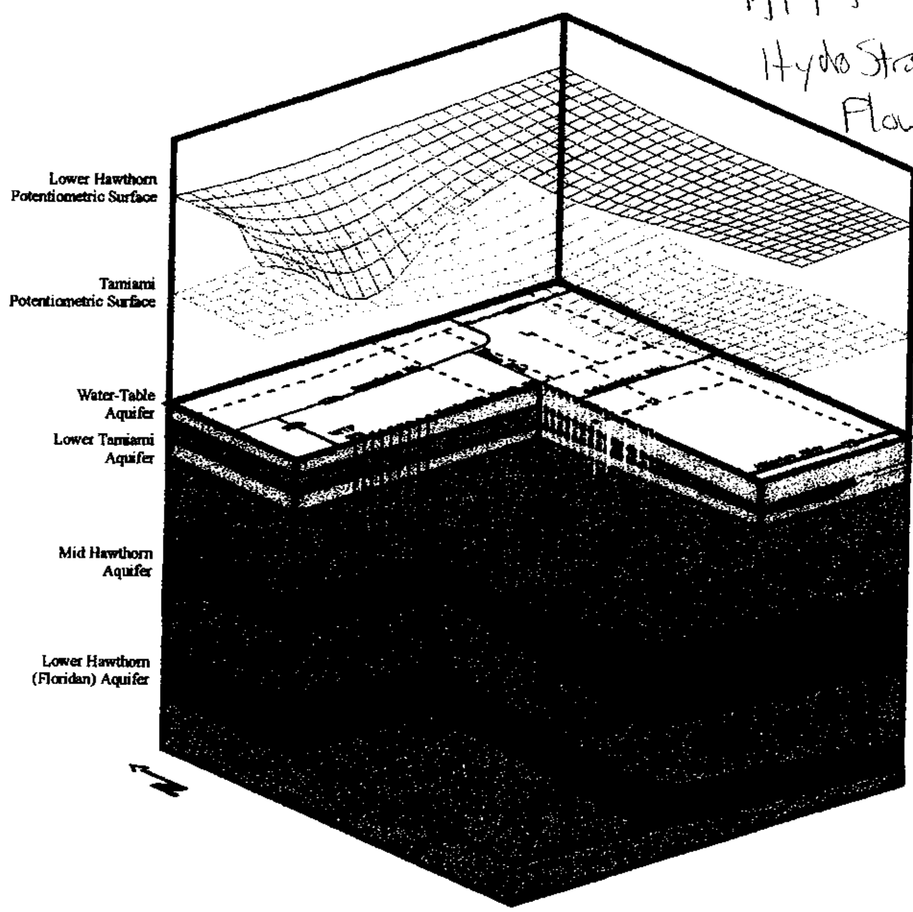
MARTIN 335

COLLIER COUNTY UTILITIES BRACKISH WATER WELLFIELD STUDY

Volume 1: Report

MC-5000

API'S
HydroStrat
FlowChar.



Prepared for:

Board of County Commissioners
Collier County Government

October, 1995

MISSIMER INTERNATIONAL

COLLIER COUNTY UTILITIES
BRACKISH WATER WELLFIELD STUDY
COLLIER COUNTY, FLORIDA

Prepared for:

Board of County Commissioners
Collier County Government
3301 E. Tamiami Trail
Naples, Florida 33962

October, 1995

by:

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

Project No.
FH4-26

Thomas M. Missimer, P.G. #144
Licensed Professional Geologist
President

W. Kirk Martin, P.G. #079
Licensed Professional Geologist
Vice President, Hydrology Division

MISSIMER INTERNATIONAL INC.

October 25, 1995

Mr. Pete Schalt
Office of Capital Projects Management
Collier County Government Center, Bldg. D
3301 East Tamiami Trail
Naples, FL 33962-4902

Transmittal: Report on Hydrogeologic Investigation of Brackish Water Sources

Dear Pete:

We are pleased to submit 5 copies of our final report entitled "Collier County Utilities Brackish Water Wellfield Study." The report documents the results of the investigation which shows that a substantial supply of brackish water is available beneath Collier County to meet public supply needs for many years. Optimum brackish water wellfield design is given for 12 MGD, 20 MGD, and 30 MGD scenarios. Raw data as well as analyses are also provided within the two volumes.

We appreciate the working relationship maintained through the project scope and look forward to working with the county toward implementation of the recommendations.

Yours sincerely,

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

WKM:lk

FH4-26.1

8140 College Parkway, Suite 202
Fort Myers, Florida 33919

(941) 432-9494
FAX (941) 432-9453

TABLE OF CONTENTS

TABLE OF CONTENTS - Continued:

TABLE OF CONTENTS - Continued:

LIST OF FIGURES

Continued:

LIST OF FIGURES

Continued:

LIST OF FIGURES

LIST OF FIGURES - Continued:

LIST OF FIGURES - Continued:

LIST OF FIGURES - Continued:

LIST OF FIGURES - Continued:

LIST OF FIGURES - Continued:

LIST OF TABLES

EXECUTIVE SUMMARY

Western Collier County contains a substantial quantity of freshwater stored within the shallow aquifer system. However, a combination of factors, including localized overuse of the resources, changes in the regulation of water use, and the occurrence of water with an unsuitable chemistry, preclude the further economic development of these resources. In order to comply with provisions of the Lower West Coast Regional Water Supply Plan (South Florida Water Management District) and to locate the most economic supply of water for the future, the county initiated study of the brackish groundwater resources in areas near the population centers.

Brackish water occurs in aquifers ranging from 200 to 1200 feet below land surface. These aquifers contain water with dissolved chloride concentrations ranging from 250 to 2300 mg/l in the study area. By comparison, seawater has an average dissolved chloride concentration of 19,000 mg/l. Water from these aquifers can be treated economically using low pressure reverse osmosis technology. The combination of brackish source water with the reverse osmosis treatment process allows production of a very high quality potable water, which meets all current and anticipated future primary and secondary drinking water standards.

The purposes of this investigation were to locate one or more sources of treatable brackish water, to assess the quantity of water available for use, to assess the pumping-induced, long-term changes in water quality with time, to obtain sufficient hydrogeologic information to assure the long-term viability of the source and to obtain a water use permit from the South Florida Water Management District. The investigation involved the drilling of numerous test wells, the collection of aquifer yield data, the collection of water quality with depth in each penetrated aquifer, and the evaluation of impacts on the quantity and quality of water for various development scenarios using sophisticated computer models.

Based on the completed hydrogeologic investigation, a source of high quality, brackish water was located in the Lower Hawthorn Aquifer at depths ranging between 600 and 800 feet below surface. In the vicinity of the North Collier County Water Treatment Facility, the Lower Hawthorn Aquifer has the demonstrated capability to yield the 12 MGD required for this expansion of the facility. The aquifer can also yield additional water supply up to a volume of 30 MGD without significant adverse affects on the groundwater system.

During the hydrogeologic investigation, it was also discovered that freshwater occurs within the uppermost part of the Hawthorn Aquifer System in the northeast portion of the study area. This previously undiscovered source of water supply may be used in the future. Based on all hydrogeologic investigations conducted on the Intermediate and upper Floridan Aquifer Systems in Collier County to date, it is concluded that there is a sufficient supply of raw water to meet the long-term needs of Collier County for the next 50 years without the need to develop higher salinity water sources with associated higher treatment costs.

1.0 CONCLUSIONS AND RECOMMENDATIONS

1.1 Conclusions

- As part of a regional hydrogeologic study of raw water supplies to meet potable demand within the County Utility System, groundwater sources were evaluated to a depth of 1200 feet beneath North Collier County. Review of pre-existing data indicated two potential brackish water sources; the Hawthorn Zone I Aquifer and the Lower Hawthorn Aquifer.

- Test wells were constructed and hydrologic tests conducted to evaluate the potential yield of the two aquifers. Based on the geology, water quality, and production capacity, the Lower Hawthorn Aquifer was chosen as the primary source of feedwater for the proposed North County Regional Water Treatment Plant (NCRWTP) reverse osmosis expansion.

- Testing and analysis of the Lower Hawthorn Aquifer indicate that the unit consists primarily of dolomite and dolomitic limestone with a high degree of secondary (solution) porosity. The aquifer occurs at a depth of approximately 600 to 700 feet below land surface in the area and ranges in thickness between 100 and 180 feet. Dissolved chloride concentrations of water within the aquifer range from approximately 400 mg/l in the northeast part of the study area to approximately 2300 mg/l in the southwest part of the study area. Average chloride concentration near the NCRWTP is approximately 2200 mg/l. Aquifer transmissivity averages approximately 500,000 gpd/ft but ranges as high as approximately 2,500,000 gpd/ft. Storativity ranges from 1.0×10^{-5} to 4.0×10^{-5}. The leakance is estimated to be approximately 1.0×10^{-4} gpd/ft^3.

- Hydraulic and solute transport computer models of the Lower Hawthorn Aquifer System were developed to simulate aquifer response in terms of drawdown and water quality changes that may result due to the proposed withdrawal of up to 12 MGD from the aquifer. An initial wellfield design was evaluated using these computer models to estimate the maximum amount of drawdown that would occur in the aquifer caused by the proposed withdrawals and the associated salinity changes over a 40-year period. A relatively small drawdown of less than 10 feet in the aquifer at the center of the wellfield is anticipated based on the model results. The solute transport model indicated that over a 40-year period of pumping the wellfield, the dissolved chloride concentration within the Lower Hawthorn Aquifer could increase from approximately 1700 to 2200 mg/l, allowing the proposed membrane treatment facility to operate economically during the entire period. Additional model simulation using wellfield withdrawals of 20 MGD and 30 MGD resulted in maximum dissolved chloride concentration change of less than 1000 mg/l or from 1700 to 2500 mg/l over the 40-year simulation period. Results of all solute model runs indicate that changes in aquifer water quality are not significant and well within design parameters for low pressure reverse osmosis treatment.

1.2 Recommendations

- The initial wellfield configuration should consist of 10 wells in an east-west alignment spaced approximately 1000 feet apart. The wells and associated transmission piping would lie along the north side of Vanderbilt Beach Road in Golden Gate Estates near the NCRWTP. The wellfield should include 8 primary and 2 secondary (back-up) wells capable of producing a combined 12± MGD of raw water to supply the finished R.O. product water supply of 8± MGD with reserve or emergency capacity.

- The production wells should be constructed with fiberglass (FRP) casings extending to a depth of approximately 700 feet below land surface and should have total depths of approximately 800 feet. The casings should be 12-inch diameter with the upper 100 feet increased to 16-inch diameter to allow for adequate pump sizing.

- A hydrogeologist should supervise construction of the new wells and recommend specific cased and total depths based on lithologic analysis of formation samples obtained during drilling. A well completion report that describes the drilling and testing procedures utilized during well construction should be prepared by the hydrogeologist.

- Step-drawdown pump tests should be conducted on the newly constructed production wells. Pump setting depths and withdrawal rates should be determined based on results of the step-drawdown tests. Submersible pumps should be installed in the wells for production purposes.

- 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 should be used to evaluate any proposed wellfield expansion scenarios. Continuation of the wellfield to the east on the initial alignment is considered the most likely scenario for wellfield expansion based on the available data.

- An application should be submitted to the SFWMD for modification/renewal of the county utilities water use permit. The permit modification will include the addition of the proposed Lower Hawthorn Aquifer wellfield and concomitant increase in average and maximum daily allocations. Data collected during this investigation should be used in support of the permit application.

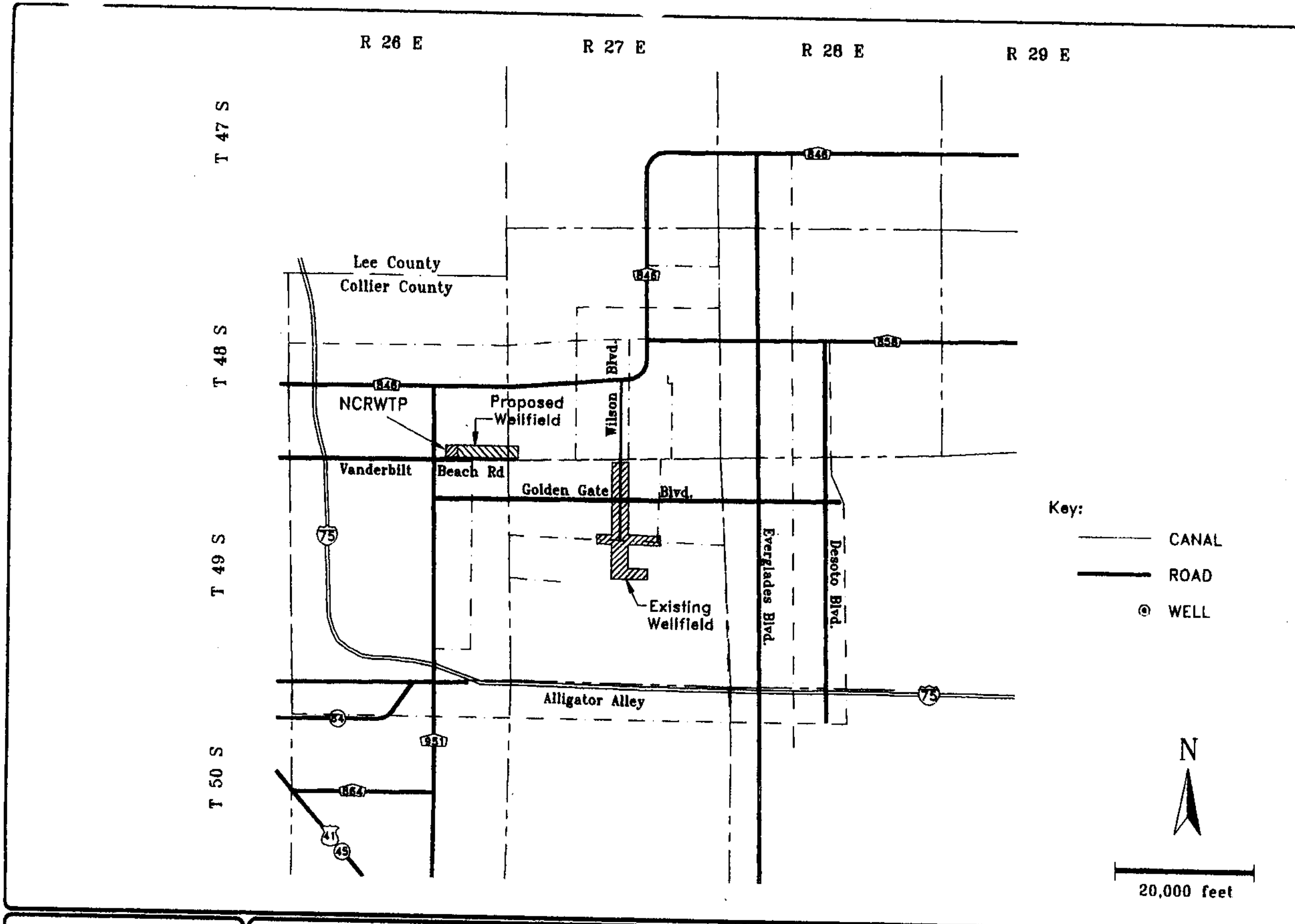
- An evaluation of data collected for the Hawthorn Zone 1 indicate that this zone may be favorable for an ASR (aquifer storage and recovery) project. Factors to consider when selecting an injection zone for aquifer storage include: the degree of confinement above and below the injection zone, the hydraulic gradient, and the ability of the zone to receive and return injected water in the same quantity and quality at which it was injected. The overlying clays identified by lithologic and geophysical data for test wells drilled in the area indicate the Hawthorn Zone 1 is well confined. Additionally, water quality and transmissivity values appear to lie within a range of values acceptable to ASR. While it is beyond the scope of this study to investigate the storage potential of the Hawthorn Zone 1 aquifer, additional testing would be necessary in the event that the county would require a storage zone in the Golden Gate area.

2.0 INTRODUCTION

A hydrogeologic investigation was conducted in the Golden Gate Estates area of Collier County in order to locate and evaluate the saline groundwater sources within the area of the North County Regional Water Treatment Plant (NCRWTP) for treatment by reverse osmosis. The area of study is shown in Figure 2-1. The NCRWTP was put into production in December of 1993 to initially treat feedwater from the Lower Tamiami Aquifer by the membrane softening process. The Lower Tamiami wellfield has a current maximum capacity of approximately 30 MGD. A previous study of the Lower Tamiami Aquifer indicated that it had very high production potential but that regulatory constraints would limit total yield to about 50 MGD (Missimer & Associates, Inc., 1990). With the City of Naples wellfield capacity at approximately 20 MGD and the county wellfield at 30 MGD, little to no permittable production capacity remains from the Lower Tamiami Aquifer in the area.

Investigations for alternative freshwater sources resulted in supplies that showed good yield characteristics but that were high in color, sulfur, organics, and bacteria; conditions that would create difficulties with the treatment of the raw water source. Withdrawals from these freshwater supplies could also adversely affect wetlands, which is undesirable and not permitted under state guidelines. Increasing restrictions placed on freshwater withdrawals by the South Florida Water Management District and more stringent standards on drinking water quality by the Florida Department of Environmental Regulation necessitated an evaluation of raw water source and a treatment technology that:

1) would exceed or meet current and probable future water quality regulations,
2) would provide large production potential without substantial restrictions on future use, and
3) would provide maximum flexibility to meet changing demand and regulation scenarios.



MISSIMER INTERNATIONAL

Pr Name: Collier Co. Wellfield

Pr.No. FH4-26 DWG No.FH4-26GL.DWG Date: 06/30/95 Rev.No. 6

Groundwater and Environmental Services

FIGURE 2-1. LOCATION MAP OF STUDY AREA.

Based on these requirements, Collier County stipulated that the design and construction of the NCRWTP be expandable up to 20 MGD of new treatment capacity but more importantly be capable of treating a wide variety of raw water sources to a quality in excess of current standards. With future freshwater sources severely limited by regulation, an initial study of brackish water sources was conducted (Missimer & Associates, Inc., 1993) to identify deep aquifers suitable for either raw water supply for treatment by reverse osmosis or for storage and recovery of excess water available during the wet season months. The investigation indicated that potential sources of water were available within the Intermediate and upper Floridan Aquifer Systems.

The current investigation focused on identifying available brackish water sources down to a depth of 1200 feet. Two potential sources of raw water were identified; the Hawthorn Zone 1 and Lower Hawthorn aquifers. The following report presents the results from the study which included the collection and analysis of detailed data on aquifer characteristics, hydraulics, and water chemistry; and provided computer modeling of flow and water quality changes for present and future wellfield design.

3.0 SCOPE OF WORK

In order to successfully evaluate the potential brackish groundwater sources available to supply the expanded NCRWTP reverse osmosis system, the following scope of work was conducted: 1) collection and analysis of existing geologic, hydraulic, and water quality data for use in determining available brackish groundwater resources; 2) construction of test wells and monitor wells in the vicinity of the NCRWTP and adjacent areas of northwest Collier County to determine hydrostratigraphy of the Intermediate and upper Floridan Aquifer systems; 3) collection and analysis of lithologic, geophysical, water quality and specific capacity data during well construction and testing; 4) aquifer performance testing to determine transmissivity, storage coefficient and leakance values for both the Hawthorn Zone 1 and Lower Hawthorn aquifers; and 5) development of analytical computer impact models to determine an appropriate wellfield configuration for a 12 MGD withdrawal, a 20 MGD withdrawal, and a future 30 MGD withdrawal.

Additional information provided as part of the scope included: 1) collection and evaluation of water quality data for the reverse osmosis treatment plant design; 2) coordination with the South Florida Water Management District personnel to obtain information regarding modification/renewal of the county water use permit; and 3) provision of recommendations and specifications to ensure successful construction of the proposed Lower Hawthorn Aquifer wellfield.

4.0 METHODS OF INVESTIGATION

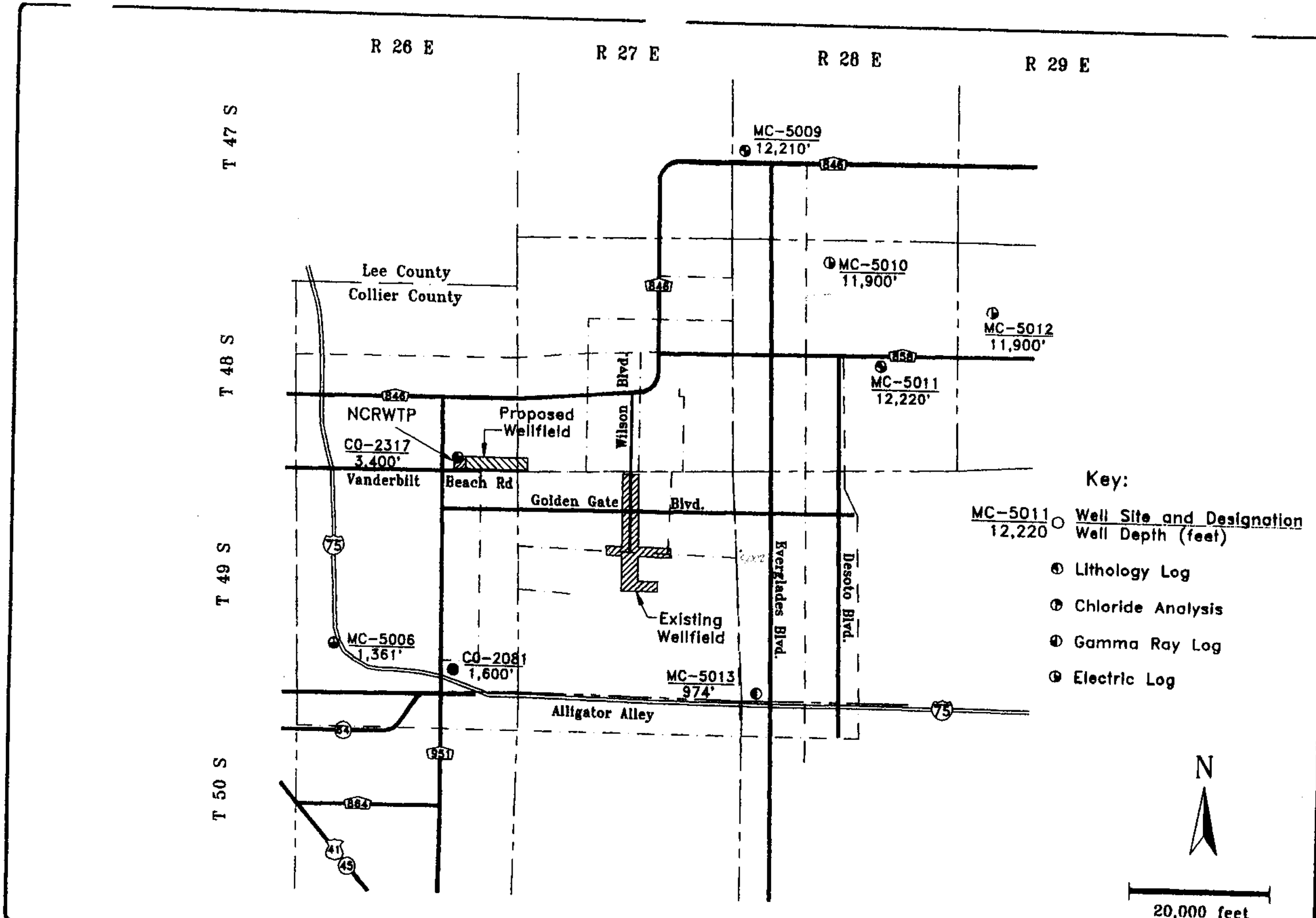
4.1 Existing Data Compilation

Geologic and hydrologic data available for northern Collier County were compiled and evaluated to obtain a preliminary assessment of the potential brackish water sources in the Golden Gate Estates area. The data sources included: the Missimer International, Inc. in-house hydrogeological data base, the United States Geological Survey (USGS) and Florida Geological Survey publications and the Bureau of Oil and Gas files, South Florida Water Management District (SFWMD) files, and university files and theses.

The locations of the wells used in the preliminary evaluation of the regional hydrogeology are shown in Figure 4-1. The information obtained from these wells was used to create structure and isopach (thickness) maps of potential production aquifers. This initial data review revealed that two aquifer zones within the Hawthorn Group merited further investigation as a potential brackish water supply source.

4.2 Test Drilling

Three initial test wells, MC-5000, MC-5001, and MC-5002, were installed in November and early December 1994, by Well Water Systems, Inc., under Missimer International, Inc. supervision. The wells were drilled so that testing of both the upper and lower aquifers of the Hawthorn Group could be accomplished along with collection of additional data on salinity with depth to 1200 feet below surface. Well cutting samples were collected on-site and described by microscope to assess lithology, color, hardness, and apparent porosity and permeability. Locations of these test wells are given in Figure 4-2. Well construction diagrams of the three initial test wells are provided in Figures 4-3 through 4-5.



MISSIMER INTERNATIONAL

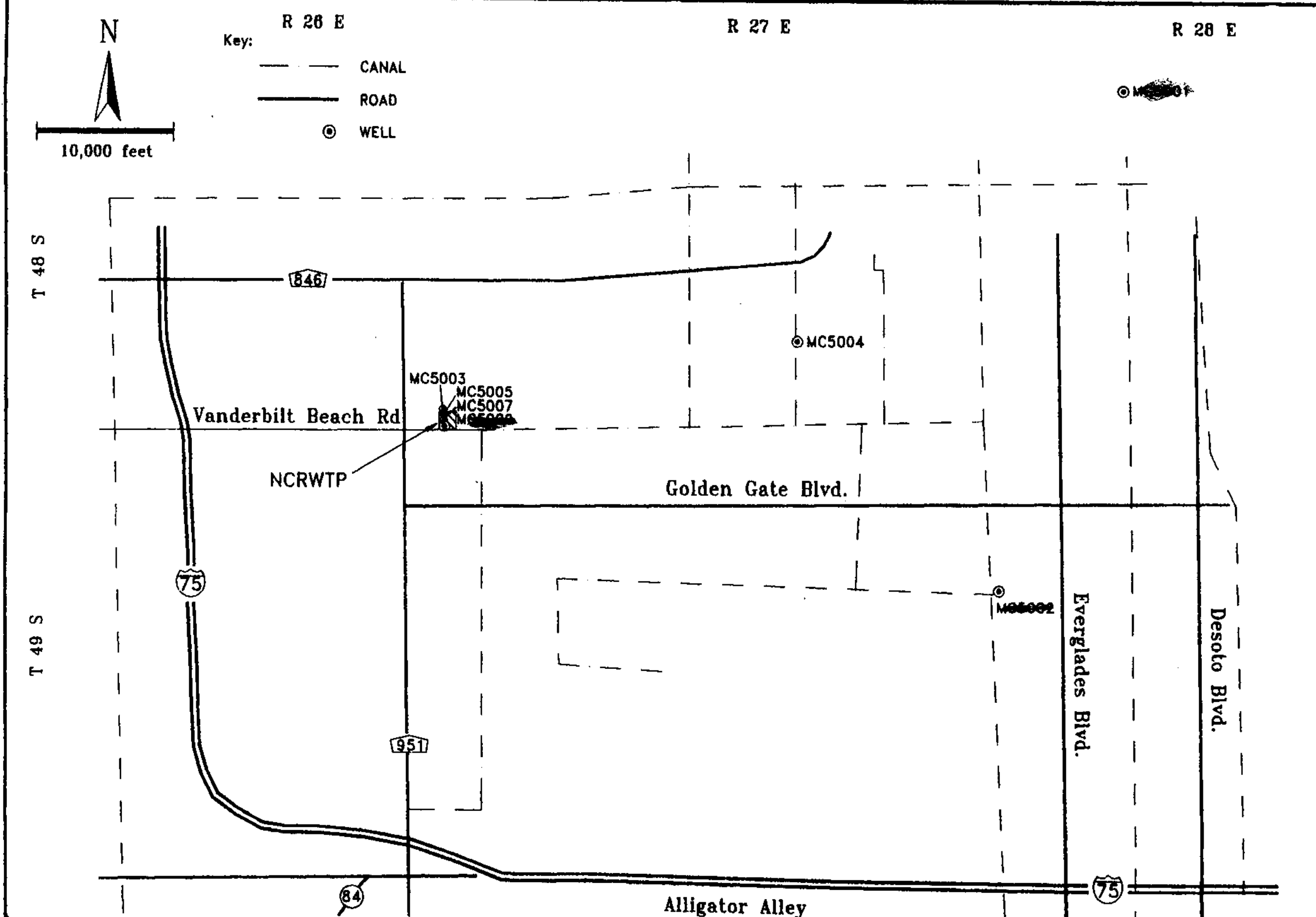
Pr Name: Collier Co. Wellfield

Pr.No. FH4-26 DWG No.FH4-26GL.DWG Date: 06/30/95 Re

Groundwater

Services

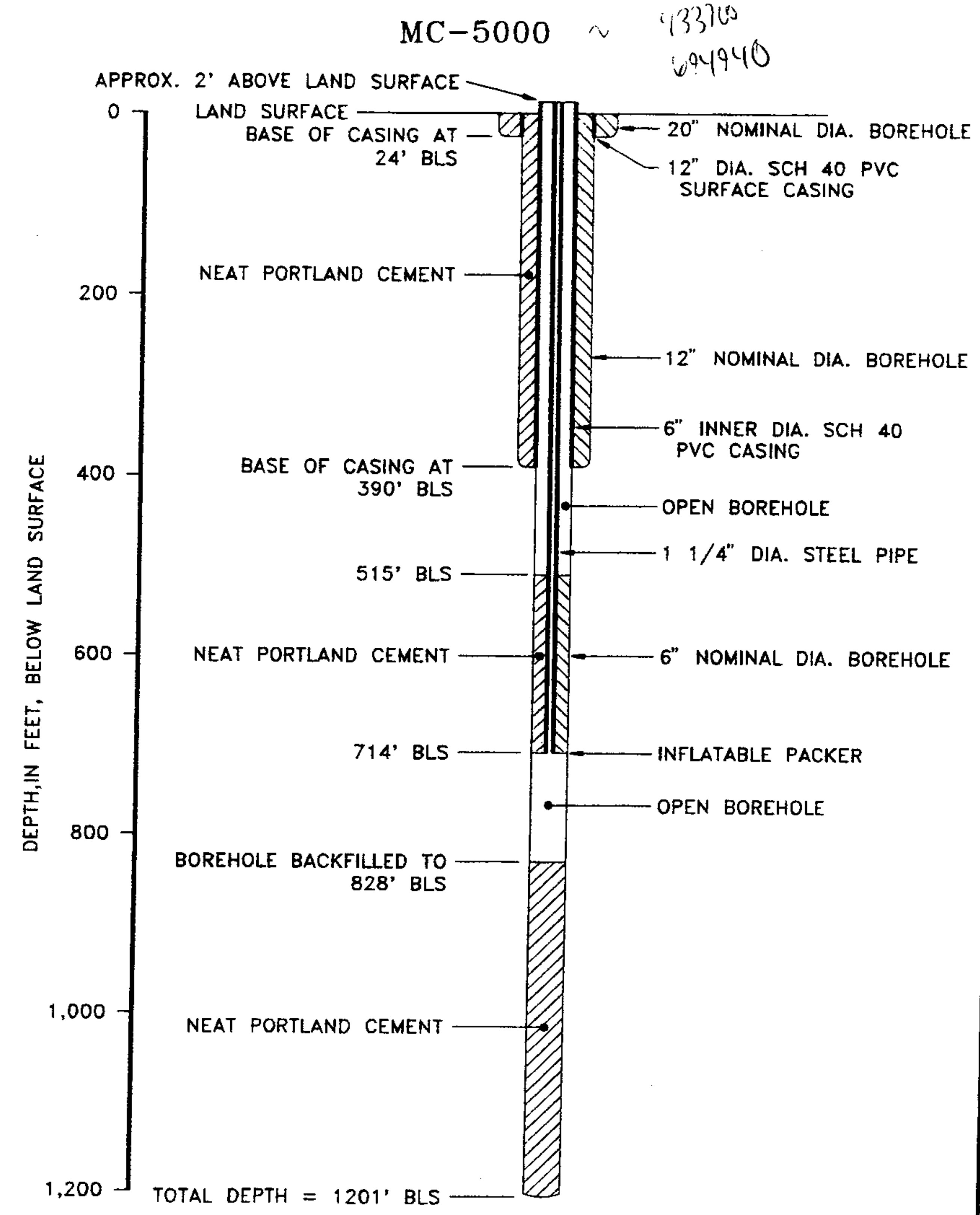
FIGURE 4-1. WELLS USED IN PRELIMINARY ANALYSIS.



MISSIMER INTERNATIONAL	Pr Name: Collier Co. Wellfield
	Pr.No. FH4-26 DWG No.FH4-26SL.DWG Date: 06/20/95 Rev.No. 1

Groundwater

FIGURE 4-2. TEST WELL LOCATIONS.

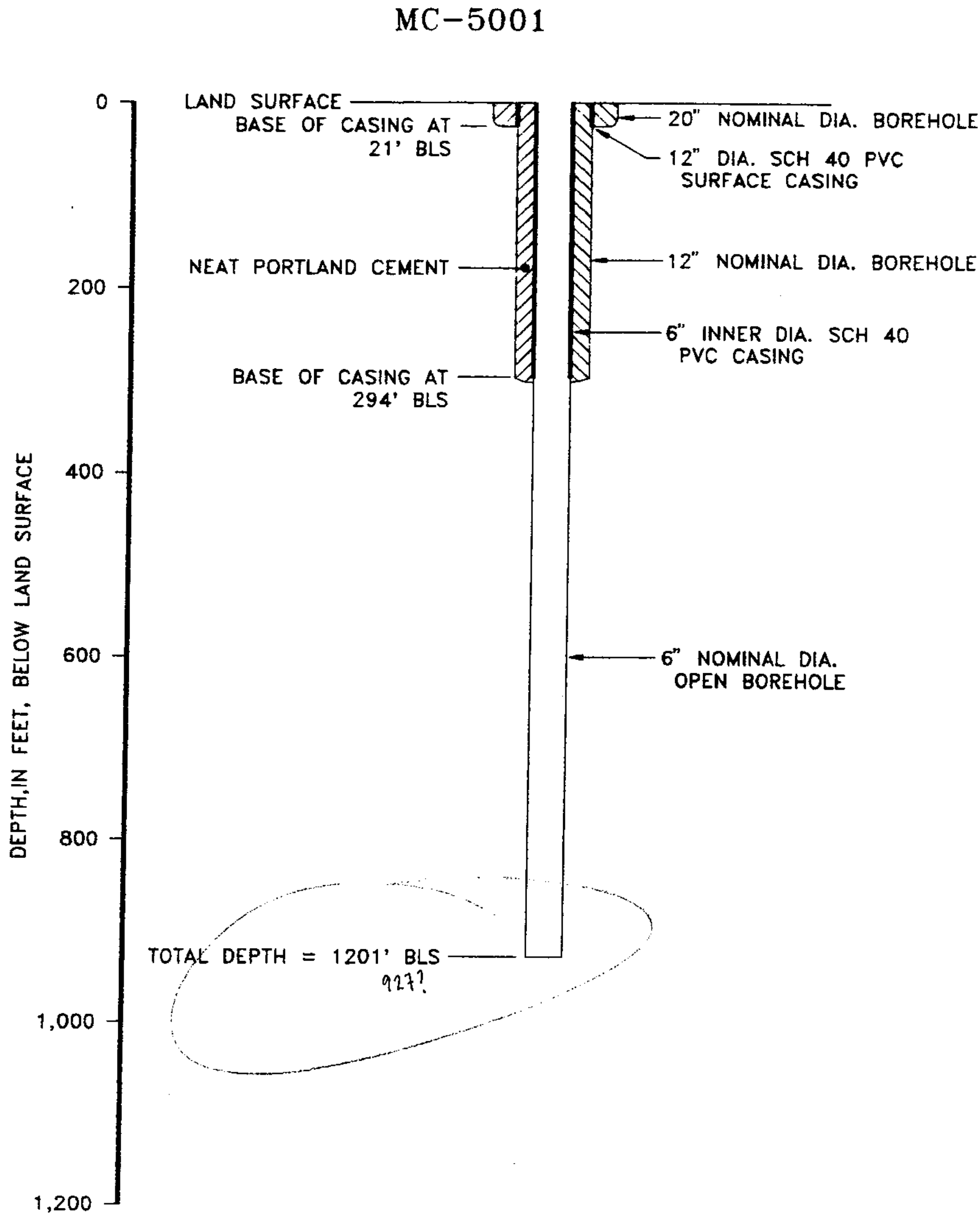


MISSIMER INTERNATIONAL

Pr Name: COLLIER COUNTY WELLFIELD	
Pr No. FH4-26	Date: 9/25/95
DWG No. FH4-26W4.DWG	Rev.No. 2

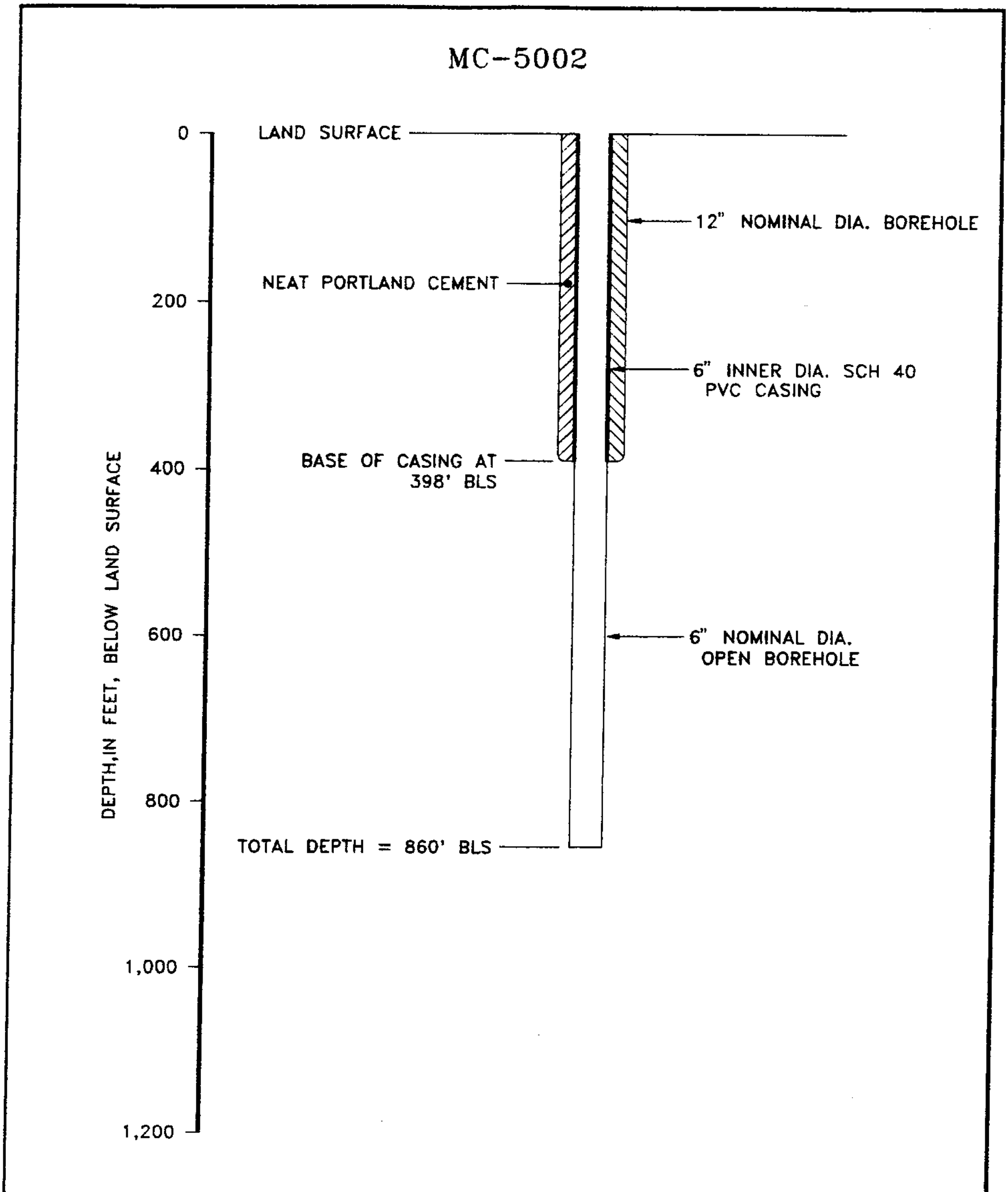
Groundwater and Environmental Services

FIGURE 4-3. CONSTRUCTION DETAIL OF WELL MC-5000.



MISSIMER INTERNATIONAL	Pr Name: COLLIER COUNTY WELLFIELD		Groundwater and Environmental Services
	Pr No. FH4-26	Date: 9/21/95	
	DWG No. FH4-26W5.DWG	Rev.No. 1	

FIGURE 4-4. CONSTRUCTION DETAIL OF WELL MC-5001.



MISSIMER INTERNATIONAL	Pr Name: COLLIER COUNTY WELLFIELD	Groundwater and Environmental Services
	Pr No. FH4-26 Date: 9/21/95	
	DWG No. FH4-26W6.DWG Rev.No. 1	

FIGURE 4-5. CONSTRUCTION DETAIL OF WELL MC-5002.

Construction of each test well followed similar methodologies with minor alterations to accommodate site specific conditions. At well sites MC-5000 and MC-5001, a 12-inch diameter Schedule 40 PVC surface casing was installed to depths of approximately 24 feet below land surface (bls) and 21 feet bls, respectively. A 20-inch nominal diameter borehole was drilled using the hydraulic rotary mud method. The surface casing was installed and the annular space was filled with neat Portland cement grout. Installation of a surface casing was unnecessary at test well MC-5002 because of site specific geologic conditions.

The test wells were then drilled using the mud-rotary method with a 11 7/8-inch diameter bit to the top of the first limestone unit within the Hawthorn Group, which occurred at 379 feet bls at MC-5000, 289 feet bls at MC-5001, and 394 feet bls at MC-5002. The boreholes were drilled 8 to 10 feet into the limestone of the Hawthorn Zone I aquifer to ensure the integrity of the casing setting. A 6-inch diameter, schedule 40 PVC casing was then installed and grouted in place using neat Portland cement. The initial grout stage was emplaced by pressure grouting through the well casing, while the remaining annular space was grouted in stages using a tremie pipe.

All of the wells were deepened using a 6-inch diameter tricone bit utilizing the reverse-air drilling method. This method allowed the collection of clean drill cuttings and water samples during drilling. The planned total depth of the wells was 1,200 feet bls, but unconsolidated sands were encountered at about 927 feet bls in well MC-5001 and 854 feet bls MC-5002, which prevented further drilling by the reverse-air method. Groundwater samples were collected at 20 foot intervals during reverse-air drilling.

Well MC-5000 was backfilled to the base of the Lower Hawthorn Aquifer (828 feet bls) with neat Portland cement and subsequently converted to a dual-zone piezometer, isolating the Lower Hawthorn and Hawthorn Zone I aquifers. An inflatable packer connected to the surface with a 1¼-inch diameter galvanized steel casing was set near the top of the Lower Hawthorn Aquifer (714 feet bls) and the annular space was filled with neat Portland cement to near the base of the Hawthorn Zone 1 Aquifer (515 feet bls).

Following construction and testing of these initial deep wells, four additional wells were constructed to obtain hydraulic and water quality data on individual sites and aquifers (Figure 4-2). Test well MC-5004 was installed for further hydrogeologic evaluation of the Lower Hawthorn Aquifer. The test well was drilled using the mud rotary method with a 7 7/8-inch bit to the top of the Lower Hawthorn Aquifer at 682 feet. A 4-inch schedule 40 PVC casing was installed and grouted in place using neat portland cement. The well was subsequently deepened using a 3 7/8-inch bit to a total depth of 800 feet. Well cutting samples were collected during all phases of drilling by an on site hydrogeologist.

Two wells, MC-5003 and MC-5005 were constructed at the NCRWTP site specifically for test production use during high-yield performance tests on the Hawthorn Zone 1 and Lower Hawthorn aquifers. Additionally, observation well MC-5007 was drilled for more detailed monitoring of the Lower Hawthorn Aquifer during testing.

Test production well MC-5003 was drilled to a total depth of 514 feet below land surface. A 17-inch diameter borehole was drilled by the mud rotary method to the top of the Hawthorn Zone 1 Aquifer at a depth of 398 feet. A 12-inch diameter, schedule 40 PVC casing was installed and grouted in place in several stages with neat portland cement. The well was drilled to the final depth of 514 feet by the reverse air rotary method.

Test well MC-5005 was completed to the base of the Lower Hawthorn Aquifer which occurred at a depth of 800 feet below land surface. A 15-inch diameter borehole was drilled to 125 feet using the mud rotary method. The borehole was then deepened using a 13-inch diameter bit to a depth of 700 feet. A 6-inch diameter schedule 40 PVC casing was installed from a depth of 125 feet to 700 feet. The casing diameter was increased from 6-inches to 8-inches (using a reducer bushing fitting) from 125 feet to land surface to allow for test pump installation. After completion of casing installation, the borehole was drilled to the final depth using the reverse air method.

Monitor well MC-5007 was drilled to a total depth of 760 feet below land surface. An 8-inch diameter borehole was drilled to a depth of 717 feet by mud rotary drilling and a 4-inch diameter schedule 40 PVC casing was installed and grouted. The well was deepened to 760 feet using the reverse air method. Details of test wells constructed for this investigation are given in Table 4-1.

4.3 Geophysical Logging

Wireline geophysical logs were run by Southern Resource Exploration, Inc., under Missimer International supervision on each test well to provide additional hydrogeologic data and to assure the construction integrity of the wells. Geophysical logs were run prior to setting the surface casing on wells MC-5000, MC-5001, and MC-5002, including; gamma ray, spontaneous potential, 16 and 64-inch normal resistivity, single point resistivity, and caliper logs. After well completion, gamma ray, spontaneous potential, 16 and 64-inch normal resistivity, caliper, flowmeter, temperature, and fluid resistivity logs were run.

Gamma ray, caliper, spontaneous potential, and resistivity logs were also run on wells MC-5003, MC-5004, and MC-5005 upon well completion.

4.4 Water Chemistry

Groundwater samples were collected at 20 feet intervals during reverse-air drilling and analyzed for specific conductance and dissolved chloride concentration. Conductivity was measured in the field using a YSI Model 3000 T-L-C Meter. Eight-ounce samples were also retained for later laboratory analysis for dissolved chloride concentration. Dissolved

TABLE 4-1. **TEST WELL CONSTRUCTION DETAILS**

Well Number	Total Depth (feet below land surface)	Casing Diameter (inches)	Casing Depth (feet below land surface)	Aquifer Tapped
MC-5000 (original construction)	1200	6	390	Hawthorn Zone 1 and Lower Hawthorn
MC-5000 (Dual Zone Completion)	828	6 to 390' 1½ to 714'	390 and 714	Hawthorn Zone 1 and Lower Hawthorn
MC-5001	927	6	294	Hawthorn Zone 1 and Lower Hawthorn
MC-5002	860	6	398	Hawthorn Zone 1 and Lower Hawthorn
MC-5003	514	12	398	Hawthorn Zone 1
MC-5004	800	4	682	Lower Hawthorn
MC-5005	800	8	700	Lower Hawthorn
MC-5007	760	4	717	Lower Hawthorn

chloride and conductivity measurements were made during aquifer performance testing. The chemical parameters critical to reverse osmosis treatment design were tested for the Lower Hawthorn Aquifer at the NCRWTP site. Results of all sampling and chemical analyses are given in Section 5.0 and in the Appendix.

4.5 Aquifer Hydraulic Testing

4.5.1 Step-Drawdown Testing

Step-drawdown tests were performed on test wells MC-5000, MC-5001, MC-5002, and MC-5004. The wells were pumped using a centrifugal pump and the discharge was measured using a 3-inch orifice plate (with a manometer tube) attached to the end of a 4-inch diameter PVC discharge pipe. Static head was measured in the wells prior to test start using a pressure gauge. Water levels during pumping were measured using the wetted tape method. Each step lasted approximately 1 hour or until water levels in the wells stabilized. Step-drawdown tests were also performed on each of the two production wells to obtain additional well yield information and to aid in selecting appropriate pumping rates prior to conducting aquifer performance tests.

Well MC-5003 was pumped using an electric turbine set at approximately 65 feet bls. The discharge was measured using a totalizing propeller type flowmeter. A static water level was taken prior to pumping using a pressure gage. Water levels during pumping were measured at 5 minute intervals using the airline pressure gage method.

A step-drawdown test was performed on well MC-5005 using natural artesian flow. The rate of flow was controlled using a gate valve. The discharge was measured using a totalizing flowmeter and a 6-inch orifice plate attached to the end of a 10-inch diameter PVC discharge pipe. Water levels were measured using a pressure gauge. Results of the step-drawdown tests are summarized in Section 5 of this report.

Artesian flow rates were measured during well construction and upon completion of open hole drilling in each well. In addition, flow and potential yield data were collected for both zones through drill stem evaluations and geophysical logs.

4.5.2 Constant Rate Aquifer Performance Tests

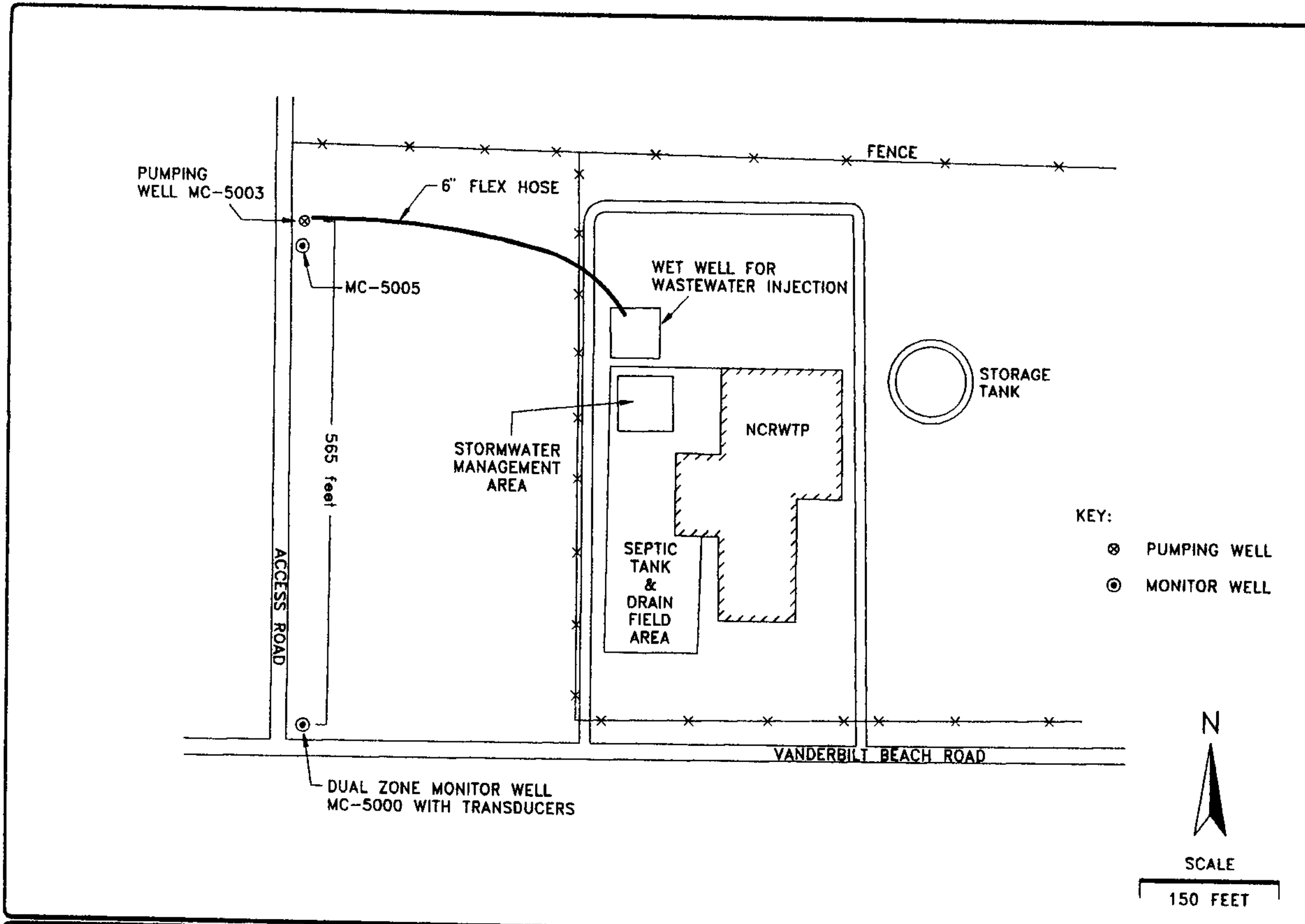
Constant rate aquifer performance tests (APT) were conducted to determine aquifer hydraulic coefficients for both Hawthorn Zone 1 and Lower Hawthorn aquifers. Test-production wells in each aquifer were pumped at continuous rates while drawdowns were recorded at specified time intervals in nearby monitor wells. Time and potentiometric water level data were measured and recorded using pressure transducers coupled to an electronic data logger. The time and drawdown data for each are provided in the Appendix. Prior to conducting each pumping test, background data were recorded in order to measure natural fluctuations of potentiometric pressures caused by tidal influence and/or barometric pressure changes.

Hawthorn Zone 1 Aquifer

Test well MC-5003 was pumped at a constant rate of 540 gpm for a period of 70 hours. The APT was started at 10:10 AM on February 3, 1995 and ended at 8:27 AM on February 6, 1995. The well was pumped using an electric submersible pump set at 65 feet below land surface. Discharge water was directed to a centrifugal pump which transmitted the water through a 6-inch flex hose to the NCRWTP injection system wet well 400 feet away. The pumping rate was monitored using a totalizing flowmeter. Drawdown was measured in the test production well during the first hour of pumping using a 60 foot airline. Drawdowns of potentiometric pressures for both the Hawthorn Zone 1 and Lower Hawthorn aquifers were recorded by means of the dual zone observation well located 565 feet away from the pumping well. Recovery of potentiometric levels was monitored for 130 minutes upon termination of pumping. 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 4-6.

