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

Project Title: **W-2C Production Wells**

Document Title: **Replacement Well Completion Report**

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MWH

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FLORIDA

PROFESSIONAL GEOLOGIST

The geological evaluation and interpretations contained in the *W-2C Production Wells Replacement Well Completion Report* prepared as part of the MWH Program Management at Risk Services for Water, Wastewater & Irrigation Facilities W-2C Work Authorization for the City of Cape Coral, were prepared by, or reviewed by, a Licensed Professional Geologist in the State of Florida.

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GLOSSARY

Term	Definition
ASTM	American Society For Testing And Materials
APT	Aquifer Performance Test
AWWA	American Water Works Association
BDL	Below Detection Limits
bls	Below Land Surface
°C	Degrees Celsius
DDC	Diversified Drilling Corporation
FAS	Floridan Aquifer System
ft	Feet
FRP	Fiberglass Reinforced Plastic
gpd	Gallons Per Day
gpm	Gallons Per Minute
IAS	Intermediate Aquifer System
LHA	Lower Hawthorn Aquifer
MCL	Maximum Contaminant Level
mgd	Million Gallons per Day
mg/L	Milligrams Per Liter
NCTMW	North Cape Test Monitoring Well
NAVD	National American Vertical Datum
NROWTP	North Reverse Osmosis Water Treatment Plant
NTU	Nephelometric Turbidity Units
pCi/L	Pico Curies Per Liter
RO	Reverse Osmosis
SAS	Surficial Aquifer System
SDI	Silt Density Index
SFWMD	South Florida Water Management District
SWROWTP	Southwest Reverse Osmosis Water Treatment Plant
TON	Threshold Odor Number
UFA	Upper Floridan Aquifer
µS/cm	Micro Siemens Per Centimeter

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 Expansion Services. This report summarizes the construction of four replacement production wells for the City of Cape Coral, Florida in the North and Southwest Wellfields. This report describes in detail the construction, aquifer testing, and water quality analysis of four new replacement production wells that extract water from the Upper Floridan aquifer (UFA). The well construction results are summarized below:

- Four replacement production wells (Wells 1N-R, 2N-R, 3N-R and 230-R) were constructed to provide raw water supply to the City of Cape Coral.

- Well 230-R replaced Well 230. Well 230, located on the Chiquita Blvd. alignment, was plugged and abandoned because of encountering poor water quality. A new location was selected for Well 230-R on the Gleason alignment that will provide water to Plant 2 at the Southwest Reverse Osmosis Water Treatment Plant (SWROWTP).

- Wells 1N-R, 2N-R, and 3N-R replaced three production wells originally drilled in the medians of Kismet and Del Prado Parkway. The replacement wells were constructed because road improvements on Kismet Parkway and Del Prado Boulevard prevented their use because of road design and public safety considerations. These wells will provide water to the North Reverse Osmosis Water Treatment Plant (NROWTP).

- The wells were constructed with 12-inch diameter FRP casing and completed with open-hole production intervals tapping the UFA.

- Water quality in the replacement wells is similar to nearby wells in the existing Southwest and North Wellfields.

- Well testing results indicate the replacement wells are capable of meeting the design capacity of 550 gpm. The wells have different production capacities based on the results of step-drawdown testing. Specific capacities range between 17.3 and 23.1 gallons per minute per foot (gpm/ft) at approximately 600 gpm.

- To minimize stress on the aquifer and maximize production, the recommended maximum pumping rates for the new production wells range from 550 to 600 gpm and the recommended pump setting depth is 120 feet below land surface (bls). Based on individual well step drawdown tests, at the proposed pumping rates, water levels in the wells are not expected to exceed 50 feet bls. However, pipeline hydraulic impacts at the North well locations (Wells 1N-R, 2N-R, and 3N-R) at the end of the raw water lines will have an effect on pumping rates and levels.

- The replacement wells are recommended for use as standby wells in times of increased demand. 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.

- 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 wells should be considered if specific capacity declines by 25% or more.

- Withdrawals from these production wells are permitted under the SFWMD Water Use Permit No. 36-00046-W. The permit, which was recently modified, allows a maximum monthly withdrawal of 1,312 million gallons from the UFA. Monitoring of the wellfield facilities is required by several Limiting Conditions of the permit.

- The re-calibration of water use accounting flow meters is required every five years under Limiting Condition No. 17 of the WUP. Limiting Condition No. 18 of the WUP requires that pumping withdrawals be recorded and submitted to the District for each production well.

- Monthly measurement of chloride concentrations in the production wells is required by Limiting Condition No. 28 of the permit. Primary and secondary water quality analysis should be performed and reviewed periodically to assess changes in wellfield water quality.

1.0 Introduction

In 2004, the City of Cape Coral 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 completion report summarizes the construction of four replacement wells. Well 230-R supplies Plant 2 of the SWROWTP and wells 1N-R, 2N-R and 3N-R supply the NROWTP. This report documents the methods and procedures used during well construction and analysis of testing, as well as conclusions and recommendations for operation.

1.1.1 Authorization

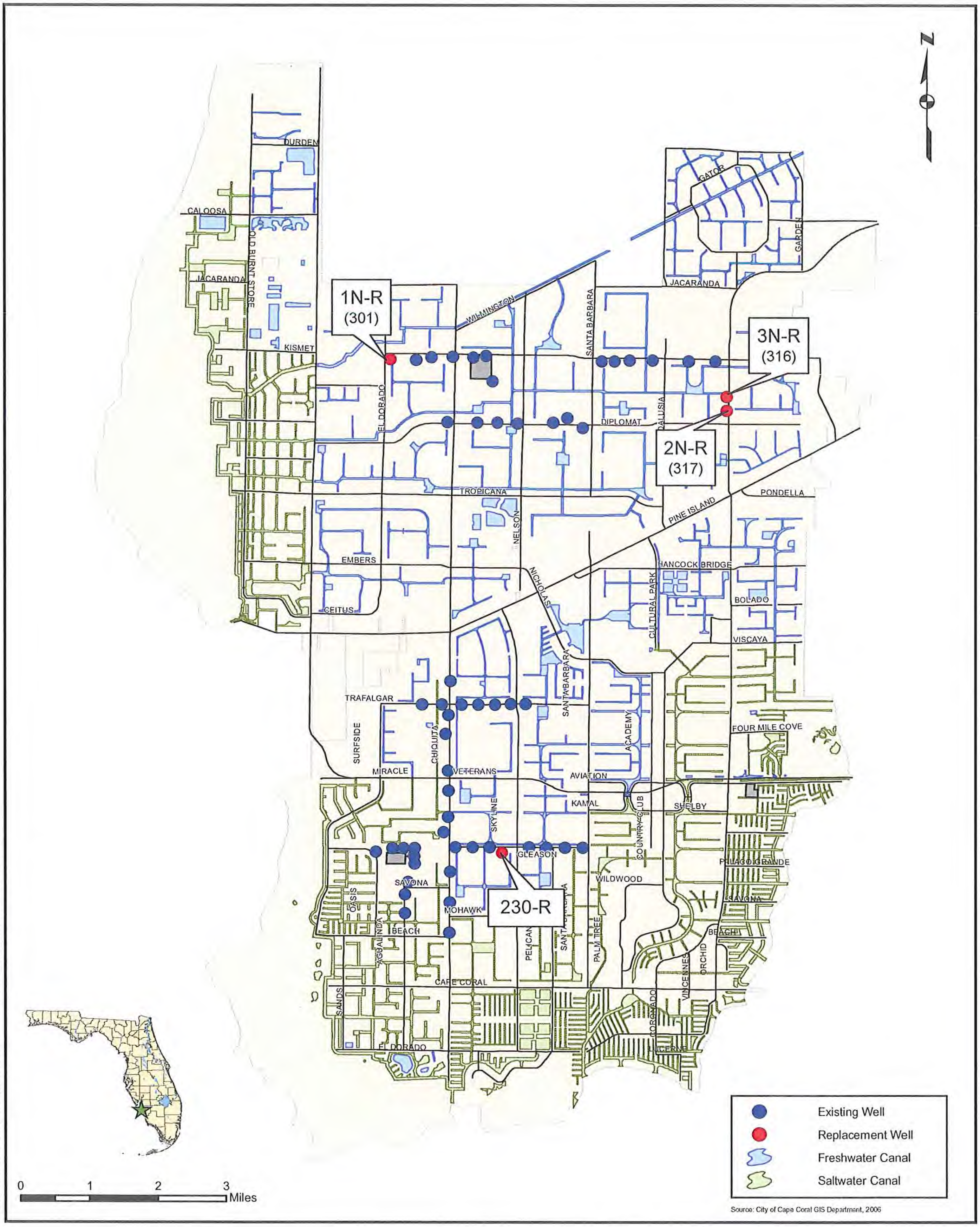
Three water supply wells previously constructed in the North Wellfield were drilled in 1990 as part of the City's Water Supply Master Plan Phase II study. The replacement wells 1N, 2N, and 3N were constructed because road improvements on Kismet and Del Prado Parkway prevented their use because of road design and public safety considerations. A fourth well, 230-R, is located in the Southwest Wellfield and replaces Well 230, which was plugged and abandoned because of poor water quality. The Cape Coral City Council authorized MWH Americas to design, permit, observe and document the construction and testing of the replacement wells. Design was conducted under W-2, approved under W-2C construction of the 4 wells by City Council on February 27, 2006. The work was conducted under P.O. No. 0815884, Change Order #2, issued by the City on February 28, 2006. The installation of submersible pumps and well vaults are being conducted under the W-3 Work Authorization.

The four replacement wells provide brackish water supply from the Cape Coral North and Southwest Wellfields. Diversified Drilling Corporation (DDC) of Lehigh Acres, Florida completed well construction of the four production wells, which began February 4, 2008 at Well 230-R and was completed on May 14, 2009 at Well 2N-R. Bacteriological clearance of the wells are to be completed before the wells are put into use.

A vicinity map showing the locations of the replacement wells within the City is shown in Figure 1-1. Individual site locations of the replacement wells are shown in Figures 1-2, 1-3 and 1-4. Wells 1N-R, 2N-R and 3N-R will supply raw water to the NROWTP and well 230-R will supply raw water to the SWROWTP to produce potable water for public supply purposes. The withdrawals are authorized by the South Florida Water Management District (SFWMD) under Water Use Permit No. 36-00046-W.

