Program Management at Risk Services for Water, Wastewater & Irrigation Facilities

Project Title: **W-2C Southwest Production Well System**

Document Title: **Southwest Wellfield Expansion Well Completion Report**

May 2007

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GLOSSARY

Term	Definition
ASTM	American Society for Testing and Materials
als	above land surface
APT	Aquifer Performance Test
bls	below land surface
ft	Foot
FRP	Fiberglass Reinforced Plastic
gpd	gallons per day
gpm	gallons per minute
hp	Horsepower
mgd	million gallons per day
mg/L	milligrams per liter
P&A	Plugged and Abandoned
Psi	pounds per square inch
RO	Reverse Osmosis
ROWTP	Reverse Osmosis Water Treatment Plant
SCADA	Supervisory Control and Data Acquisition
SDI	Silt Density Index
SFWMD	South Florida Water Management District
TDS	Total Dissolved Solids
VFD	Variable Frequency Drives

1.0 Executive Summary

In 2004, the City selected MWH as the Program Manager at Risk for the expansion of the Water, Wastewater and Irrigation Facilities and Phase 2 Utility Extension Services. This report summarizes the expansion of the Southwest Reverse Osmosis Water Treatment Plant (SW ROWTP) wellfield which is being completed as Work Authorization W-2 under the framework agreement. The plant expansion will increase the capacity of the plant to a sustainable capacity of 17.8 mgd. The current wellfield supplying raw water to the SW ROWTP consists of 26 wells that extract from the Lower Hawthorn Aquifer. This report describes in detail the construction, aquifer testing, and water quality analysis of eight new 12-inch diameter fiberglass reinforced plastic (FRP) production wells that extract from the Lower Hawthorn Aquifer (Figure 2-1). The well construction results are summarized below:

- Water Use Permit No. 36-00046-W, obtained from the SFWMD (South Florida Water Management District), includes maximum monthly withdrawal limits of 674.28 MG from the Lower Hawthorn aquifer. The permit was modified in 2006, to include the new wells. The new wells provide additional supply and increase the reliability of the wellfield.

- Eight new production wells (Well #112 and #226 through #232) were constructed. The wells were constructed with 12-inch diameter FRP casing and completed with open-hole sections in the Lower Hawthorn Aquifer. The cased depths and the total depths of the wells are summarized in Table 1-1.

Table 1-1 Well Construction Details

Well	Cased Depth (feet bls)	Total Depth (feet bls)
#112	455	721
#226	460	715
#227	429	715
#228	460	714
#229	460	712
#230*	465	695
#231	435	703
#232	470	708

* Well #230 has been plugged and abandoned

- Water quality in the wells is generally similar to other wells in the existing wellfield with the exception of wells #230 and #232. The RO (reverse osmosis) water treatment methods used by the City of Cape Coral will produce water that meets current state and federal drinking water standards.

- Based on the Step-Drawdown test results, these wells have high productive capacities and the data suggests they will meet pumping demands. Specific capacity ranges are given in Table 1-2.

Table 1-2 Specific Capacity Summary

Well	Test Pump Rates (gpm)	Specific Capacity (gpm/ft)
#112	350-950	32.9 - 40.8
#226	350-850	49.8 - 109.9
#227	350-950	42.7 - 83.9
#228	350-950	39.4 - 67.2
#229	350-950	28.5 - 53.0
#230*	350-950	26.7 - 40.9
#231	350-870	24.6 - 39.0
#232	350-950	25.2 - 36.9

* Well #230 has been plugged and abandoned

- To minimize stress on the aquifer, the recommended pumping rates for the new production wells range from 500 to 600 gpm.

- The recommended pump setting depth is 120 feet bls. At the proposed maximum recommended pumping rate of 600 gpm, pumping water levels in the wells are not expected to exceed 50 feet bls.

- Static and pumping water levels of the production wells included in this report should be measured on a monthly basis to assess well yields. Acid treatment of the well is recommended if specific capacity declines by 25% or more.

- Monthly measurement of dissolved chloride concentrations in each production well is required by the SFWMD. Primary and secondary water quality analysis should be performed and reviewed periodically to assess wellfield performance.

- A rotating pumping schedule is recommended so all wells in the wellfield are used periodically. This will distribute drawdown over a larger area and reduce the potential for adverse drawdown effects. In addition, inspection of the withdrawal facilities should be conducted on a regular basis to insure proper operation of the system.

- Well #230 was plugged and abandoned on August 23, 2006 due to high chloride concentrations ranging from 6,250 to 7,120 mg/L. A property located at 911 SW 32nd Terrace has been acquired for use as a replacement for Well #230.

- Dissolved chloride concentrations ranging from 2600 to 2900 mg/L were observed in Well #232. Based on the information obtained from the geophysical logs, it was identified that the poorer water quality was originating from the bottom portion of the borehole. MWH back plugged the lower portion of the borehole to improve water quality. Well #232 was back plugged to 634 feet bls and acidized. These operations increased well yield and improved water quality slightly.

2.0 Introduction

2.1 Authorization

In 2004, the City selected MWH as the Program Manager at Risk for the expansion of the Water, Wastewater and Irrigation Facilities and Phase 2 Utility Extension Services. This report summarizes the expansion of the Southwest Reverse Osmosis Water Treatment Plant (SW ROWTP) wellfield which is being completed as Work Authorization W-2 under the framework agreement. The Cape Coral City Council authorized MWH Americas to design, permit and supervise the construction and testing of eight new production wells in the Cape Coral Southwest Wellfield. Installation of submersible pumps and well vaults is being conducted under the W-3 Work Authorization. This report documents the methods and procedures used during well construction and testing.

The new wells provide additional supply capacity to the Cape Coral Southwest Wellfield. Diversified Drilling Corporation (DDC) of Tampa, Florida completed well construction of the eight new wells, which began on August 11, 2005 at Well #227 and was completed on April 25, 2006 at Well #230. Bacterial clearance of the wells will be completed before the wells are in production.

A map showing the location of the new wells and existing production wells is shown in Figure 2-1 and Figure 2-2. The wellfield supplies raw water to the Cape Coral Reverse Osmosis Water Treatment Plant that produces potable water for public supply purposes. The withdrawals are authorized by the South Florida Water Management District (SFWMD) under water use permit 36-00046-W.

2.2 Scope of Services

The scope of services provided during the wellfield expansion project included well design, development of technical specifications for construction and testing of new production wells, bidding services, well construction permitting, on site supervision of well construction and testing, collection and analysis of formation and water samples during drilling. Construction supervision services were also provided during installation and testing of submersible pumps, wellhead piping and other appurtenances. This report summarizes the construction and testing of the well and documents the hydrogeologic information gathered during the course of this project. Additionally, conclusions and recommendations with respect to wellfield operations of the new wells are also presented.