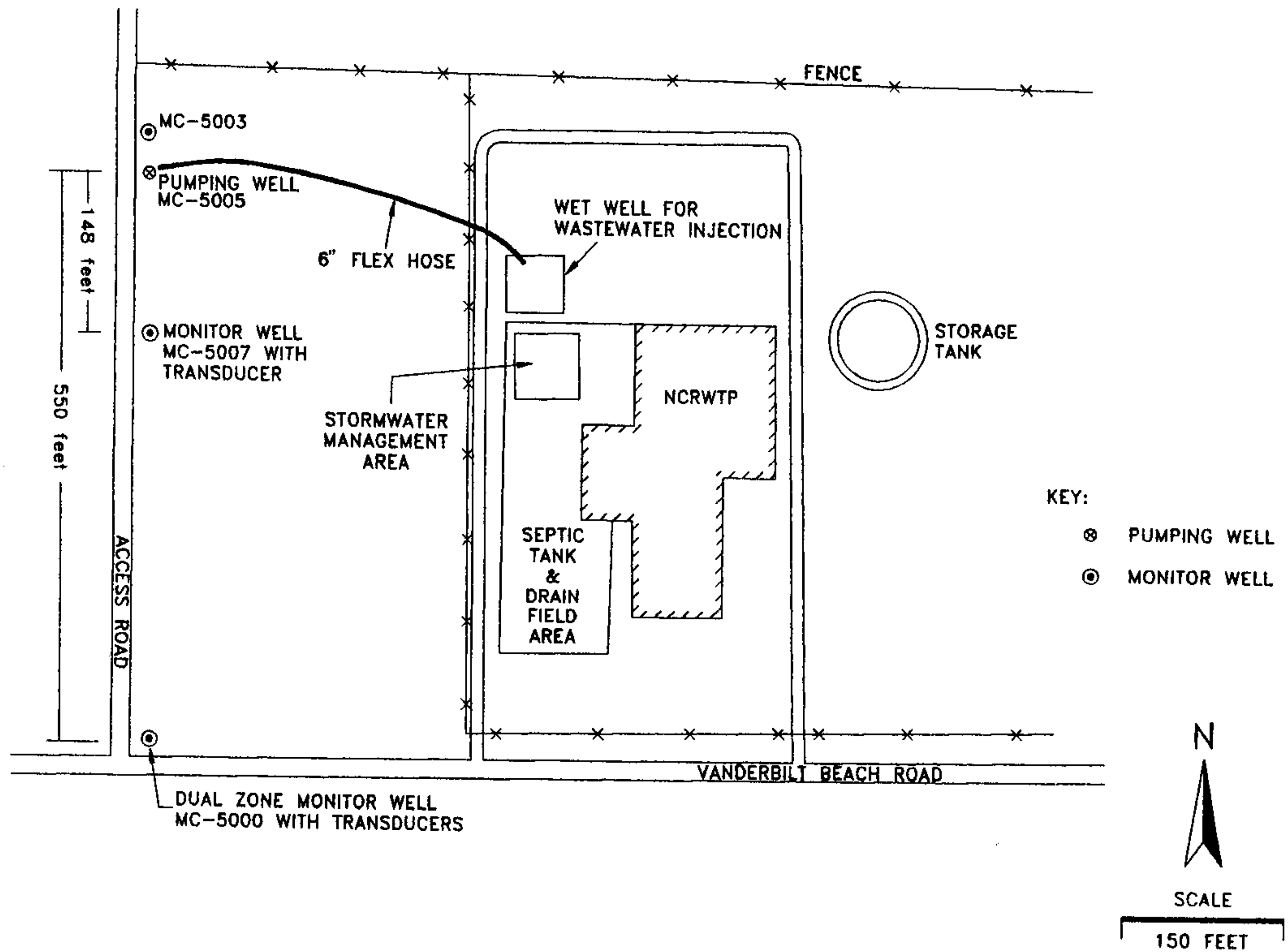
Lower Hawthorn Aquifer

A 72-hour Aquifer Performance Test of the Lower Hawthorn Aquifer was started at 9:28 AM on March 23, 1995. Lower Hawthorn well MC 5005 was pumped at a rate of 850 gpm using a 6-inch centrifugal pump. Discharge water was again routed to the injection system wet well located approximately 400 feet away. Drawdown of potentiometric pressures in the Lower Hawthorn Aquifer were recorded in two monitor wells, MC-5007 and MC-5000. Drawdown in the production well was monitored periodically using a combination vacuum and pressure gauge. A schematic diagram showing the test set up is provided in Figure 4-7.



MISSIMER INTERNATIONAL INC.	Pr Name: COLLIER COUNTY R.O. WELLFIELD Pr.No. FH4-26 DWG No.FH426-T1.DWG Date: 06/20/95 Rev.No. 5	Groundwater and Environmental Services

FIGURE 4-6. SCHEMATIC DIAGRAM OF NCRWTP HAWTHORN ZONE I AQUIFER PERFORMANCE TEST.



MISSIMER INTERNATIONAL

Pr Name: COLLIER COUNTY R.O. WELLFIELD

Pr.No. FH4-26 DWG No.FH426-T1.DWG Date: 06/20/95 Rev.No. 5

Groundwater and Environmental Services

FIGURE 4-7. SCHEMATIC DIAGRAM OF NCRWTP LOWER HAWTHORN AQUIFER PERFORMANCE TEST.

5.0 RESULTS OF INVESTIGATION

5.1 Introduction

The regional hydrogeology of northern Collier County has been generally described in parts by Boggess et al. (1981) and Knapp et al. (1986). Three major aquifer systems are present in Collier County. They are, in descending order, the Surficial Aquifer System, the Intermediate Aquifer System, and the Floridan Aquifer System (Figure 5-1). General descriptions of these aquifer systems are given in this report. The Surficial Aquifer System has been described in detail in Missimer & Associates, Inc. (1986), and is given only cursory attention in this report.

This investigation focused on the brackish water aquifers of the Intermediate and upper Floridan Aquifer Systems. Within the upper 1200 feet of strata explored, only two brackish water aquifers of significance were encountered. These were the Hawthorn Zone I and the Lower Hawthorn aquifers which are described in detail. An east-west cross section is given in Figure 5-2. Stratigraphic columns containing lithologic, geophysical, and water quality data are contained in Appendix A.

5.2 Surficial Aquifer System

The Surficial Aquifer System includes the unconfined water-table aquifer and the semi-confined Lower Tamiami Aquifer. The water-table aquifer in the study area consists of fine-grained quartz sand and sandstone belonging to the Pleistocene-aged Pamlico Sand Formation and/or the Fort Thompson Formation and light-colored fossiliferous limestones, belonging to the unnamed limestone facies (Missimer, 1992) of the Pliocene-aged Tamiami Formation. The water-table aquifer is separated from the Lower Tamiami Aquifer in wells MC-5000 and MC-5001 by the lower Tamiami confining beds, which consist of very light gray to pale olive marls belonging to the Bonita Springs Marl Member of the Tamiami Formation. The Bonita Springs Marl Member was not encountered in

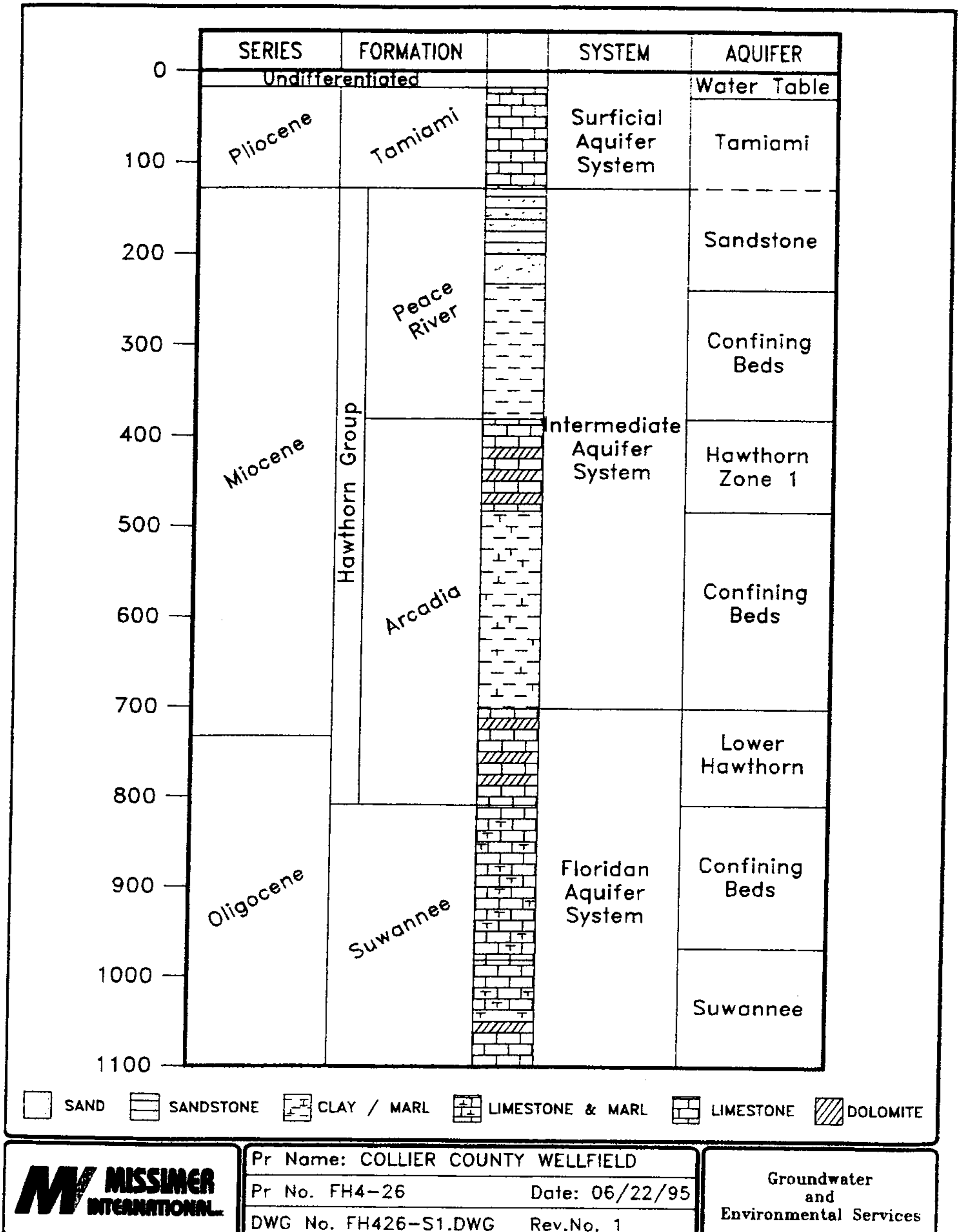


FIGURE 5-1. GENERALIZED HYDROGEOLOGY BENEATH NORTHWEST COLLIER COUNTY.

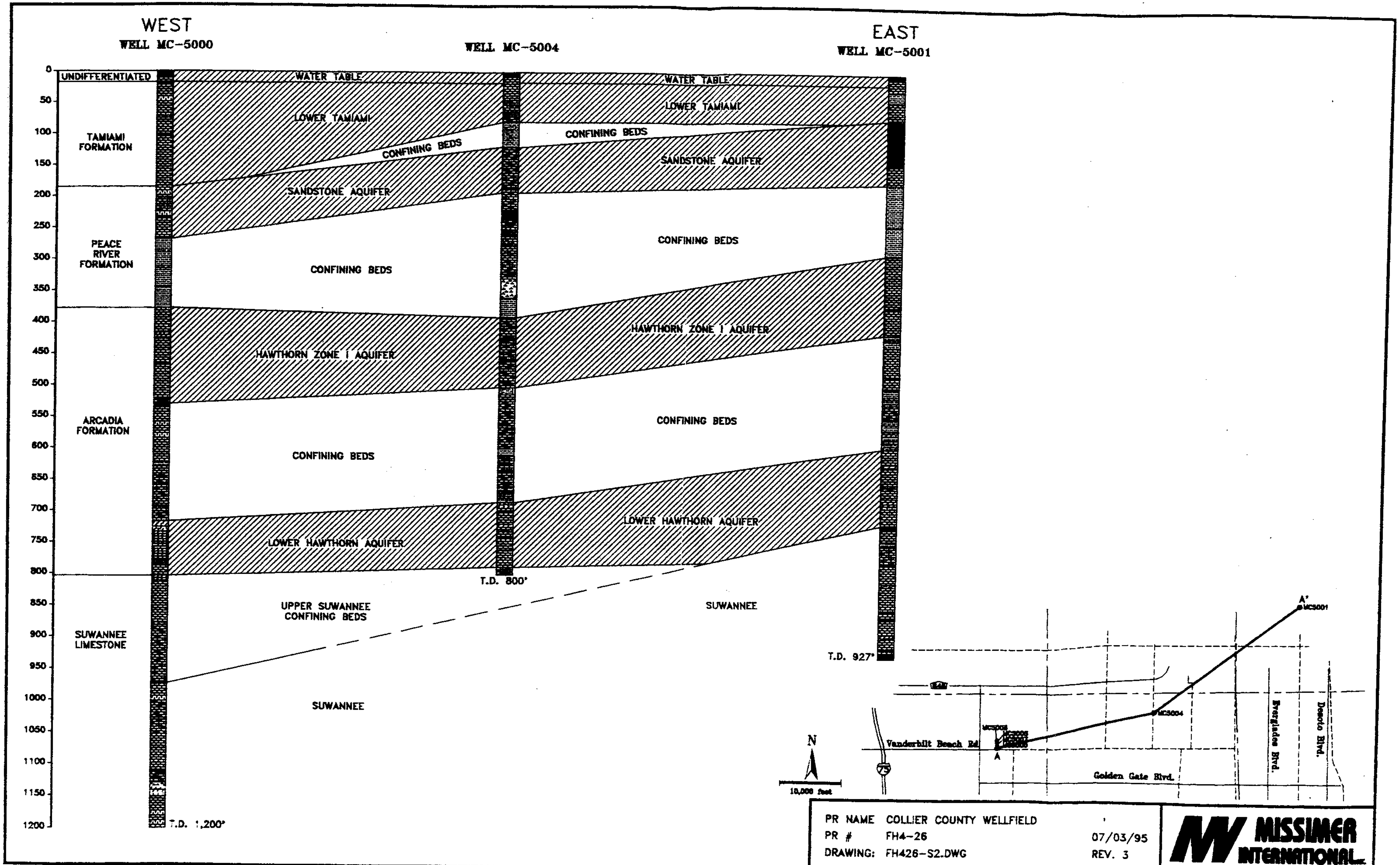


FIGURE 5-2. EAST - WEST CROSS SECTION THROUGH THE STUDY AREA.

wells MC-5002 or MC-5004, although lower permeability limestones in these areas do provide some degree of confinement between the aquifers.

The Lower Tamiami Aquifer consists of light-colored fossiliferous sandy limestones of the Ochopee Member of the Tamiami Formation. The Lower Tamiami Aquifer is currently used as a feedwater source for the membrane softening facility at the NCRWTP. Both aquifers of the Surficial Aquifer System contain fresh water and have high yield characteristics created by high permeabilities caused by secondary porosity. However, both aquifers have significant regulatory restrictions on their use because of concerns over environmental degradation (wetlands issue). For this reason, brackish water resources are being sought for future expansions of the county utility system.

5.3 Intermediate Aquifer System

5.3.1 Sandstone Aquifer

In north Collier County the Lower Tamiami Aquifer is hydraulically connected to the Sandstone Aquifer which is the uppermost hydrologic unit of the Intermediate Aquifer System. The Sandstone Aquifer consists of moderate to low permeability quartz sands, sandstones, and sandy limestones that belong to the upper part of the Peace River Formation of the Hawthorn Group. The Sandstone Aquifer is rarely used as a water source in Collier County because of the much greater water yields from the overlying Lower Tamiami Aquifer.

The base of the Sandstone Aquifer is marked by an abrupt lithologic change to the impermeable pale olive to greenish-gray clays and marls of the middle and lower Peace River Formation, which form the upper Hawthorn confining zone. The upper Hawthorn confining unit ranges in thickness from approximately 110 to 150 feet. The considerable thickness and low permeability of the clays and marls result in significant confinement of the underlying Hawthorn Zone 1 Aquifer. Lithologic and geophysical characteristics encountered during test drilling indicated the Hawthorn Zone 1 Aquifer to be a potential source of reverse osmosis feedwater.

5.3.2 Hawthorn Zone 1 Aquifer

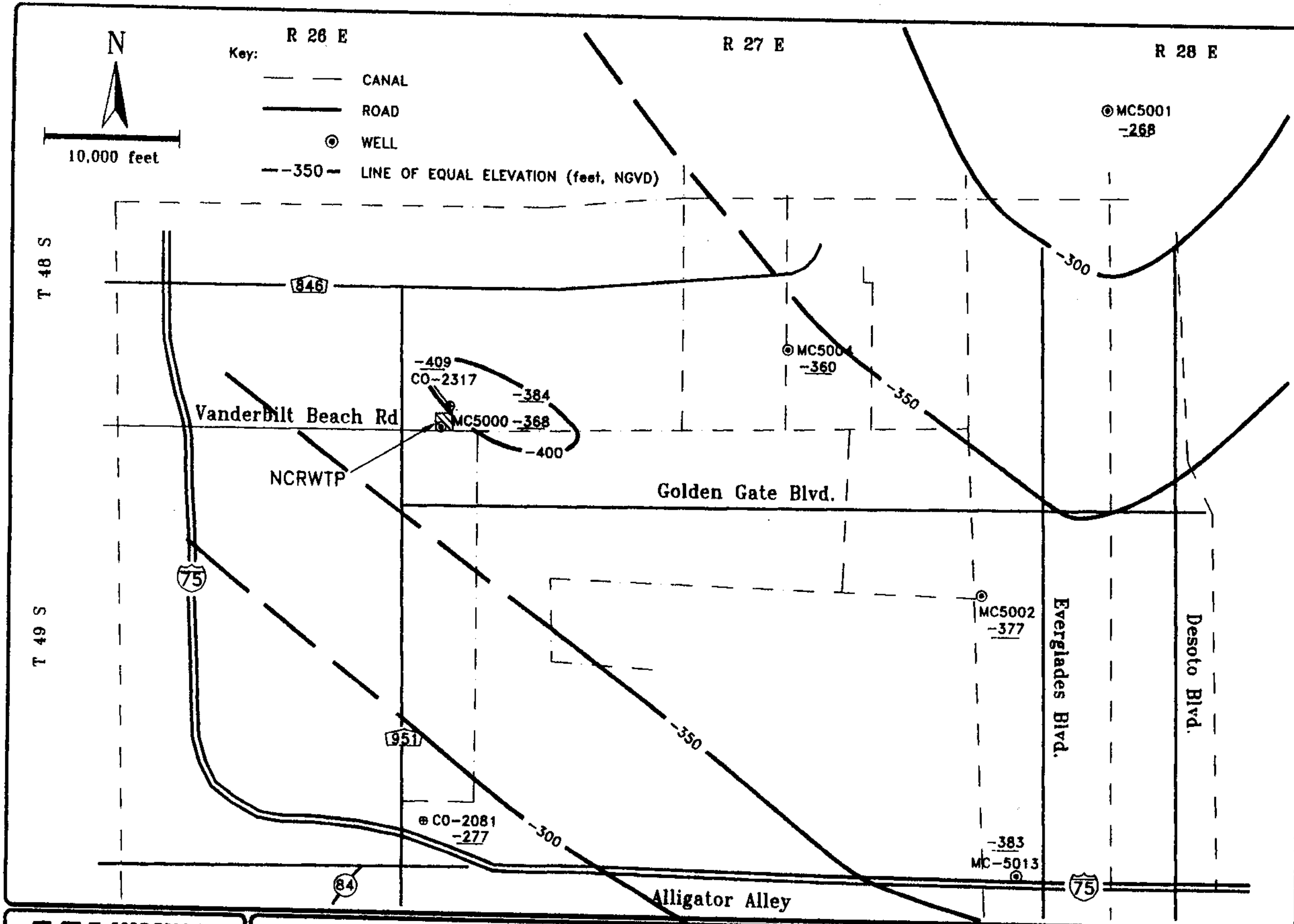
Aquifer Description

The Hawthorn Zone 1 Aquifer occurs within permeable limestone units that belong to the upper Arcadia Formation of the Hawthorn Group. The upper contact of the Hawthorn Zone 1 Aquifer is marked by a sharp downward transition from pale olive clay of the upper Hawthorn confining unit to very light gray limestone. The predominant lithologies within the aquifer are very light gray, yellowish-gray, and pale olive fossiliferous limestones. The limestones are moderately hard (semi-friable) to hard, and usually have moderate to high porosity (both intergranular and moldic after dissolution of biogenic grains). Sand-sized phosphate grains are present throughout the aquifer, usually at volumetric abundances on the order of 1-3%.

The Hawthorn Zone 1 Aquifer occurs at depths of approximately 290 to 420 feet below land surface in the study area and ranges in thickness from approximately 100 to 135 feet. The aquifer tends to thin toward the north. Structure and isopach maps for the Hawthorn Zone 1 Aquifer are provided in Figures 5-3 and 5-4.

Water Levels

Potentiometric pressures were measured in test wells tapping the Hawthorn Zone 1 Aquifer. The levels were converted to estimated NGVD reference based on land surface elevations obtained from USGS topographic maps. Figure 5-5 illustrates that a variation in potentiometric head occurs within the Hawthorn Zone 1 Aquifer. Potentiometric levels recorded in wells (MC-5001, MC-5002) to the east of the study area range between 19 and 22 feet NGVD while those levels measured from wells (MC-5000, CO-2081) in the western portion of the study area range between 32 and 35 feet NGVD. No pressure measurements were taken for the Hawthorn Zone 1 Aquifer in well MC-5004.



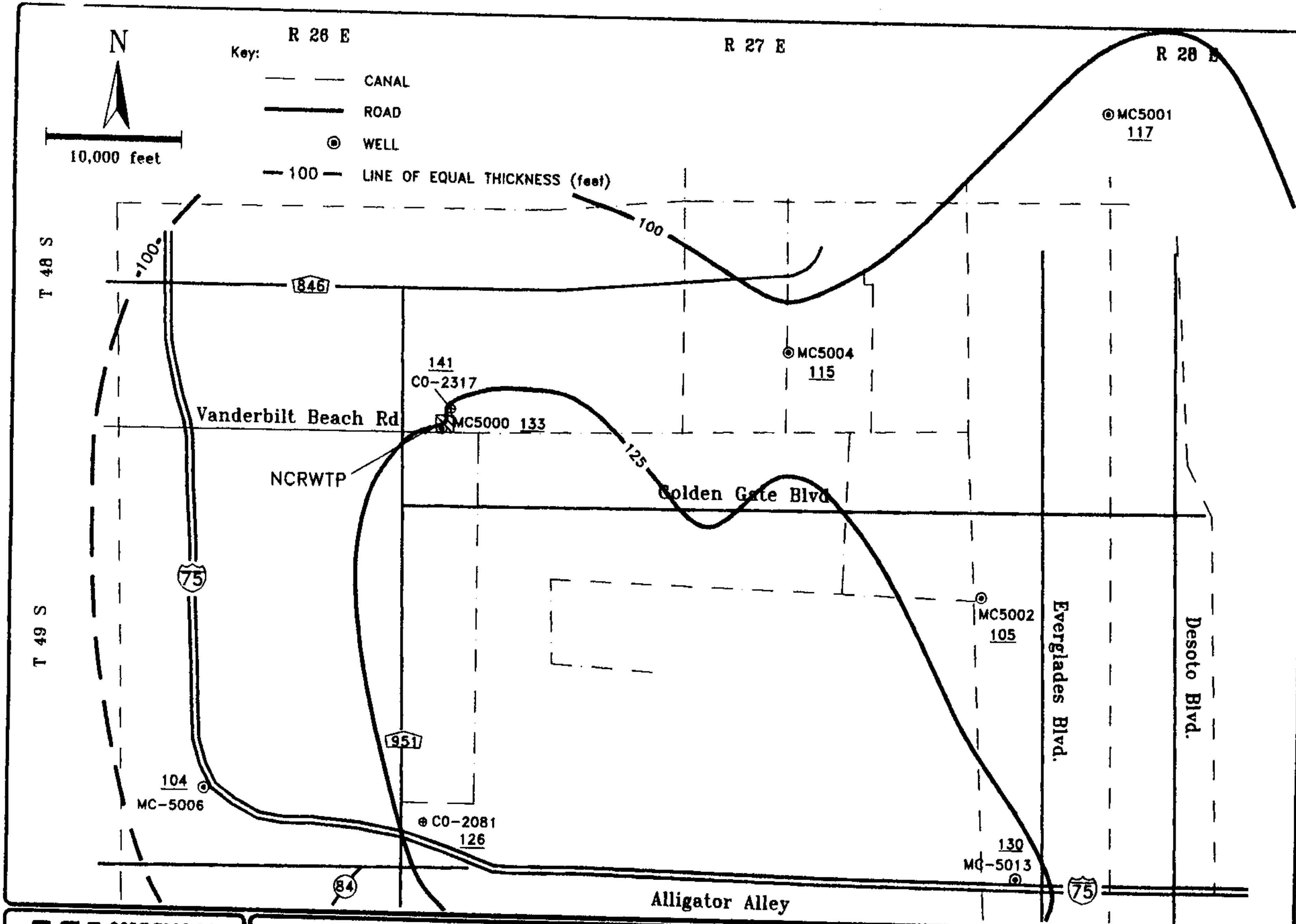
MISSIMER INTERNATIONAL INC.

Pr Name: Collier Co. Wellfield

Pr.No. FH4-26 DWG No.FH4-26SL.DWG Date: 06/27/95 Rev.No. 11

Groundwater and Environmental Services

FIGURE 5-3. STRUCTURE CONTOUR MAP - TOP OF HAWTHORN ZONE I AQUIFER, FEET BELOW (NGVD).



MISSIMER INTERNATIONAL

Pr Name: Collier Co. Wellfield

Pr.No. FH4-26 DWG No.FH4-26SL.DWG Date: 06/27/95 Rev.No. 11

Groundwater and Environmental Services

FIGURE 5-4. ISOPACH - MAP SHOWING THICKNESS OF THE HAWTHORN ZONE I AQUIFER (FEET).

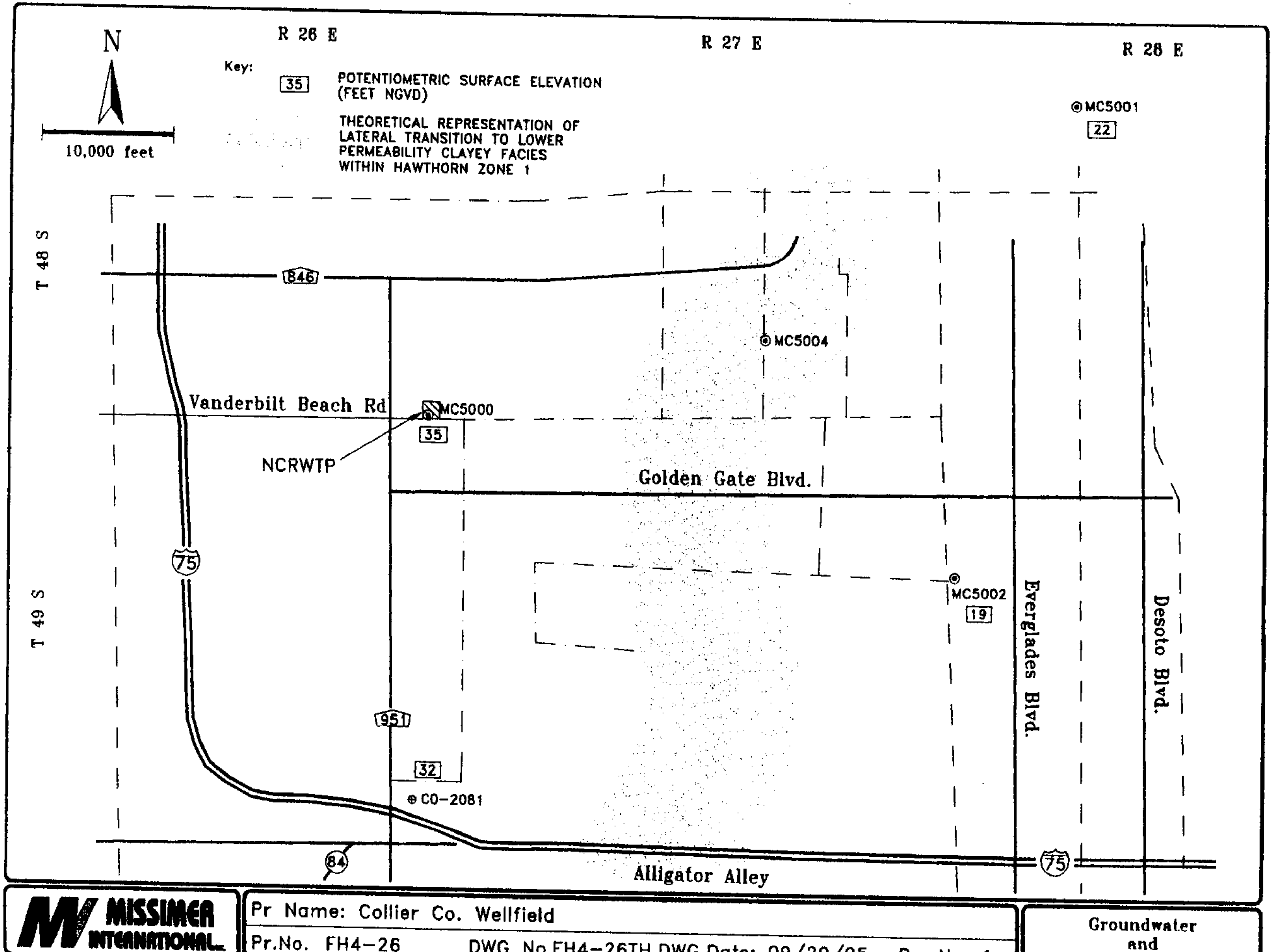


FIGURE 5-5. HAWTHORN ZONE I AQUIFER – HEAD READINGS AT INDIVIDUAL WELL LOCATIONS.

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 1 Aquifer. A lower permeability clayey lithofacies is believed to occur in the vicinity of well MC-5004 creating a lateral impediment to flow. Lithologic and geophysical contacts are easily correlated across the area. However, the head data would suggest that two separate aquifer zones have been intersected.

Low permeability clayey limestones were identified from lithologic and geophysical data within the Hawthorn Zone 1 in well MC-5004 (central area). Additionally, lithologic and resistivity logs were used to evaluate the degree of permeability within the aquifer to the east and west of MC-5004. Data observed for test wells MC-5002 and MC-5001 (eastern half of the area) indicate a highly permeable Hawthorn Zone 1. However, the lithologic and geophysical logs for wells MC-5000 and CO-2081 in the western portion of the area indicate a lower permeability zone. As observed from test wells, the variation in permeability would contribute to different changes in potentiometric head measurements that were observed laterally across the area.

Water Quality

Water samples were obtained from the test wells and analyzed for dissolved chloride concentration and specific conductance to assess water quality in Hawthorn Zone 1. The water quality data obtained for the Hawthorn Zone 1 Aquifer are summarized in Table 5-1. Water samples were also collected during aquifer performance testing. The data is provided in Table 5-2.

A map showing the trend of dissolved chloride concentrations in the aquifer is provided as Figure 5-6. Inspection of the figure indicates that dissolved chloride concentrations increase from east to west in the study area from less than 200 mg/l chloride in the northeast to over 2000 mg/l in the west. 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

TABLE 5-1. HAWTHORN ZONE I WATER QUALITY DATA

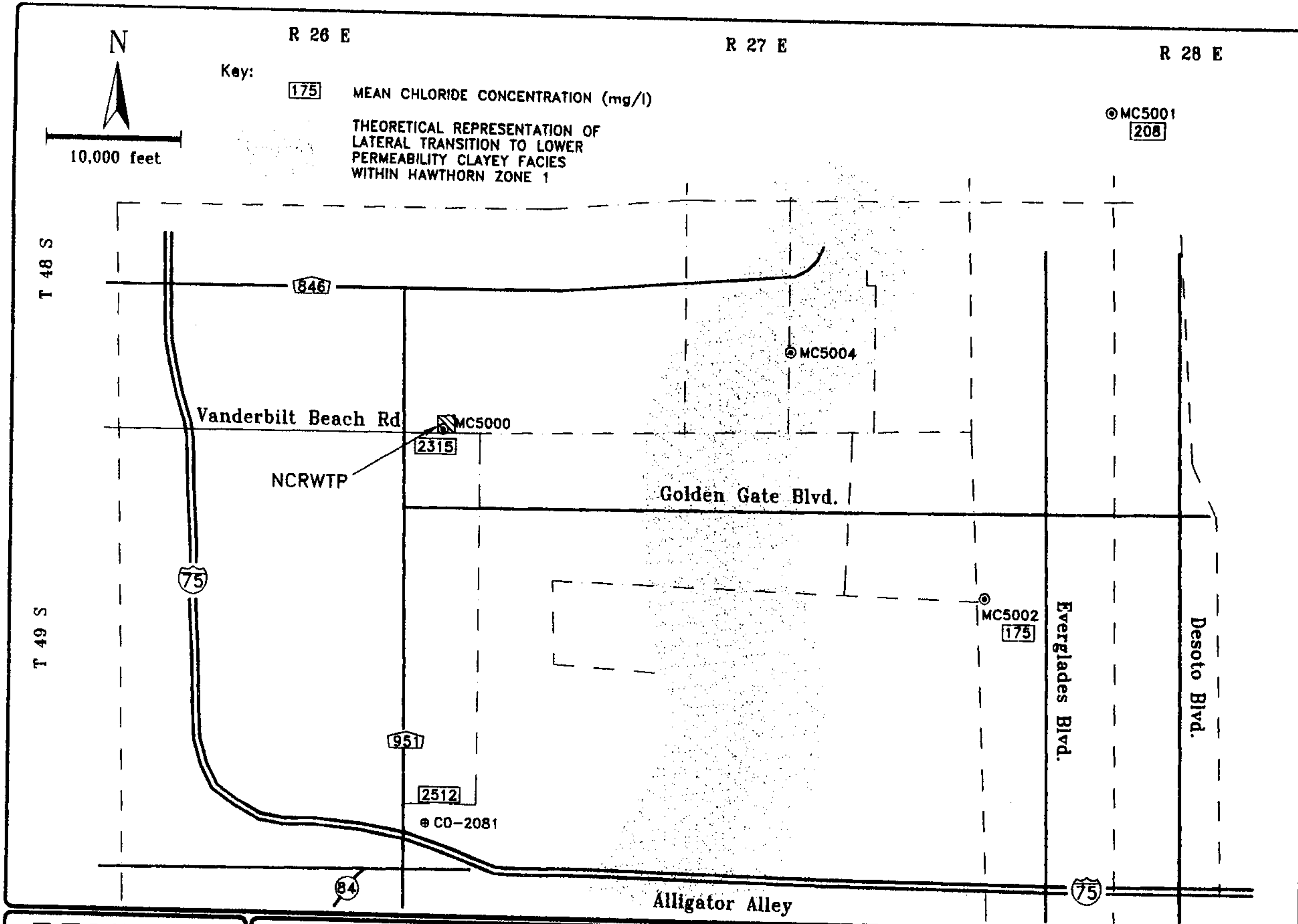
WELL	CASED DEPTH (ft, bls)	TOTAL DEPTH (ft, bls)	DISSOLVED CHLORIDE CONC. (mg/l) MEAN	DISSOLVED CHLORIDE CONC. (mg/l) RANGE	SPECIFIC CONDUCTANCE (µmhos/cm) MEAN	SPECIFIC CONDUCTANCE (µmhos/cm) RANGE
MC 5000	379	512	2,315	2,200-2420	8,450	8,100-8,680
MC 5001	289	406	208	160-280	1,388	1,300-1,480
MC 5002	394	499	175	140-180	1,985	1,950-2,030
MC 5003	398	515	2023	1960-2100	7350	7190-7490

TABLE 5-2. **WATER QUALITY DATA FOR THE HAWTHORN ZONE 1 AQUIFER COLLECTED DURING THE 70 HOUR APT TEST AT NCRWTP**

TIME OF TEST START : 10:10 AM FEBRUARY 3, 1995.

WELL MC 5003 - 12 INCH PRODUCTION WELL			
Conductivity (umohs)	Chlorides (mg/l)	Sampling Date	Sampling Time
7416	2060	FEB. 3	2:00PM
7490	2040	FEB. 3	8:00PM
7710	2100	FEB. 4	1:00PM
7360	2020	FEB. 6	8:30AM

37



MISSIMER INTERNATIONAL

Pr Name: Collier Co. Wellfield

Pr.No. FH4-26 DWG No.FH4-26TH.DWG Date: 09/29/95 Rev.No. 1

Groundwater and Environmental Services

FIGURE 5-6. HAWTHORN ZONE I AQUIFER - CHLORIDE CONCENTRATION.

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 prevents flow from west to east.

Aquifer Hydraulics

The results of the step-drawdown tests performed on the Hawthorn Zone 1 Aquifer are summarized in Table 5-3. The specific capacity data indicate that the Hawthorn Zone 1 Aquifer has a moderate to low potential yield. The low measured specific capacities reflect, to a major degree well inefficiencies related to the relatively small well diameter. Nevertheless, the data indicate that the yield potential of the upper aquifer is moderate at best.

Logarithmic and semi-logarithmic graphs of time vs. drawdown were constructed for Hawthorn Zone I based on data collected from monitor well MC-5000 during the 70-hour aquifer performance test. 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):

$$T = \frac{Q\,L(u,v)}{4\pi s} \qquad (1)$$

$$S = \frac{4Tt}{r^2\,(1/u)} \qquad (2)$$

$$L = \frac{4T\,(v)^2}{r^2} \qquad (3)$$

TABLE 5-3. HAWTHORN ZONE I STEP-DRAWDOWN TEST RESULTS

WELL MC-5000 (Static water level = 34.79 ft above NGVD)		
DISCHARGE (gpm)	DRAWDOWN (feet)	SPECIFIC CAPACITY (gpm/ft)
33	3.47	9.6
62	6.93	9.0
90	11.55	7.8

WELL MC-5001 (Static water level = 22.00 ft above NGVD)		
DISCHARGE (gpm)	DRAWDOWN (feet)	SPECIFIC CAPACITY (gpm/ft)
100	5.49	18.2
150	15.37	9.8
187	21.64	8.6

WELL MC-5002 (Static water level = 18.80 ft above NGVD)		
DISCHARGE (gpm)	DRAWDOWN (feet)	SPECIFIC CAPACITY (gpm/ft)
88	9.48	9.3
98	14.97	6.6
120	22.94	5.2

WELL MC-5003 (Static water level = 20.35 ft above NGVD)		
DISCHARGE (gpm)	DRAWDOWN (feet)	SPECIFIC CAPACITY (gpm/ft)
250	17.38	14.38
363	33.23	10.92
540	57.30	9.48

where,

T = transmissivity (ft^2/day)

Q = pumping rate (ft^3/day)

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

L = Leakance (^{1}/day)

A logarithmic plot of monitor well data is given in Figure 5-7.

A semi-log plot of drawdown vs. time was analyzed by the Jacob method to verify transmissivity and storage values from initial analysis. This graph is given as Figure 5-8. Appropriate time and drawdown data were substituted into equations (4) and (5).

$$T = \frac{2.3\,Q}{\Delta s\,4\,\pi} \qquad (4)$$

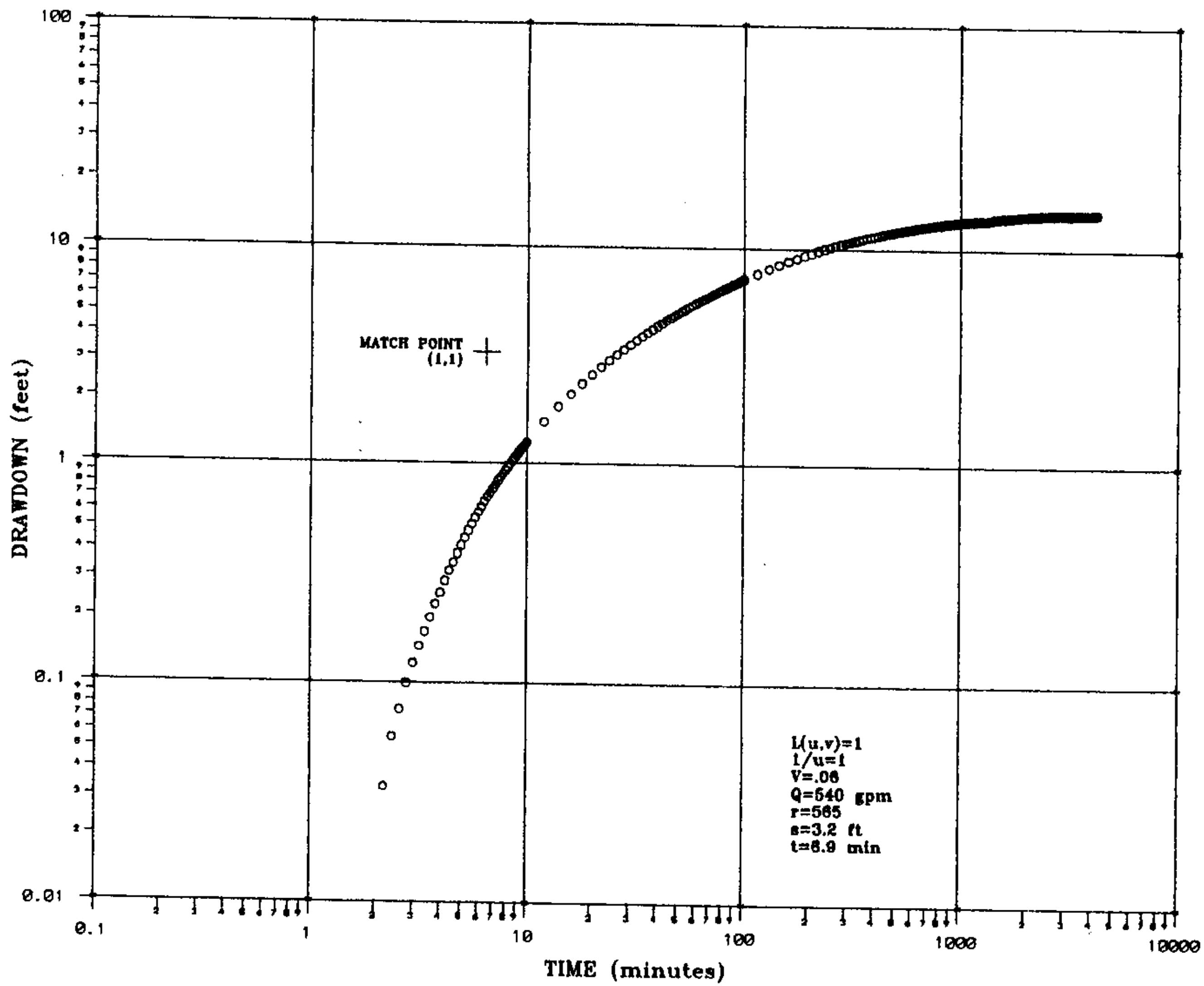
$$S = \frac{2.25\,T\,t_o}{r^2} \qquad (5)$$

where,

Δs = Head difference between log cycles (feet)

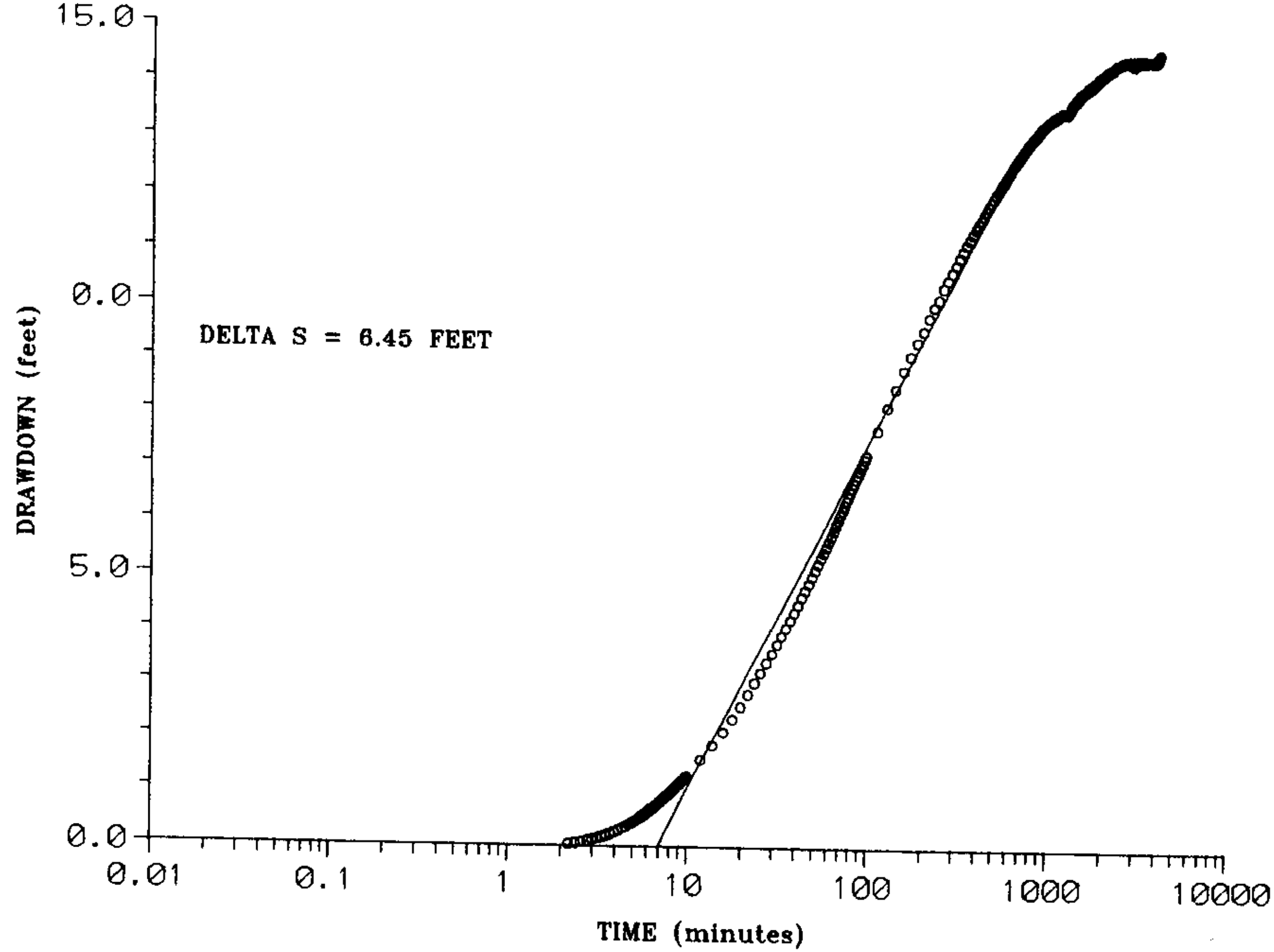
t_o = time at zero drawdown/ recovery (days)

The calculated hydraulic coefficients for Hawthorn Zone 1 are provided in Table 5-4. Overall, testing showed Hawthorn Zone I to have only a moderate potential for



MISSIMER INTERNATIONAL	Pr Name: COLLIER COUNTY R.O. WELLFIELD	Groundwater and Environmental Services
	Pr.No. FH4-26 DWG No. FH426-D2.DWG Date: 06/21/95 Rev.No. 5	

FIGURE 5-7. DRAWDOWN IN TEST WELL MC-5000 (HAWTHORN ZONE I) DURING THE AQUIFER PERFORMANCE TEST ON COLLIER COUNTY PRODUCTION WELL MC-5003 Q=540 GPM.



MISSIMER INTERNATIONAL

Pr Name: COLLIER COUNTY R.O.WELLFIELD	
Pr.No. FH4-26	DWG No. FH426-D3.DWG Date: 06/21/95 Rev.No. 5

Groundwater and Environmental Services

FIGURE 5-8. SEMI-LOG PLOT OF DRAWDOWN vs TIME IN MONITOR WELL MC-5000 (HAWTHORN ZONE I) DURING THE AQUIFER PERFORMANCE TEST ON TEST/PRODUCTION WELL MC-5003 (HAWTHORN ZONE I).

TABLE 5-4. **AQUIFER HYDRAULIC COEFFICIENTS CALCULATED FOR THE HAWTHORN ZONE 1 AQUIFER AT THE NCRWTP**

WELL	Method	Transmissivity (gpd/ft)	Storage Coefficient	Leakance (gpd/ft^3)
MC-5003	Cooper '63	19300	8.7×10^{-4}	1.5×10^{-4}
MC-5003	Jacob '50	22100	9.8×10^{-5}	NA
		20700	4.84×10^{-4}	

development of the regional raw water resource. Aquifer transmissivity is estimated at 20,000 gpd/ft, storativity at 4.8×10^{-4}, and leakance at 1.5×10^{-4} gpd/ft^3.

Although it is beyond the scope of this report to further investigate the Hawthorn Zone 1 Aquifer, the lithologic, hydraulic and water quality data collected during this investigation suggest that it may be a possible zone for aquifer storage and recovery (ASR). The hydrogeologic data is considered favorable, because the overlying clays provide good confinement and are expected to retain most of the injected water. The transmissivity and chloride values observed within this zone are also within the range of values acceptable for ASR.

The lower contact of the Hawthorn Zone 1 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 Mid-Hawthorn confining zone which separates the Hawthorn Zone 1 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 Mid-Hawthorn confining zone in the test wells ranges from 160 to 180 feet. The overall vertical hydraulic conductivity of the confining zone is very low.

5.4 Floridan Aquifer System

The Floridan Aquifer System is one of the most productive aquifers in the United States and underlies all of Florida and portions of Alabama, Georgia, and South Carolina for a total area of about 100,000 mi^2. It consists of an extensive sequence of Tertiary Age carbonate rocks that are hydraulically connected in various degrees to form a regional aquifer system. The system includes permeable sediments of the lower part of the Hawthorn Group, the Suwannee Limestone, the Ocala Group, the Avon Park Limestone, and the Oldsmar Limestone. The base of the system is generally placed at the top of the first occurrence of evaporite beds in the Oldsmar Limestone, and the top of the system is placed at the bottom of the Mid-Hawthorn confining unit.

5.4.1 Lower Hawthorn Aquifer

Aquifer Description

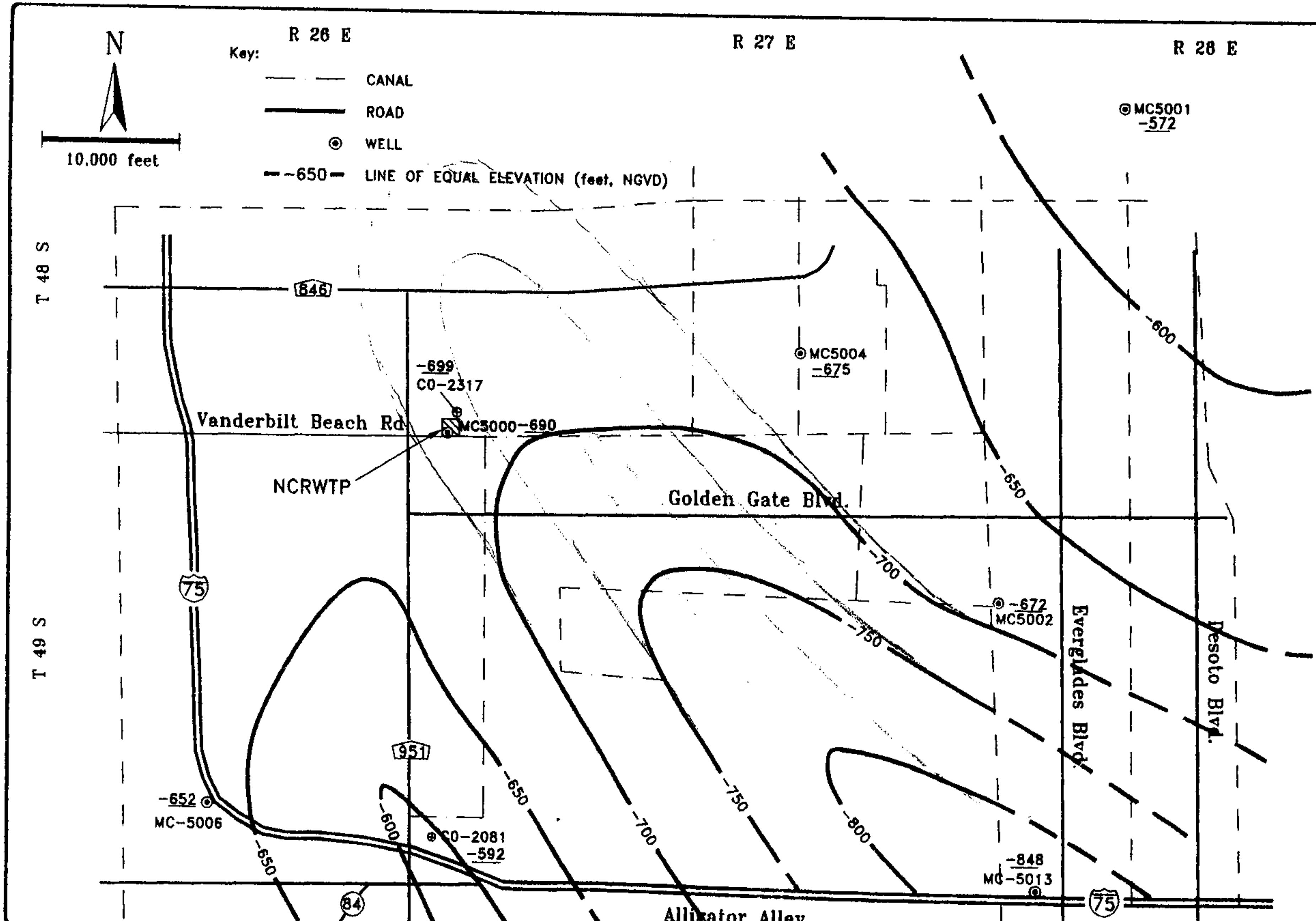
The upper boundary of the Lower Hawthorn Aquifer is marked by a sharp decrease in the abundance of marl and clay in the Lower Arcadia Formation. The Lower Hawthorn Aquifer consists predominantly of interbedded yellowish-gray fossiliferous limestones and pale olive dolomites. The Lower Hawthorn Aquifer 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 very hard, and have a variable porosity. The top of the Lower Hawthorn Aquifer occurs at depths ranging from less than 600 to over 800 feet, dipping into a southeast trending synclinal structure. The thickness of the Lower Hawthorn Aquifer ranges from 100 to 180 feet. Structure and isopach maps for the Lower Hawthorn Aquifer are provided in Figures 5-9 and 5-10.

Water Levels

A potentiometric map constructed from measured head pressure levels in wells penetrating the Lower Hawthorn Aquifer is presented as Figure 5-11. The direction of groundwater flow for the Lower Hawthorn follows the normal trend of northeast to southwest.

