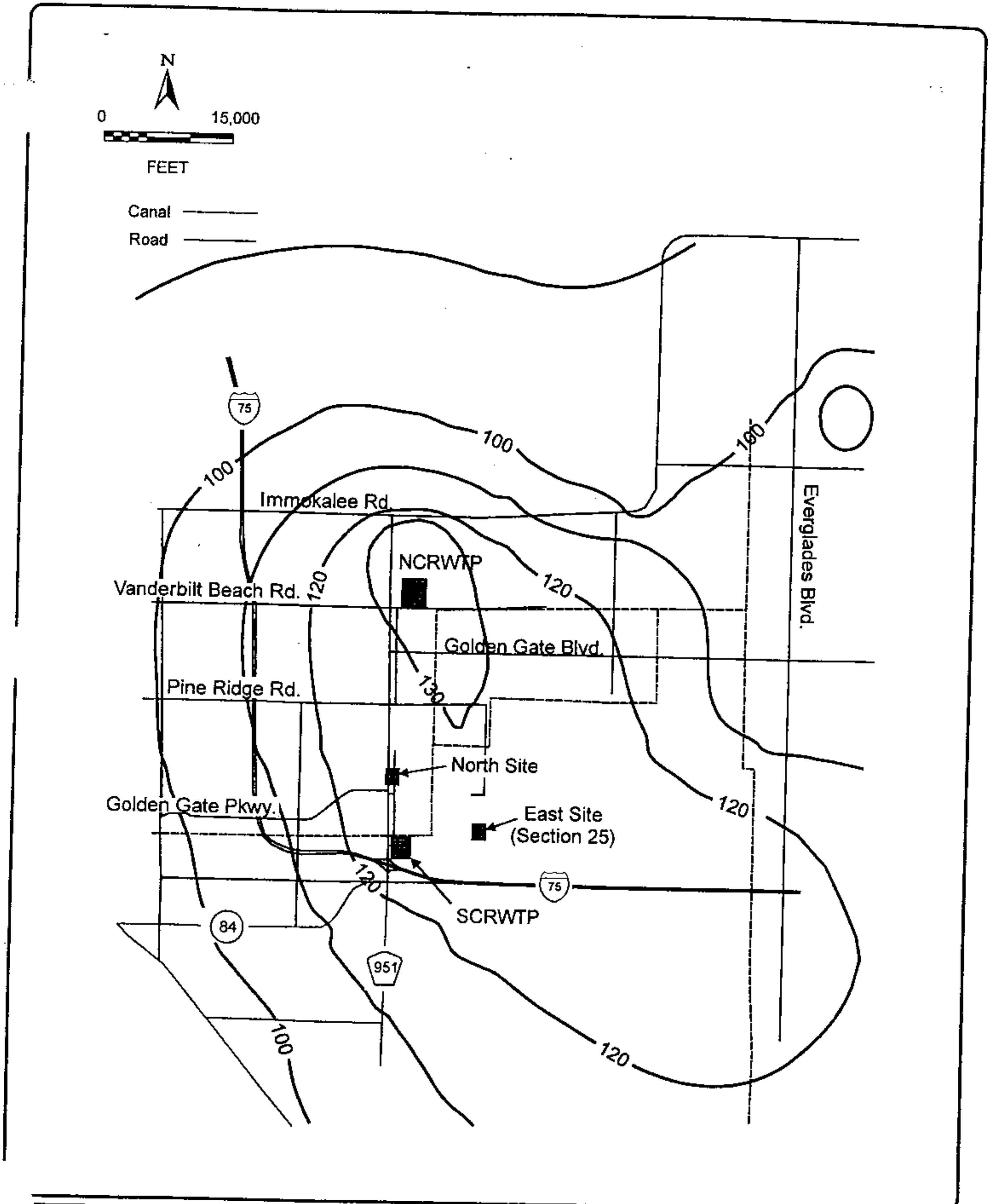

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FIGURE 4-3. THICKNESS OF HAWTHORN ZONE 1 AQUIFER (FEET).

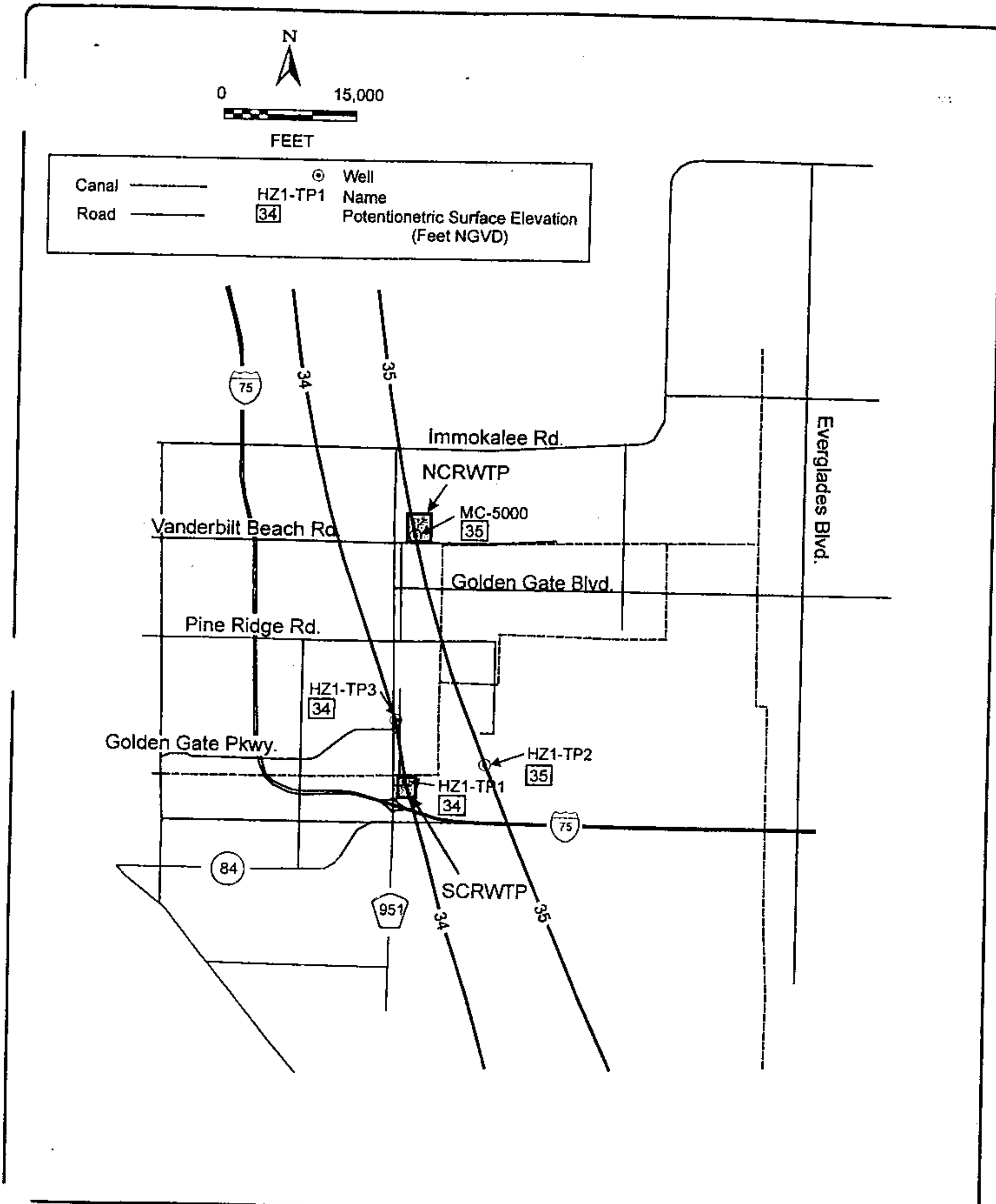

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FIGURE 4-4. POTENTIOMETRIC HEAD IN THE HAWTHORN ZONE 1 AQUIFER (FEET NGVD).

The variation in potentiometric levels observed from west to east may be explained by a lateral facies change that is responsible for two separate hydraulic units within the Hawthorn Zone I Aquifer. A lower permeability clayey lithofacies is believed to occur in the vicinity of the Golden Gate Estates area creating a lateral impediment to flow. The head data suggest that two separate aquifer zones have been intersected by the test wells. The water quality data collected for the NCRWTP RO Expansion (Collier County Utilities Brackish Water Wellfield Study, Missimer, Int., 1995) corroborates this explanation.

Recharge to the Hawthorn Zone I Aquifer is thought to occur north of the study area near south central Florida where surface sediments are in hydraulic connection with the aquifer allowing direct rainfall infiltration. The regional hydraulic gradient within the aquifer is estimated to be approximately one foot per mile or less. During pumpage, additional recharge will be induced by vertical leakage through the underlying semi-confining units. The aquifer is not known to be used in the study area. Discharge from the aquifer is primarily due to lateral outflow and leakage into other aquifers.

4.3.3 Water Quality

Water samples were obtained from the test wells constructed as part of the hydrogeologic test program during drilling and during the aquifer performance tests. The samples were analyzed for dissolved chloride concentration and specific conductance to assess salinity conditions within the Hawthorn Zone I Aquifer. The water quality data obtained for the Hawthorn Zone I Aquifer are summarized in Table 4-1. Water samples were also collected during APT tests or by opening the wells and evacuating a minimum of three well volumes prior to sampling for detailed laboratory analyses. The laboratory analyses were conducted to determine the concentration of chemical parameters critical to reverse osmosis treatment plant design. The laboratory analyses results are given in the appendix and summarized in Table 4-2.

Table 4-1. Water Quality in the Hawthorn Zone I Aquifer Test/Production Wells

Well (Site) [illegible]	Open Hole Interval (ft bls)	Dissolved Chloride Conc. (mg/l) Mean	Dissolved Chloride Conc. (mg/l) Range	Specific Conductance (umhos/cm) Mean	Specific Conductance (umhos/cm) Range
HZ1-TP1 (WTP)	295-400	2700	2600-2750	8170	7900-8220
HZ1-TP2 (East)	299-399	2600	2580-2640	8900	8800-9180
HZ1-TP3 (North)	296-420	1780	1680-1880	6700	6300-7000

A map showing the trend of dissolved chloride concentrations in the Hawthorn Zone I Aquifer is provided as Figure 4-5. This figure includes data collected during the NCRWTP RO Expansion study. Inspection of the figure indicates that dissolved chloride concentrations increase from east to west in the study area from less than 200 mg/l in the east to approximately 2700 mg/l at the SCRWTP. As discussed, this may occur as a result of a clayey lithofacies in the central portion of the area. The eastern portion of the study area is believed to be hydrologically connected to a fresher water zone to the north. Recharge in the western portion of the area is probably from a more saline water source. The lower permeability clayey facies within the central portion of the area creates a separation of the two hydraulic units and inhibits flow from west to east.

4.3.4 Aquifer Hydraulics

The yield characteristics of the Hawthorn Zone I Aquifer were evaluated based on the results of step-drawdown and constant rate aquifer performance tests conducted on the test wells constructed for this and previous investigations. The results of the step-drawdown tests performed on the Hawthorn Zone I Aquifer test/production wells installed as part of this study are summarized in Table 4-3.

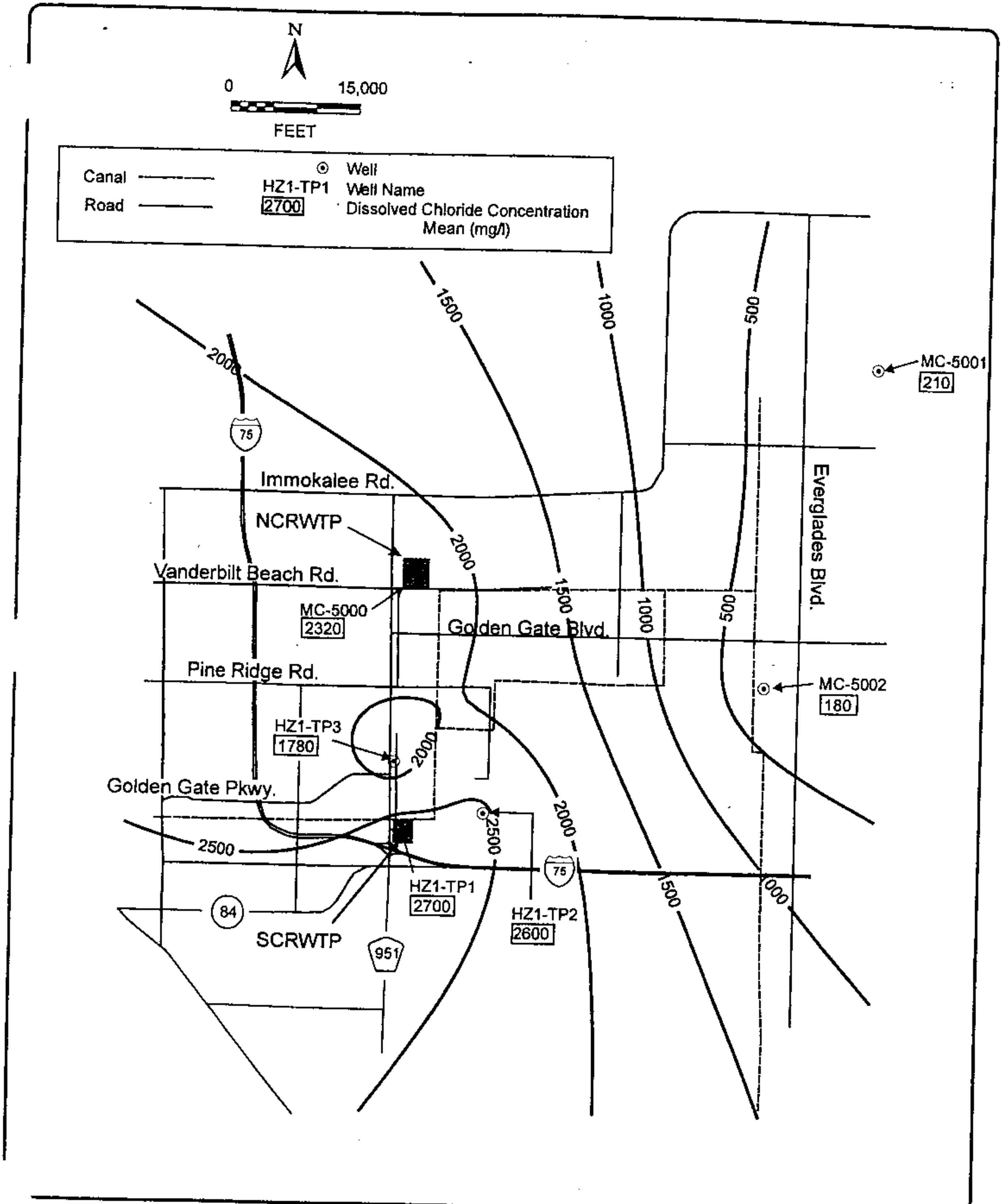

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FIGURE 4-5. DISSOLVED CHLORIDE CONCENTRATIONS (MG/L) IN THE HAWTHORN ZONE 1 AQUIFER.

Table 4-2. Hawthorn Zone I Water Quality (Laboratory Analyses)

Parameter	Well and Test Site Location		
	HZI-TPI (WTP)	HZI-TP2 (East)	HZI-TP3 (North)
Total Alkalinity (mg/l)	160	170	160
Bicarbonate Alkalinity (mg/l)	160	170	160
Total Hardness (mg/l)	1400	1400	1100
Non-Carbonate Hardness (mg/l)	1200	1200	900
Ammonia (mg/l)	0.48	0.54	0.44
Barium (mg/l)	0.03	0.03	0.02
Boron (mg/l)	0.70	0.77	0.48
Calcium (mg/l)	210	210	180
Copper (mg/l)	BDL	BDL	0.05
Iron (mg/l)	0.06	BDL	0.02
Magnesium (mg/l)	210	220	150
Manganese (mg/l)	BDL	BDL	BDL
Nickel (mg/l)	BDL	BDL	BDL
Potassium (mg/l)	70	68	42
Silicon (mg/l)	7.2	7.2	11
Sodium (mg/l)	1300	1400	850
Strontium (mg/l)	11	13	4.9
Zinc (mg/l)	BDL	BDL	0.27
Bromide (mg/l)	8.7	8.0	5.6
Chloride (mg/l)	2500	2700	1600
Fluoride (mg/l)	0.83	0.71	0.99
Sulfate (mg/l)	620	640	390
Dissolved Silica (mg/l)	15	15	15
Specific Conductance (umho/cm)	NA	NA	5200
Sulfide (mg/l)	10	9.8	1.5
Hydrogen Sulfide (mg/l)	NA	NA	0.45
Total Dissolved Solids (mg/l)	5100	5000	3900
Total Organic Carbon (mg/l)	2.6	3.3	5.8
Turbidity (NTU)	BDL	0.30	BDL
pH (units)	NA	NA	7.3

BDL – Below Detection Limit
NA – Not Analyzed

The specific capacity data indicate the Hawthorn Zone I Aquifer has a moderate to good yield potential. Aquifer performance test results also indicate the aquifer has a moderate to good yield potential.

Table 4-3. Step Drawdown Tests of the Hawthorn Zone I Aquifer Test/Production Wells

Well HZ1-TP1 (Static Water Level = 34 feet above NGVD) (SCRWTP Site)		
Discharge (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
500	25.16	19.9
630	31.61	19.9
695	37.36	18.6

Well HZ1-TP2 (Static Water Level = 35 feet above NGVD) (East Site)		
Discharge (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
440	23.93	18.4
550	31.86	17.3
720	40.81	17.6

Well HZ1-TP3 (Static Water Level = 34 feet above NGVD) (North Site)		
Discharge (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
510	20.82	24.5
620	27.85	22.3
780	38.92	20.0

Logarithmic and semi-logarithmic graphs of time vs. drawdown were constructed using data collected from monitor wells CO-2081 and HZ1-MW1 during the aquifer performance tests (pumping and flow) conducted on the Hawthorn Zone I Aquifer at the SCRWTP using HZ1-TP1 as the test/production well. The data were analyzed using the methods developed by Jacob (1950) and Cooper (1963). The logarithmic plots were compared to appropriate type curves and match points were obtained. The data were substituted into the following equations (after Cooper 1963 with appropriate unit conversions):

$$T = \frac{114.6QL(u,v)}{s} \qquad (1)$$

$$S = \frac{0.535Tt}{r^2(1/u)} \qquad (2)$$

$$k'/b' = \frac{4Tv^2}{r^2} \qquad (3)$$

where,

T = transmissivity (gpd / ft)

Q = pumping rate (gpm)

s = drawdown (feet)

$L(u,v)$ = curve function

$1/u$ = curve function

S = storage coefficient, dimensionless

t = time (days)

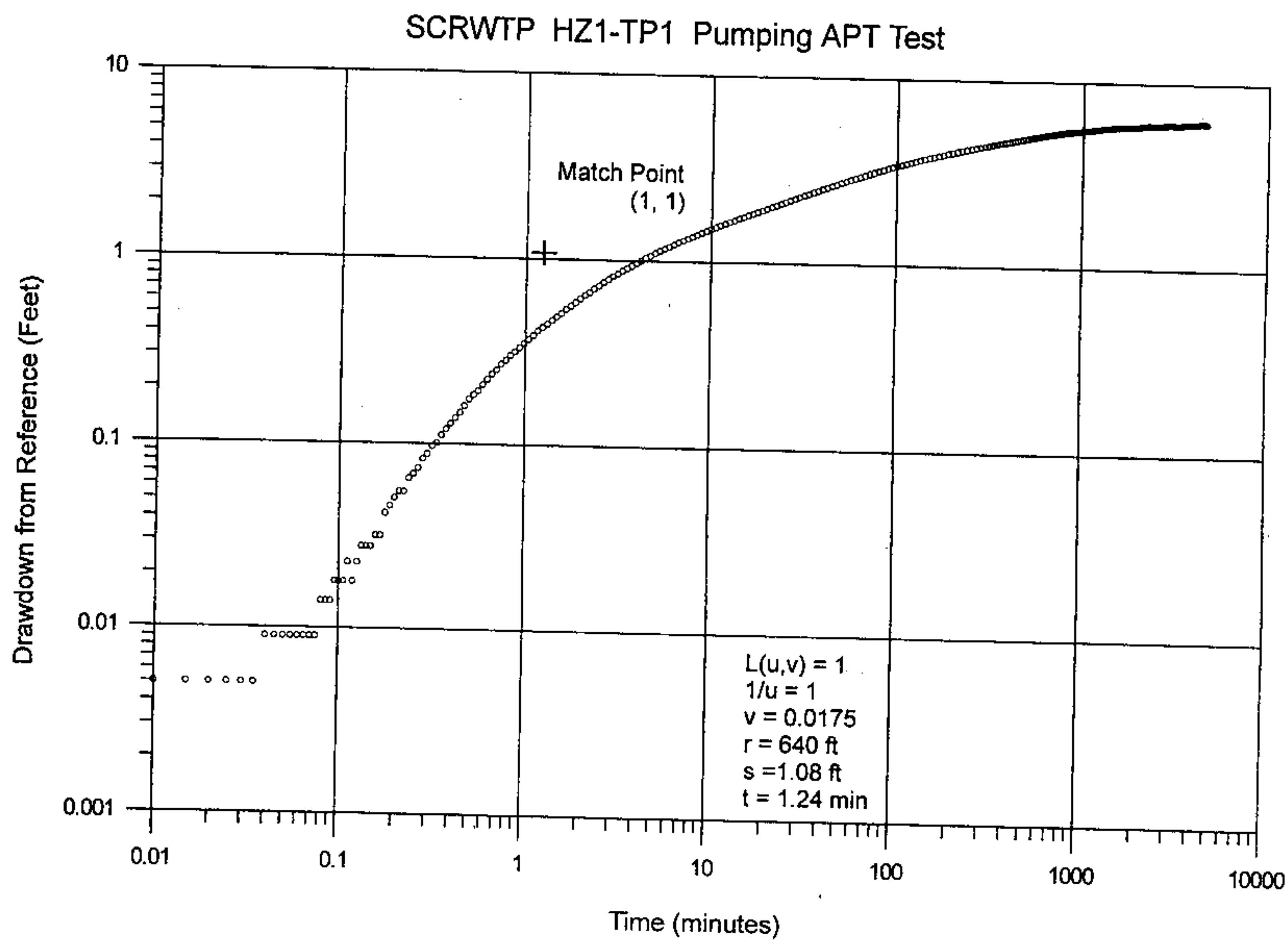
r = distance from pumped well (feet)

v = curve function

k'/b' = Leakance (gpd/ft^3)

Logarithmic plots of time versus drawdown are given in Figures 4-6 through 4-11. Figures 4-6 to 4-9 were generated using the data collected during APT tests at the SCRWTP. Both pump and flow tests of well HZ1-TP1 were conducted with water levels recorded in monitor wells HZ1-MW1 and CO-2081. Figures 4-10 and 4-11 show the results of the flow APTs at the east and north test sites using HZ1-TP2 and HZ1-TP3 as the test/production wells, respectively. The match point chosen for each curve, and the curve function v are displayed on the figures with the corresponding s and t values read off of the graphs. The hydraulic parameters calculated based on the test results are summarized in Table 4-4.

Semi-log plots of drawdown vs. time were analyzed by the Jacob method to verify the transmissivity and storage values calculated from the Cooper analysis. These graphs are given as Figures 4-12 and 4-13 for the pumped APT test of well HZ1-TP1 and show the



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Pr.No.	FH8-812	Date:	4/5/2000

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FIGURE 4-6. DRAWDOWN IN MONITOR WELL HZ1-MW1 (MC-5054) WHILE PUMPING SCRWTP TEST/PRODUCTION WELL HZ1-TP1 (MC-5055), Q = 775 GPM, R = 640 FT.