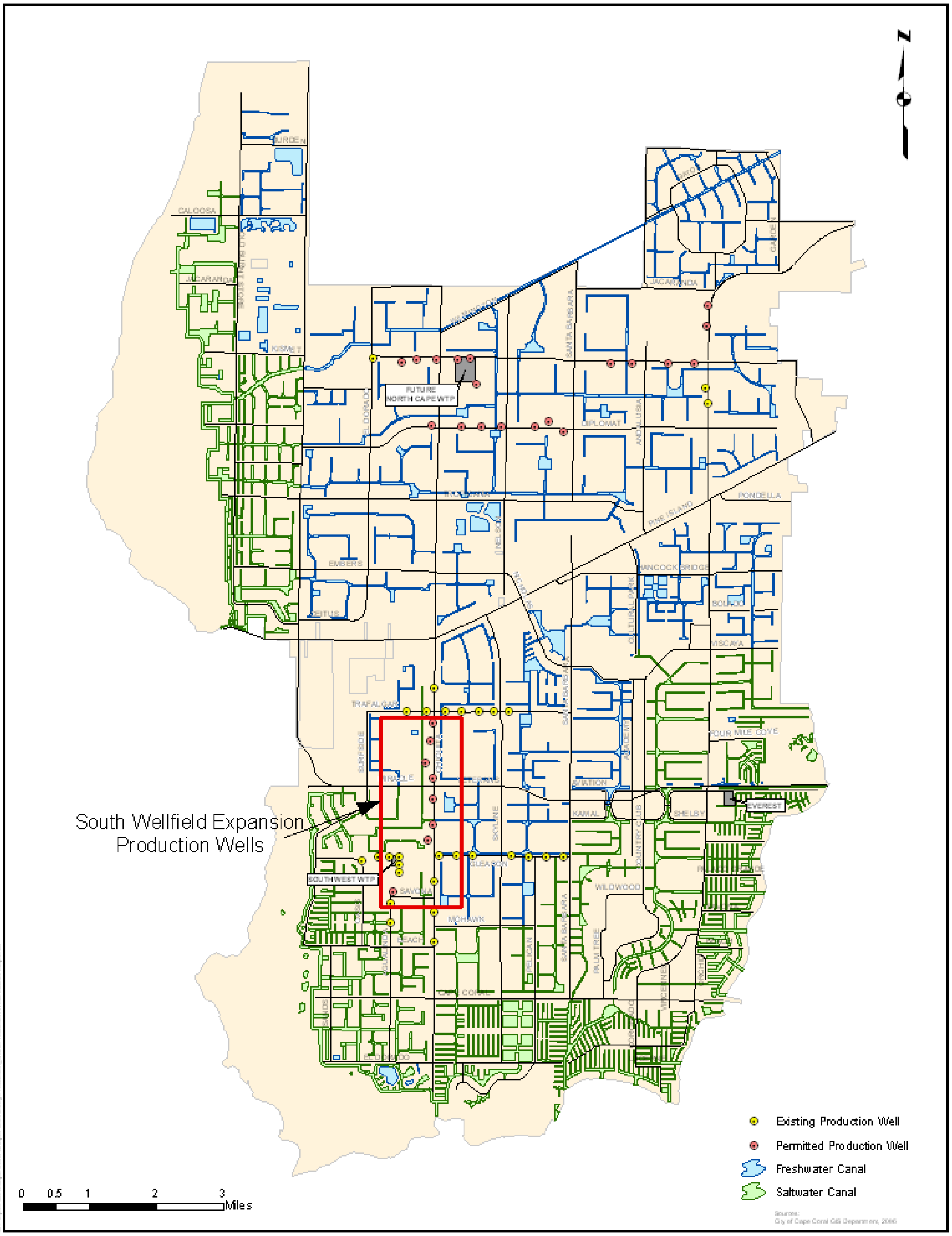


Figure 2-1 Location of South Wellfield Expansion

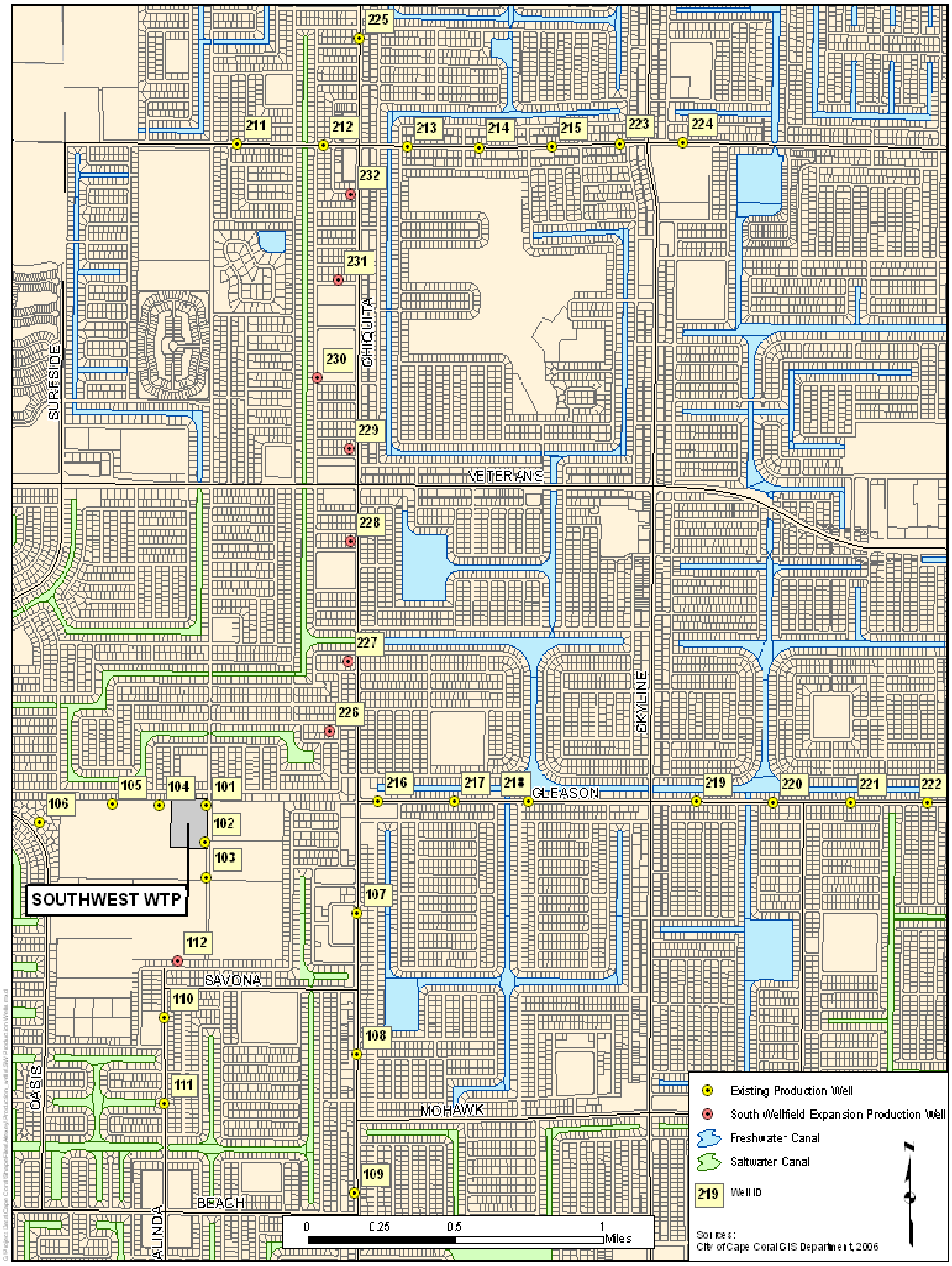


Figure 2-2 Location of W-2C Production Wells

3.0 Well Construction and Testing

3.1 Well Construction

DDC constructed, developed and tested the eight new production wells in the Cape Coral Southwest Wellfield expansion. The methods and materials used by the contractor were in accordance with the standards of the AWWA (American Water Works Association) and the technical specifications outlined in the contract documents. Construction of the wells began on August 11, 2005 at Well #227 and was completed on April 25, 2006 at Well #230.

A MWH Americas geologist supervised the drilling operations and selected casing depths and total depths of the wells based on field analysis of formation samples collected during drilling. A geologist's log of the sediments encountered during drilling is included in Appendix A.

Mud rotary and reverse air techniques were used by DDC for all drilling operations for this project. MWH Americas used formation samples (Appendix A), geophysical logs (Appendix B), and the results of specific capacity tests performed during drilling operations to determine the actual casing depths for each well. Fiberglass reinforced plastic (12 inches in diameter) was used in the construction for the eight production wells.

Construction details of the new production wells are depicted in Table 3-1 and a schematic diagram illustrating typical well construction is shown in Figure 3-1. Nominal 28-inch diameter boreholes were drilled via mud rotary method from land surface to 40-70 feet bls. DDC then installed 20-inch diameter steel casing (ASTM A53 Grade B), pressure grouted the annulus with ASTM Type II neat cement, which was allowed to cure for a minimum of 24 hours before drilling resumed. Surface and production casing setting depths of the individual wells are included in Table 3-1.

Table 3-1 Surface and Production Casing Summary

Well	20-Inch Diameter Steel Surface Casing Depth (feet bls)	12-Inch Diameter FRP Production Casing Depth (feet bls)	Total Depth (feet bls)
#112	50	455	721
#226	70	460	715
#227	40	429	715
#228	63	460	714
#229	43	460	712
#230	63	465	695
#231	63	435	703
#232	43	470	708

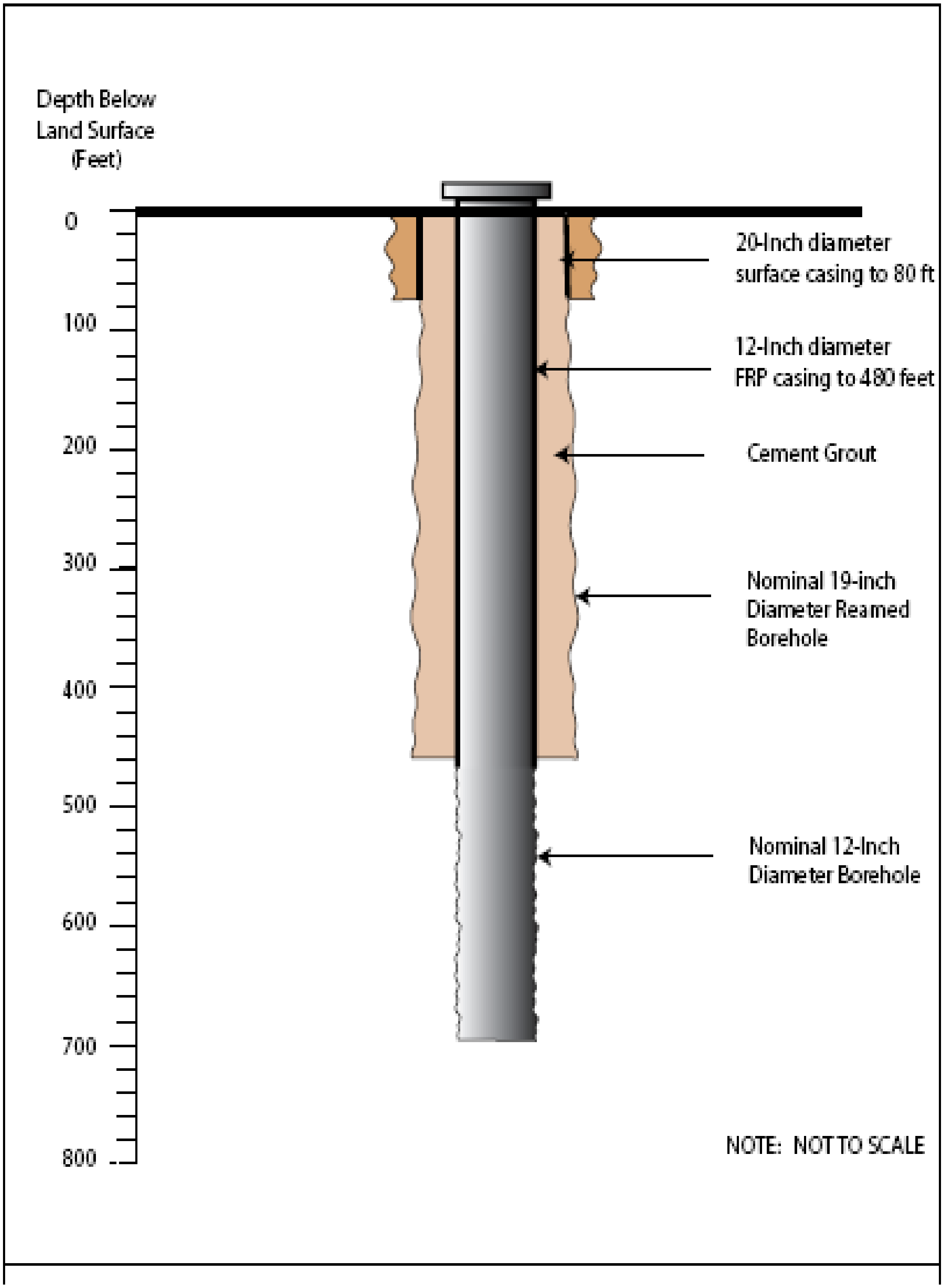


Figure 3-1 Production Well Diagram

A nominal 8-inch diameter pilot hole was drilled for each production well using the mud rotary method from the bottom of the surface casing to a depth determined by MWH Americas based on the lithology encountered. The borehole was then circulated to remove any residual debris and to stabilize it for subsequent geophysical logging. MV Geophysical Services then conducted formation evaluation and borehole logging operations which consisted of the following: XY-caliper, gamma ray, dual induction, and spontaneous potential.

Upon review of the pilot hole geophysical logs and lithologic descriptions, the pilot hole was reamed via the mud rotary method to a nominal 19-inch diameter borehole using the mud rotary method to a depth selected for production casing installation. XY-caliper and gamma ray geophysical logs were completed prior to casing installation for reference by DDC for cementing operations. Twelve-inch Fiberglass Reinforced Plastic (FRP) casing was installed between 435 and 470 feet bls. The annular space between the casing and the borehole was first pressure grouted in Stage 1 using neat cement with 6% bentonite additive followed by a course of neat cement. Stage 2 and Stage 3, if necessary, were completed with cement containing 6% bentonite. The volume and type of cement used is provided in Table 3-2.

Once the production casing was installed, DDC switched to the reverse air drilling method and drilled a 12-inch nominal diameter borehole through the production interval. To evaluate vertical variations in water quality, field parameters recorded include specific conductivity, chloride concentration, pH, and temperature. Water samples were collected approximately every 30 feet (end of each drill rod) during reverse air drilling operations. MWH Americas determined the final well depth based on interpretation of lithology, geophysical logs, water quality and apparent well yield.

Table 3-2 Casing Cementing Summary

Well	Cementing stage	Casing Type	Sacks of Cement	ASTM Type II Cement Type	Feet of Fill
#112	1	Steel	52	Neat	50
	1A	FRP	86	6% Gel	-
	1B	FRP	114	Neat	307
	2	FRP	129	6% Gel	153
#226	1	Steel	83	Neat	65
	2	Steel	3	Neat	6
	1A	FRP	175	6% Gel	-
	1B	FRP	100	Neat	379
	2	FRP	50	6% Gel	94
#227	1	Steel	76	Neat	41
	1A	FRP	182	6%	-
	1B	FRP	100	Neat	361
	2	FRP	85	6%	93
#228	1	Steel	60	Neat	64
	1A	FRP	150	6% Gel	-
	1B	FRP	100	Neat	225
	2	FRP	148	6% Gel	240
#229	1	Steel	40	Neat	43
	1A	FRP	150	6% Gel	-
	1B	FRP	90	Neat	366
	2	FRP	94	6% Gel	94
#230	1	Steel	59	Neat	63
	1A	FRP	125	6% Gel	-
	1B	FRP	100	Neat	313
	2	FRP	84	6% Gel	152
#231	1	Steel	60	Neat	63
	1A	FRP	153	6% Gel	-
	1B	FRP	100	Neat	239
	2	FRP	138	6% Gel	168
	3	FRP	24	6% Gel	28
#232	1	Steel	90	Neat	43
	1A	FRP	117	6% Gel	-
	1B	FRP	109	Neat	306
	2A	FRP	116	6% Gel	-
	2B	FRP	55	Neat	164

3.2 Well Development

Development of the completed wells commenced after reaching total depth to ensure the wells were free of sediment and of acceptable quality for Reverse Osmosis treatment. Silt Density Index (SDI) analyses, Rossum sand sampling and turbidity testing were performed to quantitatively measure suspended sediment on the water produced. Field parameters, such as specific conductivity, chloride concentration, pH and temperature measurements were also recorded during development.

The wells were developed using reverse air from near the bottom of the borehole for approximately 2 to 4 hours. The wells were further developed using straight air for approximately 6 to 8 hours with the air hose set at approximately 85 feet bls. Field parameters were collected approximately every 60 minutes during both stages of development.

Following air development, the wells were then developed via a submersible pump for 8 to 10 hours. During this phase of development, the wells were also surged every 1 to 2 hours. In addition to field parameters, water quality during pump development was also quantified with SDI analyses, Rossum sand sampling and turbidity tests. Additional water quality data is presented in Section 4.2.

3.3 Step-Drawdown Testing

Step-drawdown tests were conducted to identify specific capacity, determine operating pumping rates and submersible pump setting depths. Specific capacity is expressed in gallons per minute per foot of drawdown (gpm/ft) and is an indicator of well productivity. Each of the eight new production wells was pumped at four or five discrete pumping rates (steps) for a period of 60 minutes per step. The wells were pumped using a 60 horsepower (hp) submersible pump set at a depth between 80 to 100 feet bls. An initial pump rate of 350 gpm was increased incrementally through four or five steps to a maximum pump rate of 850-950 gpm. Water levels were measured during pumping and recovery continuously with a data logger coupled to an electronic pressure transducer. Manual measurements were made using an electronic water level indicator to verify the accuracy of the data logger measurements. The step-drawdown test data, detailing measurements recorded at 5-minute intervals, are presented in Appendix C. A summary of the test results, including the drawdown and calculated specific capacity values for each step is included in Table 3-3.

The wells exhibit good yield potential, with specific capacities that range from about 24 to 67 gpm/ft. The well yields are similar throughout the wellfield, however the step drawdown data indicate that well production is better toward the southern end of the wellfield (Wells #112, #226, #227, and #228) than in the north (Wells #229, #230, #231 and #232). The static water level prior to the beginning of the test, ranged between -16.0 and -34.1 feet bls. All step-drawdown tests were conducted under wellfield pumping conditions. The anticipated drawdown in each well, at the recommended pumping rates is discussed in Section 5.0, Wellfield Operation.

