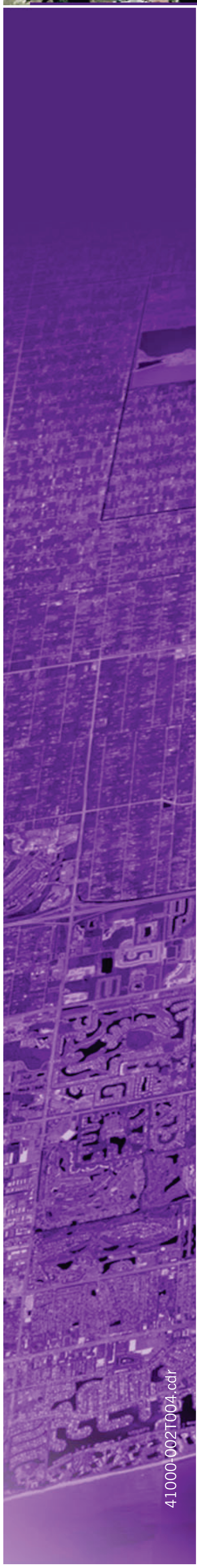
City of Naples Well Completion Report for Aquifer Storage and Recovery Well No. 3

August 2014



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August 29, 2014

Robert Middleton
Utilities Director
CITY OF NAPLES
380 Riverside Circle
Naples, Florida 34102

City of Naples
ASR Test Well No. 3
Well Completion Report

Dear Mr. Middleton:

Enclosed please find a copy of the Well Completion Report summarizing the construction and testing activities of Aquifer Storage and Recovery Well No. 3 and Monitor Well No. 3. We sincerely appreciate the opportunity to assist the City of Naples with development of their aquifer storage and recovery program.

As always, please feel free to call should you have any questions.

Very truly yours,
HAZEN AND SAWYER, P.C.

Albert Muniz, P.E. / Project Director
Vice President

c: David Graff / City of Naples
Ben Copeland / City of Naples
Justin Frederiksen / City of Naples
Robert Casey / City of Naples
H&S – 41000-007.4.7
Jim Wheatley / H&S – WTA
Alex Dunko / H&S
John Koroshec / H&S

Acknowledgements

On behalf of Hazen and Sawyer, we would like to sincerely thank all of the individuals who assisted in making this project a success. We would especially like to thank the following:

City of Naples

Mr. William Moss / City Manager

Mr. Robert Middleton / Utilities Director

Mr. Justin Frederiksen / Deputy Utilities Director

Mr. David Graff / Project Manager

Mr. Ben Copeland / Budget and CIP Manager

Mr. Robert Casey / Water Reclamation Facility Superintendent

Mr. Barry Stein / Water Reclamation Facility

Ms. Alicia Acevedo

Ms. Carol Reinhard

Ms. Zayli Perez

Florida Department of Environmental Protection

Mr. David Rhodes

Mr. Will Evans

Mr. Joseph Haberfeld

South Florida Water Management District / Big Cypress Basin

Mr. Max Guerra

Youngquist Brothers Incorporated

Mr. Cameron Webster and all of his staff

Mr. William Musselwhite

Mr. Harvey Youngquist, Jr.

Table of Contents

Tables

Figures

Appendices

Executive Summary

EXECUTIVE SUMMARY

The City of Naples has been developing alternative water supplies in an effort to reduce potable water consumption due to irrigation demands which represent the largest demand on the City's potable water system. To reduce the stress on the potable water system and reduce the City's per capita consumption, the City has moved forward with development of several alternative water supplies including use of the Aquifer Storage and Recovery (ASR) concept and use of excess surface water from the Golden Gate Canal. These initiatives have been implemented in conjunction with regulators to ensure permit compliance. Key regulators involved during development of the City's alternative water supplies include the Big Cypress Basin, the South Florida Water Management District (District), and the Florida Department of Environmental Protection (FDEP).

This component of the alternative water supply program addresses the ongoing development of the ASR system. The ASR system, which will use both reclaimed water and canal surface water, is a critical component of the City's Integrated Water Supply Plan as it assists in decreasing potable water use and therefore extending the useful life of the City raw water supplies and water treatment facilities. One ASR well, identified as ASR-1, was constructed as part of Phase 1 of the program. The second phase included construction and testing of a second ASR well (i.e., ASR-2) and two monitor wells. Monitor Well No. 1 (MW-1) is a dedicated storage zone monitor well as requested by FDEP, while Monitor Well No. 2 (MW-2) is designed to monitor the first permeable zone near the 10,000 mg/L total dissolved solids interface. This well completion report represents completion of Phase 3, and presents a summary of the construction and testing of the third ASR well (i.e., ASR-3) and third monitor well (i.e., MW-3).

The City's alternative water supply program is unique in that it utilizes both reclaimed water and excess surface water to meet irrigation demands. A WUP to withdraw excess surface water from the Golden Gate Canal was granted and allows the City to withdraw 10 million gallons per day (mgd) of excess surface water from the Golden Gate Canal. The strategy of using excess surface water from the Golden Gate Canal has many benefits as this fresh water resource is presently discharged to tide and lost without beneficial use. Hence, the project to withdraw water from the Golden Gate Canal optimizes use of the fresh water resource as additional replacement water for irrigation. In addition, discharge to tide and impacts to sensitive ecological systems is being reduced as a result of this program.

Conclusions from the construction and testing of the third ASR Well and third monitor well are as follows:

- The fresh raw water sources located in the Tamiami Formation extend to a depth of approximately 175 feet below land surface at the project site. The City of Naples uses the Tamiami Formation for water supply.
- The first brackish aquifer, known as the Hawthorn Zone 1, is present from a depth of approximately 320 to 420 feet below land surface. This aquifer contains brackish water and is not used by the City of Naples for raw water supply.
- The deepest production horizon, known as the Lower Hawthorn, exists between depths of approximately 670 to 740 feet below land surface. This zone is highly brackish and is not used by the City for raw water supply purposes.
- The 10,000 mg/L total dissolved solids interface was estimated to occur between the depths of approximately 760 to 780 feet below land surface based on information collected via geophysical logging and straddle packer tests. The 10,000 mg/L total dissolved solids interface is the base of any potential underground source of drinking water (USDW). This depth is important as FDEP has separate criteria for regulating ASR systems completed below the USDW.
- A potential storage zone was identified at ASR-3 to exist between depths of 1,150 and 1,350 feet below land surface. This zone has been targeted as a potential storage horizon as it contains water with total dissolved solids greater than 10,000 mg/L, and there appears to be separation between the targeted storage horizon and the USDW
- Adequate confinement appears to be present between the base of the USDW and the top of the potential storage zone based on packer test data.
- The storage zone has adequate hydraulic conductivity to allow injection and recovery at rates from 700 gpm (~1 mgd) to possibly 1,400 gpm (~2 mgd) based on results of the step drawdown test. The specific capacity at ASR-3 was estimated to range between 90.1 to 87.7 gpm/ft at pumping rates of 500 and 1,400 gpm, respectively.
- The 24-inch diameter final casing at ASR-3 successfully passed a casing pressure test and demonstrated mechanical integrity for an ASR type well.
- The construction and testing was completed under the contract amount and slightly over schedule.

The following recommendations are suggested based on the information collected and evaluated to date:

- Continue development of the storage zone using reclaimed water as source water and excess surface water from the Golden Gate Canal.
- Continue with implementation of the City's integrated water resources plan in support of the City's overall strategy to develop alternative water supplies.
- Continue with the funding partnership with the South Florida Water Management District / Big Cypress Basin.
- As needed, expand the ASR wellfield to optimize use of reclaimed and surface water to meet future irrigation demands.

Chapter 1.0
Introduction

1.1 Scope of Work

The City of Naples has been developing alternative water supplies in an effort to reduce potable water consumption due to irrigation demands which represent the largest demand on the City's potable water system. To reduce the stress on the potable water system and reduce the City's per capita consumption, the City has moved forward with development of several alternative water supplies including use of the Aquifer Storage and Recovery (ASR) concept and use of excess surface water from the Golden Gate Canal. These initiatives have been implemented in conjunction with regulators to ensure permit compliance. Key regulators involved during development of the City's alternative water supplies include the Big Cypress Basin, the South Florida Water Management District (District), and the Florida Department of Environmental Protection (FDEP).

This component of the alternative water supply program addresses the ongoing development of the ASR system. The ASR system, which will use both reclaimed water and canal surface water, is a critical component of the City's Integrated Water Supply Plan. Development of the alternative water supplies is critical as it assists in decreasing potable water use and therefore extending the useful life of the City raw water supplies and water treatment facilities. One ASR well, identified as ASR-1, was constructed as part of Phase 1 of the program. The second phase included construction and testing of a second ASR well (i.e., ASR-2) and two monitor wells. Monitor Well No. 1 (MW-1) is a dedicated storage zone monitor well as requested by FDEP, while Monitor Well No. 2 (MW-2) is designed to monitor the first permeable zone near the 10,000 mg/L total dissolved solids (TDS) interface. This well completion report represents completion of Phase 3, and presents a summary of the construction and testing of the third ASR well (i.e., ASR-3) and third monitor well (i.e., MW-3).

1.2 Background

The District issued Water Use Permit (WUP) No. 11-00017-W on June 21, 2010 (see **Appendix No. 1**). This permit, which expires on June 23, 2030, was an important element of the City's overall Integrated Water Supply Plan as it allows the City to continue use of their existing raw water supplies for 20 years. A key condition of the WUP is the implementation of an alternative water supply program to assist with reduction of potable water consumption which is the purpose of this project.

The City's alternative water supply program is unique in that it utilizes both reclaimed water and excess surface water to meet irrigation demands. A WUP to withdraw excess surface water from the Golden Gate Canal was issued (Permit No. 11-03205-W) on May 9, 2011 (see **Appendix No. 1**). This permit expires on May 9, 2031, and allows the City to withdraw 10 million gallons per day (mgd) of excess surface water from the Golden Gate Canal. The strategy of using excess surface water from the Golden Gate Canal has many benefits as this fresh water resource is presently discharged to tide and lost without beneficial use. Hence, the project to withdraw water from the Golden Gate Canal optimizes use of the fresh water resource as additional replacement water for irrigation. In addition, discharge to tide and impacts to sensitive ecological systems will be reduced as a result of this program.

Implementation of the City's water supply plan to use reclaimed water and excess surface water as replacement water to meet irrigation demands is well underway. A summary of accomplishments of the various programs initiated by the City are presented below:

- Integrated Water Supply Plan – Approved by Resolution on October 2, 2008
- Expansion of reclaimed water distribution system – Ongoing
- Implementation of a reclaimed water / surface water ASR program
    - Construction of exploratory well – Completed (August 2007)
    - Construction of ASR Well No. 1 – Completed (March 2010)
    - WUP for raw water supply – Completed (Permit issued June 21, 2010)
    - Permitting of three additional Class V ASR wells – Completed (August 23, 2010)
    - Construction of ASR Well No. 2, Monitor Well No. 1, and Monitor Well No. 2 – Completed (January 2011)
    - WUP for Golden Gate Canal – Completed (Permit issued May 9, 2011)
    - Approval from FDEP to commence development of the storage zone – Completed (January 28, 2011)
    - Construction of reclaimed water surface facilities – Completed (October 2012)
    - Construction of ASR Well No. 3 and Monitor Well No. 3 – Completed (July 2014)
- Investigation of stormwater ASR – Initiated

Construction and testing of the first three ASR wells and three monitor wells completes the first three phases of the City's integrated water resources plan to implement strategies for prudent use of resources and meet future demands.

It should be noted that the City continues to partner with the Big Cypress Basin / District as part of the District's grant program associated with development of alternative water supplies. To date, the City has met all milestones and the program continues to move forward successfully.

1.3 Purpose

The purpose of this report is to summarize the construction and testing activities of the third ASR well and the third monitor well located at the City's water reclamation facility. Drilling sequence, testing results, geology encountered, and storage zone information (i.e., water quality and estimated hydraulic characteristics) is summarized. Copies of permits and applicable regulatory correspondence are included in **Appendix No. 1**. Information presented in this report will be used in support of future permits and as a record of construction and testing activities.

Chapter 2.0
Well Construction and Testing

2.1 Well Construction

Construction and testing of ASR-3 and MW-3 was performed in accordance with the Contract Documents titled “City of Naples Aquifer Storage and Recovery Well No. 3 (ASR-3) and Monitor Well No. 3 (MW-3)” City of Naples Bid # 058-13. The bid was approved by the City Council on November 20, 2013 with a contract start date of December 16, 2013.

Construction of ASR-3 and MW-3 and associated pad monitor wells commenced with the issuance of a Notice-to-Proceed (NTP) on December 10, 2013. Per the NTP letter, the successful contractor, Youngquist Brothers Incorporated (YBI), was notified to commence work as of December 16, 2013. In addition, the contractor was instructed to reach substantial completion within 120 calendar days (April 15, 2014) and final completion within 150 calendar days (May 15, 2014). Construction of ASR-3 and MW-3 proceeded expeditiously. Additional testing was added to the contract to evaluate well performance. This testing extended the overall contract by several weeks.