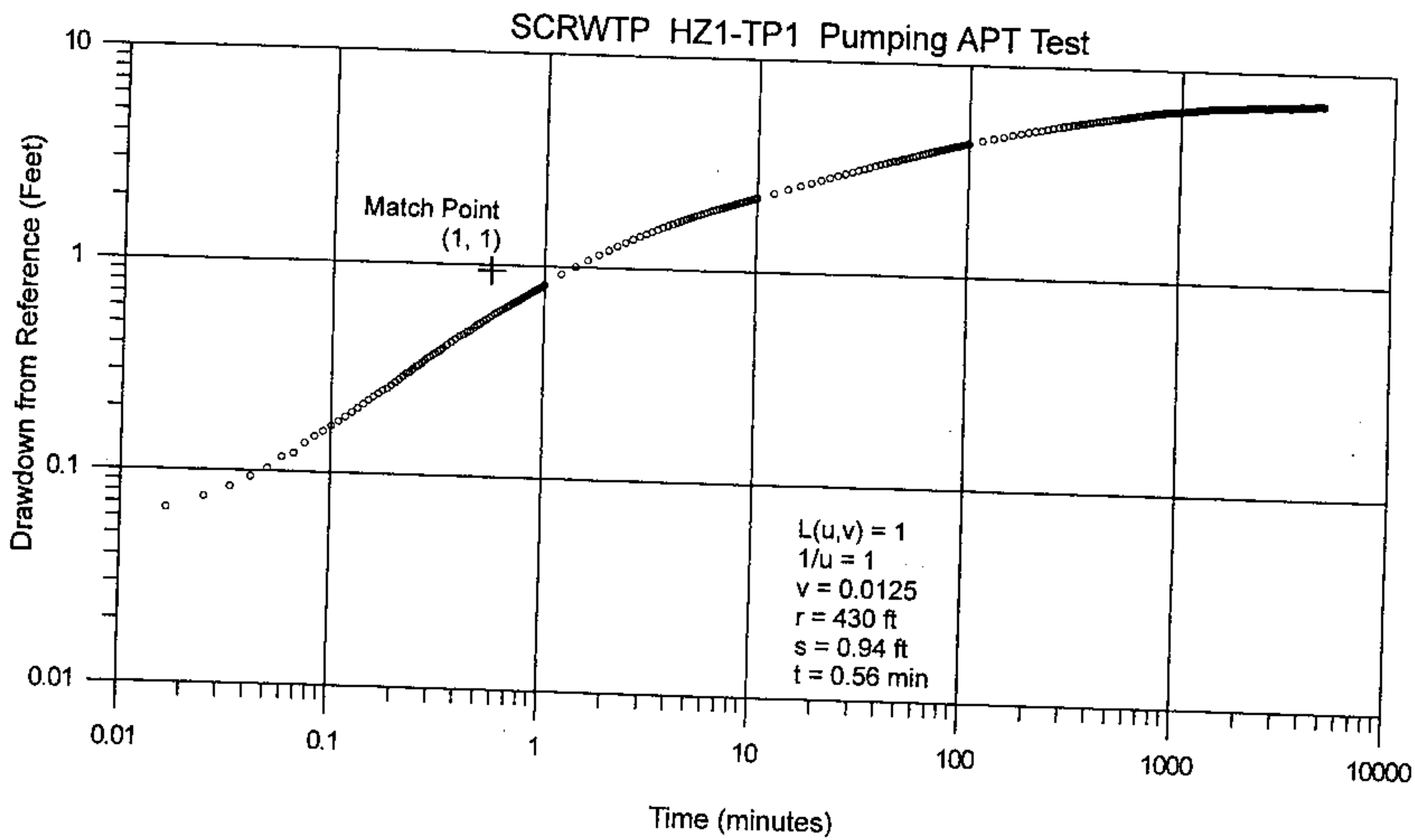

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FIGURE 4-7. DRAWDOWN IN MONITOR WELL CO-2081 WHILE PUMPING SCRWTP TEST/PRODUCTION WELL HZ1-TP1 (MC-5055), Q = 775 GPM, R = 430 FT.

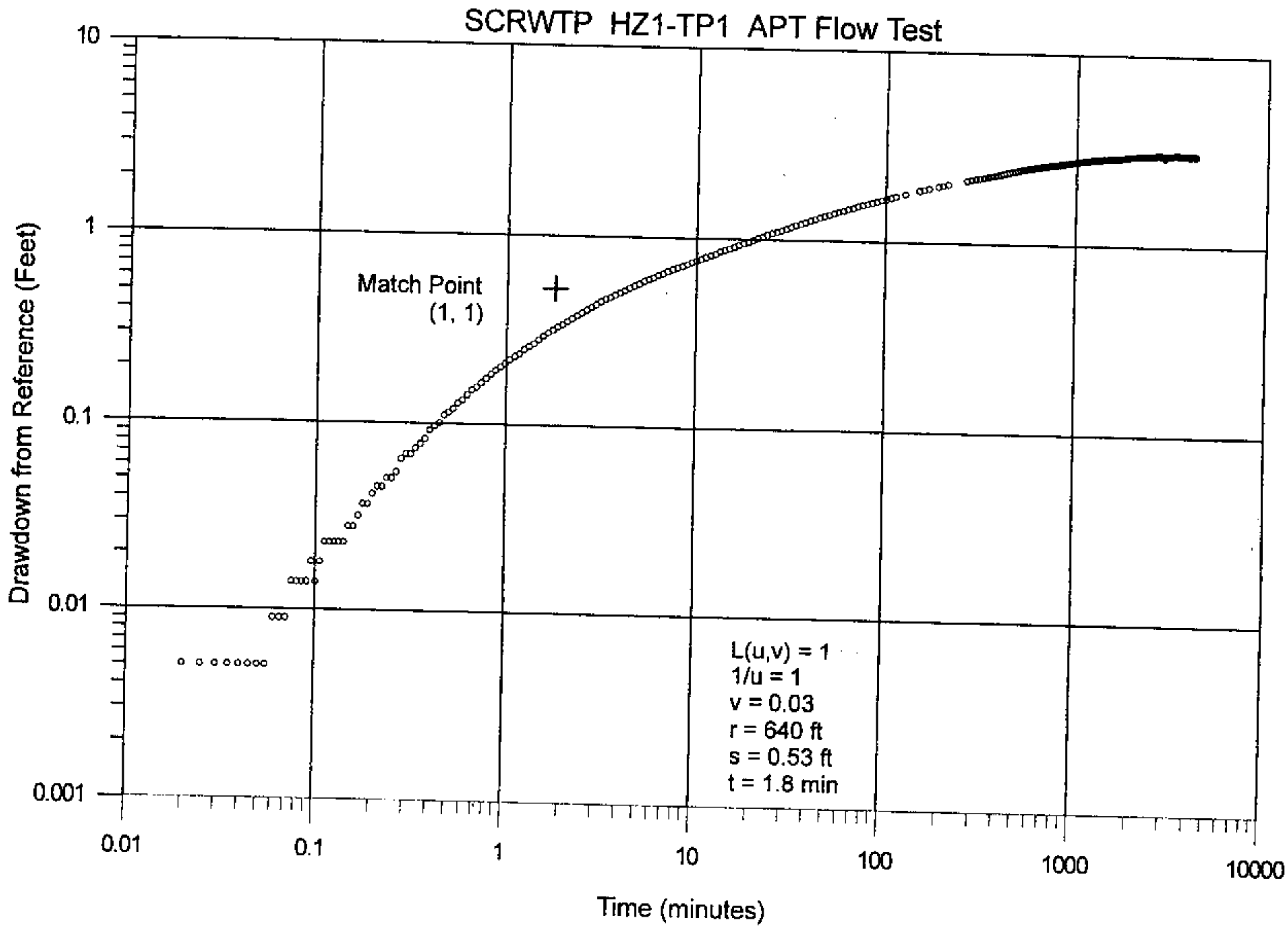

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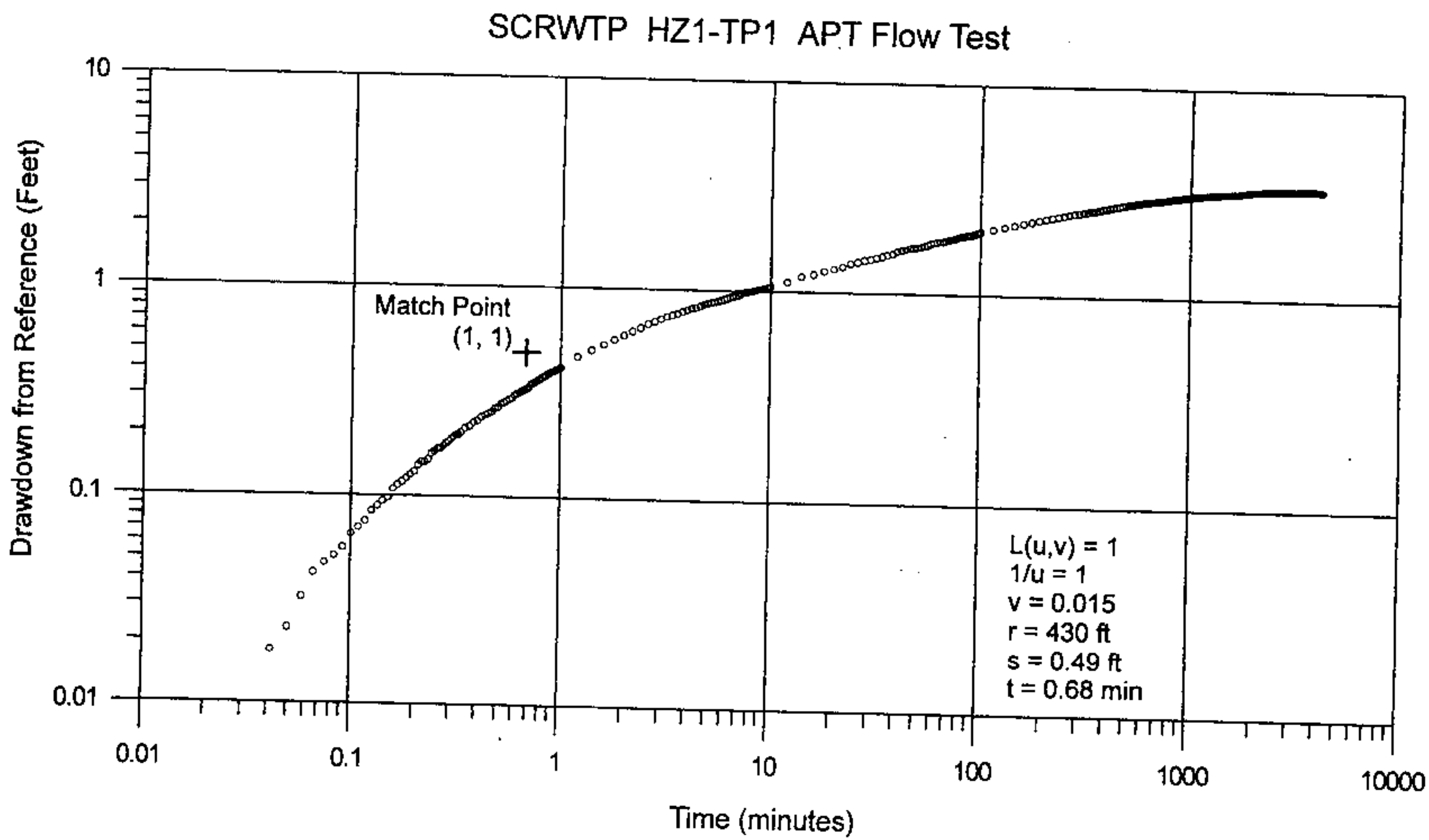
FIGURE 4-8. DRAWDOWN IN MONITOR WELL HZ1-MW1 (MC-5054) WHILE FLOWING SCRWTP TEST/PRODUCTION WELL HZ1-TP1 (MC-5055), Q = 433 GPM, R = 640 FT.



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Pr.No.	FH8-812	Date:	4/4/2000

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FIGURE 4-9. DRAWDOWN IN MONITOR WELL CO-2081 WHILE FLOWING SCRWTP TEST/PRODUCTION WELL HZ1-TP1 (MC-5055), Q = 433 GPM, R = 430 FT.

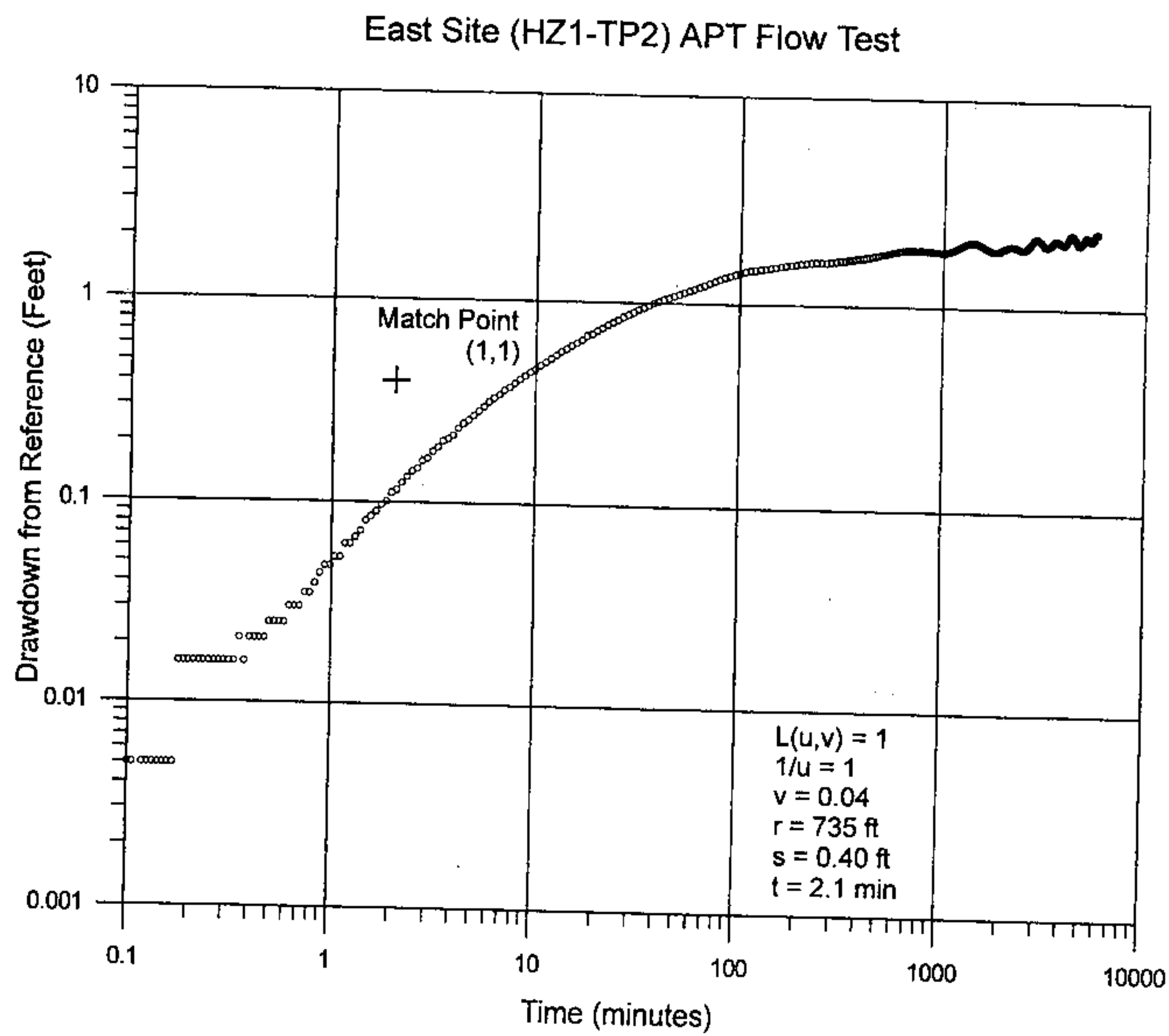

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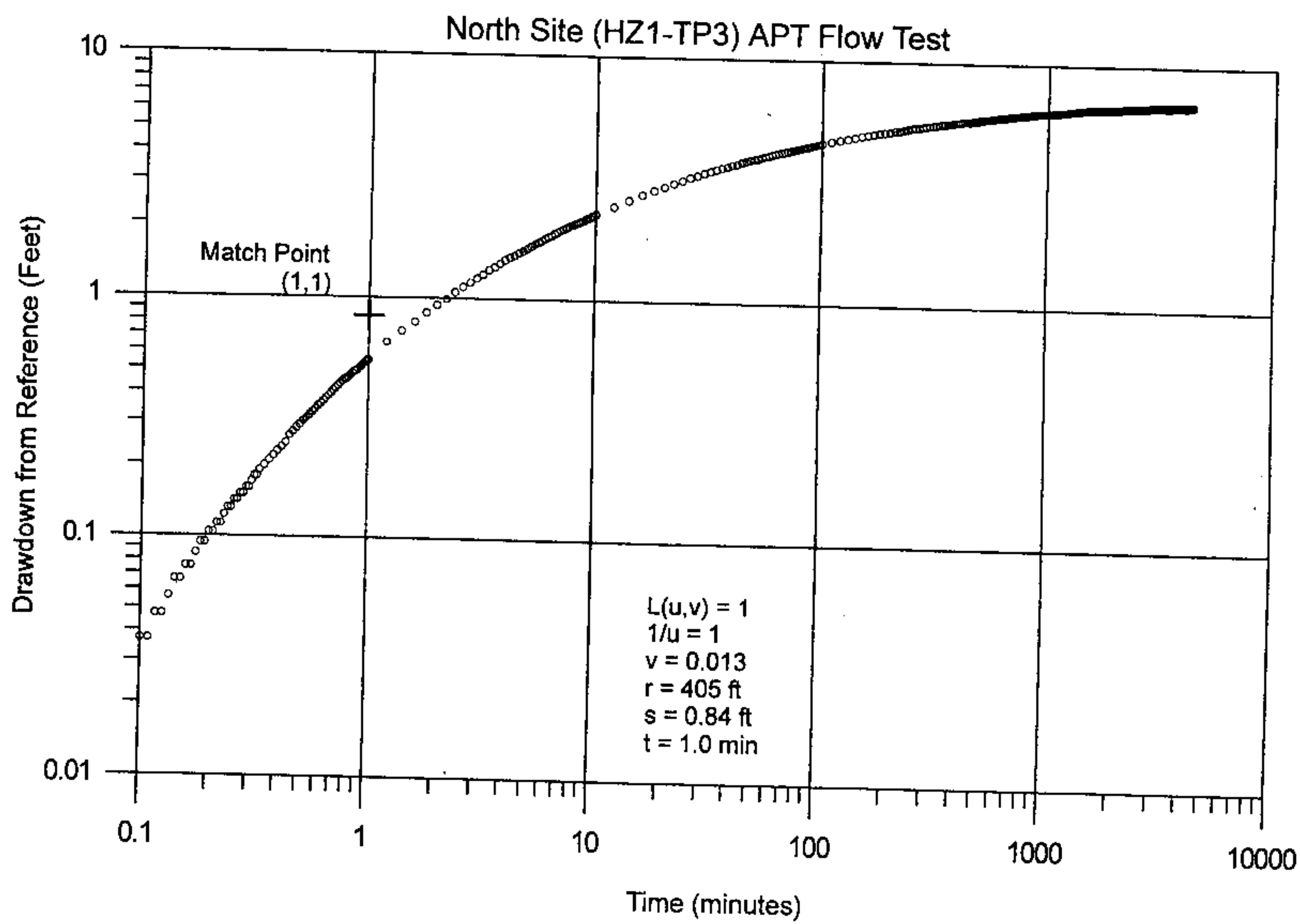
FIGURE 4-10. DRAWDOWN IN MONITOR WELL HZ1-MW2 (MC-5056) WHILE FLOWING EAST SITE TEST/PRODUCTION WELL HZ1-TP2 (MC-5057), Q = 370 GPM, R = 735 FT.



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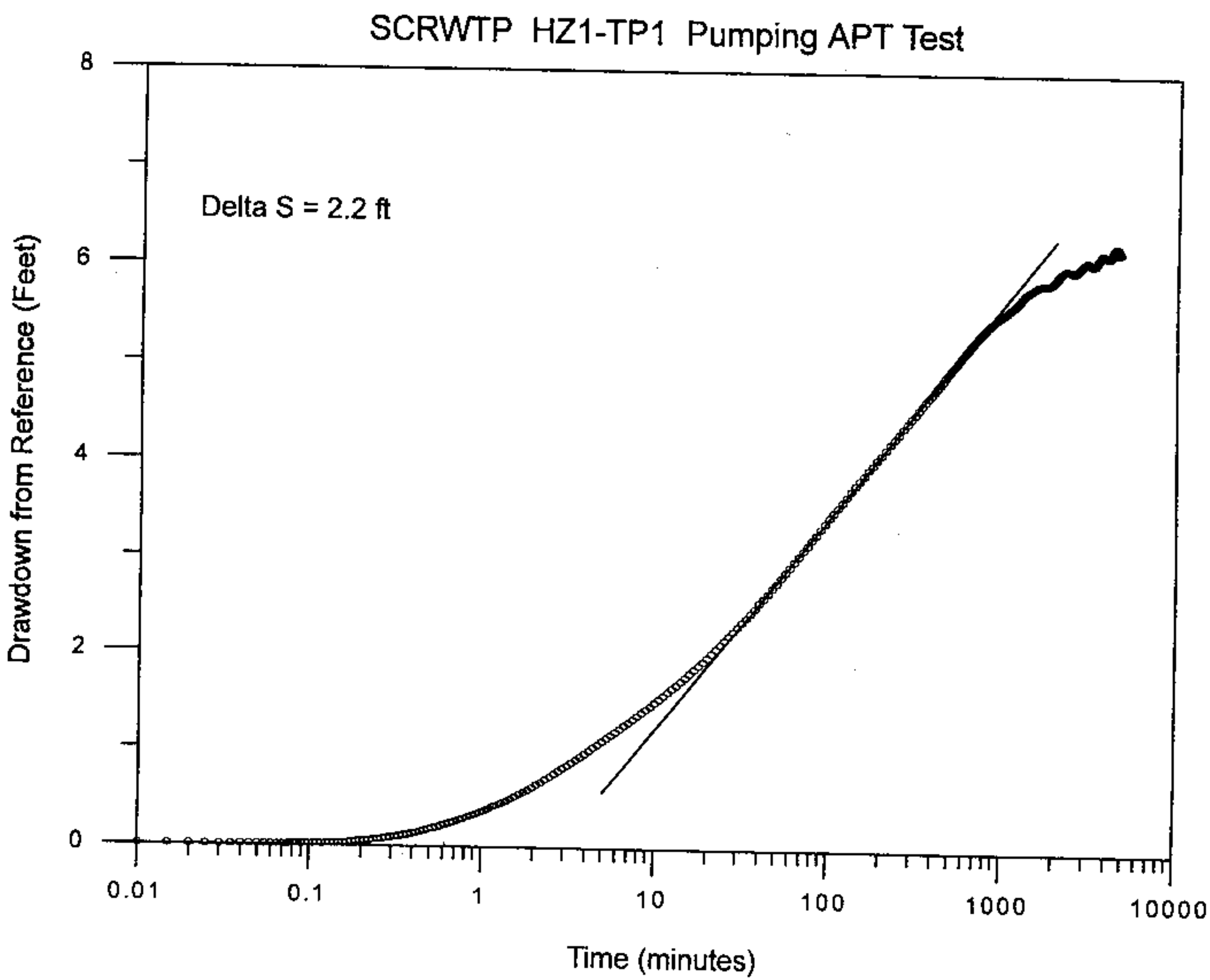
	Pr.No. FH8-812	Date: 8/15/2000	

FIGURE 4-11. DRAWDOWN IN MONITOR WELL HZ1-MW3 (MC-5066) WHILE FLOWING NORTH SITE TEST/PRODUCTION WELL HZ1-TP3 (MC-5065), Q = 380 GPM, R = 405 FT.