Table 3-3 Specific Capacities of Wells

Well #112			
Static Water Level: -19.4 feet (bls)			
Date	Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
12/01/2005	350	9.5	36.8
	500	12.6	39.7
	695	15.6	41.7
	800	20.2	39.6
	950	24.9	38.1

Well #226			
Static Water Level: -30.3 feet (bls)			
Date	Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
10/12/2005	350	5.2	67.4
	500	7.8	64.0
	650	11.6	55.9
	850	16.9	50.3

Well #227			
Static Water Level: -34.1 feet (bls)			
Date	Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
09/12/2005	350	7.8	45.0
	500	11.0	45.3
	695	16.7	41.5
	800	19.6	40.8
	950	24.6	38.6

Well #228			
Static Water Level: -23.1 feet (bls)			
Date	Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
11/22/2005	350	7.3	48.1
	500	10.6	47.3
	650	14.4	45.1
	800	19.4	41.2
	950	25.0	38.0

Table 3-3 Specific Capacities of Wells

Well #229			
Static Water Level: -23.8 feet (bls)			
Date	Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
01/12/2006	350	8.41	41.6
	500	14.1	35.5
	650	20.0	32.5
	800	26.3	30.5
	950	33.3	28.5

Well #230			
Static Water Level: -24.2 feet (bls)			
Date	Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
04/21/2006	350	9.9	35.5
	500	15.8	31.6
	650	21.2	30.7
	800	27.9	28.6
	950	35.5	26.7

Well #231			
Static Water Level: -25.4 feet (bls)			
Date	Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
03/22/2006	350	10.1	34.6
	500	15.5	32.2
	650	22.2	29.3
	800	30.3	26.4
	870	35.3	24.6

Well #232			
Static Water Level: -16.0 feet (bls)			
Date	Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
03/03/2006	350	10.4	33.7
	500	15.4	32.4
	650	22.5	28.8
	800	29.5	27.1
	950	37.7	25.2

3.4 Aquifer Testing

Aquifer Performance Tests (APT) were performed as single well tests on Production Wells #227 and #229 to evaluate aquifer properties. The tests were conducted by pumping the wells at a constant rate for eight hours. Well #227 was tested on September 13, 2005 and Well #229 was tested on January 13, 2006. Water levels measurements were made using a data logger. Following the pumping portion of the tests, recovery data was collected for a minimum of sixteen hours. Backup field water level measurements were made with an electric tape during the pumping phase and one half hour during the recovery phase of the tests.

These single well APTs were interpreted by using the Theis (1935) curve matching technique and the Cooper-Jacob (1946) straight-line method. Both solutions may be used when analyzing single well pumping test data. Plots of time-recovery and time-residual drawdown are displayed in Figures 3-2 through 3-5. A summary showing the comparative results from the Theis and Cooper-Jacob analysis methods is provided in Table 3-4.

Table 3-4 Aquifer Performance Test Results

Well	Pumping Rate (gpm)	Transmissivity Theis (gpd/ft)	Transmissivity Cooper-Jacob (gpd/ft)
#227	675	90,902	50,986
#229	600	54,027	65,972

The transmissivity calculated in Well #227 with the Theis Recovery Analysis method is 90,902 gpd/ft and with a Cooper-Jacob Analysis method, the transmissivity was calculated to be 50,986 gpd/ft. The transmissivity calculated in Well #229 with a Theis Recovery Analysis method is 54,027 gpd/ft and with a Cooper-Jacob Analysis method, the transmissivity is calculated to be 65,972 gpd/ft. Based on the site-specific hydrogeologic data collected during drilling and aquifer testing, along with supporting data from previous investigations; the Cooper-Jacob analytical model appears to best represent the conditions for both of wells. The hydraulic parameters determined from this solution are within the ranges of values previously determined for the Lower Hawthorn Aquifer in southern Cape Coral (Missimer and Associates, Inc., 1991 and ViroGroup, Inc., 1997).