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 5-5. The trend in water quality within this aquifer is similar to the Hawthorn Zone 1 Aquifer in that dissolved chloride concentrations increase from east to west across the study area. A map illustrating the distribution of dissolved chlorides for the Lower



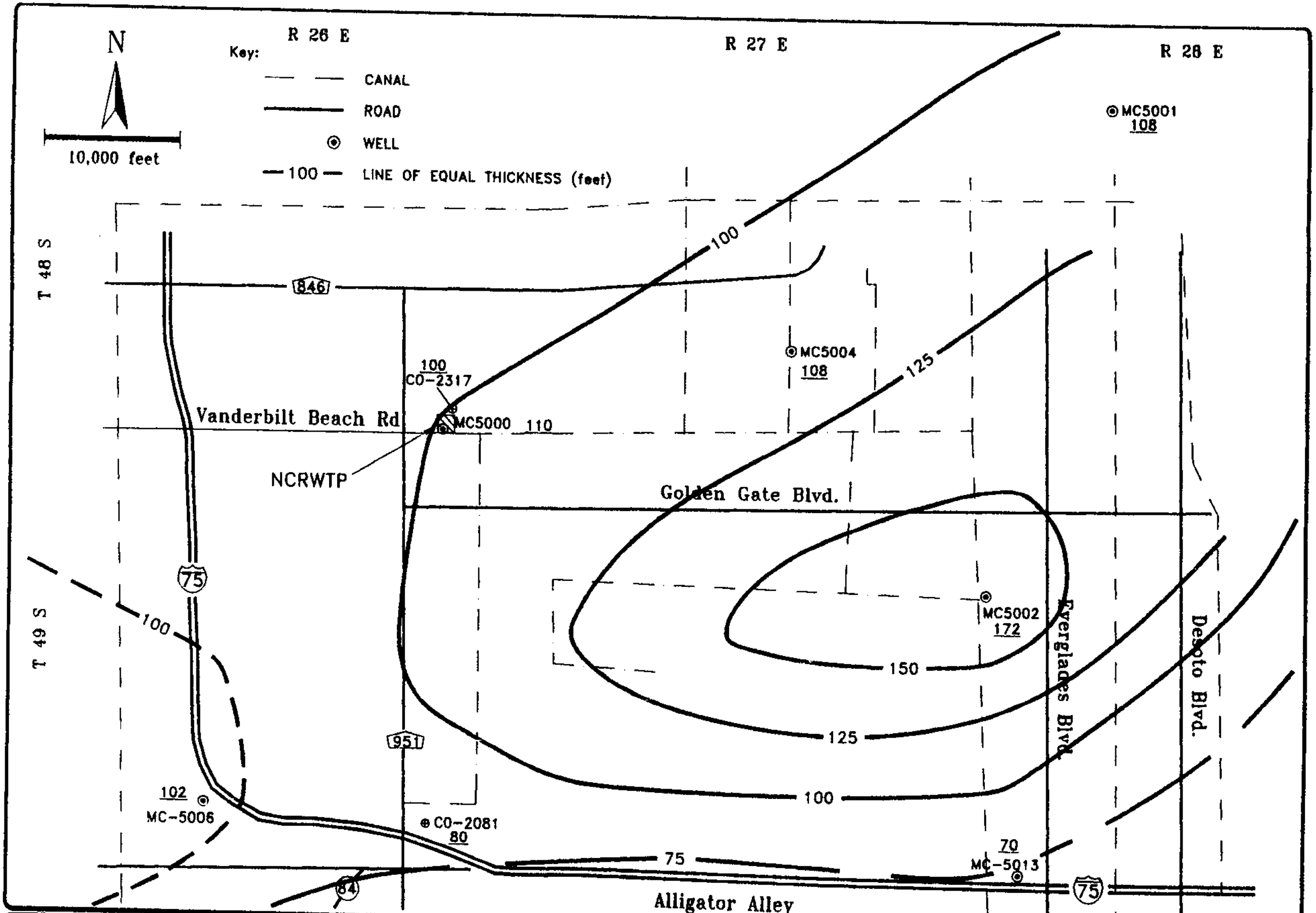
MISSIMER INTERNATIONAL

Pr Name: Collier Co. Wellfield

Pr.No. FH4-26 DWG No.FH4-26SL.DWG Date: 06/27/95 Rev.No. 11

Groundwater and Environmental Services

FIGURE 5-9. STRUCTURE CONTOUR MAP – TOP OF LOWER HAWTHORN, FEET BELOW (NGVD).

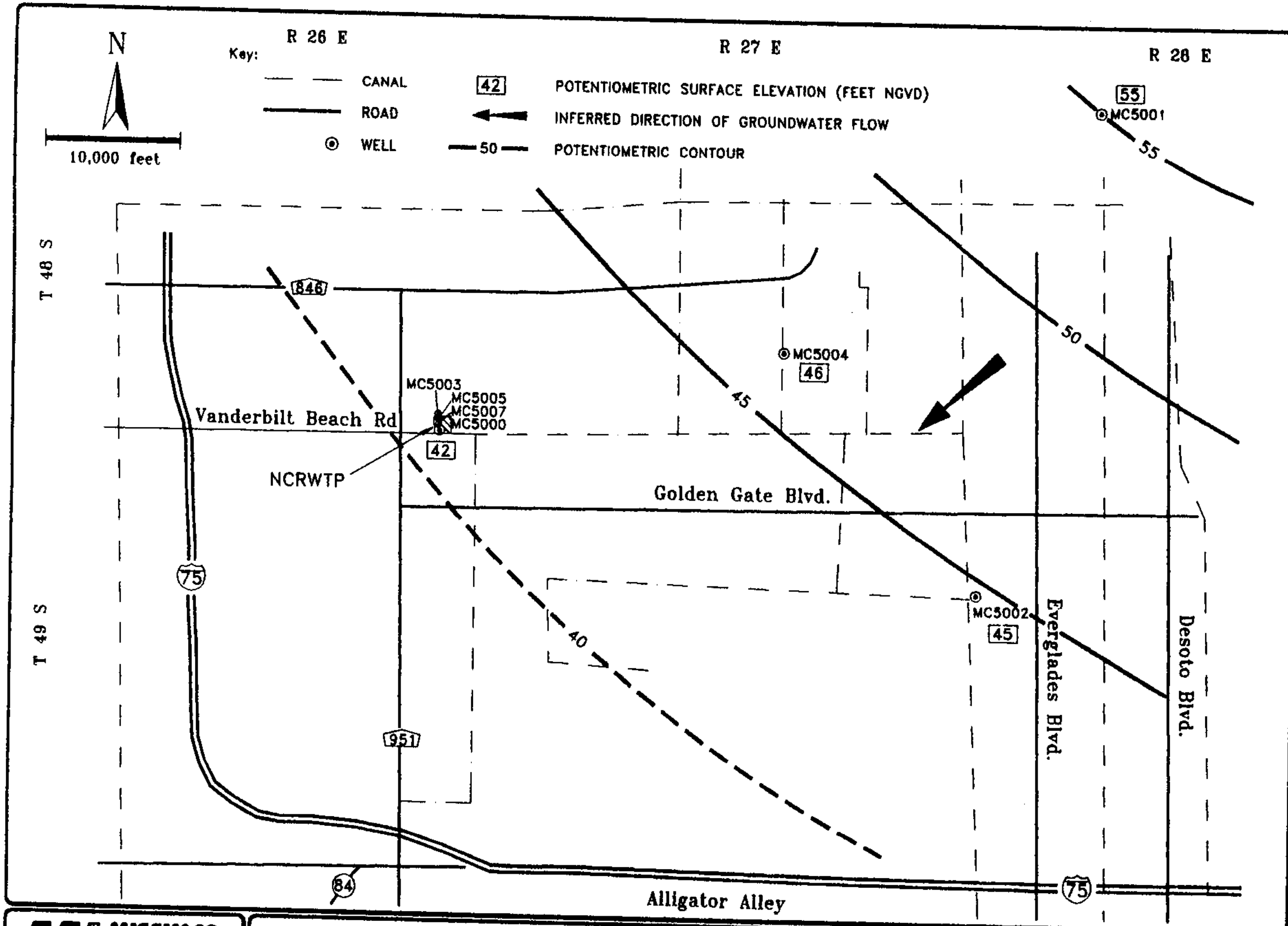


MISSIMER INTERNATIONAL

Pr Name: Collier Co. Wellfield	
Pr.No. FH4-26 DWG No.FH4-26SL.DWG Date: 06/27/95 Rev.No. 11	

Groundwater and Environmental Services

FIGURE 5-10. ISOPACH - MAP SHOWING THICKNESS OF THE LOWER HAWTHORN AQUIFER.



MISSIMER INTERNATIONAL

Pr Name: Collier Co. Wellfield

Pr.No. FH4-26 DWG No.FH4-26SL.DWG Date: 06/21/95 Rev.No. 10

Groundwater and Environmental Services

FIGURE 5-11. LOWER HAWTHORN AQUIFER – ESTIMATED POTENTIOMETRIC SURFACE.

TABLE 5-5. LOWER HAWTHORN WATER QUALITY DATA

WELL	CASED DEPTHS (ft, bls)	TOTAL DEPTHS (ft, bls)	DISSOLVED CHLORIDE CONC. (mg/l) MEAN	DISSOLVED CHLORIDE CONC. (mg/l) RANGE	SPECIFIC CONDUCTANCE (µmhos/cm) MEAN	SPECIFIC CONDUCTANCE (µmhos/cm) RANGE
MC-5000	704	814	1,953	1,660-2,340	7,402	6,550-8,350
MC-5001	592	700	655	400-820	3,690	3,070-4,130
MC-5002	685	857	1,315	910-1,520	5,544	4,180-6,240
MC-5004	682	800	560	540-560	3110	3070-3150
MC-5005	700	808	2176	2100-2220	7850	7455-7992

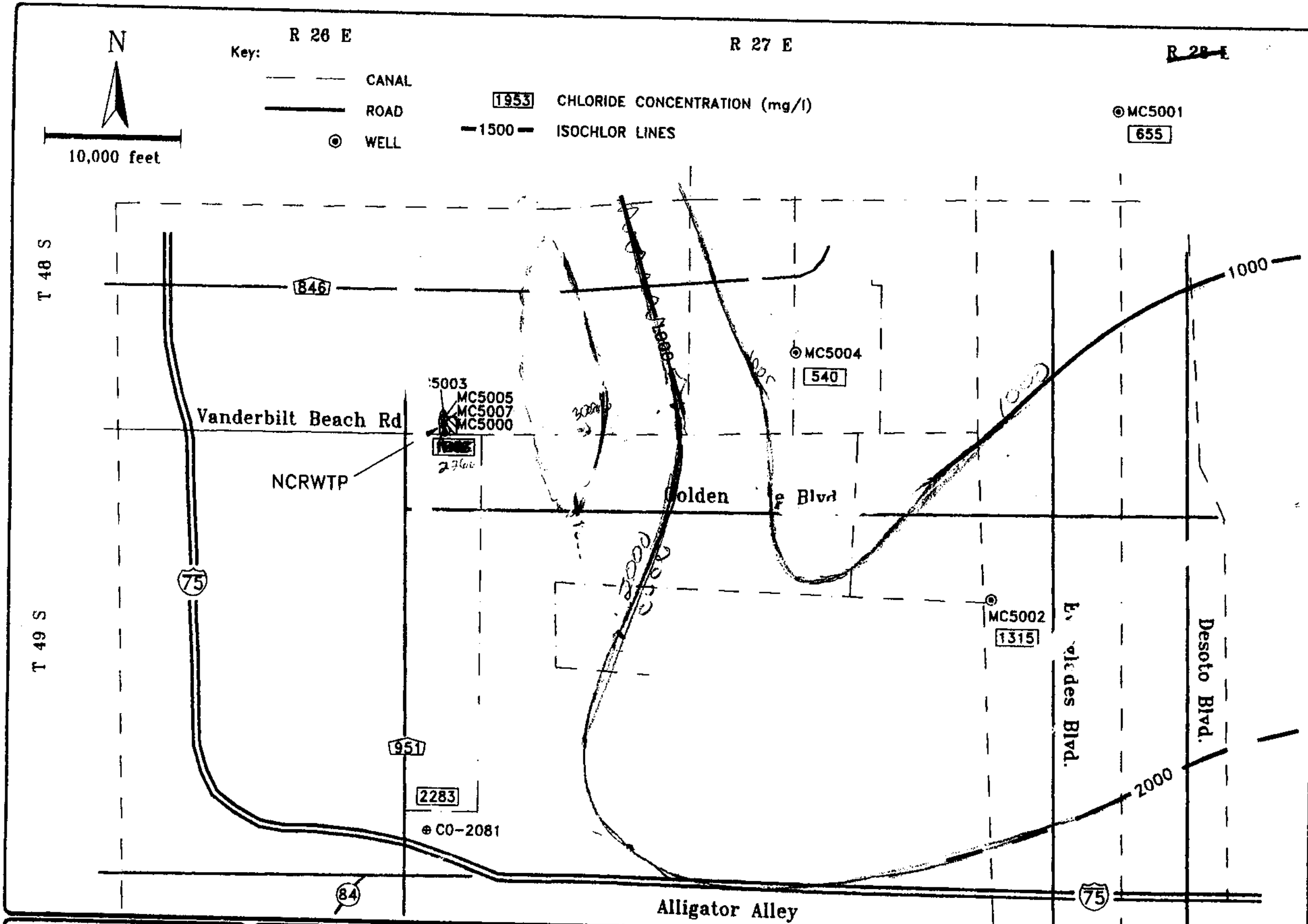
Hawthorn Aquifer is given in Figure 5-12. Data for deep wells drilled west and south of the study area at Pelican Bay and near Marco Island indicate that the lateral trend of increasing chloride concentrations west and south lessens to some degree. West of the study area water in the Lower Hawthorn Aquifer 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.

Water samples analyzed at various times during aquifer performance testing are provided in Table 5-6. Some increase in chloride concentration was noted during testing. However, this increase is attributed to short term equilibration of slightly differing water qualities within the aquifer during pumping. Also, the change was within the measurement error of the titration analysis method.

Additional water samples were collected and analyzed for typical parameters of concern for reverse osmosis treatment facilities. The primary chemical analysis was performed by B.F. Goodrich Laboratory in Brecksville, Ohio. Results of the analyses are presented in Table 5-7. Wells at the NCRWTP were chosen for the more detailed analysis to provide planning and treatment design based on the highest expected salinity from the wellfield.

Field tests for Silt Density Index (SDI), hydrogen sulfide, and Biological Activity Reaction tests were also performed on water samples from the Lower Hawthorn Aquifer at the NCRWTP. The SDI test was conducted to determine the rate at which colloidal and particle fouling would occur in the water purification system using the Lower Hawthorn Aquifer as the raw water supply. An SDI value of 1.92 was measured.

Biological Activity Reaction Tests (BART) were used to detect the presence of sulfate reducing bacteria, iron reducing bacteria and slime forming bacteria. BART tests allow rapid screening for the various bacteria and qualitative indications of presence and severity of bacterial colonies. Positive reactions were observed for all three



MISSIMER INTERNATIONAL

Pr Name: Collier Co. Wellfield

Pr.No. FH4-26 DWG No.FH4-26SL.DWG Date: 10/06/95 Rev.No. 12

Groundwater and Environmental Services

FIGURE 5-12. LOWER HAWTHORN AQUIFER – CHLORIDE CONCENTRATION.

TABLE 5-6. **WATER QUALITY DATA FOR THE LOWER HAWTHORN AQUIFER COLLECTED DURING THE 72 HOUR APT TEST AT NCRWTP**

TIME OF TEST START: 9:28AM MARCH 23, 1995.

WELL MC 5005 - 8 INCH PRODUCTION WELL			
Conductivity (uhoms)	Chlorides (mg/l)	Sampling Date	Sampling Time
7970	2240	MARCH 23	12:00 AM
8050	2260	MARCH 24	1:30 PM
8130	2290	MARCH 26	9:30 AM

TABLE 5-7. WATER QUALITY DATA FOR LOWER HAWTHORN PRODUCTION ZONE - NCRWTP

Cations	Conc. (ppm)	Drinking Water Standards (ppm)
Ammonium	0.60	10.0
Barium	0.03	1.0
Boron	0.82	1.0
Calcium	174.00	NA
Copper	0.01	1.0
Iron	0.01	0.30
Magnesium	167.40	125
Potassium	50.51	20
Silicon	8.13	20.0
Sodium	1427.20	160
Strontium	12.4	NA
Anions	**Conc. (ppm)**	**Drinking Water Standards (ppm)**
Chloride	2286.72	250
Fluoride	1.50	2.4
Sulfate	794.37	250

Additional Parameters	Conc.	Drinking Water Standards
Alkalinity, Total (ppm $CaCO_3$)	194.0	NA
Alkalinity, Bicarbonate (ppm $CaCO_3$)	194.0	NA
Carbon, Total Organic (ppm)	2.6	NA
Carbon Dioxide (As Ion, Calculated) (ppm)	18.3	NA
Hydrogen Sulfide (mg/l H_2S)	5.5	.01 - .1
Hardness, Total (ppm $CaCO_3$)	1124.7	NA
Silica, Total (ppm SiO_2)	17.4	NA
Silica, Reactive (ppm SiO_2)	16.8	NA
THM Formation Potential (ug/l)	170	100
TDS (ppm)	4268	500
Turbidity (NTU)	0.3	1.0
SDI	1.92	< 3.0 desired

TABLE 5-7.

WATER QUALITY DATA FOR
LOWER HAWTHORN PRODUCTION ZONE - NCRWTP
-Continued-

Foulants	Calculated Concentration
Calcium Carbonate Scaling Index*	1.2 ppm
Calcium Sulfate	78.9 %
Calcium Fluoride	8354.6%
Barium Sulfate	1121.1%
Silica	88.7%

*If the % of saturation exceeds 100 then antiscalant is required.
Projection of brine % of Saturation @ 80% recovery

microorganism groups within a 7-day period indicating that moderate bacterial populations are present in the Lower Hawthorn Aquifer. In addition, more detailed bacteriologic testing was conducted by Tri-Tek Laboratories in Orlando. The results of these analyses are given in Appendix 6.

<u>Aquifer Hydraulics</u>

The results of step drawdown tests performed on the Lower Hawthorn Aquifer are summarized in Table 5-8. The estimated artesian discharge from the uncapped 6-inch casings are approximately 890 gallons per minute (gpm) from well MC-5000, 910 gpm from well MC-5001, and 420 gpm from well MC-5002. These artesian total flows are the sum of the discharges from the Hawthorn Zone 1 and Lower Hawthorn aquifers and any minor flows from permeable strata within the Mid-Hawthorn confining zone. Cumulative flow diagrams were prepared for wells MC-5000, MC-5001, and MC-5002, using the flow meter and caliper logs (Figures 5-13 through 5-15). The diagrams illustrate the approximate percentage of the total discharge of the well that is occurring at different depths in each well. The cumulative flow diagrams suggest that the bulk of the artesian flow in each well comes from the Lower Hawthorn Aquifer, with subsidiary contributions from the Hawthorn Zone I Aquifer and the limestones underlying the Lower Hawthorn Aquifer. The flowmeter and caliper logs for well MC-5000, reveal that the bulk of the artesian flow from the Lower Hawthorn aquifers is coming from a relatively thin section of apparently vuggy and/or fractured dolomite bed at approximately 755 feet bls. An approximate equilibrium artesian flow rate of 700 gpm was measured in well MC-5005.

Logarithmic and semi-logarithmic graphs of time vs. drawdown were constructed for Lower Hawthorn Aquifer based on data collected from monitor wells MC-5000 and MC-5007 during the 72-hour aquifer performance test. 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):

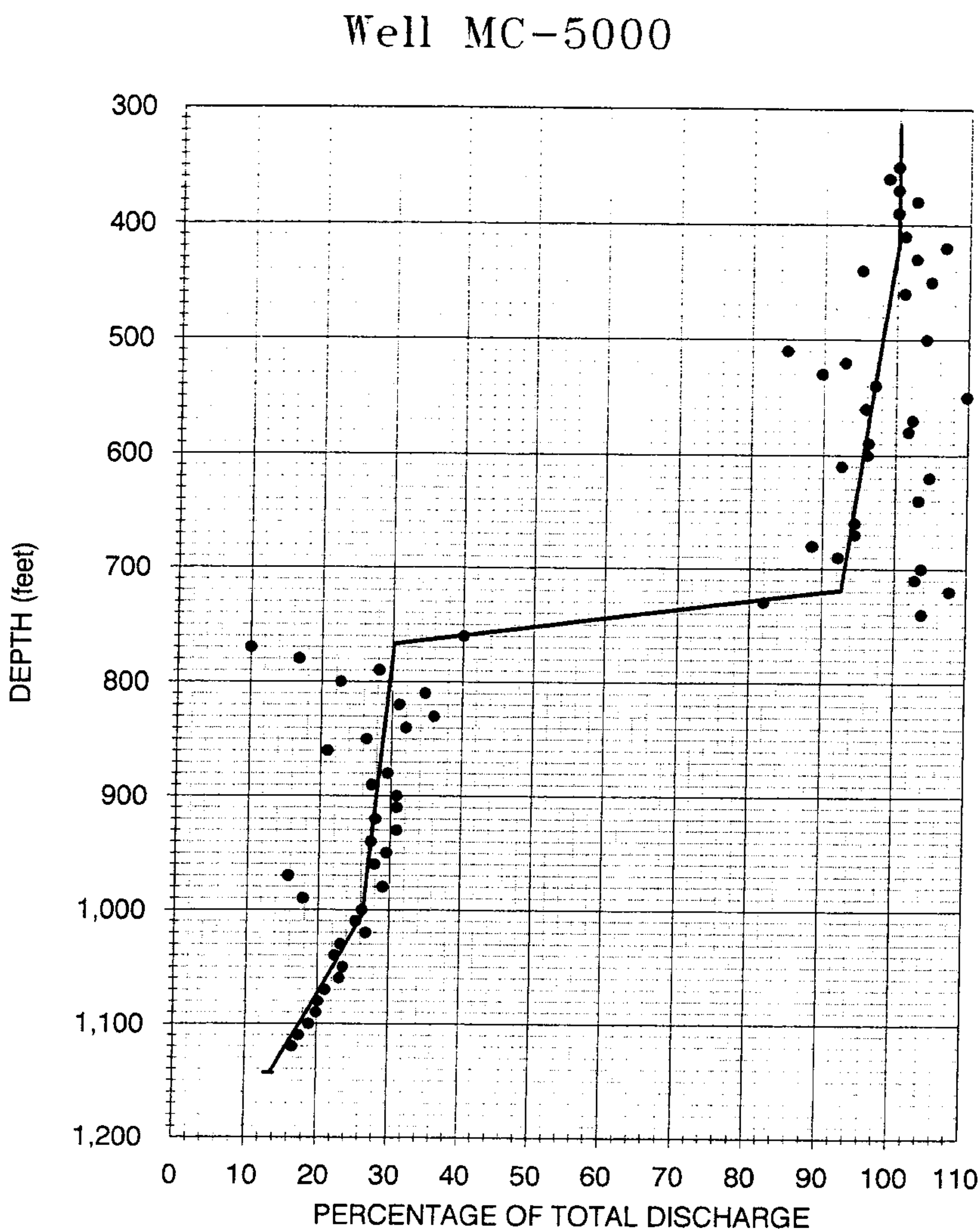
TABLE 5-8. LOWER HAWTHORN AQUIFER STEP-DRAWDOWN TEST RESULTS

WELL MC-5004 (Static water level = 47.34 above NGVD)		
DISCHARGE (gpm)	DRAWDOWN (feet)	SPECIFIC CAPACITY (gpm/ft)
33	32.47	1.02
37	40.44	.91
40	47.29	.85
47	57.06	.82

WELL MC-5005 (Static water level = 41.72 above NGVD)		
DISCHARGE (gpm)	DRAWDOWN (feet)	SPECIFIC CAPACITY (gpm/ft)
320	5.77	55.46
420	10.16	41.34
520	14.32	36.31
604	18.24	33.11
685	22.64	30.26

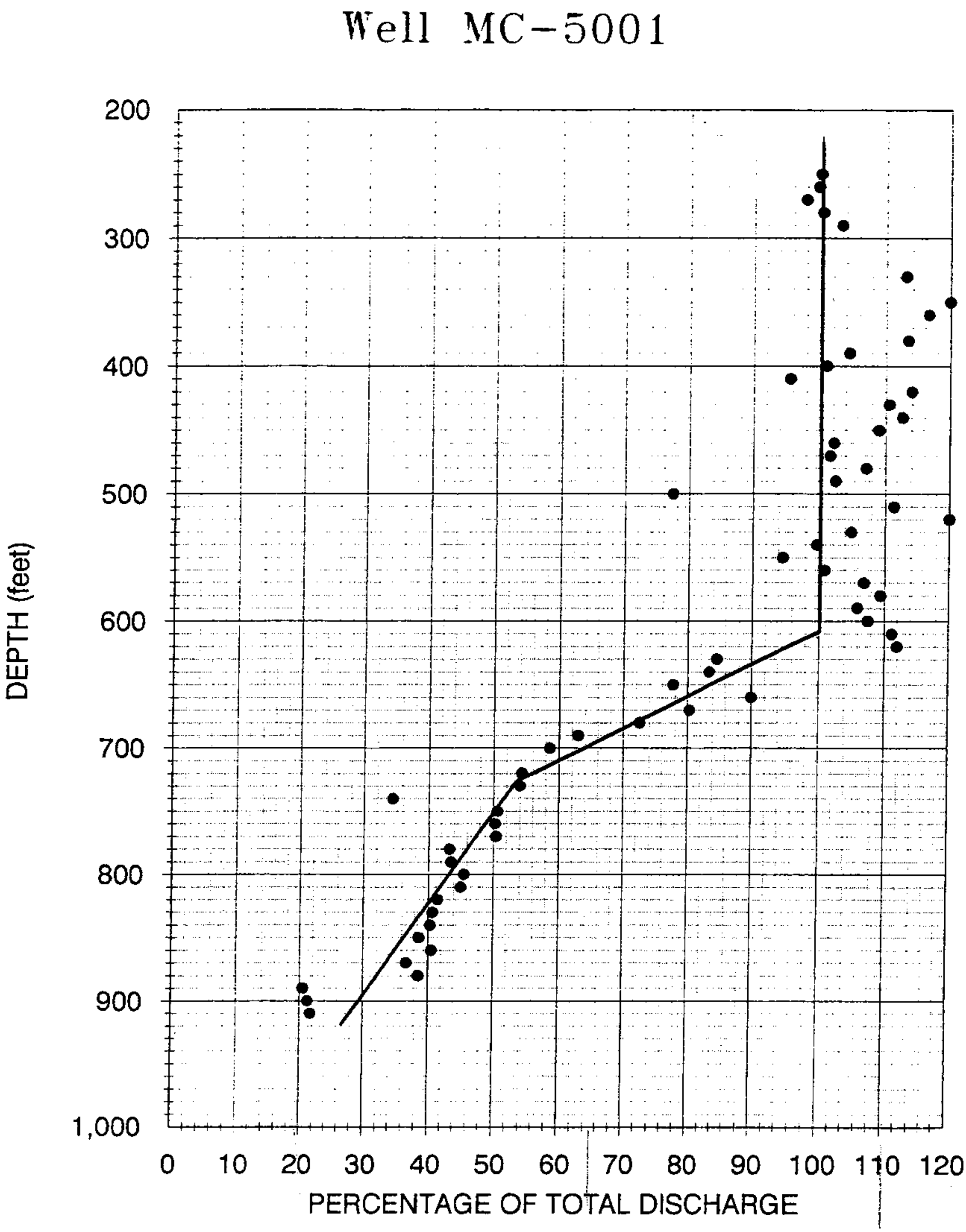
Additional data for step-drawdown tests are provided in the appendix.

The low specific capacity values determined by pump testing well MC-5004 are possibly due to formation change caused by the mud drilling operation or problems associated with obtaining pressure measurements within the flow of the well during the pump test. The results are not considered representative of the hydraulic characteristics of the aquifer at this location.



MISSIMER INTERNATIONAL	Pr Name: COLLIER CO. WELLFIELD	Groundwater and Environmental Services
	Pr No. FH4-26 Date: 06/21/95	
	DWG No. CUT&PASTE Rev.No. 1	

FIGURE 5-13. CUMMULATIVE FLOW DIAGRAM; WELL MC-5000; VANDERBILT BEACH RD. EXTENTION, GOLDEN GATE ESTATES, COLLIER CO., FLORIDA.

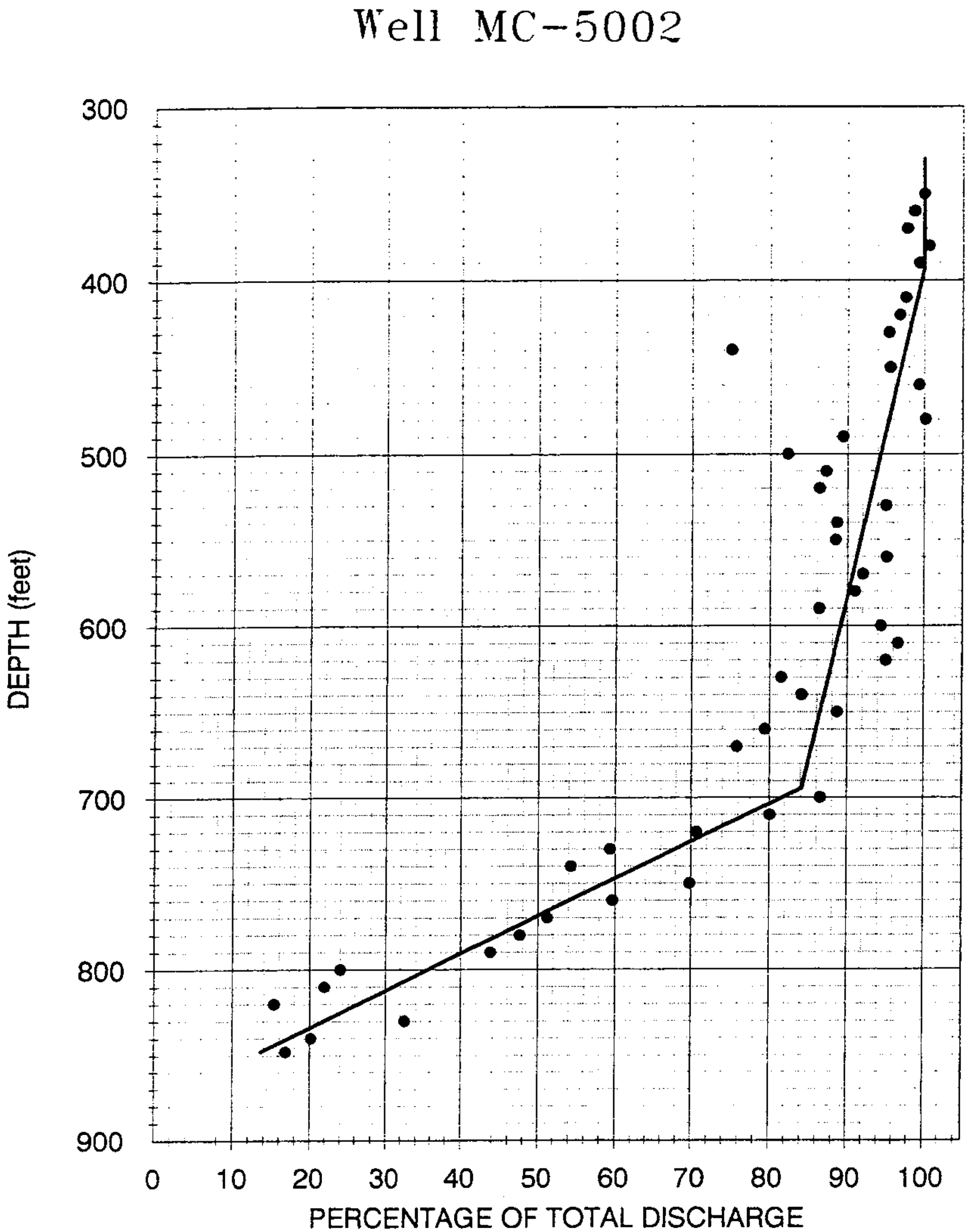


MISSIMER INTERNATIONAL

Pr Name: COLLIER CO. WELLFIELD	
Pr No. FH4-26	Date: 06/21/95
DWG No. CUT&PASTE	Rev.No. 1

Groundwater and Environmental Services

FIGURE 5-14. CUMMULATIVE FLOW DIAGRAM; WELL MC-5001; 40th Ave. OFF OF 43rd Ave. N.E., GOLDEN GATE ESTATES, COLLIER CO., FLORIDA.



MISSIMER INTERNATIONAL

Pr Name: COLLIER CO. WELLFIELD
Pr No. FH4-26 Date: 06/21/95
DWG No. CUT&PASTE Rev.No. 1

Groundwater and Environmental Services

FIGURE 5-15. CUMMULATIVE FLOW DIAGRAM; WELL MC-5002; 10th Ave. S.E., WEST OF EVERGLADES BLVD., GOLDEN GATE ESTATES, COLLIER CO., FLORIDA.

$$T = \frac{Q\,L(u,v)}{4\,\pi\;s} \qquad (1)$$

$$S = \frac{4\,T\,t}{r^2\,(1/u)} \qquad (2)$$

$$L = \frac{4T\,(v)^2}{r^2} \qquad (3)$$

where,

T = transmissivity (ft^2/day)

Q = pumping rate (ft^3/day)

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

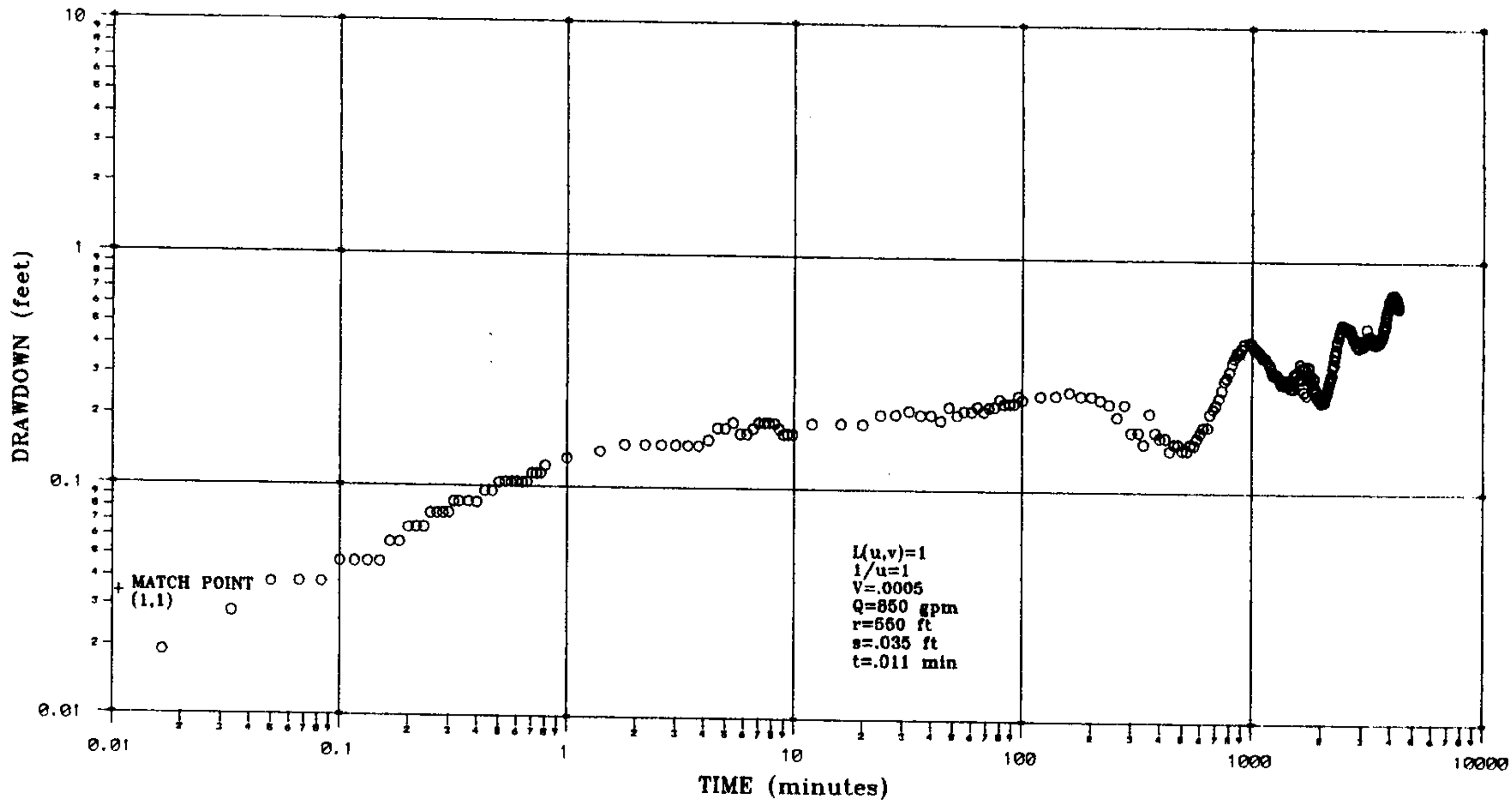
L = Leakance (^{1}/days)

Logarithmic plots of drawdown vs. time are given for each of the monitor wells in Figures 5-16 and 5-17.

Semi-log plots of drawdown vs. time were analyzed by the Jacob (1950) method to verify transmissivity and storage values from initial analysis (Figures 5-18 and 5-19). Appropriate time and drawdown data were substituted into equations (4) and (5).

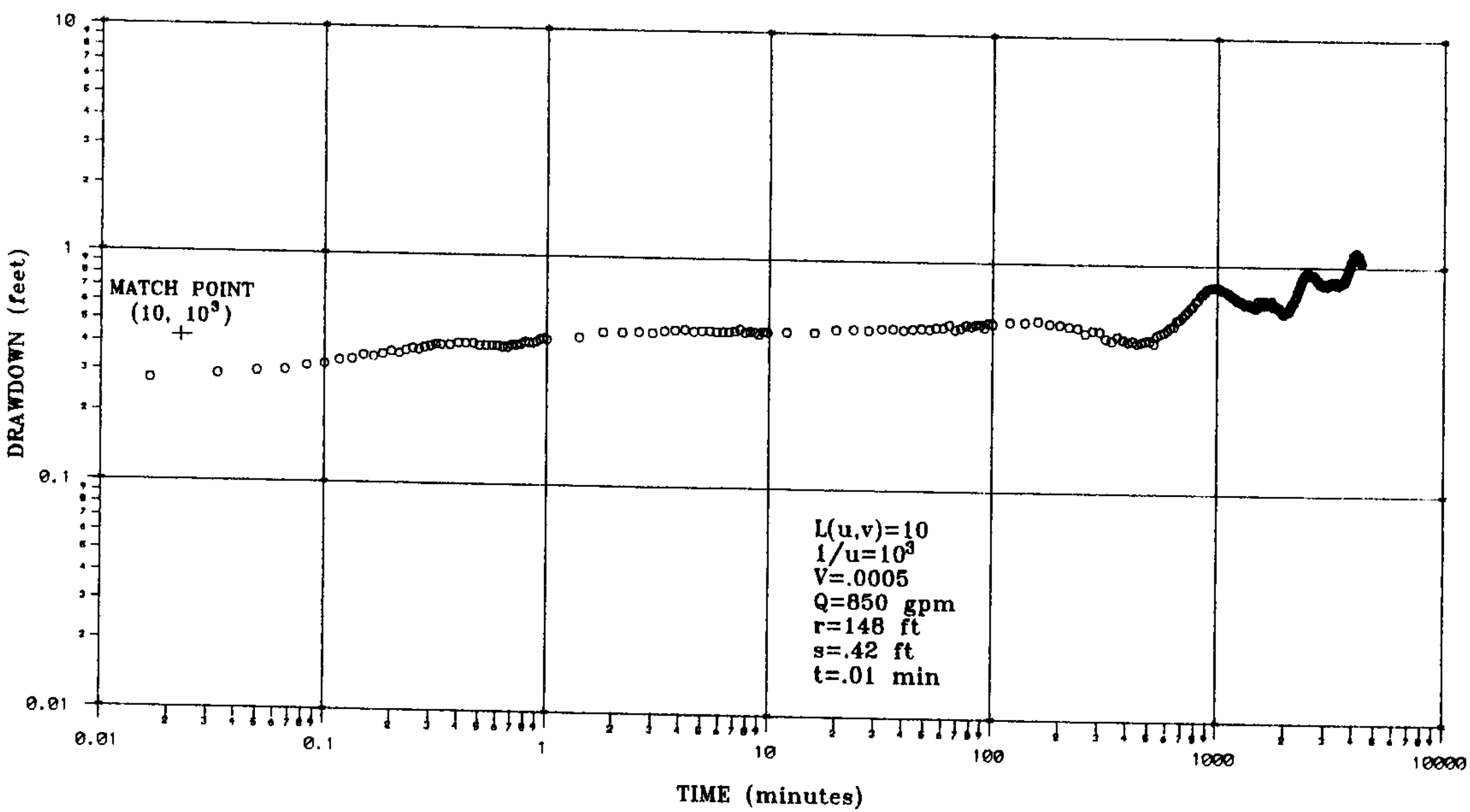
$$T = \frac{2.3\,Q}{\Delta s\,4\,\pi} \qquad (4)$$

$$S = \frac{2.25\,T\,t_o}{r^2} \qquad (5)$$



MISSIMER INTERNATIONAL	Pr Name: COLLIER COUNTY R.O.WELLFIELD	Groundwater and Environmental Services
	Pr.No. FH4-26 DWG No.FH426-D4.DWG Date: 06/21/95 Rev.No. 6	

FIGURE 5-16. DRAWDOWN IN TEST WELL MC-5000 (LOWER HAWTHORN AQUIFER) DURING THE AQUIFER PERFORMANCE TEST ON PRODUCTION WELL MC-5005 Q=850



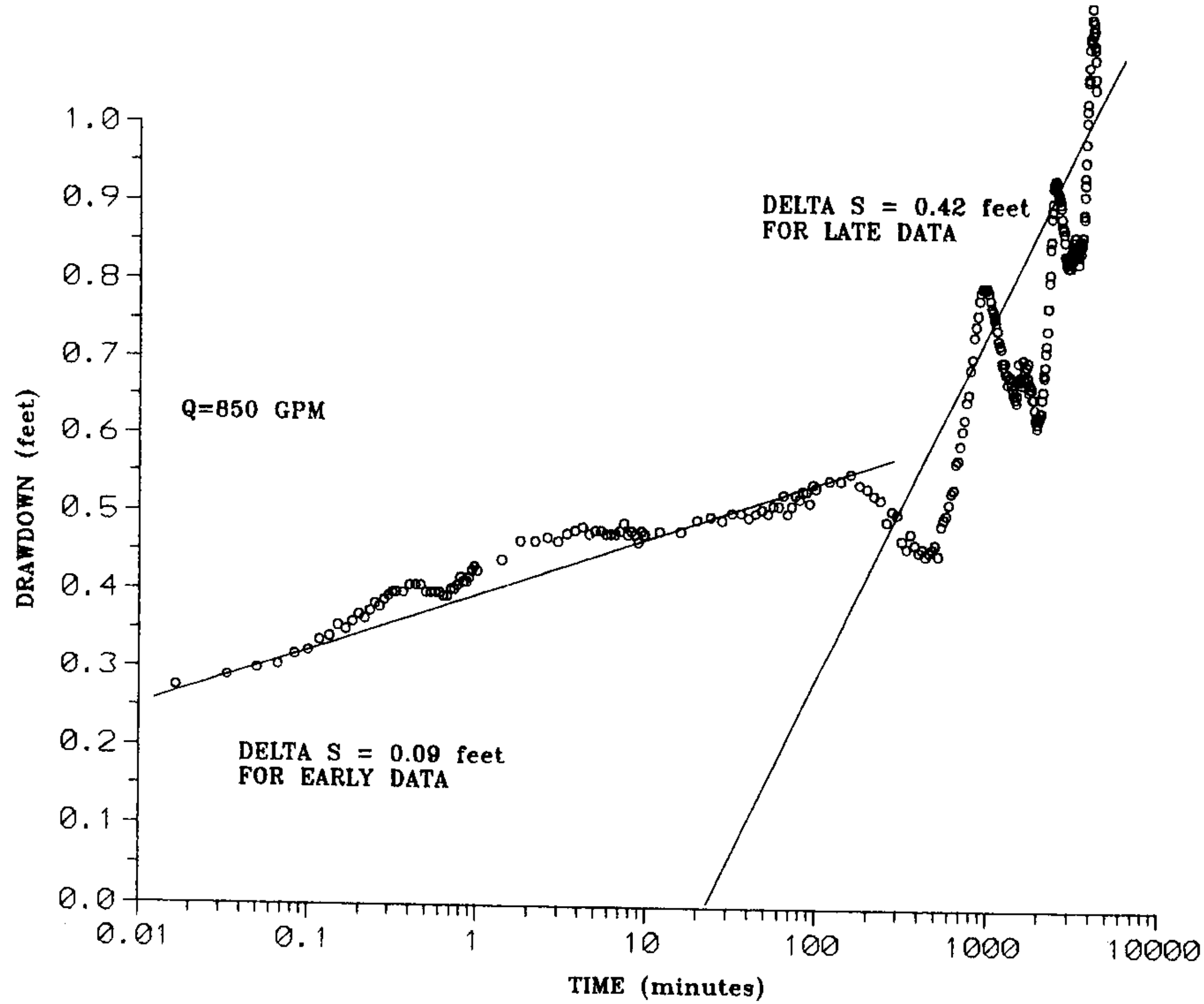
MISSIMER INTERNATIONAL

Pr Name: COLLIER COUNTY R.O. WELLFIELD

Pr.No. FH4-26 DWG No.FH426-D1.DWG Date: 06/21/95 Rev.No. 5

Groundwater and Environmental Services

FIGURE 5-17. DRAWDOWN IN TEST WELL MC-5007 (LOWER HAWTHORN AQUIFER) DURING THE AQUIFER PERFORMANCE TEST ON COLLIER COUNTY PRODUCTION WELL MC-5005 Q=850.

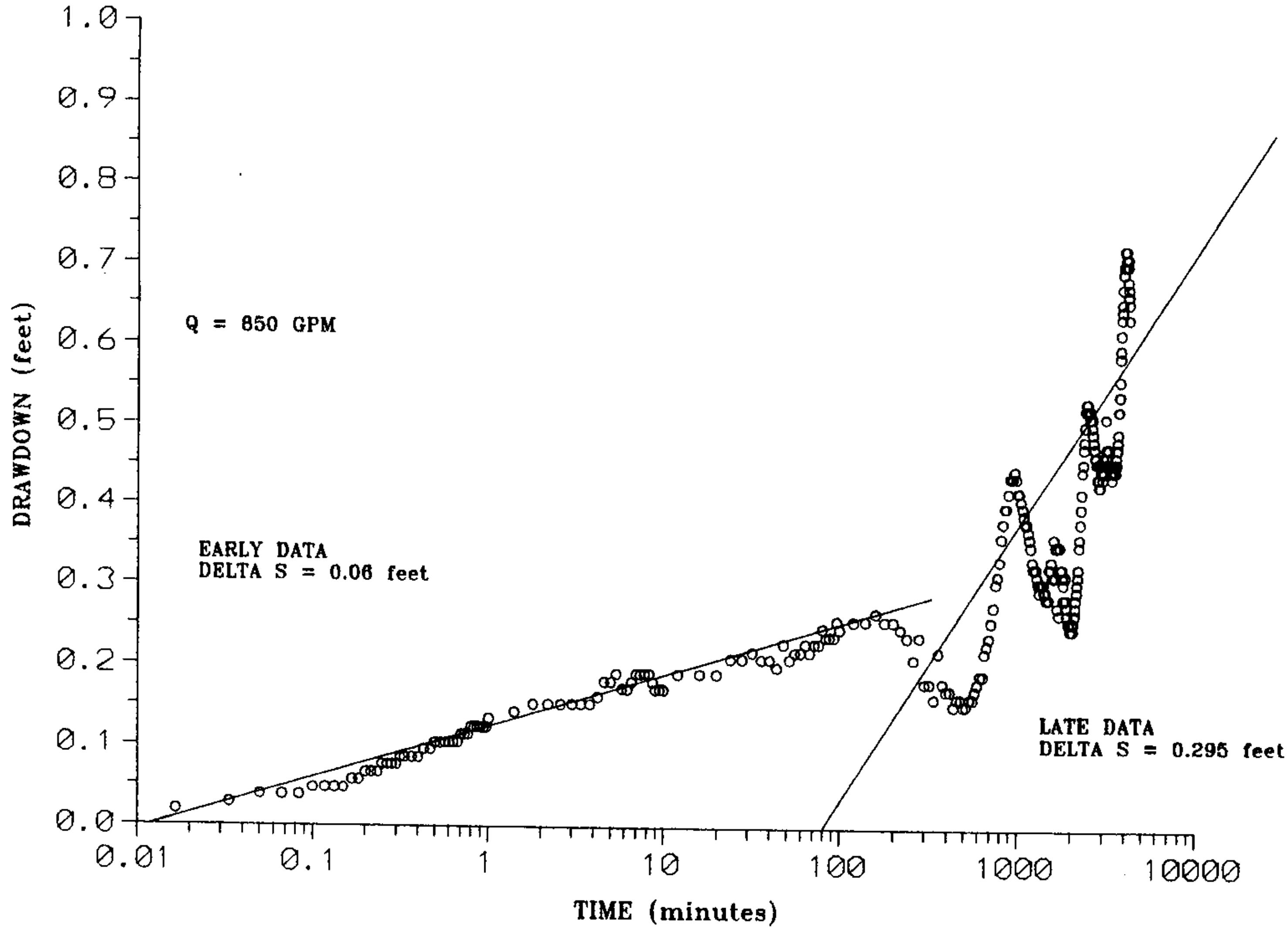


MISSIMER INTERNATIONAL

Pr Name: COLLIER COUNTY R.O. WELLFIELD	
Pr.No. FH4-26	DWG No. FH426-D5.DWG Date: 06/21/95 Rev.No. 5

Groundwater
and
Environmental Services

FIGURE 5-18. SEMI-LOG PLOT OF DRAWDOWN vs TIME IN MONITOR WELL MC-5007 DURING THE AQUIFER PERFORMANCE TEST ON TEST PRODUCTION WELL MC-5005 (LOWER HAWTHORN AQUIFER).



MISSIMER INTERNATIONAL	Pr Name: COLLIER COUNTY R.O. WELLFIELD		Groundwater and Environmental Services
	Pr.No. FH4-26	DWG No.FH426-D6.DWG Date: 06/21/95 Rev.No. 5	

FIGURE 5-19. SEMI-LOG PLOT OF DRAWDOWN vs TIME IN MONITOR WELL MC-5000 (LOWER HAWTHORN AQUIFER) DURING THE AQUIFER PERFORMANCE TEST ON TEST PRODUCTION WELL MC-5005 (LOWER HAWTHORN AQUIFER).

where,

Δs = Head difference between log cycles (feet)

t_o = time at zero drawdown/recovery (days)

The calculated hydraulic coefficients for the Lower Hawthorn Aquifer are provided in Table 5-9.

Analyses of the time-drawdown data recorded in Lower Hawthorn monitor wells MC-5000 and MC-5007 indicate that a hydraulic boundary condition may exist in the area of the NCRWTP. This boundary likely occurs as cavernous permeability near the test site gives way to less cavernous or more matrix type groundwater flow. Calculated transmissivity in either case remains very high with values ranging from approximately 500,000 gpd/ft to over 2,500,000 gpd/ft. A plot of the early data produced a flat curve which implied that equilibrium drawdown occurred rapidly. A graph of later data showed that drawdown was once again occurring after approximately eight hours of pumping. The late drawdown occurred as the cone of depression around the pumping well reached the boundary of the highly cavernous portion of the aquifer. Under these conditions, a calculation of hydraulic coefficients based on either early or late data could lead to erroneous predictions.

Additionally, analysis of drawdown indicates the influence of tidal fluctuations. Based on background water level data collected prior to testing, the start of the APT was timed to correspond with the beginning of a tidal peak so that ±4 hours of drawdown data could be collected without significant tidal movement. Because of the high amplitude of tide influence relative to the drawdown, attempts to correct for tidal effects based on calculated lag times met with only limited success and had no effect on analysis of the aquifer hydraulic coefficients.

During the 72-hour testing period, leakance is believed to have been masked by the very high transmissivity and boundary condition encountered in this zone. For these reasons, the following conservative values were used for purposes of computer modelling:

TABLE 5-9. **AQUIFER HYDRAULIC COEFFICIENTS CALCULATED FOR THE LOWER HAWTHORN AQUIFER AT THE NCRWTP SITE**

Well	Transmissivity (gpd/ft)	Storage Coefficient	*Leakance (gpd/ft³)
Curve Matching Method (Cooper 1963)			
MC-5000	2.8×10^6	3.7×10^{-5}	1.3×10^{-3}
MC-5007	2.3×10^6	1.0×10^{-5}	1.3×10^{-3}
Straight- Line Method - Early Data (Jacob 1950)			
Well	Transmissivity (gpd/ft)	Storage Coefficient	Leakance (gpd/ft³)
MC-5000	3.7×10^6	2.8×10^{-5}	NA
MC-5007	2.5×10^6	1.1×10^{-5}	NA
Straight - Line Method - Late Data (Jacob 1950)			
Well	Transmissivity (gpd/ft)	Storage Coefficient	Leakance (gpd/ft³)
MC-5000	7.6×10^5	4.3×10^{-2}	NA
MC-5007	5.3×10^5	1.1×10^{-1}	NA

* Leakance values could not be determined using a conventional curve match, because of tidal pressure fluctuations. The leakance values were determined by computer interation using the measured transmissivity and storativity values with the associated distances between the production well and the observation well.

Transmissivity: = 500,000 gpd/ft

Leakance: = 1.0×10^{-4} gpd/ft^3

A value of 500,000 gpd/ft, although very high, represents the lowest transmissivity expected for this zone. A leakance value of 1.0×10^{-4} gpd/ft^3 was chosen based on iterative calculations from the aquifer performance test and regionally calculated values. Both are conservative in that higher transmissivity is calculated for the aquifer near the test site and the higher leakance allows for upconing of deeper aquifer waters in modeling simulations.

5.4.2 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. The cumulative flow diagram for well MC-5000 (Figure 5-13) indicates that there is artesian water production from the Suwannee Limestone, but the quantity is much less than that of the Lower Hawthorn Aquifer.