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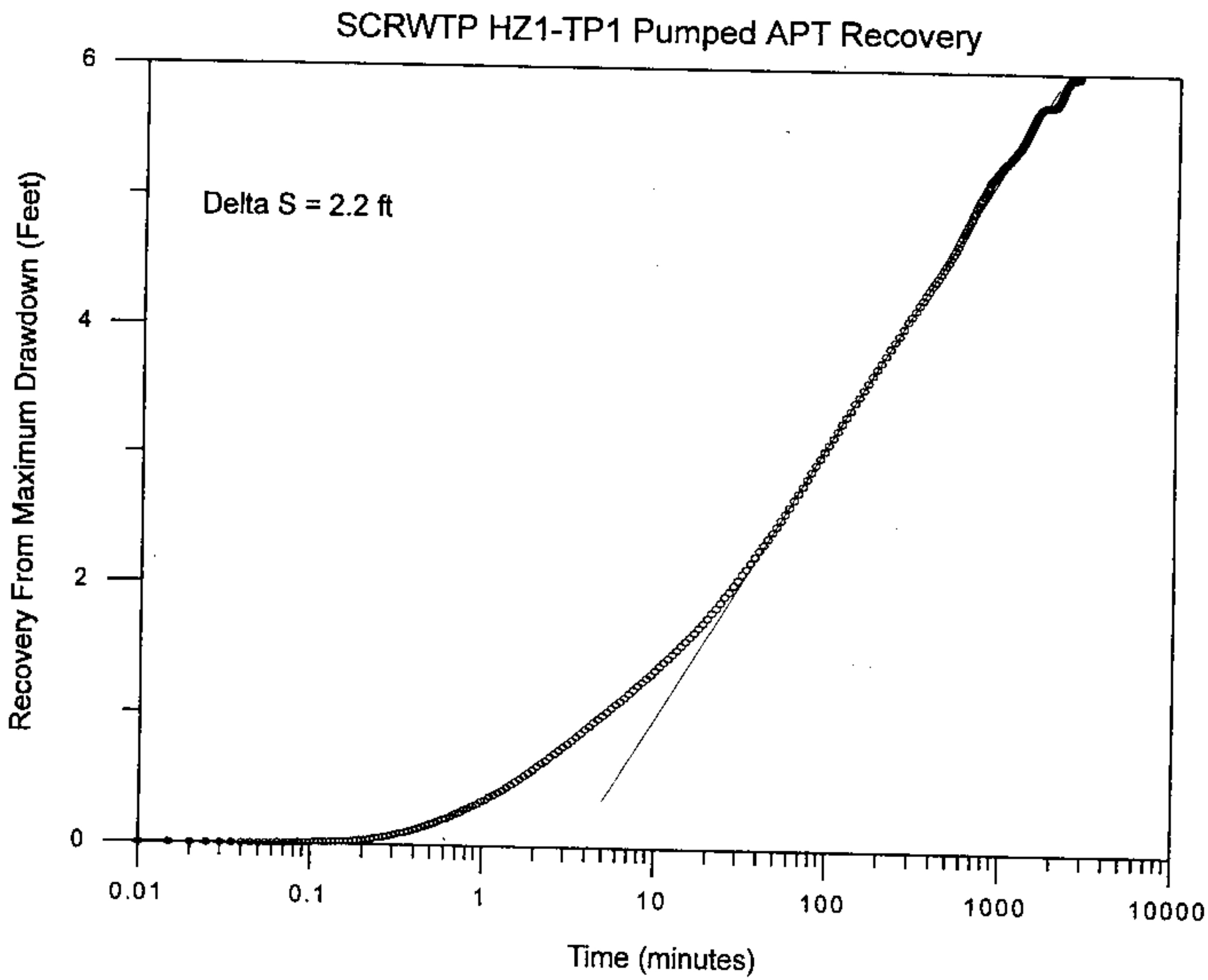
	Pr.No. FH8-812	Date: 4/5/2000	

FIGURE 4-12. SEMI-LOGARITHMIC REPRESENTATION OF DRAWDOWN IN MONITOR WELL HZ1-MW1 (MC-5054) WHILE PUMPING SCRWTP TEST/PRODUCTION WELL HZ1-TP1 (MC-5055), Q = 775 GPM, R = 640 FT.



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Pr.No. FH8-812	Date: 4/5/2000

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FIGURE 4-13. RECOVERY IN MONITOR WELL HZ1-MW1 (MC-5054) AFTER PUMPING SCRWTP TEST/PRODUCTION WELL HZ1-TP1 (MC-5055), Q = 775 GPM, R = 640 FT.

drawdown and recovery, respectively in well HZ1-MW1. The plots for well CO-2081 and the flow APT of HZ1-TP1 with both monitoring wells (drawdown and recovery) are given in the appendix. Figures 4-14 and 4-15 show the semi-log plots of drawdown and recovery in monitor well HZ1-MW2 for the East Site APT and figures 4-16 and 4-17 display similar information for the North Site APT. The time and drawdown data collected were substituted into equations (4) and (5).

$$T = \frac{264Q}{\Delta s} \qquad (4)$$

$$S = \frac{T\,t_0}{4790r^2} \qquad (5)$$

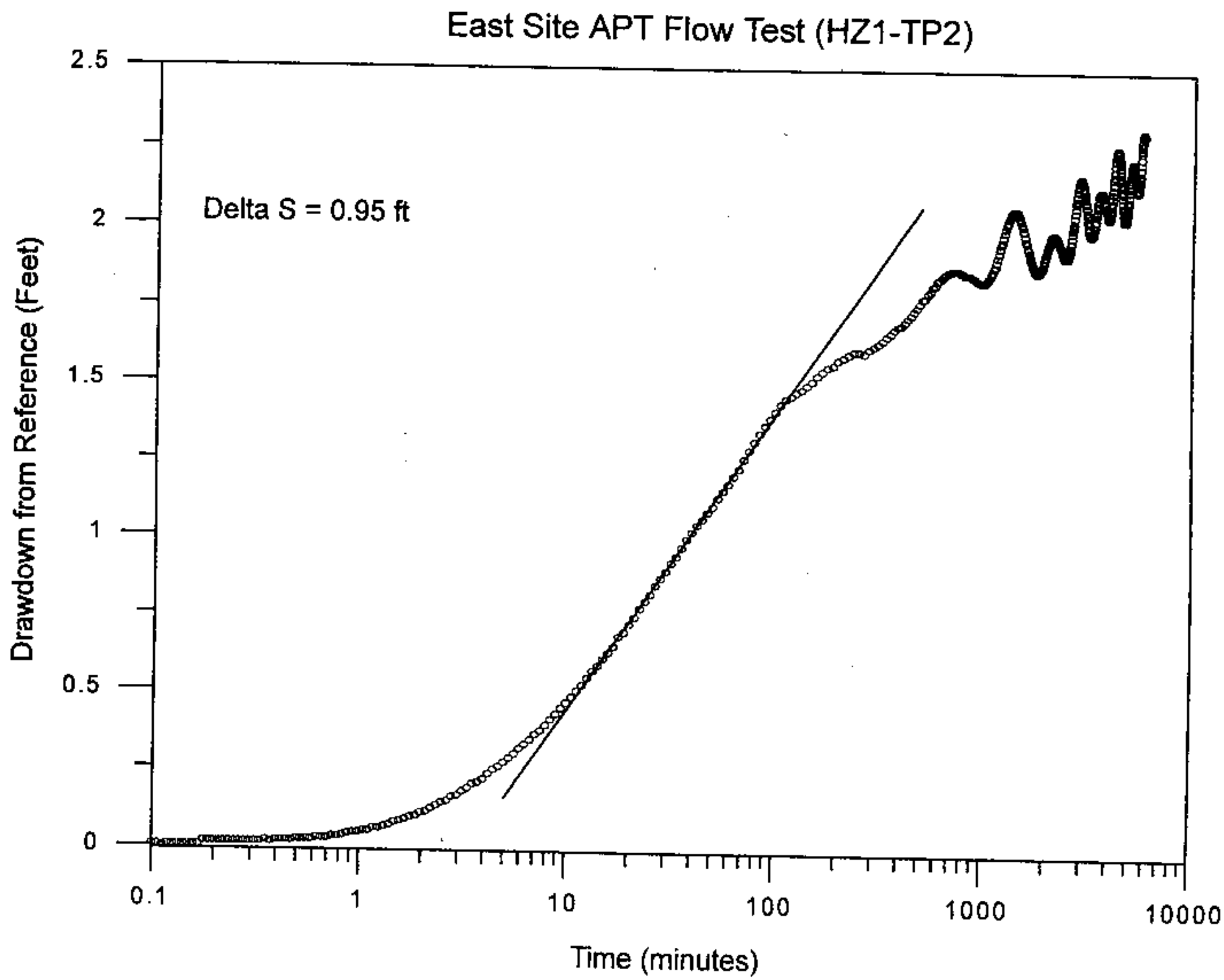
where,

Δs = Head difference between log cycles (feet)

t_0 = time at zero drawdown/ recovery (minutes)

Note that intercept time, t_0, is given in minutes in this equation (for convenience) where the convention in this report is time in days. Hydraulic parameters calculated from the APT tests, using both analysis methods, are given in Table 4-4.

The values of transmissivity calculated from the APT tests for the three test sites, and calculated/estimated from previous investigations, were used to produce a map showing regional transmissivity values in western Collier County (Figure 4-18). Note that the area south of I-75 has been assigned a value of 100,000 gpd/ft and the area north of Immokalee Road has been assigned a value of 20,000 gpd/ft based upon the available data.



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Pr.No. FH8-812		Date: 3/8/2000	

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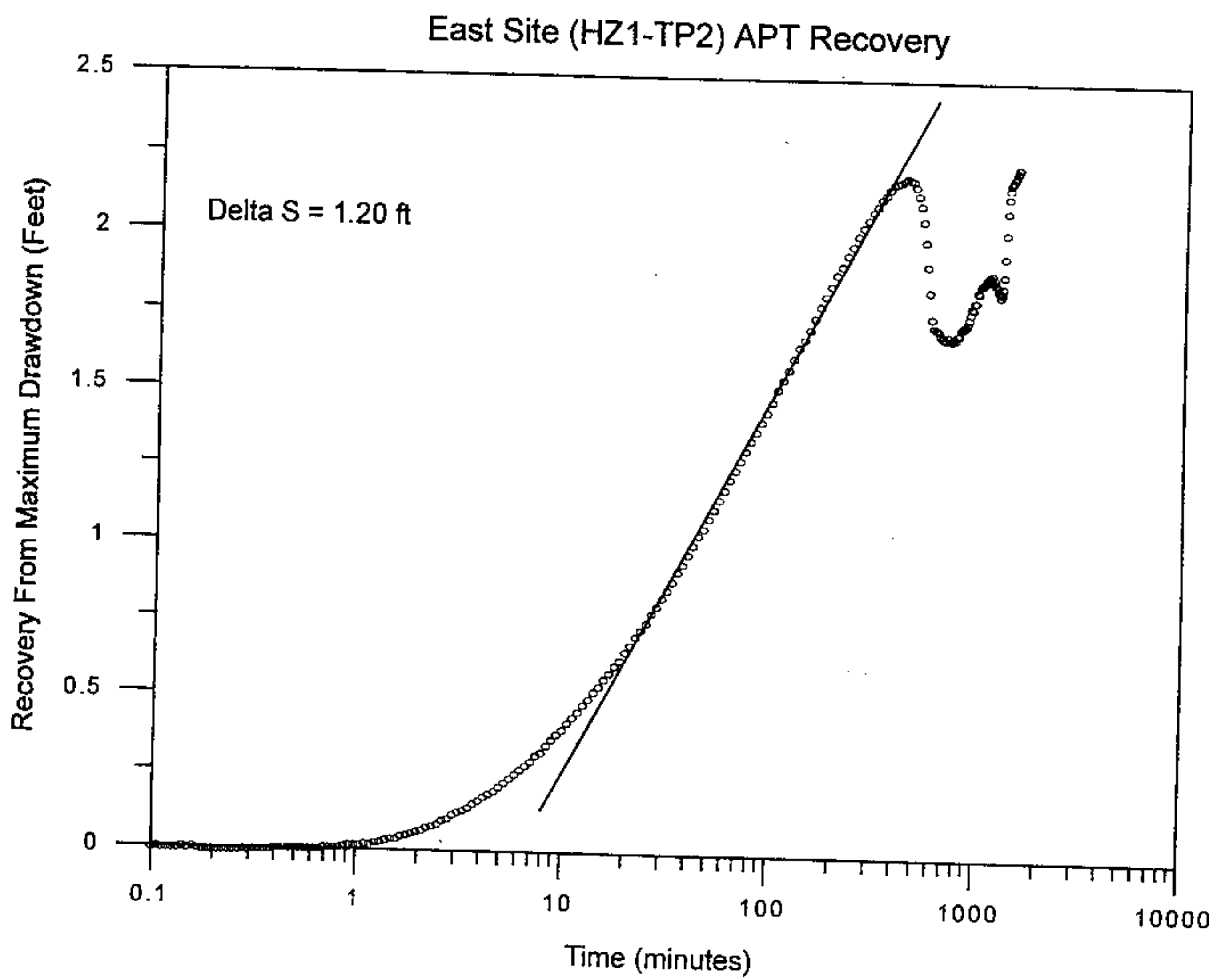
FIGURE 4-14. SEMI-LOGARITHMIC REPRESENTATION OF DRAWDOWN IN MONITOR WELL HZ1-MW2 (MC-5056) WHILE FLOWING EAST SITE TEST/PRODUCTION WELL HZ1-TP2 (MC-5057), Q = 370 GPM, R = 735 FT.



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Pr.No.	FH8-812	Date:	4/4/2000

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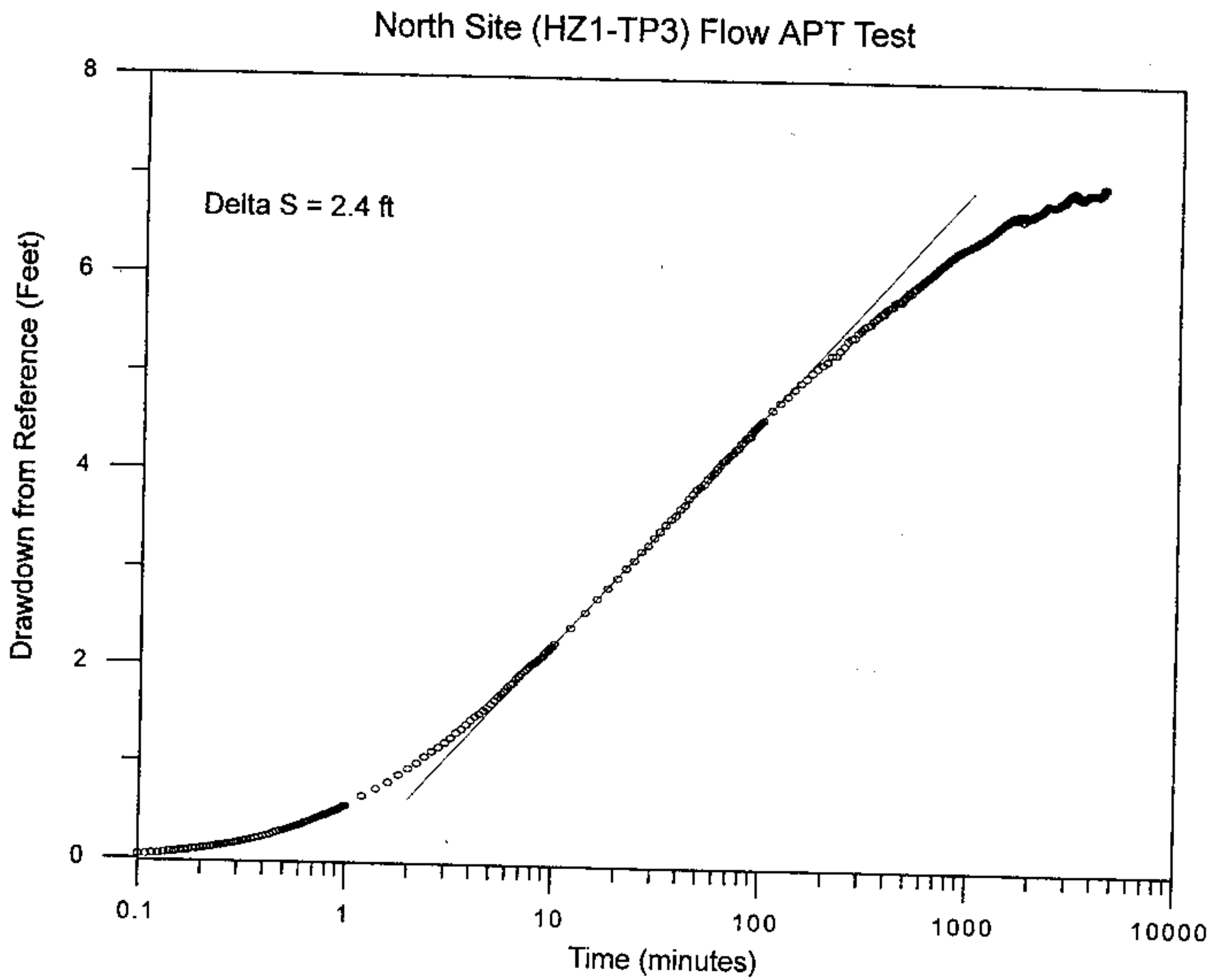
FIGURE 4-15. RECOVERY IN MONITOR WELL HZ1-MW2 (MC-5056) AFTER FLOWING EAST SITE TEST/PRODUCTION WELL HZ1-TP2 (MC-5057), Q = 370 GPM, R = 735 FT.



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Pr.No. FH8-812	Date: 8/15/2000

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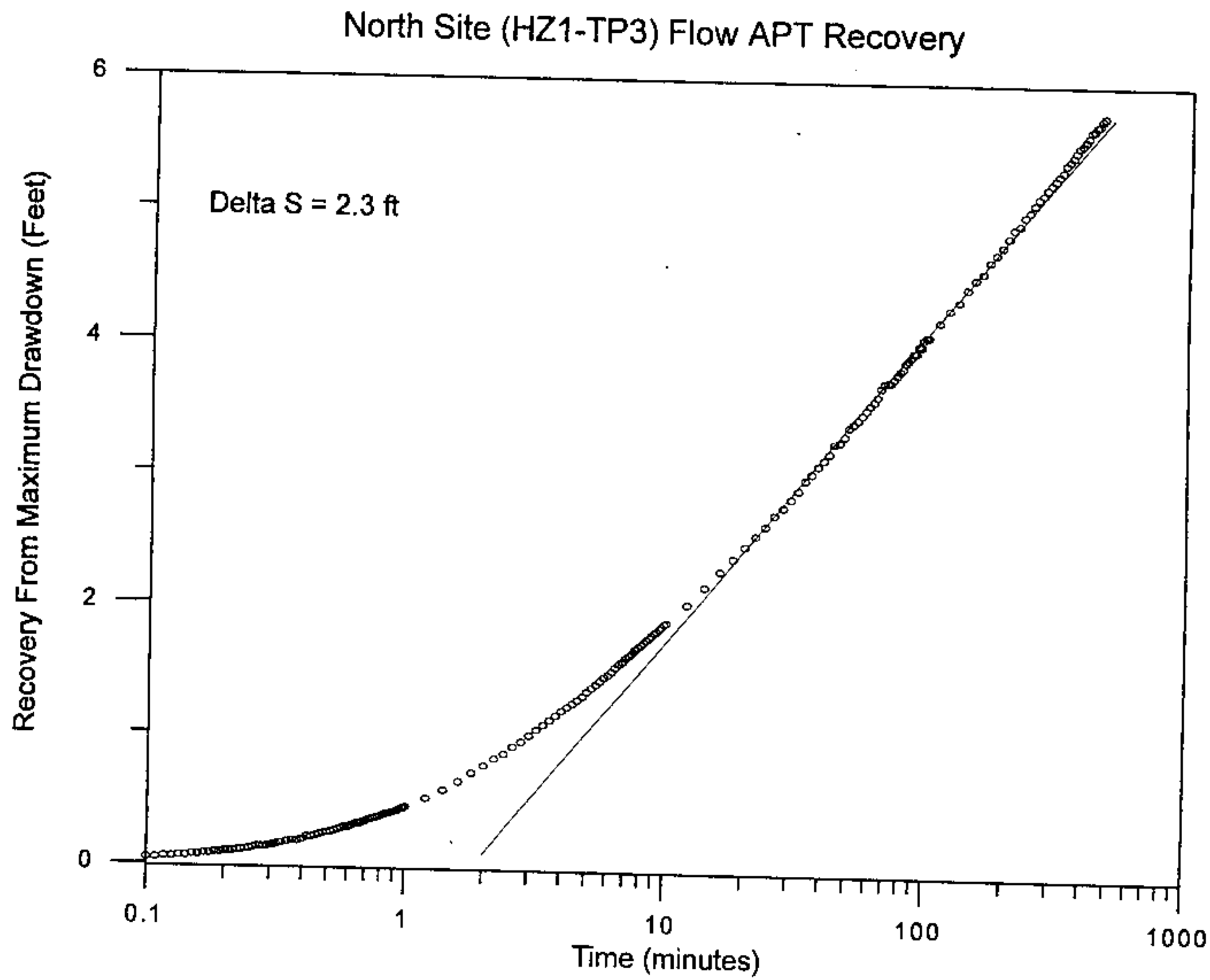
FIGURE 4-16. SEMI-LOGARITHMIC REPRESENTATION OF DRAWDOWN IN MONITOR WELL HZ1-MW3 (MC-5069) WHILE FLOWING NORTH SITE TEST/PRODUCTION WELL HZ1-TP3 (MC-5065), Q = 410 GPM (AVERAGE DURING STRAIGHT LINE TIME PERIOD), R = 405 FT.



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Pr.No.	FH8-812	Date:	8/15/2000

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FIGURE 4-17. RECOVERY IN MONITOR WELL HZ1-MW3 (MC-5069) AFTER FLOWING NORTH SITE TEST/PRODUCTION WELL HZ1-TP3 (MC-5065), Q = 380 GPM, R = 405 FT.

Table 4-4. Hydraulic Parameters Calculated for the Hawthorn Zone I Aquifer

Water Treatment Plant Site HZ1-TP1						
Test				Coefficients		
Type	Rate (gpm)	Monitor Well	Drawdown or Recovery	Transmissivity (gpd/ft)	Storage Coefficient	Leakance (gpd/ft³)
Curve Matching Method						
Flow	433	HZ1-MW1	Drawdown	94,000	1.5×10^{-4}	8.3×10^{-4}
Flow	433	CO-2081	Drawdown	102,000	1.4×10^{-4}	5.0×10^{-4}
Pumped	775	HZ1-MW1	Drawdown	96,000	1.1×10^{-4}	2.9×10^{-4}
Pumped	775	CO-2081	Drawdown	95,000	1.1×10^{-4}	3.2×10^{-4}
Straight Line Method						
Flow	433	HZ1-MW1	Drawdown	104,000	1.6×10^{-4}	N/A
Flow	433	CO-2081	Drawdown	109,000	1.5×10^{-4}	N/A
Pumped	775	HZ1-MW1	Drawdown	93,000	1.4×10^{-4}	N/A
Pumped	775	CO-2081	Drawdown	91,000	1.5×10^{-4}	N/A
Flow	433	HZ1-MW1	Recovery	85,000	3.0×10^{-4}	N/A
Flow	433	CO-2081	Recovery	88,000	4.0×10^{-4}	N/A
Pumped	775	HZ1-MW1	Recovery	93,000	1.7×10^{-4}	N/A
Pumped	775	CO-2081	Recovery	91,000	1.7×10^{-4}	N/A

East Site – HZ1-TP2						
Test				Coefficients		
Type	Rate (gpm)	Monitor Well	Drawdown or Recovery	Transmissivity (gpd/ft)	Storage Coefficient	Leakance (gpd/ft³)
Curve Matching Method						
Flow	370	HZ1-MW2	Drawdown	105,000	1.5×10^{-4}	1.3×10^{-3}
Straight Line Method						
Flow	370	HZ1-MW2	Drawdown	103,000	1.2×10^{-4}	N/A
Flow	370	HZ1-MW2	Recovery	82,000	1.9×10^{-4}	N/A

Table 4-4. Hydraulic Parameters Calculated for the Hawthorn Zone I Aquifer (Continued)

North Site (951) – HZ1-TP3						
Test				Coefficients		
Type	Rate (gpm)	Monitor Well	Drawdown or Recovery	Transmissivity (gpd/ft)	Storage Coefficient	Leakance (gpd/ft^3)
Curve Matching Method						
Flow	[illegible]	HZ1-MW3	Drawdown	43,600	8.3×10^{-5}	1.8×10^{-4}
Straight Line Method						
Flow	[illegible]	HZ1-MW3	Drawdown	45,000	5.7×10^{-5}	N/A
Flow	[illegible]	HZ1-MW3	Recovery	43,600	1.1×10^{-4}	N/A

4.4 Confinement

The lower contact of the Hawthorn Zone I Aquifer is marked by a lithologic change to interbedded marls, clays, and limestones that belong to the middle Arcadia Formation. These generally low permeability units form the confining zone that separates the Hawthorn Zone I Aquifer from the underlying Lower Hawthorn Aquifer. Whereas individual limestone beds within this confining zone may have moderate hydraulic conductivities, the overall interval has a very low water production potential. The thickness of the confining zone in the area surrounding the SCRWTP ranges from 180 to 280 feet. The overall vertical hydraulic conductivity of the confining zone is very low.

4.5 Lower Hawthorn Aquifer

4.5.1 Aquifer Description

The upper boundary of the Lower Hawthorn Aquifer is marked by a sharp decrease in the abundance of marl and clay in the Lower Arcadia Formation. The Lower Hawthorn Aquifer consists predominantly of interbedded yellowish-gray fossiliferous limestones and pale olive dolomites. The Lower Hawthorn Aquifer limestones are generally moderately hard (semi-friable to non-friable) and have a moderate to high porosity. The

Lower Hawthorn dolomites have a microsucrosic texture, are moderately hard to very hard, and have variable porosity. Figure 4-19 shows the top of the Lower Hawthorn Aquifer, which occurs at depths ranging from less than 600 to over 800 feet NGVD in the study area, dipping into a southeast trending synclinal structure. The thickness of the Lower Hawthorn Aquifer ranges from approximately 80 to 160 feet in the study area and is shown in Figure 4-20.