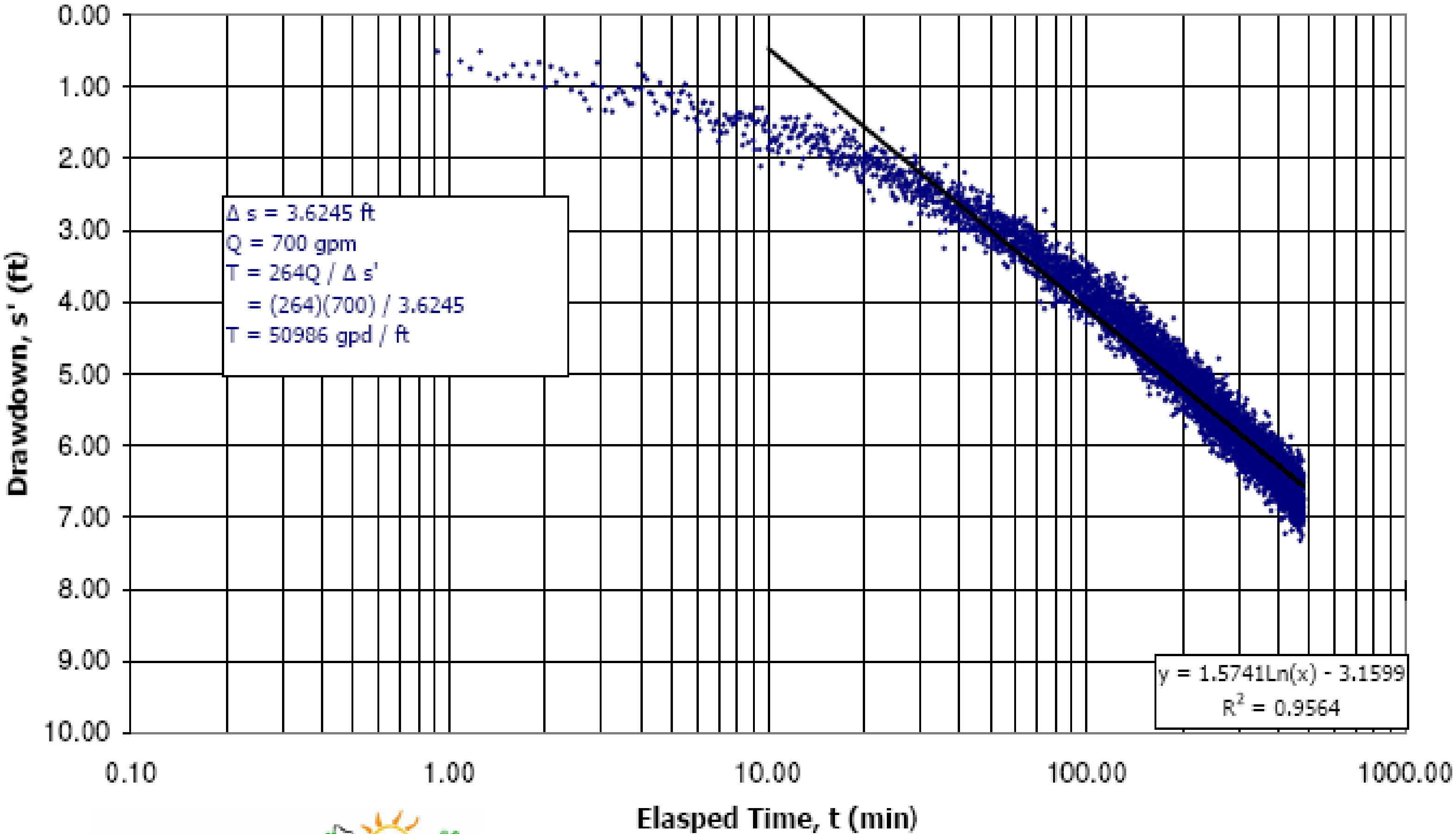


Figure 3-2 Cooper-Jacob Recovery Analysis Well #227

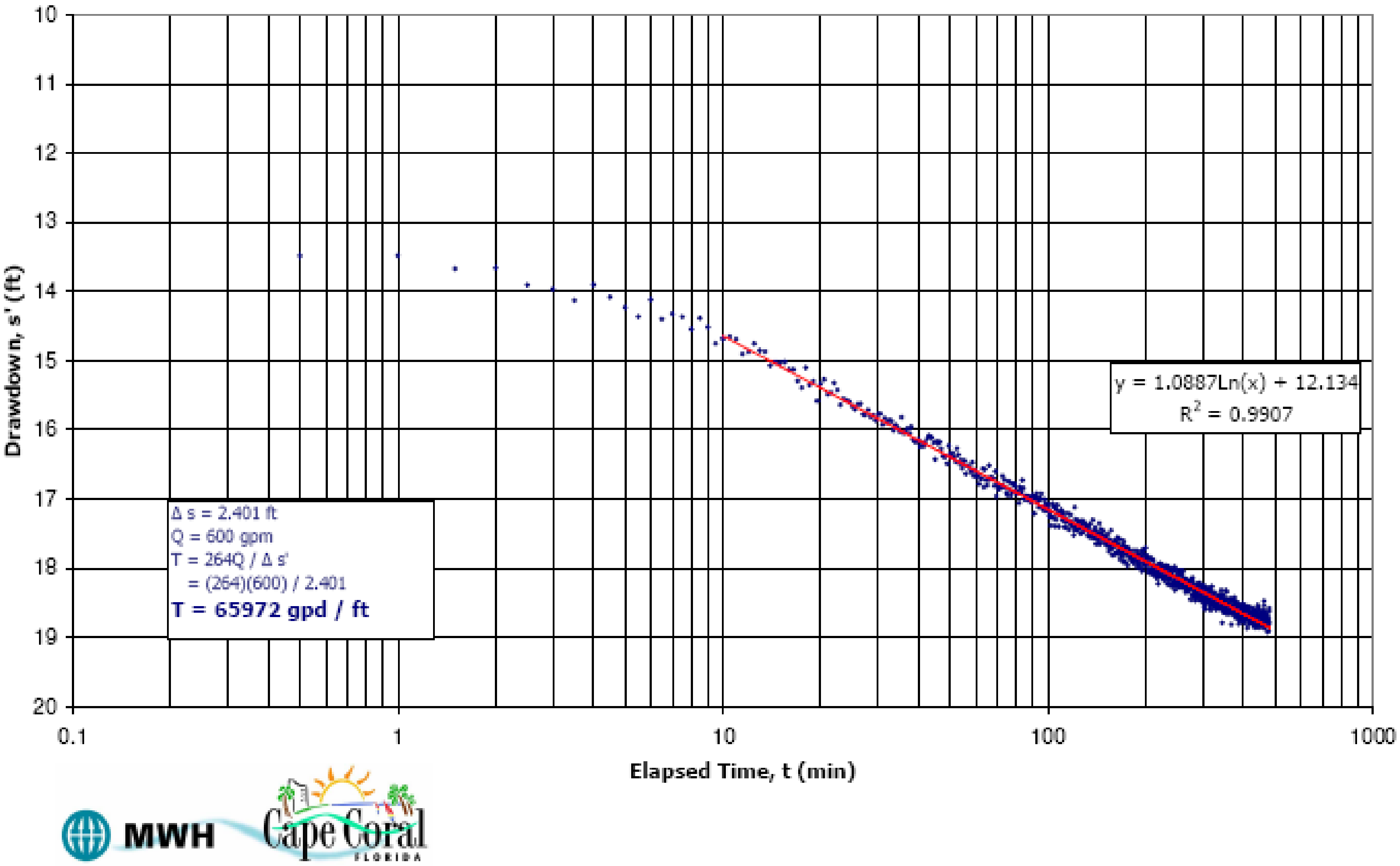


Figure 3-3 **Cooper-Jacob Recovery Analysis Well #229**

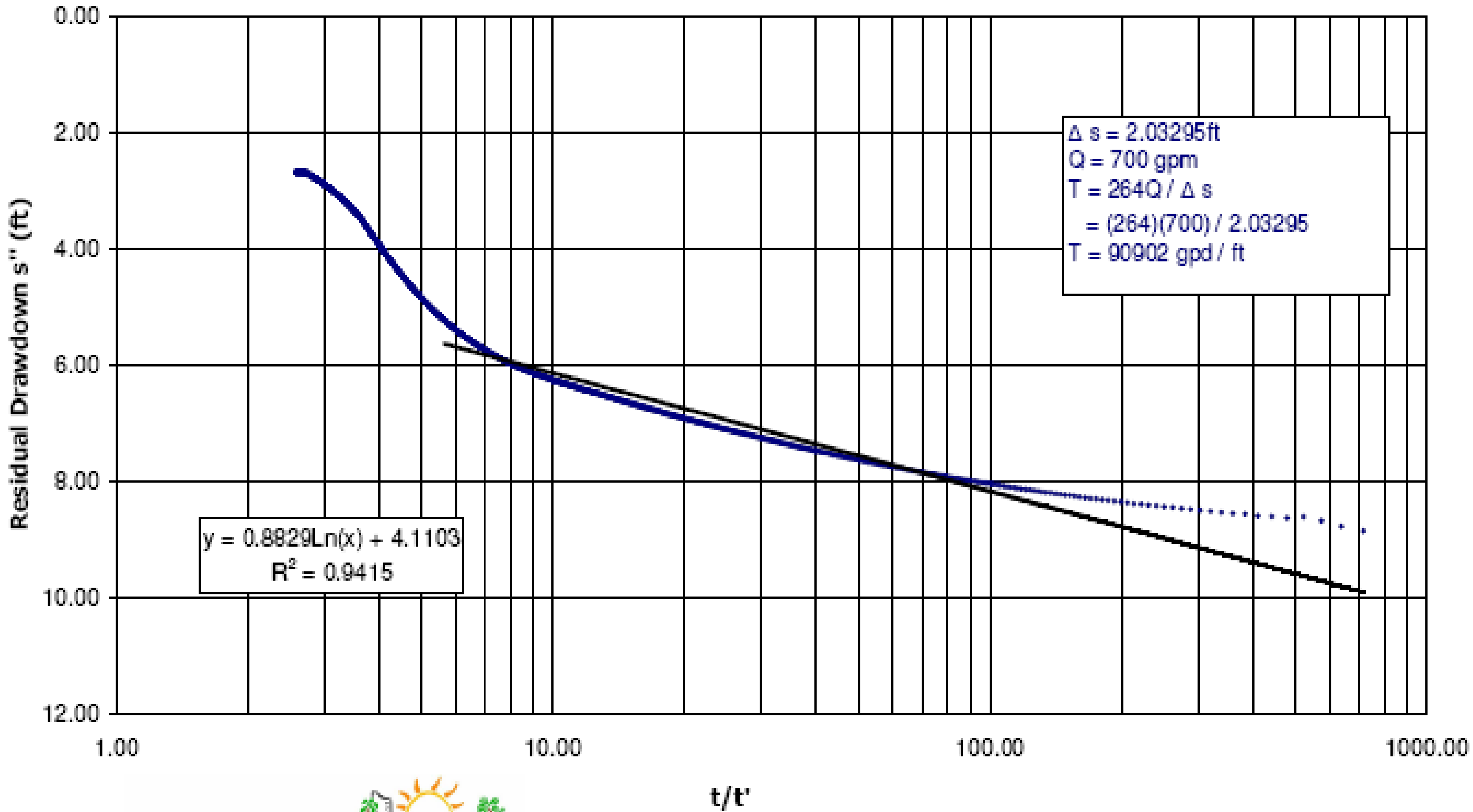


Figure 3-4 Theis Recovery Analysis Well #227

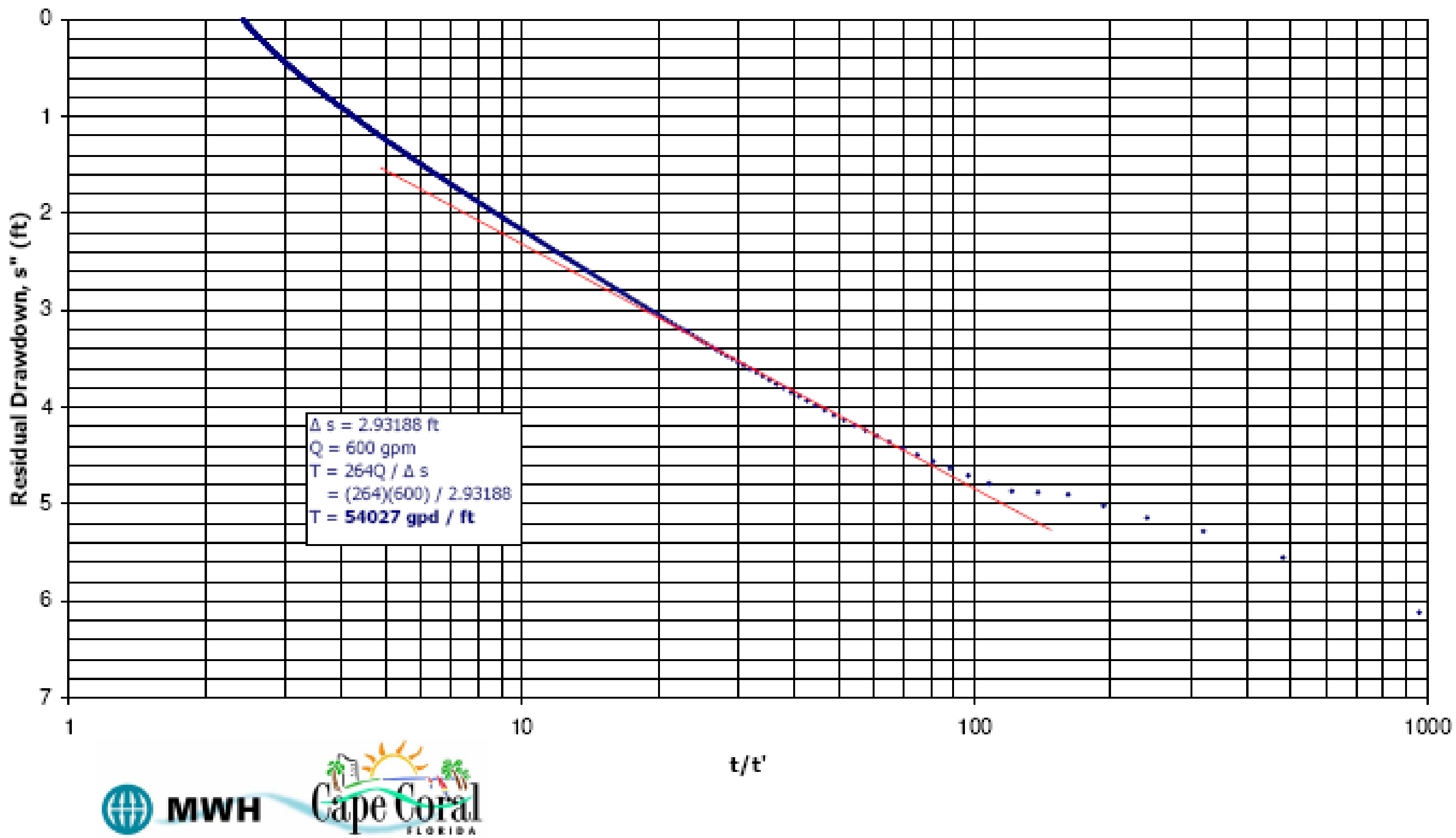


Figure 3-5 Theis Recovery Analysis Well #229

3.5 Geophysical Logging

Geophysical logging performed during the construction of the eight new production wells was designed to collect information on the hydrogeology and borehole geometry. The geophysical logging suite performed on the pilot hole included XY-caliper, natural gamma ray, spontaneous potential, and dual induction, while geophysical testing on the reamed borehole included XY-caliper and gamma ray logs. The geophysical suite collected on the open borehole to total depth included XY-caliper, natural gamma ray, spontaneous potential, dual induction, borehole compensated sonic, temperature (static and dynamic), flow meter (static and dynamic), fluid resistivity (static and dynamic) and a color borehole video.

MV Geophysical Surveys, Inc., subcontracted by DDC and under the supervision of MWH, produced the geophysical logs. A summary of all the geophysical logs run on the eight production wells is provided in Table 3-5. A CD of the geophysical logs conducted on the production wells is provided in Appendix B.

Table 3-5 Summary of Geophysical Logs

Well #	Date	Logged Interval (ft bls)	XY Caliper	Gamma Ray	Spontaneous Potential	Dual Induction	Temperature	Fluid Conductivity	Flow	Sonic Porosity	Video
112	10-26-05	0-500	X	X	X	X					
	11-7-05	0-460	X	X							
	11-21-05	0-720	X	X	X	X				X	
	12-2-05	0-720					X	X	X		X
226	9-8-05	0-503	X	X	X	X					
	9-23-05	0-472	X	X							
	10-13-05	0-715	X	X	X	X	X	X	X	X	X
227	8-17-05	0-495	X	X	X	X					
	8-25-05	0-454	X	X							
	9-1-05	0-715	X	X	X	X	X	X	X	X	
	9-14-05	0-715	X	X							X
228	10-19-05	0-495	X	X	X	X					
	10-31-05	0-465	X	X							
	11-15-05	0-713	X	X	X	X				X	
	11-28-05	0-713					X	X	X		X
229	12-14-05	0-496	X	X	X	X					
	12-27-05	0-465	X	X							
	3-7-06	0-712	X	X	X	X	X	X	X	X	X
230	3-23-06	0-491	X	X	X	X					
	3-31-06	0-465	X	X							
	4-25-06	0-695	X	X	X	X	X	X	X	X	X
231	3-2-06	0-497	X	X	X	X					
	3-8-06	0-435	X	X							
	3-21-06	0-703	X	X	X	X	X	X	X	X	X
232	1-9-06	0-520	X	X	X	X					
	2-14-06	0-470	X	X							
	3-2-06	0-708	X	X	X	X	X	X	X	X	X

Interpretations of the Flow Logs were constructed for wells #228 and #232 to determine primary and secondary flow zones in the wells. The interpretations were generated from a synthesis of the geophysical static flow logs, dynamic flow logs and the XY-caliper logs.

In Well #228, the primary flow zone, of 74% or greater flow, was measured below the FRP casing to a depth of 526 feet bls. A secondary flow zone, of 23-37% flow, occurred between 537 feet to 635 feet. Below 635 feet, the flow trends to 0%. See figure 3.6

In Well #232, the primary flow zone, of 76% or greater flow, was measured below the FRP casing to a depth of 565 feet bls. A secondary flow zone, of 41-58% flow, occurred between 586 feet and 637 feet. Below 637 feet, the flow trends to 0%. See figure 3.7

The Sonic and Dual Induction logs from Wells #112 and #226 through #232 were used to calculate a log-derived TDS plot based on the method developed by Callahan (1996) using empirical data compiled by Reese (1994). Figure 3.8 shows a plot of the log derived TDS for Well #227. This plot is typical of the southwest wellfield with total dissolved solid concentration between approximately 1000 mg/L and 2500 mg/L. A log-derived plot of TDS for Well #228 is shown in Figure 3.9. The TDS concentration in this well ranges between 600 mg/L and 6000 mg/L with a general increase in concentration with depth.