1.1.2 Scope of Services

The scope of services included well design, development of technical specifications for construction and testing of replacement production wells, bidding services, well construction permitting, on site observation and documentation of well construction and testing, collection and analysis of formation samples, and water quality analysis during drilling. Construction oversight services were also provided during installation and



Source: City of Cape Coral GIS Department, 2006

Figure 1-1 Replacement Production Well Vicinity Map

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Figure 1-2 Location of Well 1N-R

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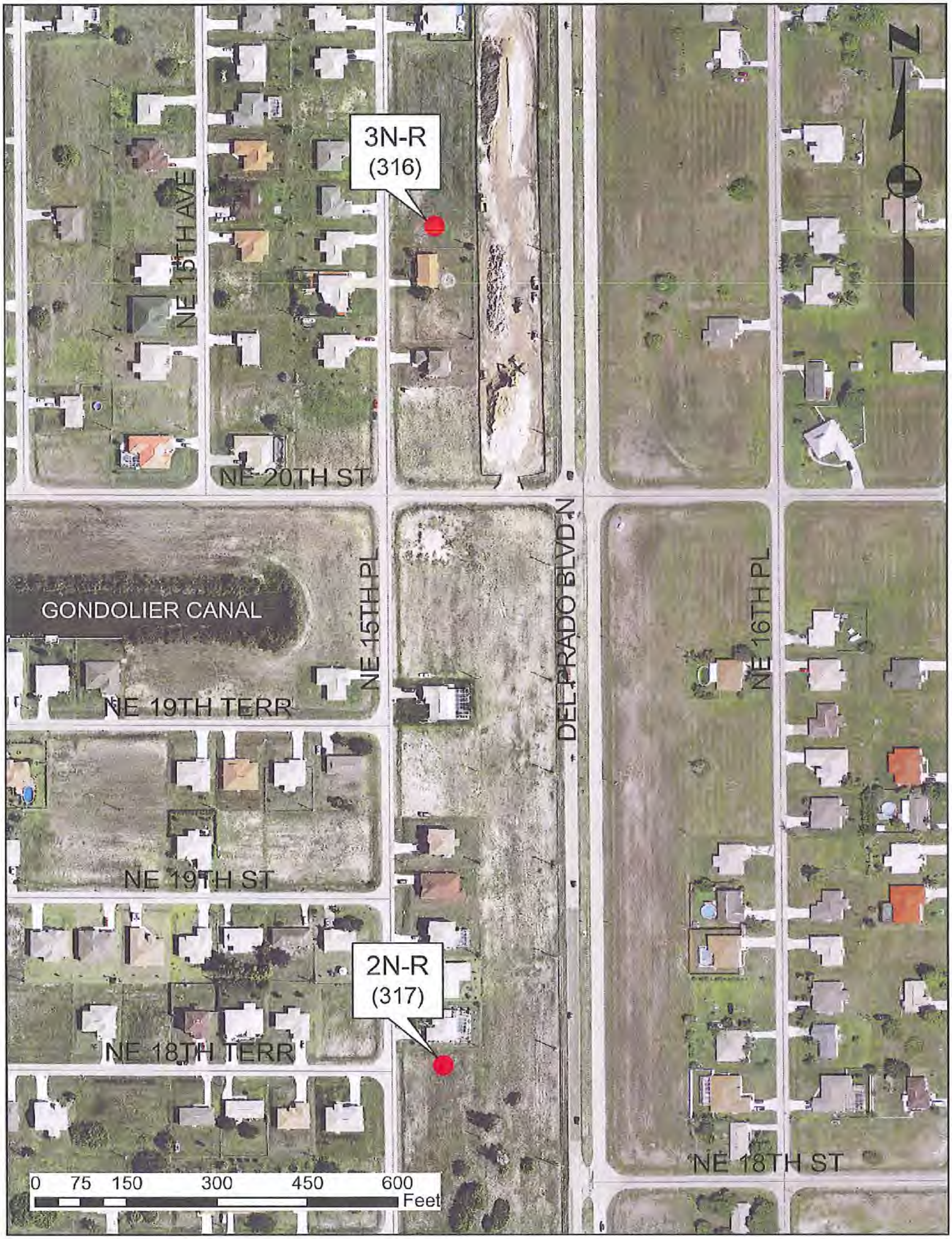

Figure 1-3 Location of Wells 2N-R and 3N-R

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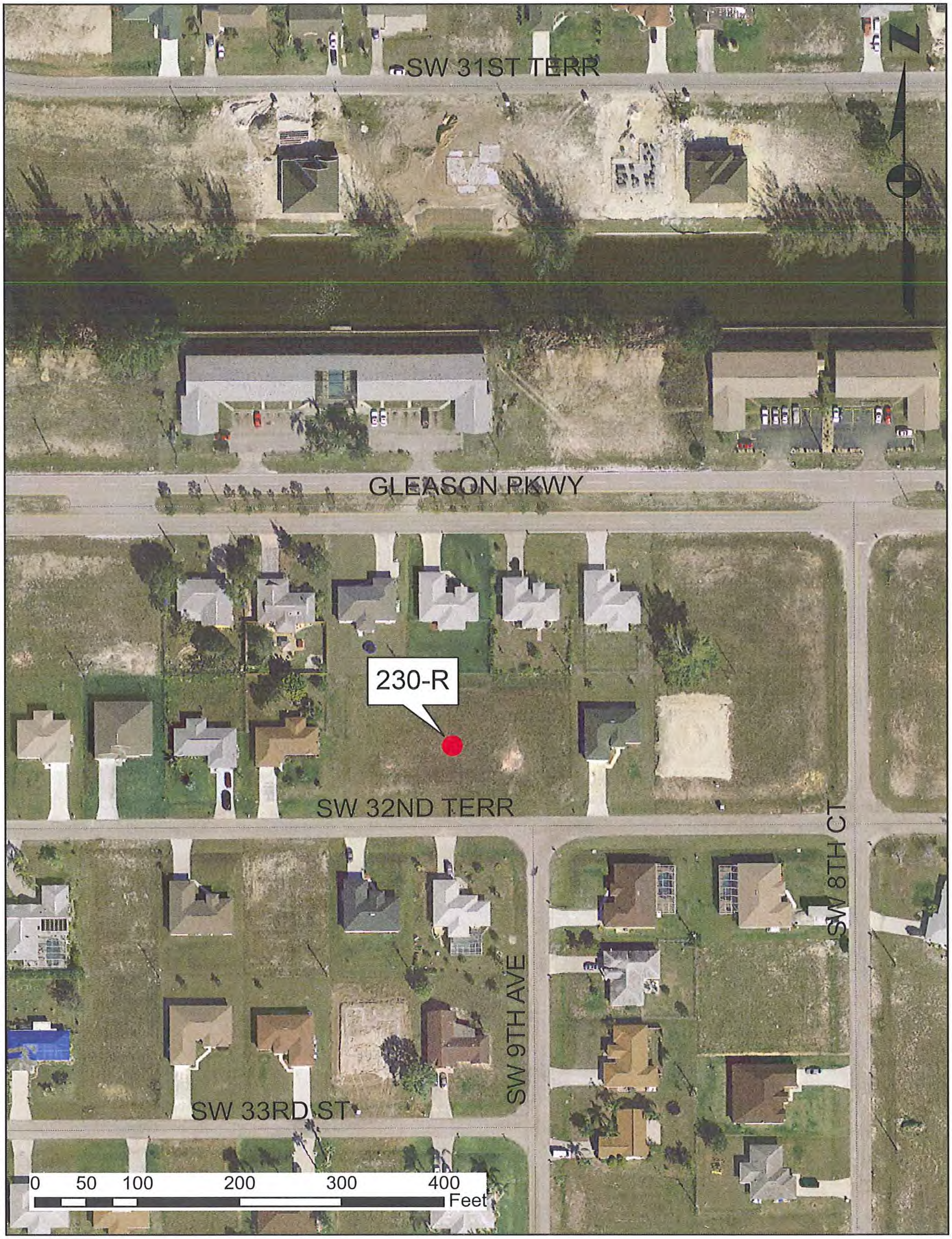

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Figure 1-4 Location of Well 230-R

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testing of submersible pumps, wellhead piping, and other appurtenances. Hydrogeologic information is presented in Section 2. Construction methods used for the completion of the wells is presented in Section 3. Testing performed to determine well production characteristics and water quality are presented in Section 4. Conclusions and recommendations with respect to operation of the replacement wells are presented in Section 5.

1.1.3 Well Nomenclature

The original well numbers were used for permitting purposes and are designated in Water Use Permits dating back to the late 1990's. The numbering consisted of the new well number followed by a wellfield letter locator, e.g. Well 1N is the first well drilled in the North Wellfield. Following start of construction of the North wellfield in 2006, the City decided on a city-wide numbering scheme that incorporates a number designator for the plant being supplied.

The South wellfield wells had previously been renamed to a 100 and 200 series numbering system to designate wells supplying Plant 1 or Plant 2 of the SWROWTP, respectively. The wells supplying the first Phase of the NROWTP were renumbered to a 300 series, and are generally numbered from west to east starting with the Kismet Parkway wellfield alignment. The new well names are cross referenced to the original permitted well ID numbers in Table 1-1 with location information.

Table 1-1 Well Names and Location Details

Permitted Well ID	**Cape Coral Well ID**	**Address**	**Latitude** (deg, min, sec)	**Longitude** (deg, min, sec)
1N-R	RO 301	2411 NW 23rd Terrace	26°41'45"	82°01'17"
2N-R	RO 317	1815 NE 15th Place	26°41'10"	81°56'33"
3N-R	RO 316	2023 NE 15th Place	26°41'20"	81°56'35"
230-R	RO 230	911 SW 32nd Terrace	26°35'29"	81°59'40"

2.0 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) the U.S. Geological Survey (Boggess, D.H., 1974; Boggess et al., 1981), and the South Florida Water Management District (Wedderburn et al. 1982; Knapp et al, 1984; 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, 1989; and MWH Americas, 2007a, 2007b, 2007c, and 2009).

Lee County is underlain by rocks of Cenozoic age to a depth of about 5,000 feet (Meyer, 1989). These rocks are composed of carbonates, with minor amounts of evaporates in the lower section and clastics in the upper section (Reese, 2000). In this Chapter, the geology and identified aquifer systems encountered during drilling and testing operations are described from youngest to oldest in age. A detailed description of the lithostratigraphy and its relationship to the hydrostratigraphy of the wellfield is provided below. A generalized hydrostratigraphic section of the subsurface in Cape Coral is shown in Figure 2-1.