4.5.2 Water Levels

A potentiometric map constructed from measured head pressure levels in wells penetrating the Lower Hawthorn Aquifer is presented as Figure 4-21. Water levels range from approximately 35 to 45 feet NGVD in the project site area and wells tapping this unit flow freely due to the natural artesian pressure. The direction of groundwater flow in the Lower Hawthorn Aquifer follows a trend of northeast to southwest with an estimated regional hydraulic gradient of approximately one foot per mile. Recharge to the aquifer is thought to occur due to direct infiltration of precipitation where the aquifer is close to land surface in the northern and central part of the state. Discharge occurs from leakage into other aquifers, lateral outflow, and from the pumping of wells. The aquifer is currently being utilized for reverse osmosis raw water supply on Marco Island and at the NCRWTP. In addition, the Lower Hawthorn Aquifer is used as a storage zone for an ASR system at the Marco lakes approximately 7 miles south of the SCRWTP. The aquifer is also utilized for irrigation water withdrawals at some locations within the project site area.

4.5.3 Water Quality

The dissolved chloride concentration and specific conductance data obtained for the Lower Hawthorn Aquifer during construction of the test wells are summarized in Table 4-5. A map illustrating the distribution of dissolved chlorides for the Lower Hawthorn Aquifer is given as Figure 4-22. Data for deep wells drilled west and south of the study

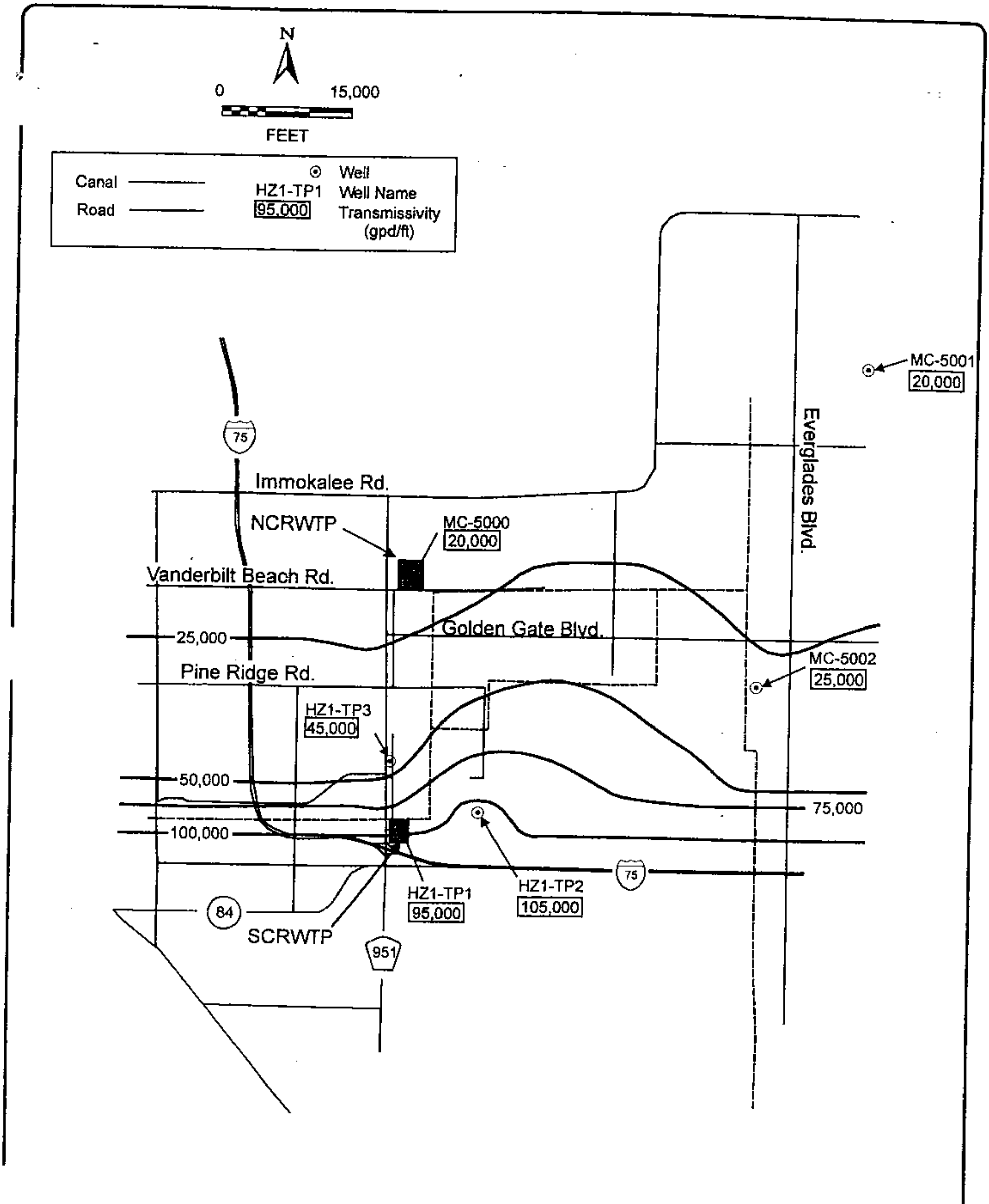
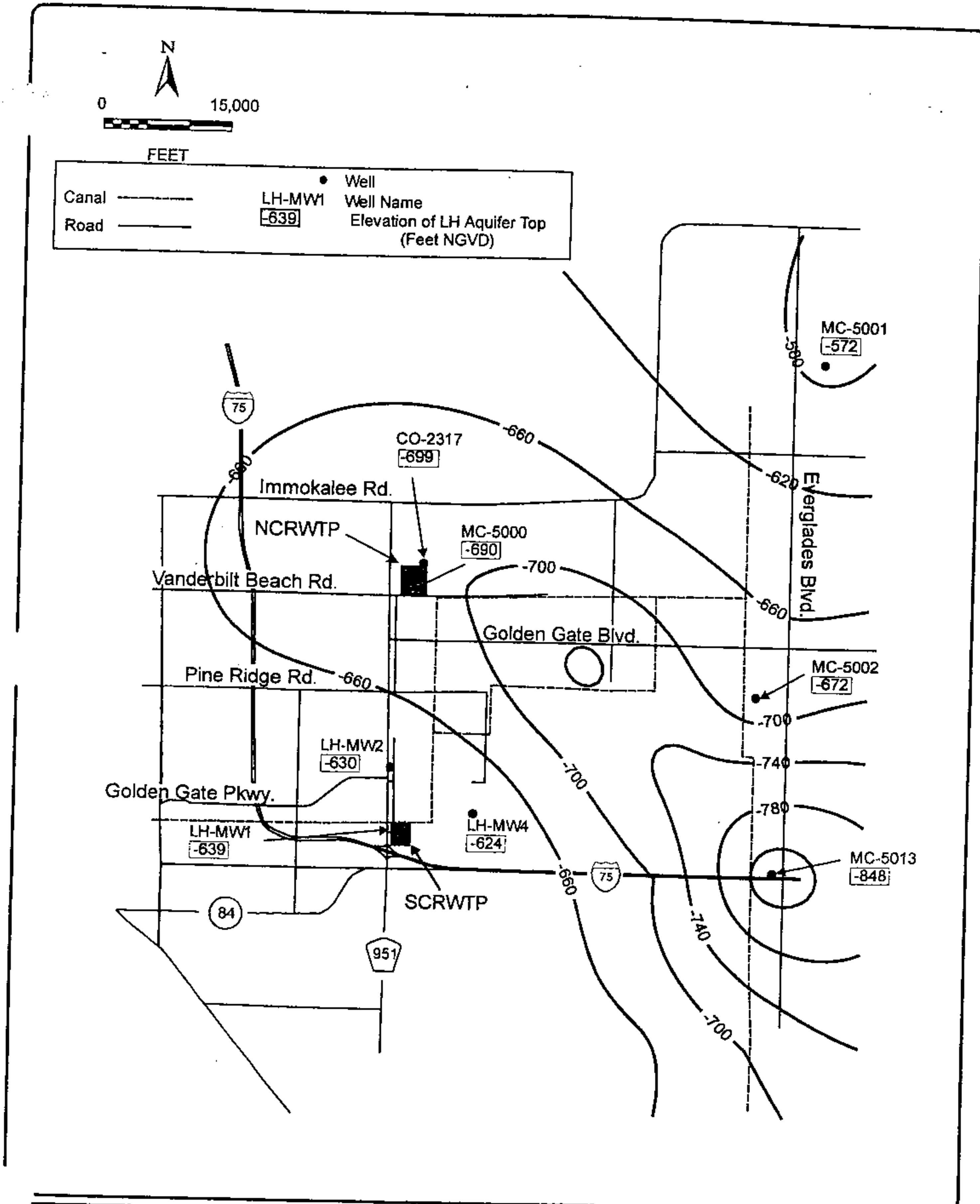


FIGURE 4-18. TRANSMISSIVITY IN THE HAWTHORN ZONE 1 AQUIFER (GPD/FT).



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Pr. No. FH8-812	Date: 9/07/00
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FIGURE 4-19. TOP OF THE LOWER HAWTHORN AQUIFER IN FEET NGVD.

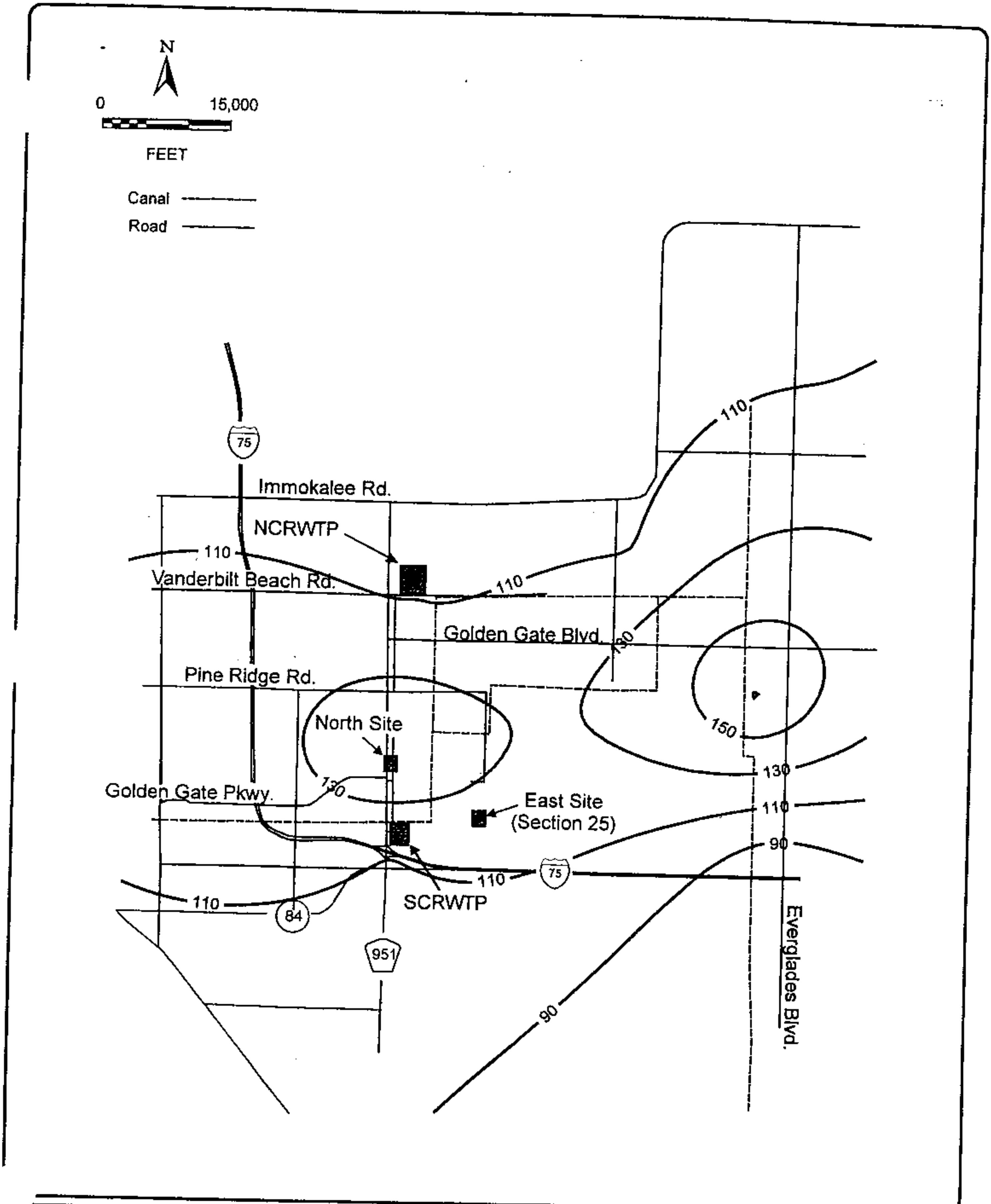

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FIGURE 4-20. THICKNESS OF THE LOWER HAWTHORN AQUIFER (FEET).

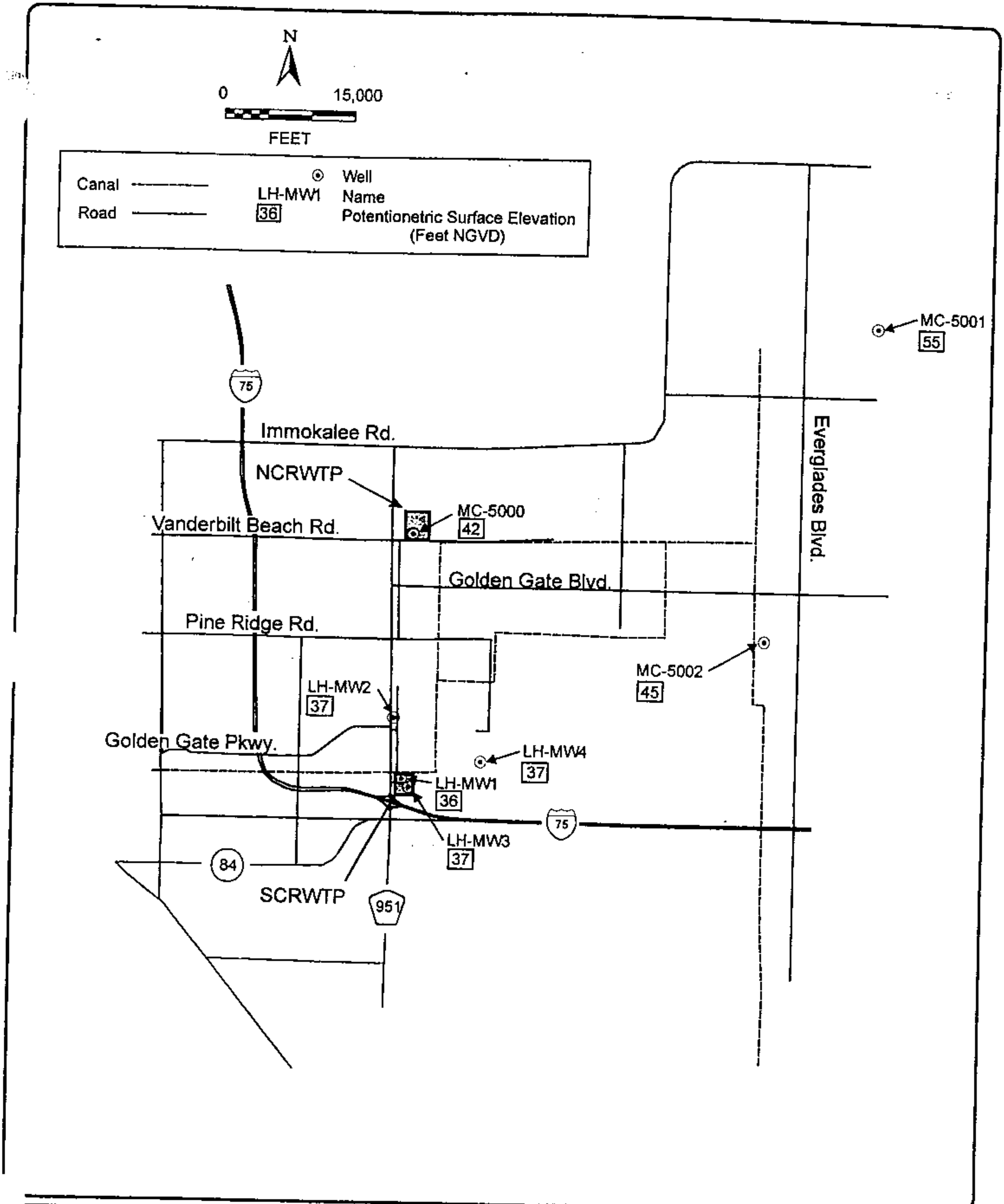

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FIGURE 4-21. POTENTIOMETRIC HEAD IN THE LOWER HAWTHORN AQUIFER (FEET NGVD).

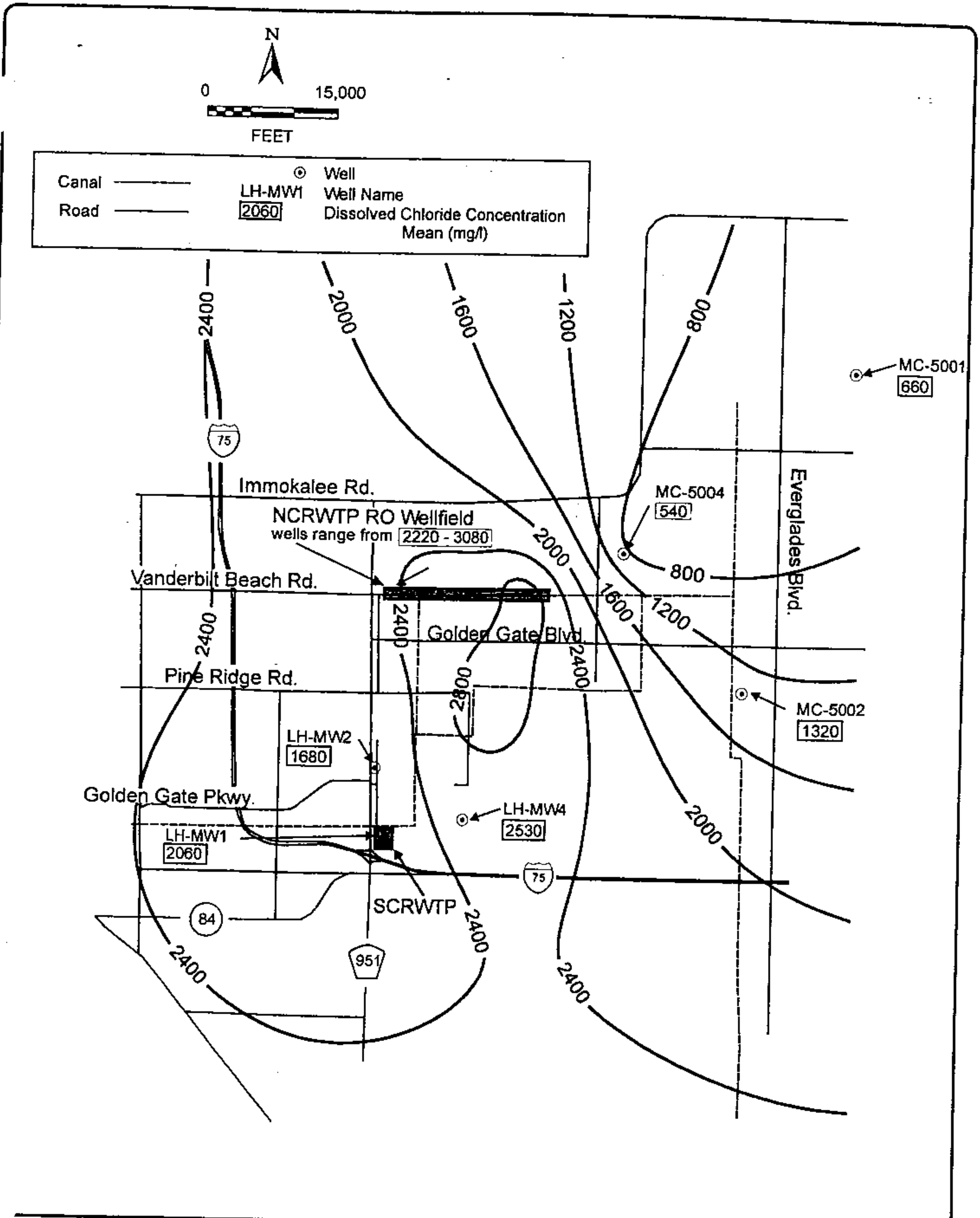

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FIGURE 4-22. DISSOLVED CHLORIDE CONCENTRATIONS IN THE LOWER HAWTHORN AQUIFER (MG/L).

area at Pelican Bay and near Marco Island indicate that a general trend of increasing chloride concentrations west and south occurs to some degree. West of the study area, water in the Lower Hawthorn Aquifer contains chloride concentrations ranging between 2000 and 3000 mg/l, while areas to the south have chloride concentrations ranging from 4000 to 6500 mg/l.

Table 4-5. Water Quality in the Lower Hawthorn Aquifer

Well (Site)	Open Hole Interval (ft bls)	Dissolved Chloride Concs (mg/l) Mean	Dissolved Chloride Concs (mg/l) Range	Specific Conductance (µmhos/cm) Mean	Specific Conductance (µmhos/cm) Range
LH-MW1 (WTP)	650-762	2060	N/A	7000	N/A
LH-MW2 (North)	640-810	1680	1400-1900	6700	5000-7400
LH-MW3 (WTP)	647-780	2110	1940-2200	7700	7200-8000
LH-MW4 (East)	635-760	2530	2280-2620	9400	7730-9890

Additional water samples were collected and analyzed for typical parameters of concern for reverse osmosis treatment facilities. Southern Analytical Laboratories in Tampa, Florida performed the chemical analyses. Results of the analyses are presented in the appendix and summarized in Table 4-6.

4.5.4 Aquifer Hydraulics

The yield potential of the Lower Hawthorn Aquifer in the study area was evaluated by testing wells constructed as part of this investigation and by reviewing data collected during previous investigations and wellfield construction projects. The results of step drawdown tests performed on the Lower Hawthorn Aquifer test wells installed for this study are summarized in Table 4-7. Results of these tests indicate that the yield of the Lower Hawthorn Aquifer in the study area is highly variable but generally lower than the

Table 4-6. Lower Hawthorn Aquifer Water Quality (Laboratory Analyses)

Parameter	Well and Test Site Location		
	LH-MW1 (WTP)	LH-MW4 (East)	LH-MW2 (North)
Total Alkalinity (mg/l)	170	180	170
Bicarbonate Alkalinity (mg/l)	170	180	170
Total Hardness (mg/l)	1300	1500	1100
Non-Carbonate Hardness (mg/l)	1100	1300	900
Ammonia (mg/l)	0.43	0.51	0.43
Barium (mg/l)	0.03	0.02	0.02
Boron (mg/l)	1.1	0.86	0.60
Calcium (mg/l)	190	250	170
Copper (mg/l)	0.02	0.13	0.04
Iron (mg/l)	0.03	0.03	0.03
Magnesium (mg/l)	190	210	160
Manganese (mg/l)	BDL	BDL	BDL
Nickel (mg/l)	BDL	BDL	BDL
Potassium (mg/l)	30	64	45
Silicon (mg/l)	15	20	12
Sodium (mg/l)	1100	1400	910
Strontium (mg/l)	29	17	17
Zinc (mg/l)	0.01	0.39	0.13
Bromide (mg/l)	5.9	8.3	5.6
Chloride (mg/l)	1900	2300	1600
Fluoride (mg/l)	1.1	0.66	1.3
Sulfate (mg/l)	590	830	500
Dissolved Silica (mg/l)	32	15	14
Specific Conductance (umho/cm)	8700	12,000	5200
Sulfide (mg/l)	2.6	BDL	2.2
Hydrogen Sulfide (mg/l)	0.88	BDL	0.66
Total Dissolved Solids (mg/l)	4700	5720	4000
Total Organic Carbon (mg/l)	1.6	4.2	1.0
Turbidity (NTU)	0.05	BDL	0.2
pH (units)	7.2	7.5	7.3

BDL – Below Detection Limit
NA – Not Analyzed

R.O. wellfield along Vanderbilt Beach Road that supplies the NCRWTP show large variations in yields along an east-west trend. Test well LH-MW4 constructed at the East test site for this investigation flows at a rate of over 500 gpm indicating the yield of the Lower Hawthorn Aquifer is very high at that location. The yield of production wells tapping this unit may vary greatly depending upon the formation permeability in the vicinity of the wells.