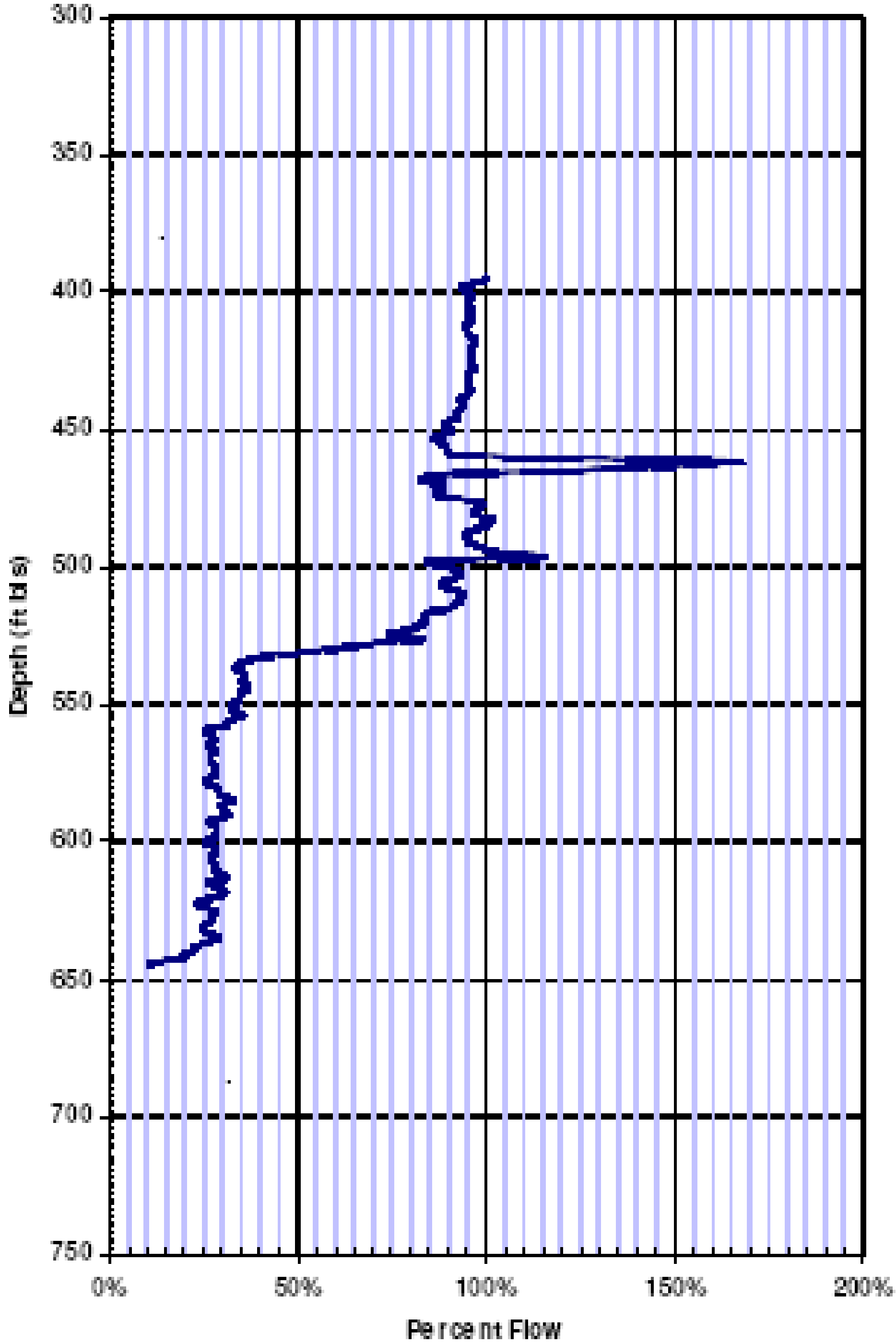


Figure 3-6 Percent Flow Well #228

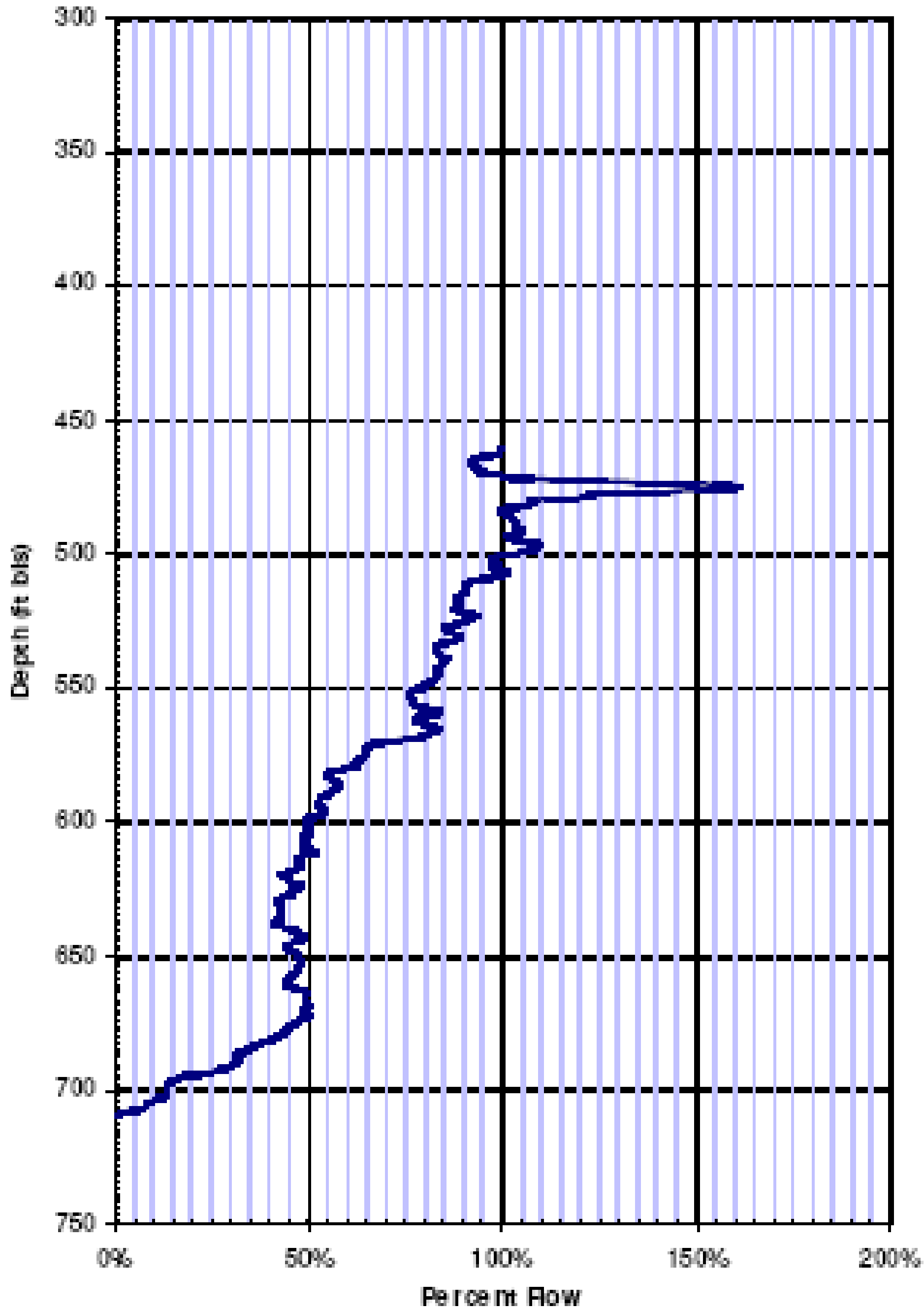


Figure 3-7 Percent Flow Well #232

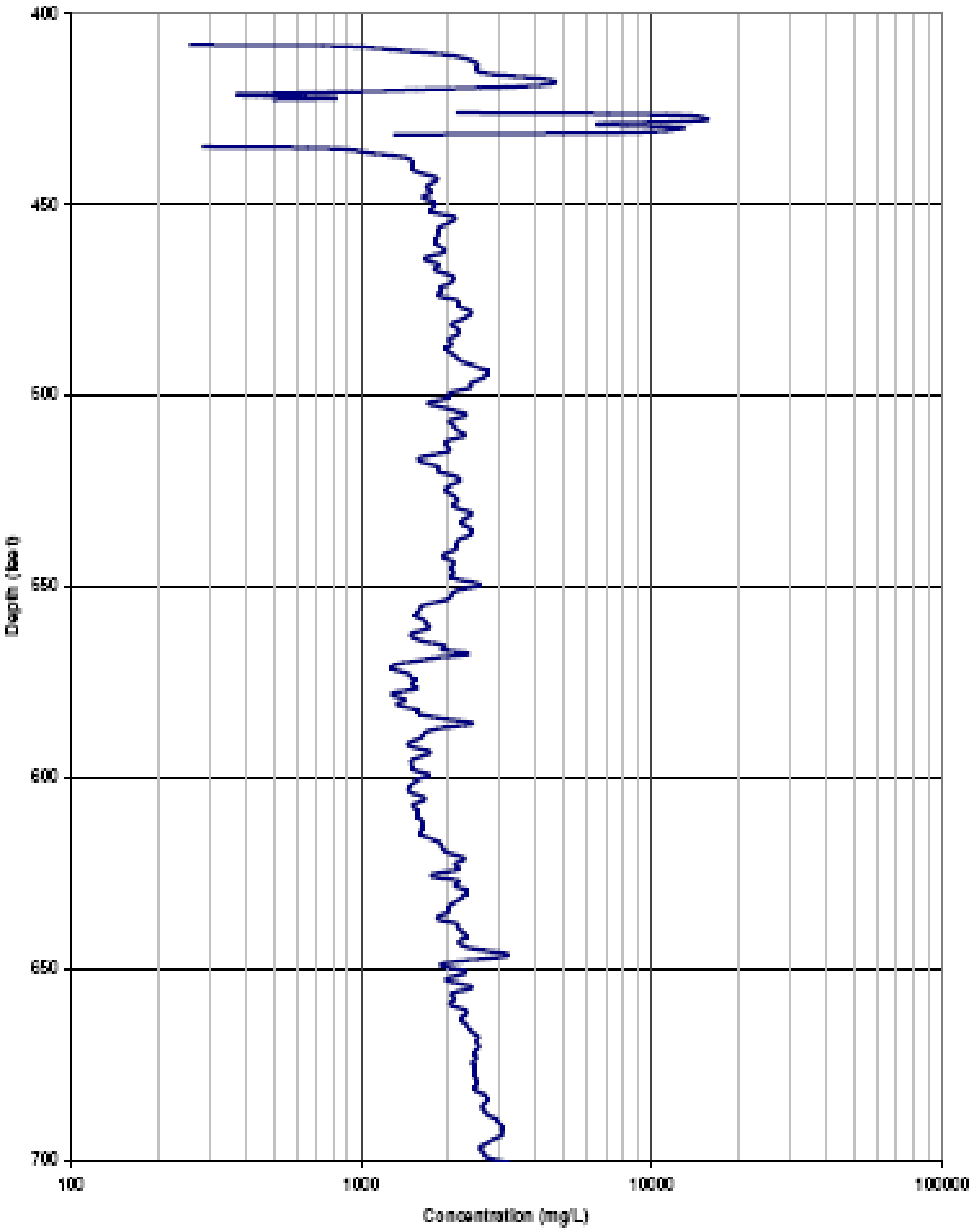


Figure 3-8 Log Derived TDS Well #227

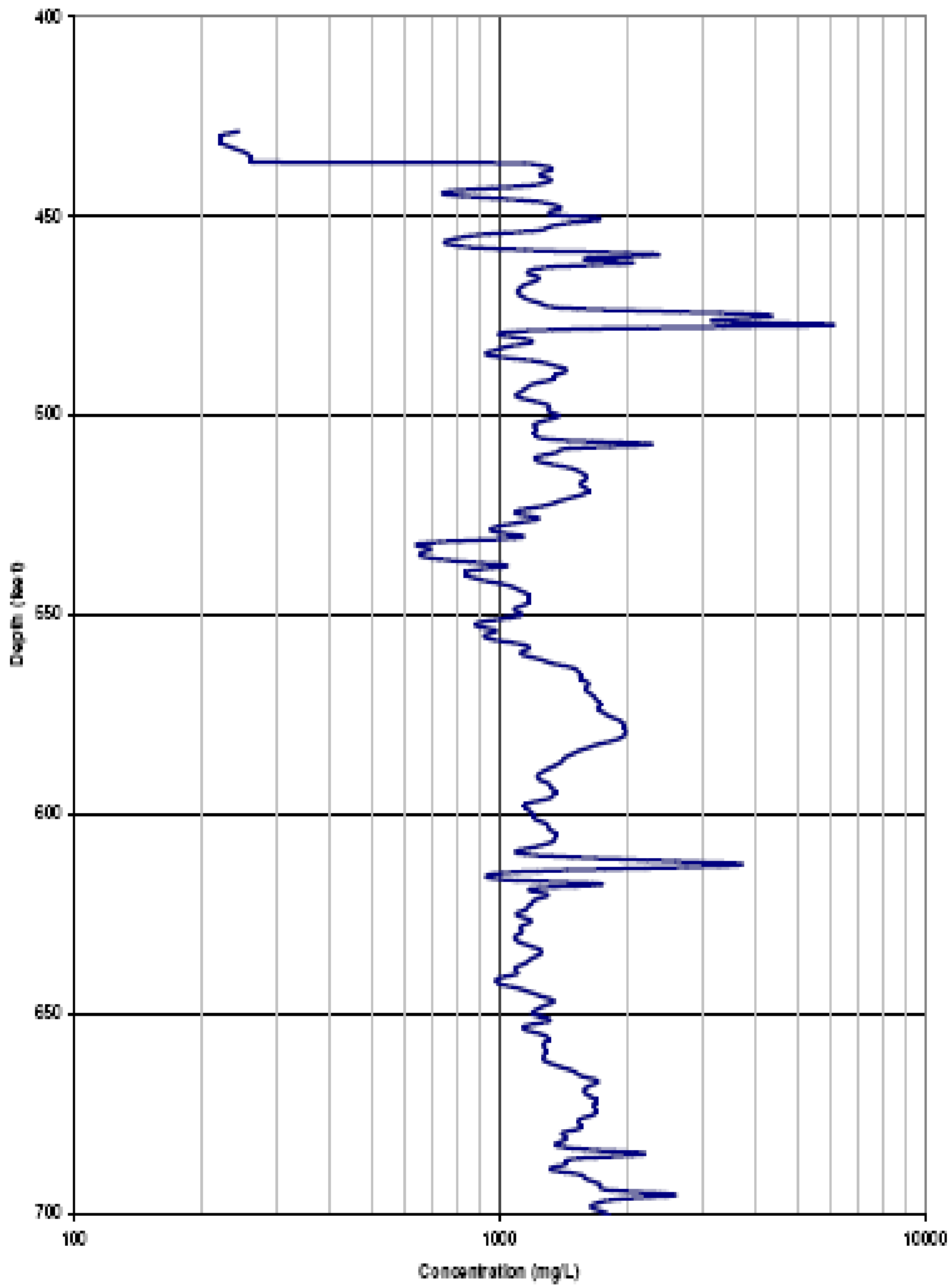


Figure 3-9 Log derived TDS Well #228

4.0 Hydrogeology

4.1 Hydrogeology

The geology and hydrogeology of Lee County had been described in a number of investigations by the Florida Geological Survey (Sproul, et. al., 1972; Missimer and Banks, 1982; Missimer and Scott, T.M., 2001) the U.S. Geological Survey (Boggess, D.H., 1974; Boggess et al., 1976; Fitzpatrick, D.J., 1986), and the South Florida Water Management District (Wedderburn et al., 1982; Bower et al., 1990). In addition, various consultant reports have submitted detailed descriptions of the subsurface geology to the City of Cape Coral Utilities Department (Missimer and Associates, 1982, 1984, 1989 and 1991).