Figure 1 shows the general location of the project site in relation to southwest Florida while **Figure 2** shows the regional location of the project site. A layout of the water reclamation facility is presented in **Figure 3**. **Figure 3** also shows the distances between wells. An exploratory well was constructed first and was subsequently converted into Monitor Well No. 1 (MW-1), which is a dedicated storage zone monitor well. Construction details of the exploratory well are presented in **Figure 4**. Construction details of ASR-1 are shown in **Figure 5** for information purposes. Phase 2 consisted of construction and testing of ASR-2, MW-1 (i.e., conversion of the exploratory well to a monitor well), and MW-2. An as-built diagram of MW-1 is presented in **Figure 6**. Upon completion of MW-1, the contractor remobilized and constructed MW-2 to monitor the first permeable zone at or near the lowermost potential underground source of drinking water (USDW). The 10,000 mg/L TDS interface is important as this marks the location of the lowermost potential USDW. The base of the USDW is defined as water having a TDS concentration of less than or equal to 10,000 mg/L. **Figure 7** shows the construction details for MW-2. The second ASR well (i.e., ASR-2) was also constructed under the abovementioned contract. Construction details of ASR-2 are shown in **Figure 8**.

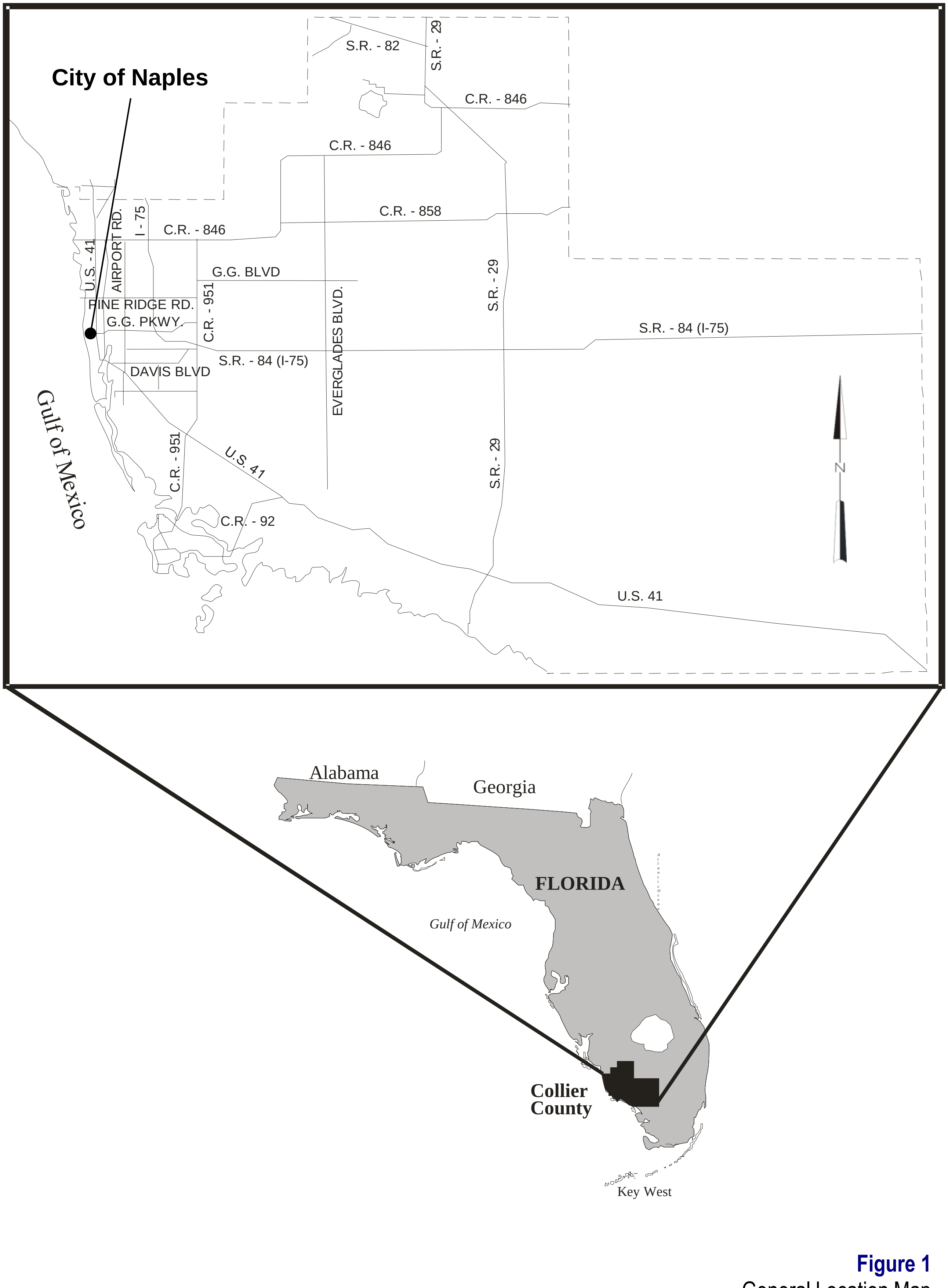

Figure 1
General Location Map

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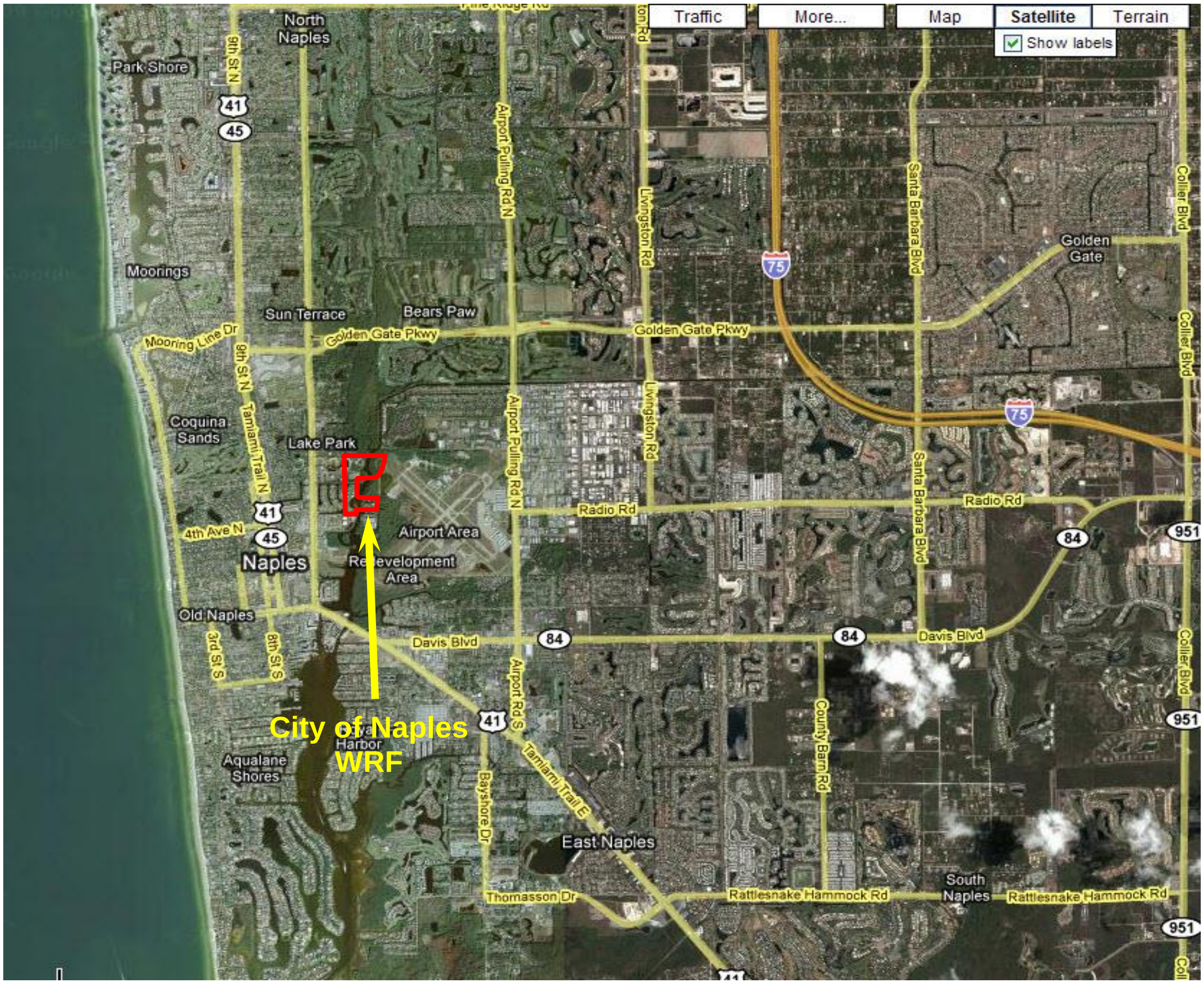

Figure 2
Site Location Map

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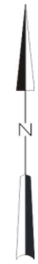

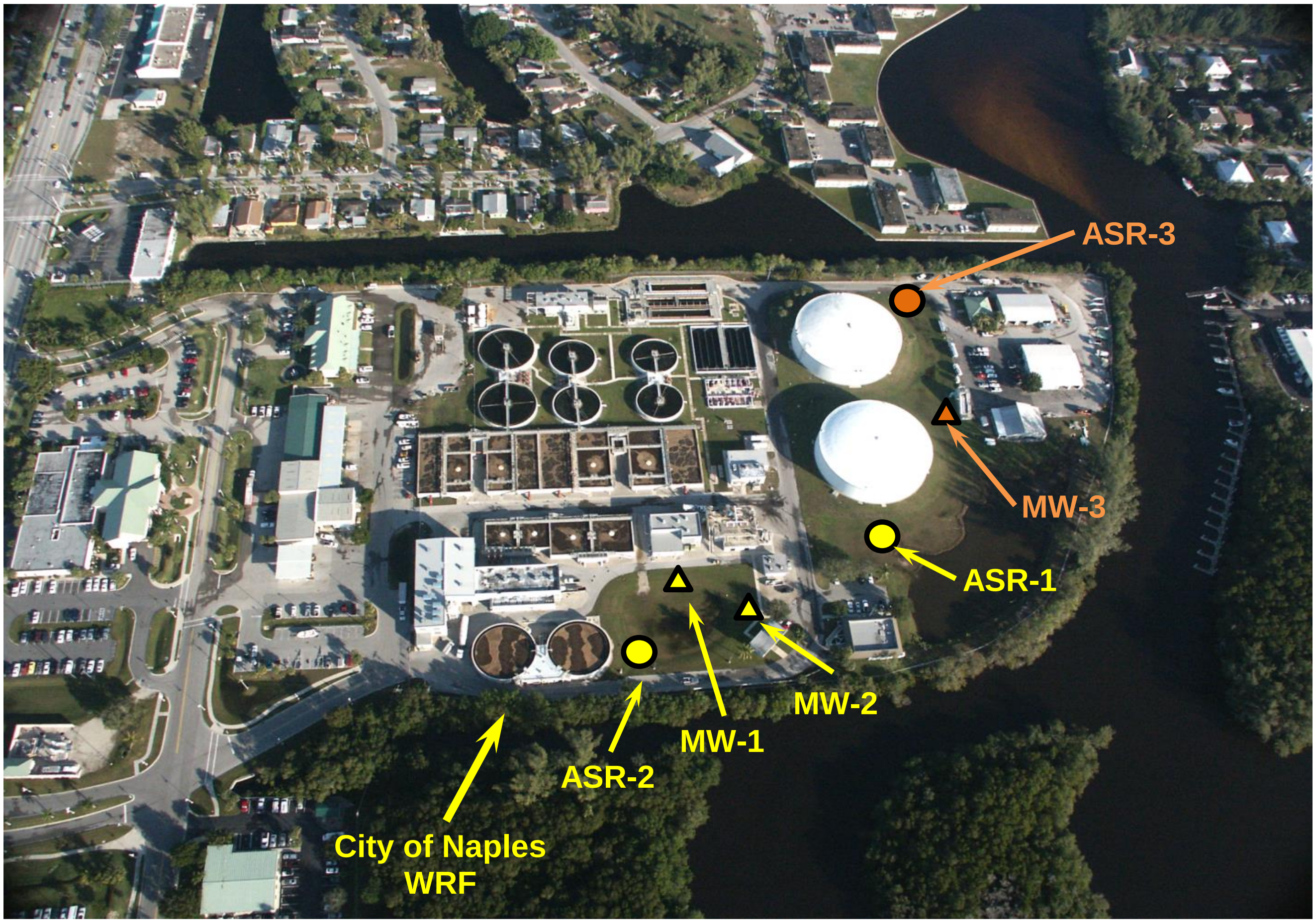

Distances between wells (in feet)