2.1.1 Lithostratigraphy

Sediments encountered during the construction of the replacement wells range in age from Late Pleistocene to Late Oligocene. MWH Americas collected geologic formation samples (well cuttings) from the pilot holes during drilling operations and described them primarily based on their dominant lithologic characteristics using the Folk (1980) classification system for carbonate rocks. Additionally, well cuttings descriptions include textural characteristics, accessory minerals, fossils, and color to characterize the formation. Lithologic logs are provided in the Report Supplement.

Pliocene-Pleistocene Series

The undifferentiated deposits encountered during drilling operations include predominately siliciclastic and carbonate deposits of the Pamlico Sand Formation and the Undifferentiated Fort Thompson/Caloosahatchee Formation. The surficial deposits consisted primarily of undifferentiated Plio-Pleistocene marine bivalvia and gastropoda shell with trace amounts of quartz sand and small percentages of clay and fossilized bone fragments. This unit was observed from the surface to depths ranging from 20 to 50 feet.

Miocene Series - Hawthorn Group

The top of the Hawthorn Group was encountered at Well 1N-R at a depth of 50 feet bls, Well 2N-R at a depth of 20 feet bls, Well 3N-R at a depth of 35 feet bls, and Well 230-R at a depth of 40 feet bls. The Hawthorn Group unconformably underlies the undifferentiated Pliocene-Pleistocene deposits, and is a lithologically complex sequence of silt, clay, calcareous clay, dolosilt, quartz sand, phosphate, limestone, and dolomite

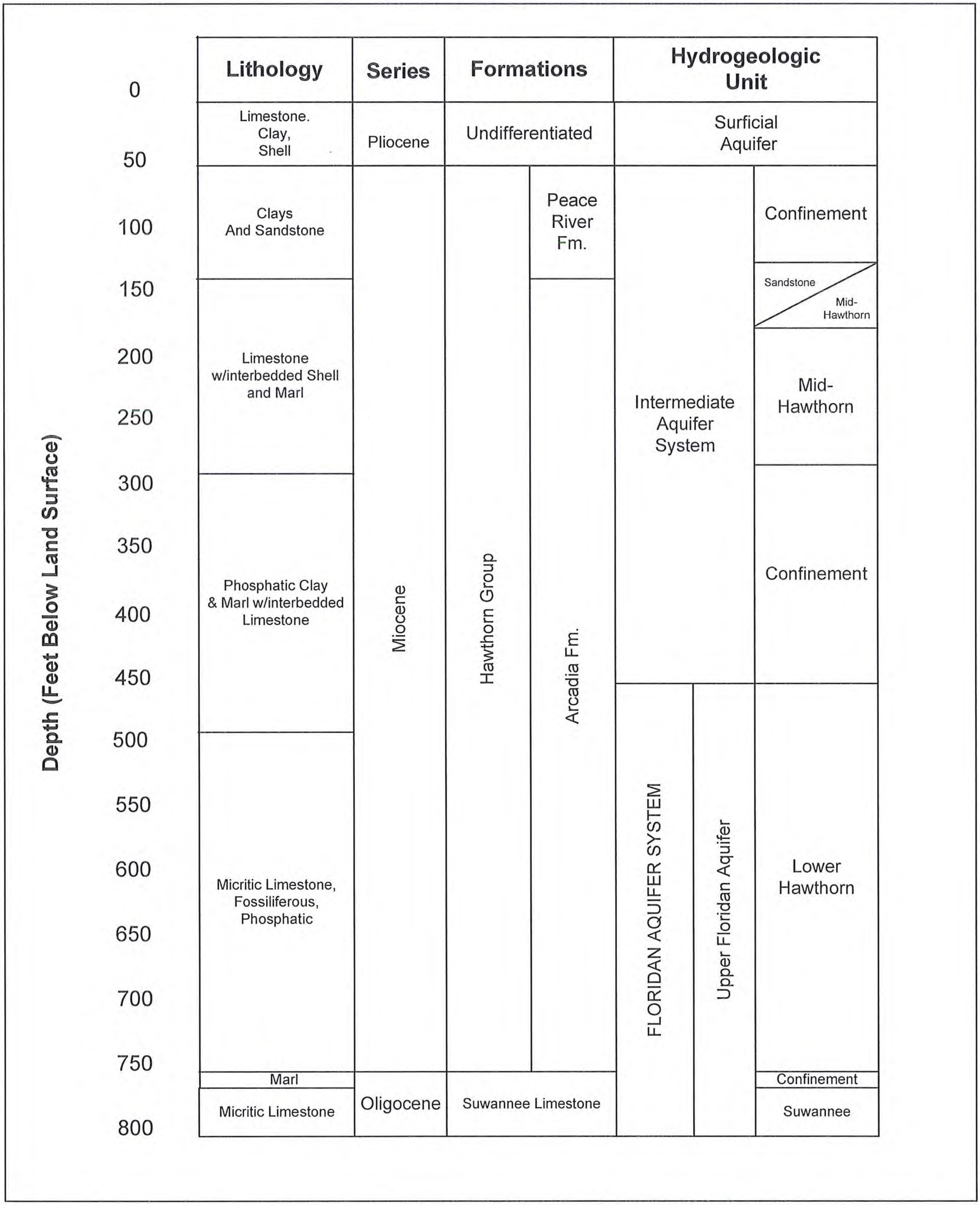

Figure 2-1 Generalized Hydrostratigraphic Section of Cape Coral

(Missimer and Associates, 1989). This regional stratigraphic unit of early Pliocene to Miocene age underlies all of South Florida. The Hawthorn Group is comprised of an upper, primarily clay unit (Peace River Formation), and a lower, primarily carbonate unit (Arcadia Formation) (Missimer and Associates, 1989). The base of the Peace River Formation contains the Lehigh Acres Sandstone Member (Missimer and Associates, 1989) and was encountered only at Well 3N-R in the interval 138 to 215 feet bls. The two formations are separated by a major regional disconformity. The top of the Hawthorn group was encountered as shallow as 20 feet bls (Well 2N-R) and the base was located as deep as 773 feet bls (Well 3N-R).

A regional disconformity separates the Peace River Formation from the Arcadia Formation (Scott, 1988 and Cunningham, et al, 2001). The lower 500 feet of the unit consists of 3 to 4 large scale, transgressive-regressive cycles. Each cycle consists of a lower thick limestone unit and an upper mixture of minor carbonate and clastic units.

Peace River Formation

The Peace River Formation of the Hawthorn Group consists of sandstones, sands, sandy limestones, dolomitic clays or dolosilts, and fossilized shell material (Scott, 1988 and Bennett and Rectenwald, 2004). The formation occurs from approximately 20 to 220 feet bls. The Peace River formation has been subdivided into two named members, the Cape Coral Clay member and the Lehigh Acres Sandstone member. The Cape Coral Clay is predominantly a light olive gray to dark greenish gray, soft, semi-cohesive, silty clay with trace amounts of fine phosphate granules. The Lehigh Acres Sandstone member consists of calcite cemented, fossiliferous, phosphatic sandstones. Minor interbedding with dark greenish gray, phosphatic clay occurs locally.

The Lehigh Acres Sandstone was encountered in one of the four production wells, Well 3N-R, in the interval 138 to 215 feet bls. The Lehigh Acres Sandstone member does not occur throughout the Peace River Formation within Cape Coral, Florida. The occurrence of this unit may represent sand ridges. These types of deposits are formed perpendicular to coastlines in areas proximal to tidal deltas where tidal ranges are relatively large and longshore currents are not strong.

Arcadia Formation

The lower part of the Hawthorn Group, the Arcadia formation, consists predominately of limestone and dolostone containing varying amounts of quartz sand, clay and phosphate grains (Scott, 1988). The Arcadia Formation is important from a resource viewpoint as a water supply source for the City of Cape Coral. Hydrologically, it incorporates several aquifers and confining units identified within the Hawthorn Group (Scott, 1988).

The top of the Arcadia Formation was encountered at Well 1N-R at a depth of 160 feet bls, Well 2N-R at a depth of 180 feet bls, Well 3N-R at a depth of 220 feet bls, and Well 230-R at a depth of 110 feet bls. The formation is lithologically complex, containing beds of varying thickness. The limestones are light to yellowish gray micrites and biomicrites with moderate to good porosity. The formation is interbedded with yellowish gray marl or lime mud and occasional light olive gray dolomitic silty clay. Phosphate grains and granules are common to abundant throughout the Arcadia Formation. The base of the Arcadia Formation can be identified by a yellowish gray marl and a decrease in phosphate content.

Oligocene Series

Suwannee Limestone

The top of the Suwannee Limestone was encountered at Well 1N-R at a depth of 708 feet bls, Well 2N-R at a depth of 730 feet bls and Well 3N-R at a depth of 773 feet bls. The Suwannee Limestone was not encountered at Well 230-R. A regional disconformity separates the Hawthorn Group from the Suwannee Limestone. The contact between these two formations is described as a thin to absent, moderately consolidated limestone, interbedded with lime mud or marl. The contact between the Hawthorn Group and the Suwannee Limestone was identified based on interpretations from the lithology, available in the Report Supplement and the geophysical logs, available in Appendix A.

The Suwannee Limestone is yellowish gray or very pale orange micrite to biomicrite, a trace of phosphate, with a medium-grained calcarenitic texture. The unit is composed of moderately to well-sorted foraminifera, pelloids, and abraded echinoderm and mollusk fragments. The contact between the Hawthorn Group and the Suwannee Limestone is marked by an attenuation in gamma radioactivity and generally coupled with higher sonic transit times as compared to the basal facies of the Arcadia Formation.

2.1.2 Hydrostratigraphy

Three major aquifer systems underlie Cape Coral, Florida: the Surficial Aquifer System (SAS), the Intermediate Aquifer System (IAS), and the Floridan Aquifer System (FAS). These aquifer systems are composed of multiple, discrete aquifers separated by low permeability semi-confining units that occur throughout this Tertiary/Quaternary age sequence.