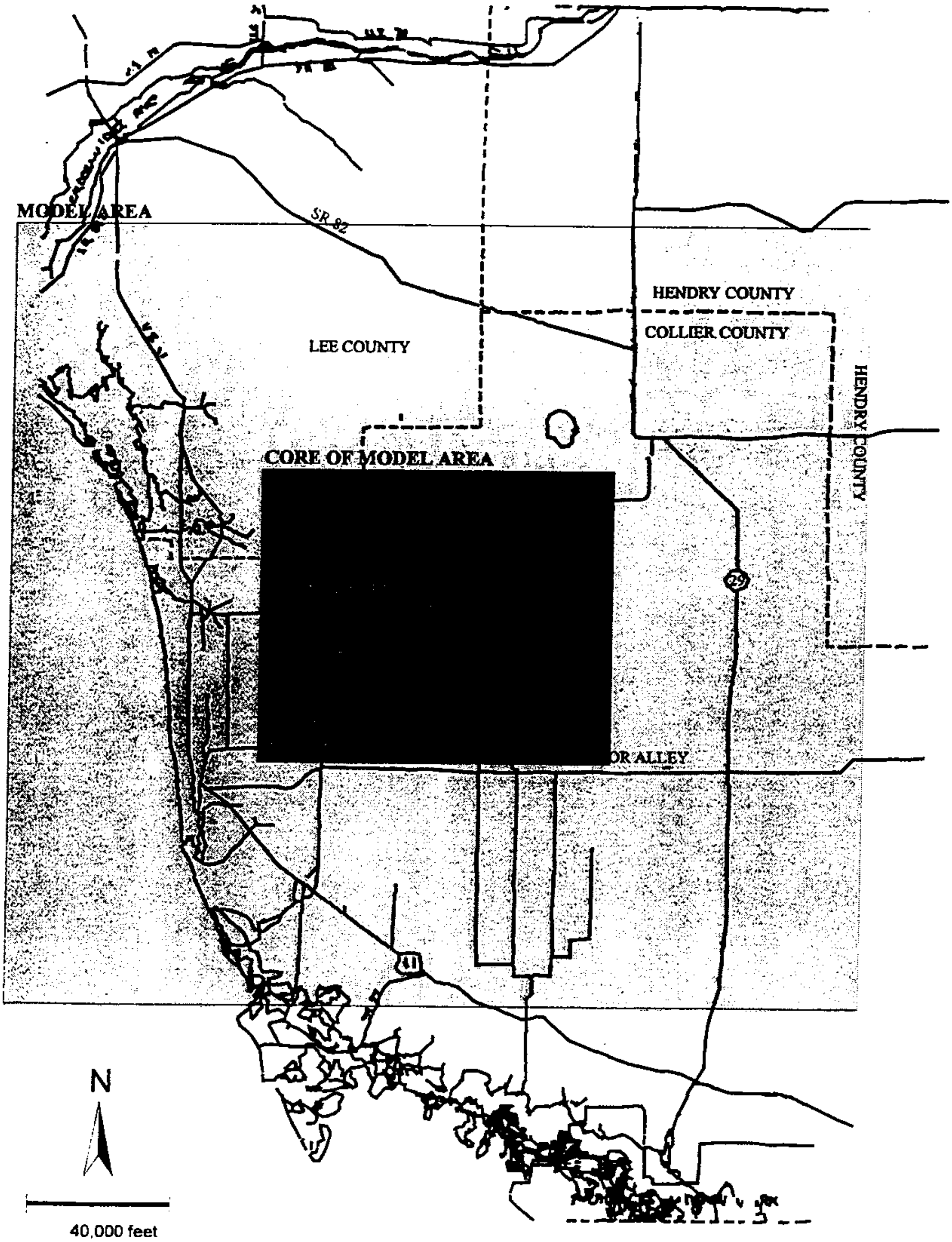
The groundwater samples collected from the Suwannee Limestone in well MC-5000 had a relatively constant dissolved chloride concentration, similar to that of the Lower Hawthorn Aquifer ($\approx$ 2,200 $\pm$ 200 mg/l). The groundwater samples collected from well MC-5001 had a trend of increasing chloride concentration with depth, with values ranging from 800 mg/l at 720 feet to 1,380 mg/l at 920 feet. A groundwater sample collected from well MC-5002 near the top of the Suwannee limestone had a chloride concentration of 1410 mg/l.

6.0 GROUNDWATER MODELING AND WELLFIELD CONFIGURATION

6.1. Introduction

Groundwater modeling of the Intermediate and Upper Floridan aquifer system was required to select optimal wellfield locations and to determine potential hydraulic impact and changes in groundwater quality that would result from the proposed withdrawals from new wellfields. Drawdowns and changes in water quality resulting from design withdrawal rates were determined for various wellfield locations through a number of alternative modeling scenarios. Potential wellfield locations were selected for the proposed Collier County Lower Hawthorn Aquifer withdrawals based on hydrogeologic conditions, site availability, site accessibility, distance to the water treatment plant, construction logistics and economics. The modeled area covers the northern portion of Collier County centering around the North County Regional Water Treatment Plant (NCRWTP) and extending into southern Lee County and western Hendry County. The core model area is in the center of the modeled area and encompasses the NCRWTP and the proposed Collier County Lower Hawthorn Aquifer wellfield sites. A map of the model area is presented in Figure 6-1.

Flow and solute transport models of the area were developed using tested and verified codes capable of simulating aquifer response to groundwater withdrawals and density dependent groundwater flows. The flow model was used for initial model calibrations because the significantly lower simulation time 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 transfer and density dependent flow components to the hydraulic parameters determined from the calibration model.



MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Incestigation	
Pr. No. FH4-26	Date 9/25/95
DWG No.	Rev. No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-1. MAP OF MODEL AREA SHOWING CORE MODEL AREA

6.2. Flow Models

Two flow models were developed for the site. The first, a calibration model, was discretized to provide results at a resolution suitable to depict the aquifer performance test sites. The second (predictive) model was discretized to provide results on a wellfield scale.

6.2.1 Calibration Model

A three-dimensional flow model of the site was developed using the U. S. Geological Survey's finite difference code, MODFLOW (McDonald and Harbaugh, 1988). The model was used to simulate aquifer response under aquifer performance test (APT) conditions. The model was calibrated for both Hawthorn Zone 1 and the Lower Hawthorn production zones by varying aquifer parameters such as leakance and transmissivity until simulated drawdown matched drawdown observed in the field during the APT. Model calibration was primarily limited to short term simulations due to the lack of adequate long term monitoring data on the Intermediate or Floridan Aquifer systems in the model area. 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 the Lower Hawthorn Aquifer, model updates and revisions are recommended.

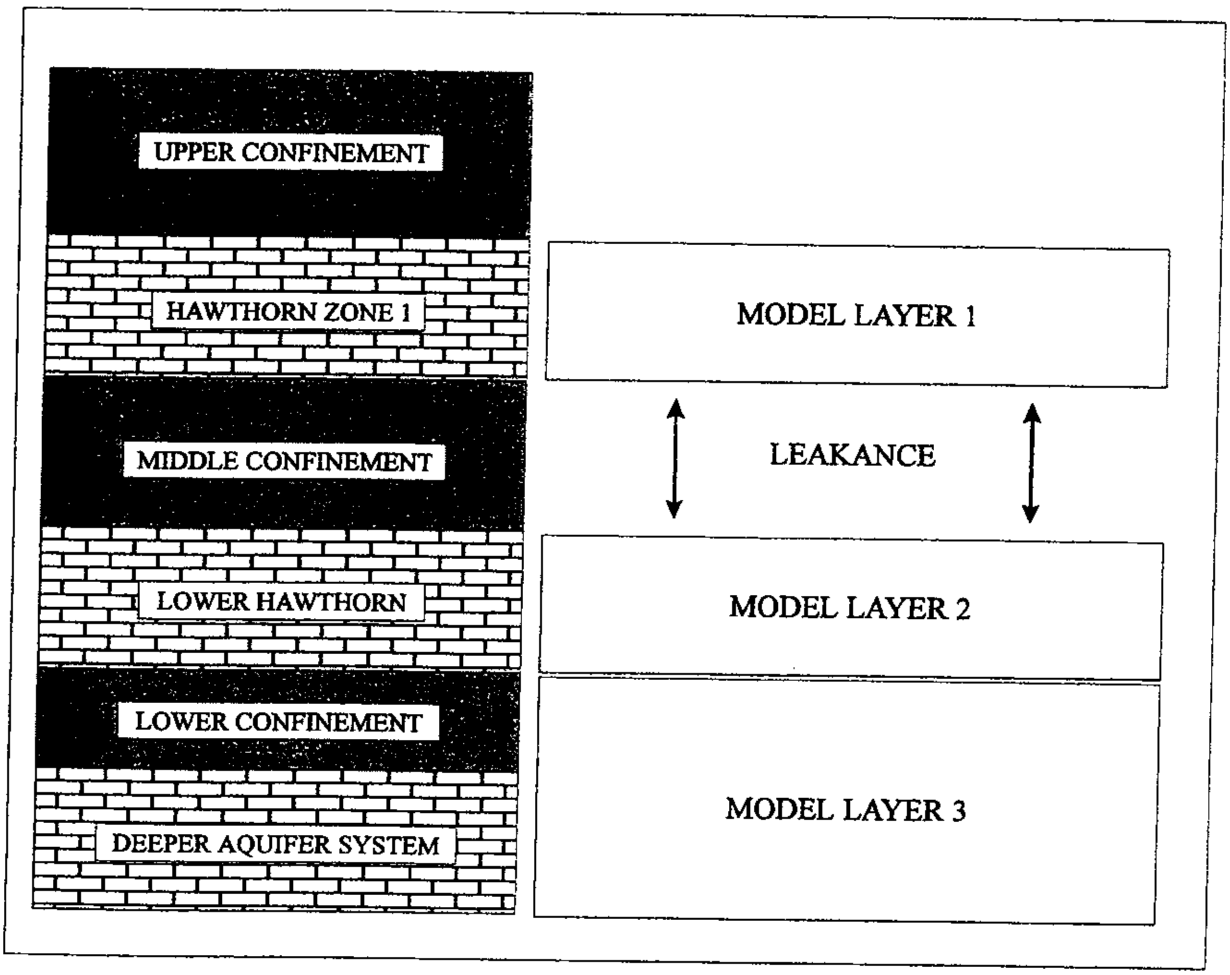
Model Design

A multi-layer representation consistent with the generalized geology of the area was used to model the Intermediate and upper Floridan Aquifer systems. The model layers correspond to observed hydrostratigraphic units identified from well logs at the site and represent Hawthorn Zone 1, the middle confining bed, Lower Hawthorn Aquifer, and the lower confining beds and underlying aquifer units. Utilizing a quasi three-dimensional modeling approach, the confining bed between Hawthorn Zone 1 and the Lower Hawthorn aquifers was represented by a leakance term that controls flow between these layers in the calibration model. Note that while the use of a leakance term to represent a semi-confining unit is suitable for flow models, it may not be appropriate for solute transport models. A model layer was therefore assigned to represent the semi-confining unit in the solute transport model. A total of three active model layers were thus used in the flow model to represent the conceptual four-layer system. A schematic representation of the conceptual model is shown in Figure 6-2.

Starting values for the aquifer hydraulic parameters were specified based on aquifer coefficients calculated from results of aquifer performance tests conducted at the NCRWTP site.

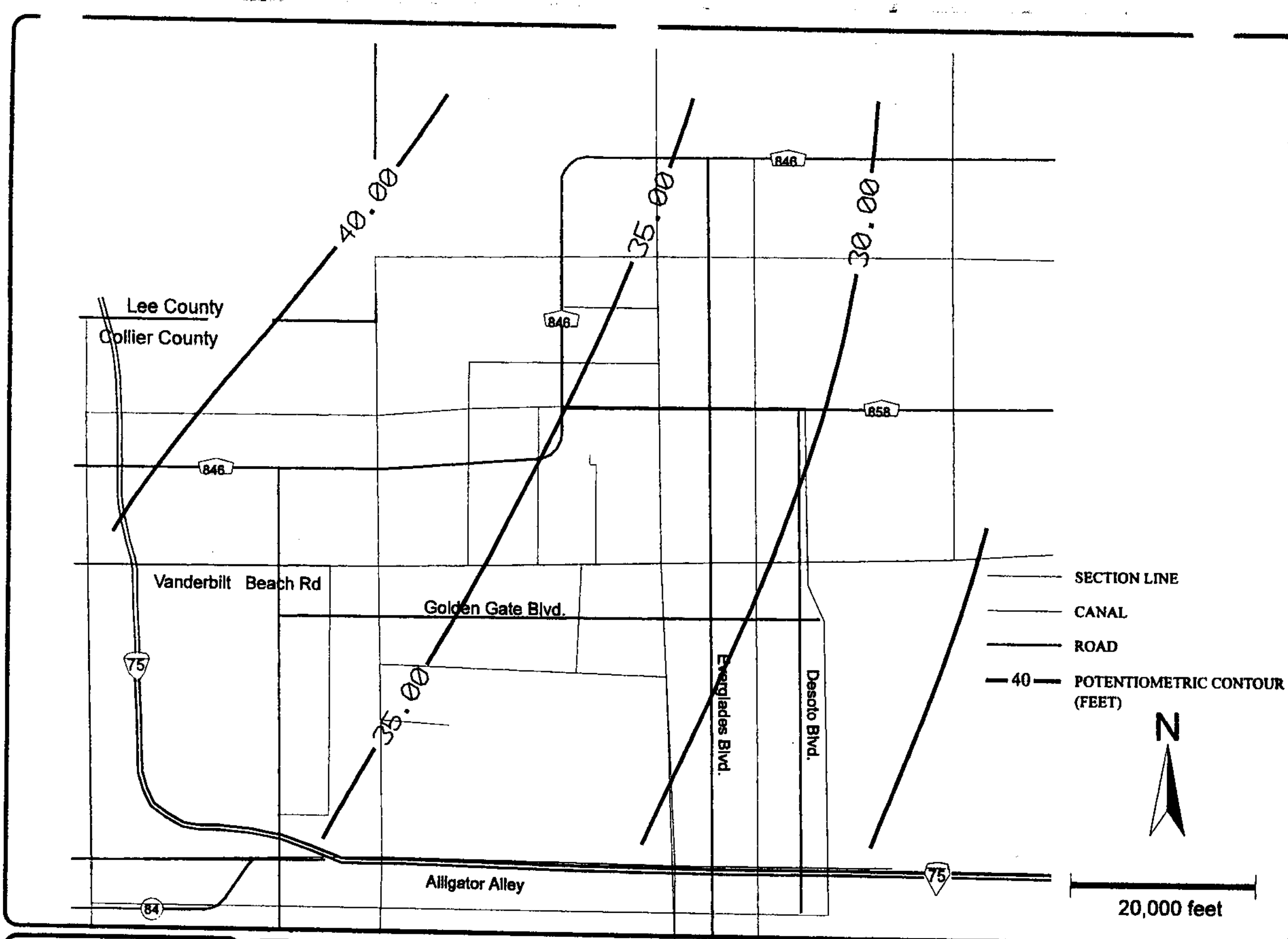
The lateral boundaries of the model were set far from the wellfield locations to minimize boundary effects on the model results. Constant heads were specified at these locations such that computed gradients closely match the natural gradient observed in the central or core model area. Figures 6-3 and 6-4 show the computed potentiometric surface over the core model area superimposed on a site map. The lowest model layer is given as a general head type boundary that depicts the semipervious lower confining beds and underlying aquifers. The uppermost model layer, representing the Hawthorn Zone 1 Aquifer, is overlain by a no-flow boundary to represent the confinement between the Surficial aquifer system and the lower portion of the Intermediate aquifer system.

A variably spaced model grid configuration was adopted for the modeling utilizing small grid spacing (for higher resolution) close to the potential wellfield locations and larger grid spacing far from these areas of interest. The smallest grids were located at the area corresponding to the APT site. The calibration model has 76 columns, 73 rows and three layers. The model grid cell configuration superimposed over a site map is shown on Figure 6-5. The model grid at the APT site superimposed over the site map is shown in Figure 6-6.



MISSIMER INTERNATIONAL, INC.	Pr. Name: Collier County RO Source Water Investigation Pr. No. FH4-26 Date: 9/25/95 DWG No. Rev. No.	GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-2. SCHEMATIC REPRESENTATION OF FLOW MODEL



MISSIMER INTERNATIONAL, INC.

Pr.Name: Collier County RO Source Water Investigation Dwn.By:

Pr.No. FH4-26 DWG No. Date: 8/8/95 Rev.No.

Groundwater and Environmental Services

FIGURE 6-3 COMPUTED POTENTIOMETRIC SURFACE FOR HAWTHORN ZONE 1 AQUIFER SUPERIMPOSED OVER SITE MAP

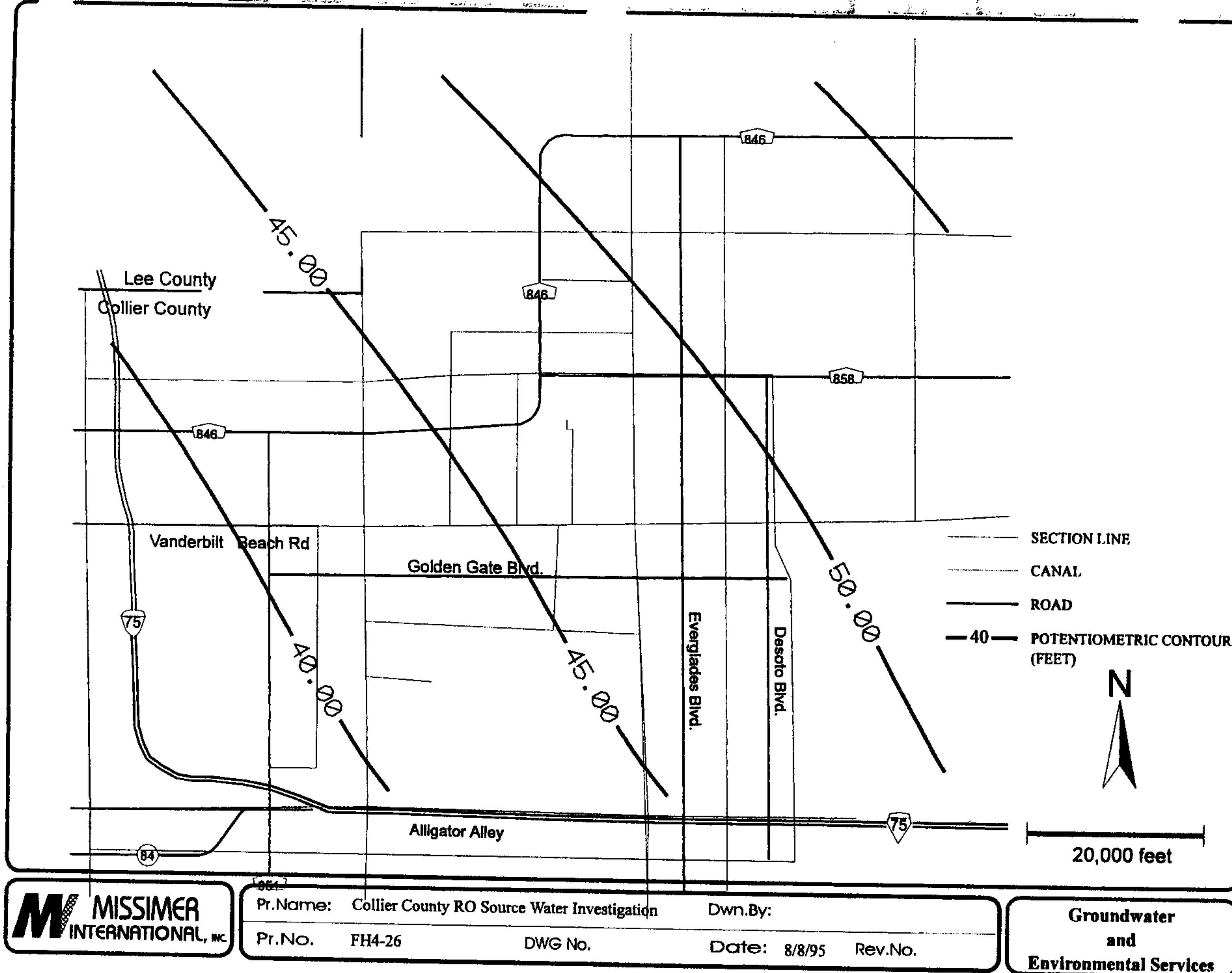
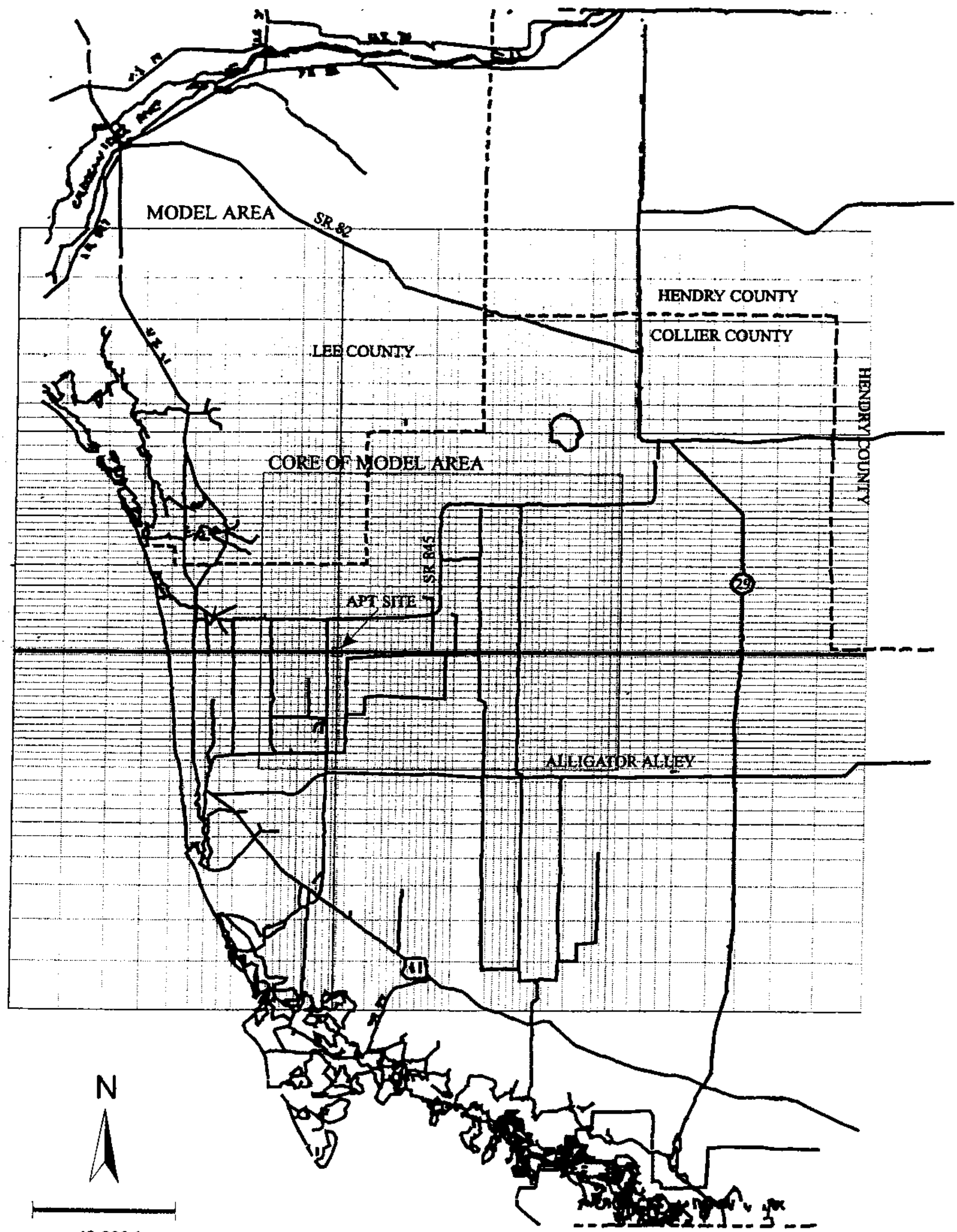


FIGURE 6-4 COMPUTED POTENTIOMETRIC SURFACE FOR LOWER HAWTHORN AQUIFER SUPERIMPOSED OVER SITE MAP

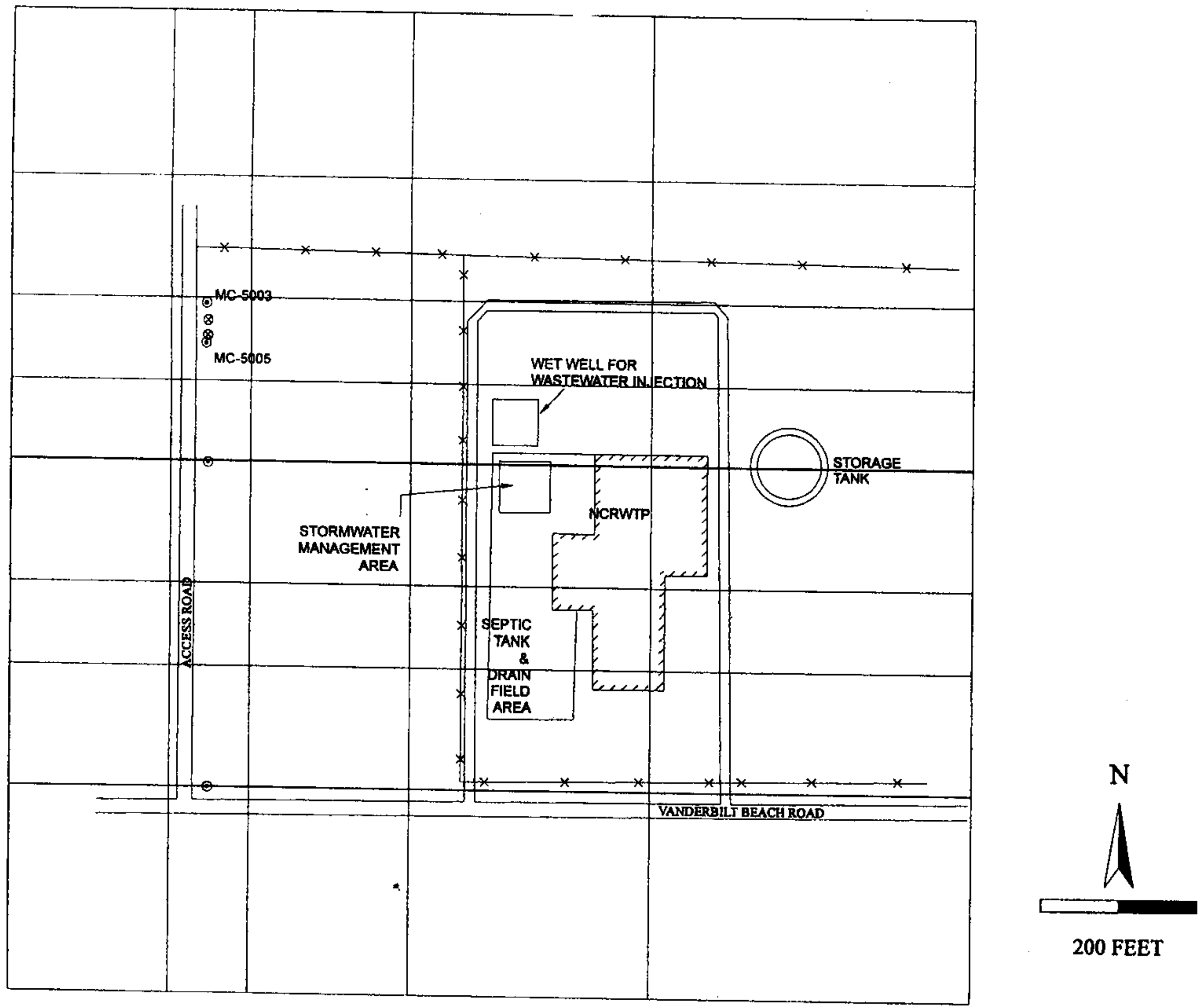


MISSIMER INTERNATIONAL, INC.

Pr. Name:	Collier County RO Source Water Investigation		
Pr. No.	FH4-26	Date:	8/8/95
DWG No.		Rev. No.	

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-5. MODEL GRID SUPERIMPOSED OVER SITE MAP (CALIBRATION MODEL)



MISSIMER INTERNATIONAL, INC.

Pr.Name: Collier County RO Source Water Investigation		Dwn.By:	
Pr.No. FH4-26	DWG No.	Date: 8/8/95	Rev.No.

Groundwater and Environmental Services

FIGURE 6-6 MODEL GRID AT APT SITE SUPERIMPOSED OVER SITE MAP

Withdrawal rates used in the calibration model were 540 gpm for the Hawthorn Zone 1 Aquifer and 850 gpm for the Lower Hawthorn Aquifer. These simulated production rates correspond to the average measured pumping rates during respective APT. Simulated duration was 72 hours from the start of pumping.

Model Calibration

The model calibration process involves adjustment of model input parameters until model output (computed water levels) closely matches water level fluctuations observed in the field. Water level data from the APT conducted in the Hawthorn Zone 1 and the Lower Hawthorn aquifers were used for model calibration. Drawdown in Hawthorn Zone 1 at a distance from the withdrawal cell approximately equal to the distance between the test production well MC-5003 and the monitor well MC-5000 was compared to the observed drawdown. Similarly, drawdowns in the Lower Hawthorn Aquifer at two locations representing monitor wells MC-5007 and MC-5000 at distances of 148 and 550 feet, respectively, from the withdrawal cell were compared to observed drawdown in these wells. Aquifer coefficients calculated from the results of the APTs were specified in the initial model. These coefficients were then refined using an iterative procedure to improve the match between the computed and observed drawdown at each of the monitor wells for each test. The coefficients resulting in the best overall fit were considered most representative of the system and used in subsequent modeling of the aquifer systems.

Where long-term data are available, typically, a steady state calibration is first conducted followed by a transient calibration. Since storage data are not required for the steady state calibration, only boundary conditions, transmissivities and leakance need be varied. The subsequent transient calibration varies storage primarily and refines the other variables slightly as necessary to improve the fit. However, because there were no long term data available at the site, direct transient calibration to short term data was necessary. For this reason, significantly more iterations for various combinations of aquifer parameters were required to arrive at an acceptable fit. The acceptable search range for each parameter was determined based on known properties of the aquifers and typical range for observed rock types. More than 900 simulations were run to determine the calibrated model parameters. The iterative procedure was stopped when justifiable changes to the aquifer parameters resulted in minimal improvement of the fit.

Typical to most model calibration processes, some differences were noticed between the computed and observed drawdowns. These may be the result of one or a combination of the factors listed below.

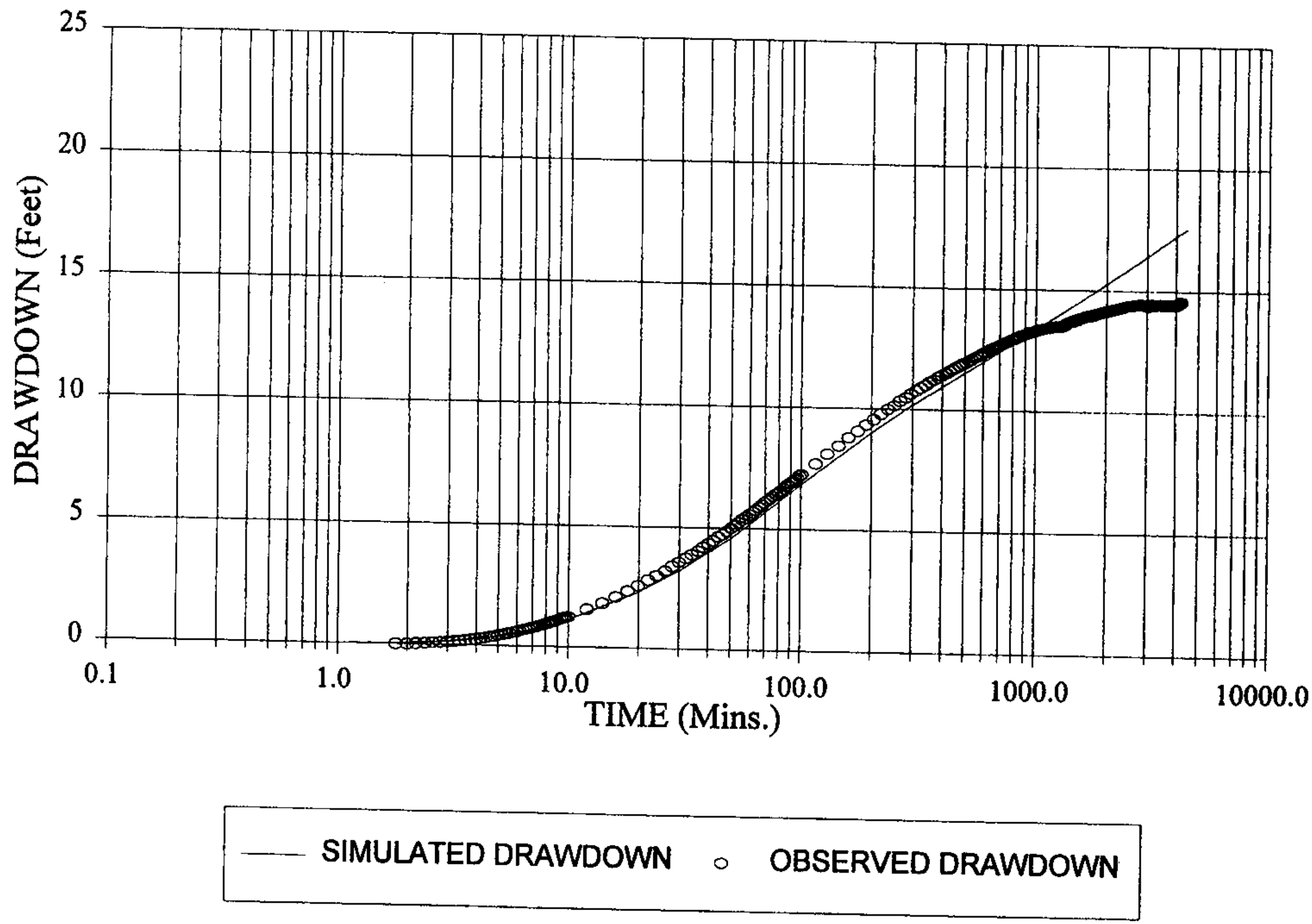
- The block centered finite difference approach used in MODFLOW computes cell-averaged water level at the center of the model cells. Observation wells rarely coincide with the center of the model cells and do not represent cell-averaged values but point measures. Small cell sizes at the observation well locations and correct grid spacing were used to minimize this error in the simulation.

- The monitoring data from the wells suggest a significant tidal influence on the aquifers which was not simulated by the model. While the tidal fluctuations are significant over a short duration (in the order of hours), they become insignificant over the long-term due to averaging (on the order of months or years).

- Local heterogeneity, including but not limited to cavernous zones and lower permeability strata may exist in the aquifer but are not represented by the model. The effect of such local heterogeneity becomes less significant when considering flow on a regional scale. It however remains significant when considering solute transport due to the possible formation of preferred flow paths.

Comparisons between model simulated drawdown and drawdown measured during aquifer tests at the site are shown in Figures 6-7 and 6-8a and b. The figures show a reasonably good fit for the entire test period with simulated and measured drawdowns matching closely.

SIMULATED AND OBSERVED DRAWDOWN
(MC 5000)



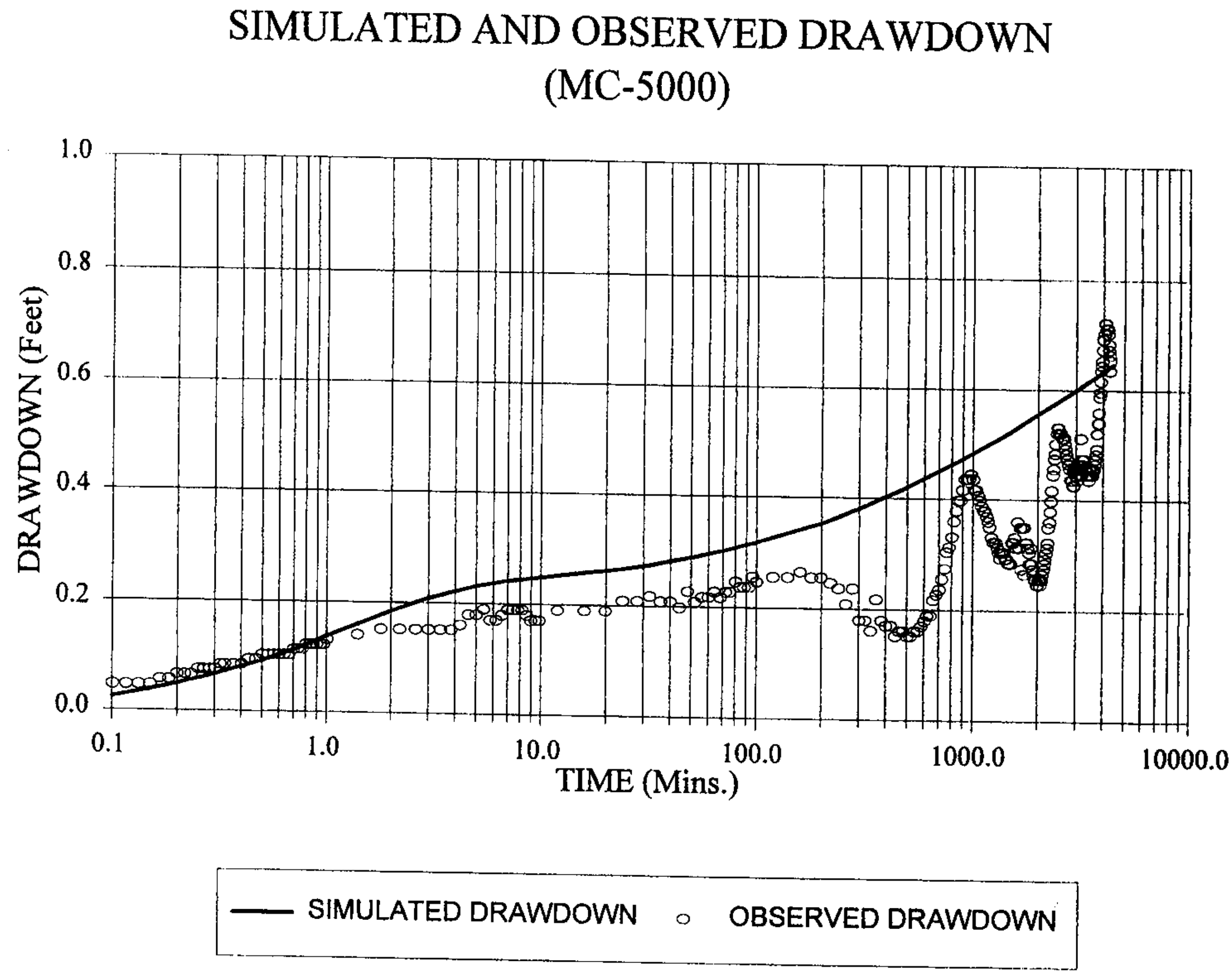
MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-7 PLOT OF MODEL SIMULATED AND OBSERVED DRAWDOWN IN HAWTHORN ZONE 1 AQUIFER



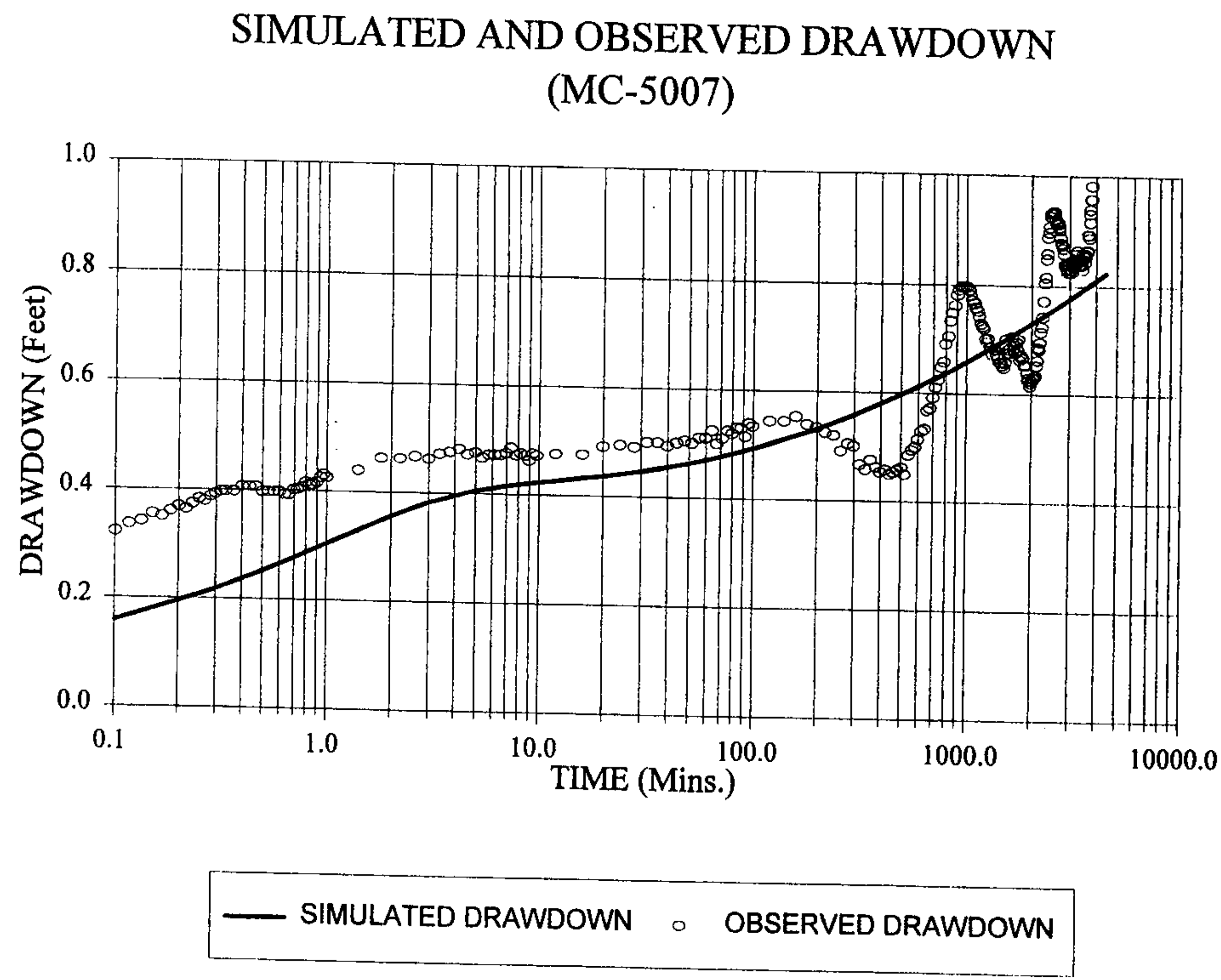
MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-8a PLOT OF MODEL SIMULATED AND OBSERVED DRAWDOWN IN THE LOWER HAWTHORN AQUIFER



MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation	GROUNDWATER AND ENVIRONMENTAL SERVICES
Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.	

FIGURE 6-8b PLOT OF MODEL SIMULATED AND OBSERVED DRAWDOWN IN THE LOWER HAWTHORN AQUIFER

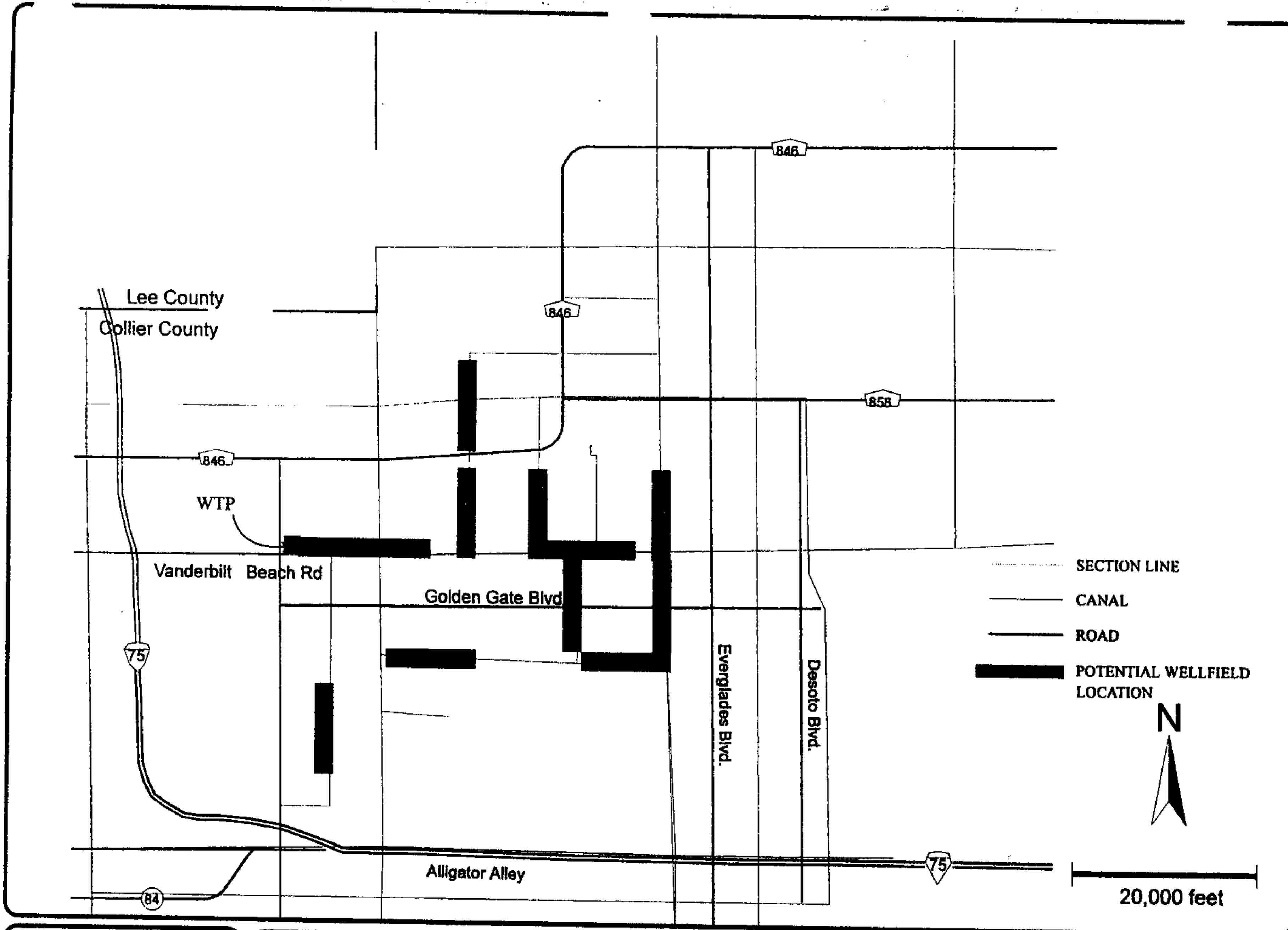
The undulation in water level observed in the field data are attributed to tidal influences which were not incorporated in the groundwater flow model.

Note that the calibrated model parameters, as is the case with all but the simplest numerical models, are non unique. Similar computed water levels may be obtained by a different combination of model input parameters. The calibrated model however results in the best representation of the aquifer system using the most realistic and justifiable aquifer parameters based upon known hydrogeology of the site.

A potential limitation of the model construct and calibration with regard to the desired application is the duration of data available for the calibration. The model was calibrated for a 72-hour period corresponding to the APT conducted in each of the production zones. In application however, the model would predict expected aquifer changes for extended periods spanning several years. The degree of accuracy or reliability of the model for the long-term is limited since there is no record of its performance over extended periods of time. The model, however, retains its utility as a good tool for comparing several simulation options under identical conditions. Its utility would benefit from improvement and refinement over time as more (long-term) data become available.

6.2.2 Predictive Model

The predictive flow model was used to simulate drawdown in the Lower Hawthorn Aquifer resulting from withdrawal of the proposed design flows of 12 MGD to 30 MGD from various wellfield configurations. The process involved several simulations utilizing different wellfield specification files. Each file corresponds to a different wellfield location and/or alignment. A schematic representation of the candidate wellfield locations is presented in Figure 6-9. Selection of potential wellfield locations for modeling was based on hydrogeologic conditions, site availability, site accessibility, distance to water treatment plant, and anticipated construction logistics and economics.



MISSIMER INTERNATIONAL, INC.

Pr.Name: Collier County RO Source Water Investigation — Dwn.By:

Pr.No. FH4-26 — DWG No. — Date: 8/8/95 — Rev.No.

Groundwater and Environmental Services

FIGURE 6-9 CANDIDATE WELLFIELD LOCATIONS

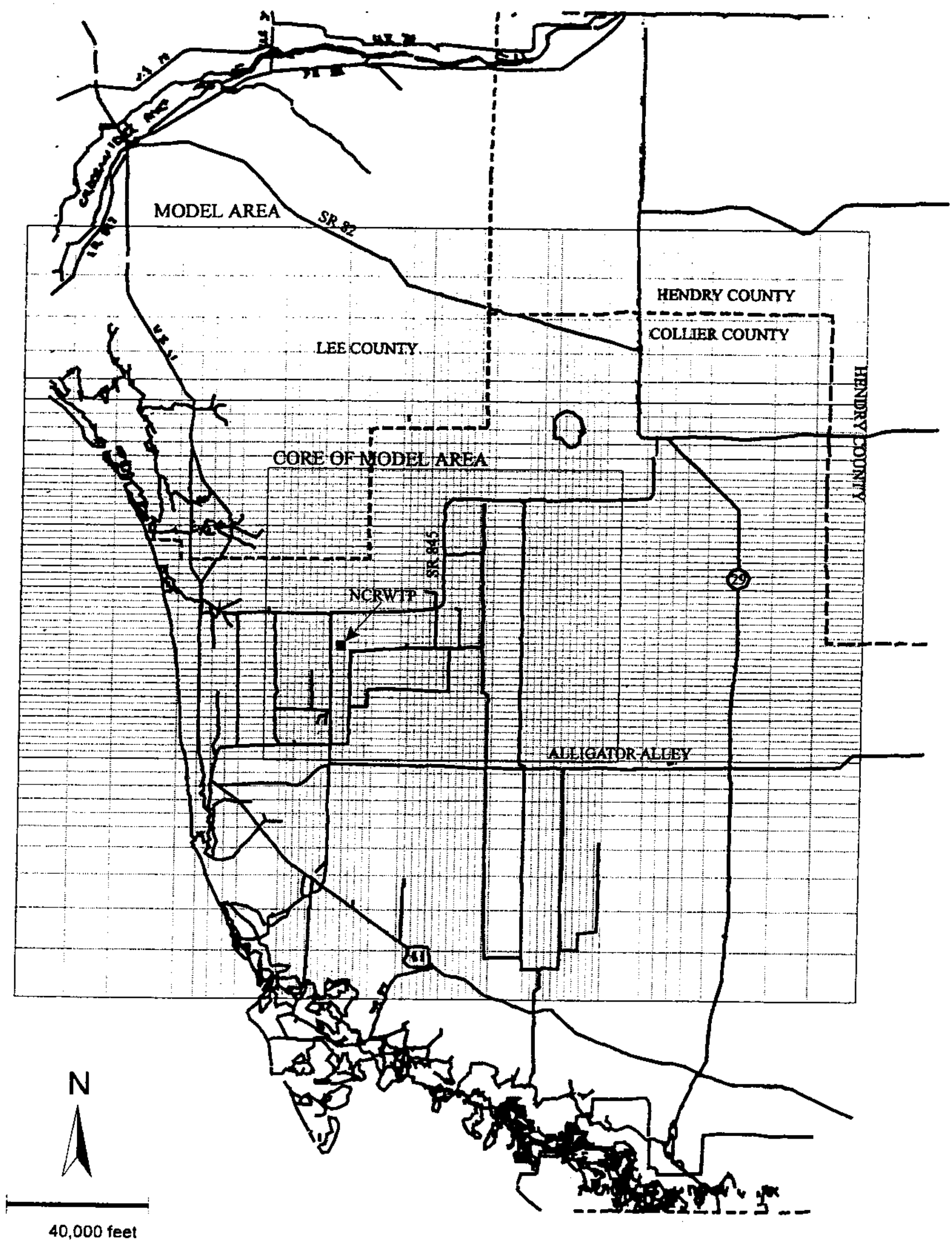
Model Design

A model design nearly identical to that used for the calibration model was constructed for predictive modeling with a slight modification made to the model grid at the APT site. A variable spaced grid was used with small grid spacing (for higher resolution) within the core model area and increasingly larger grid spacing away from the core model area. In the calibration model, the smallest model cells were at the APT site. These APT site model cells were consolidated into one single cell of identical dimensions to the rest of the core model area in the predictive model. The resulting finite difference model grid superimposed over a site map is shown in Figure 6-10. The core model area, enlarged and superimposed over the site map is presented in Figure 6-11. In the predictive model, all cells within the core model area have equal dimensions of 2000 feet by 2000 feet. A total of 13,020 elements made up of 70 columns, 62 rows and three layers comprise the model.

As with the calibration model, the boundary of the model was set far from the core model area to minimize boundary effects on the model results. The specified boundaries were maintained. The steady state potentiometric surface resulting from the specified boundary conditions closely matches observed water levels across the project area and serves as starting heads for model simulation. The applied boundary conditions were fixed for subsequent model simulations and ensure that the effects of the regional gradient at the site were incorporated into the model.

6.3 Solute Transport Model

A solute transport computer model of the Intermediate and Upper Floridan aquifer system was developed in order to determine the potential changes in water quality that might result from the proposed wellfield withdrawals. Chloride concentration being a good indicator of overall water quality in a confined brackish water aquifer was used in the solute transport modeling. Subsequent discussion of water quality in this report is in terms of dissolved chloride concentrations.

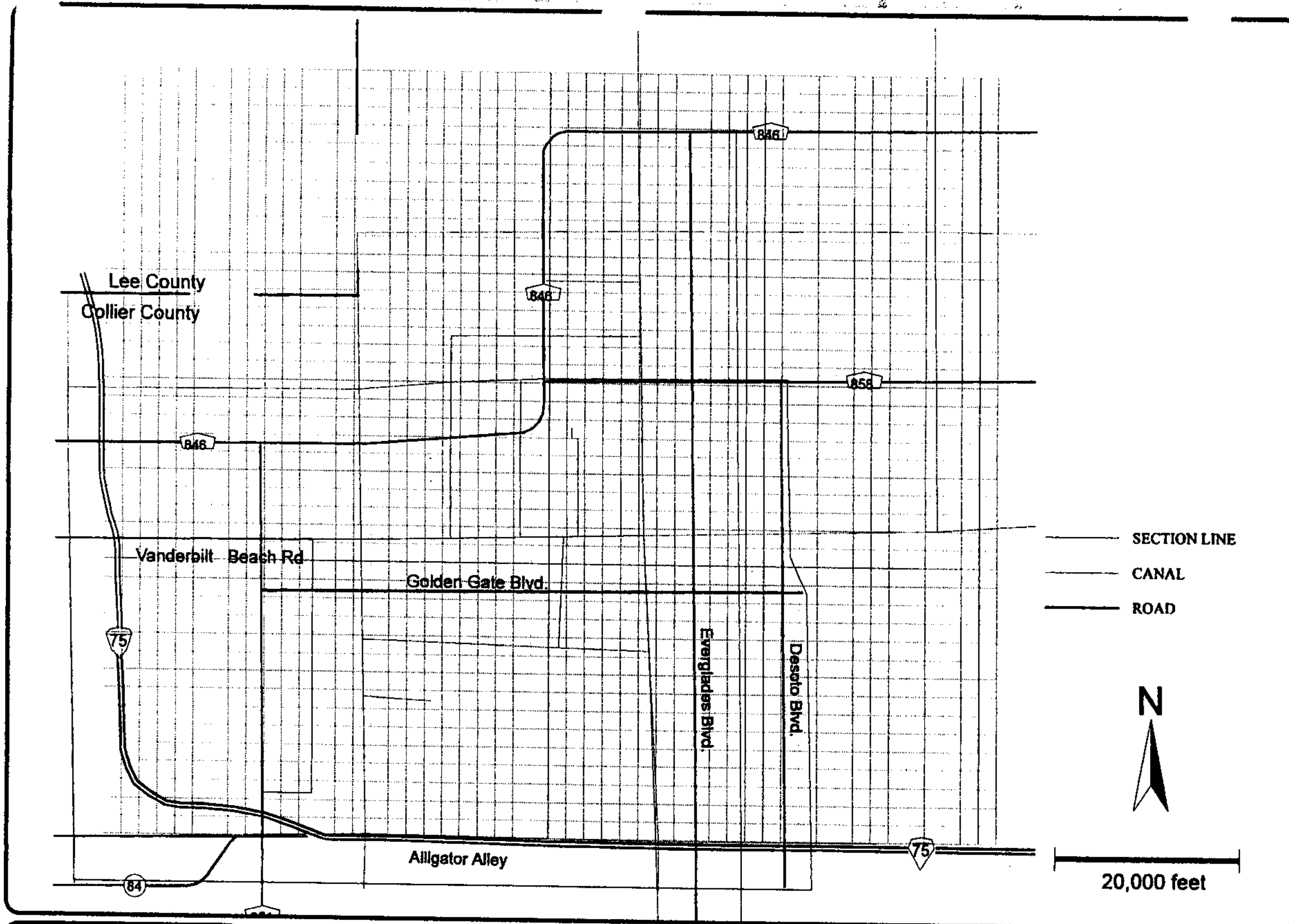


MISSIMER INTERNATIONAL, INC

Pr. Name: Collier County RO Source Water Investigation	
Pr. No. FH4-26	Date: 8/8/95
DWG No.	Rev. No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-10. MODEL GRID SUPERIMPOSED OVER SITE MAP (PREDICTIVE MODEL)



MISSIMER INTERNATIONAL, INC.