	ASR-1	ASR-2	ASR-3	MW-1	MW-2	MW-3
ASR-1	---	339.2	427.2	256.1	198.8	302.2
ASR-2	339.2	---	723.9	116.5	140.4	622.3
ASR-3	427.2	723.9	---	611.5	596.8	141.0
MW-1	256.1	116.5	611.5	---	86.8	516.8
MW-2	198.8	140.4	596.8	86.8	---	487.3
MW-3	302.2	622.3	141.0	516.8	487.3	---

Figure 3
Site Layout

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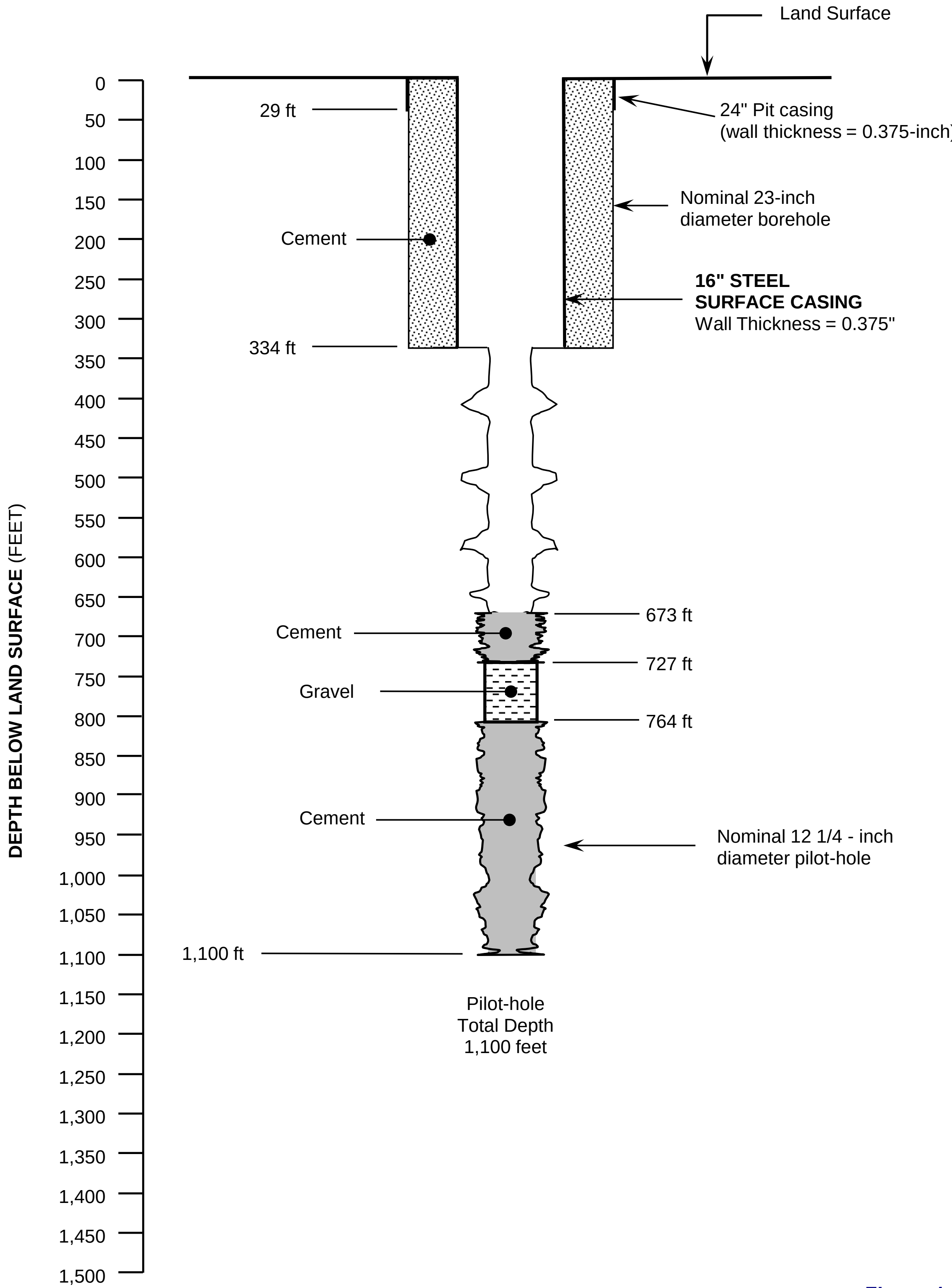

Figure 4
Exploratory Test Well
Construction Details

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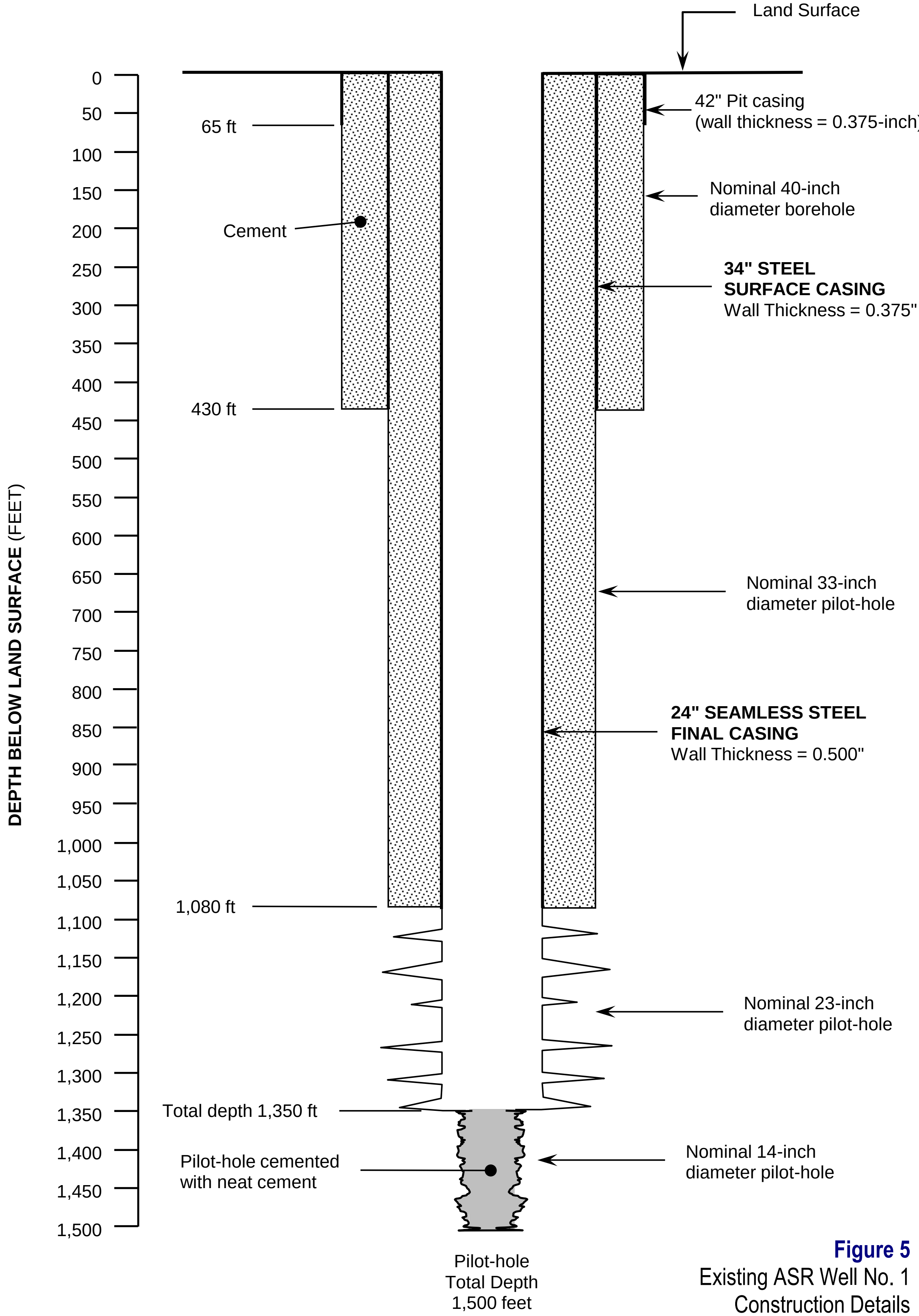

Figure 5
Existing ASR Well No. 1
Construction Details

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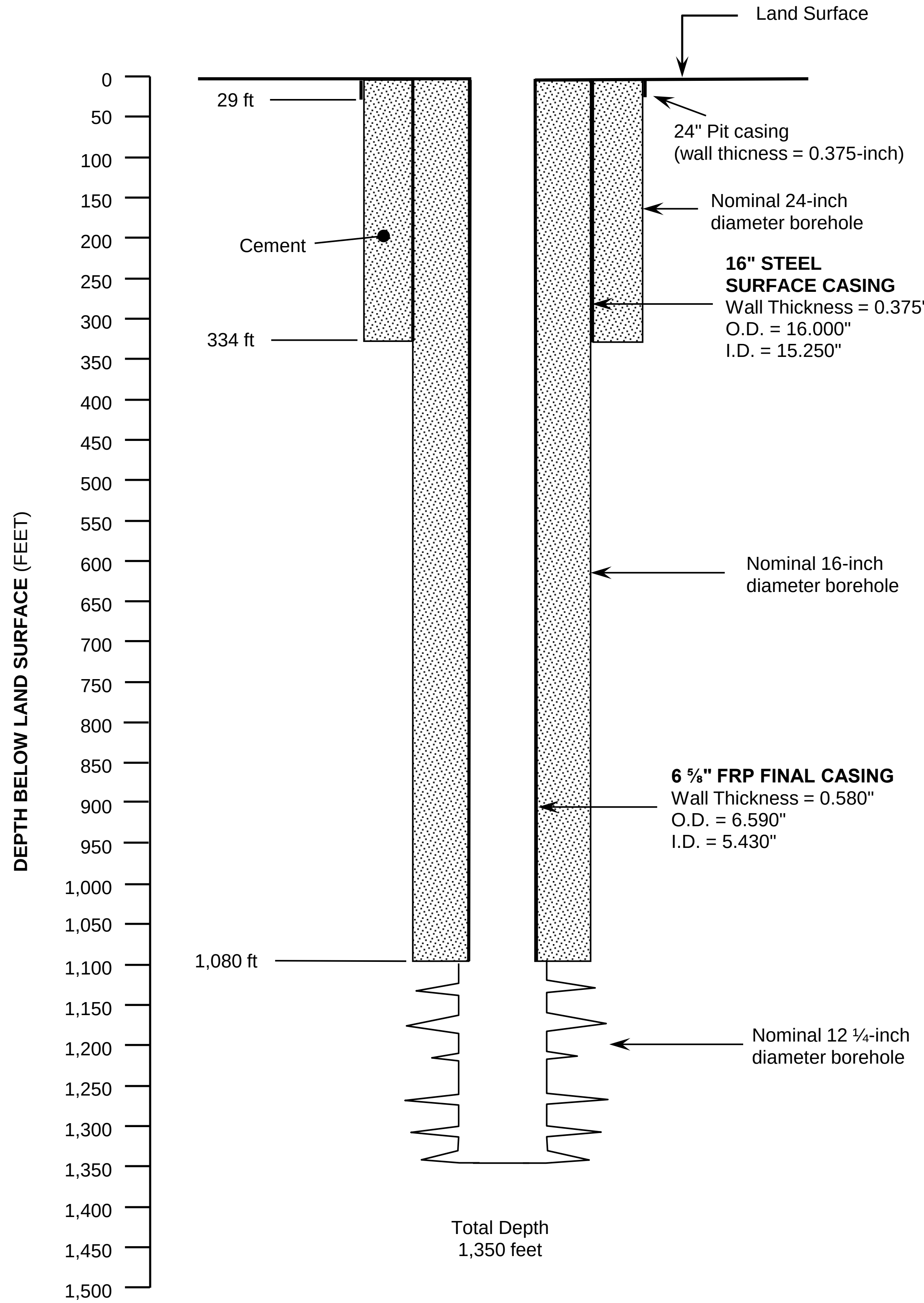