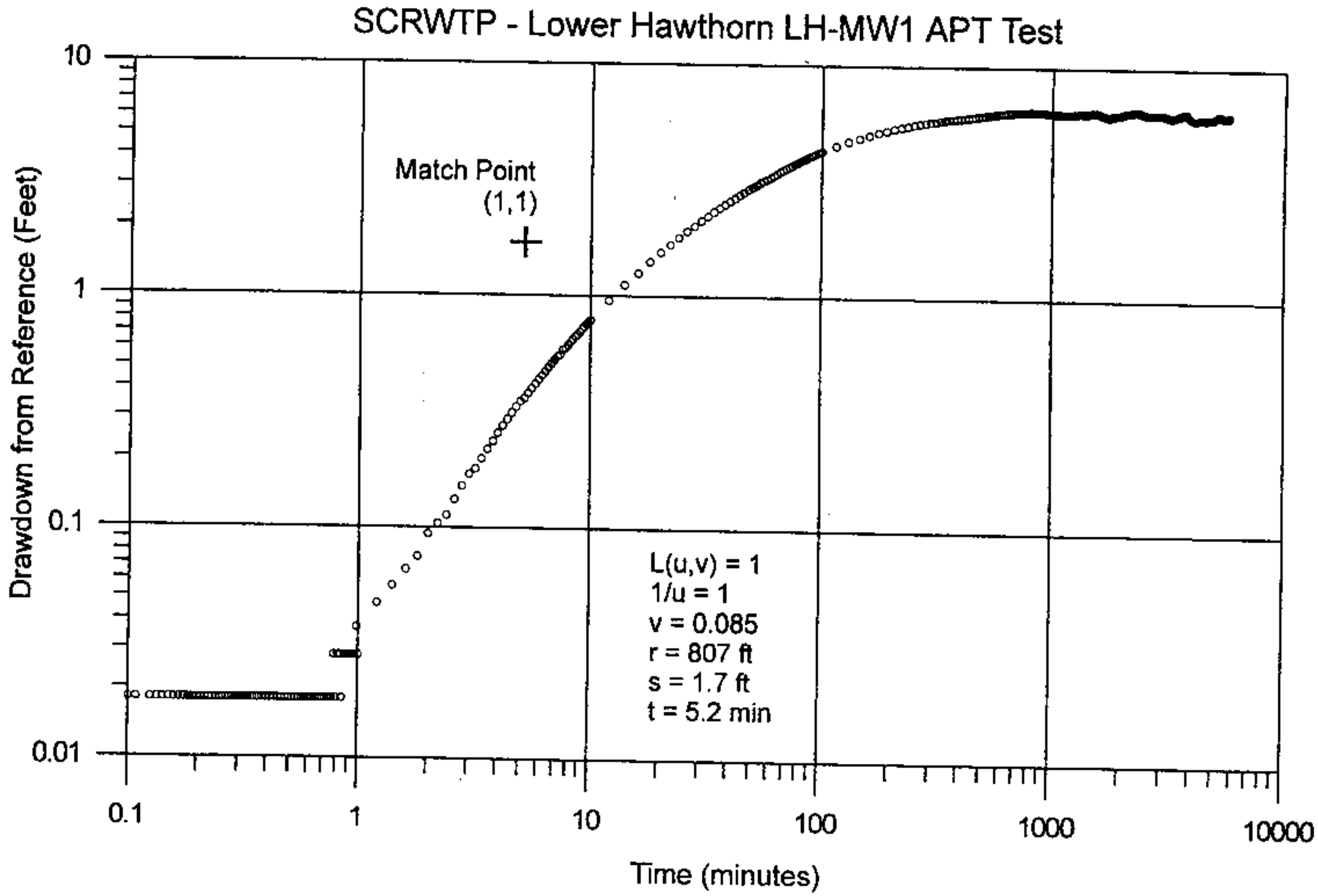
Table 4-7. Step Drawdown Tests of Lower Hawthorn Aquifer Test Wells

Well LH-MW1 (Static Water Level = 36 feet above NGVD) (SCRWTP site)		
Discharge (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
260	25.91	10.0
280	30.61	9.1

Well LH-MW2 (Static Water Level = 37 feet above NGVD) (North site)		
Discharge (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
128	24.42	5.2
150	35.25	4.3
167	41.52	4.0

Logarithmic and semi-logarithmic graphs of time vs. drawdown were constructed using the data collected from Lower Hawthorn Aquifer monitor well LH-MW3 during the 96-hour aquifer performance test conducted by pumping well LH-MW1 at the water treatment plant site. Data were analyzed using the methods developed by Jacob (1950) and Cooper (1963). The logarithmic plot was compared to the appropriate type curve and a match point was obtained. The data were substituted into the Equations (1), (2), and (3). The logarithmic plot of drawdown vs. time is displayed in Figure 4-23.

Semi-log plots of drawdown vs. time and recovery vs. time were analyzed by the Jacob (1950) method to verify transmissivity and storage coefficient values calculated using the Cooper analysis (Figures 4-24 and 4-25). Appropriate time and drawdown/recovery data were substituted into Equations (4) and (5). The calculated hydraulic coefficients for the Lower Hawthorn Aquifer are provided in Table 4-8. The single well APT tests



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Pr.No.	FH8-812	Date:	8/15/2000

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FIGURE 4-23. DRAWDOWN IN MONITOR WELL LH-MW3 (MC-5067) WHILE PUMPING SCRWTP TEST WELL LH-MW1 (MC-5060), Q = 320 GPM, R = 807 FT.

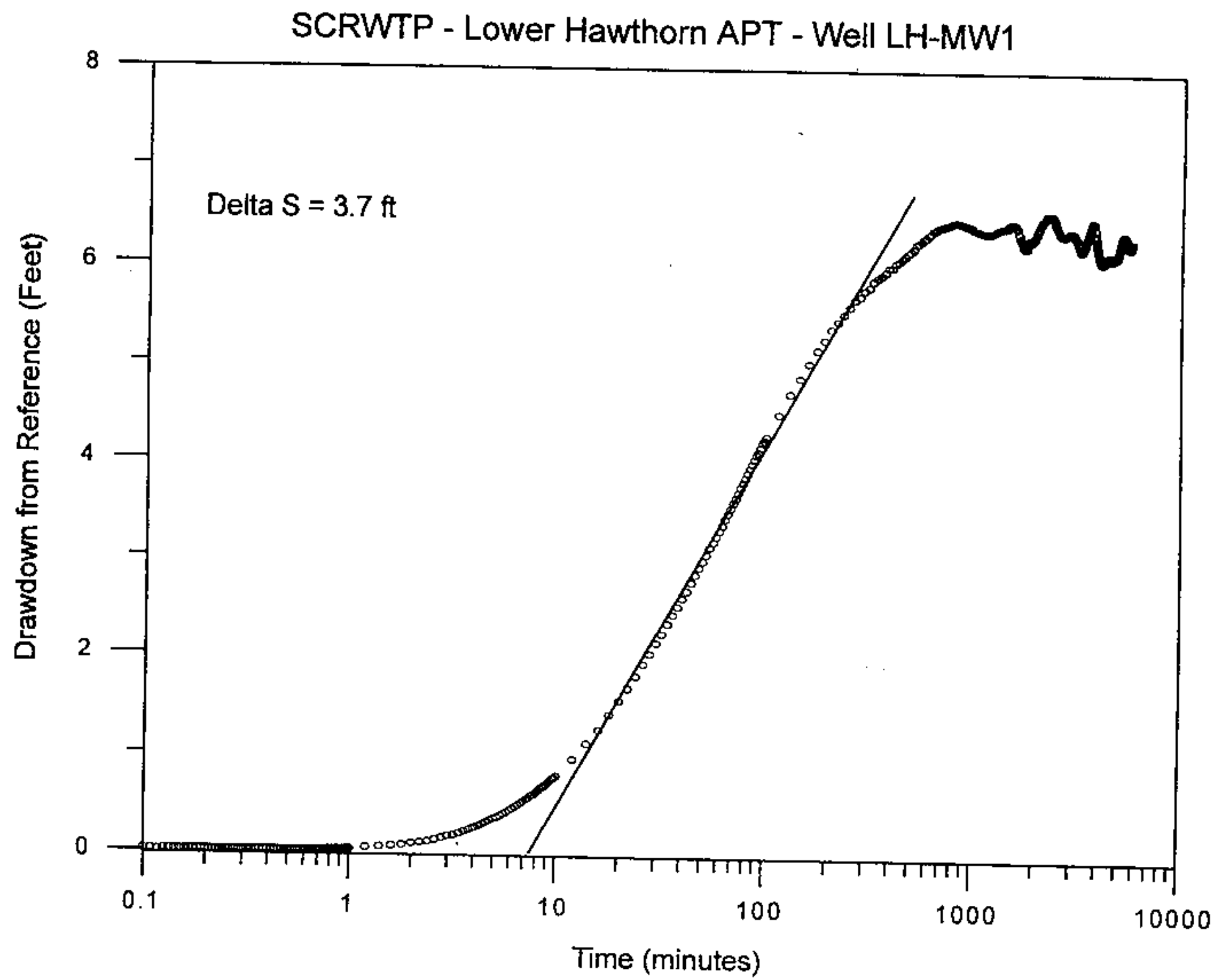

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FIGURE 4-24. SEMI-LOGARITHMIC REPRESENTATION OF DRAWDOWN IN MONITOR WELL LH-MW3 (MC-5067) WHILE PUMPING SCRWTP TEST WELL LH-MW1 (MC-5060), Q = 320 GPM, R = 807 FT.

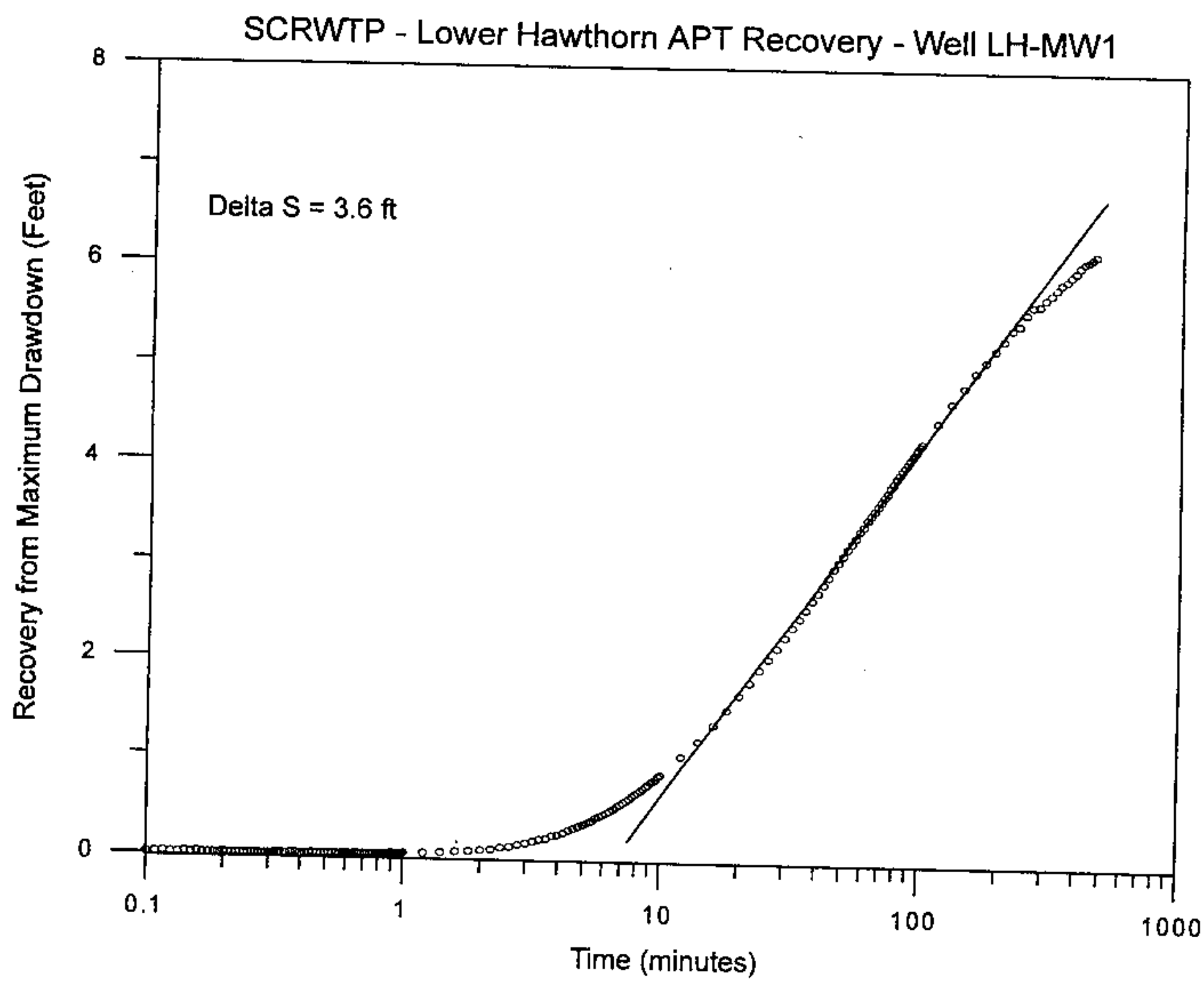

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FIGURE 4-25. RECOVERY IN MONITOR WELL LH-MW3 (MC-5067) AFTER PUMPING SCRWTP TEST WELL LH-MW1 (MC-5060), Q = 320 GPM, R = 807 FT.

Table 4-8. Hydraulic Parameters Calculated for the Lower Hawthorn Aquifer

Water Treatment Plant Site LH-MW1						
Test				Coefficients		
Type	Rate (gpm)	Monitor Well	Drawdown or Recovery	Transmissivity (gpd/ft)	Storage Coefficient	Leakance (gpd/ft³)
Curve Matching Method						
Pumped	320	LH-MW3	Drawdown	21,500	6.3×10^{-5}	9.5×10^{-4}
Straight Line Method						
Pumped	320	LH-MW3	Drawdown	22,800	9.8×10^{-5}	N/A
Pumped	320	LH-MW3	Recovery	23,500	9.4×10^{-5}	N/A

North Site – LH-MW2						
Test				Coefficients		
Type	Rate (gpm)	Monitor Well	Drawdown or Recovery	Transmissivity (gpd/ft)	Storage Coefficient	Leakance (gpd/ft³)
Straight Line Method						
Flow	113	LH-MW2	Recovery	10,100	N/A	N/A

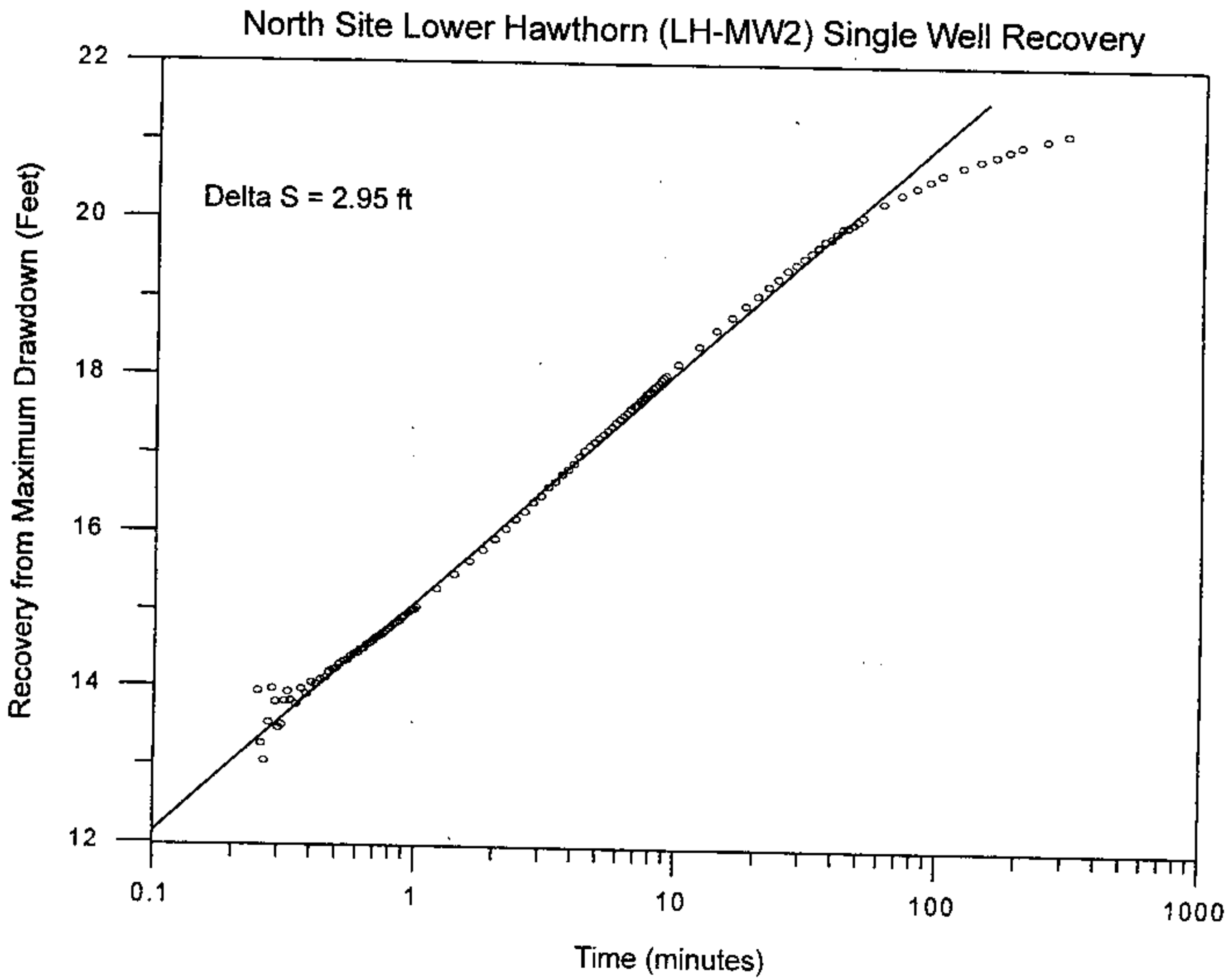
East Site – LH-MW4						
Test				Coefficients		
Type	Rate (gpm)	Monitor Well	Drawdown or Recovery	Transmissivity (gpd/ft)	Storage Coefficient	Leakance (gpd/ft³)
Straight Line Method						
Flow	560	LH-MW4	Recovery	260,000	N/A	N/A

performed on wells LH-MW2 and LH-MW4 were also analyzed used the Jacob method on semi-log plots of recovery vs. time. Figure 4-26 gives the semi-log plot of recovery vs. time after well LH-MW2 was allowed to flow under artesian pressure at a rate of 113 gpm for a period of 68 hours. Six hours of recovery data were collected and graphed. Figure 4-27 gives the semi-log plot of recovery vs. time after well LH-MW4 was allowed to flow under artesian pressure at a rate of 560 gpm for a period of 21 hours. Recovery data were collected for 100 minutes after the well was shut-in and subsequently graphed.

The values of transmissivity calculated from the APT tests for the three test sites and calculated/estimated from previous investigations, were used to produce a map showing regional transmissivity values for the Lower Hawthorn Aquifer in western Collier County (Figure 4-28).

4.6 Underlying Units

The Lower Hawthorn Aquifer is underlain by yellowish-gray fossiliferous limestones that belong to the Suwannee Limestone unit of the Floridan Aquifer System. The limestones generally have both moderate porosity and hardness. There is artesian water production potential from the Suwannee Limestone, but the yield is likely less than that of the Lower Hawthorn Aquifer and salinity levels typically increase with depth.



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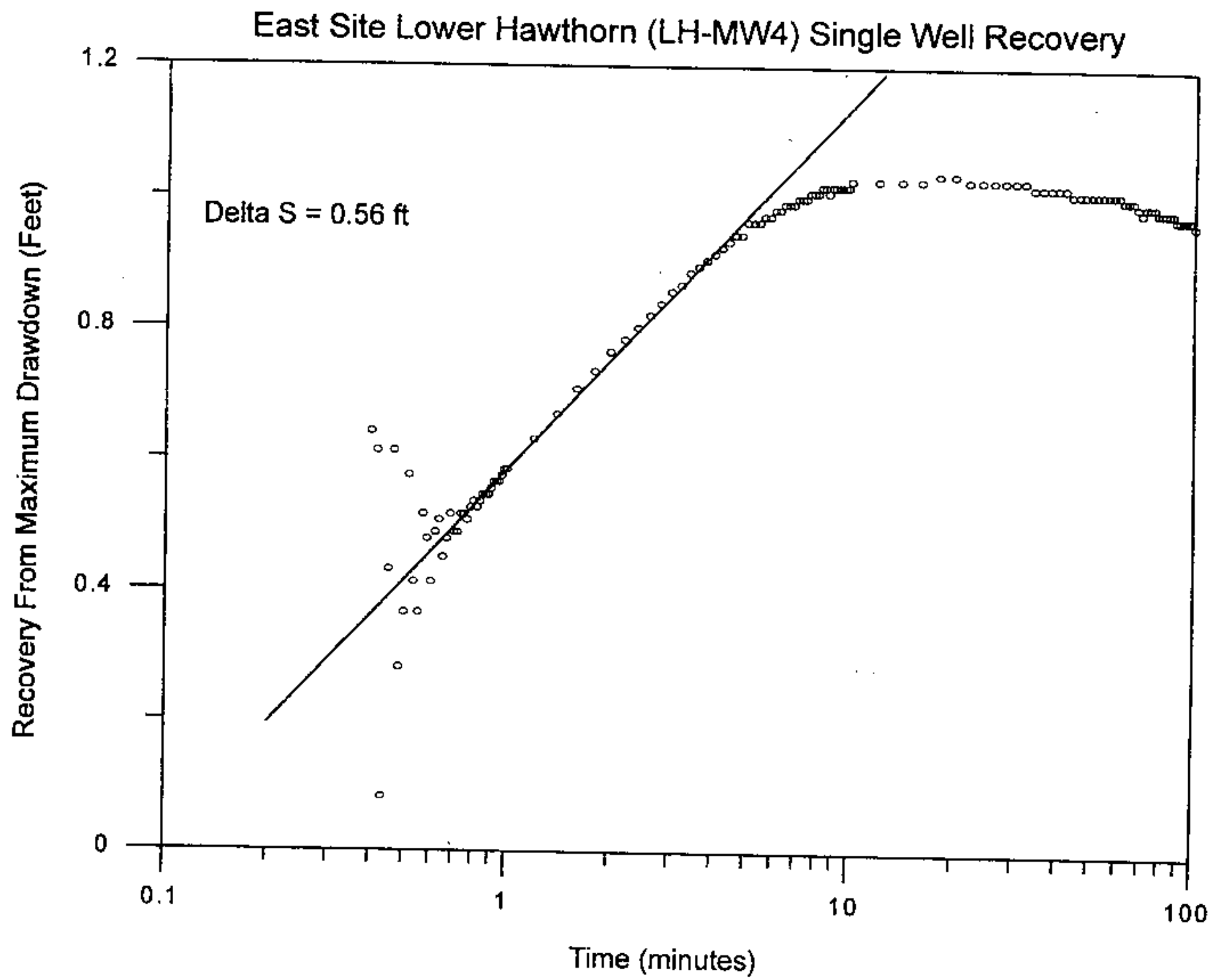
Pr.No. FH8-812	Date: 8/4/2000	

FIGURE 4-26. RECOVERY IN WELL LH-MW2 (MC-5066) AFTER THE SINGLE WELL AQUIFER PERFORMANCE TEST. Q = 113 GPM.



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Groundwater and Environmental Services

FIGURE 4-27. RECOVERY IN WELL LH-MW4 (MC-5068) AFTER THE SINGLE WELL AQUIFER PERFORMANCE TEST, Q = 560 GPM.