Surficial Aquifer System

The SAS consists of the water-table aquifer and hydraulically connected units above the top of the first occurrence of laterally extensive and vertically persistent beds of much lower permeability (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986). In Cape Coral, the SAS occurs within the undifferentiated Plio-Pleistocene water saturated sediments of the Pamlico Sand Formation and Undifferentiated Fort Thompson/Caloosahatchee strata. The base of the surficial aquifer occurs at contact with the Cape Coral Clay Member of the Hawthorn Group at depths ranging from 20 to 50 feet bls in the four replacement wells. The aquifer is unconfined and in direct contact with atmospheric pressure. Recharge to the aquifer originates principally from rainfall, with some secondary recharge emanating from leakage from surface water bodies and up gradient groundwater flow. Discharge from the surficial aquifer occurs through evapotranspiration, drainage to surface water bodies, downward leakance, lateral flow, and pumping of wells.

Intermediate Aquifer System

Aquifers that lie beneath the SAS and above the FAS in southwestern Florida are grouped within the IAS (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986). The IAS does not outcrop in the Cape Coral area and contains water under confined conditions (Miller, 1986).

Multiple productive horizons within the IAS, separated by low permeability interaquifer confining units, were identified during drilling and testing operations. The Sandstone Aquifer, intermittently present in Cape Coral, occurs within the Lehigh Acres Sandstone member of the Peace River formation and was only encountered at Well 3N-R in the interval 138 to 215 feet bls. The aquifer consists of friable sandstone in a calcareous matrix, with thin interbedding of cohesive clay towards the base.

A second productive horizon, locally called the Mid-Hawthorn Aquifer, occurs within limestones in the upper part of the Arcadia Formation of the Hawthorn Group (Knapp *et al.*, 1986 and Miller, 1986). The Mid-Hawthorn Aquifer, although previously used by Cape Coral as a municipal water supply source, does not yield large quantities of water and is not a viable source for public water supply. The transmissivity of the aquifer in the City ranges from 10,000 to 20,000 gallons per day per foot (gpd/ft) (Missimer & Associates, 1989). Discharge from the aquifer is due to pumping and lateral outflow to down gradient 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 in the future by the SFWMD due to the water level periodically approaching minimal operational levels during the dry season. The minimum operation level for confined aquifers is 20 feet above the top of the aquifer.

Floridan Aquifer System

The FAS is defined as a vertically continuous sequence of permeable carbonate rocks of Tertiary age that are hydraulically connected in varying degrees, and whose permeability is generally several orders of magnitude greater than that of the rocks that bound the system above and below (Miller, 1986). The FAS in the City of Cape Coral is composed predominately of limestone with dolomitic limestone and dolomite. The FAS is further subdivided into the Upper Floridan Aquifer (UFA), Middle Confining Unit, and Lower Floridan Aquifer. The UFA was the only Floridan Aquifer System hydrogeologic unit encountered during the construction of the four wells. The top of the FAS, as defined by the Southeastern Geological Society AdHoc Committee on Florida Hydrostratigraphic Unit Definition (1986) coincides with the top of a vertically continuous permeable early Miocene to Oligocene-age carbonate sequence.

Upper Floridan Aquifer

Locally, the UFA occurs from approximately 340 to 1,200 feet bls and consists primarily of permeable zones in the Lower Hawthorn Aquifer and Suwannee Limestone. In Cape Coral, the UFA is considered the only suitable potential source of groundwater for public water supply. The most transmissive portion of this zone occurs near the top, coincident with an unconformity at the top of the Oligocene age formations (Miller, 1986).

The Lower Hawthorn Aquifer (LHA) occurs within the Arcadia Formation of the Hawthorn Group and makes up the upper most part of the Upper Floridan aquifer. The limestones are moderately hard, have a moderate to high intergranular porosity and shell beds, and can have high moldic porosity. The LHA 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).

The top of the LHA was encountered at Well 1N-R at a depth of 480 feet bls, Well 2N-R at a depth of 500 feet bls, Well 3N-R at a depth of 540 feet bls, and Well 230-R at a depth of 500 feet bls. The thickness of the LHA is also variable, with an associated variability in production characteristics.

Raw water production for the City is predominantly from the LHA. The potentiometric surface of the LHA in northern Cape Coral ranges between 16 and 22 feet above land surface at the three replacement wells drilled in northern Cape Coral to 21 feet below land surface for Well 230-R, located in southern Cape Coral. The potentiometric surface in Cape Coral decreases to the southwest and the four replacement wells are consistent with that trend.

Groundwater flow direction in the LHA is generally to the southwest. The aquifer is recharged primarily from outside the county in central Florida. The hydraulic characteristics of the LHA vary considerably in aerial extent. The transmissivity of the LHA beneath Cape Coral is estimated to be approximately 24,000 to 92,000 gpd/ft based on published data (Missimer and Associates, Inc., 1991). The storage coefficient is estimated at 5.7×10^{-5} to 2.0×10^{-4} and leakance from 4.6×10^{-4} to 1.5×10^{-2} gpd/ft^3 (Missimer and Associates, Inc., 1991). The leakance direction within the LHA is primarily down to the underlying Suwannee Limestone through a semi-confining layer separating the two aquifers.

The top of the Suwannee Limestone in the replacement wells was encountered at depths between 708 and 773 feet bls, with variable confinement from the LHA above. Regional confining beds between the two aquifers vary in thickness 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 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 transmissivity of the upper part of the Suwannee Limestone in Cape Coral ranges from approximately 20,000 to 68,000 gpd/ft, with a storage coefficient of 2.5 x 10^{-4}, and a leakance of 1 x 10^{-2} gpd/ft^3 (Missimer and Associates, 1989 and MWH Americas, 2009).

3.0 Well Construction and Development

Design Services and Engineering Services During Construction were conducted by MWH Americas (MWHA). The Construction Manager was MWH Constructors (MWHC) who conducted work under a Contract Manager at risk contract framework. MWHA designed and managed the construction of the four replacement production wells. A typical production well diagram is presented as Figure 3-1. Well construction included borehole drilling and installation of surface casing and final casing. A MWHA geologist observed the drilling operations and selected casing depths and total depths of the wells based on physical and chemical characteristics of the borehole. Specifically, field analysis of formation samples, water quality, apparent well yield, and geophysical testing during drilling were conducted during well construction. Well development was performed following well construction and included water quality analysis and measurement of suspended solids.

3.1.1 Well Construction

The well construction was performed by Diversified Drilling Corporation (DDC) of Lehigh Acres, Florida, who was subcontracted to MWHC. DDC used mud rotary and reverse air techniques during drilling operations. Formation samples were collected and archived in 10-foot intervals. The methods and materials used by the contractor were in accordance with the standards of the American Water Works Association (AWWA), the American Society for Testing and Materials (ASTM), and the technical specifications outlined in the contract documents.

Construction of the wells began on February 4, 2008 at Well 230-R and was completed on May 14, 2009 at Well 2N-R. Nominal 28-inch diameter boreholes were drilled via mud rotary method from land surface to 40 feet bls into the first confining unit. A 20-inch diameter steel casing (ASTM A53 Grade B) was installed into the confining unit. The steel casing was then grouted in place with ASTM Type II neat cement, which cured for a minimum of 12 hours before drilling resumed.

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 MWHA 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, Youngquist Brothers and Aquifer Data Systems conducted formation evaluation and borehole logging operations at various stages in construction as detailed in section 4-3.

Upon review of the geophysical logs and lithologic descriptions, the pilot hole was reamed via the mud rotary method to a nominal 19-inch diameter borehole to a depth selected for final well casing installation. Caliper and gamma ray geophysical logs were completed prior to casing installation for reference during cementing operations. Fiberglass Reinforced Plastic (FRP) casing, 12-inch diameter, was installed in the four production wells. The annular space between the casing and the borehole was grouted in place to land surface. Surface and final casing setting depths of the individual wells

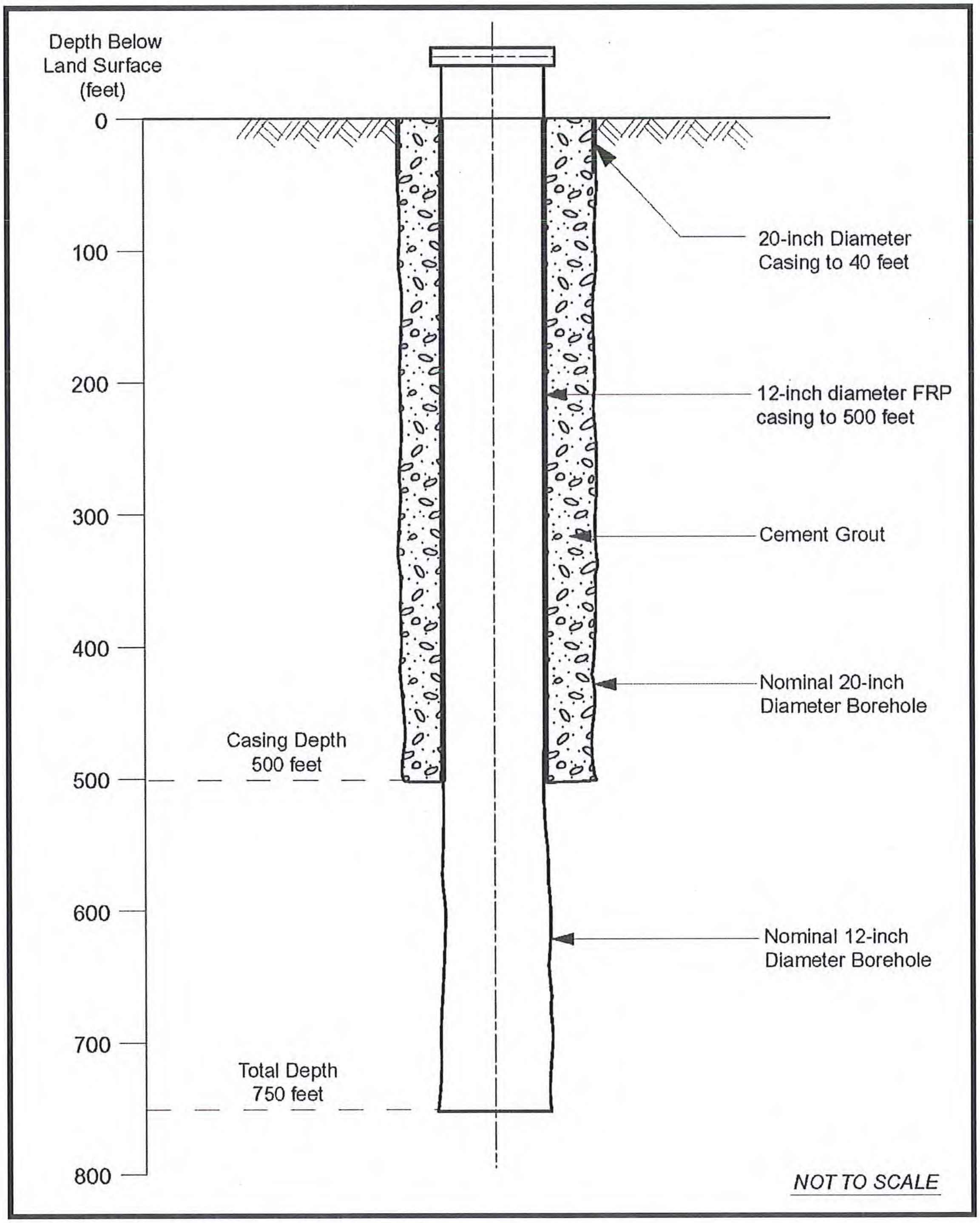

Figure 3-1 Typical Production Well Diagram

are included in Table 3-1. A summary of the volume and type of cement used is provided in Table 3-2.