Figure 6
Existing Monitor Well No. 1
Construction Details

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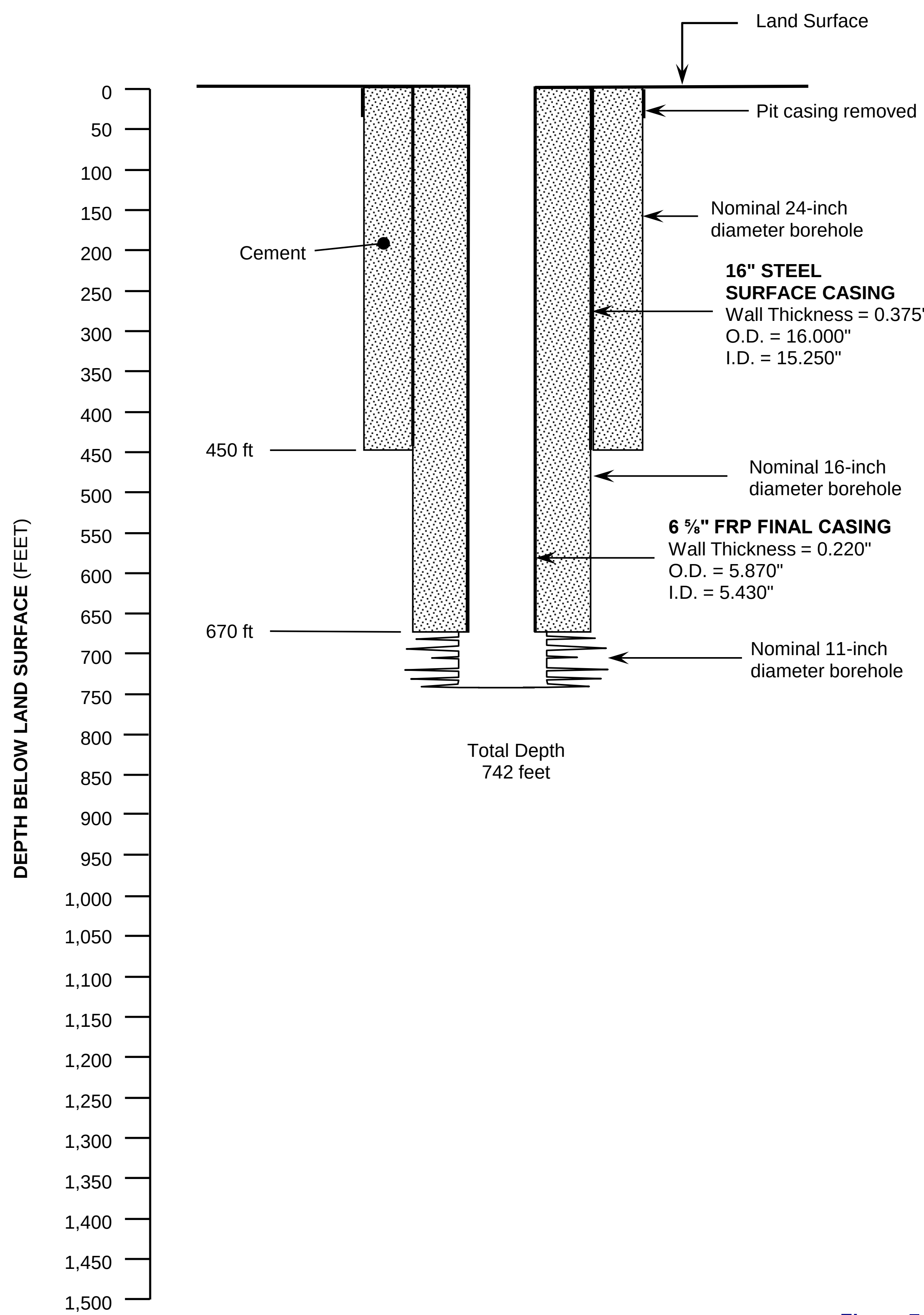

Figure 7
Existing Monitor Well No. 2
Construction Details

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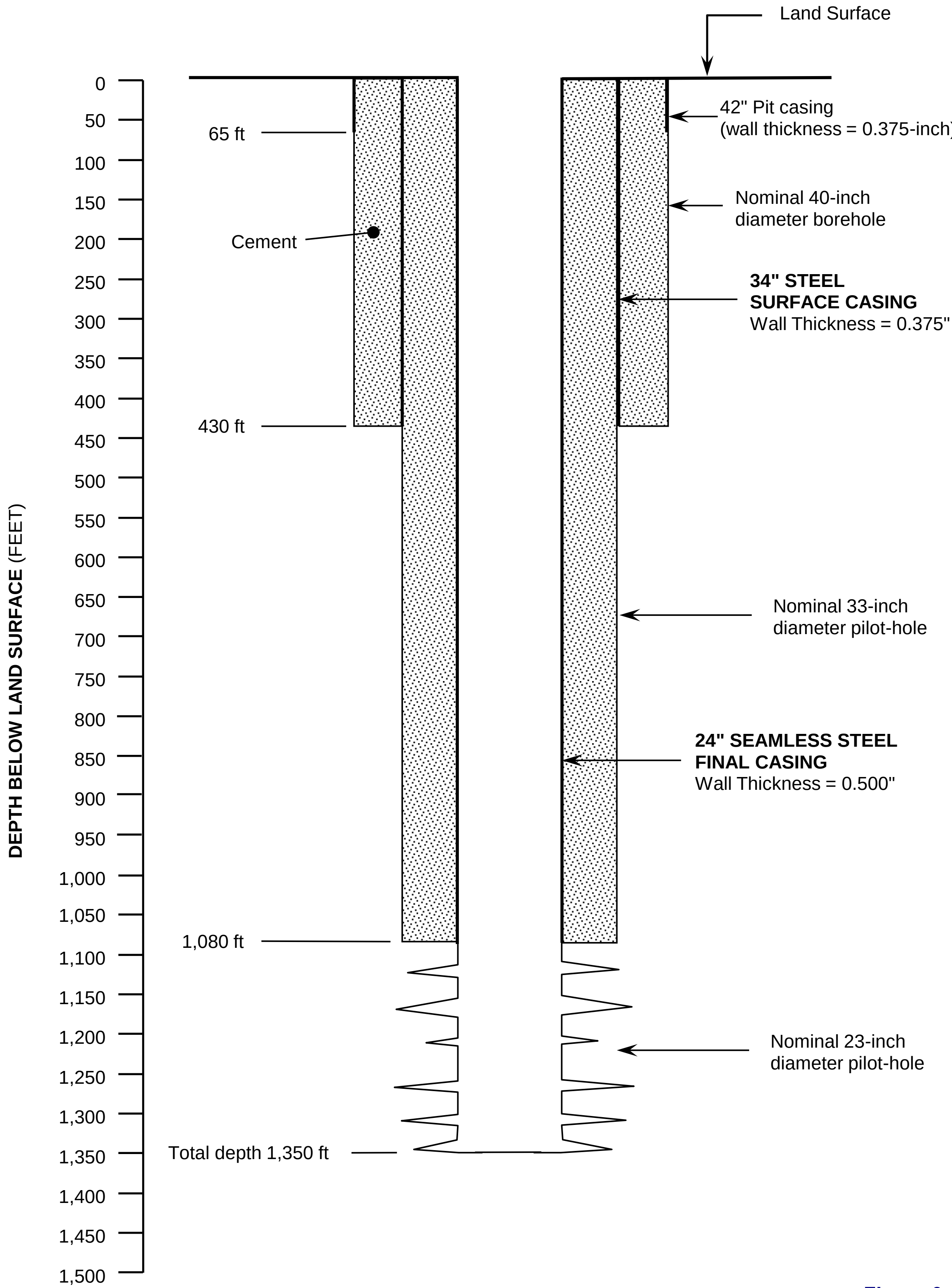

Figure 8
Existing ASR Well No. 2
Construction Details

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Phase 3 of the City's ASR program consisted of construction and testing of ASR-3 and MW-3. Both wells were completed in general accordance with the contract documents. Construction details of ASR-3 and MW-3 are presented in **Figures 9 and 10**, respectively. **Table 1** presents a summary of the key dates during the construction and testing of ASR-3 and MW-3.

Table 1 – Summary of Key Dates

Identification	Description	Date
Project Start	Notice-to-Proceed	December 16, 2013
ASR Test Well No. 3 (ASR-3)	Set 34" casing to 430 feet	February 5, 2014
	Set 24" casing to 1,150 feet	April 8, 2014
	Conduct step drawdown test	May 16, 2014
	Conduct aquifer withdrawal test	May 19, 2014
	Collect background water samples	May 19, 2014
	Conduct casing pressure test	April 14, 2014
Monitor Well No. 3 (MW-3)	Set 16" casing to 430 feet	April 18, 2014
	Set 6 ⅝" FRP casing to 670 feet	April 30, 2014
	Collect background water samples	May 16, 2014

The drilling of ASR-3 generally proceeded as identified in the project specifications. The project specifications identified an outline of a drilling plan with the intention of making modifications to the plan as site specific conditions warranted. The plan included setting casing at selected depths to maintain the borehole integrity during drilling and to facilitate the proposed testing.

To consistently record down-hole depth, well measurements were recorded in terms of depth below land surface and / or elevations. Actual depths of casings are identified in the record drawings. Construction and testing of the wells generally proceeded as follows:

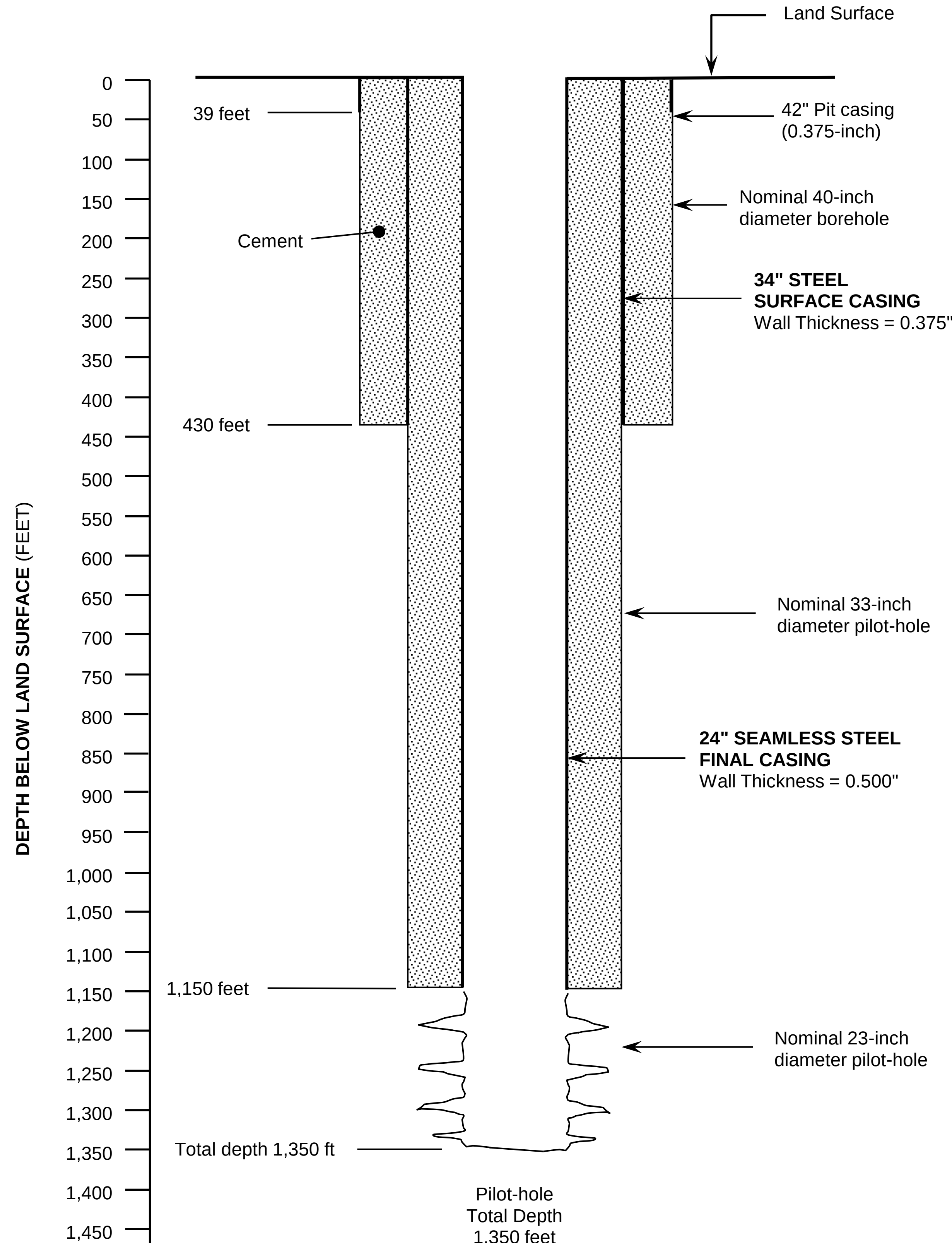

Figure 9
ASR Well No. 3
Construction Details

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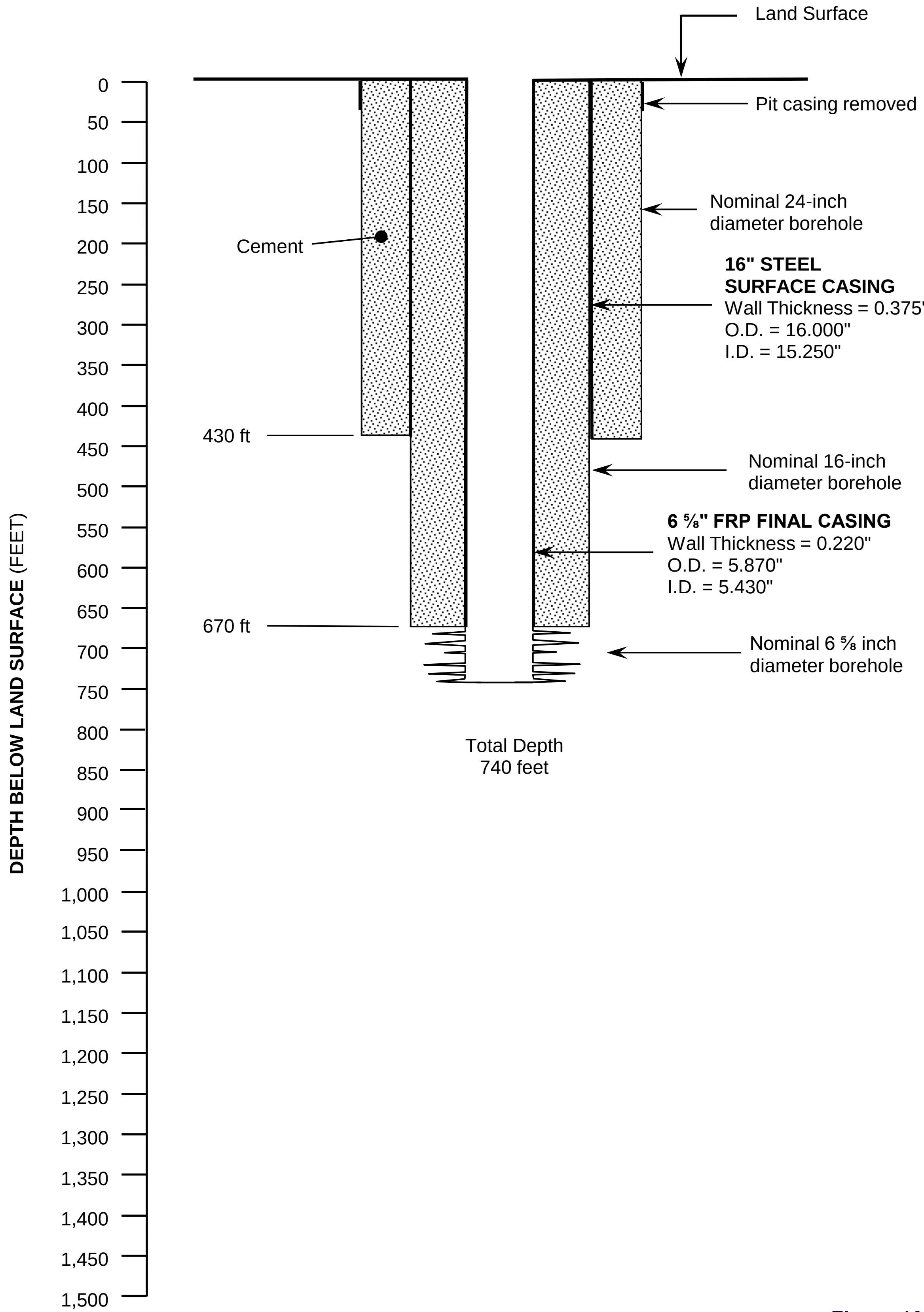

Figure 10
Monitor Well No. 3
Construction Details

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Aquifer Storage and Recovery Well No. 3 (ASR-3)

- Mobilized equipment and performed necessary site work and installed pad monitor wells and pit casing
- Drilled a nominal 12-¼ inch diameter pilot-hole to approximately 450 feet below land surface using the mud rotary drilling methods and performed geophysical logging
- Reamed borehole to nominal 42-inch diameter to a depth of 430 feet below land surface and logged the reamed hole
- Set and cemented 430 feet of 34-inch diameter (0.375-inch wall thickness) steel surface casing
- Drilled 12-¼ inch diameter pilot-hole to a depth of 1,350 feet below land surface using reverse-air drilling methods and performed geophysical logging
- Conducted straddle packer tests
- Reamed pilot-hole to nominal 34-inch diameter to the approved depth of 1,154 feet below land surface
- Set and cemented 24-inch diameter (0.500 inch wall thickness) seamless steel final casing to a depth of 1,150 feet below land surface
- Conducted casing pressure test
- Drilled nominal 24-inch diameter pilot-hole to a depth of 1,350 feet below land surface using reverse-air drilling method
- Performed geophysical logging
- Cemented pilot-hole to approximately 1,350 feet below land surface
- Drilled a nominal 24-inch diameter borehole to approximately 1,350 feet below land surface using the reverse-air method
- Developed well
- Performed step drawdown test
- Performed geophysical logging
- Performed pump test
- Collected background water samples
- Disinfected well and installed wellhead
- Demobilized and restored site

Monitor Well No. 3 (MW-3)

- Mobilized equipment and performed necessary site work and installed pit casing
- Drilled nominal 16-inch diameter hole to a depth of approximately 435 feet and performed geophysical logging
- Set and cemented 16-inch diameter steel casing to a depth of 430 feet
- Drilled nominal 16-inch diameter hole to a depth of 673 feet and performed geophysical logging
- Set and cemented 6-⅝ inch FRP casing to a depth of 670 feet (FRP casing has an outside diameter of 5.870 inches, an inside diameter of 5.430 inches, and a wall thickness of 0.220 inches)
- Drilled nominal 6-inch diameter borehole to a depth of 740 feet and developed monitor zone
- Performed geophysical logging
- Collected background water sample and analyzed for primary and secondary drinking water parameters including priority pollutants
- Installed wellhead
- Demobilized and restored site

Information collected during the construction and testing of MW-3 and ASR-3 was forwarded to FDEP and the City with progress reports that were submitted on a weekly basis during the construction phase of the project. **Appendix No. 2** contains copies of District well completion reports prepared by YBI.

2.2 Data Collection

Data was collected during the construction and testing of ASR-3 and MW-3 using various methods and procedures as described in this Section. Geophysical logging was performed by YBI Geophysical Logging Division. Water analyses was performed by Sanders Laboratories, which is a certified laboratory.

Daily progress and activities were monitored and recorded during construction and testing. The Engineer prepared daily progress reports during well construction along with weekly summaries. The Contractor prepared independent daily reports. Conditions encountered during drilling were observed and noted. Activities related to the installation of well casings, cementing or other materials, as well as their quantities, were recorded. Copies of the daily and weekly progress reports were transmitted on a weekly basis to the Fort Myers and Tallahassee offices of FDEP.

2.3 Geologic Samples

Samples of drilled cuttings were collected and analyzed from the drilling of ASR-3 and MW-3. Circulation time (the time required for drilled cuttings to reach the surface) was calculated on a regular basis to ensure that accurate sample depths were recorded. After initial examination, the Engineer's on-site personnel described the samples. A geologic description of each sample was entered into a log. The cuttings were classified in accordance with the scheme of Dunham (1962). Descriptions of each sample are included in **Appendix No. 3**. Two sets of drill cuttings were bagged in 5-foot intervals. After the wells were completed, the Contractor sent one set of these samples to the Florida Bureau of Geology in Tallahassee, Florida.

2.4 Casing

Casing heat numbers stamped on the casing were verified in the field with the mill certificates prior to running casings in the hole. Copies of the casing mill certificates are presented in **Appendix No. 4**. Cementing plans for each casing string were proposed by the Contractor and reviewed by the Engineer prior to cementing. After accepting the proposed plan, casing was set and cemented. A summary of cementing was included in the weekly progress reports. The casing schedule for construction of the abovementioned wells is presented in **Table 2**.

Table 2 – Casing Schedule

Casing Run	Diameter (inches)		Depth (feet)	Material	Wall Thickness (inches)
	Inside	*Outside*			
ASR Well No. 3					
Pit Casing	41.250	42.000	39	Steel	0.375
Surface Casing	33.250	34.000	430	Steel	0.375
Final Casing	23.000	24.000	1,150	Steel	0.500
Total Well Depth	---	---	1,350	---	---
Monitor Well No. 3					
Pit Casing	23.250	24.000	38	Steel	0.375
Surface Casing	15.250	16.000	430	Steel	0.375
Final Casing	5.430	6.590	670	FRP	0.580
Total Well Depth	---	---	740	---	---

2.5 Geophysical Logs

Geophysical logging was used to obtain information of underground conditions at various stages during the construction and testing of ASR-3 and MW-3. In general, geophysical logging was conducted at the completion of each stage of borehole drilling. These logs assisted in identifying the geologic formations encountered, quantifying water quality with respect to depth, identifying confining sequences and production horizons. The geophysical logs performed, including a brief description of the information provided by the logs, are as follows:

- X-Y Caliper – Identification of borehole diameter and geometry
- Gamma Ray – Measurement of the natural gamma ray radiation of the formation, used as a tie-in between logs
- Dual Induction Log (resistivity log) – Identifies differentiation between limestone and dolomite beds, and, along with the gamma ray log, is useful in the correlation of lithologic units
- Borehole Compensated Sonic Variable Density Log (VDL) – Identification of the confining sequences, as well as identification of zones that could cause problems during cementing
- Flow Meter Surveys – Determination of where fluid may be entering or exiting the borehole
- Temperature – Provides a profile of static and dynamic temperature of the borehole, may be useful in determining fluid movement
- Fluid Resistivity – Provides information related to the salinity
- Televisions Survey – Determination of where structural features (bedding planes, fractures, vugs and voids) are located

Geophysical logs were transmitted to FDEP members on a weekly basis during construction once the logs were available. Copies of the logs can be found in CD format in **Appendix No. 5**. A summary of the geophysical logs is presented in **Table 3**. Information obtained from the geophysical logs was reviewed along with geologic samples to prepare a hydrogeologic profile of the formations encountered. **Figure 11** presents a generalized hydrogeologic section from data collected.

Table 3 – Geophysical Logging Schedule

Construction Phase	Interval	Date	Geophysical Logs
Aquifer Storage and Recovery Well No. 3			
12-1/4 inch pilot-hole	0 to ~ 450 feet	22-Jan-14	X-Y caliper, Gamma ray, Dual induction LL3, and Spontaneous potential
42-inch reamed hole	0 to ~ 433 feet	04-Feb-14	X-Y caliper and Gamma ray
12-1/4 inch pilot-hole	0 to ~ 1,350 feet	27-Feb-14	X-Y caliper, Gamma ray, Bore-hole compensated sonic w/ variable density, Dual induction LL3, Spontaneous potential, Temperature, Log derived water quality, and Television survey
12-1/4 inch pilot-hole	0 to ~ 1,350 feet	04-Mar-14	Television survey
34-inch reamed hole	0 to ~ 1,150 feet	04-Apr-14	X-Y caliper and Gamma ray
24-inch casing	1,150 feet	13-Apr-14	Temperature logs after each cement stage
24-inch hole	1,150 to 1,350 feet	24-May-14	X-Y caliper and Gamma ray
Final hole	0 to 1,350 feet	29-May-14	Television survey
Monitor Well No. 3			
22-inch reamed hole	0 to ~ 435 feet	18-Apr-14	X-Y caliper and Gamma ray
12-1/4 inch hole	0 to ~ 670 feet	29-Apr-14	X-Y caliper and Gamma ray
5-1/4 inch final hole	0 to ~ 734 feet	03-May-14	X-Y caliper, Gamma ray, Bore-hole compensated sonic w/ variable density, Dual induction LL3, Spontaneous potential, Fluid Conductivity, and Temperature
5-1/4 inch final hole	0 to ~ 734 feet	03-May-14	Television survey