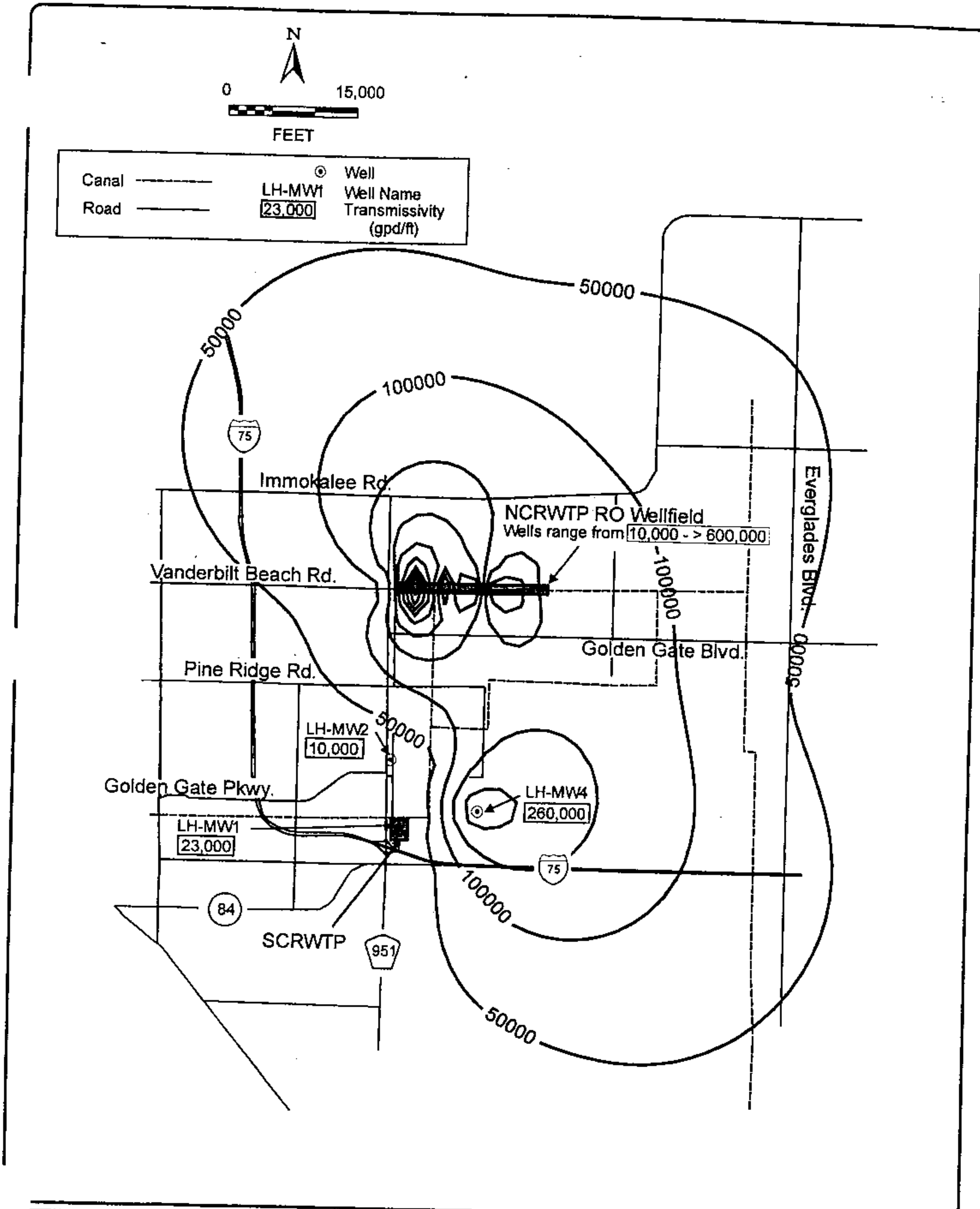


FIGURE 4-28. TRANSMISSIVITY IN THE LOWER HAWTHORN AQUIFER (GPD/FT).

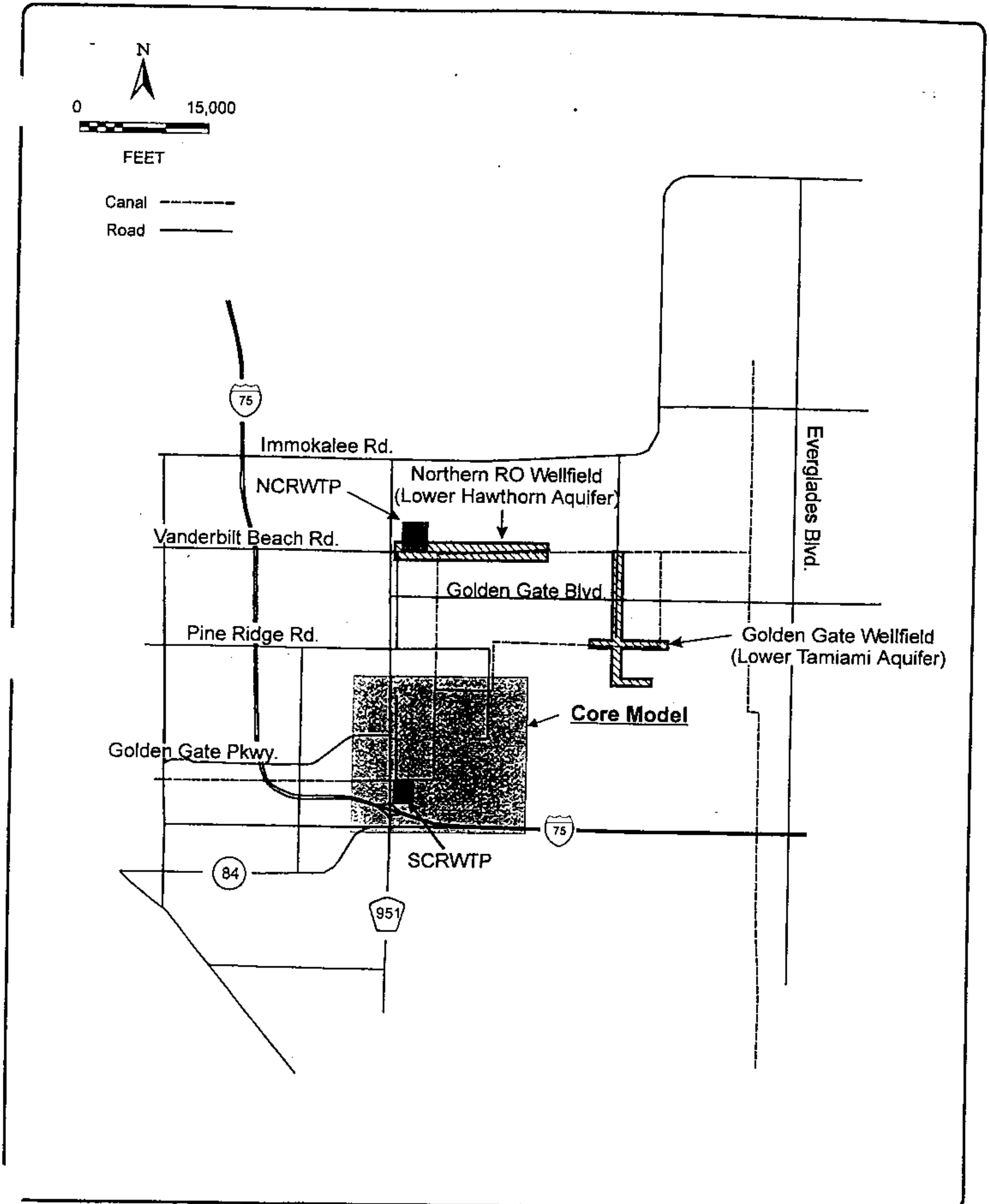
5.0 GROUNDWATER MODELING AND WELLFIELD DESIGN

5.1 Introduction

Groundwater modeling of the Intermediate and Upper Floridan aquifer system was performed to aid in the design of the Collier southern reverse osmosis wellfield. The primary objective of the modeling was to select optimal production well locations and to determine potential drawdown impacts (flow model) and changes in groundwater quality with time (solute transport model) that would result from the proposed large-scale withdrawals for public supply purposes. Potential wellfield locations were selected for the proposed Hawthorn Zone I Aquifer and Lower Hawthorn Aquifer withdrawals based on hydrological conditions, site availability, site accessibility, distance to the water treatment plant, construction logistics and economics. Preferential consideration was given to well sites on land currently owned or controlled by the county within a two-mile radius of the SCRWTP. Preliminary, analytical "desktop" model simulations were conducted to evaluate a large number of potential wellfield alignment scenarios prior to conducting the final, detailed flow and solute transport models. The input of other team members including Collier County staff and the project engineers was integral to the selection of production well locations. The modeled area covers the western portion of Collier County centering on the SCRWTP and extending into southern Lee County and western Hendry County. A finer mesh grid is utilized and more data are available in the area of greatest interest, which is referred to as the core model. The core model area is in the center of the modeled domain and encompasses the SCRWTP (Figure 5-1).

A three-dimensional groundwater flow and solute transport model was developed in 1995 for the Collier north reverse osmosis wellfield, which is located near the North County Regional Water Treatment Plant (NCRWTP) (Missimer International, 1995). That model, referred to as the original model in this report, was adopted for this study. Some of the data used in the original model were used in this study.

The flow model for the southern reverse osmosis wellfield was constructed initially using the original model and updating it with geologic and aquifer hydraulic data collected in



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	Pr. No. FH8-812 Date: 7/20/00	
	DWG No. Rev. No.	

FIGURE 5-1. MAP SHOWING THE CORE AREA OF THE GROUNDWATER MODEL.

the vicinity of the SCRWTP as part of the hydrogeologic test program. The model grid was altered to produce a finer grid near the test wells that were used for calibration purposes. The flow model was calibrated using data obtained from pumping tests conducted during the hydrogeologic test program. It was used for initial model calibrations because the significantly lower simulation time, compared to the solute transport model, allowed more rapid processing of the iterative runs required to determine an optimal solution. The aquifer hydraulic parameters resulting in the best fit between simulated and observed aquifer response were determined through the calibration process. The solute transport model was subsequently developed to incorporate chemical mass transport and density dependent flow components with the hydraulic parameters determined from the calibration model.

5.2 Software

The three-dimensional groundwater flow simulation program, MODFLOW, developed by the U. S. Geological Survey (McDonald and Harbough, 1988) was used to develop the flow model. One of the basic assumptions of MODFLOW is that fluid density is constant. This assumption is valid in many applications of groundwater models. However, when the flow field is affected by solute concentration, variation of fluid density must be accounted for. Under this situation, a computer program that solves coupled flow and solute transport equations is required.

In this study, MODFLOW was used for flow model calibration, and the final solute transport simulations were performed using SEAWAT (Guo and Benett, 1998), a computer program that couples a modified version of MODFLOW to the popular transport code, MT3D (Zheng, 1989). Density terms are added to MODFLOW, and flow is calculated from fresh water head gradients and density difference terms. The resulting flow field is passed to MT3D for a concentration calculation; a new density field is then calculated and fed back into MODLFOW in an iterative procedure. SEAWAT has been tested in solving several problems and has yielded good agreement with published solutions. It can be applied to horizontal or sloping aquifers, and it can be used for three-dimensional simulations.

SEAWAT provides a convenient tool for the simulation of variable-density flow, in that it utilizes familiar software. All the major features of MODFLOW and MT3D are preserved. Except for minor changes in the MODFLOW Basic Package input file, input files for SEAWAT are identical to the standard MODFLOW/MT3D input files, and they can be generated using existing preprocessor programs for MODFLOW/MT3D. SEAWAT has been used in a number of projects conducted by the U.S. Geological Survey in recent years. The selection of SEAWAT for this project was primarily based on the convenience of data conversions, since SEAWAT uses standard MODFLOW and MT3D input files.

5.3 Flow Model Design

The original model has 5 layers, 62 rows and 70 columns. Additional rows and columns were added to the original model to accurately locate new test wells constructed as part of this investigation and proposed production wells. The new grid system has 5 layers, 131 rows and 125 columns. The spacing is irregular, with 100-foot by 100-foot cells in the area of interest expanding up to 14,000-foot by 14,000-foot cells at the boundaries. The entire model encompasses a 45 by 42 mile area of Collier, Lee, and Hendry counties.

Three model layers were used to represent the Hawthorn Zone I Aquifer, the Lower Hawthorn Aquifer and the Suwannee Aquifer, respectively. These model layers correspond to observed hydrostratigraphic units identified from well logs near the SCRWTP site. Utilizing a quasi-three dimensional modeling approach, the semi-confinement between the Hawthorn Zone I Aquifer and the Lower Hawthorn Aquifer, as well as the confining beds between the Lower Hawthorn Aquifer and the underlying Suwannee aquifer system were represented by a leakance term that controls flow between these layers. This 3-layer, quasi-three dimensional model was used to calibrate the flow model.

It should be noted that while the use of a leakance term to represent a semi-confining unit is suitable for flow models, it is not adequate for solute transport models. The actual thickness of a semi-confining unit is required in solute transport simulations. The layer depths were retained from the original model and thicknesses are variable within each layer. The thickness and depth of both the Hawthorn Zone I Aquifer and Lower Hawthorn Aquifer were shown in the previous chapter (Figures 4-2, 4-3 and 4-19, 40-20). The total depth of the model is approximately 1600 feet.

5.4 Model Calibration

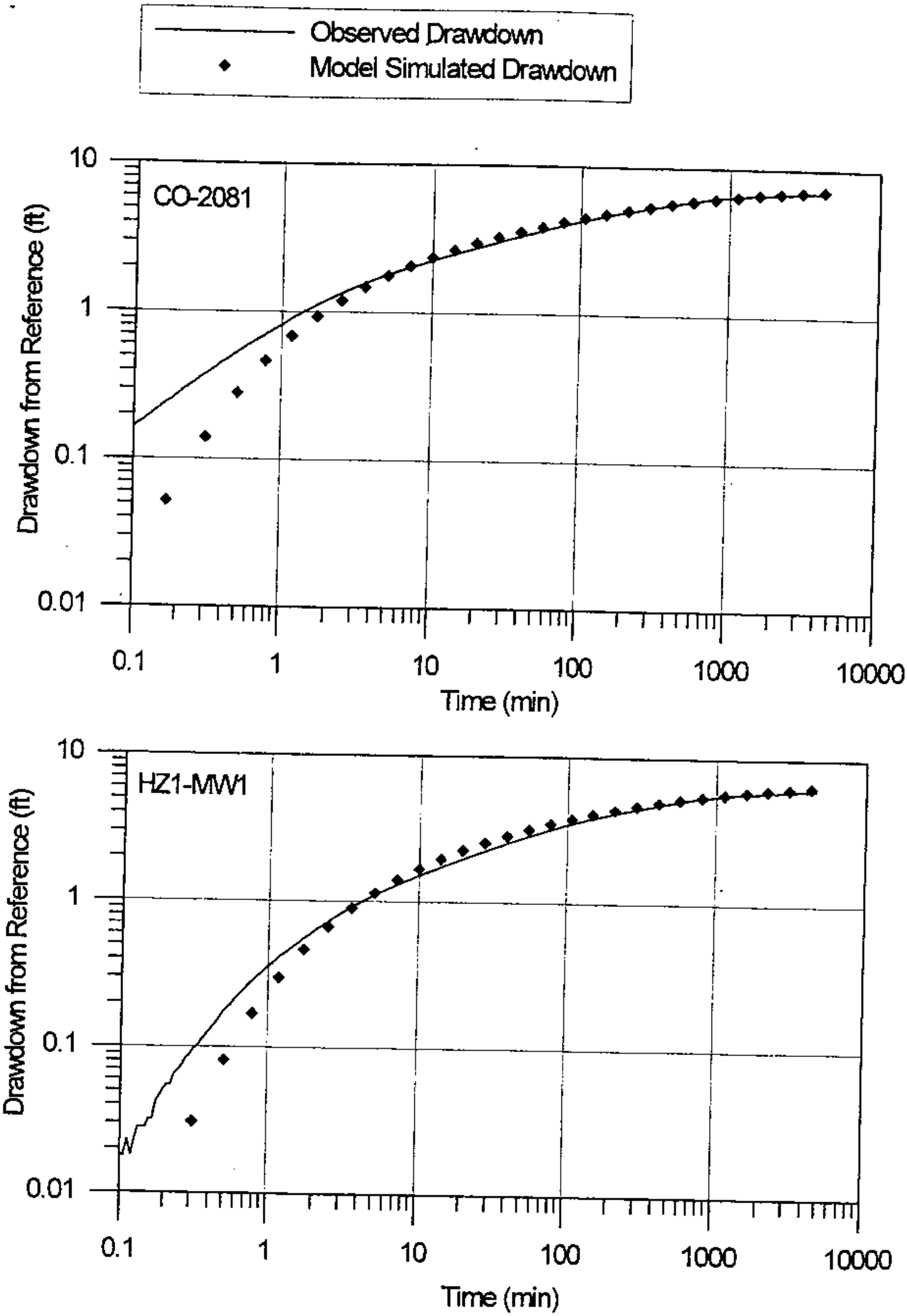
The model was first calibrated to the aquifer performance tests (APTs) conducted in the study area. The model was calibrated for both the Hawthorn Zone I Aquifer and the Lower Hawthorn Aquifer production zones by varying aquifer parameters until the simulated drawdown approximately matched the drawdown observed in the field during the APTs. During the calibration, aquifer hydraulic parameters were determined when the best fit between model calculated and observed drawdowns was obtained.

Model calibration was primarily limited to short term simulations due to the lack of adequate long term monitoring data on the aquifer systems. Such long-term data would be very useful in conducting a steady state or long term transient calibration of the model. As more data become available with the proposed use of groundwater from both the Hawthorn Zone I and the Lower Hawthorn aquifers, model updates and revisions are recommended.

At the SCRWTP site, aquifer performance testing was conducted on both the Hawthorn Zone I and Lower Hawthorn aquifers. The transmissivities calculated from the APTs using curve-matching techniques were incorporated into the regional transmissivity grid that was used to produce Figures 4-18 and 4-28. These regional transmissivities in both the Hawthorn Zone I and Lower Hawthorn aquifers were imported into the calibration model and were not altered during the final calibration process. During initial stages of the calibration process, blocked off areas of transmissivity were altered to determine the model's sensitivity to this hydraulic parameter. The parameters which were altered to provide the best fit between observed and model calculated drawdowns are: storage in both the Lower Hawthorn and Hawthorn Zone I aquifers, the leakance between those two aquifers, the leakance between the Lower Hawthorn and the underlying aquifer (Suwannee), and the transmissivity in the Suwannee. Figure 5-2 shows the drawdown data from the pumping APT at the SCRWTP and the corresponding model simulated drawdown after calibration for monitor wells HZ1-MW1 and CO-2081. After approximately one minute, the match is very good. Tables of the residuals between measured and modeled drawdowns are given in the appendix as Tables C-1 through C-5. The mean residuals for this APT are 0.147 feet and 0.132 feet, respectively for monitor wells HZ1-MW1 and CO-2081. The differences in the initial minute could be due to borehole storage effects and/or due to errors in the APT observations associated with pumping rate fluctuations in the early stages of the test.

Model-simulated drawdowns versus the measured values from APTs at the east test site (HZ1-TP2) and the north test site (HZ1-TP3) are given in Figure 5-3. Once again, the match is very good with the data from the north test site after the initial minute. As for the east site, slight changes in storage and leakance could be made to the model to more accurately simulate the observed data; however, it was decided to keep these values constant for the layer as the model result is conservative, therefore, changes were not made. The absolute mean residuals between the measured and modeled drawdown for the APTs at the north and east test sites are 0.098 feet and 0.261 feet, respectively. Figure 5-4 displays the best fit of the model simulated drawdown versus the observations made in monitor well LH-MW3 during the APT of the Lower Hawthorn Aquifer at the SCRWTP site. After the first few minutes, the match is again very good. The absolute mean residual was 0.136 feet for this test.

The final calibrated hydraulic parameters used in the solute transport model are given in Table 5-1. This model is a 5-layer model; therefore, the semi-confining units between the aquifers were assigned typical values of transmissivity and storage for semi-confining units. For the leakance, a high value was given to the top of the confinement. When creating the true 5-layer, three-dimensional model from the 3-layer, quasi-3D model, the added confining layers must correctly simulate the flow while creating the proper vertical



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Pr. No. FH8-812	Date: 9/18/00
DWG No.	Rev. No.

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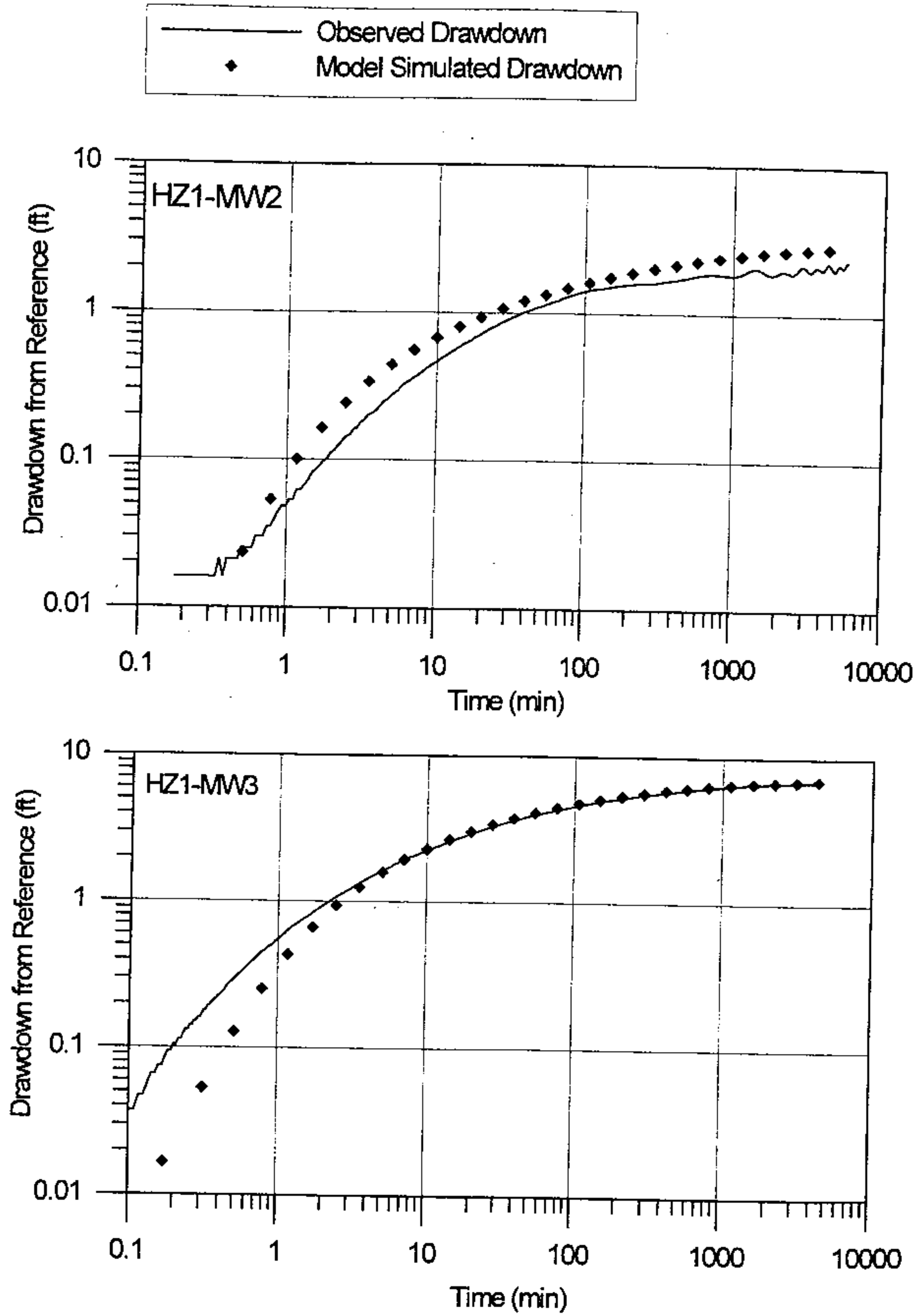
FIGURE 5-2. CALIBRATIONS OF MODEL SIMULATED AND OBSRVED DRAWDOWNS IN HAWTHORN ZONE 1 AQUIFER MONITOR WELLS CO-2081 AND HZ1-MW1 DURING THE APT AT THE SCRWTP SITE.



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Pr. Name: SCRWTP RO EXPANSION	
Pr. No. FH8-812	Date: 9/18/00
DWG No.	Rev. No.