Table 3-1 Well Construction Details

Well ID	Completion Date	Production Casing Type	Casing ID (inches)	Casing Depth (feet bls)	Total Depth (feet bls)
1N-R	5-28-08	FRP	12	500	762
2N-R	5-14-09	FRP	12	745	1100
3N-R	7-7-08	FRP	12	590	883
230-R	4-22-08	FRP	12	505	720

Table 3-2 Casing Cementing Summary

Well	Cement Stage	Casing Type	Volume (Barrels)	ASTM Type II Cement	Feet of Fill
1N-R	1	Steel	1.3	Neat	40
	1A	FRP	97	6%	-
	1B	FRP	21	Neat	500
2N-R	1	Steel	9	Neat	40
	1A	FRP	31	6%	-
	1B	FRP	31	Neat	378
	2	FRP	59	6%	367
3N-R	1	Steel	13	Neat	40
	1A	FRP	70	6%	-
	1B	FRP	44	Neat	510
	2	FRP	14	6%	80
230-R	1	Steel	14	Neat	40
	1A	FRP	43	6%	-
	1B	FRP	30	Neat	134
	2	FRP	50	6%	209
	3	FRP	39	6%	162

Once the production casing was installed, reverse air drilling methods were used to complete the wells. A nominal 12-inch diameter borehole was drilled through the production interval. Production intervals varied in thickness from a minimum of 215 feet (Well 230-R) to a maximum of 355 feet (Well 2N-R). Water samples were collected and specific capacity testing conducted approximately every 20-30 feet (at end of each drill rod) during reverse air drilling operations. To evaluate vertical variations in water quality, field parameters recorded include specific conductivity, chloride concentration, pH, and temperature. MWHA determined the final well depth based on interpretation of lithology, water quality and apparent well yield. Final well depths ranged from 720 ft bls (Well 230-R) to 1100 ft bls (Well 2N-R).

3.1.2 Well Development

Development of the completed wells commenced after reaching total depth to ensure the wells were of acceptable quality for reverse osmosis treatment. Air development and pump development were used to ensure that the wells were free of sediments. The development techniques used for each well were dependant on the physical state of the boreholes upon completion of drilling and the surface drainage available. Field parameters, such as specific conductivity, chloride concentration, pH, and temperature measurements were recorded during development. Additionally Silt Density Index (SDI) analyses, Rossum sand sampling and turbidity testing were performed to quantitatively measure suspended solids of the water produced.

After the completion of construction, the wells were developed using reverse air or straight air for approximately 4 - 8 hours. Water samples were collected approximately every 60 minutes during air development and analyzed for field parameters.

Following air development, the wells were then developed with a submersible pump set between 60 and 100 feet bls. Pump development typically lasted for 4 to 10 hours. During this phase of development, the wells were generally surged every 1 to 2 hours. In addition to the field parameters, water samples were collected and analyzed for sand content and silt density index to quantify suspended solids during development. The productions wells were sufficiently free of suspended particulate matter after using these development methods. The final water quality and suspended solids measurements during pump development are presented in Table 3-3 and 3-4, respectively. A more detailed analysis for each well is provided in Appendix C.

Table 3-3 Final Pump Development Water Quality

Well Number	**Specific Conductivity** (µS/cm)	**pH** (S.U.)	**Temperature** (°C)	**Chloride Concentration** (mg/L)
1N-R	2,649	7.37	30.28	775
2N-R	2,316	7.50	29.80	462
3N-R	1,931	7.70	29.70	675
230-R	1,796	7.17	23.83	575

°C-Degrees Celsius
µS/cm- Micro Siemens per Centimeter
mg/L- Milligrams per Liter
S.U.-Standard Units

Table 3-4 Final Pump Development Suspended Solids

Well Number	**Pump Rate** (gpm)	**SDI** (unitless)	**Sand** (ppm)	**Turbidity** (NTU)
1N-R	975	0.65	0.35	1.16
2N-R	1,025	0.74	0.40	0.33
3N-R	950	0.40	0.44	2.09
230-R	875	1.41	0.84	0.74

ppm – parts per million
gpm – gallons per minute
NTU-Nephelometric Turbidity Units

4.0 Hydrogeological Testing and Data Collection

A MWHA geologist documented the testing and data collection operations of the four production wells. Testing included step-drawdown tests, water quality analysis and geophysical logging. Water quality and specific capacity measurements were recorded in 20-30 foot intervals. Step-drawdown testing was performed to determine specific capacity of individual production wells. Water quality testing and analysis were also performed to characterize the geochemistry of the production wells. Geophysical logging was performed at specific phases of well construction and at completion.

4.1.1 Water Quality During Drilling

Water quality was recorded at 20-30 foot intervals (depending on drill pipe length) in the pilot hole during open circulation reverse-air drilling. Samples were collected from the discharge point of the fluid circulation system. The samples were analyzed on-site for specific conductivity, chloride, pH and temperature. The water samples from reverse-air drilling method provide an indication of relative water quality trends versus depth. Pilot hole water quality measurements are presented in Appendix C. Reverse-air water quality samples indicated both specific conductivity and chloride measurements generally increased with depth.

4.1.2 Specific Capacity During Drilling

Specific capacity testing was performed at 20-30 foot intervals in the pilot hole during reverse-air drilling. Drilling operations were halted while each test was conducted to determine static water level in the pilot hole and the flow rate developed during airlifting. The resultant specific capacity measurement is an approximate indication of flow at that depth, relative to the rest of the pilot hole. Results of the specific capacity with depth are provided in Appendix D. Specific Capacity measurements during drilling operations indicate a gradual increase in productivity with depth.

4.1.3 Step-Drawdown Testing

Upon completion of well drilling and development, step-drawdown tests were conducted to measure specific capacity at various pumping rates, determine operational pump rates and determine submersible pump setting depths. Each of the four production wells were 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 submersible pump set at a depth between 60 to 100 feet bls. An initial flow rate of at least 200 gallons per minute (gpm) was increased incrementally through four or five steps to a maximum pump rate of approximately 1,000 gpm. The static water level prior to the beginning of the test, ranged between +22.0 feet above land surface at Well 2N-R to -24.0 feet below land surface at Well 230-R. The static water level measurements represent potentiometric surfaces prior to pumping. Water levels were measured continuously during pumping and recovery 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 E.

Specific capacity is expressed in gallons per minute per foot (gpm/ft) of drawdown and is an indication of well productivity. The wells exhibit yield potential with specific capacities that range from 17.3 to 23.1 gpm/ft at approximately 600 gpm. A summary of the test results, including the drawdown and calculated specific capacity values for each step, is included in Table 4-1. The variability of the well production rates reflects the heterogeneous nature of the Lower Hawthorn and Suwannee Aquifers. The test results show the four replacement wells have relatively high yields. The anticipated drawdown in each well at the recommended pump rates is discussed in Section 5.0.

Table 4-1 Step Drawdown Test Results

Well 1N-R		
Static Water Level: +15.6 feet above land surface		
Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
260	9.7	26.8
550	23.7	23.2
600	26.0	23.1
800	39.5	20.3
970	51.6	18.8

Well 2N-R		
Static Water Level: +22.0 feet above land surface		
Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
400	18.0	22.2
600	30.0	20.0
800	40.7	19.6
1000	52.8	18.9

Well 3N-R		
Static Water Level: +20.0 feet above land surface		
Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
200	10.6	18.9
425	24.5	17.4
600	34.6	17.3
775	48.7	15.9
950	63.0	15.1

Well 230-R		
Static Water Level: -24.0 feet below land surface		
Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)
390	4.9	79.6
550	24.5	22.4
700	35.1	19.9
875	49.6	17.6

4.1.4 Production Water Quality

The field and laboratory water quality results obtained indicate that the water quality in the new wells is suitable for reverse osmosis treatment. The four replacement production wells were sampled and analyzed by Sanders Laboratories Inc., Nokomis, Florida for Primary & Secondary drinking water standard parameters. Analytical results of Primary & Secondary drinking water parameters are provided in Table 4-2. The complete laboratory results are provided in Appendix F.

Inorganic constituents included in the primary drinking water standards were all below detection limits (BDL) or below practical quantitation limits (BQL) in the new production wells except chloride, fluoride, iron, odor, sodium, and sulfate. Constituents that exceed the drinking water standard maximum concentration level (MCL) are shown in Table 4-2. As anticipated, the brackish raw water supplying the NROWTP exceeds the primary drinking water standard MCL of 160 mg/L for sodium in all four wells with concentrations in the wellfield ranging from 280 mg/L in Well 1N-R to 365 mg/L in Well 3N-R. Additionally, elevated levels of Radium 226 (detected in wells 1N-R, 2N-R, and 3N-R) and Gross Alpha particle activity (detected in wells 1N-R, 2N-R, and 3N-R) of naturally occurring radionuclide's exceed the primary drinking water standard MCLs of 5 and 15 pico Curies per liter (pCi/L), respectively. No organic contaminants were detected above practical quantitation limits in any of the replacement production wells.

Typical for brackish water, the raw water from these production wells exceeds Secondary drinking water MCLs for chloride (250 mg/L), TDS (500 mg/L), sulfate (250 mg/L), and odor (3 threshold odor number). Groundwater samples from the wells exceeded the drinking water standard for chloride with concentrations in the wellfield ranging from 508 mg/L in Well 230-R to 784 mg/L in Well 1N-R. Similarly, groundwater samples from the wells exceeded the drinking water standard for TDS with concentrations ranging from 1,240 mg/L in Well 230-R to 1,600 mg/L in Well 1N-R. Samples from three of the four wells exceeded the drinking water standard for sulfate with concentrations ranging from 203 mg/L in Well 230-R to 315 mg/L in Well 3N-R. Samples from all four wells exceeded the drinking water standard for odor with concentrations ranging from 8 in Well 230-R to 50 threshold odor number (TON) in Well 2N-R.