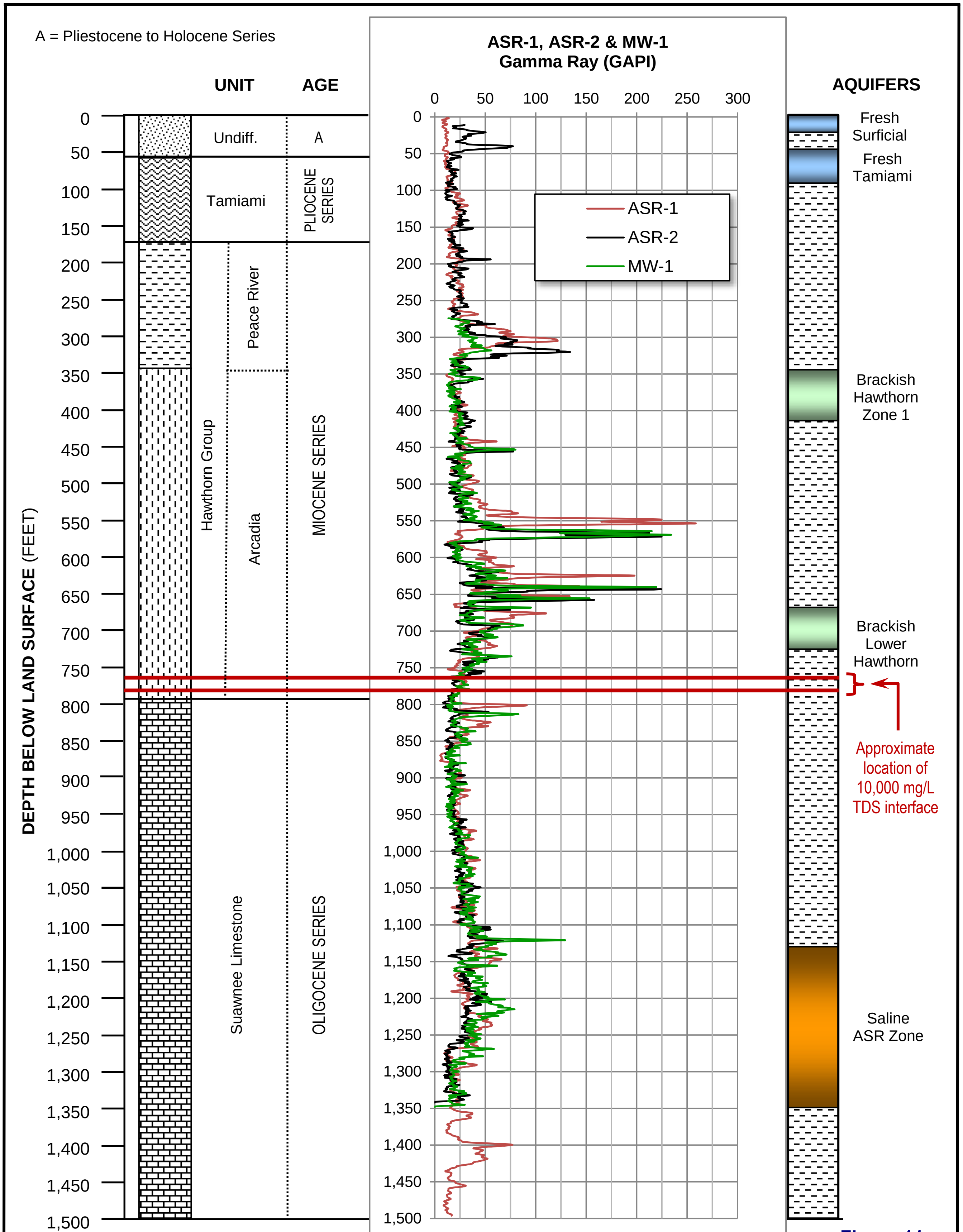

Figure 11

Generalized Hydrogeologic Section from ASR and Monitor Wells

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2.6 Video Logs

Video surveys were made with the camera lens in two positions; down-hole with a radial view and up-hole with a horizontal rotating position. Air development and / or artesian flow were used to displace suspended solids from the well prior to performing the television survey. The open-hole survey allowed for visual inspection of formations encountered in the borehole, as well as to observe potential fractures and water-producing zones. Acceptable picture clarity was obtained in the surveys.

2.7 Coring

Rock cores were not obtained during drilling of ASR-3 as they were previously obtained during various stages of drilling at ASR-2 to collect additional information of the subsurface conditions. Cores collected during drilling of ASR-2 were based on specific intervals estimated from data collected at ASR-1 and MW-1. This information was collected to demonstrate confinement between the base of the USDW and the targeted storage horizon. **Table 4** presents a summary of results from the previously collected core testing.

Table 4 – Estimated Hydraulic Conductivity from Cores

Interval (depth in feet)			**Well**	**Hydraulic Conductivity**	
				Vertical Conductivity (cm / sec)	**Horizontal Conductivity** (cm / sec)
810	to	810.3	ASR-2	1.7 x 10 -5	1.3 x 10 -5
811	to	811.3	ASR-2	6.0 x 10 -9	9.2 x 10 -9
813	to	813.3	ASR-2	1.3 x 10 -8	2.1 x 10 -8
815	to	815.3	ASR-2	4.8 x 10 -8	6.7 x 10 -8
965	to	965.3	ASR-2	1.3 x 10 -4	1.9 x 10 -4
981	to	981.3	ASR-2	1.0 x 10 -3	4.1 x 10 -5
985	to	985.3	ASR-2	8.6 x 10 -5	1.2 x 10 -4
989	to	989.3	ASR-2	9.0 x 10 -4	2.5 x 10 -3
991	to	991.3	ASR-2	5.4 x 10 -4	9.9 x 10 -4
994	to	994.3	ASR-2	9.3 x 10 -6	1.7 x 10 -5
996	to	996.3	ASR-2	2.3 x 10 -7	8.3 x 10 -7
1,013	to	1,013.3	ASR-2	1.3 x 10 -4	3.4 x 10 -4
1,015	to	1,015.3	ASR-2	4.6 x 10 -6	1.3 x 10 -3
1,024	to	1,024.3	ASR-2	2.3 x 10 -6	8.2 x 10 -6
1,025	to	1,025.3	ASR-2	1.3 x 10 -6	3.1 x 10 -5
1,068	to	1,068.3	ASR-2	4.3 x 10 -6	6.8 x 10 -5
1,115	to	1,115.3	ASR-2	7.0 x 10 -8	6.4 x 10 -8
1,116	to	1,116.3	ASR-2	6.8 x 10 -8	6.9 x 10 -8

2.8 Packer Tests

Straddle packer tests were performed on the 12-¼ inch diameter pilot-hole of ASR-3. Packer tests were conducted at intervals to support demonstration of confinement, and to identify potential zones of interest.

Packer testing was performed by setting two inflatable packers (plugs) at selected depths and pumping from the interval between the packers. The packers were used to isolate zones to perform drawdown and recovery tests. The straddle packer intervals were selected based on reviewing and interpreting information from geophysical logs, lithology, and other packer tests. A total of three straddle packer tests were performed at ASR-3.

The packers were lowered into the pilot-hole to the selected interval on the 6-⅝ inch (outside) diameter drill pipe, inflated and seated against the formation. A 4-inch diameter submersible pump was lowered into the drill pipe approximately 200 feet to introduce stress on the isolated interval. Prior to starting the tests, each zone was developed free of any drilling fluids by means of air lifting and pumping until the specific conductance stabilized. The isolated zone was then allowed to recover from development before beginning the pumping test. During drawdown and recovery, water level measurements were obtained using a data logger attached to a pressure transducer (In-situ Hermit 3000). The method of analysis used on the data collected and recorded during the packer tests was the Modified Non-Equilibrium Formula derived by Cooper and Jacob (1946). The equation of the Cooper-Jacob method is as follows:

Jacob Modified Equation

$$T = \frac{264Q}{\Delta s'}$$

Where:

T = Coefficient of Transmissivity (gpd/ft)

Q = Pumping Rate (gpm)

$\Delta s'$ = Calculated Drawdown in one log cycle (feet)

Estimated Hydraulic Conductivity

$$K = \frac{T}{b}$$

Where:

K = Hydraulic Conductivity

b = Thickness of interval tested (feet) or 17 feet

The calculated hydraulic conductivity from the packer tests are presented in **Table 5**. The packer data plots are presented in **Appendix No. 6**. Based on the stabilization of the fluid specific conductance prior to starting the packer tests and the drawdown characteristics of the data, the hydraulic conductivity values presented from the packer tests are considered valid.

Table 5 – Estimated Hydraulic Conductivity from Packer Tests

Well	Test Interval	Test Period	Pumping Rate	Specific Capacity	Estimated Hydraulic Conductivty
			(gpm)	(gpm / ft)	(cm / sec)
ASR-1	785 - 805	Recovery	69	1.459	3.2111 x 10-4
ASR-2	806 - 823	Recovery	27	0.283	2.5000 x 10-4
ASR-3	**825 - 842**	**Recovery**	**0.5**	**0.007**	**3.8548 x 10-6**
ASR-3	**853 - 870**	**Recovery**	**24**	**0.205**	**1.7578 x 10-4**
ASR-2	944 - 960	Recovery	47	0.384	3.6000 x 10-4
ASR-3	**968 - 985**	**Recovery**	**38**	**0.381**	**3.9759 x 10-4**
ASR-2	978 - 994	Recovery	73	1.027	9.7000 x 10-4
ASR-1	1,005 - 1, 025	Recovery	65	3.009	1.8998 x 10-4
ASR-2	1,012 - 1,028	Recovery	66	0.854	4.1000 x 10-4
ASR-2	1,030 - 1,046	Recovery	74	0.986	8.9000 x 10-4
ASR-2	1,075 - 1,125A	Recovery	85	1.177	N / A
ASR-1	1,105 - 1,125	Recovery	26	0.364	7.8574 x 10-5
ASR-2	1,125 - 1,225A	Recovery	86	15.997	N / A
ASR-2	1,225 - 1,350A	Recovery	87	16.078	N / A

gpm = gallons per minute

gpm / ft = gallons per minute per foot of drawdown

cm / sec = centimeters per second

A = packer test performed to assess specific capacity of interval

2.9 Casing Pressure Test

On April 14, 2014, the 24-inch diameter final casing at ASR-3 was pressurized to 152.50 pounds per square inch (psi). The pressure test was started at 12:50 PM. Pressure readings were recorded at five minute increments for a period of one hour. The final pressure reading after 60 minutes was 150.00 psi. FDEP allows a variance of up to 5% of the initial pressure which would allow an increase or decrease of 7.63 psi during the one hour test period. The actual pressure change observed at the end of 60 minutes was 2.50 psi or 1.64%, which is within the allowable 5% limits. Results of the casing pressure test are included in **Appendix No. 7** along with a copy of the pressure gauge calibration certificate.

2.10 Step-Drawdown and Pumping Test

A step drawdown test was conducted on May 16, 2014 to obtain information on the selected storage zone. The testing included collection of background water levels, pumping water levels, and recovery water levels. A copy of the test data is included in **Appendix No. 8**. Test data is presented in both tabular and graphical form.

The step drawdown test consisted of four steps whereby the well was pumped at rates of approximately 500, 700, 1,000, and 1,400 gallons per minute (gpm). Drawdown measurements were collected and the specific capacity of ASR-3 was estimated as shown below in **Table 6**:

Table 6 – Step Drawdown Test Results

Pumping Rate (gpm)	**Drawdown** (feet)	**Specific Capacity** (gpm/ft)
500	5.549	90.1
700	7.799	89.8
1,000	11.340	88.2
1,400	15.962	87.7

In addition to the step drawdown test, a withdrawal test was conducted on May 19, 2014, to estimate the transmissivity of the storage zone. The test consisted of a background period, and a pumping period, and a recovery period. **Table 7** presents a summary of the pumping tests and step drawdown test conducted at the various wells at the project site.

The withdrawal test at ASR-3 was conducted at a constant pumping rate of approximately 755 gpm for a period of 735 minutes. Drawdown was observed to be 8.644 feet suggesting a specific capacity for ASR-3 of 87.3 gpm/ft. Based on the data collected, transmissivity of the storage zone is estimated to be 50,000 gpd/ft. This estimate for transmissivity was calculated using the Modified Non-Equilibrium Formula derived by Cooper and Jacob (1946). The data collected during the 72-hour pump test is included in **Appendix No. 8**.

Table 7 – Historical Step Drawdown Test and Pumping Test Results

Activity	Pumping Well	Pumping Data Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
Step Drawdown Test	ASR-1	700	5.640	124.1
	ASR-1	1,400	12.180	114.9
	ASR-1	2,100	19.450	108.0
Step Drawdown Test	ASR-2	660	9.311	70.9
	ASR-2	1,000	14.894	67.1
	ASR-2	1,400	22.146	63.2
	ASR-2	2,000	33.480	59.7
Pump Test	ASR-2	1,320	21.104	62.5
Step Drawdown Test	**ASR-3**	**500**	**5.549**	**90.1**
	ASR-3	**700**	**7.799**	**89.8**
	ASR-3	**1,000**	**11.340**	**88.2**
	ASR-3	**1,400**	**15.962**	**87.7**
Pump Test	**ASR-3**	**755**	**8.644**	**87.3**

2.11 Background Water Quality

In addition to the water quality collected during the drilling and testing of wells MW-1, MW-2 and ASR-1, representative background water samples were collected from MW-3 and ASR-3 to further establish baseline conditions. Copies of the laboratory results are included in **Appendix No. 9**. **Table 8** presents select background water quality parameters.

Table 8 – Background Water Quality

Well	Interval	Chloride (mg/L)	TDS (mg/L)	Conductivity (µmhos/cm)	Arsenic (mg/L)	Sodium (mg/L)	Sample Date
ASR-1	1080'-1350'	17,800	28,600	47,500	0.0040	11,000	03/27/10
ASR-2	1080'-1350'	15,600	25,400	43,500	0.0026	9,700	11/22/10
ASR-3AB	1150'-1350'	3,080	4,500	10,200	0.0230	1,640	05/19/14
MW-1	1080'-1350'	14,900	26,900	31,600C	0.0026	9,100	06/17/10
MW-2	670'-742'	4,350	7,980	12,800	0.0020	2,700	10/08/10
MW-3	670'-740'	2,350	3,980	8,150	0.0005	12,100	05/16/14

A - Site has an active ASR storage zone.

B - Conducitivity is a field measurement.

C - This value appears to be an apparent lab error and is most likely a transposition error and should be 41,600.