Pr.Name: Collier County RO Source Water Investigation		Dwn.By:	
Pr.No. FH4-26	DWG No.	Date: 8/8/95	Rev.No.

Groundwater and Environmental Services

FIGURE 6-11 GRID OF CORE MODEL AREA SUPERIMPOSED OVER SITE MAP

6-11 CDR

The solute transport model code used for the Collier brackish water project was developed using the SWIFT /486 code. SWIFT (Sandia Waste-Isolation Flow and Transport Model, Cranwell and Reeves, 1981; Reeves et al., 1986a, b) was initially developed for the USGS (named SWIP, Survey Waste Injection Program) in 1976 for assessing the effect of deep well injection of waste into saline aquifers. The code has since evolved to incorporate several other desirable features that make it very appropriate for the simulation of complex groundwater flow/transport scenarios including density dependent flow associated with both lateral and vertical saline-water intrusion in aquifer systems.

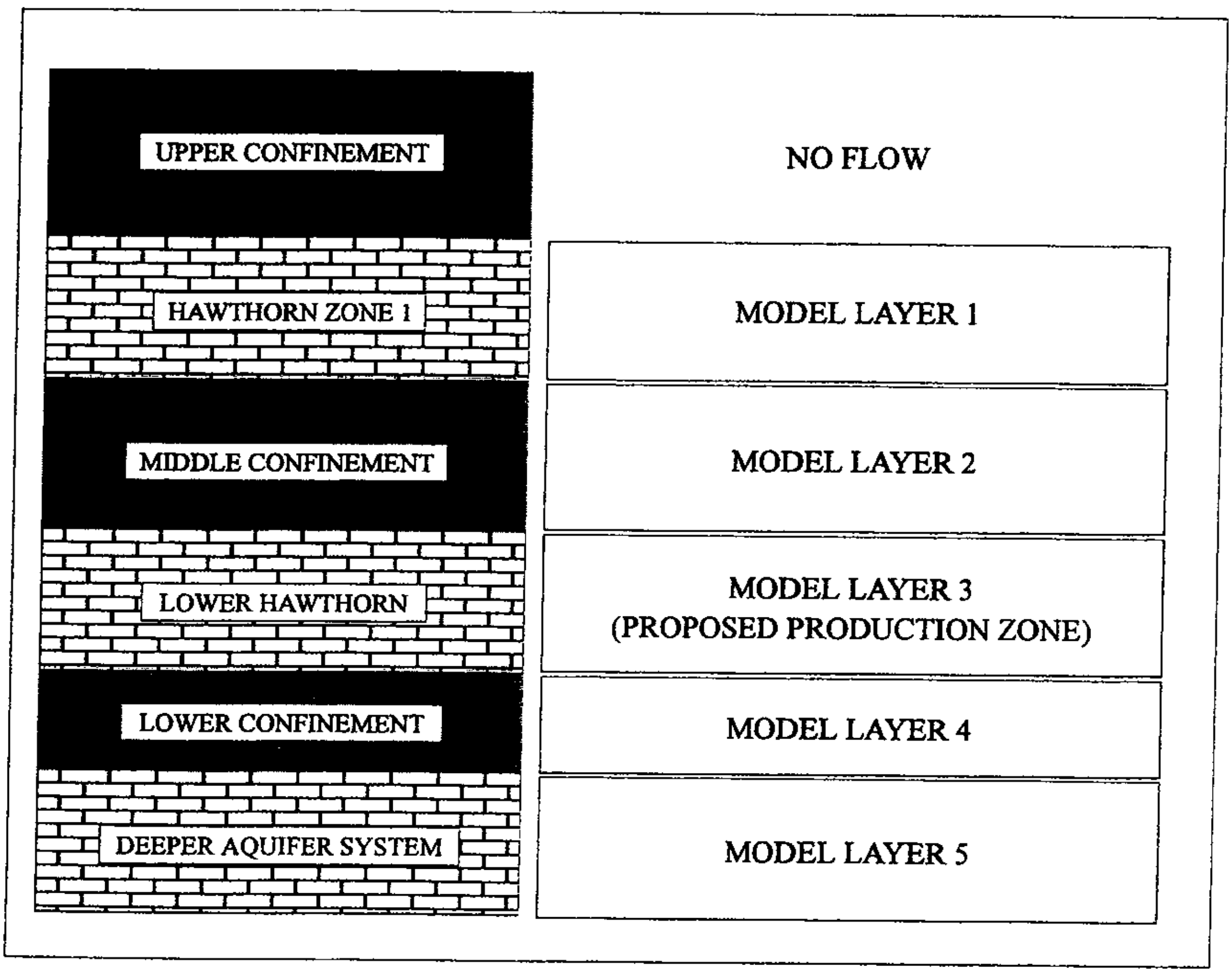
6.3.1. Conceptual Model Design

The areal extent of the solute transport model coincides with the flow models. A solute transport model covering a smaller area would require less computational overhead and would typically be desirable for this reason. However, mapping of water quality in the Lower Hawthorn Aquifer within the large model area shows that dissolved chloride concentrations increase significantly to the southwest and reduce appreciably to the northeast. While pressure effect from distant sources can be easily implemented with appropriately selected boundary conditions, representation of solute transport effect and off-site contribution cannot be so easily implemented. A near field model representing the immediate locale of the wellfield would preclude the direct inclusion of the varying chloride concentrations and would only indirectly represent them by specified boundary conditions. The effect would be to introduce some degree of error in the estimate of lateral solute transport. Inclusion of data from locations within the anticipated range of influence of the wellfield is necessary especially in cases where lateral solute transport or vertical upconing may be significant. The additional computational overhead/demand of a larger scale solute transport model is justified by the reduction in error due to specified boundaries. The large boundary cells for the larger scale model present a challenge in the selection of solute transport solution technique that minimizes numerical dispersion while ensuring no over/undershoot errors. Sensitivity analyses on several of the input parameters, including dispersivity show the nature and degree of effect of each parameter on the solute transport model results and help in qualifying and interpreting the model results.

Model cell grid dimensions are identical to those used in the predictive flow model. The solute transport model however, utilizes a five-layer representation of the Intermediate and Floridan aquifer systems. A fully three-dimensional representation of the aquifers and 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 models. The five model layers thus represent the Hawthorn Zone 1, 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 deemed necessary as it represents a potential source of higher salinity water beneath the proposed production zone. A schematic representation of the solute transport model layers and corresponding aquifers and confining beds is shown in Figure 6-12.

Aquifer hydraulic parameters and data inputs to the flow model were also used for the solute transport model. Additional data required for solute transport modeling were obtained from field measurements and data reported in literature and include such information as vertical and lateral distribution of dissolved chloride concentration, fluid density and viscosity, vertical hydraulic conductivity of the confining beds, dispersivity, and compressibility of water and matrix. A summary of input data used for the solute transport model is presented in Table 6-1.

Pressure along the four vertical edges of the solute transport model were specified as in the flow model to reproduce a background gradient similar to the observed regional gradients. The selected boundary condition ensures incorporation of the effects of regional flow in the model results.



MISSIMER INTERNATIONAL, INC

Pr. Name: Collier County RO Source Water Investigation			
Pr. No. FH4-26	Date: 8/8/95		
DWG No.	Rev. No.		

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-12. SCHEMATIC REPRESENTATION OF SOLUTE TRANSPORT MODEL

6-12.CDR

TABLE 6-1 SUMMARY OF AQUIFER PROPERTIES USED IN SOLUTE TRANSPORT MODEL

PROPERTY		Hawthorn Zone 1	Middle confining beds	Lower Hawthorn	Lower confining beds	Underlying aquifers
Model Layer		1	2	3	4	5
Hydraulic Conductivity						
Horizontal	ft/day	22 - 88	0.1 [1]	240 - 4800 [2]	64	85
Vertical	ft/day	0.22	6E-06	60	0.48	4.3
Leakance	1/day	→	3E-07 [1]	← →	0.0013	←
Thickness	ft	80 - 141	140 - 408	61 - 172	80 - 331	600+-
Top	ft NGVD	252 - 406.3	335 - 547	565 - 848	668 - 920	1000+-
Bottom	ft NGVD	335 - 547	565 - 848	668 - 920	1000+-	1600+-
Porosity		30%	30%	30%	30%	30%
Dispersivity						
Longitudinal	ft	→	→	75	←	←
Transverse	ft	→	→	10	←	←
Initial chlorides	mg/l	175 - 2650	318 - 3639	422 - 4619	565 - 5601	600000%

1 Leakance between layers 1 and 3 (and kv of layer 2) set low to represent tight confinement

2 Constant value of 668.45 ft/day used in conservative model

Transport of dissolved chloride in groundwater is primarily controlled by advection and hydrodynamic dispersion. The advective component of flow is dependent on the flow velocities and usually represents the principal means of transport. Flow velocities are computed internally during model simulation. Dissolved chloride transport is not retarded to any significant degree.

Hydrodynamic dispersion which combines the effects of mechanical dispersion and molecular diffusion also contributes to chloride transport. The effect of dispersion becomes more prominent where velocities are small. Longitudinal and transverse dispersivity are specified in the model based upon conventional dispersion theories. Laboratory scale dispersivities typically are lower than one foot. Field scale longitudinal dispersivity, however, have been reported from less than 10 feet to hundreds of feet depending upon scale of the experiments (Freeze and Cherry, 1979; Domenico and Schwartz, 1990). Review of various modeling studies reveal longitudinal dispersivity ranging between 50 and 300 feet and transverse dispersivity ranging between 5 and 60 feet (Anderson et al. 1988; Wexler E. J. 1988; Geotrans Inc., 1991; HydroGeologic Inc., 1992). Longitudinal and transverse dispersivity of 75 and 10 feet, respectively, were used in the solute transport modeling for this study. Sensitivity analyses using higher and lower values were conducted. The effect of molecular diffusion is assumed to be negligible compared to advection and dispersion and is therefore not represented within the model.

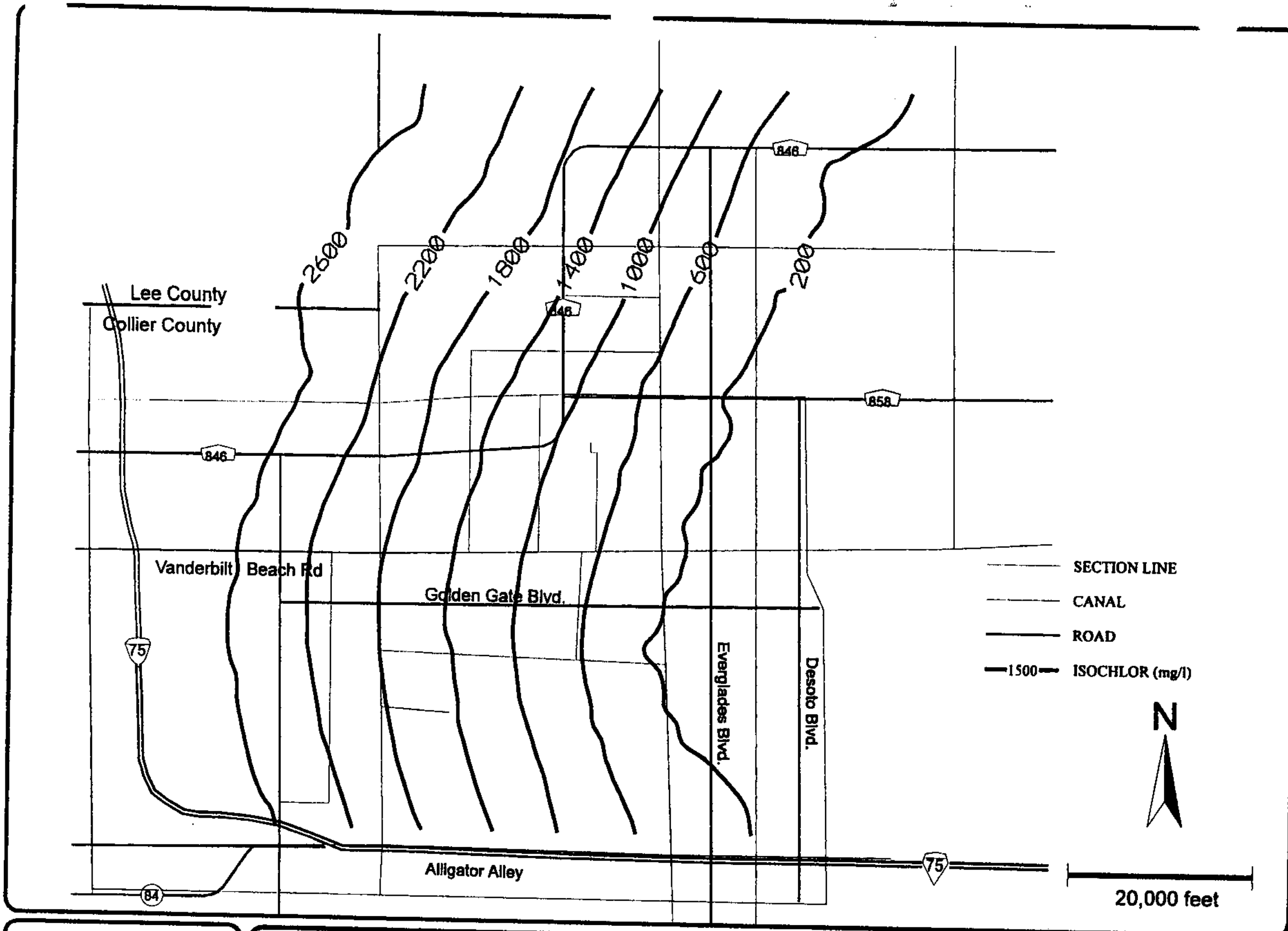
For each of the model scenarios examined, a number of simulations were run for a 40-year period. While flow conditions in constant density fluids typically can equilibrate over a period of days or weeks, solute transport changes, especially those which tend to affect the flow regime, can take significantly more time to equilibrate often on the order of decades or more. This occurs because changes in the chloride concentrations can result in density dependent flows which in turn affects the chloride concentrations. The variations in water levels resulting from the change in dissolved chlorides reduce with time as the system approaches equilibrium. The 40-year simulation thus ensures that the model results indicate long-term effects of the specified withdrawal.

Initial chloride concentrations in the model were specified using data obtained from wells completed in the various aquifers. While the available information is limited in areal extent, it is available in greater detail by depth for each test well. This enabled a detailed vertical discritization/specification of chloride concentration. The contour of initial distribution of dissolved chlorides for the Hawthorn Zone 1 and Lower Hawthorn aquifers are presented in Figures 6-13 and 6-14. A schematic diagram representing chloride variation with depth at various well locations is presented in Figure 6-15. The concentration of chlorides outside the model domain is implicitly specified by fixed chloride concentrations at the model boundaries. All flow into the model area across each boundary cell is assigned a concentration equal to the dissolved chloride concentration specified at that boundary 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.

Chloride concentrations are specified as normalized concentrations in the model. The normalized concentration or dimensionless concentration varies between zero and one and is the ratio of chloride concentration measured in milligrams per liter (mg/l) to sea water represented as 19,000 mg/l. A dissolved chloride concentration of 1,200 mg/l would thus be represented as 1,200/19,000 = 0.0632 in the model input files. Fresh water therefore has a normalized concentration of zero and sea water a normalized concentration of one.

6.3.2. Model Initialization, Assumptions and Limitations

Simulated water level data obtained from the solute transport model were compared to that obtained from the flow model. Slight variations were observed between the



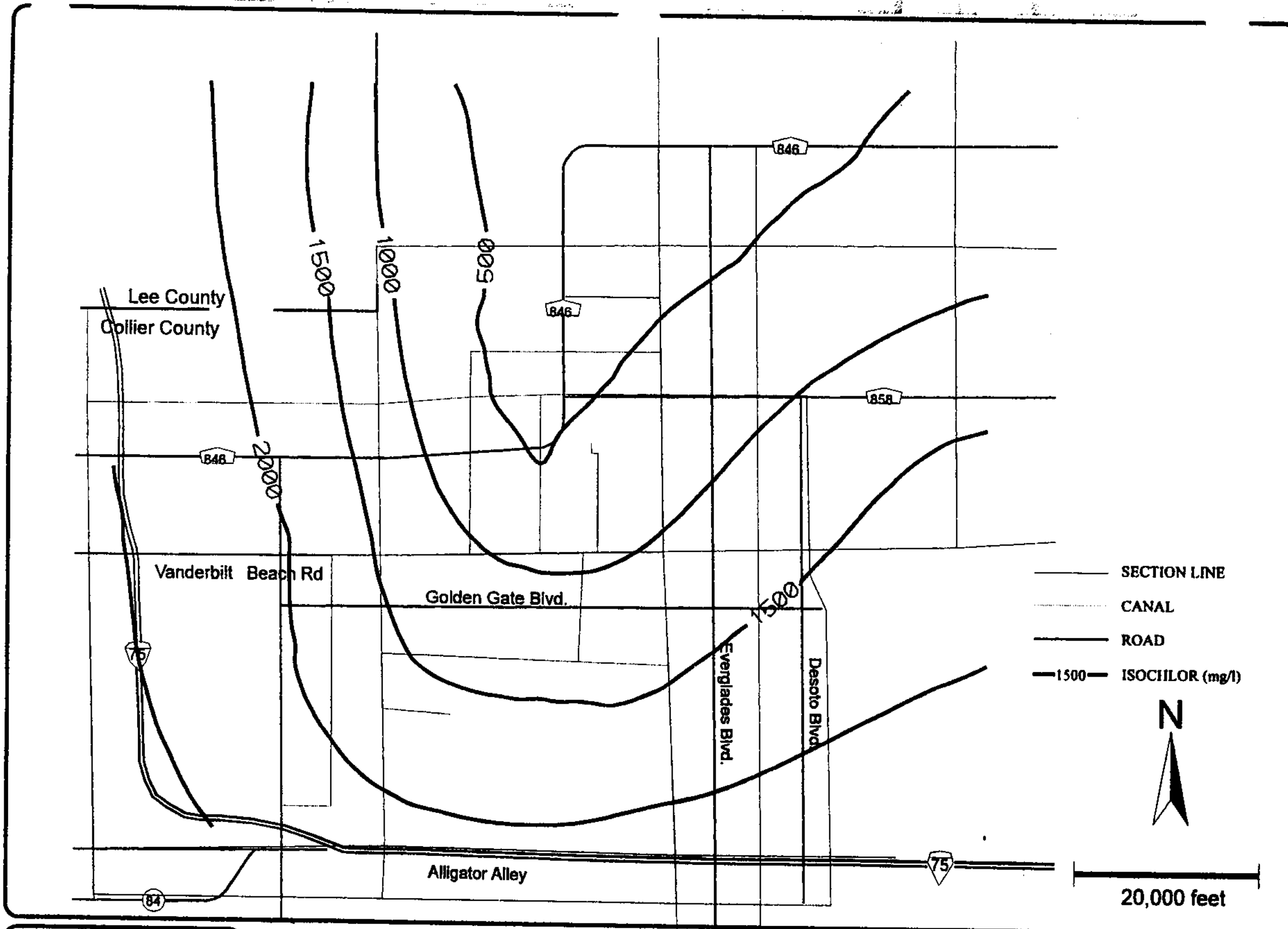
MISSIMER INTERNATIONAL, INC.

Pr.Name: Collier County RO Source Water Investigation		Dwn.By:	
Pr.No. FH4-26	DWG No.	Date: 8/8/95	Rev.No.

Groundwater and Environmental Services

FIGURE 6-13 CONTOUR MAP OF INITIAL DISTRIBUTION OF DISSOLVED CHLORIDES IN HAWTHORN ZONE 1 AQUIFER

6-13&14 CDR



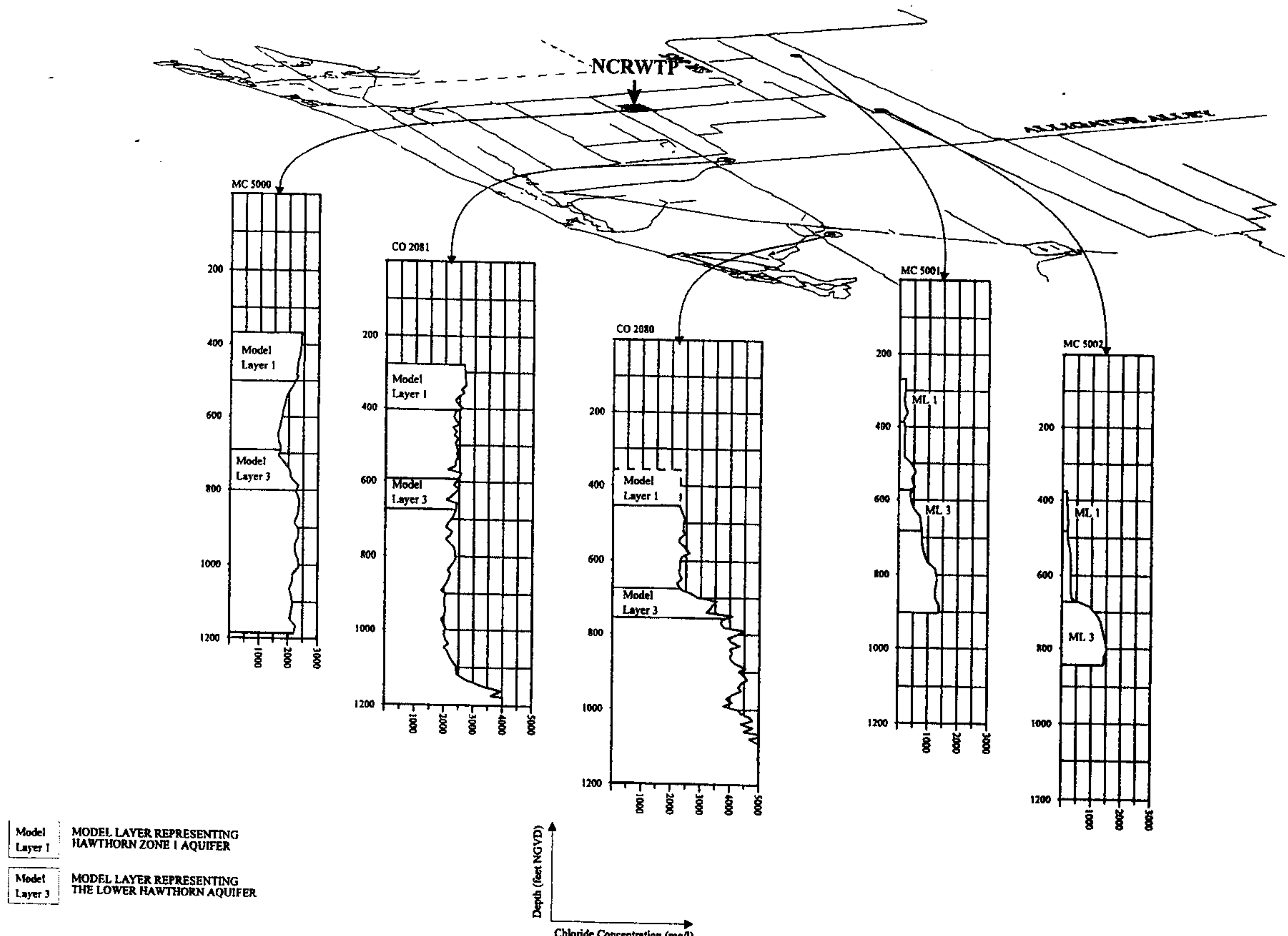
MISSIMER INTERNATIONAL, INC.

Pr.Name: Collier County RO Source Water Investigation		Dwn.By:	
Pr.No. FH4-26	DWG No.	Date: 8/8/95	Rev.No.

Groundwater and Environmental Services

FIGURE 6-14 CONTOUR MAP OF INITIAL DISTRIBUTION OF DISSOLVED CHLORIDES IN LOWER HAWTHORN AQUIFER

6-13&14 CDR



MISSIMER INTERNATIONAL, INC

Pr.Name: Collier County RO Source Water Investigation		Dwn.By:	
Pr.No. FH4-26	DWG No.	Date: 8/8/95	Rev.No.

Groundwater and Environmental Services

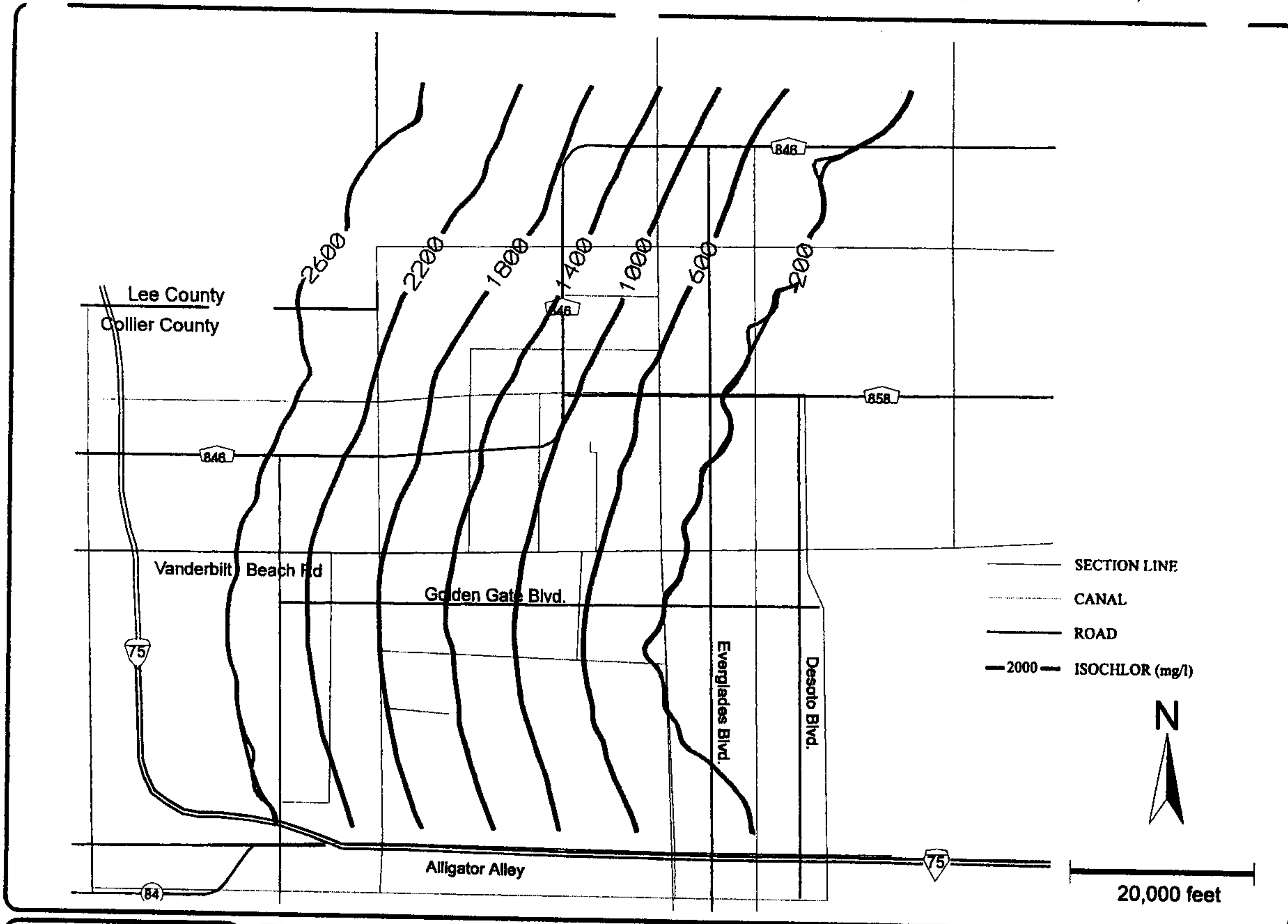
FIGURE 6-15 PLOT OF CHLORIDE CONCENTRATION WITH DEPTH AT VARIOUS WELL LOCATIONS

6-15.cdr

computed equivalent fresh water head computed by the flow model and solute transport model. This variation is attributed to the influence of variable density (and corresponding density dependent flow) not considered in the flow model but incorporated into the solute transport model. The computed background gradients in both cases sufficiently depict the observed gradients.

Based upon the specified starting chloride conditions, a no withdrawal scenario was simulated to determine the change in dissolved chloride concentration with time over the model area. Figures 6-16 and 6-17 show initial chloride concentration contours and chloride concentration contour for both the Hawthorn Zone 1 and Lower Hawthorn aquifers at the end of 10 years with no pumping. Assuming that the existing observed dissolved chloride distribution represents a fairly stable (close to steady state) situation, a close match between the long-term simulation and the current conditions would suggest suitable model construct. The comparison presented in Figures 6-16 and 6-17 shows a good agreement between the computed and observed dissolved chloride distribution. Plots of chloride concentration versus time at model cells within the core model area (in the vicinity of the NCRWTP) were generated for each model construct and show minimal changes in chloride concentration over time for the zero withdrawal model simulations.

Because available data on the brackish water aquifers in Collier County are so limited, the level of confidence placed in model accuracy needs to be proportionally tempered. In order to provide a higher level of confidence and appropriately bracket a range of possible results for prudent planning and design, two solute transport models were developed. The first model represents the calibrated model that incorporates model input and parameters from the flow model calibration process. The second, referred to herein as the conservative model, specifies a constant hydraulic conductivity for the Lower Hawthorn Aquifer equal to the lowest value determined from aquifer testing. The model is conservative in that due to the lower hydraulic conductivity, a greater gradient is induced, which results in greater potential for saltwater movement. Further conservative



MISSIMER INTERNATIONAL, INC.

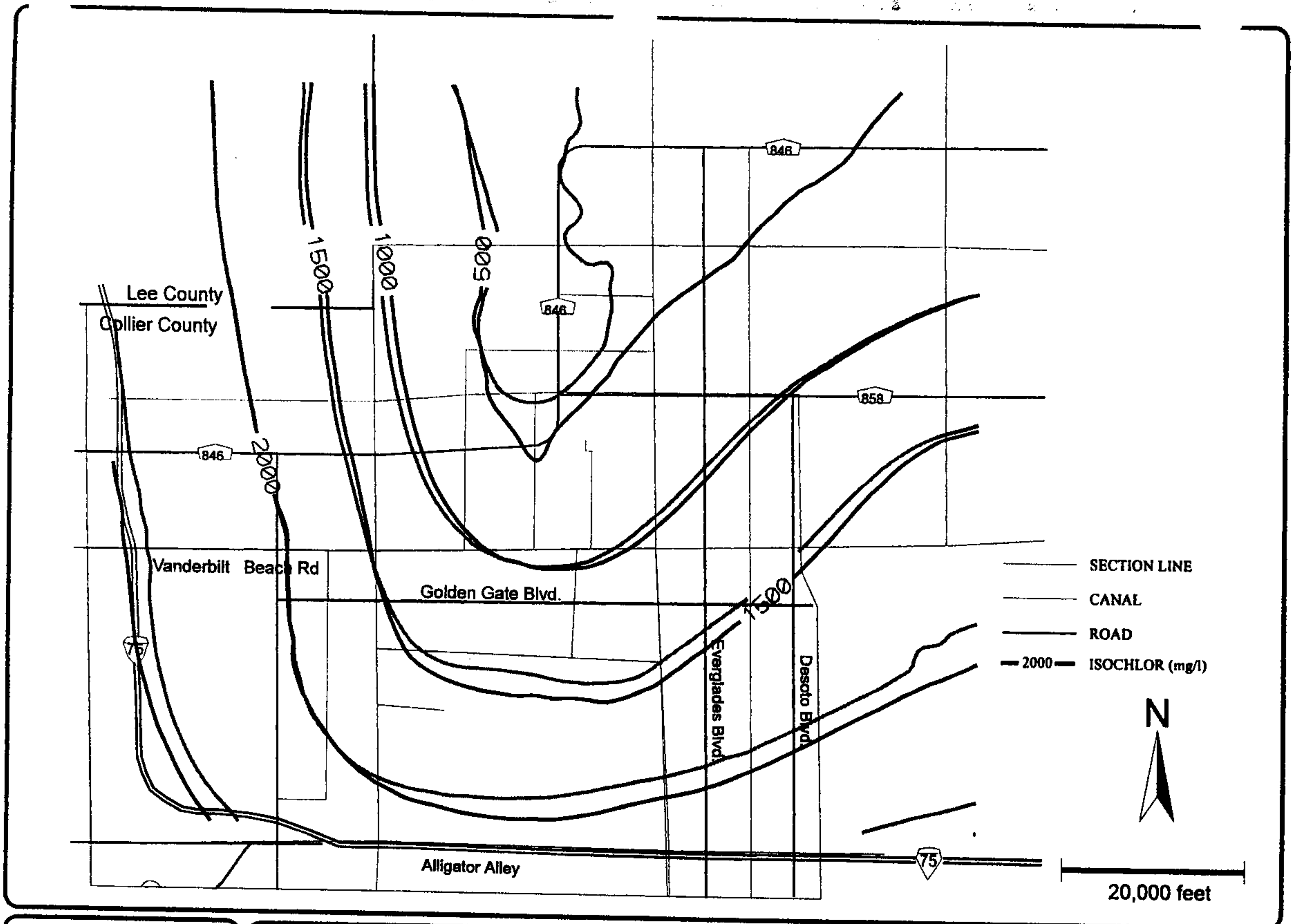
Pr.Name: Collier County RO Source Water Investigation | Dwn.By:

Pr.No. FH4-26 | DWG No. | Date: 8/8/95 | Rev.No.

Groundwater and Environmental Services

FIGURE 6-16 INITIAL AND SIMULATED HAWTHORN ZONE 1 CHLORIDE DISTRIBUTION AT THE END OF TEN YEARS WITH NO WITHDRAWLAS

6-16R17.CDR



MISSIMER INTERNATIONAL, INC.

Pr.Name: Collier County RO Source Water Investigation
Dwn.By:
Pr.No. FH4-26
DWG No.
Date: 8/8/95
Rev.No.

Groundwater and Environmental Services

FIGURE 6-17 INITIAL AND SIMULATED LOWER HAWTHORN CHLORIDE DISTRIBUTION AT THE END OF TEN YEARS WITH NO WITHDRAWLAS

6-16R17 CDR

measures such as increasing the chloride concentration of the underlying aquifers and increasing leakance are examined through sensitivity analyses.

To determine the effect of various model input parameters and assumptions on the simulated hydraulic head and chloride concentrations, and establish the degree of sensitivity of the model results to key model input parameters, a sensitivity analysis was conducted. Parameters to which the model results are most sensitive represent those for which future data would result in most benefit for subsequent refinement of the model. A total of fourteen sensitivity runs were conducted to investigate the effect of transmissivity, vertical hydraulic conductivity (and hence leakance), dispersion coefficient and initial chloride concentration of the aquifers underlying the Lower Hawthorn Aquifer on the model results. Results of the sensitivity analyses are presented in Section 6.3.5 of this report.

The effect of transmissivity on the simulated chloride concentration was investigated by running four simulations using each of the model constructs. Transmissivity specified within the model for the proposed production layer was multiplied by a factor of 2, 1.5, 0.8 and 0.5 respectively in each of the sensitivity runs. The degree of change in simulated chloride concentrations provides an indication of the sensitivity of the model to specified transmissivity.

The vertical hydraulic conductivities specified for each model layer in the solute transport model were computed based on the leakance determined during calibration of the flow model. Sensitivity runs to investigate the effect of higher and lower values of leakance on the computed chloride distribution help to determine the effect on model results of an over or underestimated leakance. Four model simulations were run using different leakance values for the model layer representing the production zone and the underlaying aquifer and confining bed. The sensitivity simulations were conducted with leakances of 10 times, 2 times, 0.5 times and 0.1 times the initial specified leakance. A limited change in computed chlorides would indicate insensitivity (or little sensitivity) to leakance while a large change would suggest sensitivity to leakance.

The dispersivities used in the solute transport model were specified based on a review of literature. A series of model runs were conducted using different values of dispersivity to determine the changes in simulated chloride concentrations resulting from higher or lower dispersivities than were applied in the model. Since dispersivity was estimated for the study, an understanding on its impact on model results was deemed necessary. Three sensitivity runs were conducted for each of the model constructs using longitudinal and transverse dispositions of 50-5, 150-15, and 250-25 feet.

The chloride concentration in the underlying aquifer directly below the lower confining beds was set at 6,000 mg/l within the model. This is higher than observed chloride concentrations at depth, which range from just over 2,000 mg/l to 5,000 mg/l. Higher chloride concentration specified represents a conservative estimate to incorporate some of the uncertainty associated with data from the deeper aquifer system. Three sensitivity runs, one using a lower concentration, and two others using higher concentrations of chloride were made to determine the effect on simulated chloride levels. Chloride concentrations of 4,000, 8000 and 12,000 mg/l in the model layer representing the underlying aquifers were specified in the sensitivity simulations.

6.3.3. Model Application

For both the calibrated and the conservative model, a 40-year simulation was conducted using three different withdrawal rates. The first was a withdrawal of 12 MGD from the Lower Hawthorn Aquifer in the area proximal to the treatment plant to meet the approximate need of the NCRWTP expansion currently being developed. The second withdrawal scenario involved the withdrawal of 20 MGD from the area proximal to the wellfield. This run was required to document impact associated with the maximum day need of the current application for water use on file with the SFWMD. A total of 30 MGD from two or more well clusters was simulated in the third scenario for purposes of raw water design for long-term demand increases. Each scenario is described in more detail below. Note that for each withdrawal scenario, a constant pumping rate is applied for the duration of the simulation. During implementation, it is expected that withdrawals would increase with time based on demand until the designed capacity is attained. The simulated withdrawal scenarios therefore conservatively represent aquifer response to sustained withdrawals at the design withdrawal rates.

Case I (12 MGD)

Withdrawal of 12 MGD from 10 wells located at 1000 feet centers was simulated in each of the calibrated and conservative models. In each case, the model cell size was 2000 feet square, thus two wells were simulated in each of five model cells to represent the wellfield. A forty-year transient simulation was conducted using small time steps of 1 to 30 days at early times in the model when the maximum changes are anticipated. The time steps were increased to 90 to 360 days by the end of the 40-year simulation. The results of the simulation are presented and discussed in Section 6.3.4 of this report.

Case II (20 MGD)

Based on projected demands required for consumptive use permit application, a 10-year maximum day demand of 20 MGD was established. While it is unlikely to withdraw at this maximum daily rate continuously for several years, the permit application requires the determination of potential changes in chloride concentration that may result from a sustained withdrawal at this rate. This no doubt represents a significantly conservative approach which though necessary for permit application is not appropriate for design. Eight adjacent model cells were used to represent the wellfield for this scenario. The assigned withdrawals correspond to fifteen wells producing approximately 1000 gpm located at 1000 feet centers. As was the case with the 12 MGD wellfield, a forty-year transient simulation was conducted.

Case III (30 MGD)

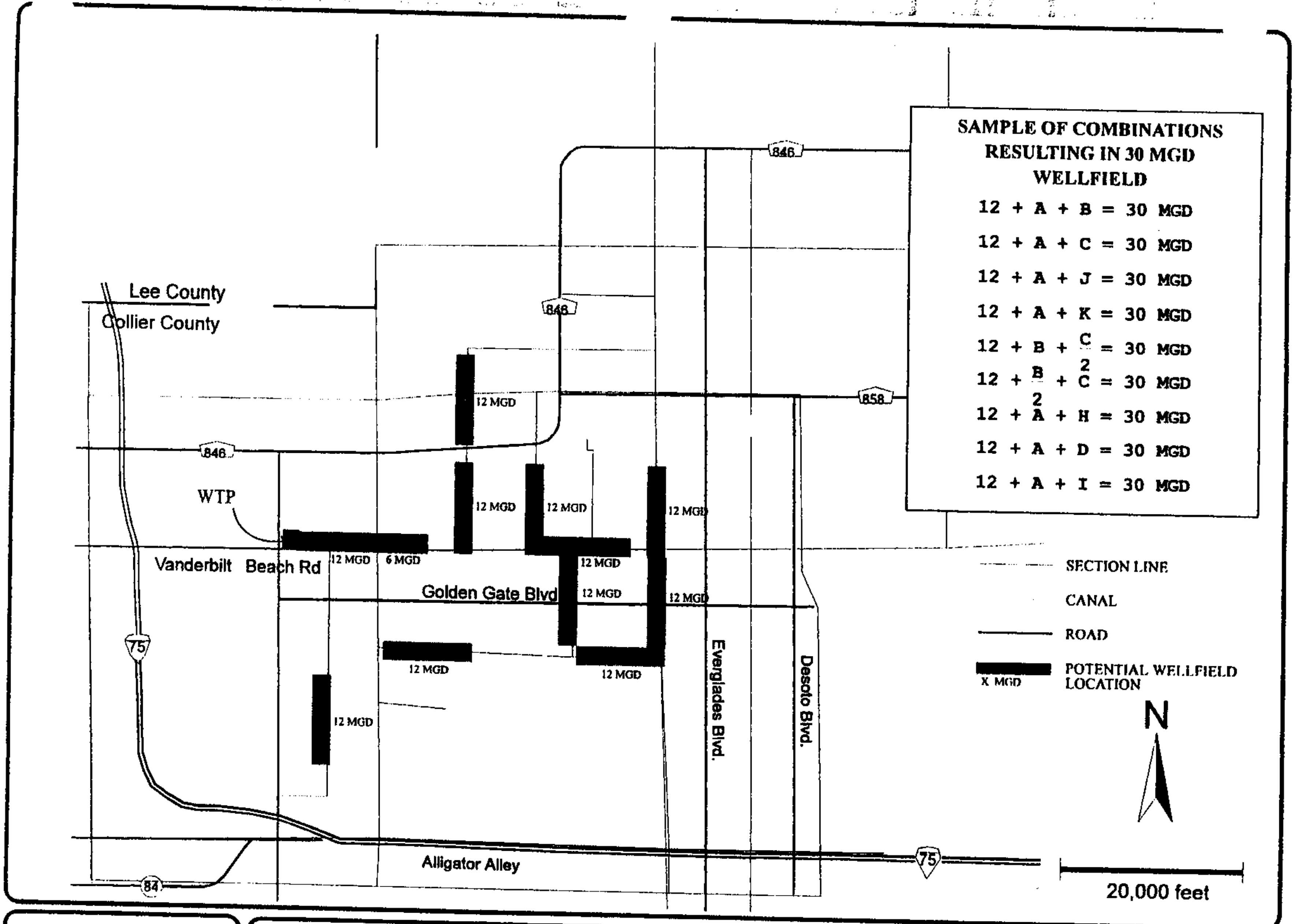
A series of alternative locations and combination of locations producing a combined 30 MGD withdrawal were considered in this case. A schematic representation of the potential wellfield locations with assigned withdrawal is shown in Figure 6-18. Results from four alternative scenarios for each of the two model constructs are presented in this report. The model results were used in evaluating the potential wellfield locations with a view to selecting the most suitable for development.

6.3.4. Model Results

The results of the various scenarios simulated are presented. In each case a discussion of the calibrated model construct is followed by a discussion of the conservative model construct.

Base Line Simulation

A base line simulation was conducted to determine the change in chloride concentration resulting from modeling assumptions and parameters for each modeling construct under conditions of no Lower Hawthorn Aquifer withdrawals. This information provides a means of differentiating between changes occurring as a result of wellfield pumpage and those occurring based on the model construct. Figures 6-19a and b show chloride concentration over a 40-year period in the area of the proposed wellfield for the calibrated and conservative models. In both cases, there is minimal change in chloride resulting from background activities. The computed chloride changes from subsequent modeling would therefore represent changes resulting mainly from wellfield activities. Chloride concentrations for a particular wellfield alignment are obtained by averaging simulated chloride concentration at model cells representing the wellfield. The reported concentration thus represents the average quality of raw water produced in the simulated wellfield and not that of any single well.



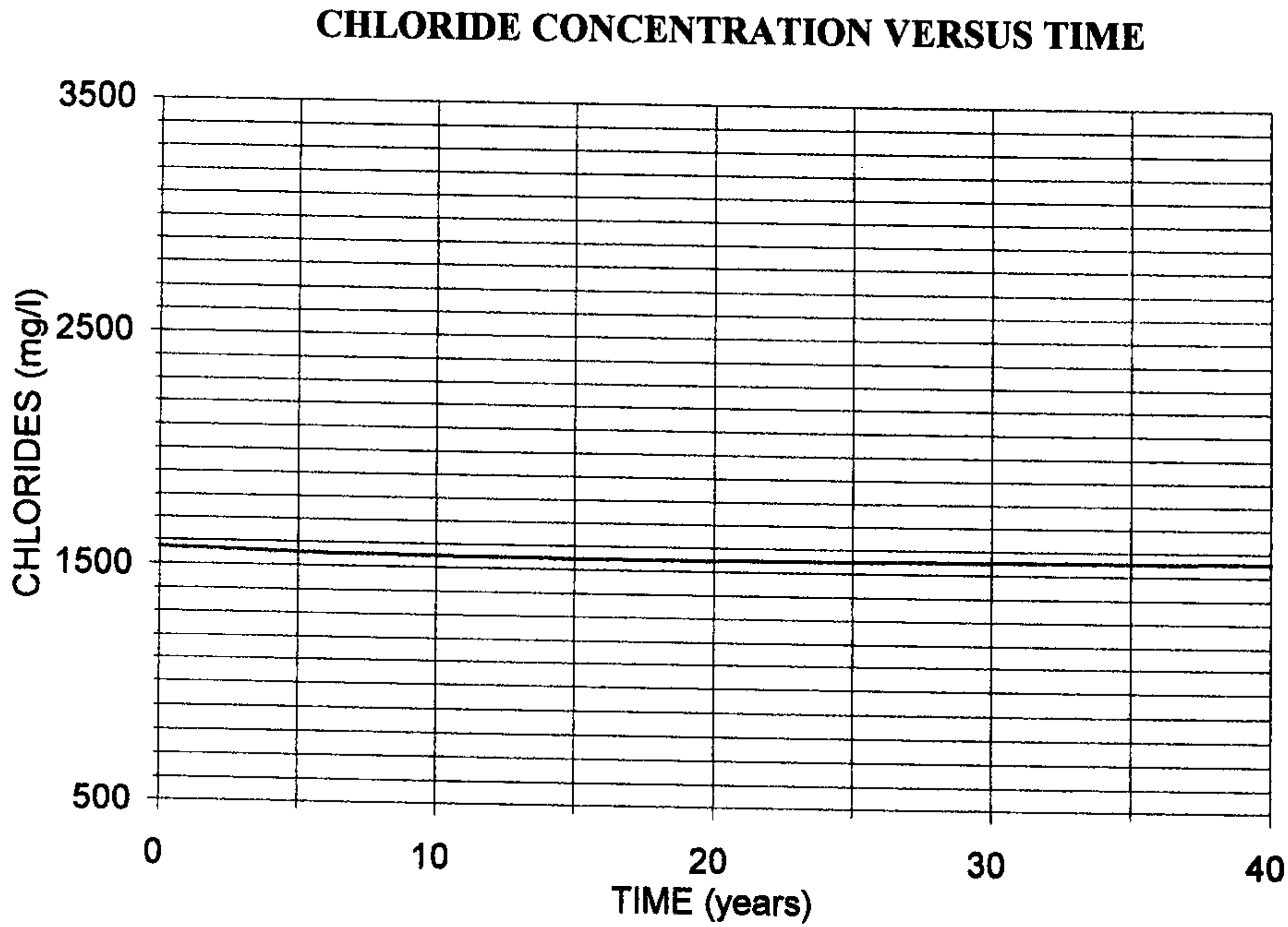
MISSIMER INTERNATIONAL, INC.

Pr.Name: Collier County RO Source Water Investigation		Dwn.By:	
Pr.No. FH4-26	DWG No.	Date: 8/8/95	Rev.No.

Groundwater and Environmental Services

FIGURE 6-18 POTENTIAL WELLFIELD LOCATIONS SHOWING ASSIGNED WITHDRAWAL RATES

6-18 CDR



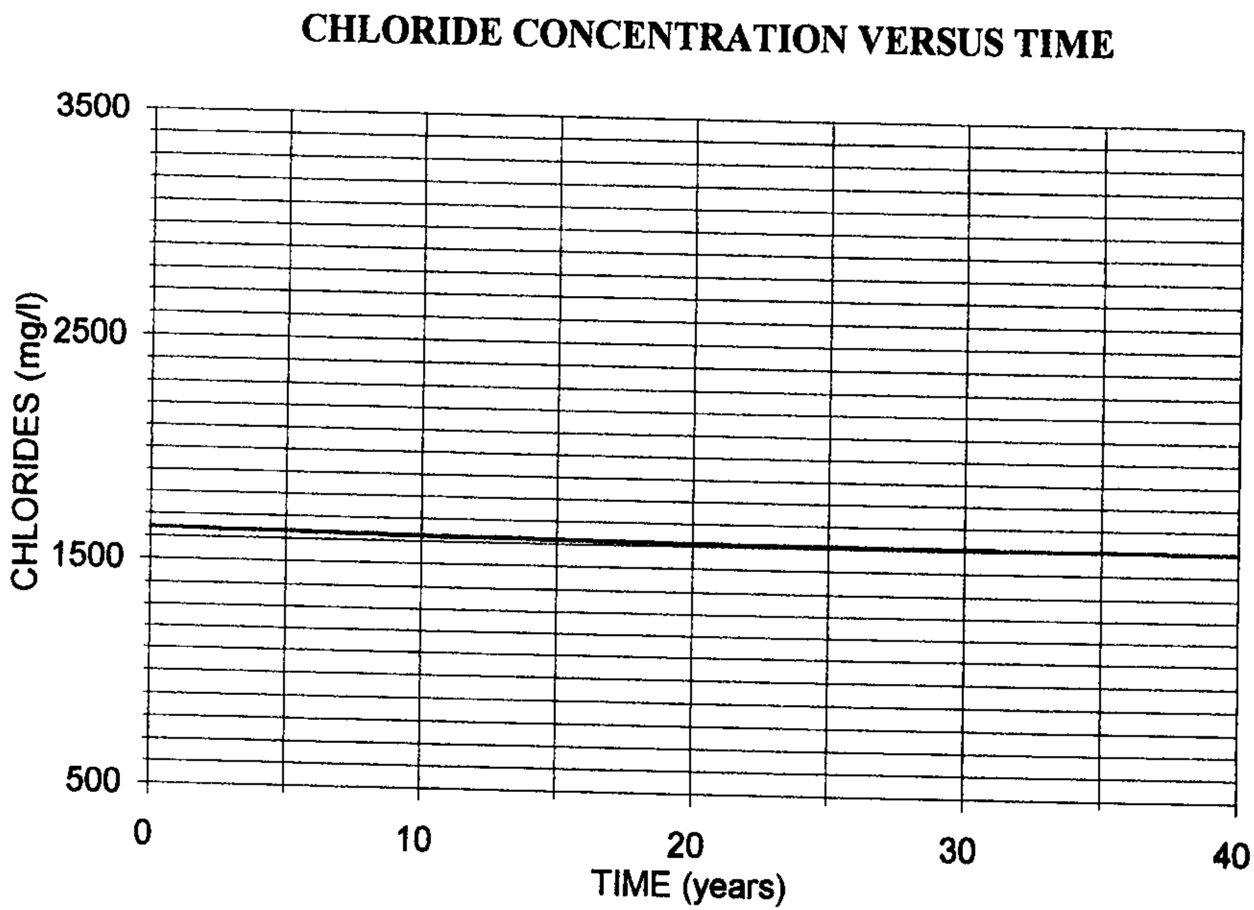
MISSIMER INTERNATIONAL, INC

Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-19a SIMULATED CHLORIDE CONCENTRATION WITH ZERO WITHDRAWAL FROM WELLFIELD (CALIBRATED MODEL)



MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-19b SIMULATED CHLORIDE CONCENTRATION WITH ZERO WITHDRAWAL FROM WELLFIELD (CONSERVATIVE MODEL)

Case I

The desired finish water production rate from the proposed reverse osmosis plant is 8 MGD. A raw water supply of approximately 12 MGD is required assuming the recovery efficiency of the plant is about 70 percent. While a higher recovery efficiency is anticipated, the lower percentage is used as a conservative measure.

In simulating the 12 MGD wellfield, 10 wells located adjacent to the treatment plant and extending approximately 10,000 feet eastward were considered. The proposed wellfield was thus located in an area where aquifer performance tests yielded relatively high transmissivities. It also corresponds to the portion of the model area for which the most reliable information is presently available.

The results of Case I model simulations, for the calibrated model construct, are presented in Figures 6-20 to 6-22. A contour of simulated potentiometric surface of the Lower Hawthorn Aquifer superimposed over a site map is shown in Figure 6-20. The drawdown contour superimposed over a site map is given in Figure 6-21. A maximum drawdown of between 7 and 8 feet occurs at the location of the proposed wellfield. This represents the cell averaged drawdown at the wellfield for the calibrated model construct. A plot of the corresponding change in chloride at the wellfield is presented in Figure 6-22 and shows an increase in chlorides of approximately 230 mg/l over the 40-year simulation period. The average wellfield chloride concentration rises from approximately 1700 mg/l to approximately 1930 mg/l over the 40-year period. The low drawdown results in minimal vertical migration at the wellfield. Lateral flow into the wellfield due to the regional gradient is from the northeast, a region of relatively lower chlorides. Note that the simulated change in chloride at the wellfield represents an averaged value and that actual chloride concentration at each model cell representing the wells would differ from this average depending upon its location within the wellfield. The minimum changes in chloride concentrations were observed in the easternmost wells and the greatest changes in the westernmost well.