The groundwater samples for the completed wells were also analyzed for major cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) and anions (Cl^-, $CaCO_3$, and $SO4^{2-}$). Table 4-3, contains the major cation and anion results from the groundwater samples collected from each well. Ionic balance ratios were calculated from each groundwater sample to determine the accuracy of the data. The percentages of error calculated from the ionic balance of each groundwater sample were 10% or below making the results acceptable (McGinnes, 2005).

The data in Table 4-3 indicates that sodium (Na^+) and chloride (Cl^-) are the dominant ions for the brackish water wells in the North and South Wellfield. The results from the inorganic analysis are plotted on a Piper Trilinear diagram in Figure 4-1.

Monthly measurement of dissolved chloride concentrations in production wells is required by the SFWMD. Primary and secondary water quality analysis should be performed and reviewed periodically to assess wellfield water quality changes over time.

Table 4-2 Water Quality Results

Constituent	Unit	MCL	1N-R	2N-R	3N-R	230-R
Primary Inorganic						
Antimony	mg/L	0.006	BDL	BDL	BDL	BDL
Arsenic	mg/L	0.05	BDL	BDL	BDL	BDL
Asbestos	mg/L	7	BDL	BDL	BDL	BDL
Barium	mg/L	2	0.045	0.026	0.033	0.016
Beryllium	mg/L	0.004	BDL	BDL	BDL	BDL
Cadmium	mg/L	0.005	BDL	BDL	BDL	BDL
Chromium	mg/L	0.1	BDL	BDL	BDL	BDL
Cyanide	mg/L	0.2	BDL	BDL	BDL	BDL
Fluoride	mg/L	4.0	1.2	1.4	1.3	2.2
Lead	mg/L	0.015	BDL	BDL	BDL	BDL
Mercury	mg/L	0.002	BDL	BDL	BDL	BDL
Nickel	mg/L	0.1	BDL	BDL	BDL	BDL
Nitrate	mg/L	10	BDL	BDL	BDL	BDL
Nitrite	mg/L	1	BDL	BDL	BDL	BDL
Selenium	mg/L	0.05	BDL	BDL	BDL	BDL
Sodium	mg/L	160	365	320	280	336
Thallium	mg/L	0.002	BDL	BDL	BDL	BDL
Radionuclides						
Radium 226	pCi/L	-	14	6.3	5.9	2.4
Radium 228	pCi/L	-	BDL	BDL	BDL	BDL
Gross Alpha	pCi/L	15	90	16	29	10
Secondary Inorganic						
Aluminum	mg/L	0.2	BDL	BDL	BDL	0.138
Chloride	mg/L	250	784	522	714	508
Copper	mg/L	1	BDL	BDL	BDL	BDL
Fluoride	mg/L	2	1.2	1.4	1.3	2.2
Iron	mg/L	0.3	BDL	BDL	0.045	0.362
Manganese	mg/L	0.05	BDL	BDL	0.002	0.003
Silver	mg/L	0.1	BDL	BDL	BDL	BDL
Sulfate	mg/L	250	275	304	315	203
Zinc	mg/L	5	0.003	BDL	0.005	0.035
Color	CU	15	5	5	5	5
Odor	TON	3	12	50	17	8
pH (field)	SU	6.5-8.5	7.52	7.46	7.46	7.74
Total Dissolved Solids	mg/L	500	1,600	1,360	1,590	1,240

Table 4-3 Summary of Major Cation and Anion Laboratory Results

Well Name	Cations (mg/L)				Anions (mg/L)			Ionic Balance % Error	TDS (mg/L)
	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	Alka as $CaCO_3$	SO_4^{2-}		
1N-R	365	18.4	116	88.6	784	122	275	10	1,600
2N-R	320	18	80	75	522	147	304	2	1,360
3N-R	280	21.4	102	83.7	714	141	315	-7	1,590
230-R	336	20.7	57.6	71.0	508	320	203	0	1,240

mg/L - milligrams per liter
% - percent
TDS- total dissolved solids
Alka - Alkalinity

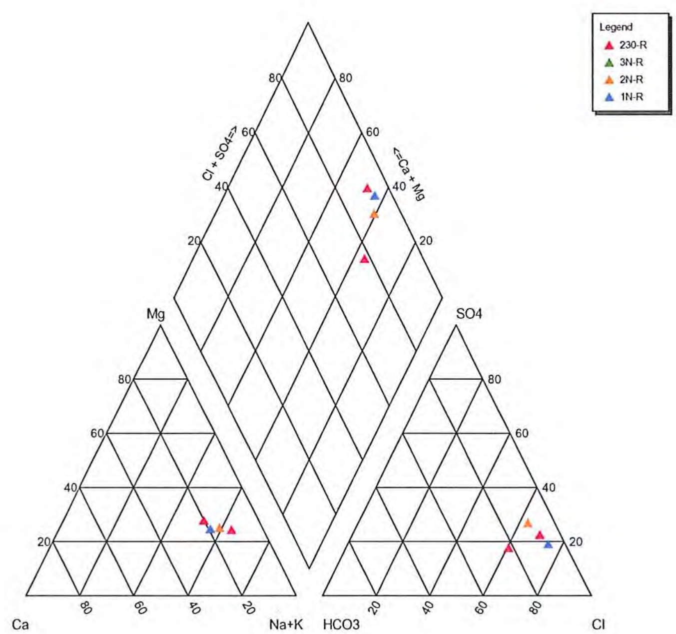

Figure 4-1 Piper Trilinear Diagram of Inorganic Constituents

4.1.5 Geophysical Logging

Geophysical logging was conducted by MV Geophysical Surveys, Inc., Youngquist Geophysical Services and Aquifer Data Systems, subcontracted by DDC and under the supervision of MWHA on each new production well. Geophysical logging performed during the construction was designed to collect information on the hydrogeology and borehole geometry. The geophysical logging suites performed on the pilot hole included XY-caliper, natural gamma ray, spontaneous potential, dual induction and borehole compensated sonic. Geophysical logging 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 survey.

A summary of all the geophysical logs run on the four replacement wells is provided in Table 4-4. Geophysical logs and video surveys conducted on the production wells are provided in Appendix A.

Table 4-4 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	Comments
1N-R	4-11-08	0-523	X	X	X	X						9.625-inch Pilot Hole
	4-18-08	0-502	X	X								18.75-inch Reamed Hole
	5-28-08	0-762	X	X	X	X	X	X	X	X	X	Final Logging
2N-R	3-12-09	0-810	X	X	X	X				X		7.875-inch Pilot Hole
	4-1-09	0-748	X	X								18.75-inch Reamed Hole
	4-7-09	0-748	X									18.75-inch Ream to Rework
	5-14-09	0-1100	X	X	X	X	X	X	X	X	X	Final Logging
3N-R	5-14-08	0-603	X	X	X	X						9.625-inch Pilot Hole
	6-3-08	0-593	X	X								18.75-inch Reamed Hole
	7-7-08	0-883	X	X	X	X	X	X	X	X	X	Final Logging
230-R	2-11-08	0-430	X	X	X	X						9.25-inch Pilot Hole
	2-13-08	0-500	X	X	X	X						9.25-inch for Additional Depth
	3-14-08	0-513	X	X								18.75-inch Reamed Hole
	4-22-08	0-720	X	X	X	X	X	X	X	X	X	Final Logging

5.0 Wellfield Operation

5.1.1 Well Pumping Equipment and Pumping Rates

A submersible well pump manufactured by Goulds Corporation, model No. 9CNLC (316 Stainless Steel) was installed in all four replacement wells. The Goulds pumps are equipped with a 50 hp electric motor and set on a 6-inch diameter Certa-Lock PVC column pipe to a depth of 120 feet bls. The operating range for the pump is from approximately 400 to 800 gpm.

To minimize stress on the aquifer, the recommended pumping rates for the new replacement wells range from 550 gpm to a maximum of 600 gpm. At the proposed maximum recommended pumping rates, pumping water levels in the wells are not expected to exceed 50 feet bls. The pump setting depth and recommended pumping rates are summarized in Table 5-1.

Based on the well performance test results obtained to date and the velocity capacities of a 12-inch diameter casing and open hole, there is no need to change the currently designed well sizing. The production wells are being constructed using 12-inch diameter FRP production casing which is adequate for the target production rates for these wells.

Well production in the UFA is variable, reflecting the heterogeneous nature of the carbonate aquifer. The specific capacities in the new wells range from 17.3 gpm/ft (Well 3N-R) to 23.1 gpm/ft (Well 1N-R) with a pumping rate at approximately 600 gpm.

Table 5-1 Recommended Pump Settings and Pumping Rates

Well ID	Casing Depth (feet bls)	Pump Setting Depth (feet bls)	Recommended Pumping Rate (gpm)
1N-R	500	120	600
2N-R	745	120	600
3N-R	590	120	600
230-R	505	120	550

5.2 Wellfield Operation

5.2.1 North Wellfield

The NROWTP is currently in the final phase of construction. The North Wellfield expansion will increase the finished water to nearly 30 million gallons per day (mgd), with 12 mgd provided by the NROWTP.

The North Wellfield consists of 22 production wells supplying the NROWTP. Of those 22 wells supplying the NROWTP, up to of 7 wells will provide standby capacity with all four trains operating. A summary of the water demands and production of the NROWTP, assuming all the trains are operating, is provided in Table 5-2.

Table 5-2 North Treatment Plant Production Summary

Process	Phase 1
Raw Water (gpm)*	10,060
Wells in Operation	19
Number of Trains	4
Bypass (gpm)	1,380
Feed Flow per Train (gpm)	2,170
Permeate Flow Per Train (gpm)	1,730
Blended Product (gpm)	8,300

*Assuming the average production per well is 550 gpm.

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.

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 may be recommended if specific capacity declines by 25% or more. Wells with high specific capacities may not be rehabilitated at the same frequency as wells with a much lower specific capacity.

5.2.2 Southwest Wellfield

The SWROWTP 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 1-1.