41000-007 WELL COMPLETION REPORT

2.12 Project Schedule and Construction Costs

The City of Naples bid the referenced work in one bid package. Bids were advertised on September 20, 2013, and a pre-bid meeting was held on October 7, 2013. One addendum was issued on October 11, 2013, to clarify questions raised during the pre-bid meeting. The bid opening was held on October 21, 2013, and a recommendation letter was submitted on October 30, 2013, recommending award of the contract to Youngquist Brothers, Inc. in the amount of $1,250,000.00. The City Council approved award of the contract on November 20, 2013. As previously noted, a Notice-to-Proceed was issued for December 16, 2013 (City Bid No. 058-13). A final completion date, based on 150 calendar days, was set for May 15, 2014.

A summary of the original and modified contracts is provided below:

Original Contract

Contractor	Youngquist Brothers, Inc.
Part 1 – Construction of ASR-3	$920,000.00
Part 2 – Construction of MW-3	$226,810.00
Part 3 – Allowance	$50,000.00
Total Bid	$1,196,810.00

Actual Contract:

Contractor	Youngquist Brothers, Inc.
Part 1 – Construction of ASR-3	$880,240.00
Part 2 – Construction of MW-3	$216,330.00
Part 3 – Additional Work[1]	$54,000.00
Total Bid	$1,150,570.00

1 – Testing added to evaluate efficiency of lowering final casing depth

Below is a summary of the project financials which incorporate the final project close-out change order:

Contract Amount	$1,196,810.00	
Actual Amount	$1,096,570.00	
Balance	$ 100,240.00	(under budget by 8.38% without additional testing)
Additional work[1]	$ 54,000.00	
Total Contract	$1,150,570.00	
Balance	$ 46,240.00	(under budget by 3.86%)

2.13 ASR Program

YBI was able to mobilize immediately upon receipt of the NTP. I should be noted that additional testing was initiated to test the merits of further isolating the storage zone horizon. This testing was added to the contract to optimize use of the equipment needed to install temporary piping without additional mobilization charges. Well completion of ASR-3 and MW-3 was accomplished by June 2014.

This project is the third component of a multi-phase ASR program that the City of Naples is implementing to develop a reclaimed water / surface water ASR system. Completion of this project represents closure of one element of the City's water supply plan to use reclaimed water and excess surface water as replacement water to meet irrigation demands and reduce potable water use. Development of the storage zone is ongoing using reclaimed water and excess surface water from the Golden Gate Canal.

Milestones for implementation of the various programs initiated by the City are presented below:

- Integrated Water Supply Plan – Approved by Resolution on October 2, 2008
- Expansion of reclaimed water distribution system – Ongoing
- Implementation of a reclaimed water / surface water ASR program
  - Construct exploratory well – Complete
  - Construct ASR Well No. 1 – Complete
  - Construction of Monitor Well No. 1 – Complete
  - Construction of Monitor Well No. 2 – Complete
  - Construction of ASR Well No. 2 – Complete
  - Permitting of additional Class V ASR wells – Complete

  - Construction of surface facilities for ASR system – Complete
  - Construction of surface water ASR facilities from the Golden Gate Canal – Complete
  - Development of the ASR storage horizon using reclaimed water – Ongoing

- Investigation of stormwater ASR – Initiated

Chapter 3.0
Subsurface Conditions

3.1 Generalized Geologic Setting

Information obtained during drilling and testing of the third ASR well and third monitor well were used in conjunction with previous data collected to formulate the general geologic setting at the project site. The geophysical logging, drill cuttings, cores, packer testing and withdrawal testing data collected were used to confirm the presence of a suitable confining sequence and to determine the targeted storage zone. The data collected show similarity with the underground conditions encountered at the project site while drilling the other wells. A summary of the data evaluation and analysis are presented in this section.

The stratigraphic sequence underlying the City of Naples water reclamation facility site was determined from microscopic analysis of drill cuttings, correlation with geophysical logs run on pilot-holes drilled for the ASR-1, ASR-2, ASR-3, MW-1, MW-2, and MW-3 wells, and comparison with similar projects in southwest Florida. The stratigraphic units penetrated by the site wells were, from the surface downward, the undifferentiated Quatenary Deposits (Pleistocene to Holocene), the Tamiami Formation (Pliocene), the Hawthorn Group consisting of the Peace River Formation and the Arcadia Formation (Micoene), and the Suwannee Limestone (Oligocene). A lithologic description of the cuttings from ASR-3 and MW-3 is included in **Appendix No. 3**. Copies of the geophysical logs, which were previously submitted with weekly reports, are included in **Appendix No. 5**, which contains a CD of the logs.

<u>Pleistocene to Holocene Series</u>

Undifferentiated Quaternary Sediments – The undifferentiated sediments at the project site are characterized by yellowish brown to light gray, organics, fine to medium-grained quartz sand and shell. The undifferentiated sediments extend from land surface to an approximate depth of 60 feet at the project site.

<u>Pliocene Series</u>

Tamiami Formation – The Tamiami Formation at the site is characterized by brownish gray sandy limestone, shelly sandstone, and quartz sandstone. The Tamiami Aquifer is layered and contains several horizons that can be used for water supply purposes. This aquifer is present from depths of approximately 40 feet to 130 feet in the area of the City's wellfields. The deeper portions of the Tamiami Aquifer are commonly known as the Lower Tamiami and are the primary unit used by the City for water supply. The Coast Ridge Wellfield withdraws from a horizon between 48 feet to 96 feet in depth, while the East Golden Gate Wellfield withdraws from a production zone between 37 feet to 137 feet below land surface. An important aspect of the Lower Tamiami is the natural separation that exists between the upper water table aquifer and the Lower Tamiami; and between the Lower Tamiami and the deeper Sandstone Aquifer and a production horizon known as Hawthorn Zone 1. The unit is indicated by a low uniform gamma ray responses noted in the geophysical logs. The contact of the sandy limestone in the Tamiami Formation with the underlying greenish clay of the Hawthorn Group is distinctive. Evaluation of data suggests that the Tamiami Formation extends from approximately 60 feet to 175 feet below land surface at the project site.

Miocene Series

Hawthorn Group – The Hawthorn Formation contains both the Peace River Formation and the underlying Arcadia Formation. At the ASR test well site, the Hawthorn Group is characterized by greenish-gray calcareous sandy clay, clayey-sand, and light brownish-gray sandy limestone. The unit is indicated by a consistent, moderate gamma ray signature with a sharp peak in the gamma ray response at the base of the unit at approximately 790 feet. There is a distinct change in lithology from light-colored sandy limestone of the overlying Tamiami Formation to greenish clay at the top of the unit at around 175 feet. The base of the Hawthorn Group is estimated to be around 790 feet below land surface.

The slightly brackish Hawthorn Zone 1 production horizon is present at the project site between the approximate depths of 320 feet and 420 feet. This aquifer is used in some parts of the region for water supply purposes, but there are no wells within several miles of the project site. The City of Naples does not use the brackish Hawthorn Zone 1 production zone for water supply purposes. Additional separation is present between the Hawthorn Zone 1 production zone and the Lower Hawthorn production zone. The brackish Lower Hawthorn production zone extends from 670 feet to 740 feet at the project site and is not used for water supply purposes by the City. This production zone is used for water supply purposes by others in the area, but all users are located several miles from the project site. Underlying the Hawthorn Group is the Suwannee Limestone which extends from approximately 790 feet to the total depth of the ASR test well (i.e., 1,500 feet).

Oligocene Series

Suwannee Limestone – The Suwannee formation at the project site is characterized by shelly sandy clay. The top of the unit is indicated by a shift in the gamma ray log to higher counts, and by a reduction in borehole size, indicated by the caliper log, at approximately 790 feet. The reduction in borehole size appears to be related to the greater competency

of the Suwannee formation relative to the overlying Arcadia Formation. The base of the Suwannee formation was not established as the pilot-hole only extended to 1,500 feet.
A summary of the estimated geologic formations conditions encountered at the City of Naples water reclamation facility from data collected during construction and testing of ASR-1, ASR-2, ASR-3, MW-1, MW-2, and MW-3 is presented below:

Formation Name	Interval		Approximate Thickness
	from	to	
Undifferentiated Quaternary Deposits	0	~ 60	60
Tamiami Formation	~ 60	~175	115
Hawthorn Group	~ 175	~790	615
Suwannee Limestone	~ 790	1,500 ?	710 ?

Note: All numbers are in feet below land surface

3.2 Hydrogeologic Setting

There are several production horizons in the area surrounding the project site. The primary and closest raw water supply source is the Tamiami Formation. This unit is the primary source for raw water supply for the City of Naples and other neighboring utilities. Production from this horizon is low to moderate. Water quality is generally fresh, but may become brackish near the Gulf of Mexico.

A production zone known as the Hawthorn Zone 1 is moderately productive and also used in some areas for water supply purposes. This production zone is found at the project site from approximately 320 to 420 feet below land surface. The zone is artesian and contains water that is considered brackish. The City of Naples does not use this zone for raw water supply.

Near the base of the Hawthorn Group is a production horizon known as the Lower Hawthorn. The zone can be brackish to almost saline. At the project site, the zone has moderate to high productivity and is artesian. Concentrations of TDS are near 10,000 mg/L in this horizon at the project site. The 10,000 mg/L TDS interface is important as this marks the location of the lowermost potential USDW (i.e., water having a TDS concentration of less than or equal to 10,000 mg/L).

A potential storage zone below the USDW was further defined during this phase of the City's ASR program. **Table 6** presents a summary of specific capacity data from pumping test at ASR-1, ASR-2 and ASR-3. As shown in the table, the specific capacity of ASR-3 is approximately 87.7 gpm/ft when pumping at a rate of 1,400 gpm. This value falls between the specific capacity of ASR-1 and ASR-2, which had values of 124.1 gpm/ft and 63.2 gpm/ft, respectively.

Based on the findings to date and discussions with FDEP, a potential storage zone between 1,150 and 1,350 feet was selected at ASR-3. A relatively deep depth of 1,150 feet was chosen for the final casing seat to minimize the low production zones of the open borehole which contain high saline waters that adversely affect recovery efficiencies. ASR-1 and ASR-2 set the final casing string to a depth of 1,080 feet.

3.3 Water Quality

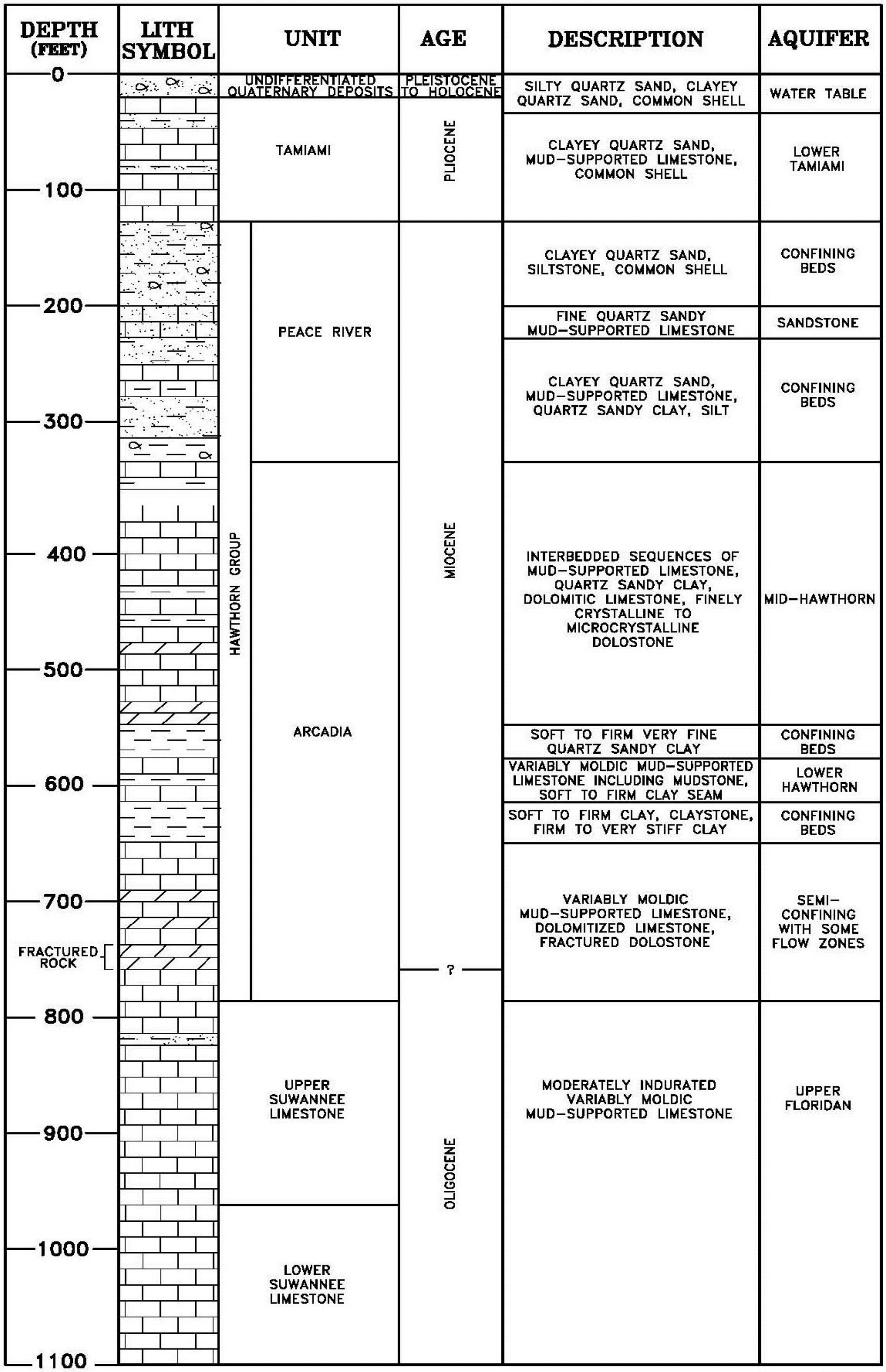
The base of the USDW at this site was previously identified by performing water quality analysis on samples obtained from packer tests and geophysical log interpretation. Data compiled from geophysical logs, including the dual induction log, was useful in determining the base of the USDW. This data along with the log derived water quality log appears to place the base of the USDW somewhere between 760 feet and 780 feet below land surface. This data was confirmed by the water quality results of the packer test conducted in ASR-1 between 785 and 805 feet that yielded a TDS concentration of 12,000 mg/L. The packer test conducted at ASR-2 between 806 and 823 feet showed a slightly lower TDS value which is most likely due to the influence of the highly productive Lower Hawthorn productive zone which contains brackish water. **Figure 11** shows the location of the USDW as established from previous testing with respect to the production zones.