GROUNDWATER
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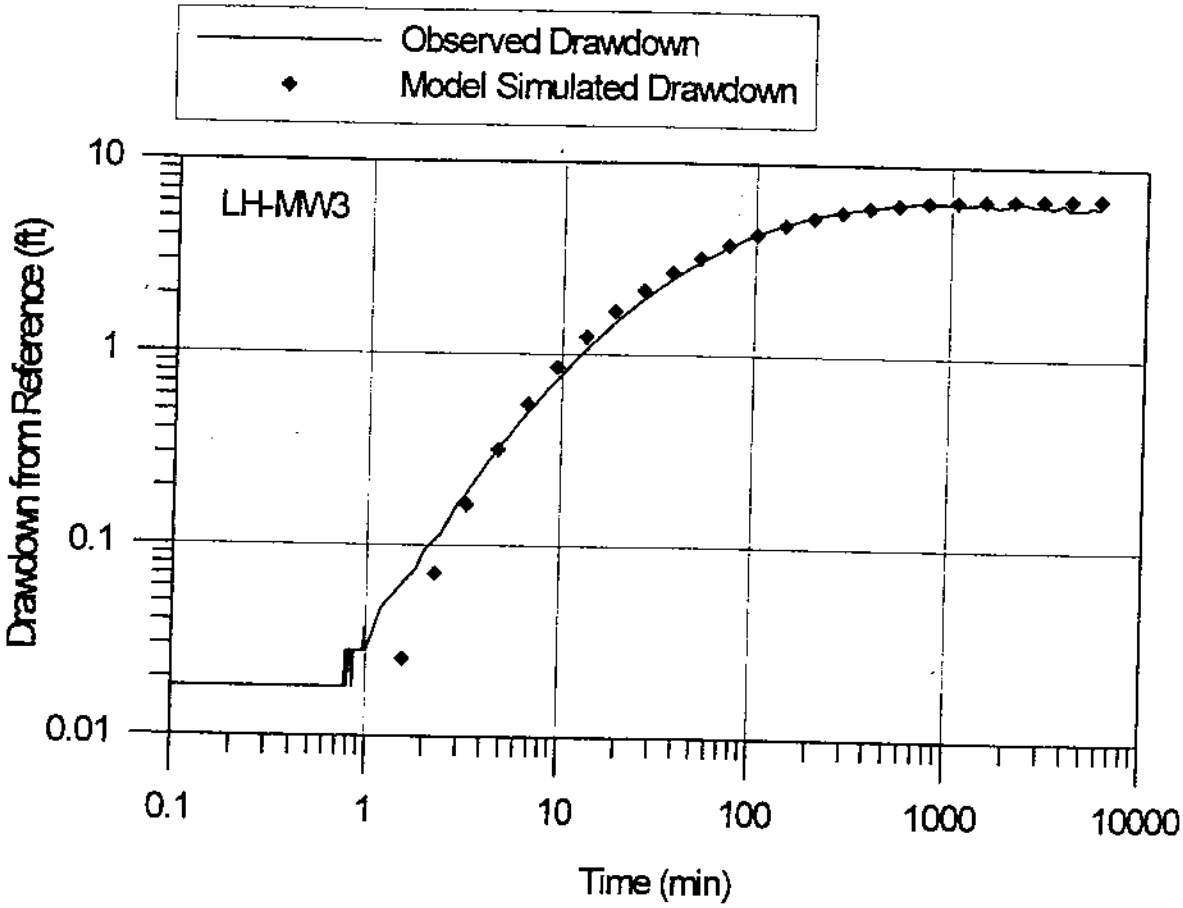
FIGURE 5-3. CALIBRATIONS OF MODEL SIMULATED AND OBSERVED DRAWDOWNS IN THE HAWTHORN ZONE 1 AQUIFER FOR APT'S AT THE EAST (HZ1-MW2) AND NORTH (HZ1-MW3) SITES RESPECTIVELY



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Pr. No. FH8-812	Date: 9/18/00	
DWG No.	Rev. No.	

FIGURE 5-4. CALIBRATION OF MODEL SIMULATED AND OBSERVED DRAWDOWN IN LOWER HAWTHORN AQUIFER MONITOR WELL LH-MW3 DURING THE APT AT THE SCRWTP SITE

distance over which the solute needs to travel. By using a low transmissivity, a large leakance on one boundary, and the calibrated leakance on the other; the direction of flow in the confining layer is nearly vertical, and the vertical hydraulic conductivity is approximately the same as in the quasi-3D approach. The solute transport model constructed using the hydraulic parameters in Table 5-1 was verified to yield the same drawdown curves in the short term as the calibration model and the same drawdown as the quasi-3D model when run to steady state.

Table 5-1. Model Hydraulic Parameters

Model Layer	Transmissivity (near SCRWTP) (gpd/ft)	Transmissivity (away from site) (gpd/ft)	Storage	Leakance (to layer beneath) (gpd/ft^3)
1	100,000	20,000 – 100,000	8×10^{-5}	7.5
2	750	750	1×10^{-5}	6×10^{-4}
3	25,000	10,000 – 600,000	6×10^{-5}	7.5
4	750	750	1×10^{-5}	9×10^{-4}
5	210,000	210,000	6×10^{-5}	N/A

5.5 Solute Transport Model

A solute transport computer model of the Hawthorn Zone I and the Lower Hawthorn aquifers was developed in order to determine the potential changes in water quality that might result from the proposed wellfield withdrawals. Dissolved chloride concentration, being a good indicator of overall water quality in a confined brackish water aquifer, was selected as the representative chemical parameter for the solute transport modeling. Subsequent discussion of water quality in this section of the report is in terms of dissolved chloride concentrations.

The areal extent of the solute transport model coincides with the flow model. Model cell grid dimensions are identical to those used in the flow model. The solute model, however, uses a five-layer representation of the aquifer system. A fully three-dimensional representation of the aquifers and the confining beds was implemented so that confining beds were represented as distinct model layers as opposed to implicitly specified through leakance terms as simulated in the flow model. The five model layers thus represent the Hawthorn Zone I Aquifer, the middle confining beds, the Lower Hawthorn Aquifer, the lower confining beds and the underlying deep aquifer system including the Suwannee and Ocala aquifers. Inclusion of the influence of the deeper aquifer system was necessary as it represents a source of higher salinity water beneath the proposed production zones.

Aquifer hydraulic parameters and data input from the flow model were also used for the solute transport model. Additional data required for solute transport modeling include layer thickness, initial dissolved chloride concentration, porosity, and dispersivity. These data were obtained from field measurements and data reported in the literature.

Transport of dissolved chloride in groundwater is primarily controlled by advection and hydrodynamic dispersion. The advective component of solute transport is dependent on flow velocities and usually represents the principal means of solute movement. Flow velocities are computed internally during model simulation. Dissolved chloride is typically treated as a conservative species, so that its transport is not retarded to any significant degree.

Hydrodynamic dispersion combines the effects of mechanical dispersion and molecular diffusion. The effect of dispersion becomes more pronounced where groundwater flow velocities are small. Longitudinal and transverse dispersivity are normally determined through model calibration. Values of dispersivity measured in the laboratory typically are less than one foot. Field values for longitudinal dispersivity, however, have been reported from less than 10 feet to hundreds of feet depending on the scale of the field experiments (Freeze and Cherry, 1979). Review of various modeling studies reveals longitudinal dispersivity ranging from 50 feet to 300 feet and transverse dispersivity ranging from 5 feet to 60 feet. Longitudinal and transverse dispersivity of 100 and 50 feet, respectively, were used in the solute transport model for this study. The effect of molecular diffusion is assumed to be negligible comparable to advection and dispersion and is therefore not represented in the model.

For each of the model scenarios examined, a number of simulations were run for a 20-year period. While flow conditions in constant density fluid typically can reach equilibrium, or steady state, over a period of weeks or months, solute concentration changes, especially those which tend to affect the flow regime, can take significantly more time to equilibrate, often on the order of years or decades. This occurs because changes in the dissolved chloride concentrations can result in density dependent flows, which in turn affect the chloride concentrations.

The variations in water levels resulting from the change in dissolved chlorides reduce with time as the system approaches equilibrium. The 20-year simulation thus ensures that the model results indicate long-term effects of the specified withdrawals.

Initial dissolved chloride concentrations in the model were specified using data obtained from test wells completed in the two aquifers of interest and underlying units. The contours of initial dissolved chloride concentration for the Hawthorn Zone I and the Lower Hawthorn aquifers were shown in Figures 4-5 and 4-22, respectively. The dissolved chloride concentration at the model boundaries is specified as constant. All flow into the model area across each model boundary cell is assigned a concentration equal to the concentration specified at that cell. The distance from the specified boundary to the area of interest was such that boundary error would be minimal within the core model area.

Due to the fluid density being a function of all the solutes in the fluid, total dissolved solids (TDS), rather than dissolved chloride concentration, is used to calculate the fluid density. However, most of the field measurements provide the chloride concentration rather than TDS. A ratio of 0.54 dissolved chloride to total dissolved solids was used to estimate the values of TDS from measured dissolved chloride concentrations.

Porosity, not required in the flow model, is another parameter used in solute transport modeling. Field measurements of porosity are very few and therefore porosity was determined based upon experience. A uniform value of 0.15 was used in upper three layers and 0.10 for the underlying units for the solute transport model in this study. By using values less than the conventional effective porosity, the particle velocity increases, which would tend to increase the migration of higher salinity from the lower layers to the production layers. This is a conservative approach.

A water quality sensitivity analysis was run for varying hydraulic parameters including leakance, transmissivity, and for longitudinal and transverse dispersion. Due to the time required to conduct the solute transport simulations, the hydraulic parameters that were analyzed were limited to those deemed most likely to affect the migration of water from the underlying higher salinity Suwannee Aquifer. Therefore, the leakance between the Lower Hawthorn and Suwannee aquifers was varied by an order of magnitude in each direction, and the transmissivity in the Lower Hawthorn Aquifer was varied by a factor of two each way. The longitudinal dispersion and the ratio of transverse to longitudinal dispersion were also varied up to an order of magnitude, in this case for all layers. The results of the sensitivity analysis are given in Appendix C.

5.6 Simulation Results

The results of the model simulations, for the calibrated model construct are presented as contours of potentiometric surface drawdowns due to pumpage from the proposed R.O. wellfield (8-MGD Scenario). The 8-MGD Scenario requires 11 wells to be pumping an average of 1 MGD of raw water each. The simulation includes 8 wells tapping the Hawthorn Zone I Aquifer and 3 wells tapping the Lower Hawthorn Aquifer (Figure 5-5). The results of the model simulations are presented in Figures 5-6 to 5-10. Figures 5-6 and 5-7 show contours of the drawdown of the potentiometric surface in the Hawthorn Zone I Aquifer superimposed over a site map. Figure 5-6 displays the simulated drawdown that would occur due to pumping only the wells at the southern R.O. wellfield. Figure 5-7

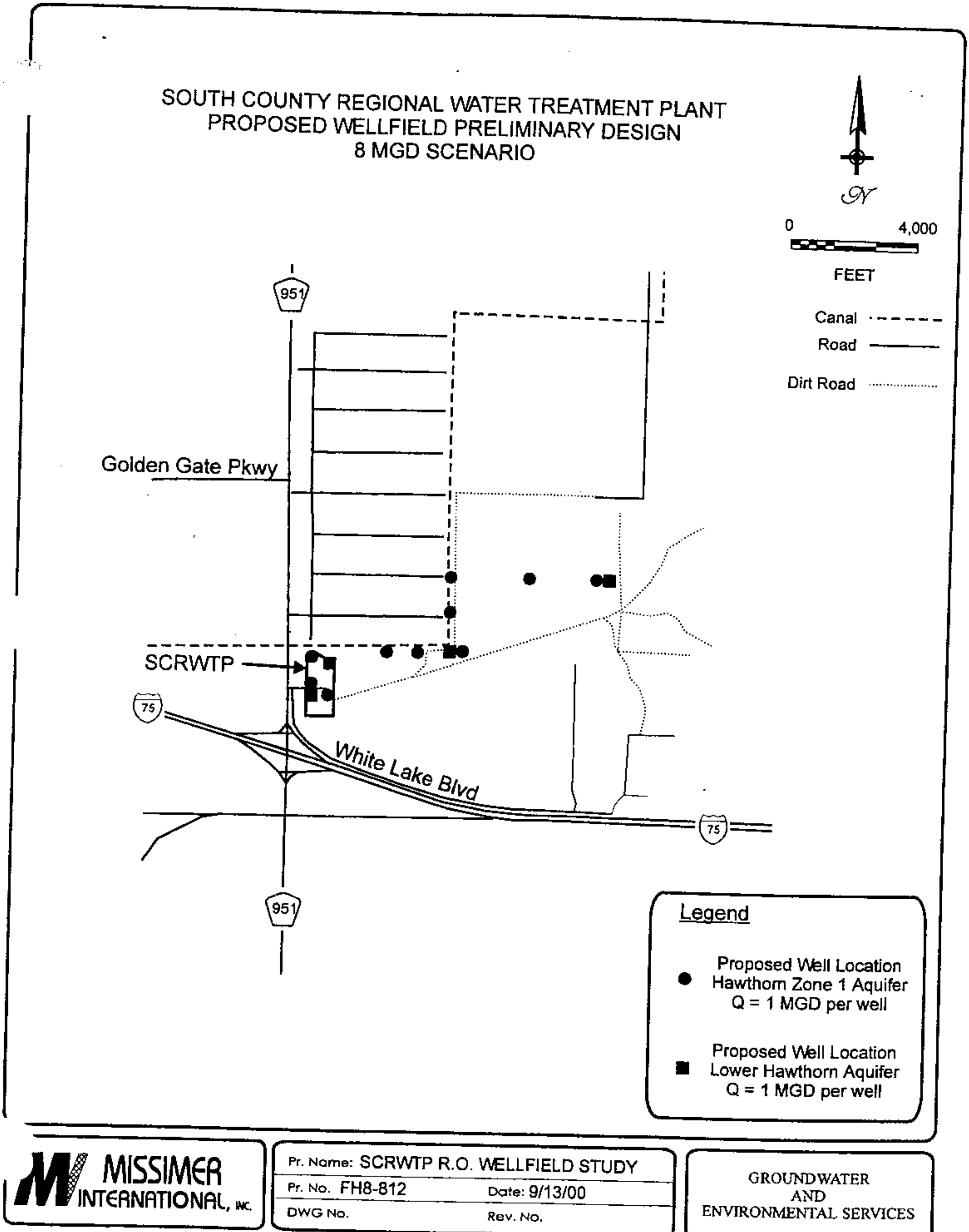
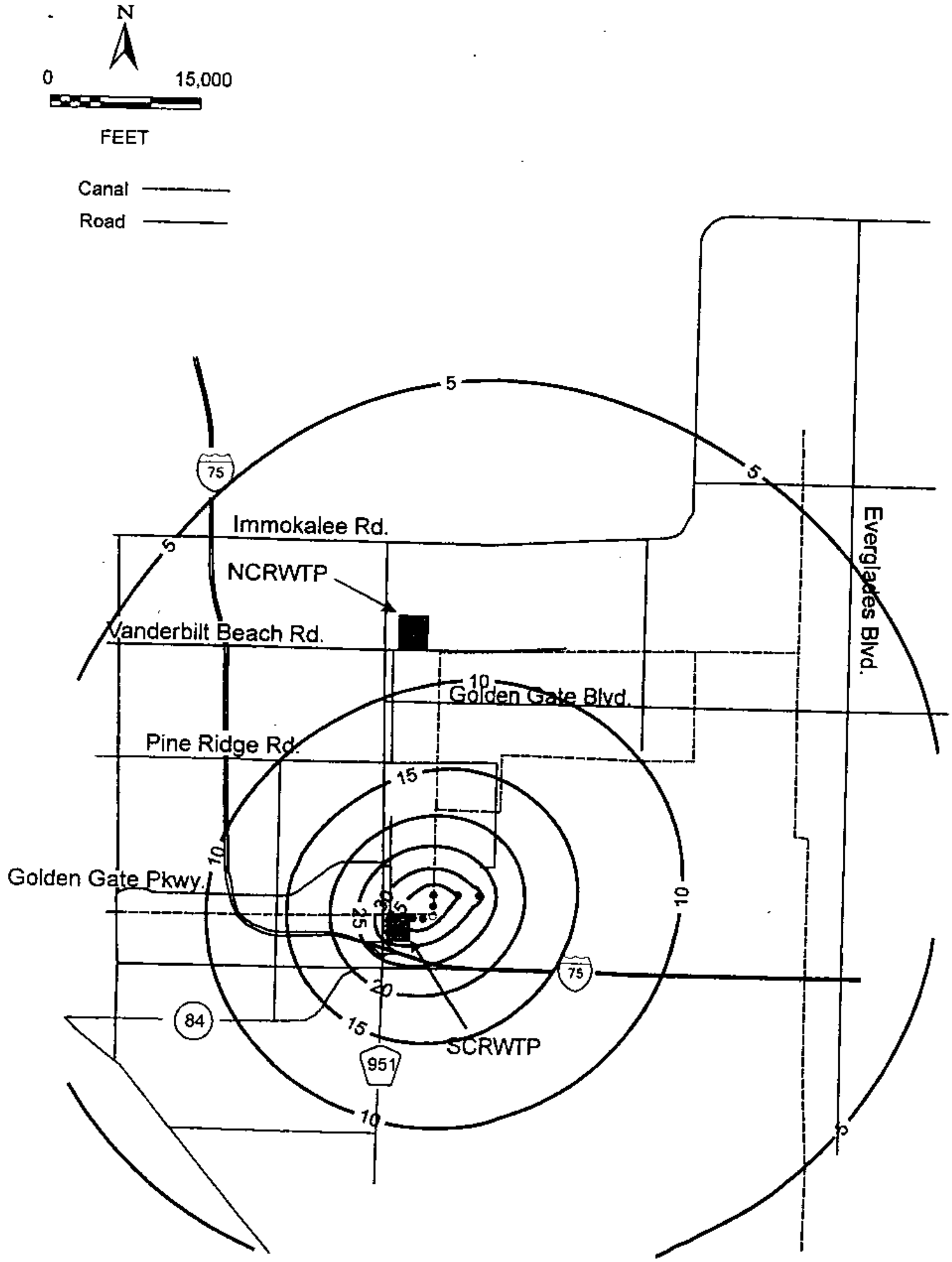


FIGURE 5-5. PROPOSED WELL LOCATIONS IN THE HAWTHORN ZONE 1 AND LOWER HAWTHORN AQUIFERS FOR THE SCRWTP R.O. EXPANSION, 8 MGD SCENARIO (3 WELLS ARE REDUNDANT).



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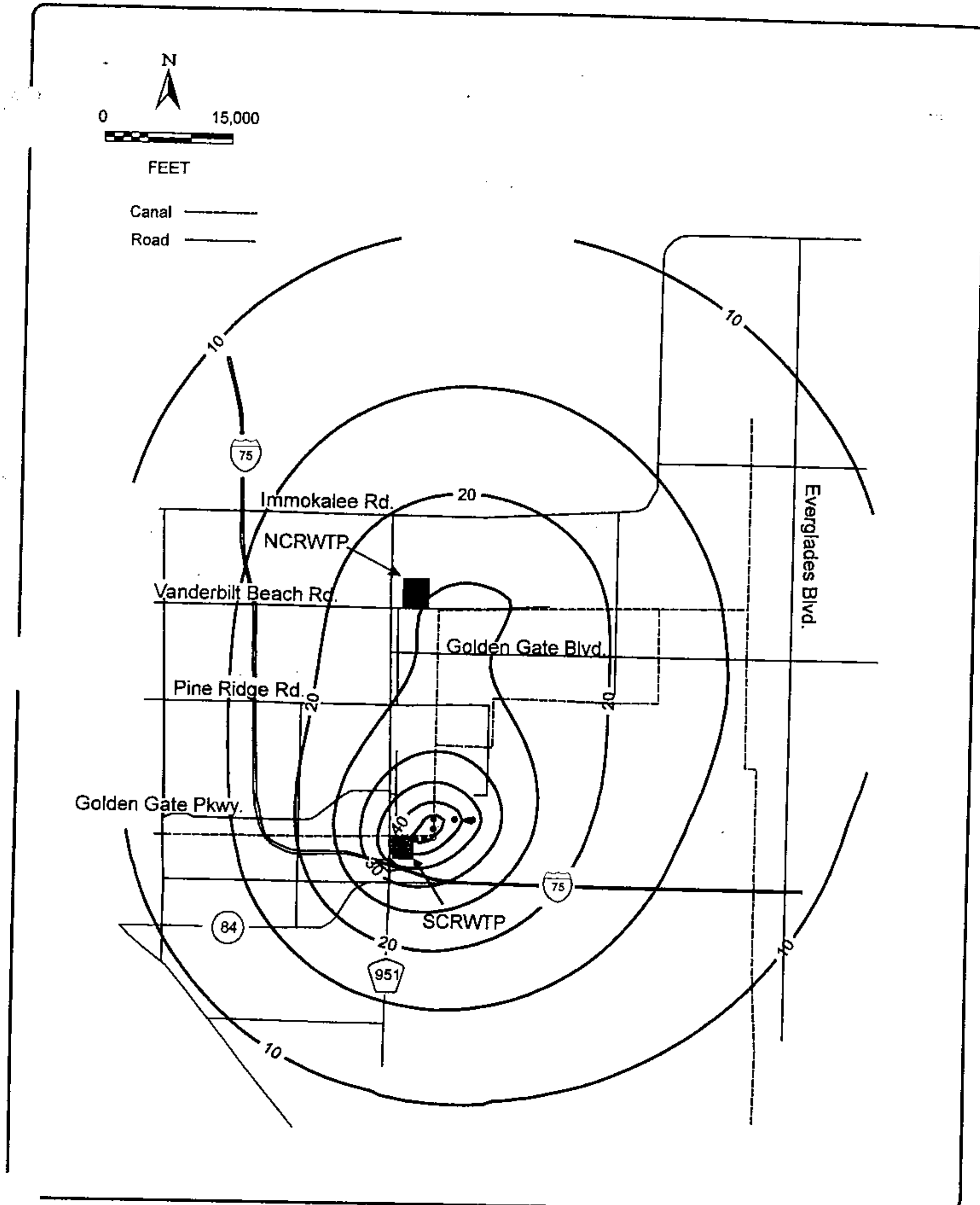
Pr. No. FH8-812	Date: 9/13/00
DWG No.	Rev. No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 5-6. DRAWDOWN IN THE HAWTHORN ZONE 1 AQUIFER DUE TO PUMPAGE FROM THE HAWTHORN ZONE 1 AND LOWER HAWTHORN AQUIFERS AT THE SCRWTP ONLY (8 MGD SCENARIO).



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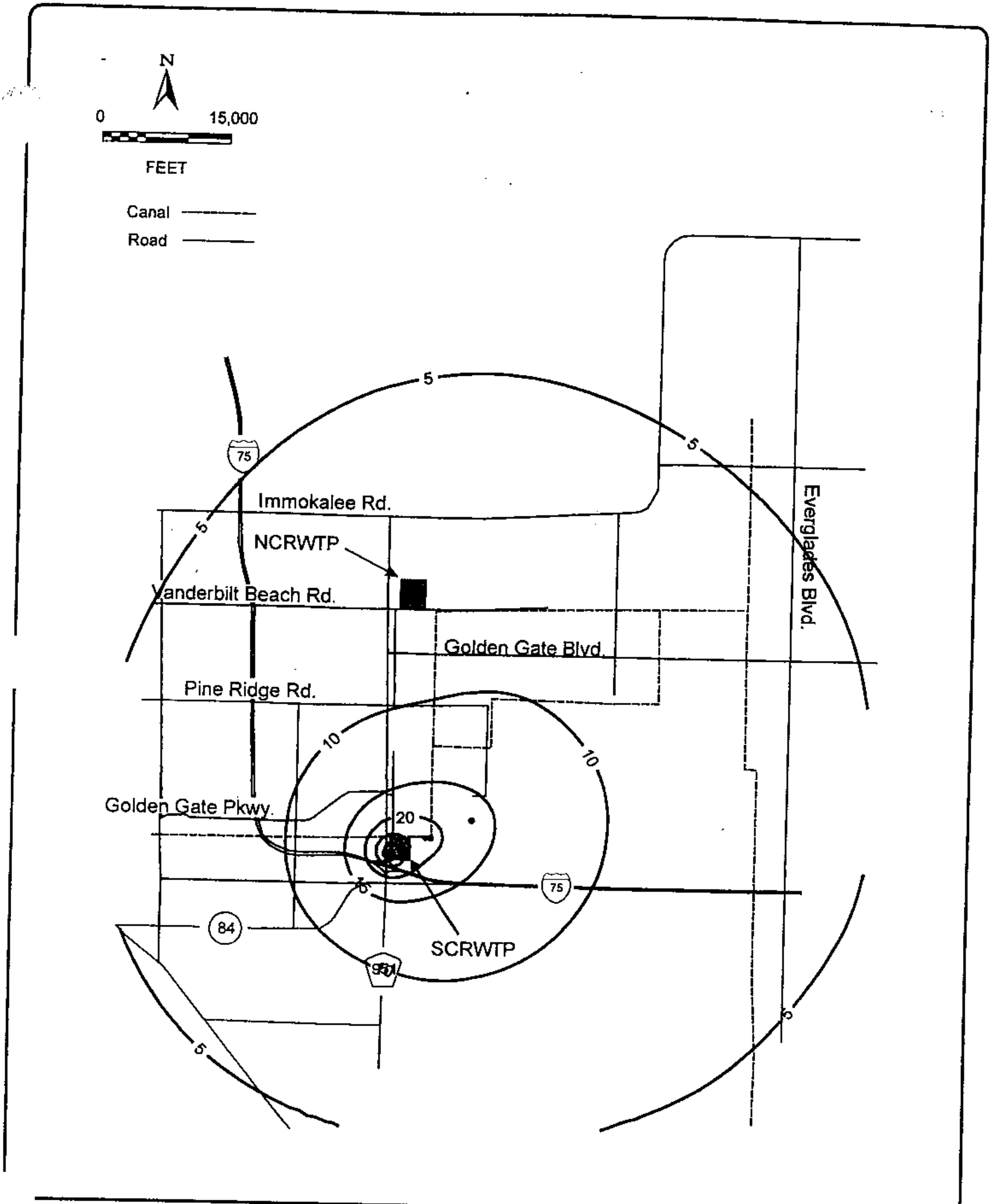
Pr. No. FH8-812	Date: 9/13/00
DWG No.	Rev. No.