In Cape Coral, the Intermediate and Floridan Aquifer Systems provide the only suitable potential sources of groundwater for public supply. Although not considered a viable source for public supply, the Mid-Hawthorn aquifer of the Intermediate Aquifer System is described because of its extensive use for domestic and self-supply purposes. In Southwest Florida, the Lower Hawthorn Aquifer is considered the uppermost aquifer of the Floridan Aquifer System. The Suwannee Aquifer is a deeper aquifer of the upper Floridan Aquifer and is a potential water source. A generalized hydrostratigraphic section of the subsurface in Cape Coral is shown in Figure 4-1. A North to South hydrogeologic cross section of the Southwest Wellfield is shown in Figure 4-2.

<u>Mid-Hawthorn Aquifer</u>

The Mid-Hawthorn Aquifer (also referred to as the “Hawthorn Zone I Aquifer”) occurs within limestones in the upper part of the Arcadia formation of the Hawthorn Group. The predominant lithology is gray fossiliferous limestones. These limestones are commonly biomicritic and have a moderate to high porosity. The aquifer occurs at a depth of approximately 100 feet bls in the southern part of the City and 150 feet in the northern part of the City (Missimer and Associates, Inc., 1989). The thickness of the Mid-Hawthorn Aquifer, within Cape Coral, ranges from 50-100 feet.

Although previously used by Cape Coral as a municipal water supply source, the Mid-Hawthorn Aquifer does not yield large quantities of water, and is not a viable source for public supply. The transmissivities of the aquifer in the City range from 10,000 to 20,000 gpd/ft (Missimer & Associates, 1984). Discharge from the aquifer is due to pumping and lateral outflow to downgradient areas. At present, the Mid-Hawthorn Aquifer is used extensively for private domestic water supply purposes in Cape Coral. The potentiometric surface of the aquifer has declined over the past forty years due to increased use and over-pumping. Additional use may be restricted by the SFWMD because the potable level periodically approaches minimal operational levels during the dry season. This level for confined aquifers is 20 feet above the top of the aquifer.

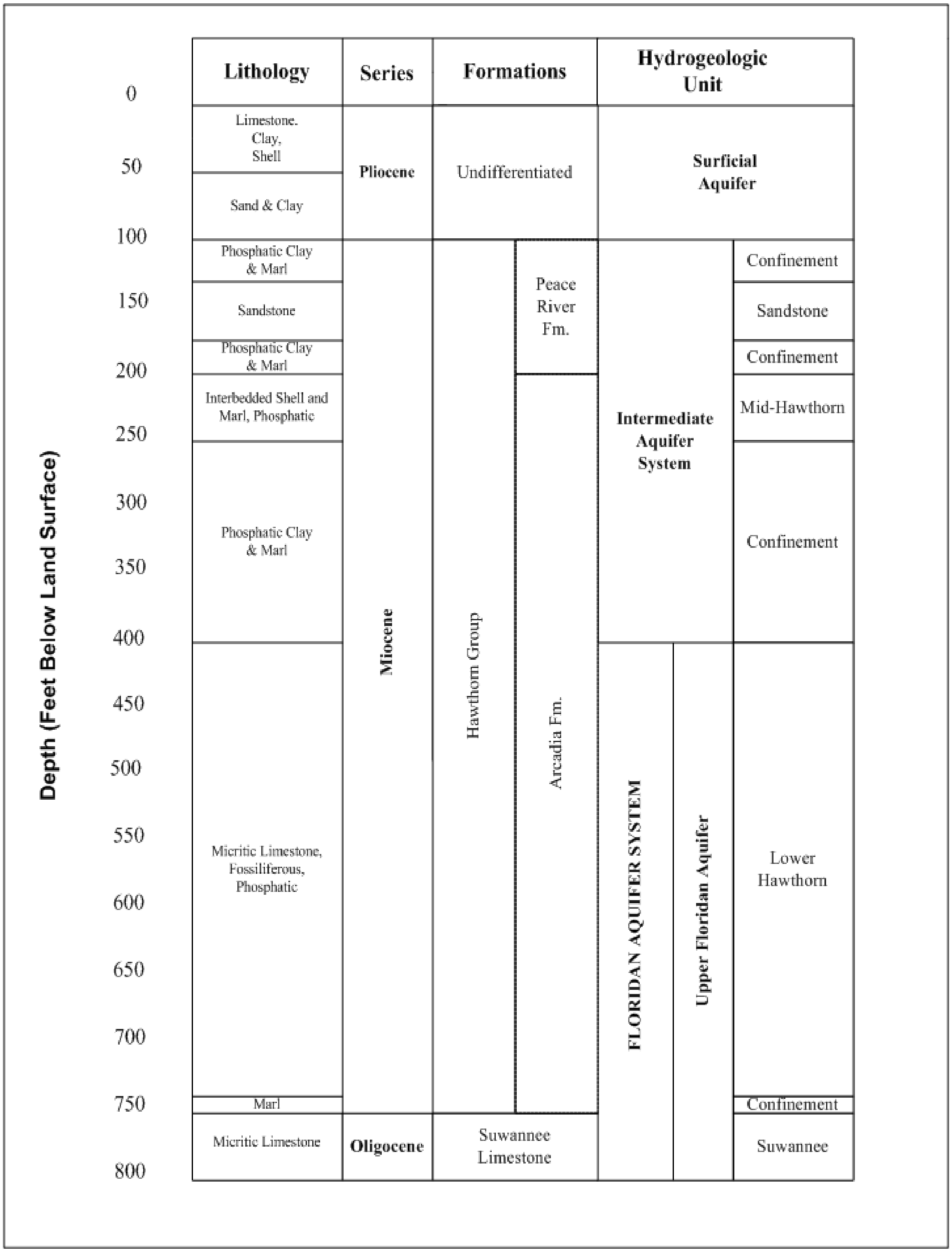


Figure 4-1 Generalized Hydrostratigraphic Section for Cape Coral

Lower Hawthorn Aquifer

The Lower Hawthorn Aquifer occurs within the lower portion of the Arcadia Formation of the Hawthorn Group and makes up the upper most part of the Upper Floridan aquifer. The predominant lithology consists of white to light-gray, quartz sandy, micritic limestone containing minor amounts of dolomites, phosphate grains and some beds of abundant fragments of mollusk and gastropod shells and other fossils (Reese, 2000). Commonly the limestones are moderately hard and have a moderate to high intergranular porosity and the shelly beds can have high moldic porosity. The Lower Hawthorn Aquifer dolomites or dolomitic limestones typically have a microsucrosic texture, are very hard and have variable porosities. The top of the aquifer occurs at depths ranging from approximately 400 to 600 feet bls in Cape Coral and extends to a depth of 700 to 800 feet bls (Missimer and Associates, Inc, 1991)

Raw water production for the Cape Coral RO wellfield is currently from the Lower Hawthorn Aquifer. The eight recently constructed wells were completed in the Lower Hawthorn aquifer. The pre-development potentiometric surface of the aquifer in Cape Coral ranged between 25 and 35 feet NGVD based on regional data (Missimer and Associates, Inc., 1991).

Suwannee Limestone

The top of the Suwannee Limestone is generally estimated to be at approximately 700 to 800 feet bls in Cape Coral, with variable confinement from the Lower Hawthorn Aquifer above. A regional disconformity separates the Hawthorn Group from the Suwannee Limestone (Reese, 2000). Confining beds between the two aquifers vary from a few feet to almost 100 feet and consist of interbedded carbonate clays, marls, and limestones and/or dolomites of variable permeability (Missimer and Associates, Inc., 1991). The contact between the Hawthorn Group and the Suwannee Limestone is marked by an attenuation of the natural gamma activity on geophysical logs. The degree of confinement ranges from moderate to poor and exhibits a hydraulic connection in most instances (Missimer and Associates, Inc., 1991).

The Suwannee Limestone is divided into upper and lower units separated by variable confining units of limestone and marl of low permeability. The upper part of the Suwannee Limestone is composed of calcarenitic limestones, while the lower part of the Suwannee Limestone is composed of similar limestone though less permeable due to interbedding and increased lime mud and fine grained material (Missimer and Associates, Inc., 1991).

The depth of the Suwannee Limestone occurs from approximately 800 to 1,050 feet bls, and ranges in thickness from 100 to 400 feet. The transmissivity of the upper part of the Suwannee Limestone in Cape Coral ranges from approximately 50,000 to 68,000 gpd/ft, with a storage coefficient of 2.5 x 10-4, and a leakance of 1 x 10-2.

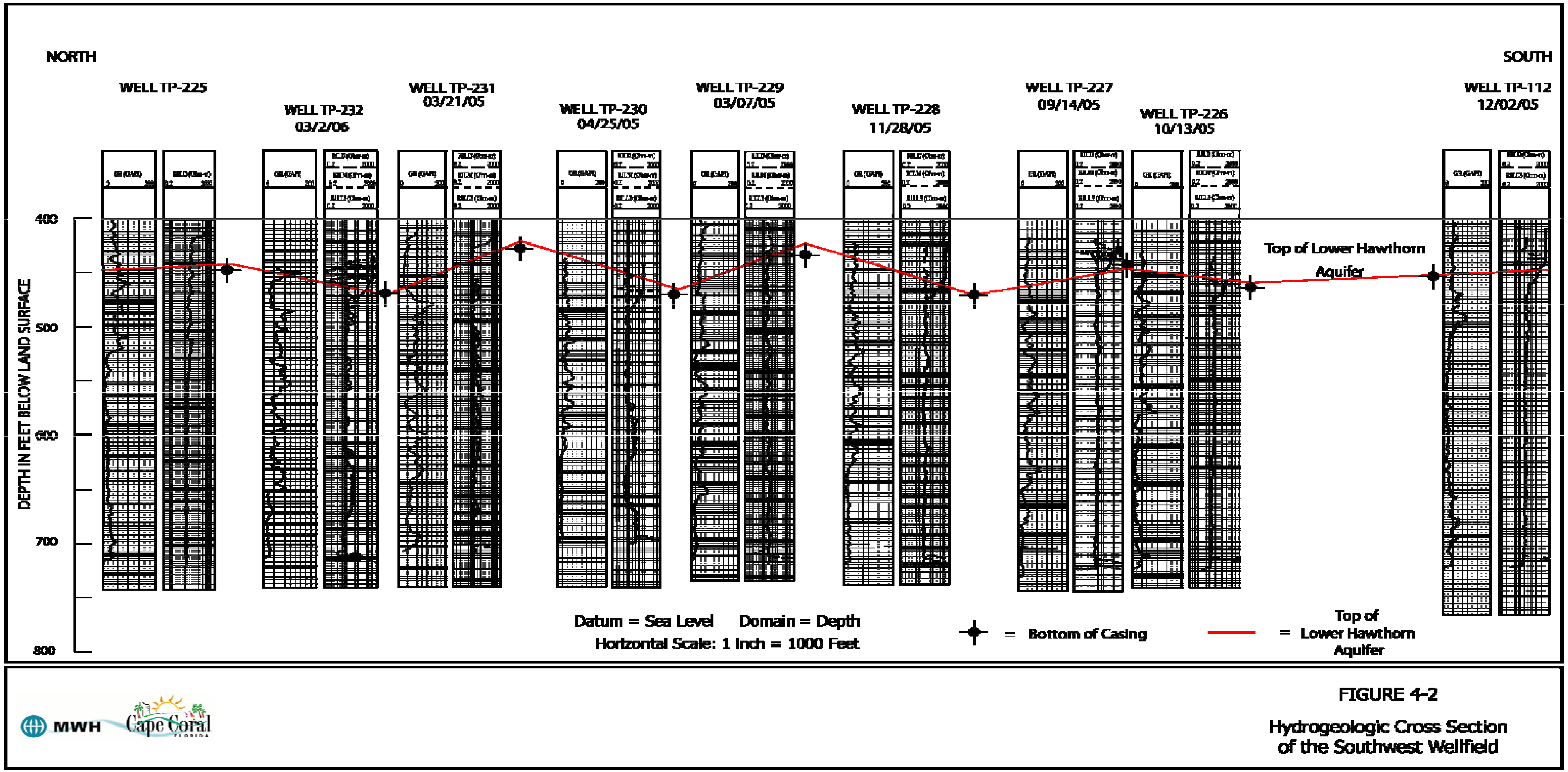


Figure 4-2 Hydrogeologic Cross Section of the Southwest Wellfield

4.2 Water Quality

Water samples were collected from the new production wells during the construction, well development, and testing phases. During reverse air drilling, water samples were collected at 30-foot intervals to record vertical water quality variations with depth. The parameters analyzed were specific conductance, dissolved chloride, pH and temperature. Specific conductance was measured using a Myron L. Company conductivity meter model ARH1. Dissolved chloride concentration was measured using the Hach silver nitrate digital titration method. A summary of the water quality data are presented in Tables 4-1 and 4-2. The water quality for wells #112, #226, #227, #228, #229 and #231 are about average for the Cape Coral wellfield. A summary of the suspended solids data are presented in Table 4-3. All SDI results were within acceptable limits for the SW ROWTP.