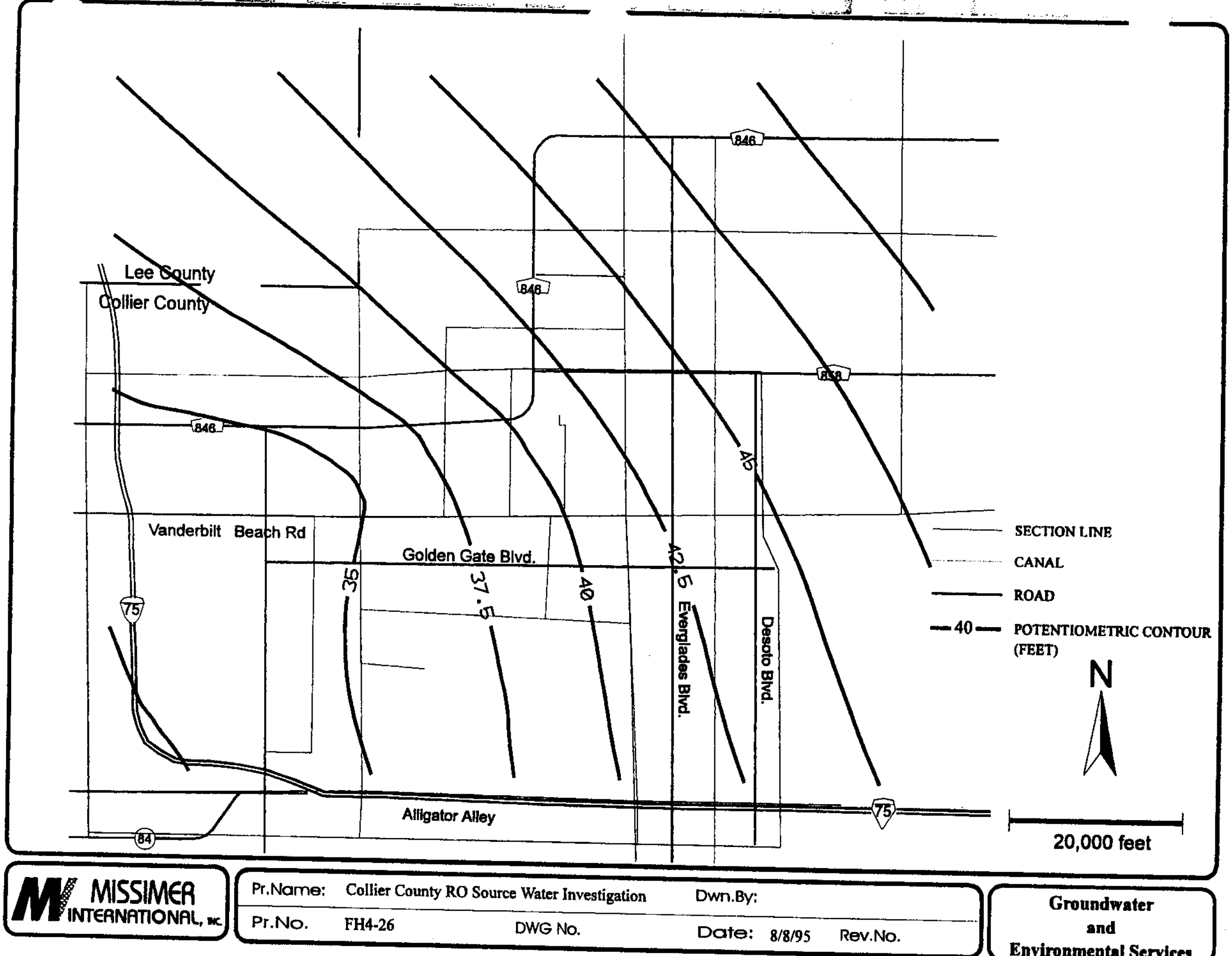
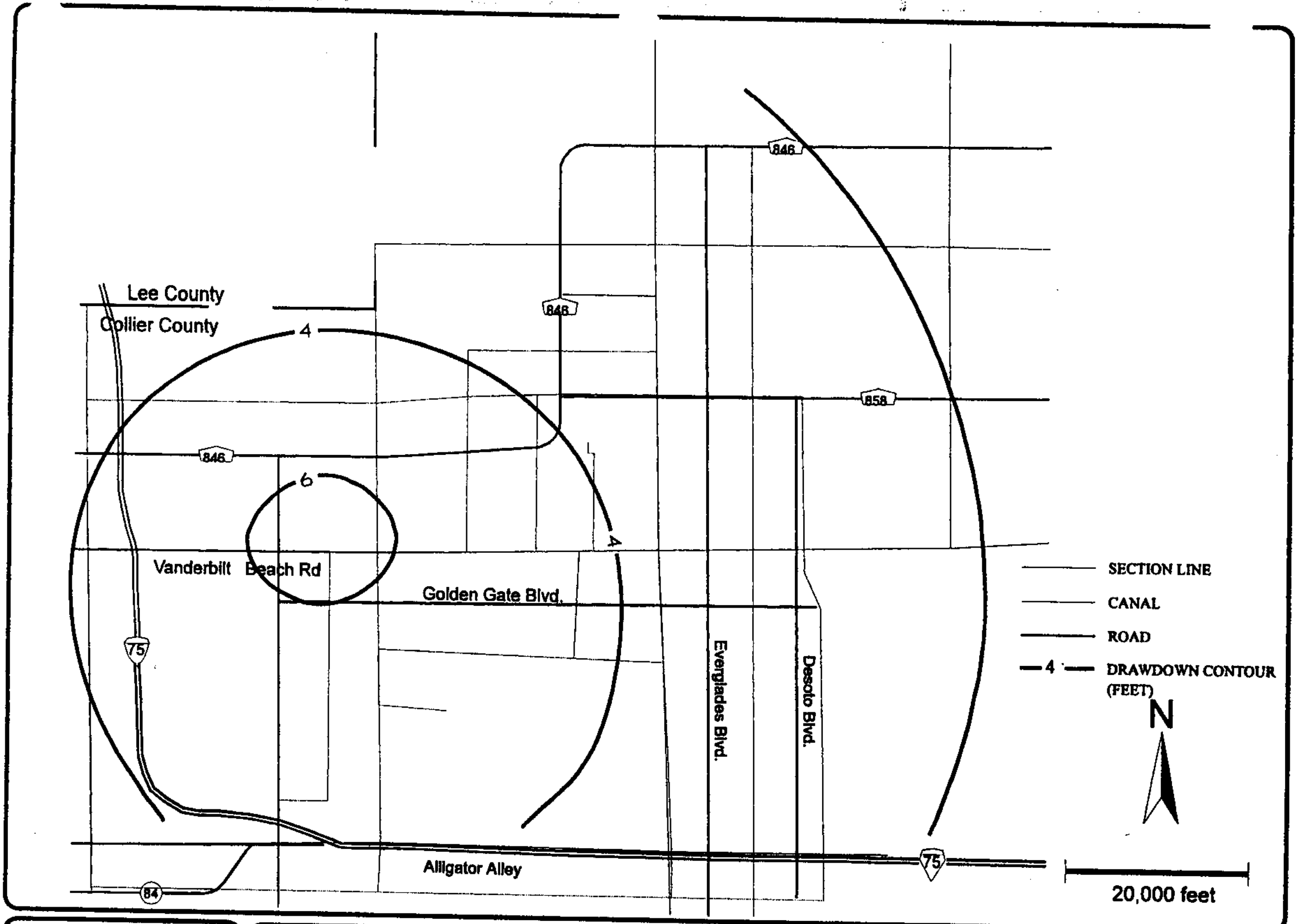


FIGURE 6-20 CONTOUR MAP OF SIMULATED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER FOR A 12 MGD WELLFIELD BASED ON THE CALIBRATED MODEL CONSTRUCT



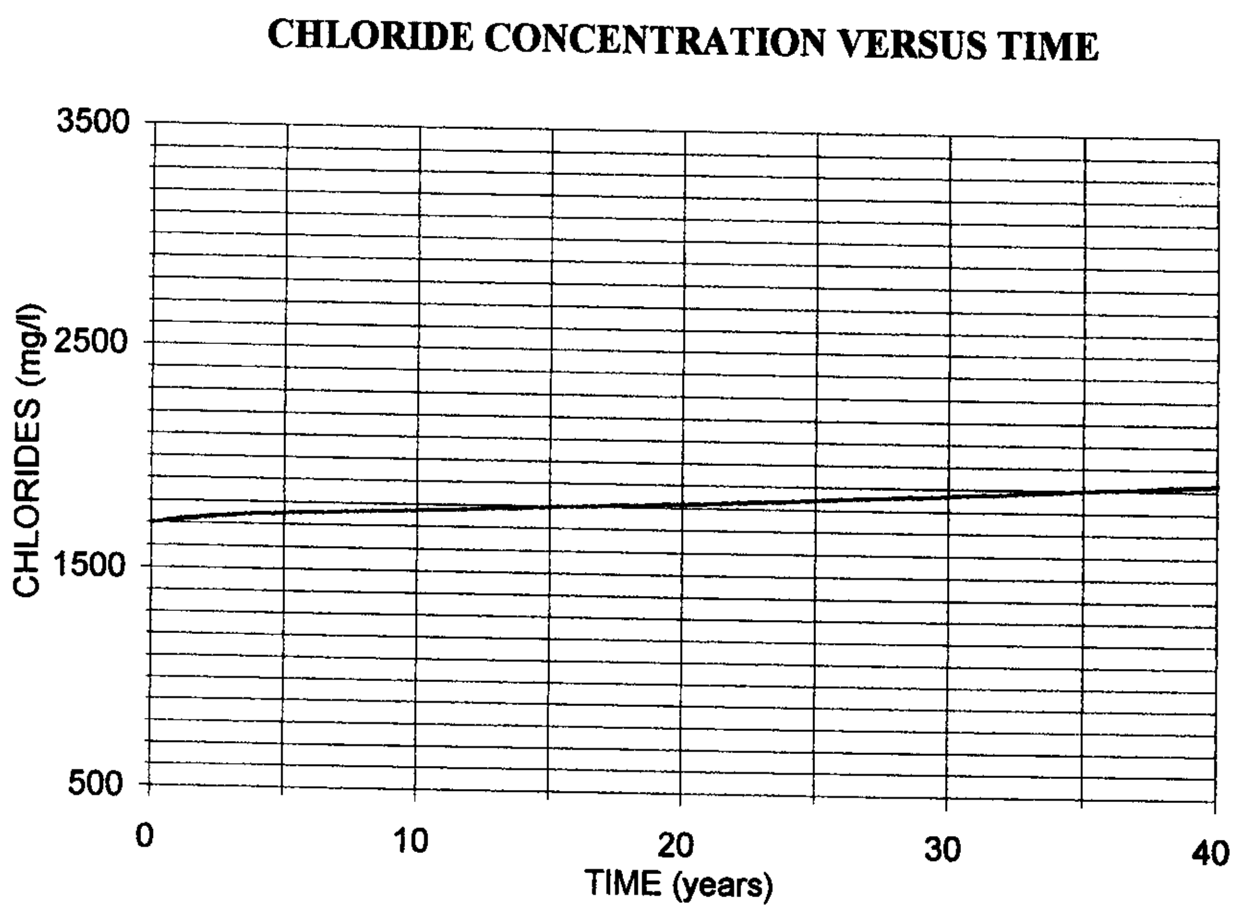
MISSIMER INTERNATIONAL, INC.

Pr.Name:	Collier County RO Source Water Investigation	Dwn.By:	
Pr.No. FH4-26	DWG No.	Date: 8/8/95	Rev.No.

Groundwater and Environmental Services

FIGURE 6-21 CONTOUR MAP OF DRAWDOWN IN THE LOWER HAWTHORN AQUIFER FOR A 12 MGD WELLFIELD BASED ON THE CALIBRATED MODEL CONSTRUCT

6-20821.CDR



MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation	GROUNDWATER AND ENVIRONMENTAL SERVICES
Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.	

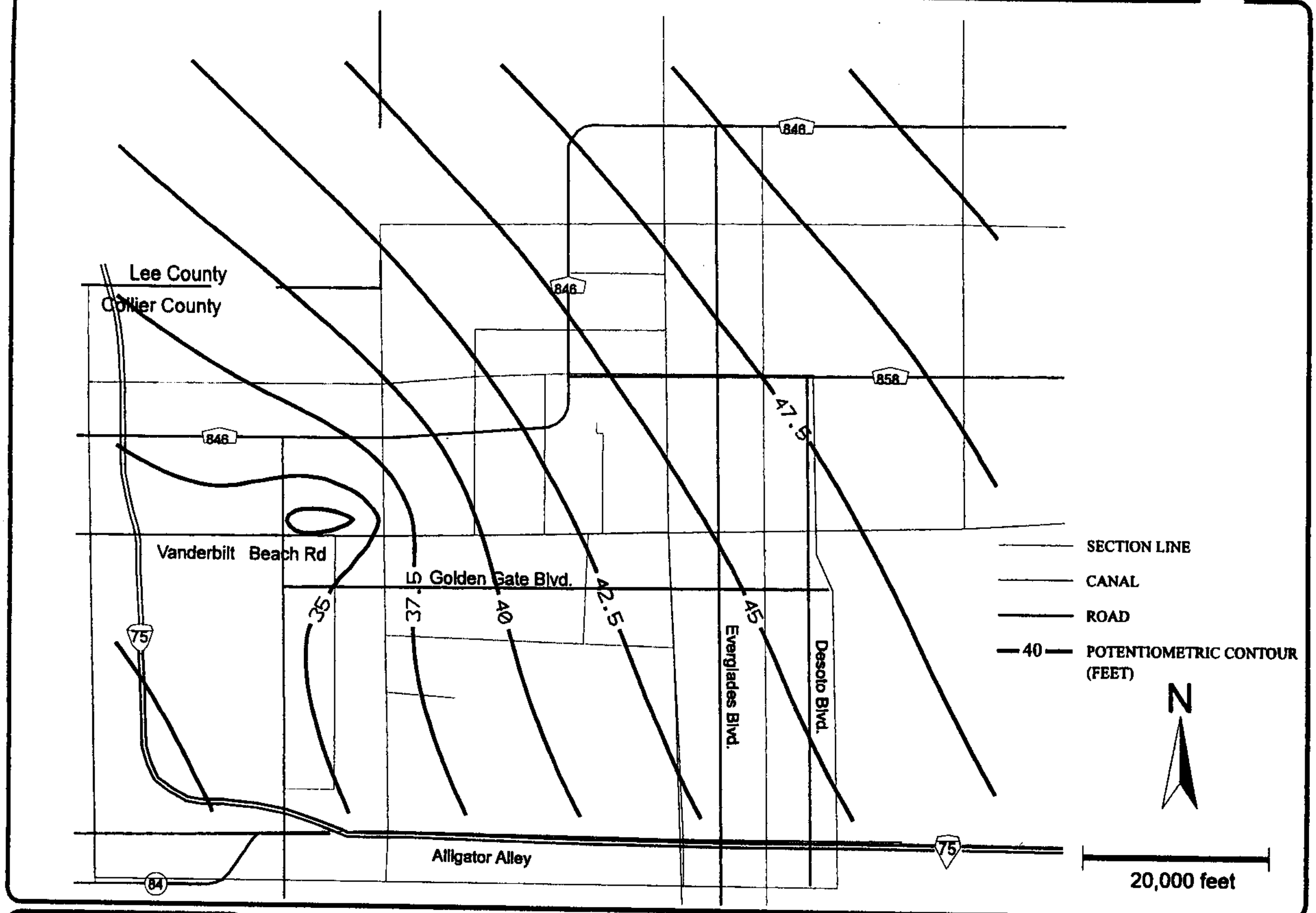
FIGURE 6-22 SIMULATED CHLORIDE CONCENTRATION FROM 12 MGD WELLFIELD (CALIBRATED MODEL)

The corresponding results for the conservative model are shown in Figures 6-23 through 25. The drawdown at the wellfield in this case is approximately 10 feet (see Figure 6-24) and the simulated changes in chloride concentration are greater in this case. The simulated chloride concentrations increased by about 650 mg/l over the 40-year period. Figure 6-25 shows an increase in chloride concentration from approximately 1750 mg/l to 2400 mg/l during the simulation period. Difference in starting chloride concentration for each model constructs is attributed to difference in computed chloride at the wellfield location during model initialization.

Case II

The Case II simulation depicts withdrawal of 20 MGD from the region extending 14,000 to 15,000 feet eastward from the water treatment plant site. The results for the calibrated model construct are shown in Figures 6-26 through 28. The potentiometric surface at the end of the 40-year simulation is presented in Figure 6-26. The drawdown resulting from well withdrawals is in excess of 12 feet in the well cells (see Figure 6-27). The corresponding change in chloride concentration is presented in Figure 6-28 and shows a 500 mg/l increase in chlorides over the 40-year simulation period. The average wellfield chloride concentration rises from approximately 1600 mg/l to approximately 2100 mg/l by the end of the simulation period. The starting wellfield chloride concentration differs for each modeling scenario due to difference in number and location of model cells that represent the wellfield.

Similar results for the conservative model are presented in Figures 6-29 to 6-31. Figure 6-29 shows the computed potentiometric surface at the end of 40 years. Maximum drawdown at the well cells was computed at between 14 and 16 feet. A contour map of the simulated drawdown superimposed over a site map is shown in Figure 6-30. The plot of change in chloride concentration with time (Figure 6-31) shows a rise from approximately 1650 mg/l to approximately 2550 mg/l, an increase of about 900 mg/l over the 40-year simulation period.



MISSIMER INTERNATIONAL, INC.	Pr.Name: Collier County RO Source Water Investigation	Dwn.By:		Groundwater and Environmental Services
	Pr.No. FH4-26	DWG No.	Date: 8/8/95	Rev.No.

FIGURE 6-23 CONTOUR MAP OF SIMULATED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER FOR A 12 MGD WELLFIELD BASED ON THE CONSERVATIVE MODEL CONSTRUCT

6-12&24 CDR

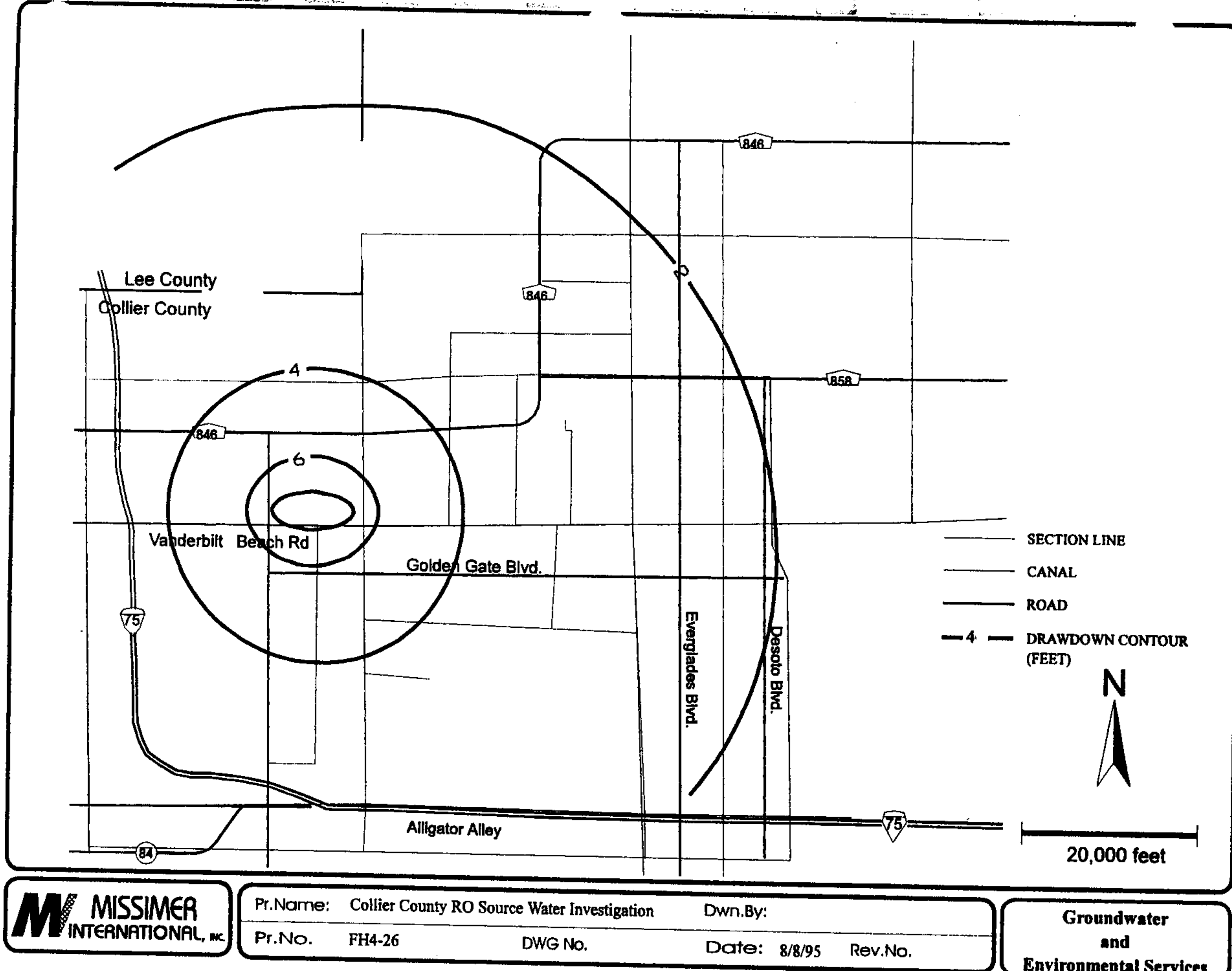
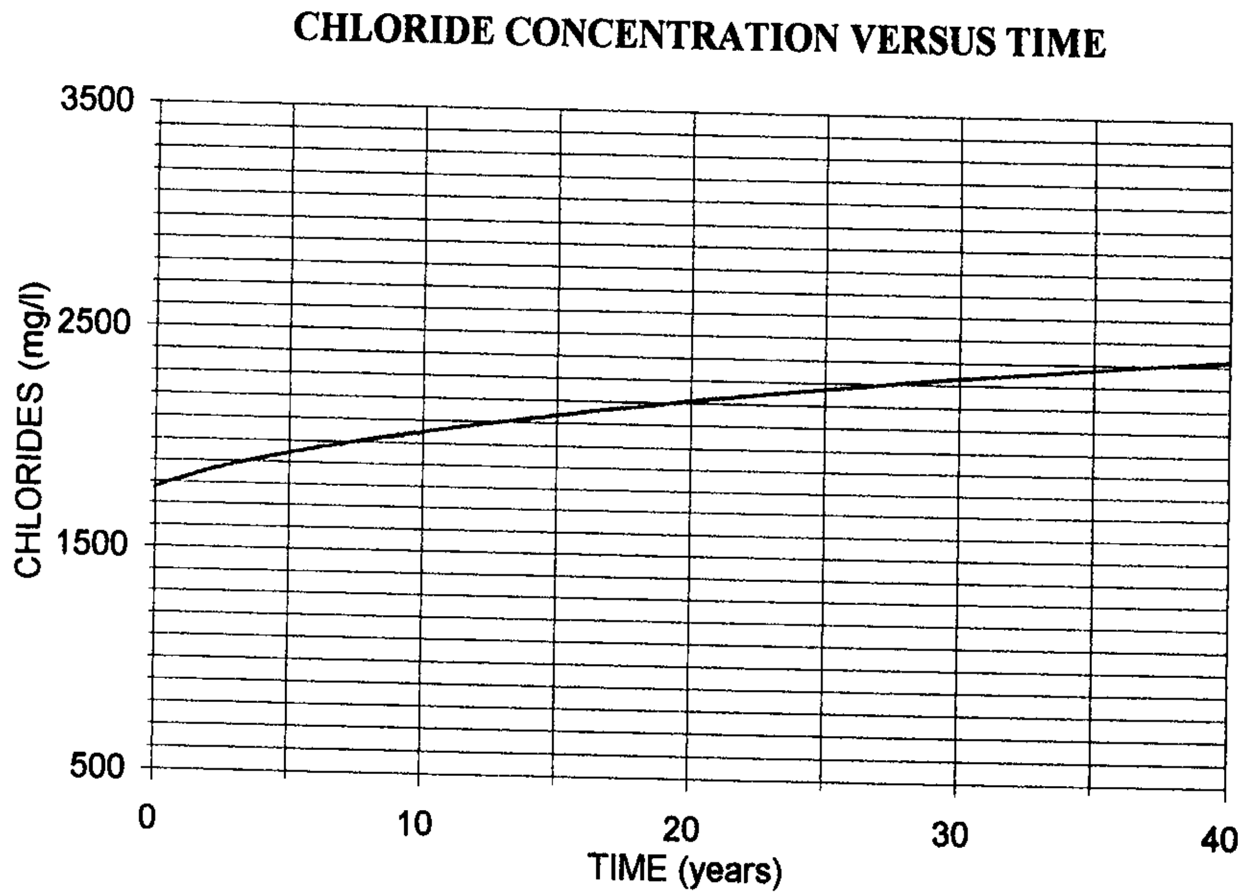


FIGURE 6-24 CONTOUR MAP OF DRAWDOWN IN THE LOWER HAWTHORN AQUIFER FOR A 12 MGD WELLFIELD BASED ON THE CONSERVATIVE MODEL CONSTRUCT



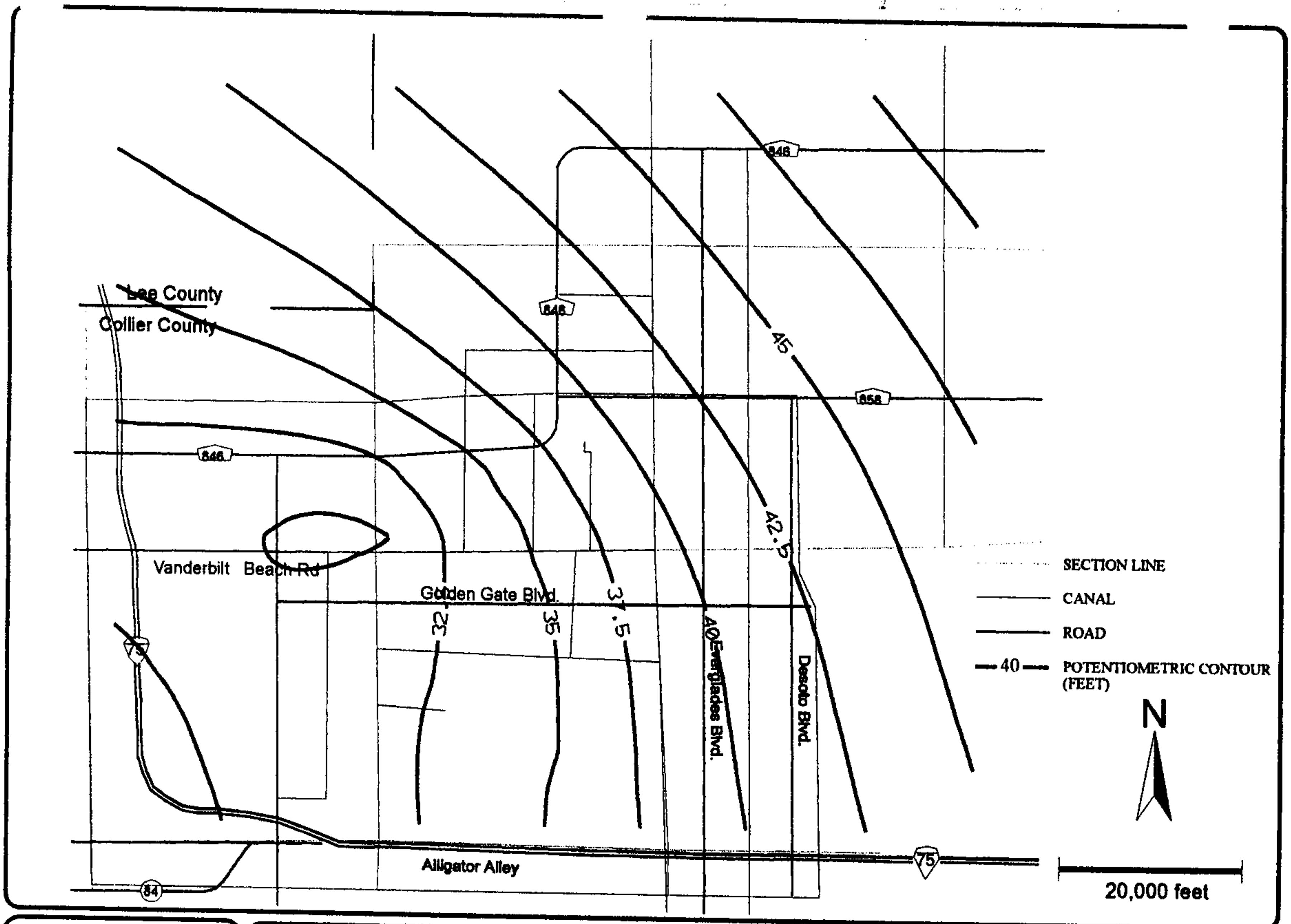
MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-25 SIMULATED CHLORIDE CONCENTRATION FROM 12 MGD WELLFIELD (CONSERVATIVE MODEL)



MISSIMER INTERNATIONAL, INC.

Pr.Name:	Collier County RO Source Water Investigation	Dwn.By:	
Pr.No. FH4-26	DWG No.	Date: 8/8/95	Rev.No.

Groundwater and Environmental Services

FIGURE 6-26 CONTOUR MAP OF SIMULATED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER FOR A 20 MGD WELLFIELD BASED ON THE CALIBRATED MODEL CONSTRUCT

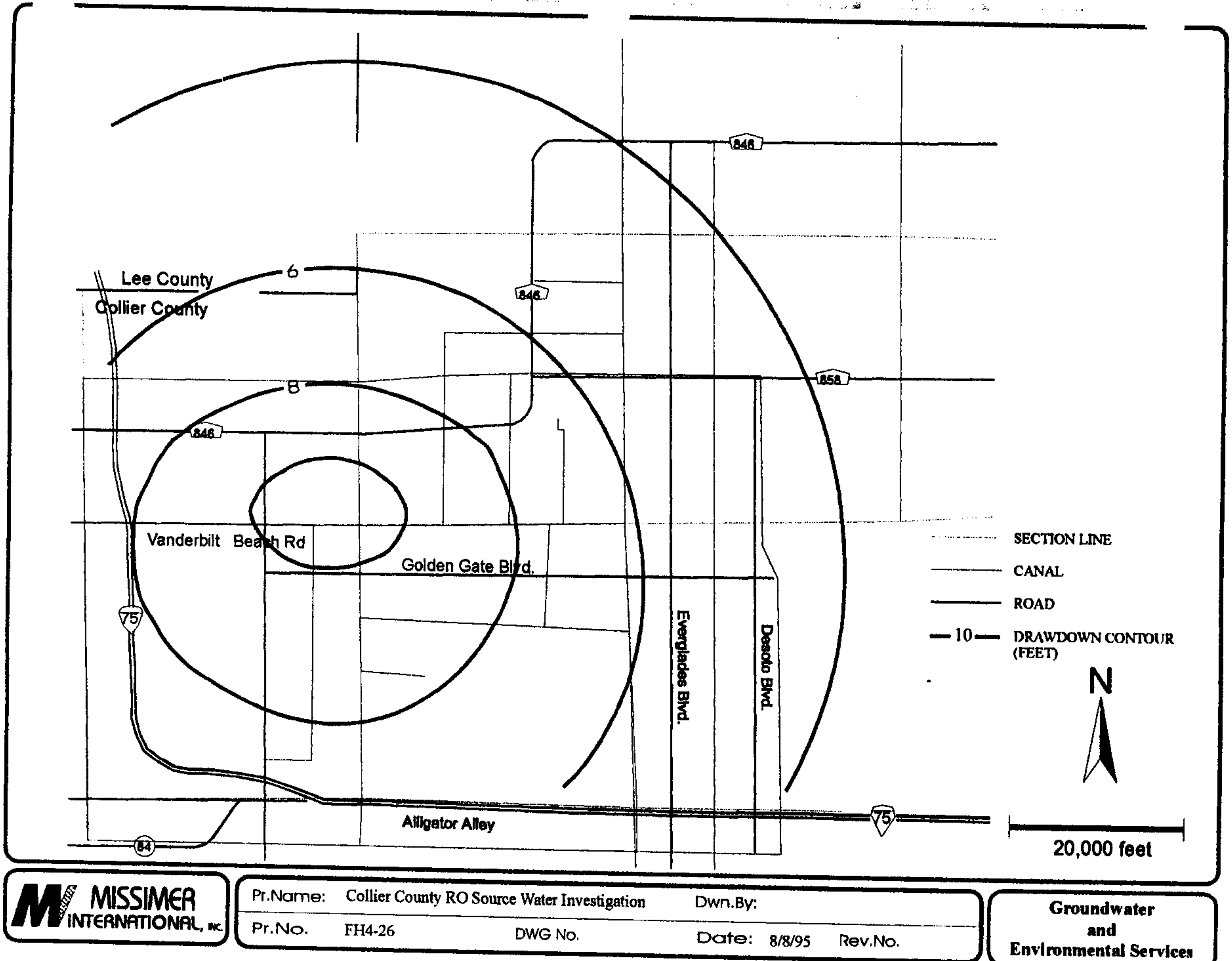
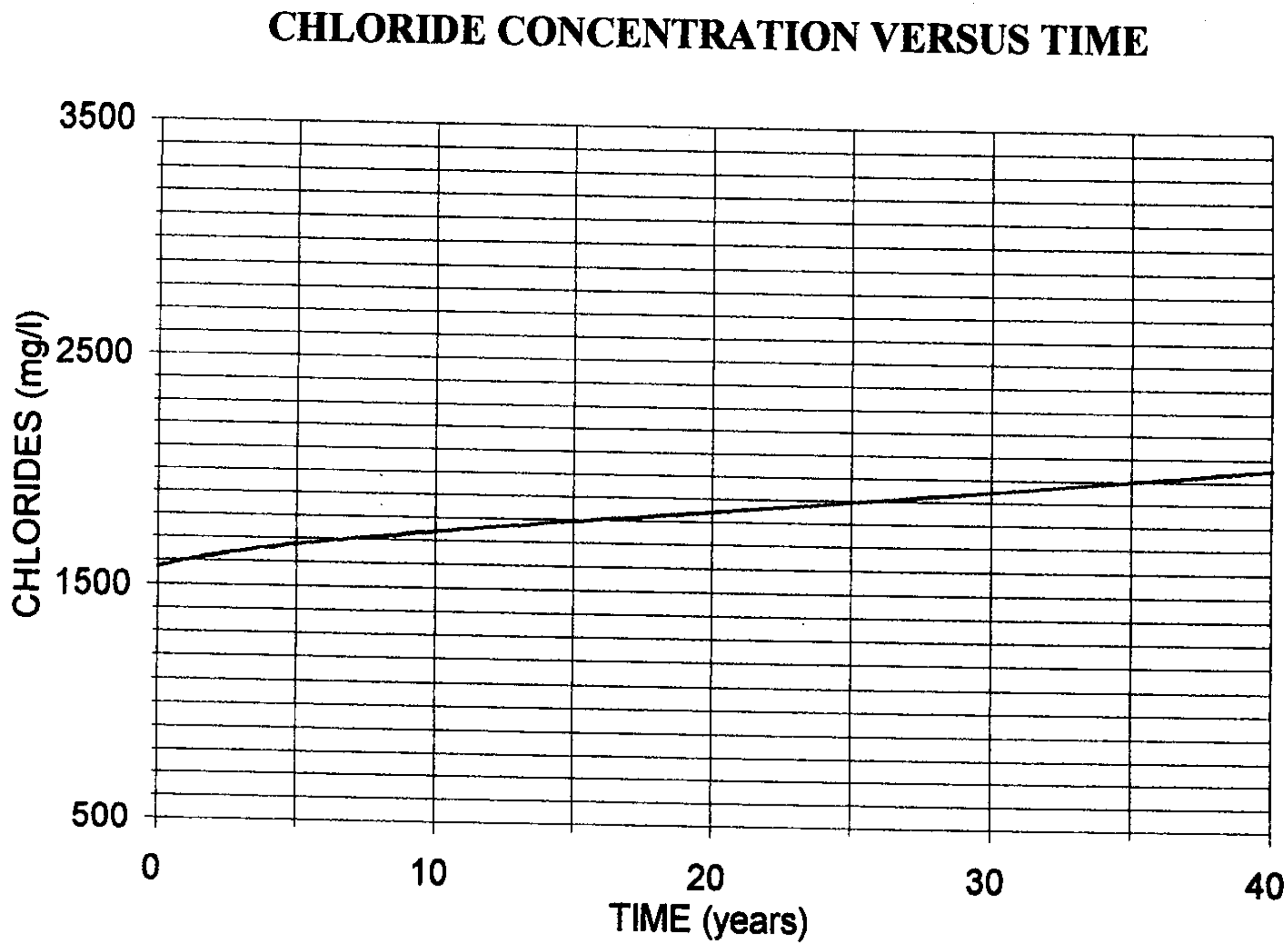


FIGURE 6-27 CONTOUR MAP OF DRAWDOWN IN THE LOWER HAWTHORN AQUIFER FOR A 20 MGD WELLFIELD BASED ON THE CALIBRATED MODEL CONSTRUCT



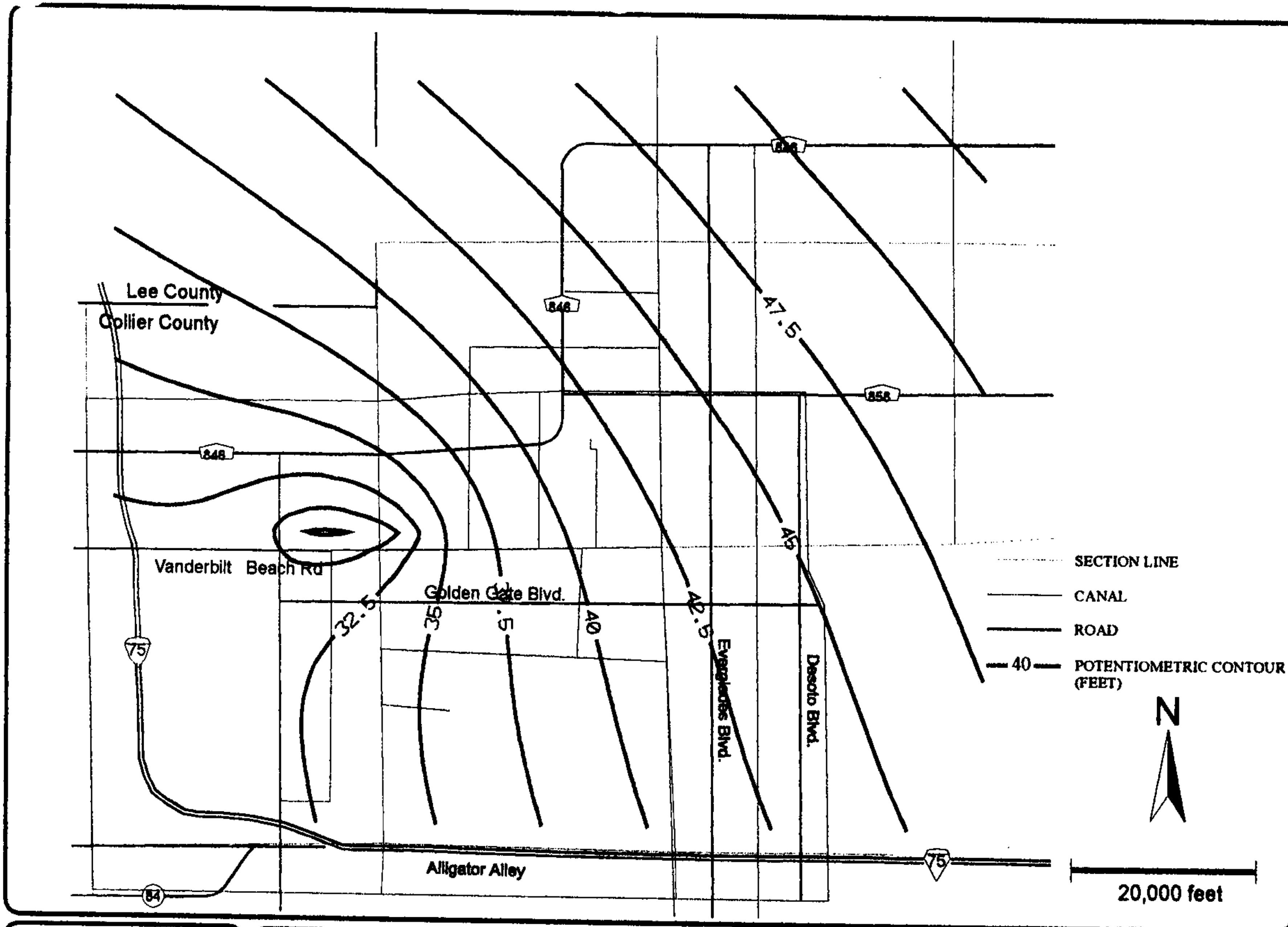
MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-28 SIMULATED CHLORIDE CONCENTRATION FROM 20 MGD WELLFIELD (CALIBRATED MODEL)



MISSIMER INTERNATIONAL, INC.	Pr.Name: Collier County RO Source Water Investigation	Dwn.By:	Groundwater and Environmental Services
	Pr.No. FH4-26 DWG No.	Date: 8/8/95 Rev.No.	

FIGURE 6-29 CONTOUR MAP OF SIMULATED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER FOR A 20 MGD WELLFIELD BASED ON THE CONSERVATIVE MODEL CONSTRUCT

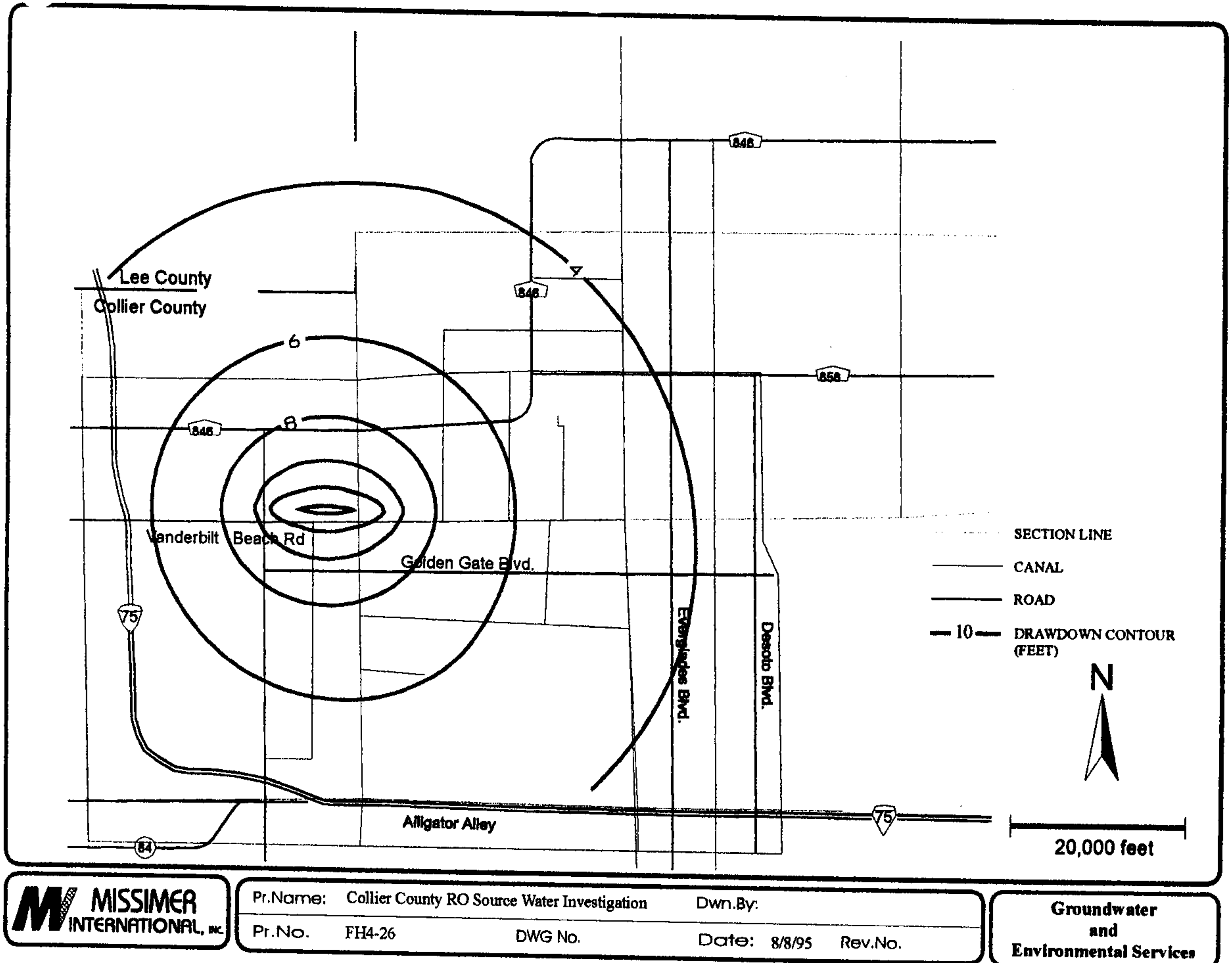
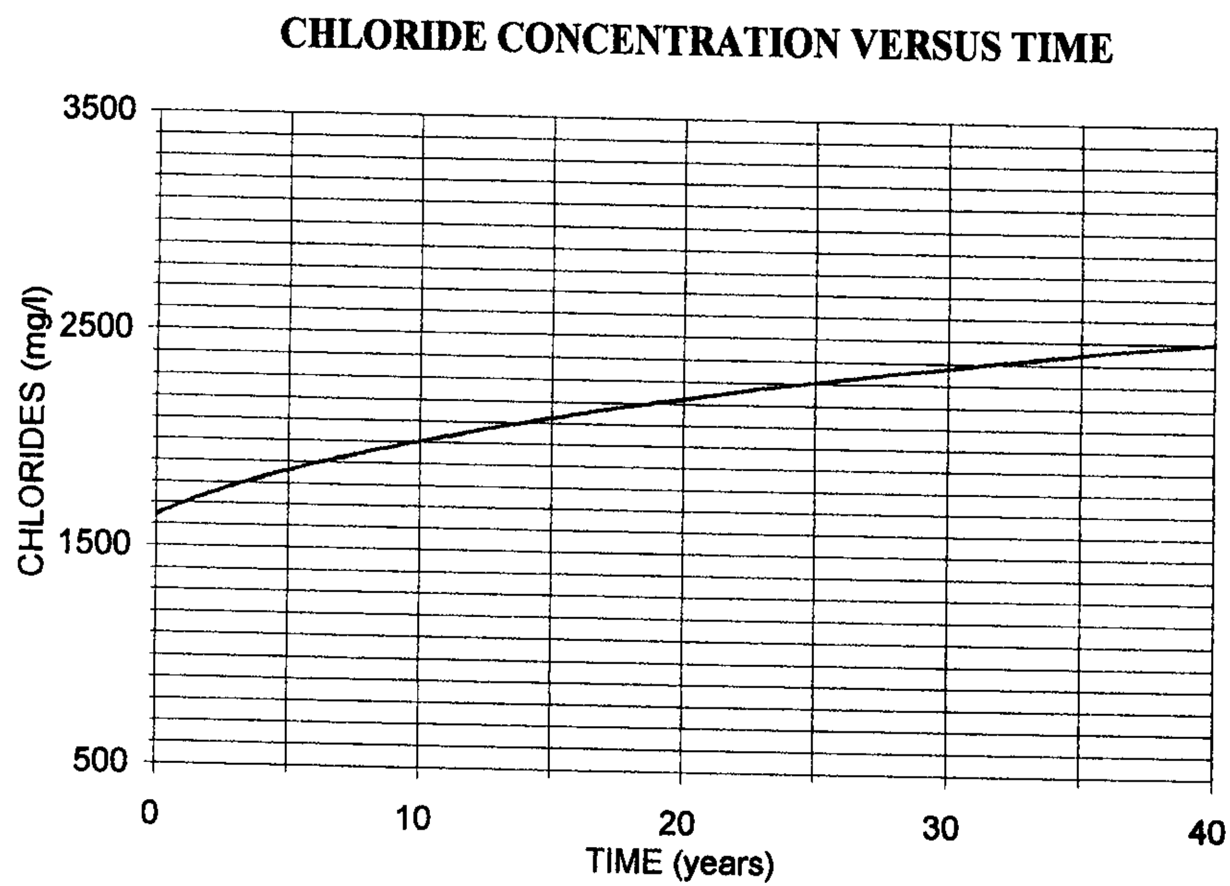


FIGURE 6-30 CONTOUR MAP OF DRAWDOWN IN THE LOWER HAWTHORN AQUIFER FOR A 20 MGD WELLFIELD BASED ON THE CONSERVATIVE MODEL CONSTRUCT

119



MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

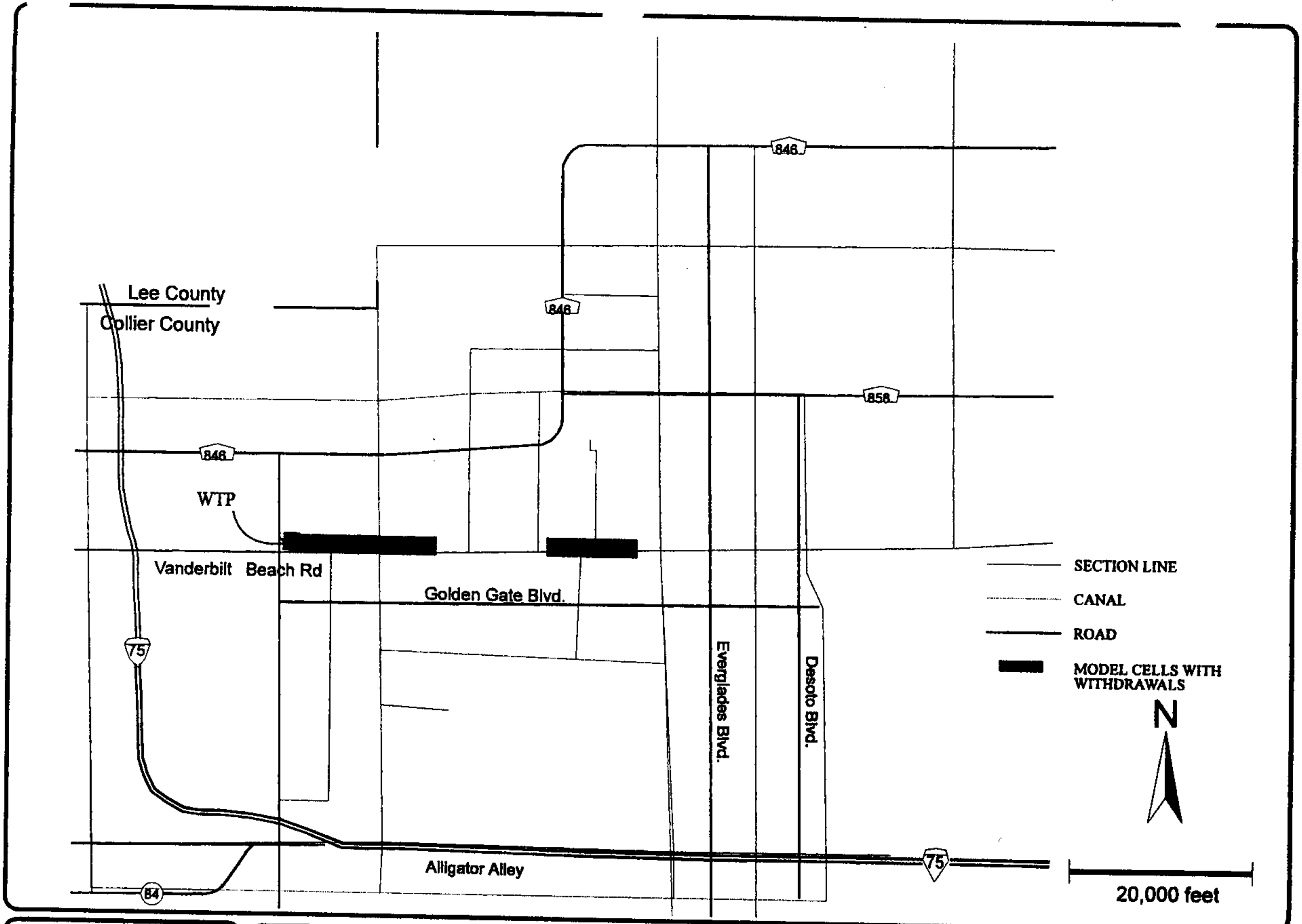
FIGURE 6-31 SIMULATED CHLORIDE CONCENTRATION FROM 20 MGD WELLFIELD (CONSERVATIVE MODEL)

Case III

Several alternative scenarios were considered during Case III simulations. The alternatives differed primarily in the location of the wells producing the required 30 MGD. Case III simulations represent modeling conducted primarily to select best locations for future wellfield development. The results of model simulation for the selected location is discussed in this section. Figures showing results from other locations are also presented for purpose of comparison.

Thirteen model cells located as shown in Figure 6-32 were used to simulate withdrawal of 30 MGD from the Lower Hawthorn Aquifer. The wellfield configuration shown in Figure 6-32 resulted in minimal interference among the well clusters. The results of the simulation are presented in Figures 6-33a to 6-35a-b. Similar results for the other considered wellfield configurations are presented in Figures 6-33b to 6-35b. Simulated potentiometric surfaces at the end of the 40-year simulation period for the selected wellfield configuration is presented in Figure 6-33a. The resulting drawdown map is presented as Figure 6-34a and shows a maximum drawdown of 16 to 18 feet. The plot of change in chloride concentration for this scenario is presented in Figure 6-35 and shows an increase in chloride concentration from approximately 1300 mg/l to approximately 2100 mg/l at the end of the 40-year simulation period.