The SWROWTP has recently undergone a plant expansion. The expansion has increased 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 recommended in the Southwest Wellfield Expansion Well Report (MWH, 2007), Well 230-R was constructed to provide the needed additional standby capacity to Plant #2. A summary of the water demands and production of the SW ROWTP assuming all the trains are on is provided in Table 5-3.

Table 5-3 Southwest 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

Currently, the operators at the SWROWTP 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 drawdown 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.

5.2.3 Monitoring and Maintenance

The SFWMD Water Use Permit No. 36-00046-W, which was recently modified, allows a maximum monthly withdrawal of 1,312 million gallons from the UFA. Monitoring of the wellfield facilities are required by Limiting Conditions of the City's Public Water Supply Water Use Permit. The most pertinent well and wellfield monitoring requirements are specified in Limiting Conditions 17, 18, 20, 28 and 29 of the WUP. Limiting Condition 18 requires that pumping records in the form of monthly withdrawals be recorded for each production well. The re-calibration of water use accounting flow meters is required every five years under Limiting Condition 17. Limiting Condition 20 requires that all "unaccounted for" distribution system losses be determined monthly and submitted to the District on a yearly basis. Limiting Condition 28 requires the permittee to make monthly chloride concentration measurements for each production well. Monitoring data required under the saline water intrusion-monitoring program is required by Limiting Condition 29.

5.2.4 Recommendations

Water quality in the wells is generally similar to other wells in the existing North and South Wellfield. The RO water treatment methods used by the City of Cape Coral will produce water that meets current state and federal drinking water standards.

Pumping records and water quality monitoring for each replacement 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 up coning, 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 in production wells with original specific capacities less than 50 gpm/ft.

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.

6.0 References

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Report Supplement

Lithologic Logs

MWH

LITHOLOGY

W-2C NORTH WELLFIELD

WELL NUMBER	1N-R
Job Number	3220194
Owner	City of Cape Coral

DEPTH (ft bls)	DESCRIPTION
0-20	Sandy Shell Fragments: greenish gray 5GY 6/1 to yellowish gray 5Y 8/1; friable; moderate induration; predominantly bivalves.
20-50	Silty Clay (50%): grayish olive 10Y 4/2; soft; moderate plasticity Shell Fragments (50%): pale yellowish brown 10YR 6/2 to white N9; moderate porosity (intergranular); predominantly bivalves.
50-70	Marly Limestone: light gray N7; micrite; friable; low intergranular permeability; trace moldic; trace bivalve shell fragments.
70-90	Marl: light gray N7; very soft; moderate plasticity; friable micrite and bivalve shell fragments (30%).
90-120	Marl: medium light gray N6; moderately stiff; high plasticity; friable micrite and bivalve shell fragments (10%).
120-140	Sand: grayish olive 10 Y 4/2; very fine grained; well sorted; sub-angular; friable micrite and bivalve shell fragments (35%).
140-160	Silty Clay: grayish olive 10 Y 4/2; moderately stiff; low plasticity; friable micrite and bivalve shell fragments (20%); trace very coarse grained phosphate.
160-190	Limestone: very light gray N8; micrite; moderately hard; poor intergranular porosity; grayish olive clay (25%); very fine grained phosphate (10%).
190-220	Limestone: white N9 to very light gray N8; biomicrite; moderately hard to friable; poor intergranular porosity; grayish olive clay (30%); very fine to fine grained phosphate (15%).
220-230	Limestone: white N9 to very light gray N8; biomicrite; moderately hard to friable; poor intergranular porosity; grayish olive clay (40%); very fine to fine grained phosphate (15%); trace polyethylene fibers from drilling mud additive.
230-250	Clay: greenish gray 5 GY 6/1; moderately stiff; low plasticity; friable micrite and bivalve shell fragments (25%); trace very fine grained phosphate; trace polyethylene fibers from drilling mud additive.
250-270	Limestone: yellowish gray 5Y 8/1 to light olive gray 5Y 6/1; micrite; moderately friable; poor intergranular porosity; grayish olive clay (40%); very fine grained phosphate (2%); trace polyethylene fibers from drilling mud additive.
270-290	Clay: light olive gray 5Y 5/2; moderately stiff; low plasticity; friable micrite and bivalve shell fragments (20%); very fine grained phosphate; trace polyethylene fibers from drilling mud additive.
290-310	Marl: light olive gray 5Y 5/2; moderately stiff; low plasticity; friable micrite and bivalve shell fragments (15%); very fine grained phosphate (7%); trace polyethylene fibers from drilling mud additive.
310-330	Limestone: yellowish gray 5Y 8/1 to light olive gray 5Y 6/1; micrite; moderately hard; poor intergranular porosity; light olive gray clay (35%); very fine grained phosphate (12%); trace sparite; trace polyethylene fibers from drilling mud additive.
330-350	Limestone: yellowish gray 5Y 8/1 to light olive gray 5Y 6/1; biomicrite; moderately hard;

DEPTH (ft bls)	DESCRIPTION
	poor intergranular porosity; light olive gray clay (35%); very fine to coarse grained phosphate (12%); trace polyethylene fibers from drilling mud additive.
350-370	Marl: light gray N7; moderately soft; moderate plasticity; friable limestone and shell fragments (25%); very fine grained phosphate (8%); trace polyethylene fibers from drilling mud additive.
370-400	Clay: very light gray N8; very soft; moderately low plasticity; friable limestone and shell fragments (10%); fine to very fine grained phosphate (10%); trace polyethylene fibers from drilling mud additive.
400-430	Marl: yellowish gray 5Y 8/1; moderately soft; moderate plasticity; moldic limestone and shell fragments (20%); very fine grained phosphate (18%); trace polyethylene fibers from drilling mud additive.
430-450	Marl: light olive gray 5Y 6/1; very soft to moderately soft; moderately low plasticity; yellowish gray 5Y 8/1 limestone shell fragments (30%); medium to very fine grained phosphate (16%); trace polyethylene fibers from drilling mud additive.
450-480	Marl: light olive gray 5Y 7/2; very soft; moderately high plasticity; yellowish gray friable limestone (15%); medium to very fine grained phosphate (5%); trace polyethylene fibers from drilling mud additive.
480-490	Limestone: yellowish gray 5Y 8/1 to light olive gray 5Y 7/2; biomicrite; friable to moderately hard; moderate intergranular porosity; yellowish gray 5Y 8/1 marl (30%); medium to very fine grained phosphate (10%).
490-497	Marl: light olive gray 5Y 7/2; very soft; moderately high plasticity; yellowish gray friable limestone (15%); medium to very fine grained phosphate (5%); trace polyethylene fibers from drilling mud additive.
497-500	Limestone: yellowish gray 5Y 8/1 to light olive gray 5Y 7/2; biomicrite; friable to moderately hard; moderate intergranular porosity; yellowish gray 5Y 8/1 marl (40%); medium grained phosphate (5%).
500-520	Limestone: yellowish gray 5Y 8/1 to medium light gray N6; micrite; moderately hard; moderately high moldic and intergranular porosity; medium grained phosphate (5%); light gray N7 marl (1-2%).
520-530	Limestone: pale yellowish brown 10YR 6/2; micrite; hard to moderately friable; moderately high vuggy porosity; trace fossils (archaias?); trace very fine grained phosphate.
540-550	Limestone: yellowish gray 5Y 8/1; micrite; friable; low vuggy and moldic porosity; very fine to medium grained phosphate (17%); trace dolomite; trace fossils.
550-572	Clay: yellowish gray 5 Y 7/2; soft to moderately soft; moderately high plasticity; trace limestone.
572-580	Limestone: yellowish gray 5Y 8/1; micrite; friable; vuggy and moldic porosity; very fine to coarse grained phosphate (20%); trace sparite.
580-595	Limestone: light olive gray 5Y 5/2; micrite; moderately friable; vuggy and moldic porosity; trace fossils; trace very fine grained phosphate.
595-600	Limestone: yellowish gray 5Y 8/1 to light gray N7; micrite; friable; high moldic porosity; trace small vugs; very fine grained phosphate (2%).
600-645	Limestone: yellowish gray 5Y 8/1 to light gray N7; micrite; moderately hard; high moldic porosity; trace small vugs; trace sparite; very fine to medium grained phosphate (2%).
645-653	Dolomite: yellowish gray 5Y 8/1; sparite; very hard; low vuggy porosity.
653-657	Clay; white N9; soft; moderate plasticity; low permeability; very fine grained phosphate (7%).
657-670	Limestone: medium light gray N6 to very light gray N8; biomicrite; high moldic porosity; very fine grained phosphate (5%); trace small vugs.
670-685	Limestone: medium light gray N6; micrite; moderate vuggy porosity; trace fossils; very fine grained phosphate (1%).
685-700	Limestone: yellowish gray 5Y 8/1 to light gray N7; micrite; friable; high moldic and vuggy porosity; trace sparite; very fine grained phosphate (2%).

DEPTH (ft bls)	DESCRIPTION
700-710	Clay; white N9; soft; low plasticity; low permeability; very fine to coarse grained phosphate (5%).
710-720	Limestone: very pale orange 10 YR 8/2; biomicrite; very hard; moderate moldic porosity; trace sparite.
720-735	Clay; white N9; soft; low plasticity; low permeability.
735-762	Limestone: very pale orange 10 YR 8/2; micrite; very hard; moderate vuggy porosity; trace sparite.

MWH

LITHOLOGY

North Wellfield
2N - Replacement

Well Number	2N-R (L1043)
Permit Number	
Job Number	3220194.363802
Owner	City of Cape Coral

Depth (ft bls)	Description
0-10	Shell Fragments (70%): very pale orange 10YR 8/2; medium light gray N6 and light gray N7; predominantly bi-valves.
10-20	Shell Fragments (70%): yellowish gray 5Y 7/2 and very light gray N8; predominantly bi-valves.
20-30	Clay (50%): yellowish gray 5Y 7/2; moderately hard. Shell Fragments (25%): medium light gray N6 and light gray N7; predominantly bi-valves. Sandstone (25%): light brown 5YR 5/6; carbonate; weathered; high porosity.
30-40	Clay: grayish olive 10Y 4/2; moderately hard; cohesive.
40-60	Clay: grayish olive 10Y 4/2; cohesive; soft.
60-80	Clay: grayish olive 10Y 4/2; cohesive; very soft.
80-90	Clay (50%): yellowish gray 5Y 7/2 to greenish gray 5GY 6/1; moderately soft. Limestone (25%): yellowish gray 5Y 7/2 and light gray N7; micrite; moderately hard; moderate porosity; trace of very fine phosphate (1-2%). Shell (25%): yellowish gray 5Y 7/2 and light gray N7.
90-110	Clay (60%): yellowish gray 5Y 7/2 to dark greenish gray 5GY 4/1; moderately soft. Limestone (20%): yellowish gray 5Y 7/2 and light gray N7; micrite; moderately hard; moderate porosity; trace of very fine phosphate (1-2%). Shell (20%): yellowish gray 5Y 7/2 and light gray N7.
110-130	Clay (80%): dark greenish gray 5GY 4/1; cohesive; moderately soft. Limestone (20%): medium light gray N6 and light gray N7; micrite; moderately hard; moderate porosity; 2-3% medium phosphate; trace of shell fragments.
130-140	Clay (90%): dark greenish gray 5GY 4/1; cohesive; moderately soft; sandy; silty. Limestone (10%): light gray N7; micrite; moderately hard; moderate porosity; 2-3% medium phosphate.
140-150	Marl (50%): yellowish gray 5Y 7/2 to very light gray N8; soft. Limestone (50%): yellowish gray to very light gray N8; micrite; moderately high moldic porosity; 7-8% medium to coarse phosphate.