Analysis of primary and secondary water quality parameters of water samples were performed on the newly constructed production wells following well construction and testing. Photocopies of the laboratory analytical reports for the primary and secondary testing are provided in Appendix C. The results of the water quality measured for the new production wells, with the exception of Wells #230 and #232, are similar to others in the Cape Coral wellfield. Water quality in production Wells #230 and #232 was poorer than production wells previously drilled in Cape Coral. In all wells, potable water standards were exceeded for certain parameters, such as chloride, total dissolved solids, and sodium, which is characteristic of brackish water aquifers and typical of other Lower Hawthorn Aquifer production wells in Cape Coral. The reverse osmosis treatment method used by the City of Cape Coral will produce water that will meet all applicable drinking water standards.

Table 4-1 Water Quality Data during Drilling

Production Well	Average Specific Conductance (µS/cm)	Average Chloride Concentration (mg/L)
#112	2144	427
#226	2903	499
#227	2611	732
#228	2722	479
#229	1879	532
#230	9867*	3443*
#231	2496	513
#232	5677*	1986*

Table 4-2 Water Quality Data during Development

Production Well Number	Date	Pumping Condition	Specific Conductance (µS/cm)	Dissolved Chloride Concentration (mg/L)
#112	11/30/05	Pump Development	2300	588
#226	10/11/05	Pump Development	3080	538
#227	09/8/05	Pump Development	3060	698
#228	11/18/05	Pump Development	2280	475
#229	01/11/05	Pump Development	4080	388
#230	4/20/06	Pump Development	17890*	7500*
#231	3/21/06	Pump Development	2480	212
#232	03/01/06	Pump Development	8670*	3190*

*Values are adjusted from initial measurements due to field equipment malfunction to accurately reflect water quality conditions encountered.

Table 4-3 Suspended Solids Data during Development

Well	Date	Condition	Pump Rate (gpm)	SDI* (unitless)	Sand* (ppm)	Turbidity* (NTU)
#112	11/30/05	Pump Development	1050	3.00	0.88#	1.33
#226	10/11/05	Pump Development	650	0.33	0.10	0.28
#227	09/09/05	Pump Development	1100	0.25	0.01	0.91
#228	11/18/05	Pump Development	1000	0.96	1.06	4.60
#229	01/11/06	Pump Development	780	0.60	0.75	0.74
#230	4/20/06	Pump Development	700	4.13	0.18	4.61
#231	3/21/06	Pump Development	850	1.30	0.26	0.36
#232	03/01/06	Pump Development	600	3.00	0.32	0.57

* Last recorded value at end of Pump Development
# Sand content measurement from Step Rate Test

5.0 Wellfield Operation

5.1 Well Pumping Equipment and Pumping Rates

A submersible well pump manufactured by Crown Pump Corporation, model 8M-700-2 (316 Stainless Steel) was installed for Well #112 and #226 through #232. The pump is equipped with a 50 hp electric motor and is set on a 6-inch diameter Certa-Lok PVC column pipe. The operating range for the pump is from approximately 400 to 800 gpm. The maximum recommended pumping rate for Production Wells #112, #226 through #232 is 600 gpm. The pump setting depth and recommended pumping rates are summarized in Table 5-1.

Table 5-1 Recommended Pump Settings and Pumping Rates

Well	Production Casing Depth (feet bls)	Pump Setting Depth (feet bls)	Recommended Pumping Rate (gpm)
#112	455	120	550
#226	460	120	600
#227	429	120	600
#228	460	120	550
#229	460	120	500
#230	465	P&A	P&A
#231	435	120	500
#232	470	120	500

5.2 Wellfield Operation

The SW ROWTP is comprised of two separate treatment plants known as Plant 1 and Plant 2. The two plants operate as separate treatment facilities and are supplied by separate wells and pipeline facilities. A map showing the locations of the wells feeding the two treatment plants is provided in Figure 2-2.

The SW ROWTP is currently undergoing a plant expansion. The expansion will increase the capacity of the plant to a sustainable capacity of 17.8 mgd. This includes a firm capacity of one train down per plant. As part of this wellfield expansion, one additional well (Well #112) has been drilled in the Plant 1 wellfield to meet rotational capacity. The additional wells that were drilled for Plant 2 (Wells #226 through #232) are required for increased production capacity and rotational capacity. A summary of the water demands and production of the SW ROWTP assuming all the trains are on is provided in Table 5-2.

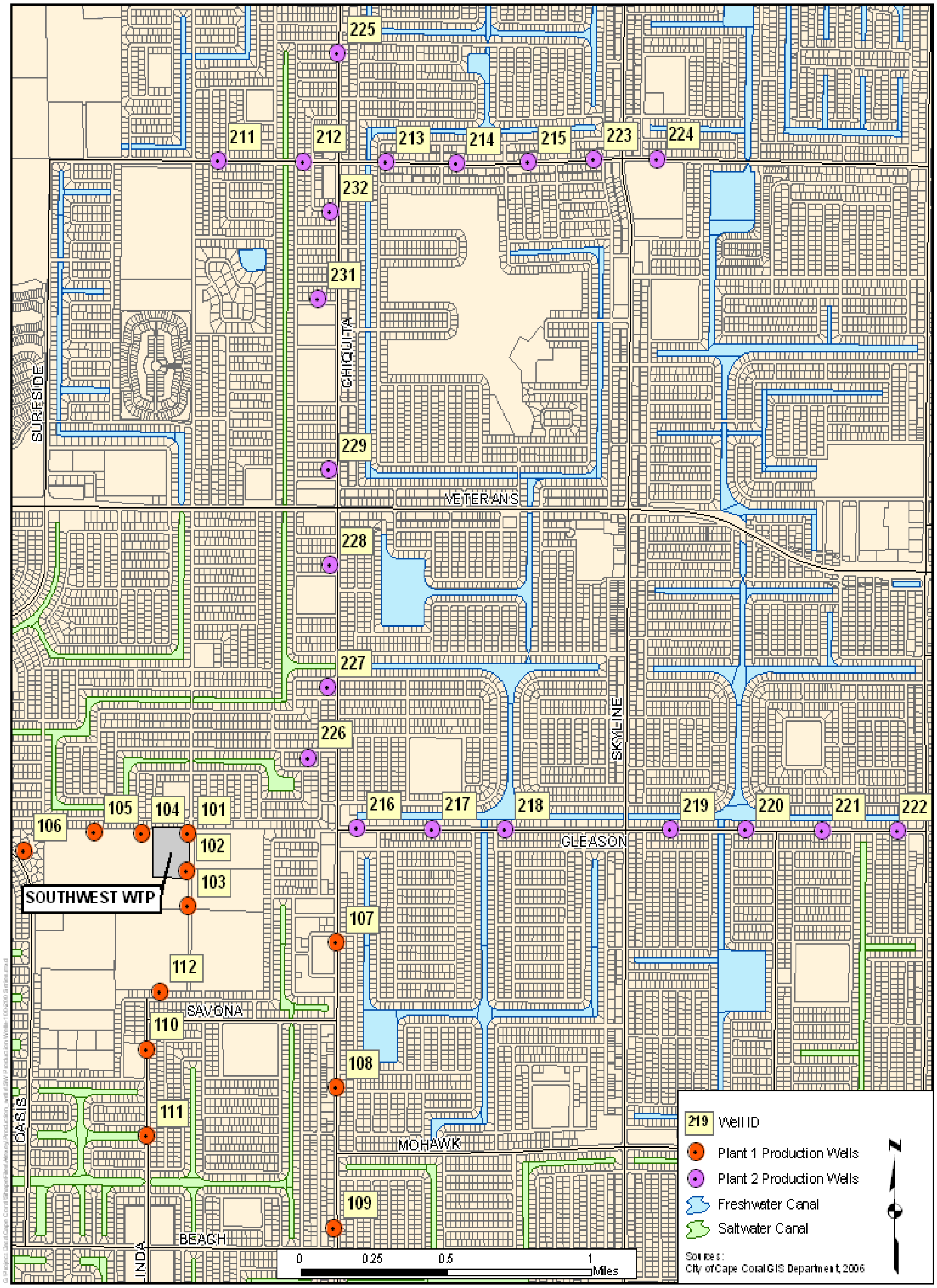


Figure 5-1 Locations of Plant 1 and Plant 2 Production Wells

Table 5-2 Treatment Plant Production Summary

Process	Plant 1	Plant 2
Raw Water (gpm)	5,659	9,752
Wells in Operation*	10	18
Number of Trains	10	8
Bypass (gpm)	1,019	1,752
Feed Flow per Train (gpm)	464	1,000
Permeate Flow Per Train (gpm)	371	850
Blended Product (gpm)	4,731	8,552

*Assuming the average production per well is 550 gpm.

Currently, the operators at the SW ROWTP choose the amount of water the plant will produce. Once that is set, the operators will manually turn on the appropriate number of wells at flow rates with acceptable drawdowns via the plant Supervisory Control and Data Acquisition (SCADA) system. The operators use the pressures on the trains to determine if more or less wells need to be brought on line or if the flow rates of the wells need to be adjusted. The City is in the process of installing variable frequency drives (VFD) at all the wells to control the flow rates of the wells. The current method of wellfield operation should be continued.

Historical performance regarding water quality and quantity provides a basis for operators to decide which wells to use, or not use, on a routine basis. RO plant staff has compiled production well data since the plant started operations. The data available in digital format allows historical production records to be presented and evaluated to aid in wellfield operational decisions. Plots of recent individual well production and historical water quality trends, as indicated by Total Dissolved Solids (TDS) concentration, are provided in Figures 5-2 and 5-3.

Recent annual average well production rates indicate that lower producers include Wells #106 and #109, and the higher producers include Wells #102, #104, #110, and #216, and #217 (Figure 5-2). Historical water quality records indicate that better water quality is produced in Well #106, and the poorer water quality is produced in Wells #104, #105, #213, #214, and #215 (Figure 5-3). The wells having the poorest water quality should be pumped at lower rates or used on a standby basis. Based on the most recent water quality data it is recommended that, wells #104, 105 and #214 should be used on a standby or intermittent basis.