3.4 Confinement Analysis

The approach to the evaluation of vertical confinement at the City of Naples water reclamation facility site included review of available borehole geophysical, and analysis of geological data and open-hole testing data. This information was used to identify intervals from 760 feet (i.e., base of the USDW) to 1,080 feet that exhibited confining properties. The vertical confinement provided by each interval was then evaluated. Particular attention was paid to locating beds of limestone, dolomite, clay or marl that have low vertical hydraulic conductivities and are not penetrated by fractures and/or solution cavities. Such tight beds provide the primary vertical confinement of the injected fluids. **Figure 12** presents a generalized geologic column derived from wells drilled on site.

3.4.1 Identification of Confining Units

The presence of satisfactory confining sequences between 760 and 1,080 feet below land surface was established during the drilling of ASR-1. A letter previously submitted to the



Source: City of Naples - Integrated Water Resources Plan Final Report (Tetra Tech); July 2008
ASR Well EW-1

Figure 12
Generalized Geologic Column
from Exploratory Test Well

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FDEP documented the presence of this confinement on site. This letter from the Engineer is dated December 7, 2009, and is referred to as "the 24-inch diameter casing seat request". Comparison of information collected during drilling and testing of ASR-2 has confirmed the presence of confinement as previously documented. In fact, a series of cores were collected and analyzed, and packer testing was performed at ASR-2 to clearly establish the presence of a suitable confinement. Packer test data are summarized in **Table 5**, while core results are presented in **Table 4**.

3.4.2 Geophysical Logs

The geophysical logs for ASR-2, MW-1, and previously constructed ASR-1 were examined in detail for the presence of units of rock that could provide vertical confinement for injected fluids. A combination of sonic, caliper and resistivity logs were used to identify well-cemented limestone and / or dolomite beds that would be expected to have low matrix porosities and hydraulic conductivities. The television survey was used to locate fractures and / or cavernous zones that could be conduits for vertical fluid flow. Information on the orientation and thickness of beds was also obtained from the television survey.

The development and conditioning of the wells prior to logging is not an issue for the sonic, caliper, gamma ray, temperature, and resistivity logs as these logs were designed to and are often run in mudded boreholes. Fine scale features, such as bed contacts, are readily distinguishable on the television survey, which indicates that borehole conditions did not have a significant adverse effect on log quality.

3.4.3 Characterization of Well Cuttings

Cuttings collected during the drilling of MW-3 and ASR-3 were examined in detail for lithology. The cuttings were grab samples collected at 5-foot intervals during the construction of the well. The lithology of the limestone cuttings was characterized using the limestone classification scheme of Dunham (1962). The most common grain types were silt to fine-sand sized rounded carbonate grains that are described as either peloids (fecal pellet-shaped grains of indeterminate origin) or as bioclasts (transported fossil fragments). The mineralogy of the samples (calcite versus dolomite) was confirmed by reaction with dilute hydrochloric acid. Dolomite was classified according to crystal size as being either microcrystalline (crystals are not visible with the low-powered microscope), finely crystalline (1/64 to 1/16 mm) or medium crystalline (1/16 to 1/4 mm).

3.4.4 Packer Test Data

Straddle packer test data collected during the drilling of ASR-3 and compared with previous packer test data collected while drilling ASR-1 and ASR-2 to assess hydraulic conductivity. The straddle packer data collected to evaluate hydraulic characteristics were analyzed using the Cooper and Jacob (1946) modification of the Theis (1935) non-equilibrium equation (i.e., the straight line method). The transmissivity values calculated from both the pumping and recovery phase data for each test were similar. The summarization of the results of the packer tests is attached and as described below.

A total of three packer tests were conducted at ASR-3. The packer tests were designed to collect information on hydraulic characteristics. Results from the packer testing for ASR-3 are included in **Appendix No. 6** with a summary of the data shown below. Hydraulic conductivities were estimated using water-level recovery data (i.e., residual drawdown) and applying the Modified Jacob method of analysis as shown below:

Jacob Modified Equation

$$T = \frac{264Q}{\Delta s'}$$

Where:

T = Coefficient of Transmissivity (gpd/ft)

Q = Pumping Rate (gpm)

∆s’ = Calculated Drawdown in one log cycle (feet)

Estimated Hydraulic Conductivity

$$K = \frac{T}{b}$$

Where:

K = Hydraulic Conductivity

b = Thickness of interval tested (feet) or 17 feet

Results of Estimated Hydraulic Conductivity

Interval	**Q**	**∆s**	**T**	**b**	**K**
	(gpm)	(feet)	(gpd / ft^2)	(feet)	(cm / sec)
825-842	0.5	95	1.39	17	3.8548E-06
853-870	24	100	63.36	17	1.7578E-04
968-985	38	70	143.31	17	3.9759E-04

It should be noted that the hydraulic conductivity values calculated from the packer test data are largely a function of horizontal hydraulic conductivities. Packer test data thus tend to overestimate vertical hydraulic conductivities. For example, a packer test performed on an interval containing one or more high hydraulic conductivity horizontal beds inter-bedded between very low hydraulic conductivity beds would give a high hydraulic conductivity value whereas the interval would have a very low vertical hydraulic conductivity. **Table 5** summarizes the hydraulic conductivity derived from the packer tests.

Packer test data collected between the estimated USDW and the targeted storage zone indicated good confining characteristics. Additional data previously obtained from cores further confirmed the degree of confinement present.

3.4.5 Criteria for Identification of Confinement Units

Beds or intervals of rock that are likely to offer good vertical confinement were identified using the following criteria:

- Low sonic transit times
- Variable density log (VDL) pattern consisting of straight parallel vertical bands, where lithology is relatively uniform, or a "chevron" pattern of continuous parallel bands, where the formation consists of inter-bedded rock with differing densities and/or degrees of consolidation. Fractured rock typically has an irregular VDL log pattern
- Low hydraulic conductivities calculated using packer pump test data
- A high degree of cementation as observed in microscopic examination of cuttings and core samples
- Borehole diameters on caliper logs close to the bit size
- Absence of evidence of fractures on the television survey
- Core data

3.4.5.1 Confinement Intervals

An analysis of confinement was performed to evaluate units that provide separation between the proposed storage zone and the USDW. This analysis was conducted using the confinement properties of the strata between the base of the USDW (760 to 780 feet) and 1,080 feet (i.e., the top of the storage zone).

Interval from 750 to 1,000 feet below land surface – This interval consists predominantly of light-colored limestone. Wackestones and packstones are the most common lithologies. The wackestones and packstones are interbedded with beds of carbonate-mud rich lithologies (fossiliferous mudstones and grainstones). The borehole television log indicates that the beds are horizontal and range in thickness from approximately 0.5 to 10 feet. The bedding appears to consist of stacked sequences of carbonate sand-rich (wackestones and packstones) and carbonate mud-rich (packstones to mudstones) limestones. The mudstone and wackestone beds, which have low macroporosities and are well cemented, can provide better vertical confinement than the thicker grainstone and packstone beds.

Packer tests were performed in the three ASR Wells over the interval 785 to 805 feet bls within this confinement interval and yielded hydraulic conductivities ranging from 3.8×10^{-5} to 7.7×10^{-3} cm/sec. No evidence of vertical fractures or solution cavities are visible on the survey video survey. The geological and geophysical data for this interval are characteristic of good vertical confinement.

Interval from 1,005 to 1,150 feet below land surface – This interval consists of interbedded light-colored limestones and dolomites. Grainstones and packstones are the most common lithologies. The grainstones and packstones are interbedded with beds of carbonate-mud rich lithologies (fossiliferous mudstones and wackestones). The borehole television log indicates that the beds are horizontal and range in thickness from approximately 0.5 to 10 feet. The bedding appears to consist of stacked sequences of carbonate sand-rich (grainstones and packstones) and carbonate mud-rich (packstones to mudstones) limestones. The mudstone and wackestone beds, which have low macroporosities and are well cemented, can provide better vertical confinement than the thicker grainstone and packstone beds.

Packer tests were performed in ASR-1 over the intervals 1,005 – 1,025 and 1,105 – 1,125 feet below land surface within this confinement interval and yielded hydraulic conductivities ranging from 7.8×10^{-4} to 1.8×10^{-3} cm/sec. No evidence of solution cavities was visible on the borehole televiewer log or the television survey video. The geological and geophysical data for this interval are characteristic of good vertical confinement.

3.4.5.2 Confinement Summary

A comparison of data collected from ASR-1, ASR-2, ASR-3, MW-1, MW-2, and MW-3 were analyzed to evaluate the presence of adequate confinement at the project site for the intended use (i.e., reclaimed water ASR). More specifically, the drilling and testing plan for ASR-3 was designed to collect additional information to further define confinement (i.e., additional packer tests) at the City's water reclamation facility site. This information was useful in confirming the presence of suitable confinement between the base of the USDW and the top of the proposed storage zone. A total of 18 rock cores have been collected while drilling ASR-2, and three additional packer tests were performed at ASR-3. The test results indicate the presence of good confinement between the USDW and the storage zone.

Chapter 4.0
Conclusions and Recommendations

4.1 Conclusions

The purpose of this report is to summarize the construction and testing activities of the third ASR well (ASR-3) and the third monitor well (MW-3) located at the City of Naples Water Reclamation Facility. This information will be used in support of future permits and as a record of construction and testing activities.

Conclusions from the construction and testing of the ASR Test Well No. 3 (ASR-3) and Monitor Well No. 3 (MW-3) are as follows:

- The fresh raw water sources located in the Tamiami Formation extend to a depth of approximately 175 feet below land surface at the project site. The City of Naples uses the Tamiami Formation for water supply
- The first brackish aquifer, known as the Hawthorn Zone 1, is present from a depth of approximately 320 to 420 feet below land surface. This aquifer contains brackish water and is not used by the City of Naples for raw water supply
- The deepest production horizon, known as the Lower Hawthorn, exists between depths of approximately 670 to 740 feet below land surface. This zone is highly brackish and is not used by the City for raw water supply purposes
- The 10,000 mg/L TDS interface was estimated to occur between the depths of approximately 760 to 780 feet below land surface based on information collected via geophysical logging and straddle packer tests. The 10,000 mg/L TDS interface is the base of any potential USDW. This depth is important as FDEP has separate criteria for regulating ASR systems completed below the USDW
- A potential storage zone was identified at ASR-3 to exist between depths of 1,150 and 1,350 feet below land surface. This zone has been targeted as a potential storage horizon as it contains water with TDS greater than 10,000 mg/L, and there appears to be separation between the targeted storage horizon and the USDW
- Adequate confinement appears to be present between the base of the USDW and the top of the potential storage zone based on packer test data
- The storage zone has adequate hydraulic conductivity to allow injection and recov-

ery at rates from 700 gpm (~1 mgd) to possibly 1,400 gpm (~2 mgd) based on results of the step drawdown test. The specific capacity at ASR-3 was estimated to range between 90.1 to 87.7 gpm/ft at pumping rates of 500 and 1,400 gpm, respectively

- The 24-inch diameter final casing at ASR-3 successfully passed a casing pressure test and demonstrated mechanical integrity for an ASR type well
- The construction and testing was completed under the contract amount and slightly over schedule

4.2 Recommendations

The following recommendations are suggested based on the information collected and evaluated to date:

- Continue development of the storage zone using reclaimed water as source water and excess surface water from the Golden Gate Canal
- Continue with implementation of the City's integrated water resources plan in support of the City's overall strategy to develop alternative water supplies
- Continue with the funding partnership with the South Florida Water Management District / Big Cypress Basin
- As needed, expand the ASR wellfield to optimize use of reclaimed and surface water to meet future irrigation demands