GROUNDWATER
AND
ENVIRONMENTAL SERVICES

FIGURE 5-7. DRAWDOWN IN THE HAWTHORN ZONE 1 AQUIFER, 8 MGD PUMPAGE SCENARIO AT THE SCRWTP (HAWTHORN ZONE 1 AND LOWER HAWTHORN AQUIFERS) AND 8 MGD PUMPAGE SCENARIO (LOWER HAWTHORN) AT THE NCRWTP.



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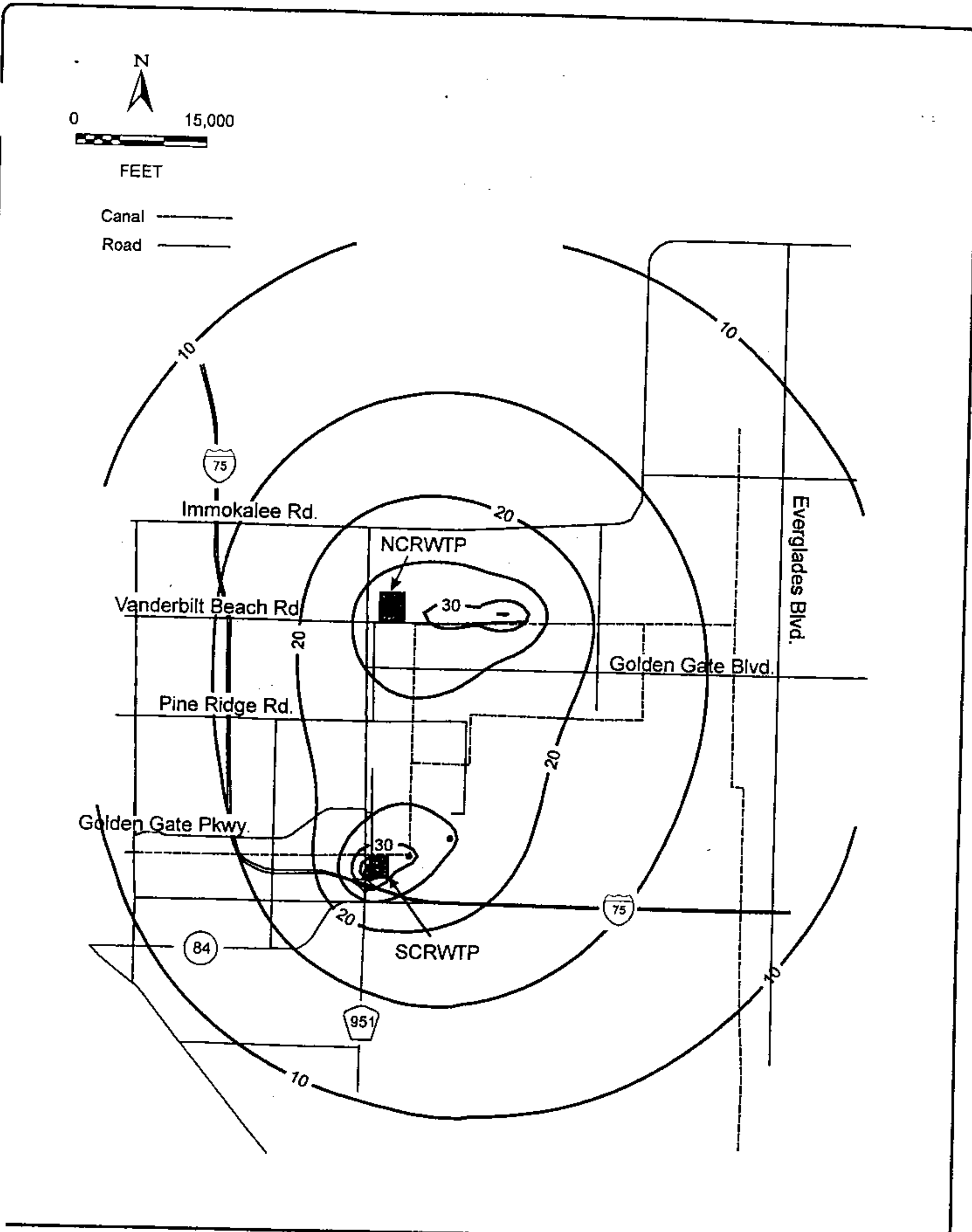
DWG No.	Rev. No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 5-8. DRAWDOWN IN THE LOWER HAWTHORN AQUIFER DUE TO ONLY THE SCRWTP R.O. WELLFIELD PUMPAGE, (8 MGD SCENARIO).



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Pr. Name: SCRWTP RO EXPANSION

Pr. No. FH8-812 Date: 9/13/00

DWG No. Rev. No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

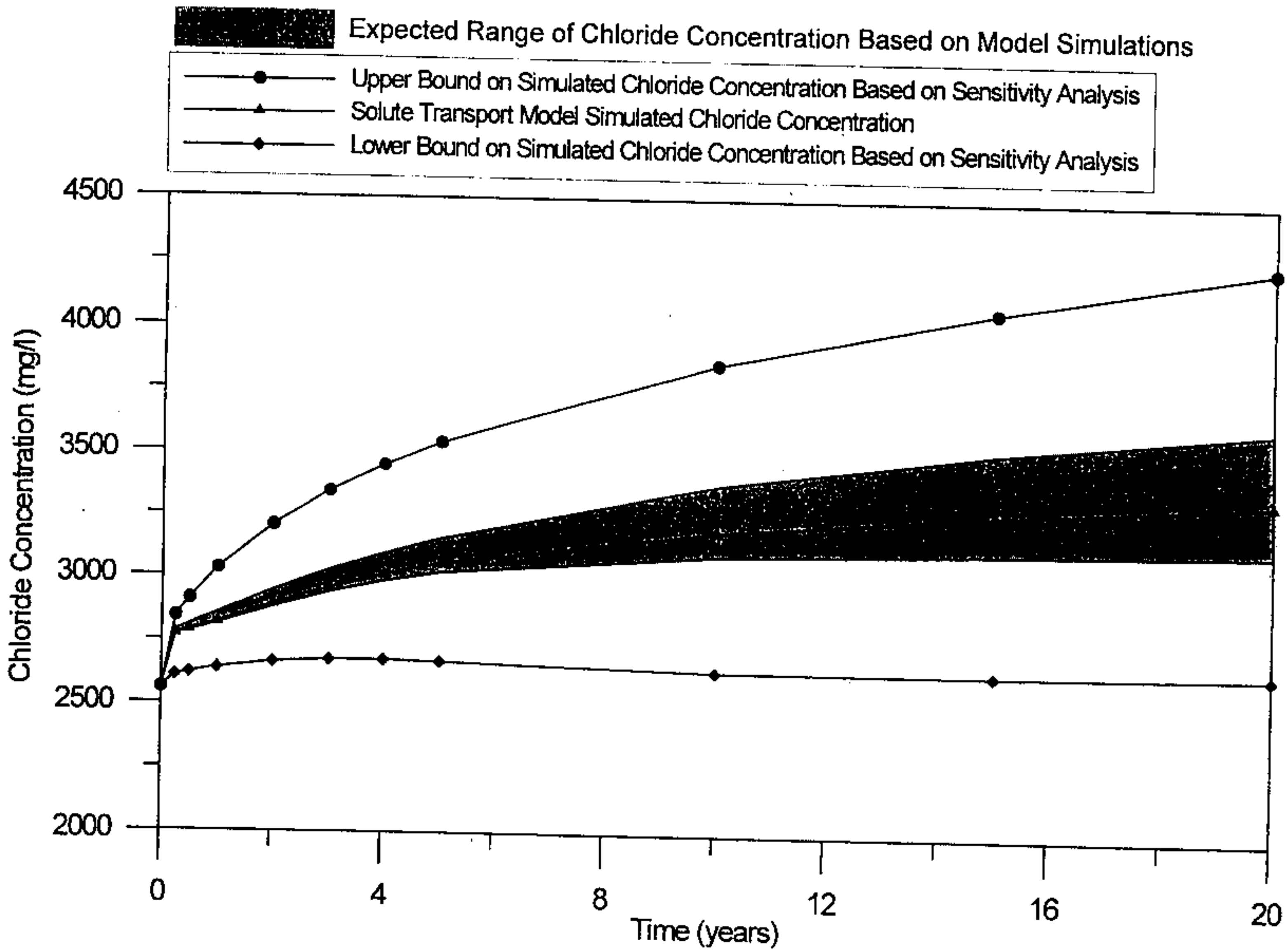
FIGURE 5-9. DRAWDOWN IN THE LOWER HAWTHORN AQUIFER, 8 MGD PUMPAGE SCENARIO AT THE SCRWTP AND 8MGD PUMPAGE SCENARIO AT THE NCRWTP.

includes pumpage from the NCRWTP's R.O. Wellfield, which taps only the Lower Hawthorn Aquifer but adds some regional drawdown in the Hawthorn Zone I Aquifer due to inter-aquifer leakage effects. The pumpage from the northern wellfield is assumed to be 11 MGD, which again is approximately the amount required to produce 8 MGD of finished water. Figures 5-8 and 5-9 display the contours of the simulated drawdown in the Lower Hawthorn Aquifer due to pumpage from the 8-MGD Scenario. Figure 5-8 displays the simulated drawdown that would occur due only to the wells at the southern R.O. wellfield. Figure 5-9 includes pumpage from the NCRWTP Lower Hawthorn aquifer R.O. wellfield at 11 MGD.

The maximum drawdown in the Hawthorn Zone I Aquifer when both wellfields are pumping 11 MGD of raw water is expected to be approximately 50 feet near the center of the southern R.O. wellfield. The simulated maximum drawdown in the Lower Hawthorn Aquifer for the same scenario is approximately 40 feet near the SCRWTP. The drawdowns in Figures 5-6 through 5-9 are cell averaged calculations, therefore, maximum well drawdowns could be significantly higher. Drawdowns of the potentiometric surface in each of the model layers were simulated using a steady state run of the 5-Layer model. These results were compared to a similar run of the quasi-3D model used for calibration and found to be the same.

A plot of the anticipated change in dissolved chloride concentration from the southern R.O. wellfield is given in Figure 5-10 for a 20-year simulation. Both the southern and the northern R.O. wellfields were pumping at 11 MGD, which is the raw water requirement for the 8-MGD scenarios. The solute transport model was run to reflect a period of twenty years and the dissolved chloride concentration at each of the pumping wells was recorded. The raw water is combined to create an average concentration for the water going to the SCRWTP.

The upper and lower bounds of the dissolved chloride concentration of the water obtained from the southern R.O. wellfield based upon the sensitivity analyses are also shown on Figure 5-10. These bounds are the anticipated maximum range of expected dissolved chloride concentrations due to the large changes to the calibrated model. The shaded area



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Groundwater and Environmental Services

FIGURE 5-10. SIMULATED WATER QUALITY WITH TIME FROM THE COMBINED WATER OF 8 HAWTHORN ZONE 1 WELLS AND 3 LOWER HAWTHORN WELLS PUMPING 11 MGD OF RAW WATER (8 MGD SCENARIO) AT THE SOUTHERN R.O. WELLFIELD.

represents the most likely range of dissolved chloride concentration that is expected at the SCRWTP over a twenty-year period based upon the 11-MGD raw water pumpage scenario at both the northern and southern R.O. wellfields.

The computer modeling results show that some deterioration of water quality in the Hawthorn Zone I and Lower Hawthorn aquifers will occur with time due to pumpage, when water with a higher dissolved chloride concentration moves into the production wells. The change in water quality should be a gradual process. Within the 20-year simulation period, the dissolved chloride concentration of the raw water should remain below 4500 mg/l based upon the proposed wellfield design and pumpage rates. Sensitivity analyses indicate that the simulated changes in dissolved chloride concentration with time are not very sensitive to the transmissivity of the production aquifer. However, the model results are sensitive to changes in the leakance below the Lower Hawthorn Aquifer and to vertical dispersivity, parameters for which some degree of uncertainty exist.

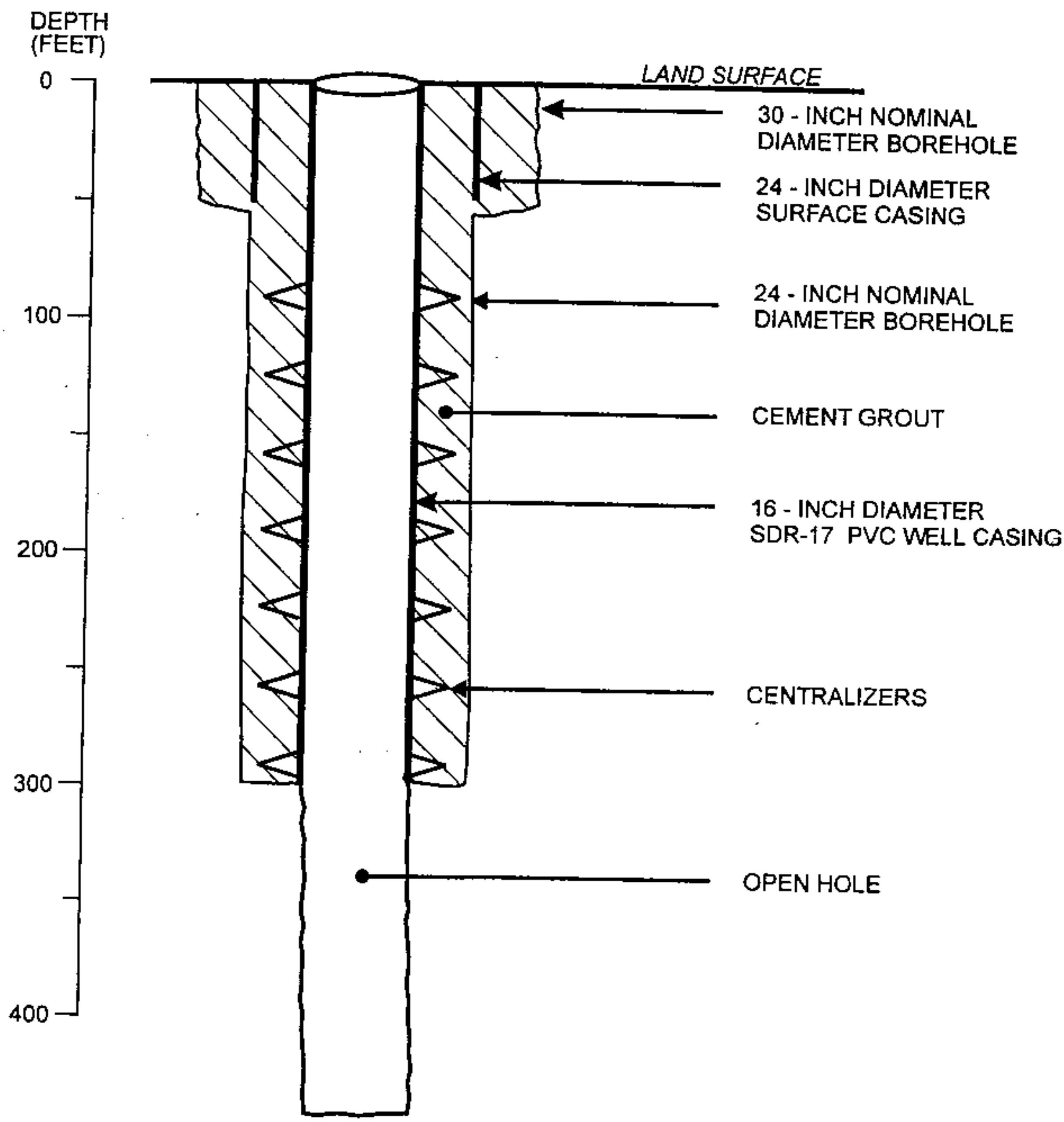
5.7 Wellfield Configuration

An 11 MGD wellfield is required to produce feedwater for the proposed 8 MGD (finished water) reverse osmosis treatment facility at the SCRWTP assuming a recovery efficiency of approximately 75%. Eleven wells each pumping at an average rate of approximately 700 gpm are required to produce the desired raw water withdrawal amount. Fourteen wells are proposed so that three redundant or backup wells will be available in the event pump failure or other problems prevent pumpage from one of the primary production wells. The wells will tap both the Hawthorn Zone I (10 wells) and Lower Hawthorn (4 wells) aquifers. The initial wellfield design includes five wells at the SCRWTP and nine wells in an approximate east-west alignment extending into Section 25 with well spacings ranging from less than 1000 feet at the plant up to 2000 feet in Section 25. Well spacings of less than 1000 feet will have to be utilized at the SCRWTP site due to space limitations. The proposed production well locations are shown on Figure 5-5.

5.8 Production Well Design

Design recommendations for the proposed production wells are based on desired and anticipated pumping rates, state well construction requirements, general guidelines for reverse osmosis supply wells, and site specific information obtained during test well construction. The proposed reverse osmosis wells tapping the Hawthorn Zone I Aquifer should be constructed with 16-inch diameter PVC casings extending to a depth of approximately 300 feet below land surface and should have total depths of approximately 420 feet. The reverse air drilling technique should be used for the open hole sections of the wells. A hydrogeologist should supervise construction of the wells and recommend specific cased and total depths for each well based on lithologic analysis of formation samples obtained during drilling. A schematic diagram showing proposed construction details for the wells is provided as Figure 5-11. The Lower Hawthorn Aquifer production wells should be constructed in a similar fashion with minor changes. The casings should be 12-inch diameter with the upper 120 feet of casing increased to 16-inch diameter to allow for adequate pump sizing. A schematic diagram showing the proposed construction details for the Lower Hawthorn Aquifer wells is provided as Figure 5-12. Step-drawdown pump tests should be conducted on all of the production wells after they are completed to assess well yield. Silt Density Index (SDI) tests should be conducted while the wells are being pump tested to evaluate sediment production from the wells. The wells should be disinfected following the completion of testing and equipped with submersible pumps for withdrawal purposes. Pump setting depths, production rates, and motor horsepowers for each well should be determined based on results of the step-drawdown testing. Pump setting depths are anticipated to range from 60 to 100 feet below land surface with an average production rate of 700 gpm per well. Withdrawal rates for the wells may range from 350 to 1000 gpm when the R.O. plant is in operation.

COLLIER COUNTY SOUTHERN REVERSE OSMOSIS WELLFIELD
HAWTHORN ZONE 1 AQUIFER PRODUCTION WELLS



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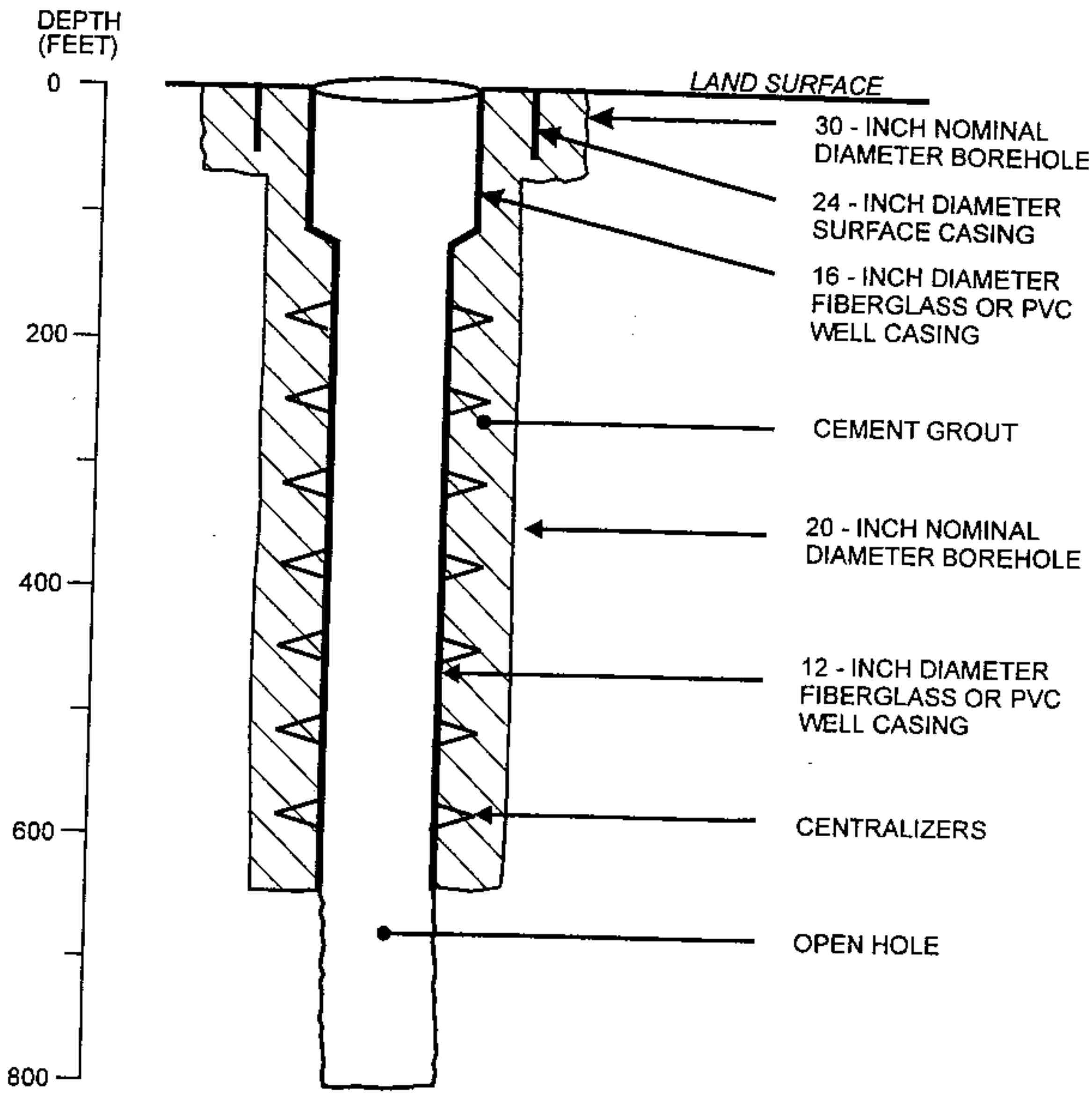
Pr. Name: SCRWTP RO EXPANSION			GROUNDWATER AND ENVIRONMENTAL SERVICES
Pr. No. FH8-812	Date: 10/09/2000		
DWG No.	Rev. No.		

FIGURE 5-11. PROPOSED CONSTRUCTION DETAILS FOR THE COLLIER COUNTY SOUTHERN REVERSE OSMOSIS WELLFIELD HAWTHORN ZONE 1 AQUIFER PRODUCTION WELLS.

COLLIER COUNTY SOUTHERN REVERSE OSMOSIS WELLFIELD
LOWER HAWTHORN AQUIFER PRODUCTION WELLS



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	Pr. No. FH8-812	Date: 10/09/2000	
	DWG No.	Rev. No.	

FIGURE 5-12. PROPOSED CONSTRUCTION DETAILS FOR THE COLLIER COUNTY SOUTHERN REVERSE OSMOSIS WELLFIELD LOWER HAWTHORN AQUIFER PRODUCTION WELLS.

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