Figure 5-2 Average Well Production Rates 2003-2005

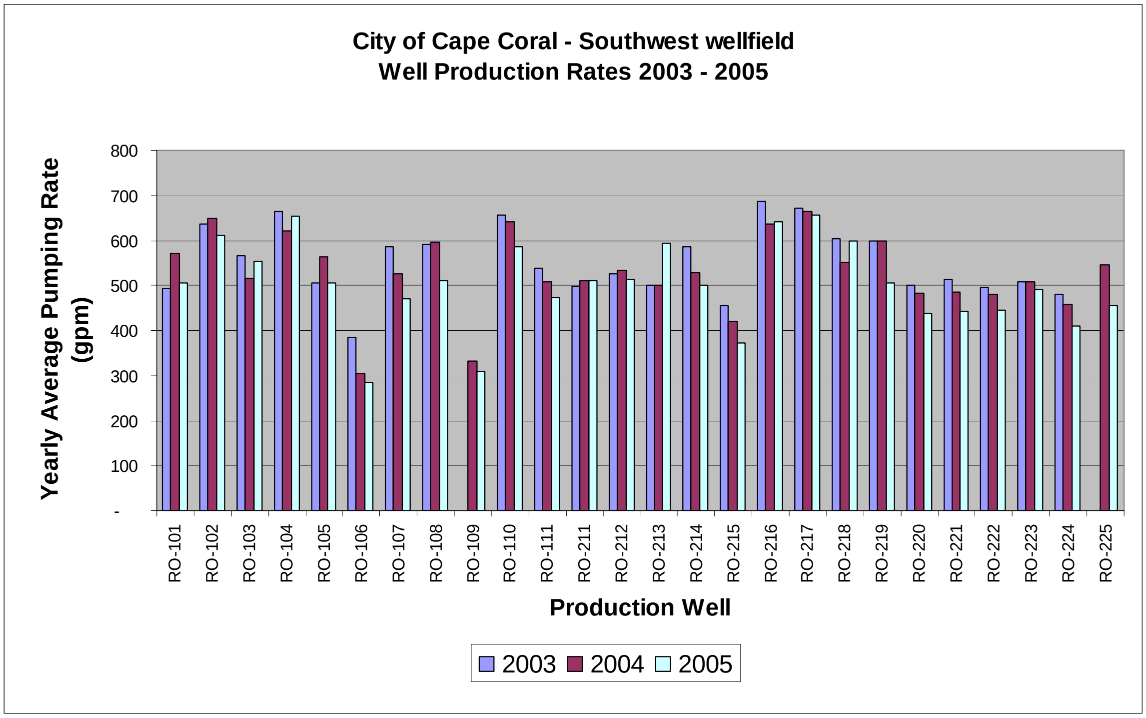
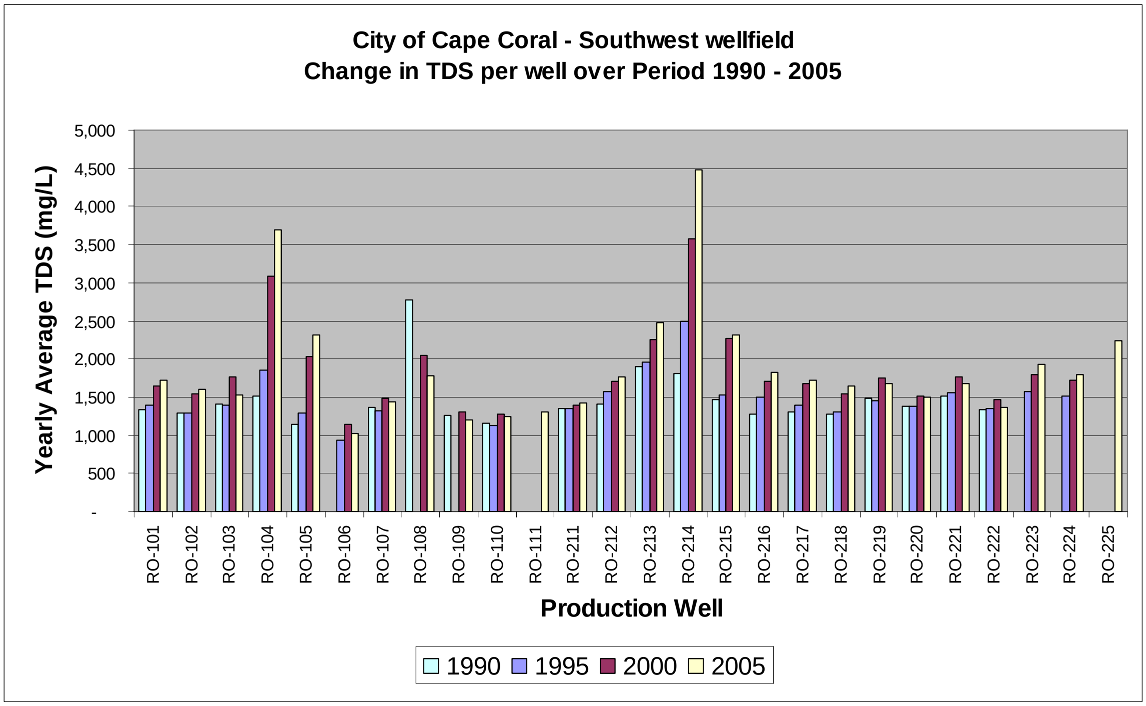


Figure 5-3 TDS Changes in South Wellfield



Historical pumpage records for the existing wells, and recommended production rates for the recently installed wells were used to determine the number of wells available to meet plant production needs, along with well standby capacities. The plant raw water needs detailed in Table 5-2 assumes a production rate of 550 gpm per well. Raw water needs following completion of the expansion are summarized in Table 5-3, and are based on historical and proposed production rates. Two scenarios for Plant 2 are provided: one with, and one without Well #230. The locations of the wells supplying Plants 1 and 2 are shown in Figure 5-1.

Table 5-3 Anticipated Wellfield Production

	No. of Wells	RO Train Needs (gpm)	All Wells Pumping (gpm)	1 Well Standby (gpm)	2 Wells Standby (gpm)	3 Wells Standby (gpm)
Plant 1	12	5,659	6,151	5,638	5,126	4,613
Plant 2 (w/ Well #230)	22	9,752	11,374	10,857	10,340	9,823
Plant 2 (w/o Well #230)	21	9,752	10,824	10,308	9,793	9,278
Notes: Existing well production rate based on 5-year average production rates						
New well production rates are those recommended in Table 5-1.						

It is recommended that one or more standby wells be maintained to allow wellfield flexibility and rotational capacity. Table 5-3 indicates that the Plant #1 wellfield (Wells #101-112) can meet total RO train needs with one well not operating (1 well standby). However, because of water quality and quantity issues with certain Plant #1 wells (wells #104, #106, and #109, respectively), additional sources of water should be considered to supply Plant #1. Table 5-3 also indicates that the Plant #2 wellfield (Wells #211 to #229, #231 and #232) can meet total RO train needs with two wells not operating. Again, water quality problems are present in Wells #214, and in Well #232, which supply Plant #2. A replacement well for the plugged Well #230 should therefore be pursued to provide the needed additional standby capacity.

5.3 Monitoring and Maintenance

Monitoring of the wellfield facilities are required by Limiting Conditions of the City's Public Water Supply Water Use Permit (WUP #36-00046-W) issued by the SFWMD. The most pertinent well and wellfield monitoring requirements are specified in Limiting Conditions 17, 18, 19, 23 and 30 of the WUP.

Limiting Condition 17 requires that pumpage records in the form of daily withdrawals be recorded for each production well. The re-calibration of water use accounting flow meters is required every five years under Limiting Condition 18. Limiting Condition 19 requires that all "unaccounted for" distribution system losses be determined monthly and submitted to the District on a yearly basis. Limiting Condition 23 requires the permittee to make monthly chloride concentration measurements for each production well. Maintenance of the wellfield including repairing or replacing inoperative well casing, valves, and controls is required under Limiting Condition 26. Monitoring data required under the saline water intrusion monitoring program is required by Limiting Condition 30.

Pumpage records and water quality monitoring of each production well should continue to be conducted on a monthly basis. The City has done an outstanding job in keeping wellfield operating records for over 25 years. The pumping and monitoring data should be reviewed on a yearly basis and evaluated for trend analysis using statistical methods. This will allow operational changes to be initiated if any potentially harmful trends, such as saline water intrusion or upconing, are indicated by the evaluation.

Careful monthly monitoring of pumping water levels in production wells should be conducted to assess declines in well yield over time. In the event that well yields decrease due to calcium carbonate precipitation or bacteria encrustation, acidification and redevelopment of the affected well may be required. Well rehabilitation work should be initiated when the specific capacity of the well declines by 25% or more.

5.4 Recommendations for Wells #230 and #232

The water quality in production Wells #230 and #232 was poorer than production wells previously drilled in Cape Coral. The construction details are provided in Table 1-1 and the complete water quality analyses performed by Sander Laboratories are provided in Appendix E.

<u>Production Well #230</u>

Geophysical logs, the video borehole log and water quality data collected upon completion of well drilling indicated that unusual conditions were present in the well that had not been encountered previously in Cape Coral at this depth. Water quality results were confirmed by RO Plant staff and Sanders Laboratory concurrently, with well chloride concentrations ranging from 6,250 to 7,120 mg/l. The well was back plugged on May 6 through 8, 2006 to 566 feet. The well was back plugged to prevent potential inter-aquifer flow from the zone below 600 feet into shallower portions of the Lower Hawthorn aquifer. The well was subsequently plugged and abandoned on August 23, 2006.

Alternate locations were evaluated for a replacement to Well #230. Because of the unusual subsurface conditions encountered at that site, alternate locations within 500 feet of the subject well were not considered. The other limitations in locating a replacement well include maintaining the approximate 1,000 feet inter-well spacing, proximity to raw water pipeline, and pipeline hydraulic capacity. Three locations considered were 1) Trafalgar Parkway west of Well #211, 2) Chiquita Boulevard north of Well #225, and 3) Gleason Parkway between Wells #218 and #219.

The Gleason Parkway well replacement location meets all of the above criteria and is therefore the best option. Two properties were identified that fall within the proper inter-well spacing and the hydraulic impacts of adding Well #230 to the Gleason Parkway raw water pipeline will be minimal.

The potential drawbacks to using this location include property cost/availability and wellfield interference drawdown. The latter was evaluated by using an analytical groundwater model to determine the additional drawdown that could result by adding an 8^{th} well along the Gleason Parkway alignment. This evaluation represents a worse-case scenario because all wells in the alignment would not likely be pumping at the same time. Model results indicate that drawdown at the Well #230 replacement location while pumping all wells in the Gleason alignment at 500 gpm per well would be approximately 10 feet. The increased drawdown at the nearest wells (#218 and #219) resulting from pumping the Well #230 replacement at 500 gpm would be approximately 4 feet.

<u>Production Well #232</u>

Well #232 was initially constructed to a total depth of 708 feet bls and cased to 470 feet bls. Dissolved chlorides in the well ranged from 2,600 to 3,190 mg/L. The average dissolved chloride concentration in the Lower Hawthorn Aquifer for the City of Cape Coral ranges from 500 to 700 mg/L. Geophysical logs (dual induction and resistivity) identified higher chloride concentrations occurred in the bottom 68 feet (640 to 708 feet bls) of the borehole. In this lower interval, the borehole compensated sonic log identified highly fractured rock. These fractures, along with the higher chloride concentrations suggest the presence of vertical fractures tapping a deeper source of poor water quality in the Floridan Aquifer System.

It was initially recommended to back plug Well #232 to approximately 620 feet bls using ASTM Type II neat cement. In December 2006, a total of 57 ft^3 neat cement was pumped via the tremie method into the bottom of the borehole in two stages (Stage 1 = 32 ft^3, Stage 2 = 25ft^3). The neat cement was hard tagged at 644 feet bls. It was recommended by MWH to stop back plugging operations at this stage and conduct a specific capacity test. During the specific capacity test, field water quality parameters (temperature, pH, specific conductance, and chlorides) were measured to see if water quality had improved. The pump test results indicated that the yield of Well #232 dropped significantly and water quality had not improved. Originally, the specific capacity of Well #232 ranged from 33.7 to 25.2 gpm/ft. After back plugging operations, specific capacity ranged from 2.6 to 2.0 gpm/ft.

On January 9, 2007, a meeting was held by MWH Americas/Constructors and DDC to discuss possible remedies to Well #232. A decision was made to verify the hard tag, back plug further if necessary and acidize the well to increase productivity. The success of the well remedial operations will be contingent upon adequate flow with acceptable water quality.

MWH staff reviewed existing information (geophysics and water quality) for Well #232. The information showed evidence of fractures from 644 to 641 feet bls. These fractures may be leaving the production zone open to higher chloride concentrations from below. Stage 3 back plugging was conducted on February 21, 2007 to 634 feet bls with 7 ft^3 of neat cement. After back plugging was completed, Well #232 was acidized with 2,500 gallons of 15% hydrochloric acid on April 7, 2007. Following acidization, the well was shut in for approximately 72 hours to allow the acid to react with the carbonate formation. On April 11, 2007, a submersible pump was installed and the well was developed for approximately 50 hours until water quality stabilized. A step test was conducted on April 18, 2007; the specific capacity ranged from 24 to 20 gpm/ft. The specific capacity results improved dramatically from Stage 2 back plugging (2.6 to 2.0 gpm/ft) but did not reach original specific capacity results (33.7 to 25.2 gpm/ft). Back plugging the fractured rock may have decreased the yield of the well. Water quality in Well #232 did not improve as much as anticipated. Dissolved chlorides analyzed during the Step Test in Well #232 ranged from 2,640 to 2,740 mg/L which represents a slight improvement from the original analysis (2,600 to 2,900 mg/L). Higher chloride concentrations may be entering the production interval (470 to 634 feet bls) through sources not readily apparent from available information. Because of the high chloride concentrations still being produced from the well, it is recommended that the well be maintained for back-up use during periods of peak demand.

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