The results for the conservative model are presented in Figures 6-36 to 6-38. The potentiometric surface and drawdown are presented in Figures 6-36 and 6-37, respectively. A simulated maximum drawdown of 16 to 17 feet at the end of the 40-year simulation period was obtained. The resulting change in chloride concentrations is shown in Figure 6-38. The wellfield averaged chloride concentration rises from approximately 1325 mg/l to 2200 mg/l at the end of 40 years, an increase of 875 mg/l over the 40-year period. As can be seen from the chloride concentration plots, the various wellfield

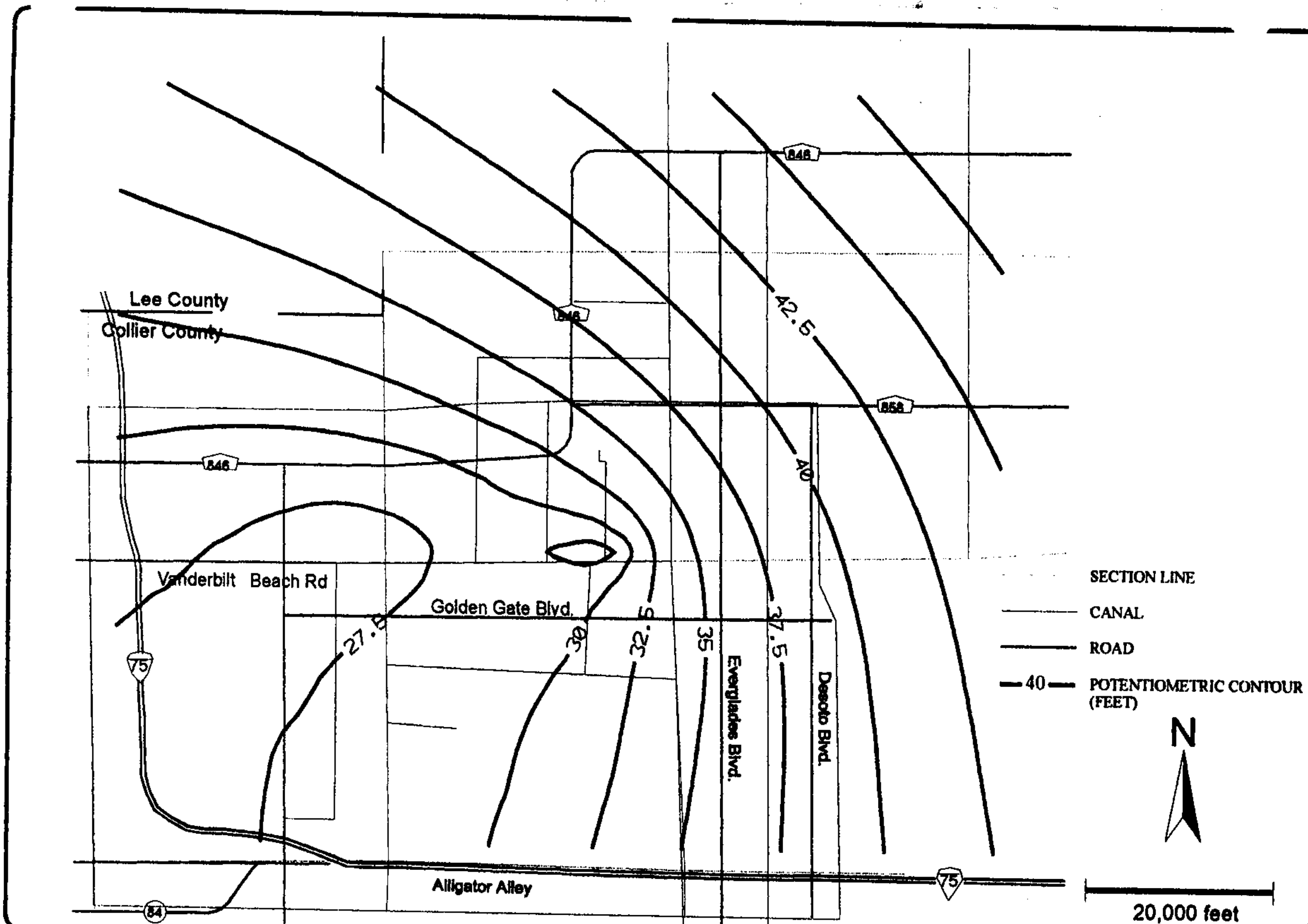


MISSIMER INTERNATIONAL, INC.

Pr.Name:	Collier County RO Source Water Investigation	Dwn.By:	
Pr.No.	FH4-26	DWG No.	Date: 8/8/95 Rev.No.

Groundwater and Environmental Services

FIGURE 6-32 SITE MAP SHOWING THIRTEEN MODEL CELLS REPRESENTING LOCATION OF 30 MGD WELLFIELD



MISSIMER INTERNATIONAL, INC.

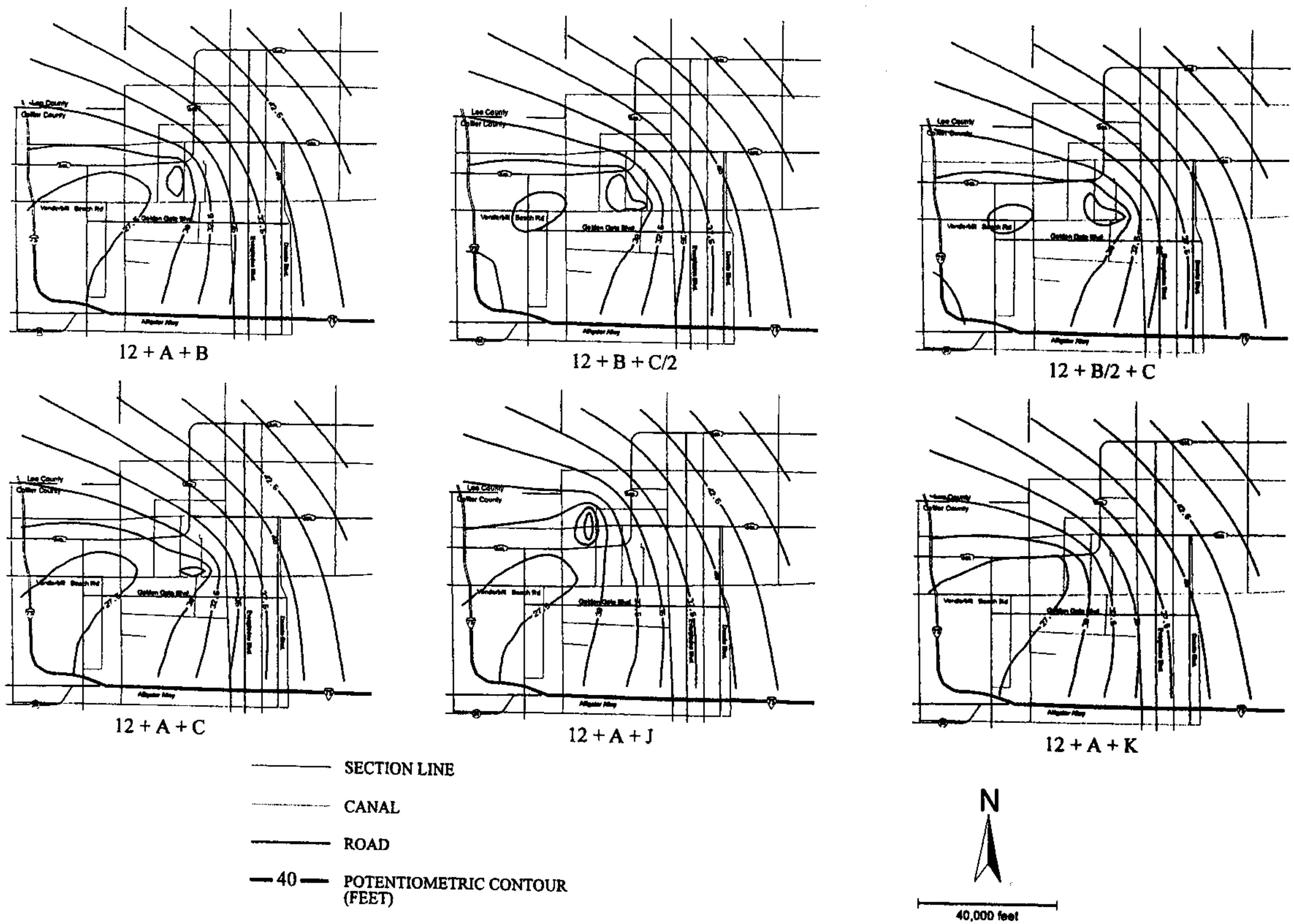
Pr.Name: Collier County RO Source Water Investigation Dwn.By:

Pr.No. FH4-26 DWG No. Date: 8/8/95 Rev.No.

Groundwater and Environmental Services

FIGURE 6-33a CONTOUR MAP OF SIMULATED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER FOR A 30 MGD WELLFIELD BASED ON THE CALIBRATED MODEL CONSTRUCT (FOR SELECTED WELLFIELD CONFIGURATION)

6-33&34 CDR



MISSIMER INTERNATIONAL, INC.

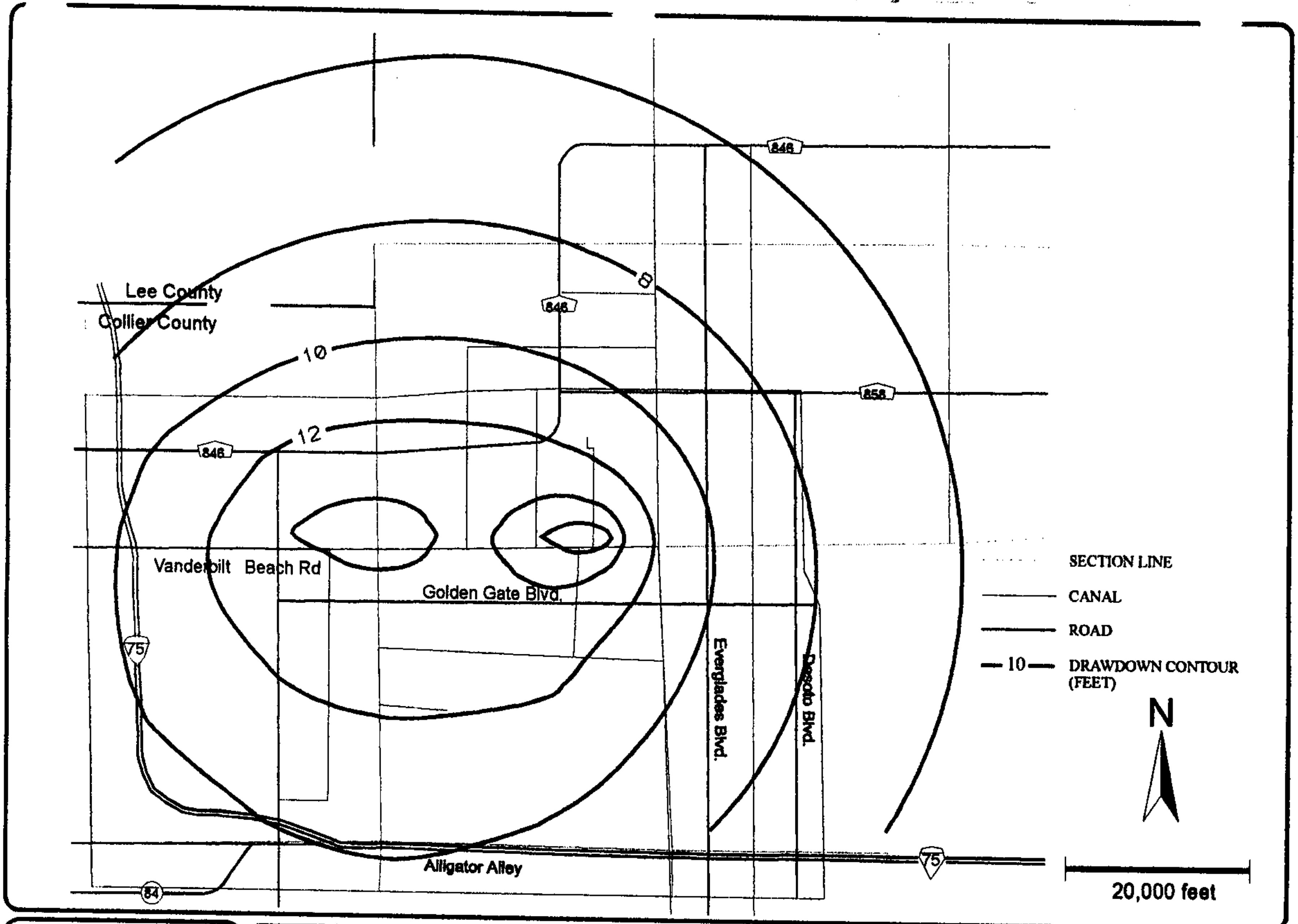
Pr.Name:	Collier County RO Source Water Investigation	Dwn.By:	
Pr.No.	FH4-26	DWG No.	Date: 8/8/95 Rev.No.

Groundwater and Environmental Services

FIGURE 6-33b CONTOUR MAP OF SIMULATED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER FOR A 30 MGD WELLFIELD BASED ON THE CALIBRATED MODEL CONSTRUCT (FOR CONSIDERED WELLFIELD CONFIGURATIONS)

6-33&34.CDR

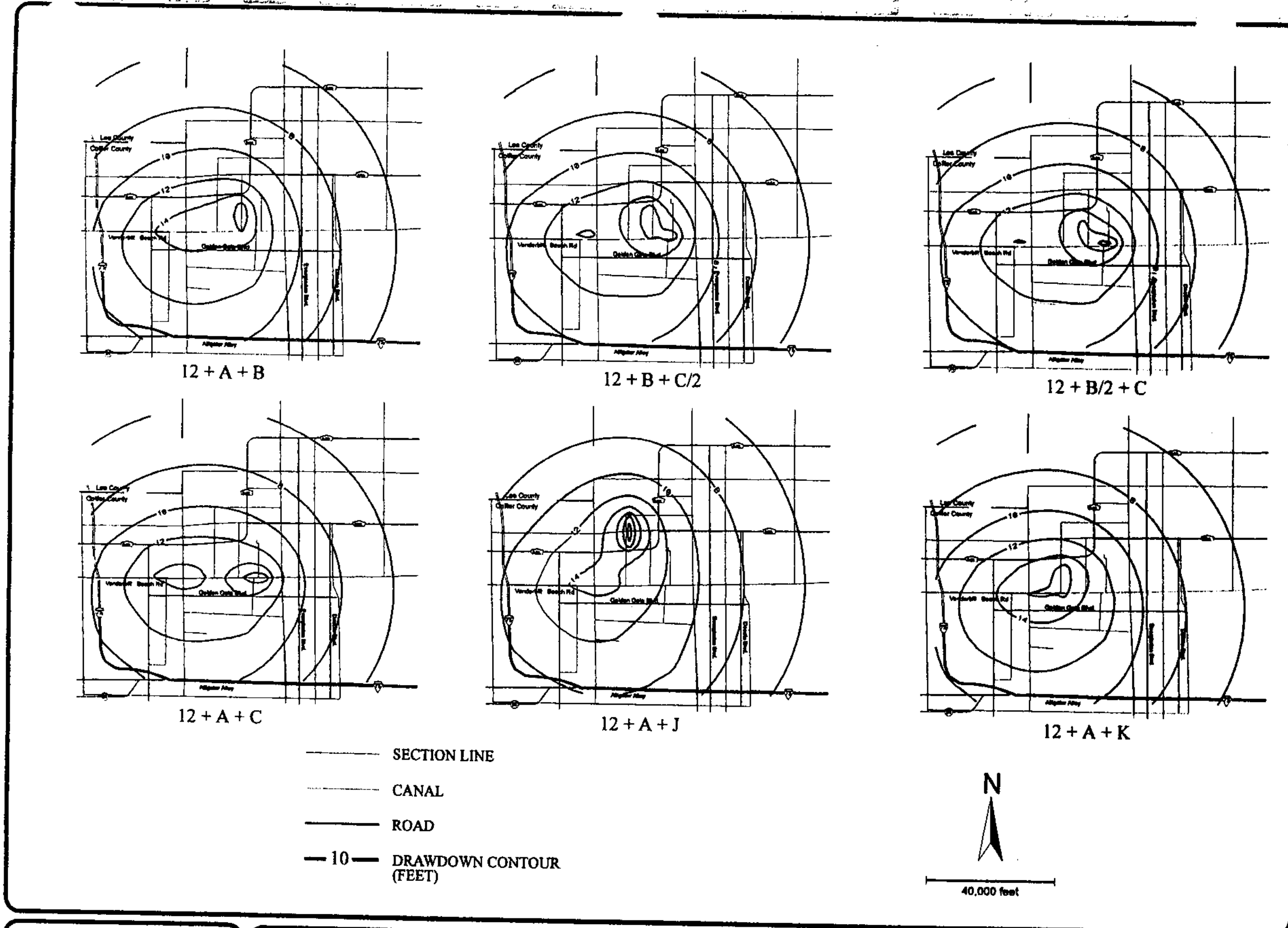
124



MISSIMER INTERNATIONAL, INC.	Pr.Name: Collier County RO Source Water Investigation	Dwn.By:	Groundwater and Environmental Services
	Pr.No. FH4-26 DWG No.	Date: 8/8/95 Rev.No.	

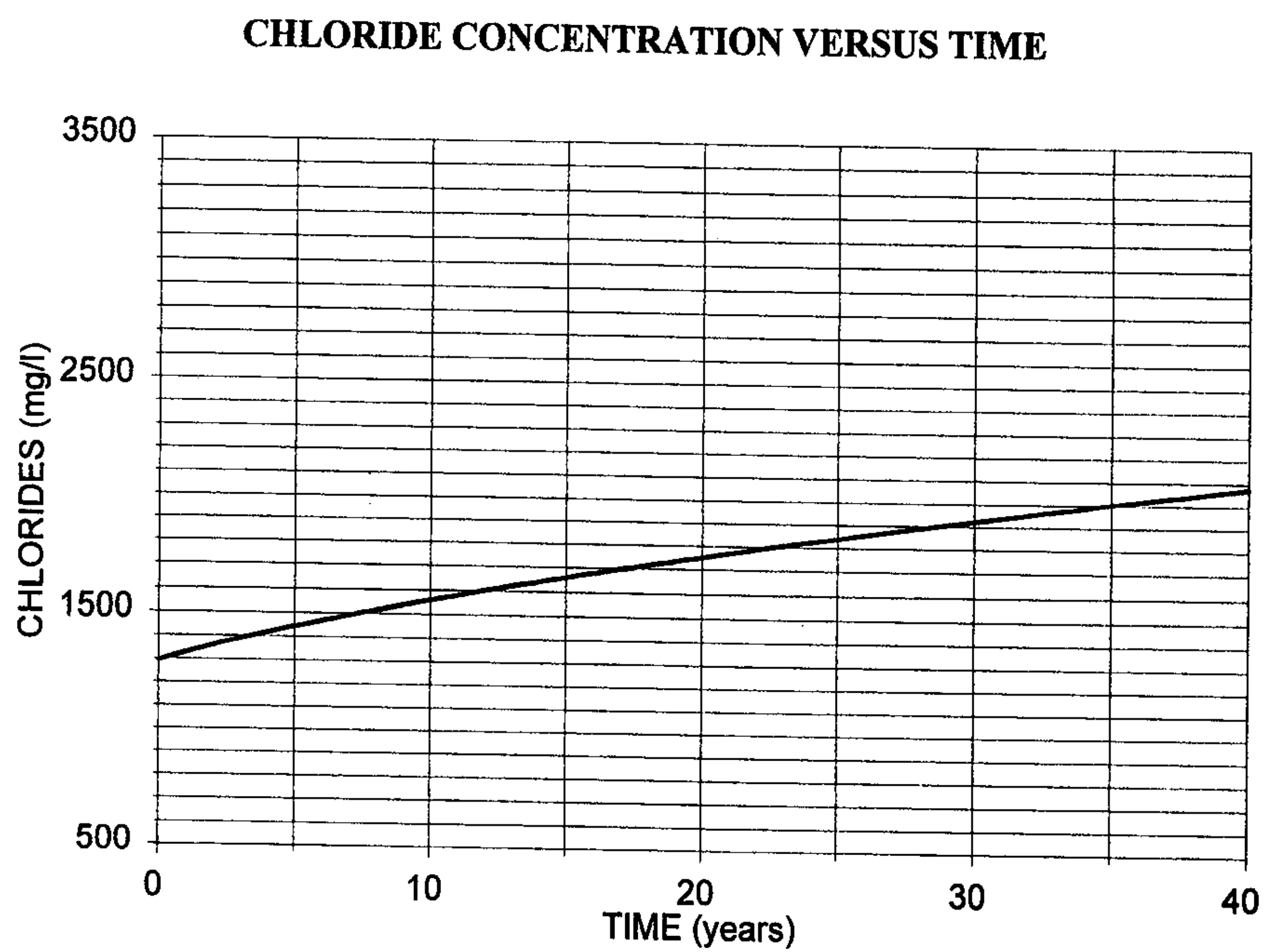
FIGURE 6-34a CONTOUR MAP OF DRAWDOWN IN THE LOWER HAWTHORN AQUIFER FOR A 30 MGD WELLFIELD BASED ON THE CALIBRATED MODEL CONSTRUCT (FOR SELECTED WELLFIELD CONFIGURATION)

6-33&34 CDR



MISSIMER INTERNATIONAL, INC.	Pr.Name: Collier County RO Source Water Investigation		Dwn.By:	Groundwater and Environmental Services
	Pr.No. FH4-26	DWG No.	Date: 8/8/95 Rev.No.	

FIGURE 6-34b CONTOUR MAP OF DRAWDOWN IN THE LOWER HAWTHORN AQUIFER FOR A 30 MGD WELLFIELD BASED ON THE CALIBRATED MODEL CONSTRUCT (FOR CONSIDERED WELLFIELD CONFIGURATIONS



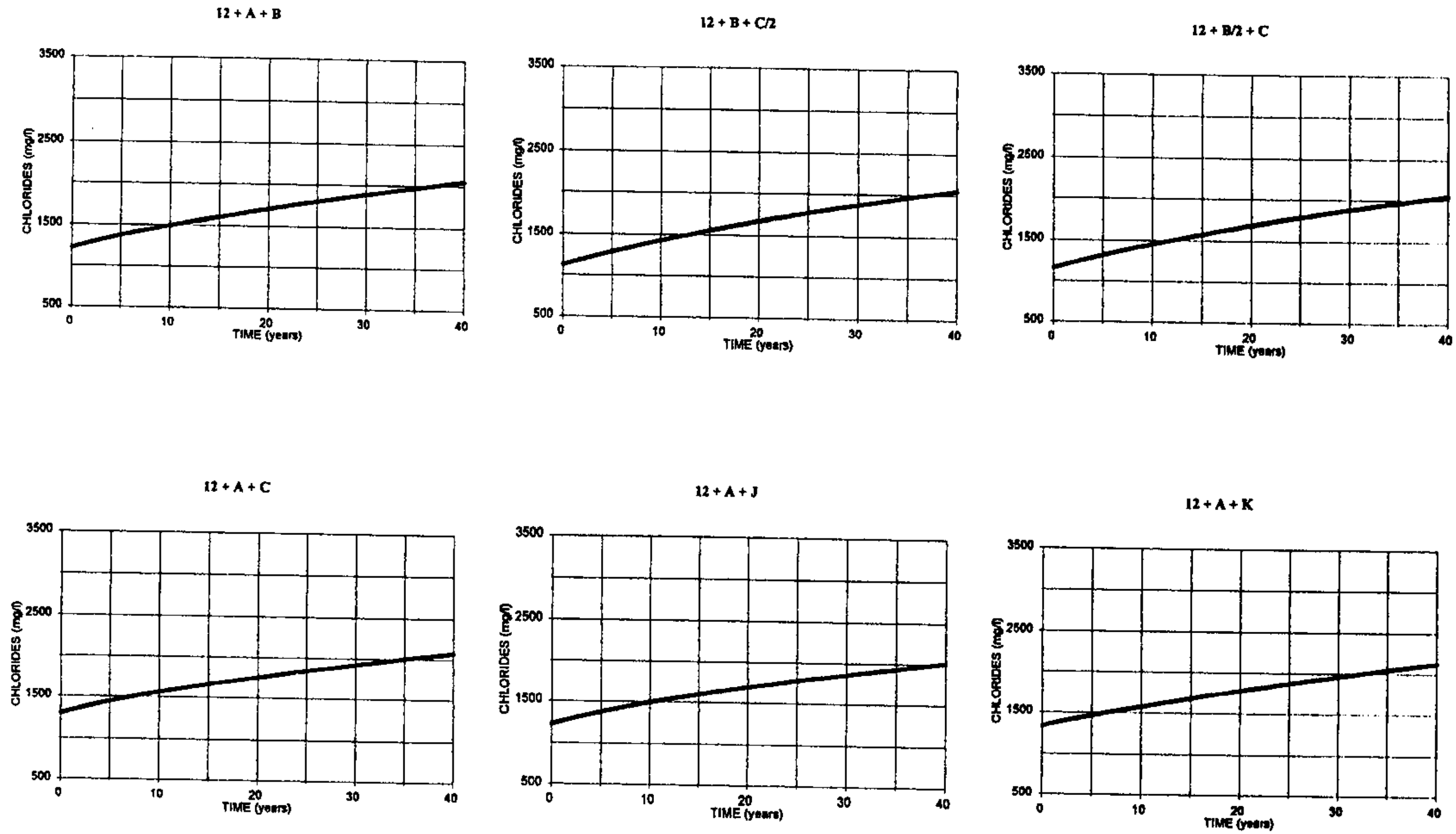
MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-35a SIMULATED CHLORIDE CONCENTRATION FROM 30 MGD WELLFIELD (CALIBRATED MODEL)



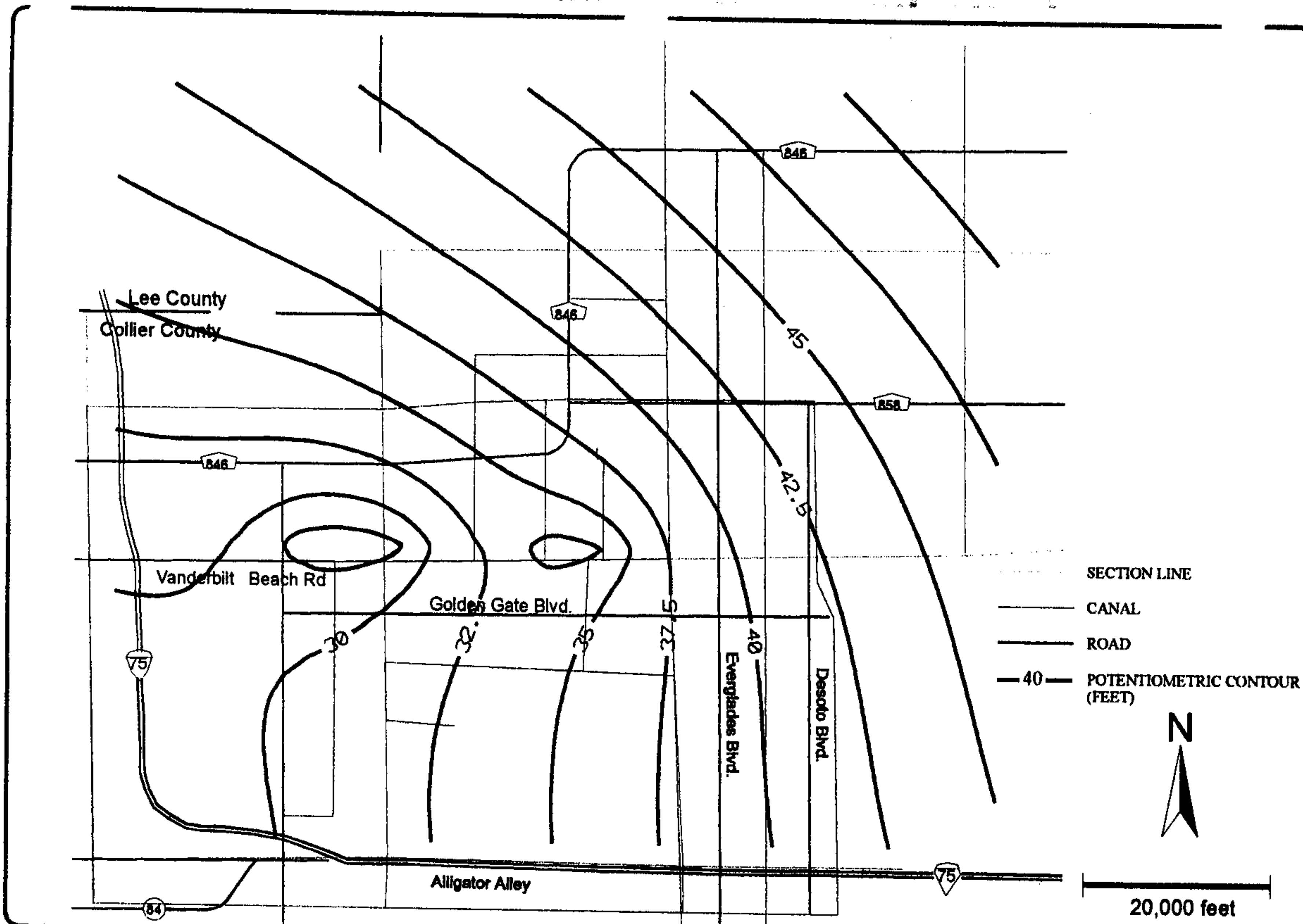
MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

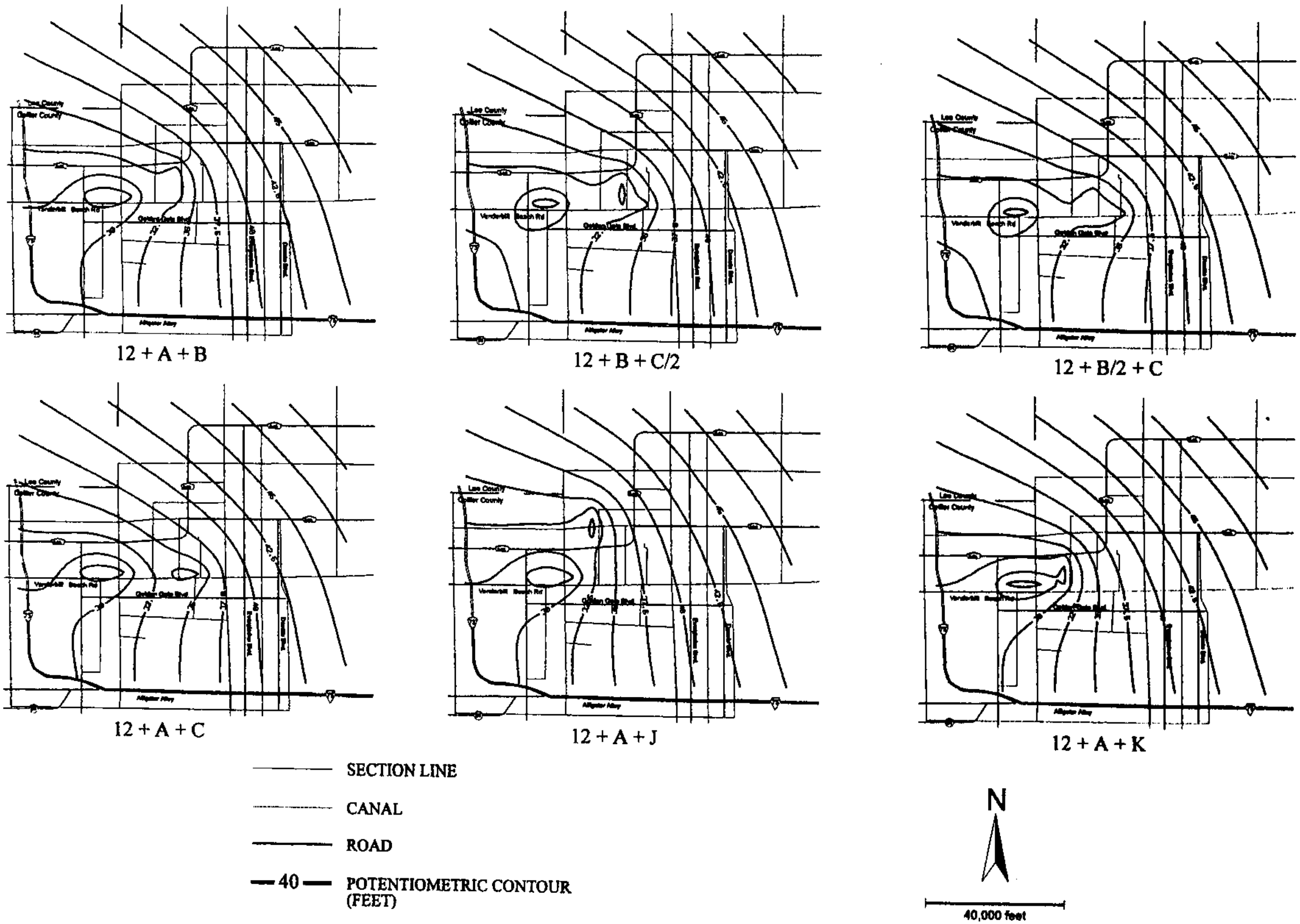
FIGURE 6-35b SIMULATED CHLORIDE CONCENTRATION FROM 30 MGD WELLFIELD (CALIBRATED MODEL, CONSIDERED WELLFIELD LOCATIONS)



MISSIMER INTERNATIONAL, INC.	Pr.Name:	Collier County RO Source Water Investigation	Dwn.By:		Groundwater and Environmental Services
	Pr.No.	FH4-26	DWG No.	Date: 8/8/95	Rev.No.

FIGURE 6-36a CONTOUR MAP OF SIMULATED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER FOR A 30 MGD WELLFIELD BASED ON THE CONSERVATIVE MODEL CONSTRUCT (FOR SELECTED WELLFIELD CONFIGURATION)

6-36A37.CDR



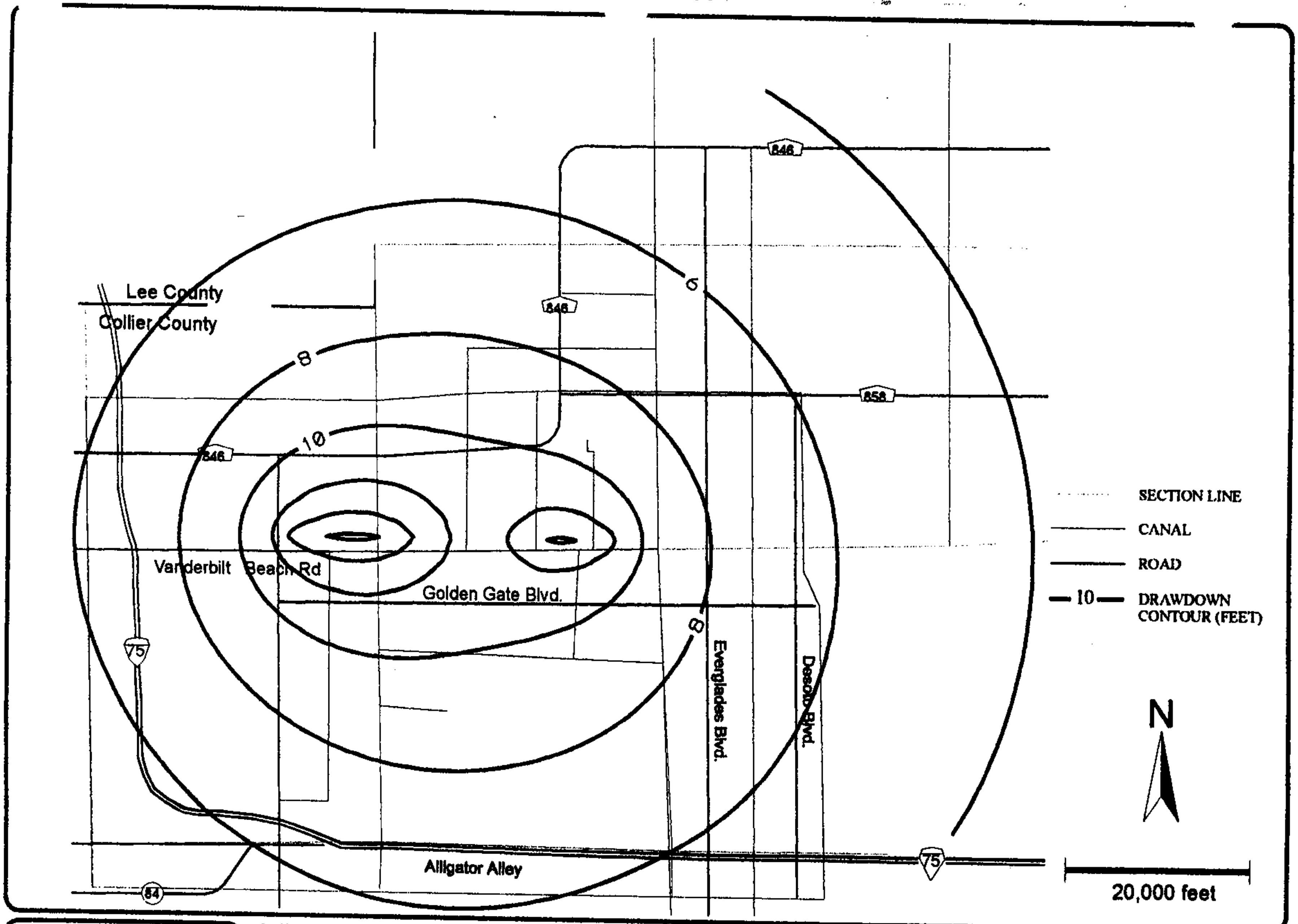
MISSIMER INTERNATIONAL, INC.

Pr.Name:	Collier County RO Source Water Investigation		Dwn.By:		
Pr.No.	FH4-26	DWG No.	Date:	8/8/95	Rev.No.

Groundwater and Environmental Services

FIGURE 6-36b CONTOUR MAP OF SIMULATED POTENTIOMETRIC SURFACE OF THE LOWER HAWTHORN AQUIFER FOR A 30 MGD WELLFIELD BASED ON THE CONSERVATIVE MODEL CONSTRUCT (FOR CONSIDERED WELLFIELD CONFIGURATIONS)

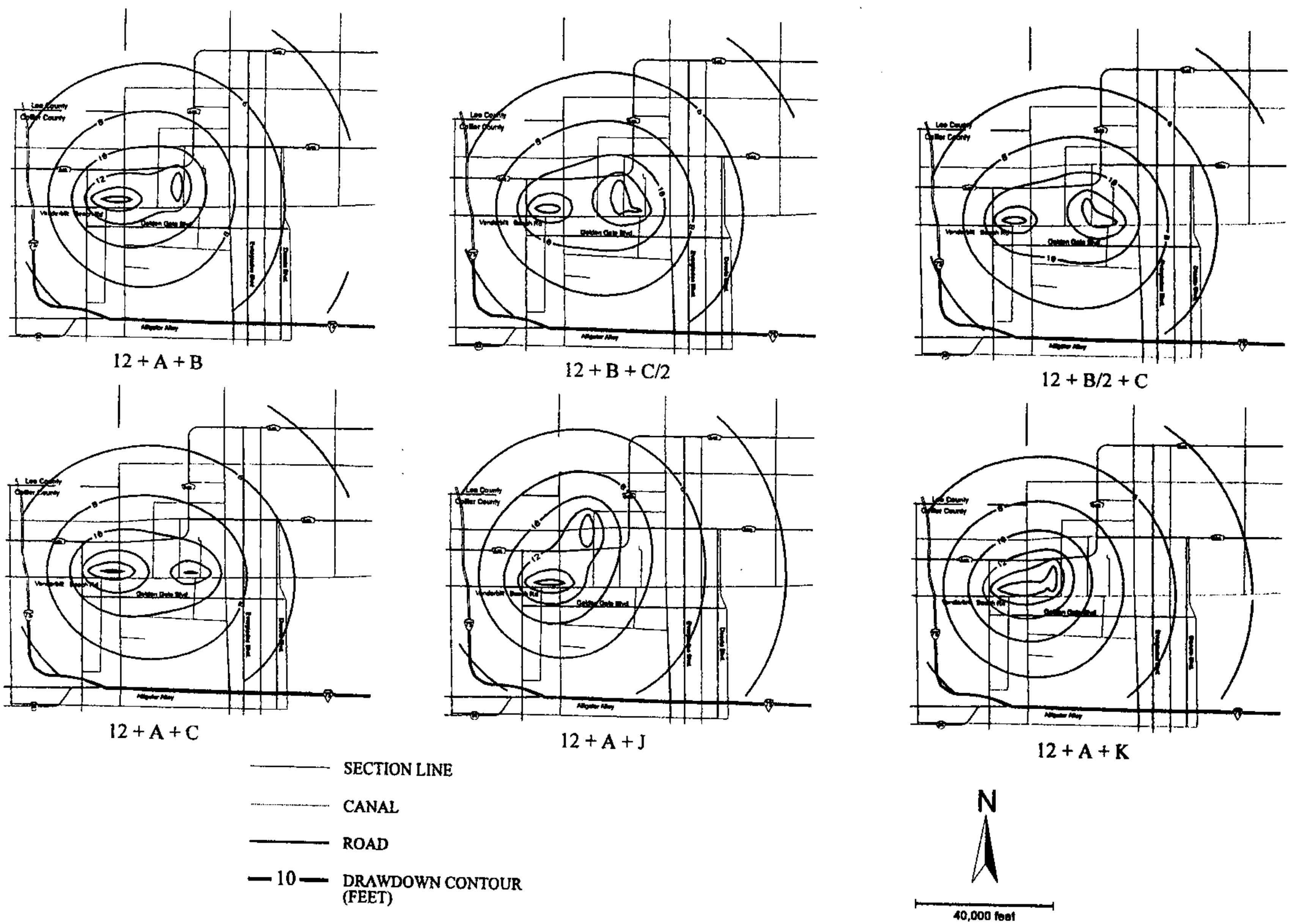
130



MISSIMER INTERNATIONAL, INC.	Pr.Name: Collier County RO Source Water Investigation		Dwn.By:	Groundwater and Environmental Services
	Pr.No. FH4-26	DWG No.	Date: 8/8/95 Rev.No.	

FIGURE 6-37a CONTOUR MAP OF DRAWDOWN IN THE LOWER HAWTHORN AQUIFER FOR A 30 MGD WELLFIELD BASED ON THE CONSERVATIVE MODEL CONSTRUCT (FOR SELECTED WELLFIELD CONFIGURATION)

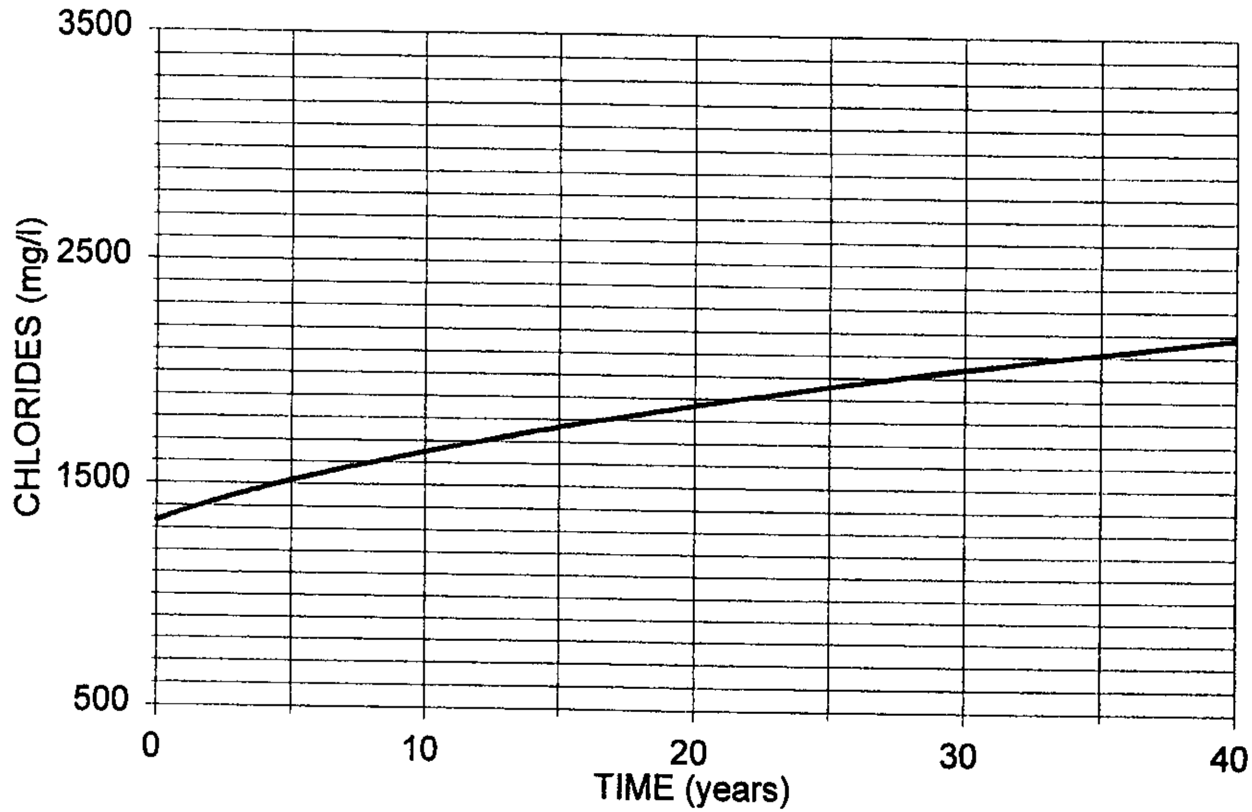
6-36a



MISSIMER INTERNATIONAL, INC.	Pr.Name: Collier County RO Source Water Investigation		Dwn.By:	Groundwater and Environmental Services
	Pr.No. FH4-26	DWG No.	Date: 8/8/95 Rev.No.	

FIGURE 6-37b CONTOUR MAP OF DRAWDOWN IN THE LOWER HAWTHORN AQUIFER FOR A 30 MGD WELLFIELD BASED ON THE CONSERVATIVE MODEL CONSTRUCT (FOR CONSIDERED WELLFIELD CONFIGURATIONS

CHLORIDE CONCENTRATION VERSUS TIME



MISSIMER INTERNATIONAL, INC.

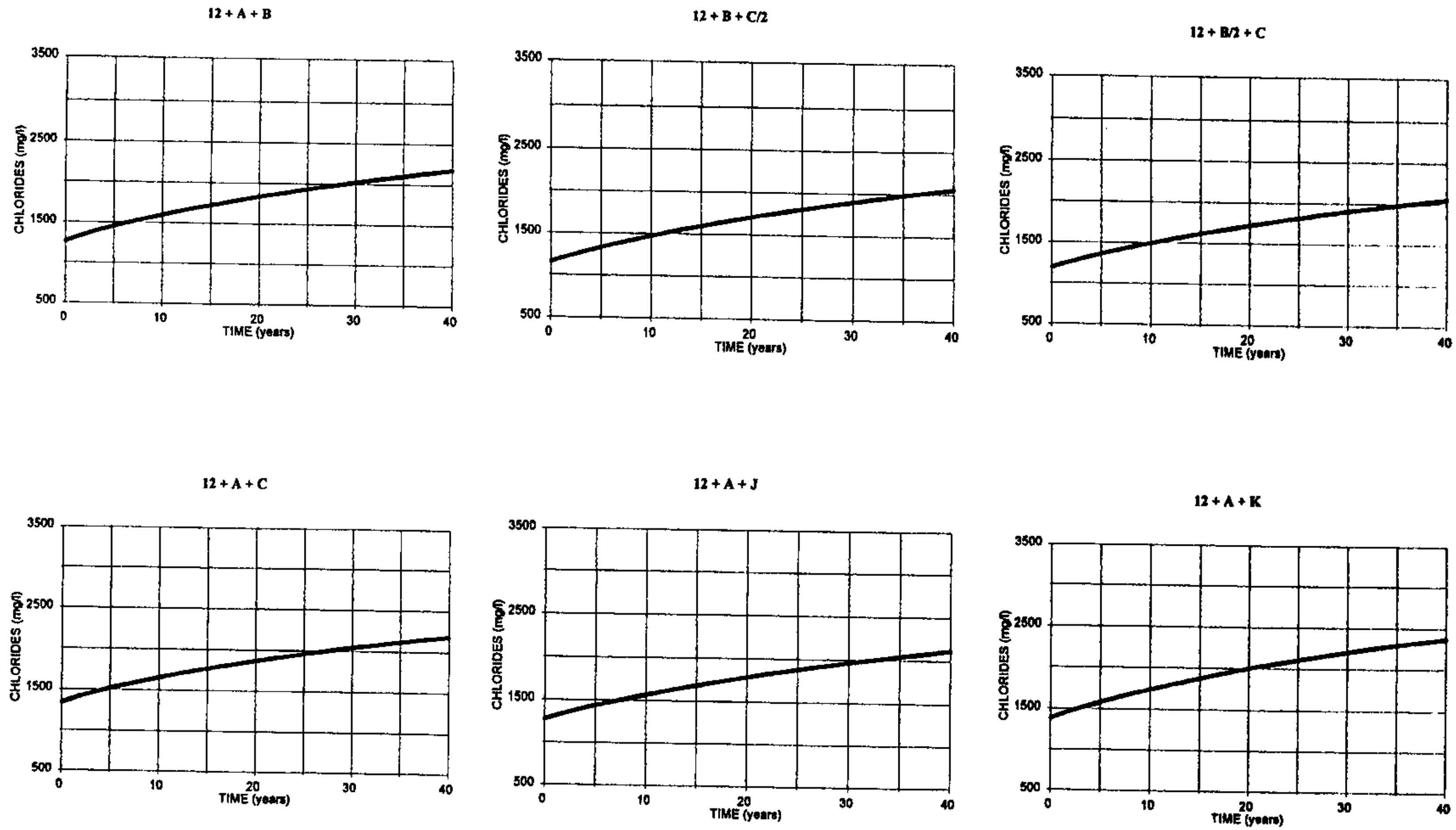
Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-38a SIMULATED CHLORIDE CONCENTRATION FROM 30 MGD WELLFIELD (CONSERVATIVE MODEL)

133



MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-38b SIMULATED CHLORIDE CONCENTRATION FROM 30 MGD WELLFIELD (CONSERVATIVE MODEL, CONSIDERED WELLFIELD LOCATIONS)

locations utilized result in a relatively similar chloride concentration change over the 40-year simulation. Selection of the preferred site was then based on well interference and anticipated piping requirements. An alternate site other than the one shown in Figure 6-32 may be selected if other criteria not considered at this time prevail.

6.3.5. Model Sensitivity

To determine the effect of key model input parameters on the simulated chloride concentrations, and determine the degree of sensitivity of the model results to these input parameters, a sensitivity analysis was done. A total of fourteen sensitivity runs were conducted to investigate the effect of transmissivity, vertical hydraulic conductivity (and hence leakance), dispersion coefficient and initial chloride concentration of the aquifers underlying the Lower Hawthorn Aquifer on the model results. The sensitivity runs were conducted using 12 MGD (Case I) withdrawal from the Lower Hawthorn Aquifer. The results of the sensitivity analyses conducted on both the calibrated and conservative models are summarized in Table 6-2.

Calibrated Model Sensitivity

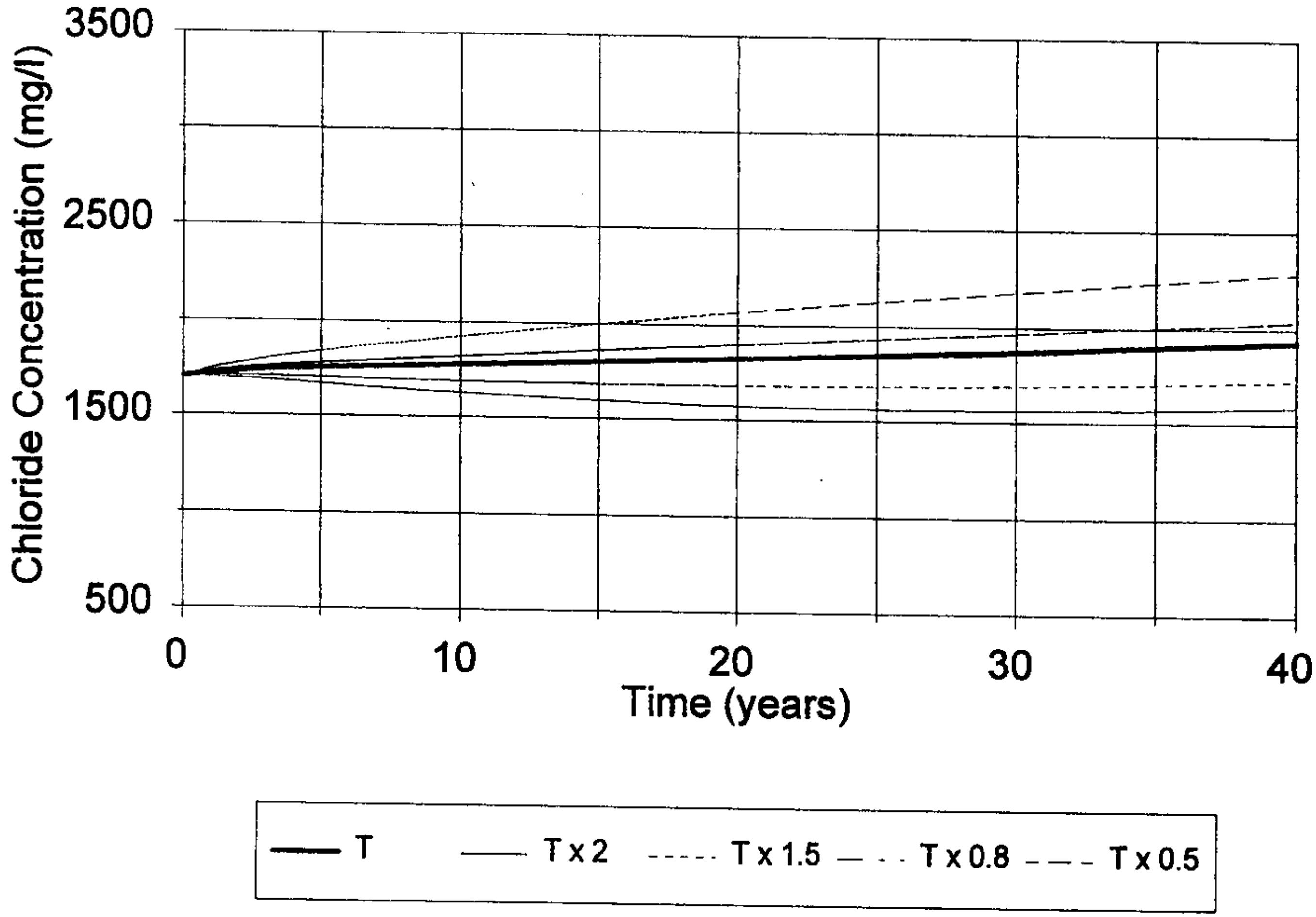
A graphical representation of the results of the sensitivity analyses is presented in Figures 6-39 to 6-42 for the calibrated model. A comparison of simulated chloride concentration using different transmissivities show that increase in transmissivity results in a lower chloride concentration (Figure 6-39). A 100% increase in transmissivity resulted in a 340 mg/l freshening at the wellfield. This is attributed in part to the lower drawdown and hence lower hydraulic gradient at the wellfield and increased lateral flow of fresher water to the wellfield from the northeastern portion of the model. A reduction in the transmissivity of 50% results in an increase in simulated chloride concentrations of 360 mg/l. This is attributed to the increased drawdown (and hence gradient) at the wellfield and the resulting increase in saline water movement from the higher chloride underlying zones. The model results show moderate sensitivity to specified transmissivity. The transmissivities applied to the model layers were determined from onsite tests and are

TABLE 6-2 SUMMARY OF MODEL SENSITIVITY ANALYSES

Parameter	#	Change	Summary of results[1]	Mg/L/Year	
				Calib.	Conserv.
Transmissivity of Lower Hawthorn Aquifer	1	Increase: 2 x Specified transmissivity (T * 2)	Decrease in concentration	8.6	14.4
	2	Increase: 1.5 x Specified transmissivity (T * 1.5)	Decrease in concentration	5	8.3
	3	Decrease: 0.8 x Specified transmissivity (T * 0.8)	Increase in concentration	2.8	4.6
	4	Decrease: 0.5 x Specified transmissivity (T * 0.5)	Increase in concentration	9	14.3
Leakance (through vertical hydraulic conductivity of Lower Hawthorn and underlying aquifers and confining beds)	5	Increase: 10 x Specified leakance (L * 10)	Increase in concentration	3.4	11.5
	6	Increase: 2 x Specified leakance (L * 2)	Increase in concentration	1.4	4.3
	7	Decrease: 0.5 x Specified leakance (L * 0.5)	Decrease in concentration	1.5	4.3
	8	Decrease: 0.1 x Specified leakance (L * 0.1)	Decrease in concentration	4.4	12.2
Dispersivity	9	$\alpha_L = 50$, $\alpha_T = 5$	Decrease in concentration	4.6	6.5
	10	$\alpha_L = 150$, $\alpha_T = 15$	Increase in concentration	7	8.7
	11	$\alpha_L = 250$, $\alpha_T = 25$	Increase in concentration	15.6	19.1
Chloride concentration of underlying aquifer	12	Decrease: From 6,000 to 4,000 mg/l	Decrease in concentration	3.2	7.5
	13	Increase: From 6,000 to 8,000 mg/l	Increase in concentration	3.1	7
	14	Increase: From 6,000 to 12,000 mg/l	Increase in concentration	8.9	20

[1] Summarized in terms of average annual change in simulated chloride concentration (Mg/L/Year).

SIMULATED CHLORIDE CHANGE FOR LARGER AND SMALLER TRANSMISSIVITY VALUES

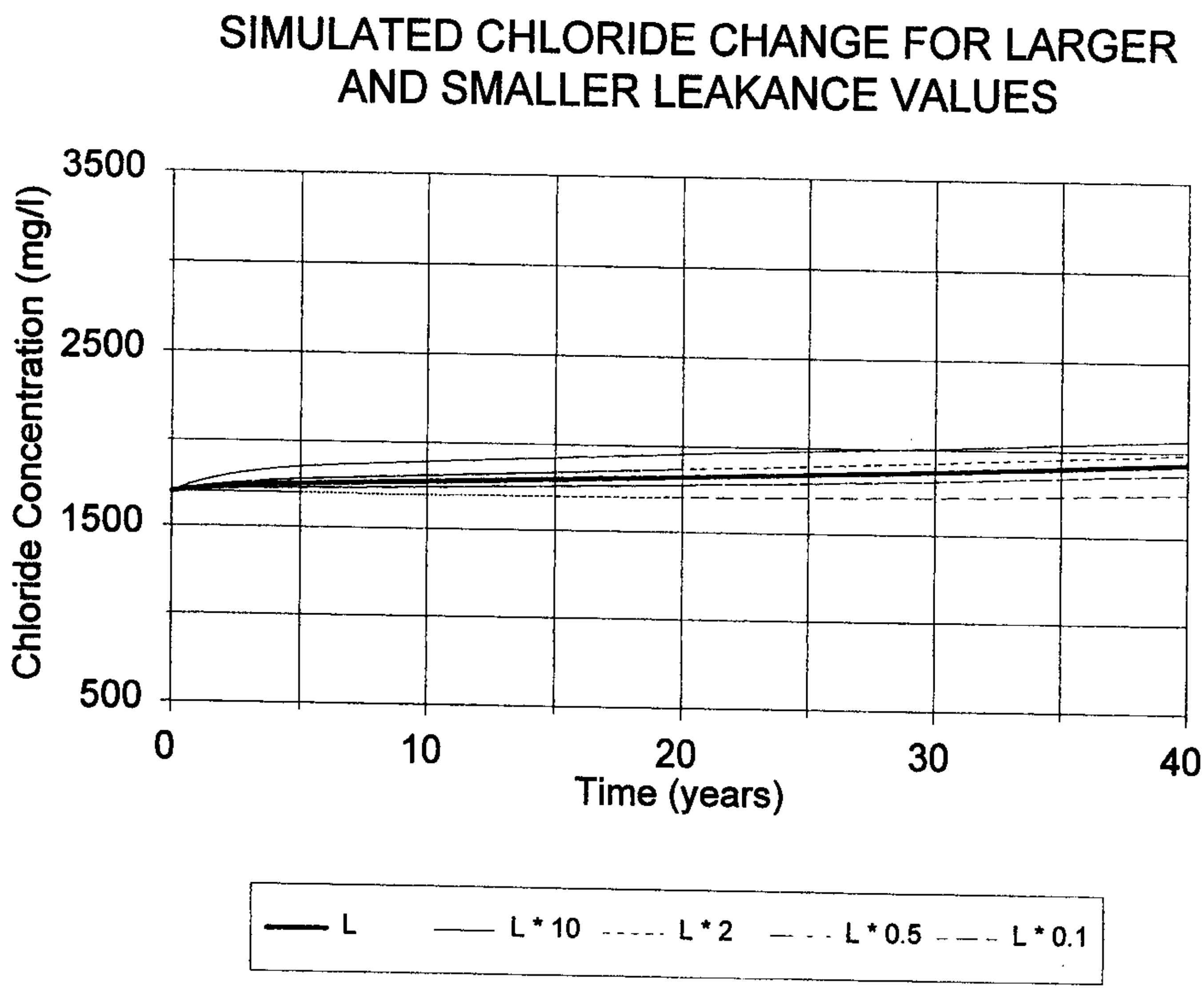


MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation	
Pr. No. FH4-26 DWG No.	Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-39 SENSITIVITY OF CALIBRATED MODEL CONSTRUCT TO SPECIFIED LOWER HAWTHORN TRANSMISSIVITY



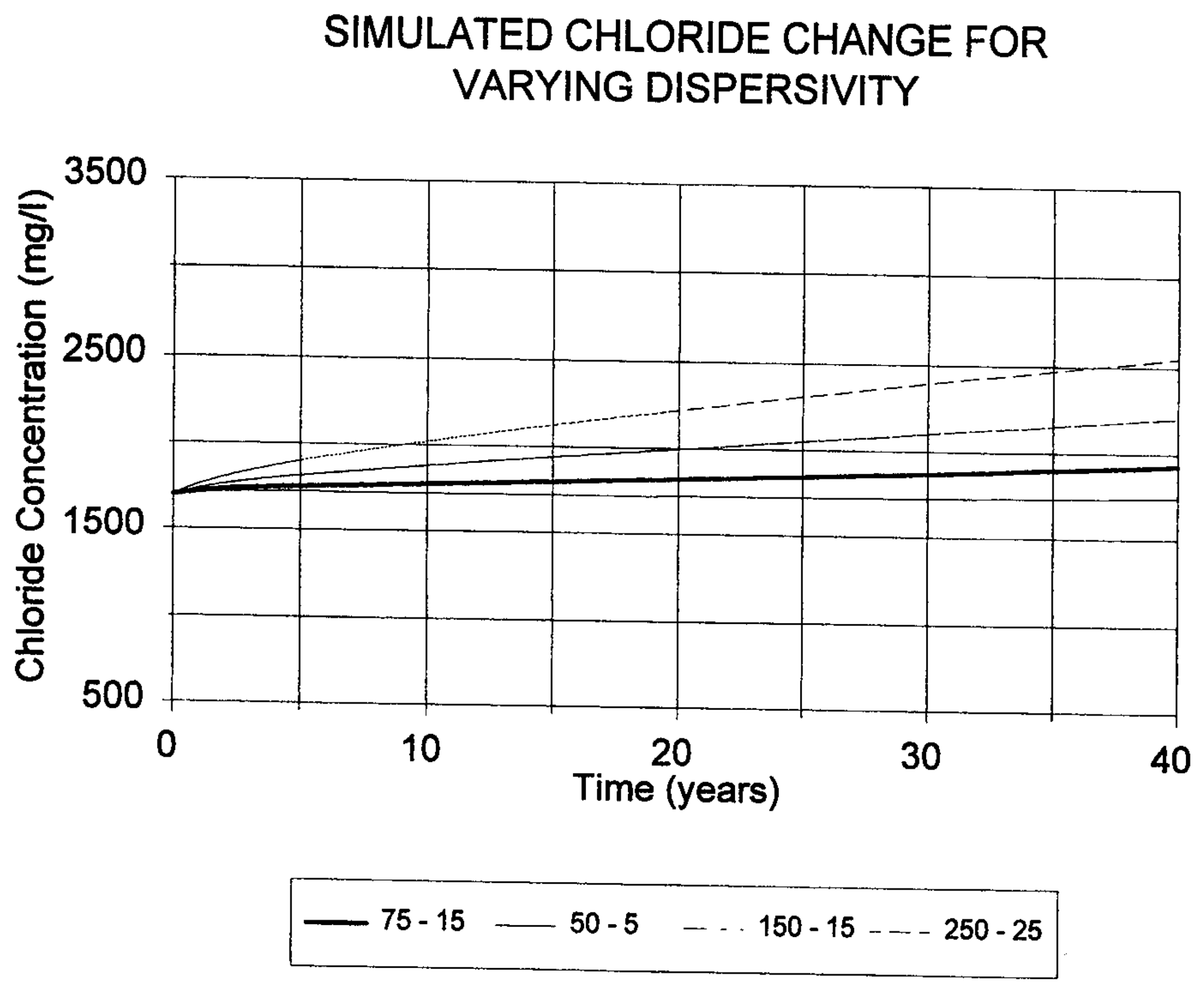
MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-40 SENSITIVITY OF CALIBRATED MODEL CONSTRUCT TO SPECIFIED LEAKANCE FOR LOWER HAWTHORN AND UNDERLYING AQUIFERS



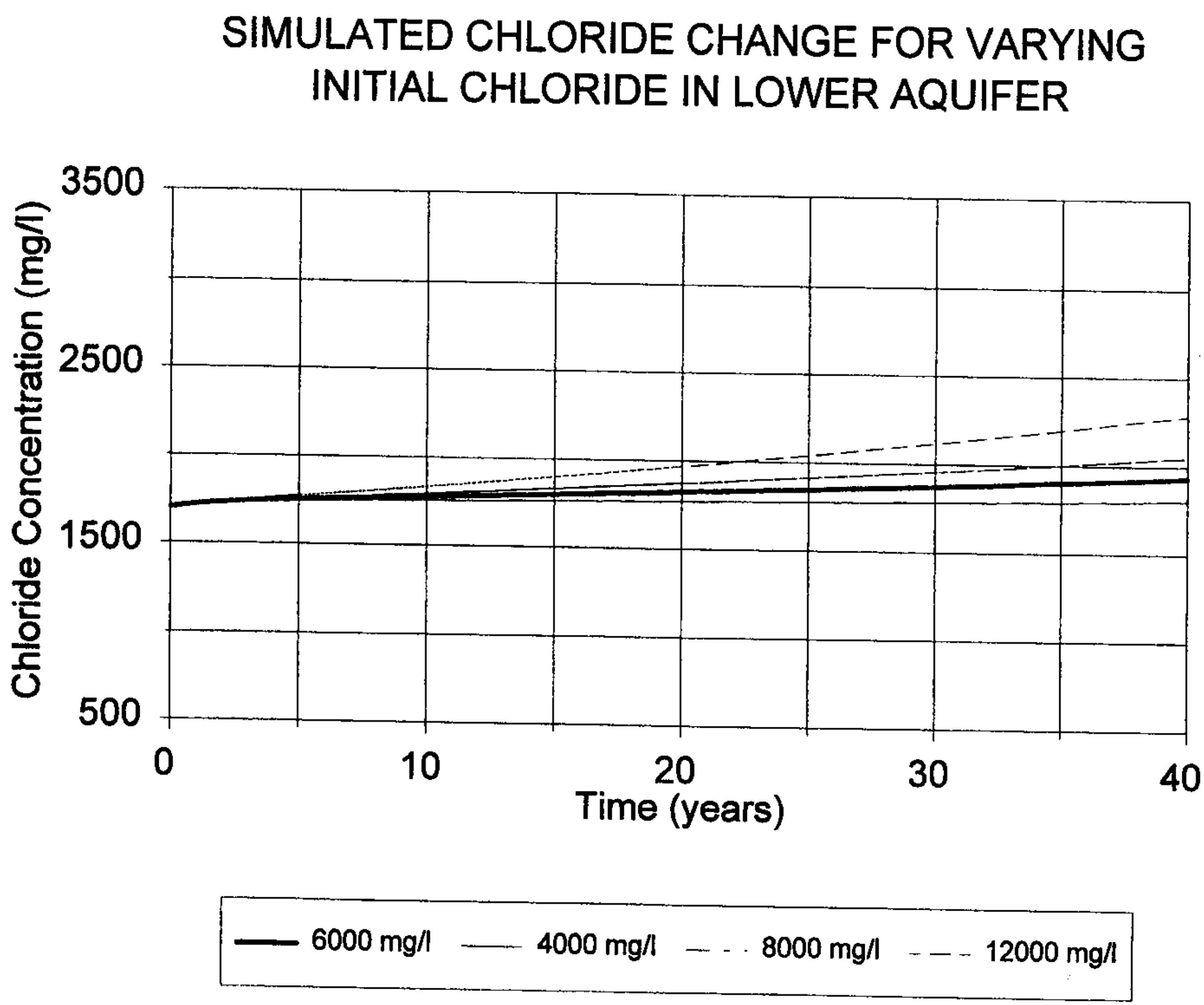
MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-41 SENSITIVITY OF CALIBRATED MODEL CONSTRUCT TO SPECIFIED DISPERSIVITY



MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-42 SENSITIVITY OF CALIBRATED MODEL CONSTRUCT TO SPECIFIED INITIAL CHLORIDE CONCENTRATION OF THE UNDERLYING AQUIFERS known with some degree of certainty for the region close to the test sites. It is unlikely that transmissivity in this region would vary greatly from the determined range. Due to the sensitivity of the model to this parameter, any determination of additional transmissivity data within the model area may result in improvement of the model if different from the estimated value.

The simulated chloride concentrations at the wellfield resulting from leakance sensitivity runs are presented in Figure 6-40. The results suggest that this simulation is not too sensitive to the specified leakance. An order of magnitude increase in leakance resulted in a dissolved chloride concentration increase of approximately 140 mg/l over a forty-year simulation period. An order of magnitude decrease in leakance resulted in a decrease of approximately 175 mg/l over the simulation period. Order of magnitude variation in estimated leakance may occur, the resulting changes to the simulated model results however are expected to be low for the calibrated model. While additional information on leakance is desirable, the potential impact on model results is lower than that of transmissivity for this scenario.

As dispersivities are increased, the simulated chloride concentrations increase. A plot of model simulated chlorides for the sensitivity runs is presented in Figure 6-41. The results show that the computed chloride at the end of a forty-year simulation period could vary by as much as 800 mg/l when longitudinal dispersivity is increased from 50 to 250. The model is therefore sensitive to this parameter which is very difficult to determine. While tracer tests may be conducted to obtain field-measured value of dispersivity, it has been shown that the result would change with the scale of the test. Improvement in the estimate of dispersivity can be made during calibration of the model to long term solute changes. Such data are not available for the project site at this time. As long term water quality data become available, a review of the model to incorporate new data and refine dispersivity estimates based on calibration to the available data is recommended.

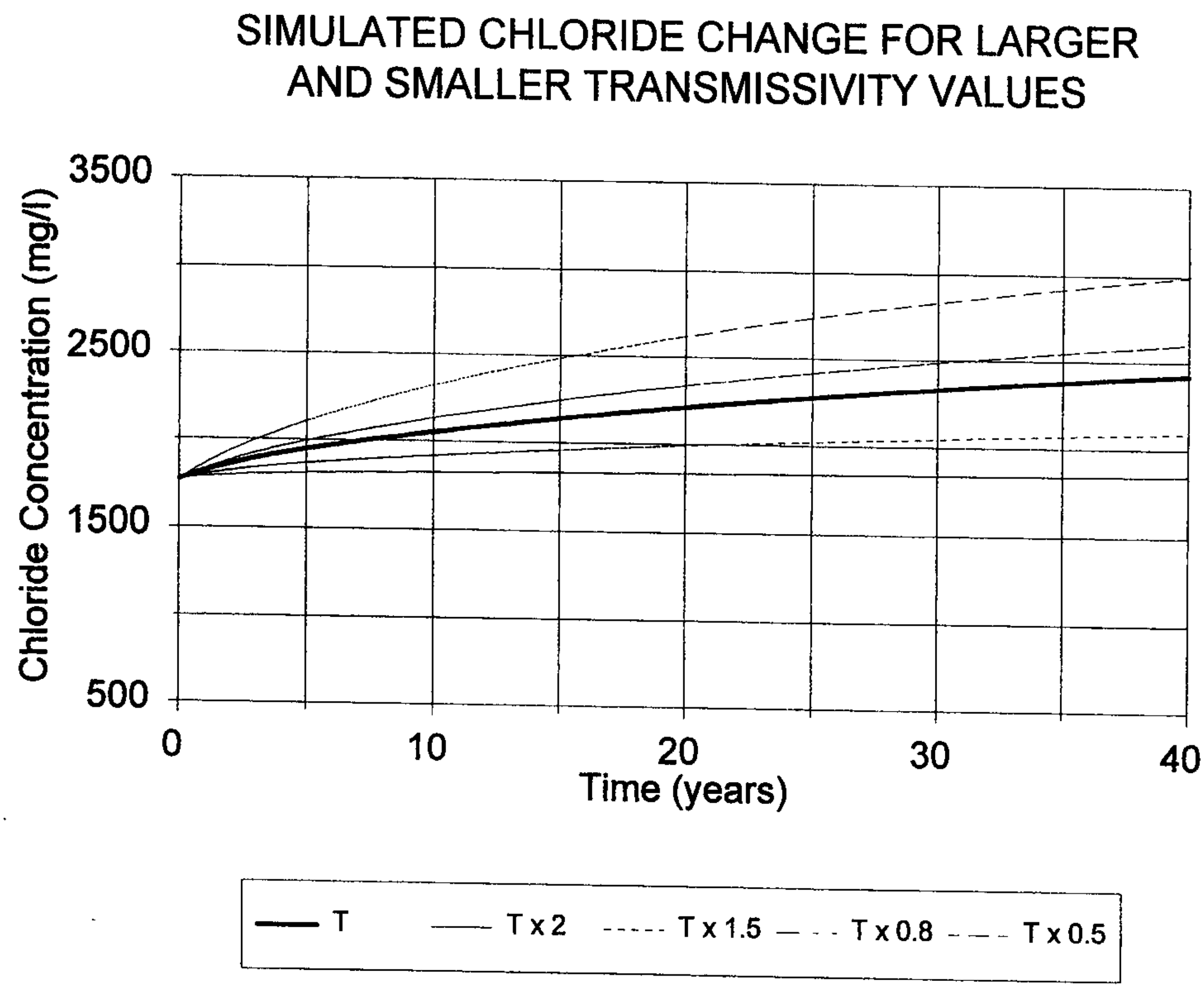
The effect of a higher chloride concentration in the underlying aquifer is shown in Figure 6-42. As can be expected, higher initial chlorides in the underlying aquifers result in higher computed chlorides at the wellfield over the forty-year simulation period. A 2000 mg/l increase or decrease in initial chlorides of the underlying aquifers resulted in an increase or decrease of approximately 125 mg/l in the simulated model results at the end of forty years. The calibrated model construct does not exhibit a great sensitivity to specified chlorides in the underlying aquifers.

Conservative Model Sensitivity

Results of sensitivity analyses on the conservative model construct show similar changes in simulated chlorides from variations of the model parameters. The magnitudes of the changes and potential significance to the model results however differ. The plots of chloride change for the sensitivity analyses conducted on the conservative model are presented in Figures 6-43 through 6-46.

As was the case with the calibrated model, the results show that the model is sensitive to the specified transmissivity in the production zone. A 20% reduction in specified transmissivity results in an increase of approximately 180 mg/l at the end of the forty-year simulation. This increases to approximately 570 mg/l for a 50% reduction in transmissivity. The increase is attributed to the higher gradients at the wellfield that result from the lower transmissivities and the associated increased solute migration from the underlying (higher chloride) aquifers.

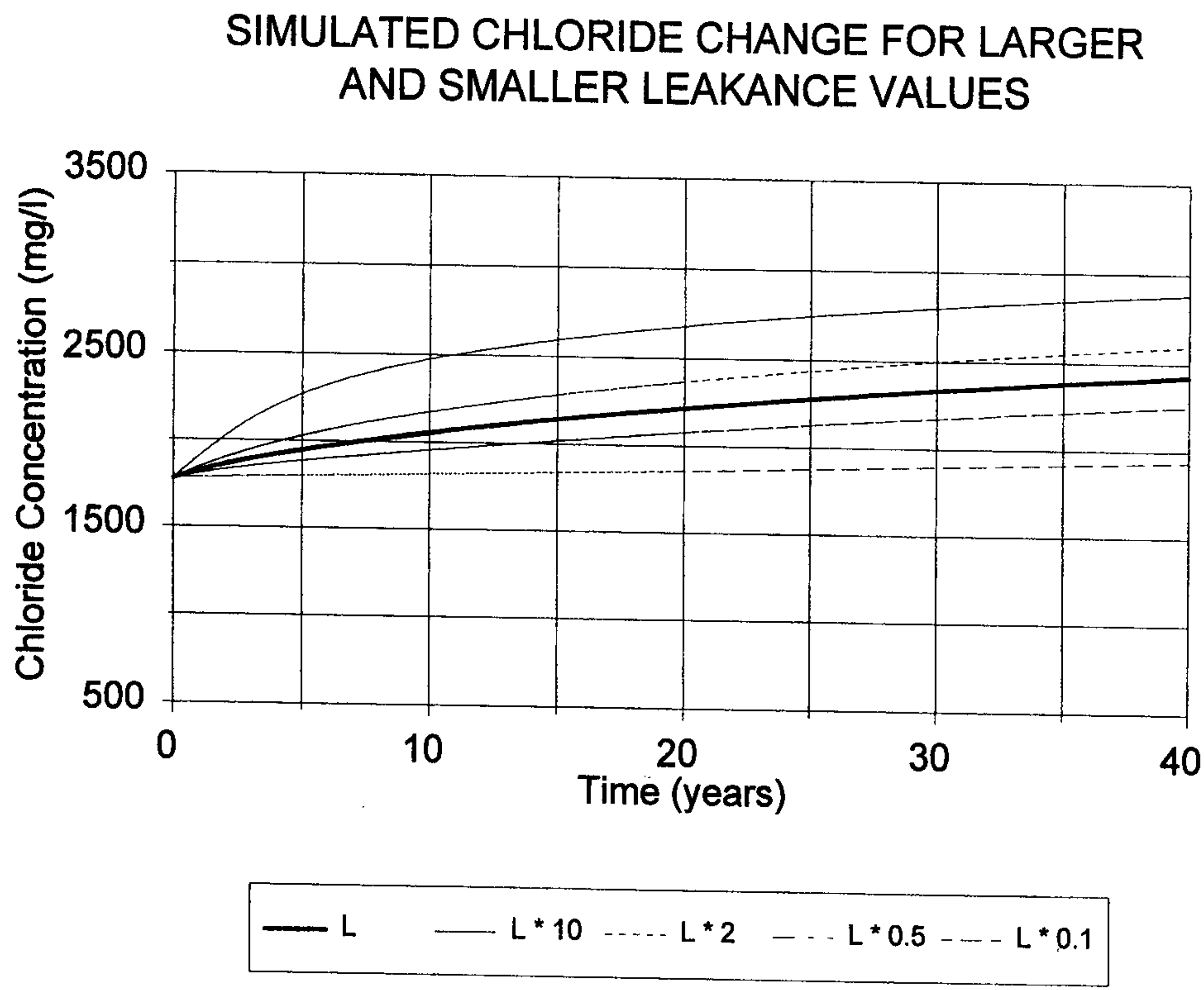
Results of the leakance sensitivity model simulations are presented in Figure 6-44. An order of magnitude increase in leakance resulted in an increase of approximately 460 mg/l over a forty-year simulation period. An order of magnitude decrease in leakance resulted in a decrease of approximately 490 mg/l over the simulation period. The model results thus appear to be sensitive to specified leakance. Additional information on leakance would therefore result in more confidence in the results of the model simulation.



MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation	GROUNDWATER AND ENVIRONMENTAL SERVICES
Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.	

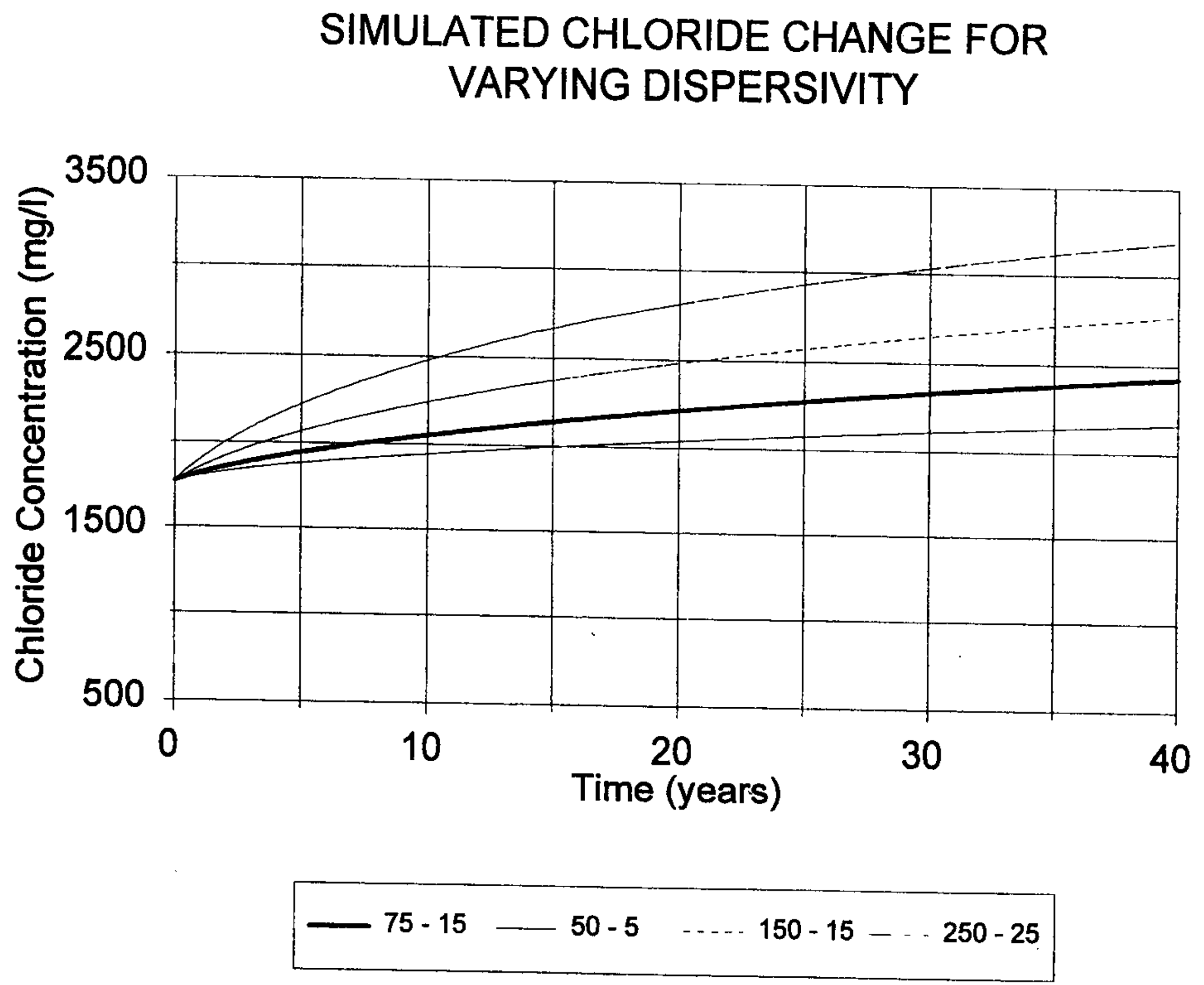
FIGURE 6-43 SENSITIVITY OF CONSERVATIVE MODEL CONSTRUCT TO SPECIFIED LOWER HAWTHORN AQUIFER TRANSMISSIVITY



MISSIMER INTERNATIONAL, INC.	Pr. Name: Collier County RO Source Water Investigation Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-44 SENSITIVITY OF CONSERVATIVE MODEL CONSTRUCT TO SPECIFIED LEAKANCE FOR LOWER HAWTHORN AND UNDERLYING AQUIFERS



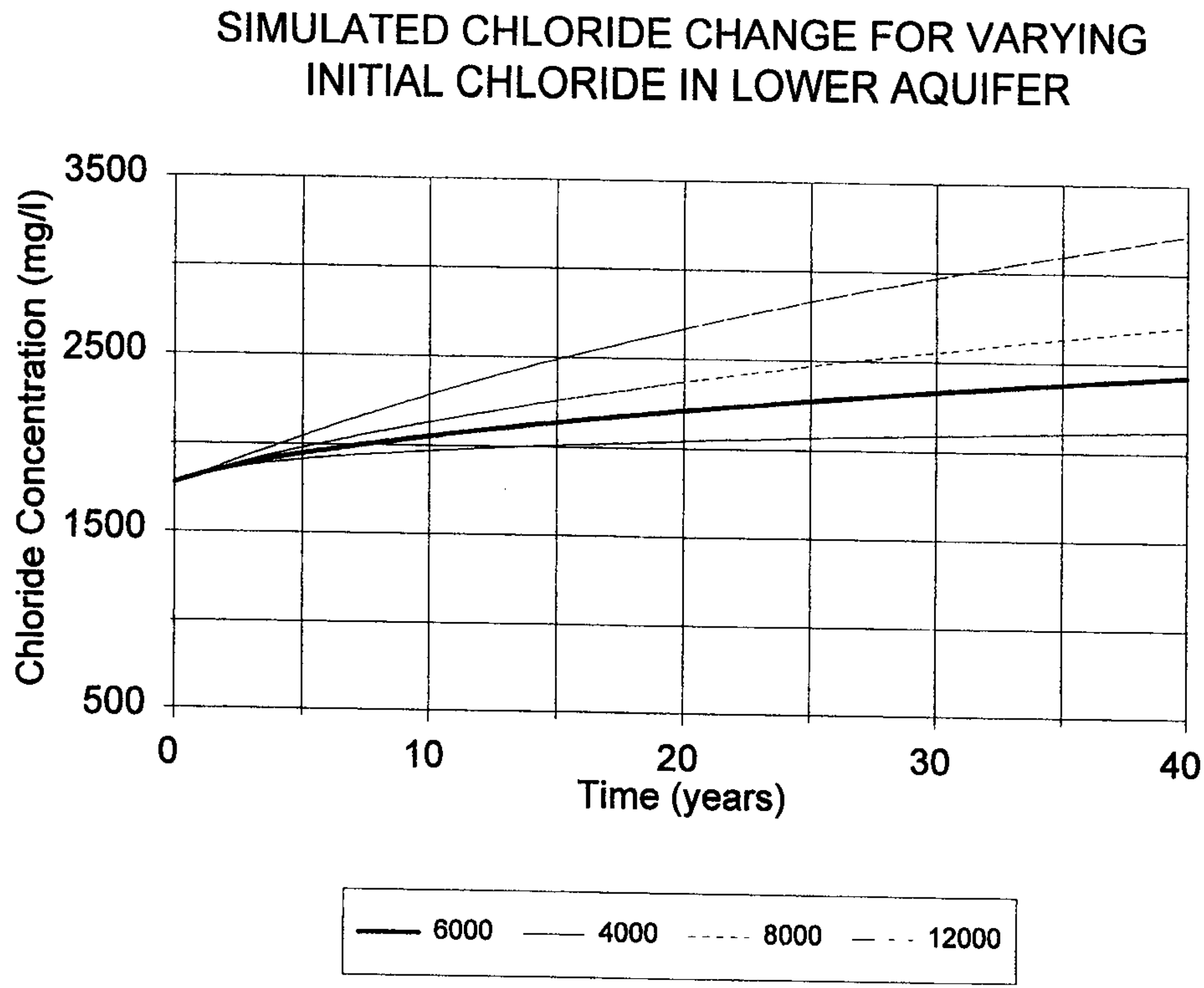
MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

FIGURE 6-45 SENSITIVITY OF CONSERVATIVE MODEL CONSTRUCT TO SPECIFIED DISPERSIVITY



MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation	GROUNDWATER AND ENVIRONMENTAL SERVICES
Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.	

FIGURE 6-46 SENSITIVITY OF CONSERVATIVE MODEL CONSTRUCT TO SPECIFIED INITIAL CHLORIDE CONCENTRATION OF THE UNDERLYING AQUIFERS

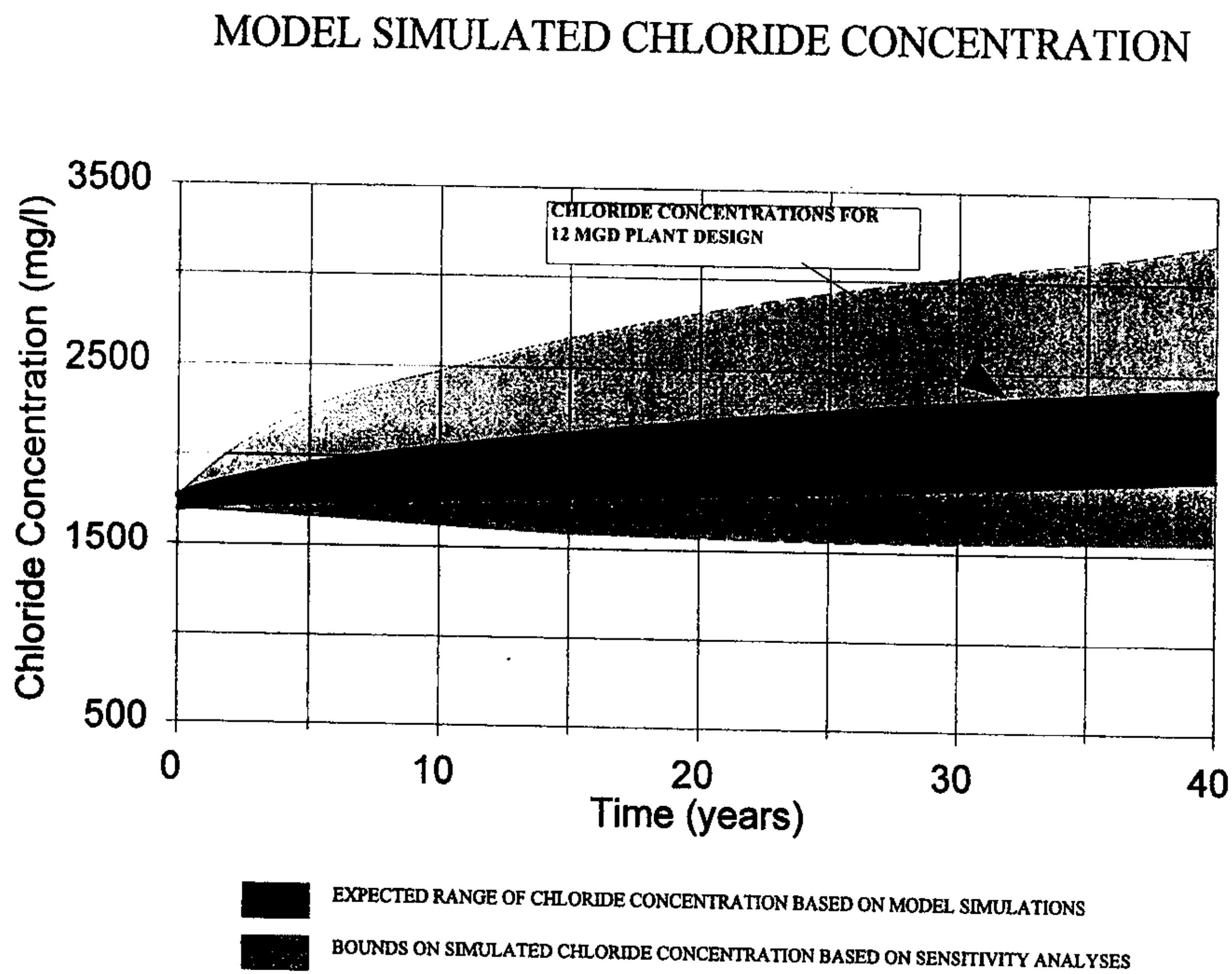
Comparison of model simulation results to data obtained during future operation of the wellfield would be useful in refinement of the model.

As dispersivities are increased, the simulated chloride concentrations increase. A plot of model simulated chlorides for the sensitivity runs is presented in Figure 6-45. The results show that the computed chloride at the end of a forty-year simulation period could vary by as much as 1025 mg/l when longitudinal dispersivity is increased from 50 to 250. The conservative model construct, like the calibrated model, is also sensitive to specified leakance.

The effect of a higher chloride concentration in the underlying aquifer is shown in Figure 6-46. Wider variation is observed with the conservative model than with the calibrated model. A 2000 mg/l increase or decrease in initial chlorides of the underlying aquifers resulted in an increase or decrease of approximately 290 mg/l in the simulated model results at the end of forty years. This represents a smaller range that the other parameters examined.

Based on the results of sensitivity analyses, an upper and lower bound on the predicted chloride concentrations was developed which represents a potential range within which the observed chloride changes are expected to fall (see Figure 6-47). As more data become available and model refinements are made the prediction envelope would constrict.

The range specified in Figure 6-47 combines information from the calibrated and conservative models as well as the sensitivity runs using each model construct. The central portion of the range is expected to encompass the actual dissolved chloride concentration change that would result during actual wellfield operation. Effects of local heterogeneity and inherent uncertainty associated with the determination of some model input may result in deviation which should fall within the outer bounds of the specified range. This result shows that, based upon model simulations, the wellfield chloride



MISSIMER INTERNATIONAL, INC.

Pr. Name: Collier County RO Source Water Investigation

Pr. No. FH4-26 DWG No. Date: 8/8/95 Rev No.

GROUNDWATER AND ENVIRONMENTAL SERVICES

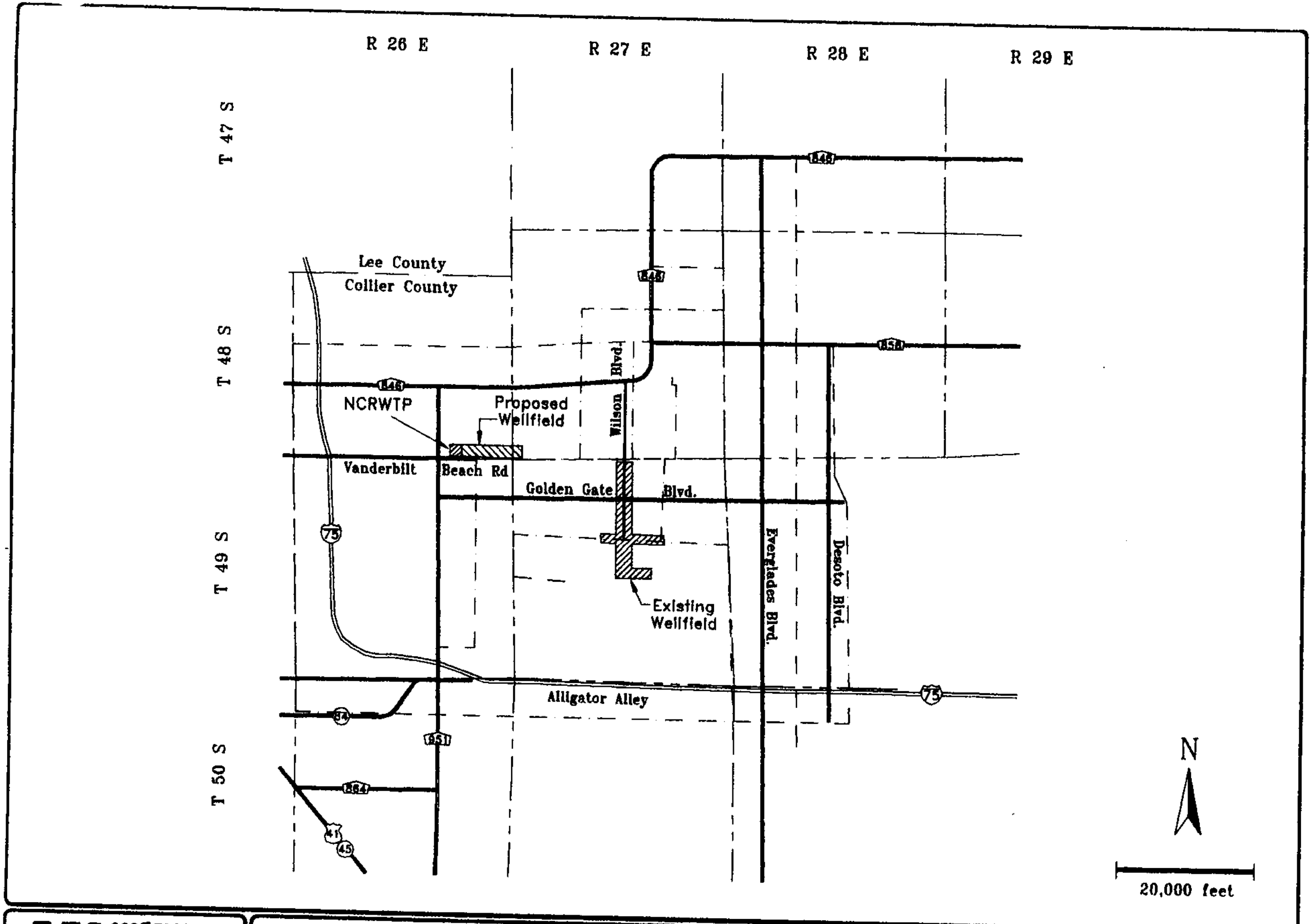
FIGURE 6-47 UPPER AND LOWER BOUNDS ON PREDICTED CHLORIDE CONCENTRATION concentrations would remain below 3500 mg/l over the 40-year simulation period. This constitutes treatable source water for the recommended treatment technology in the short- and long-term. The anticipated chloride concentration trend for withdrawals of 12 MGD as shown in Figure 6-47 predict a 40-year wellfield chloride concentration of less than 2500 mg/l. Note that even at the extreme, 40-year projections are within treatable limits for low pressure R.O. membrane plants thus requiring no plant redesign or costly modifications.

6.4 Wellfield Configuration

A 12 MGD wellfield is required to produce feedwater for the 8 MGD (finished water) reverse osmosis treatment plant. Eight wells each pumping at approximately 1000 gpm are required to produce the desired withdrawal amount. Ten wells are proposed so that two 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 initial wellfield design consists of ten wells in an east-west alignment with well spacings of approximately 1000 feet. The wellfield would be located near the North County Regional Water Treatment Plant (NCRWTP) along the Vanderbilt Beach Road extension as shown on Figure 6-48. A detailed site map showing individual well locations is provided as Figure 6-49.

6.5 Well Construction

The proposed production wells should be constructed with fiberglass (FRP) or other approved non-ferrous casings to a depth of approximately 700 feet below land surface and should have total depths of approximately 800 feet. 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. The casings should be 12-inch diameter with the upper 100 feet of casing increased to 16-inch



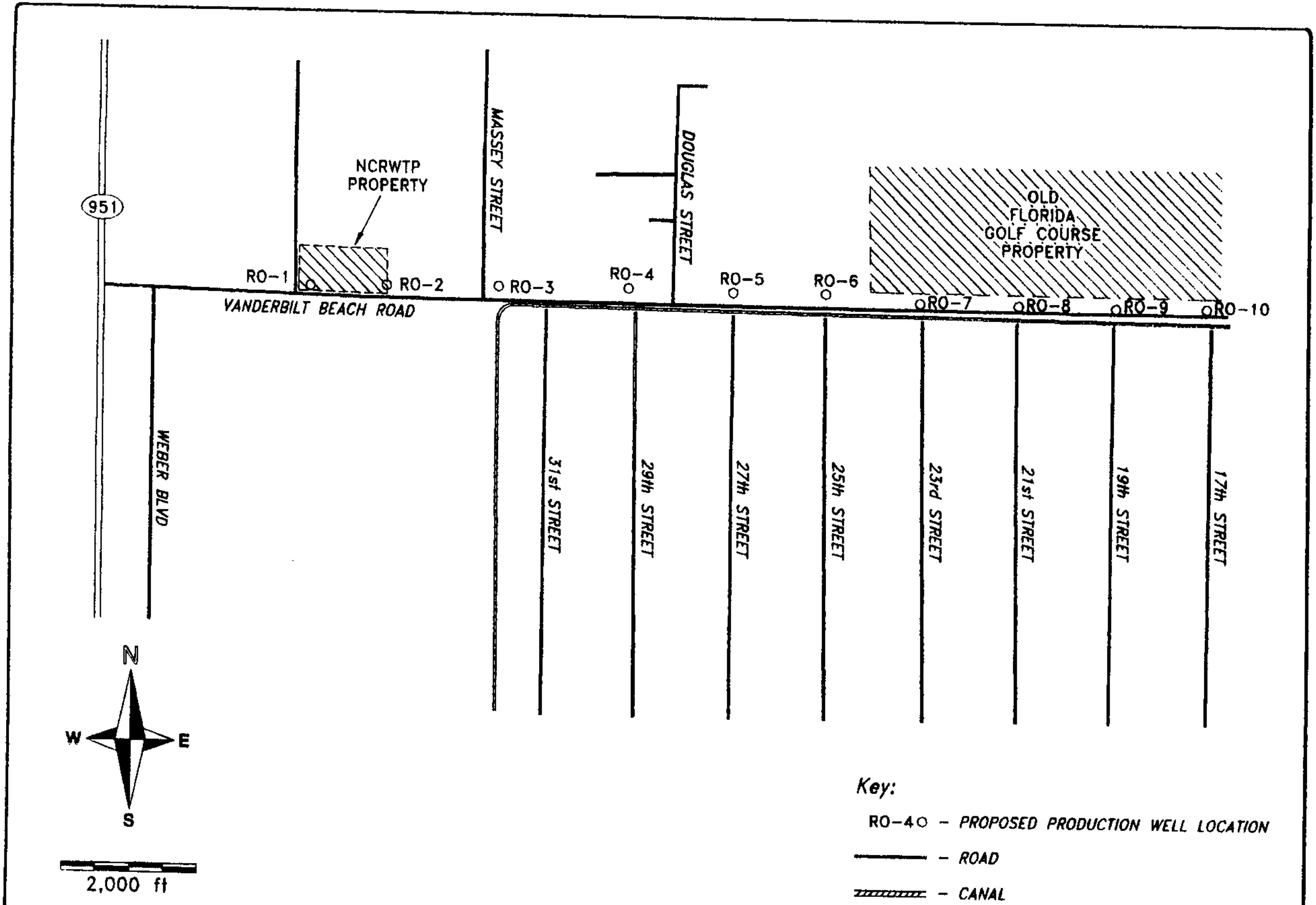
MISSIMER INTERNATIONAL

Pr Name: Collier Co. Wellfield

Pr.No. FH4-26 DWG No.FH4-26GL.DWG Date: 10/6/95 Rev.No. 7

Groundwater and Environmental Services

FIGURE 6-48. MAP SHOWING LOCATIONS OF THE EXISTING LOWER TAMIAMI AQUIFER WELLFIELD AND THE PROPOSED LOWER HAWTHORN AQUIFER WELLFIELD.



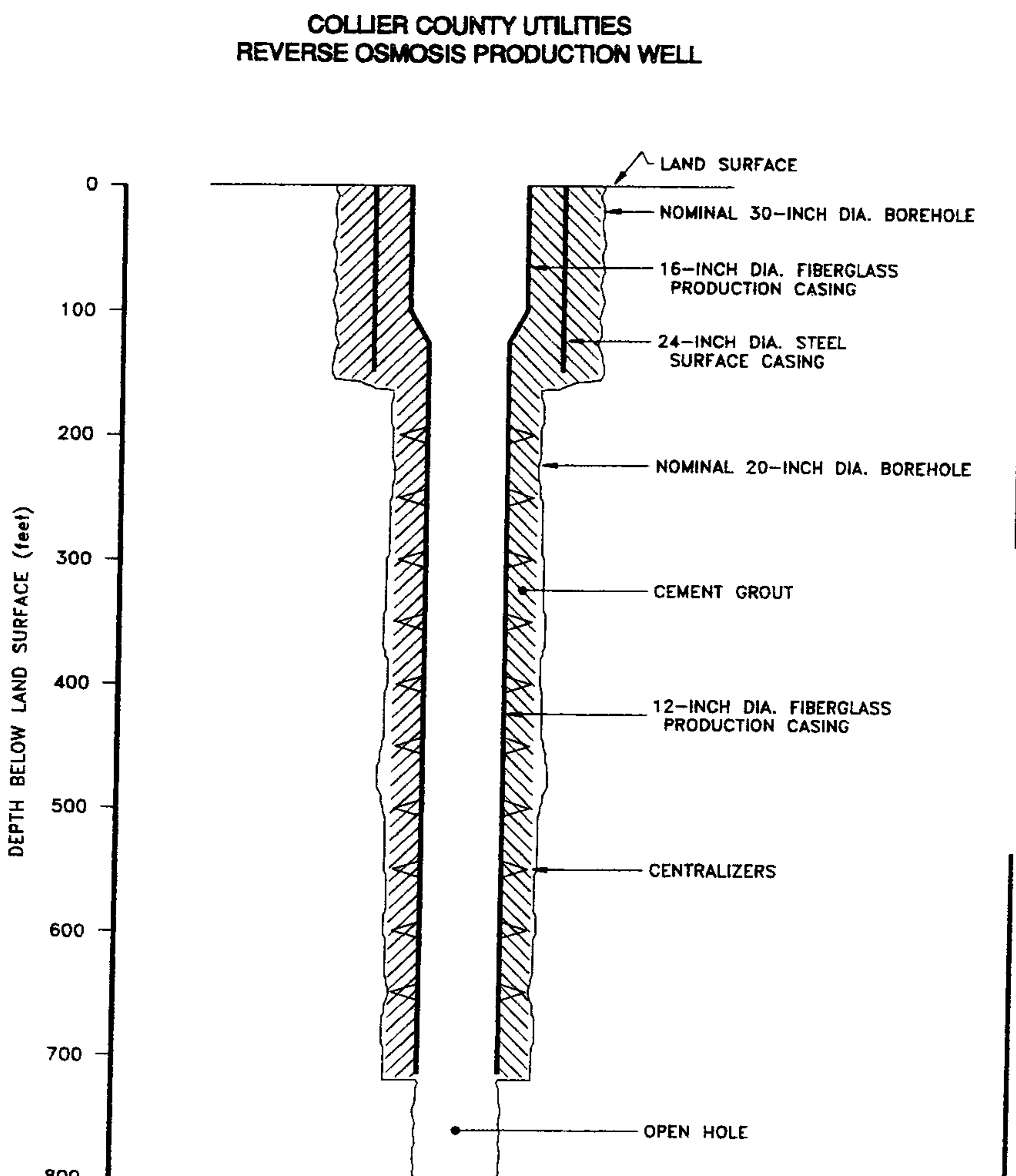
MISSIMER INTERNATIONAL

Pr Name: COLLIER COUNTY R.O. WELLFIELD	
Pr.No. FH4-26 DWG No.FH426-D7.DWG Date: 10/6/95 Rev.No. 3	

Groundwater and Environmental Services

FIGURE 6-49. DETAILED SITE MAP SHOWING PROPOSED REVERSE OSMOSIS PRODUCTION WELL LOCATIONS FOR THE NCRWTP EXPANSION, COLLIER COUNTY.

diameter to allow for adequate pump sizing. A schematic diagram showing the proposed construction details for the wells is provided as Figure 6-50. Step-drawdown pump tests should be conducted on the production wells after they are completed to assess well yield. The wells should be equipped with submersible pumps. Pump setting depths and production rates for each well will be determined based on results of the step-drawdown testing. Pump setting depths are anticipated to range from 60 to 80 feet below land surface with an average production rate of 1000 gpm per well.



MISSIMER INTERNATIONAL	Pr Name: COLLIER CO R.O. WELLFIELD		Groundwater and Environmental Services
	Pr No. FH4-26	Date: 10/6/95	
	DWG No. FH426-W2.DWG	Rev.No. 4	

FIGURE 6-50. PROPOSED CONSTRUCTION DETAILS FOR THE COLLIER COUNTY UTILITIES LOWER HAWTHORN AQUIFER PRODUCTION WELLS.

7.0 REFERENCES

Andersen, P. F., Mercer, J. W., and White, Jr., H. O., 1988, Numerical Modelling of Salt-Water Intrusion at Hallandale, Florida: Groundwater, Vol. 26, No. 5, pp. 619-630.

Boggess, D. H., Missimer, T. M., and O'Donnell, T. H., 1981, Hydrogeologic sections through Lee County and adjacent areas of Hendry and Collier counties, Florida: U.S. Geological Survey Water-Resources Investigations Open-file Report 81-638.

Cranwell, R. M., and Reeves, R., 1981, User's Manual for the Sandia Waste-Isolation Flow and Transport Model (SWIFT), Rep. NUREG/CR-2234, SAND81/2516, Sandia Nat. Lab., Albuquerque, N.M.

Domenico, P. A., Schwartz, F. W., 1990, Physical and Chemical Hydrogeology, Toronto, John Wiley & Sons, 373pp.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture, in, Ham, W. E. (ed.), Classification of Carbonate Rocks: American Assoc. Petrol. Geologists Memoir 1, p. 108-121.

Freeze, R. A., and Cherry, J.A., 1979, Groundwater, New Jersey, Prentice-Hall, Inc., 400pp.

GeoTrans, Inc., 1991, Wekiva River Basin Groundwater Flow and Solute Transport Modeling Study, Phase II: Cross Sectional Groundwater Flow and Solute Transport Model Development.

HydroGeologic, 1991, Ground-Water Flow and Solute Transport Modeling Study for Eastern Orange County, Florida and Adjoining Regions.

Knapp, M. S., Burns, W. S., and Sharp, T. S., 1986, Preliminary assessment of the groundwater resources of western Collier County, Florida: South Florida Water Management District Technical Publication #86-1, 142 pp.

McDonald, M. G., and Harbaugh, A. W., 1988, A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model: U. S. Geological Survey Techniques of Water Resources Investigations, Book 6, Chapter A1.

Missimer & Associates Inc., 1986, Hydrogeology of the Collier County Wellfield in Golden Gate Estates, Collier County, Florida: Consultants Report to Collier County, 125pp.

Missimer & Associates, Inc., 1990, Safe Yield Determination by Three-Dimensional Hydraulic Modeling of the Lower Tamiami Aquifer Beneath Golden Gate Estates, Collier County, Florida: Consultants Report to Collier County, 158pp.

Missimer & Associates Inc., 1991, Phase 1 Deep Aquifer Hydrogeologic Study, Collier County, Florida: Consultants Report to Collier County, 61pp.

Missimer, T. M., 1992, Stratigraphic relationships of sediment facies within the Tamiami Formation of southwestern Florida: Proposed intraformational correlations, in Scott, T. M., and Allmon, W. D., (eds.) Plio-Pleistocene Stratigraphy and Paleontology of Southern Florida: Florida Geological Survey Special Publication No. 36, p. 63-92.

Reeves, M., Ward, D. S., Johns, N. D., and Cranwell, R. M., 1986a, Data Input Guide for SWIFT II, The Sandia Waste-Isolation Flow and Transport Model for Fractured Media, Rep. NUREG/CR-3162, SAND83-0242, Sandia Nat. Lab., Albuquerque, N.M.

Reeves, M., Ward, D. S., Johns, N. D., and Cranwell, R. M., 1986b, Theory and Implementation for SWIFT II, The Sandia Waste Isolation Flow and Transport Model for Fractured Media, NUREG/CR-3328, SAND83-1159, Sandia Nat. Lab., Albuquerque, N.M., 1986b.

ViroGroup, Inc./ Missimer Division, 1993, North County Regional Water Treatment Plant Injection Well System Completion Report Volume 1 - Text: Consultants Report to Collier County, 94pp.

ViroGroup, Inc./ Missimer Division, 1994, Phase II Collier County Aquifer Storage and Recovery Project Technical Memorandum Volume 1: Consultants Report to Collier County, 50pp.