Depth (ft bls)	Description
150-160	Limestone (80%): yellowish gray to very light gray N8; micrite; moderately high moldic and vuggy porosity; 8-9% fine to coarse phosphate. Marl (20%): yellowish gray 5Y 7/2 to very light gray N8; soft.
160-180	Marl (80%): light gray N7 to light olive gray 5Y 6/1; soft; 7-8% very fine phosphate. Limestone (20%): light gray N7 and yellowish gray 5GY 7/2; micrite; moderately high porosity; 5-6% very fine phosphate.
180-200	Limestone: yellowish gray 5GY 7/2 and light gray N7; micrite; high moldic and vuggy porosity; trace of shell fragments; 5-6% very fine phosphate.
200-230	Limestone (70%): yellowish gray 5GY 7/2 and medium light gray N6; biomicrite; high moldic and vuggy porosity; trace of shell fragments; 5-6% very fine phosphate. Marl (30%): yellowish gray 5GY 7/2 to light olive gray 5Y 6/1; soft.
230-250	Marl (70%): yellowish gray 5GY 7/2 to olive gray 5Y 4/1; soft 8-9% very fine phosphate. Limestone (30%): yellowish gray 5GY 7/2 and very light gray N8; biomicrite; high moldic porosity; trace of shell fragments.
250-260	Marl (90%): yellowish gray 5GY 7/2 to olive gray 5Y 4/1; soft 8-9% very fine phosphate. Limestone (10%): yellowish gray 5GY 7/2 and very light gray N8; biomicrite; high moldic porosity; trace of shell fragments.
260-300	Marl (70%): yellowish gray 5GY 7/2 to light olive gray 5Y 6/1; very soft; 7-8% very fine phosphate. Limestone (30%): yellowish gray 5Y 8/1 and very light gray N8; micrite; high moldic porosity; fossiliferous; trace of shell fragments.
300-310	Marl (80%): yellowish gray 5GY 7/2 to very light gray N8; very soft; 7-8% very fine phosphate; trace of coarse phosphate. Limestone (20%): yellowish gray 5GY 7/2 and very light gray N8; micrite; moderate porosity; trace of shell fragments.
310-330	Marl (80%): Marl (80%): yellowish gray 5GY 7/2; very soft; 8-9% very fine phosphate; trace of coarse phosphate. Limestone (10%): yellowish gray 5GY 7/2; micrite; moderate porosity; trace of shell fragments. Clay (10%): yellowish gray 5Y 7/2; soft to very soft; sandy.
330-360	Marl (70%): yellowish gray 5GY 7/2 to light olive gray 5Y 6/1; soft; 8-9% very fine phosphate; trace of coarse phosphate. Clay (20%): yellowish gray 5Y 7/2; soft to moderately soft; sandy; silty; cohesive Limestone (10%): yellowish gray 5GY 7/2 and very light gray N8.
360-380	Marl (80%): yellowish gray 5GY 7/2 to light olive gray 5Y 6/1; very soft; 8-9% very fine phosphate; trace of coarse phosphate. Clay (10%): yellowish gray 5Y 7/2; soft to moderately soft; sandy; silty; cohesive Limestone (10%): yellowish gray 5GY 7/2 and very light gray N8.
380-400	Marl (50%): yellowish gray 5GY 7/2 to light olive gray 5Y 6/1; soft; 2-3% very fine phosphate; trace of coarse phosphate.

Depth (ft bls)	Description
	Clay (30%): yellowish gray 5Y 7/2; soft to very soft; silty. Limestone (20%): yellowish gray 5GY 7/2 and very light gray N8.
400-420	Marl (60%): yellowish gray 5GY 7/2 to pale olive 10Y 6/2; soft; 2-3% very fine phosphate; trace of coarse phosphate. Limestone (20%): yellowish gray 5GY 7/2 and very light gray N8; moderate porosity; friable. Clay (20%): yellowish gray 5Y 7/2; very soft silty.
420-430	Marl (60%): pale yellowish brown 10YR 6/2; soft; 1-2% very fine phosphate. Clay (30%): mottled yellowish gray 5Y 7/2 and pale yellowish brown 10YR 6/2; very soft. Limestone (10%): very light gray N8; moderate porosity; friable.
430-450	Marl (60%): pale yellowish brown 10YR 6/2; soft; 1-2% very fine phosphate. Clay (35%): mottled yellowish gray 5Y 7/2 and pale yellowish brown 10YR 6/2; very soft. Limestone (5%): very light gray N8; moderate porosity; friable.
450-480	Clay (70%): mottled greenish gray 5GY 6/1 and medium light gray N6; soft; cohesive; 2-3% very fine phosphate. Marl (20%): light gray N7; soft. Limestone (10%): very light gray N8; friable.
480-498	Clay (50%): mottled greenish gray 5GY 6/1 and medium light gray N6; soft; cohesive; 2-3% very fine phosphate. Marl (40%): light gray N7; soft. Limestone (10%): very light gray N8; friable.
498-520	Limestone (90%): white N9 and very light gray N8; sparite; moderate intergranular porosity; friable. Marl (10%): white N9 to very light gray N8; soft; 2-3% fine phosphate; trace of coarse phosphate.
520-530	Clay (60%): pale olive 10Y 6/2; soft; 1-2% fine phosphate. Limestone (40%): yellowish gray 5Y 8/1; sparite; moderately high intergranular porosity; moderately friable.
530-540	Limestone (60%): yellowish gray 5Y 8/1; sparite; moderately high intergranular porosity. Clay (40%): light greenish gray 5GY 8/1; soft; 1-2% very fine phosphate, trace of coarse phosphate.
540-560	Limestone: white N9 to very light gray N8; biosparite; hard; high intergranular and moldic porosity; 1-2% fine phosphate.
560-570	Limestone (70%): white N9; biosparite; high intergranular moldic and vuggy porosity; moderately hard; 1-2% fine phosphate; trace of coarse phosphate. Marl (30%): white N9; soft.
570-580	Limestone: white N9 to yellowish gray 5Y 8/1; biomicrite; moderately hard; high intergranular, vuggy and moldic porosity; 1-2% fine phosphate; trace of coarse phosphate.
580-590	Limestone: white N9; biomicrite; hard; high vuggy and moldic porosity
590-610	Limestone: yellowish gray 5Y 8/1; biomicrite; moderately hard; high intergranular and

Depth (ft bls)	Description
	moldic porosity; 2-3% very fine phosphate.
610-620	Limestone (90%): yellowish gray 5Y 8/1 to very light gray N8; biomicrite; moderately friable; high intergranular and moldic porosity; 4-5% very fine phosphate. Marl (10%): yellowish gray 5Y 8/1; soft.
620-640	Limestone: yellowish gray 5Y 8/1 to very light gray N8; biomicrite; friable; high intergranular and moldic porosity; 3-4% very fine phosphate.
640-660	Marl (90%) very light gray N8; soft. Limestone (10%): very light gray; micrite; very friable; moderate porosity.
660-670	Marl (70%) very light gray N8; soft. Limestone (30%): very light gray; micrite; very friable; moderate porosity.
670-680	Limestone (90%): very light gray; biomicrite; friable; moderate moldic porosity; 2-3% very fine phosphate. Marl (10%) very light gray N8; soft.
680-690	Limestone: yellowish gray 5Y 8/1; biomicrite; friable; high intergranular, vuggy and moldic porosity; 2-3% very fine phosphate; gunteri.
690-710	Limestone (90%): yellowish gray 5Y 8/1; biomicrite; moderately friable; high intergranular, vuggy and moldic porosity; 3-4% very fine phosphate. Marl (10%): very light gray N8; soft.
710-730	Limestone (90%): yellowish gray 5Y 8/1; biomicrite; moderately hard; high vuggy and moldic porosity; 3-4% very fine phosphate. Marl (10%): very light gray N8; soft.
730-740	Limestone: light gray N7 and yellowish gray 5Y 8/1; biomicrite; friable; high intergranular, vuggy and moldic porosity; 1-2% very fine phosphate; trace of coarse phosphate.
740-750	Limestone: light gray N7, medium light gray N6, grayish orange 10YR 7/4 and very pale orange 10YR 8/2; micrite; high intergranular porosity; 1-2% very fine phosphate.
750-770	Limestone: very pale orange 10YR 8/2 and light gray N7; micrite; calcarenitic; friable; high intergranular and vuggy porosity; trace of very fine phosphate.
770-790	Limestone: very pale orange 10YR 8/2 and very light gray N8; micrite; calcarenitic; friable; high intergranular and vuggy porosity.
790-820	Limestone: very pale orange 10YR 8/2; micrite; calcarenitic; friable; high intergranular and vuggy porosity.
820-870	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; moderately friable; high intergranular, vuggy and moldic porosity.
870-880	Limestone: very pale orange 10YR 8/2 and very light gray N8; biomicrite; calcarenitic; moderately friable; high intergranular, vuggy and moldic porosity.

Depth (ft bls)	Description
880-900	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; moderately friable; high intergranular, vuggy and moldic porosity.
900-910	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; friable; high intergranular and moldic porosity.
910-950	Limestone: very pale orange 10YR 8/2 and very light gray N8; biomicrite; calcarenitic; moderately hard; high intergranular, vuggy and moldic porosity.
950-960	Marl (70%): very pale orange 10YR 8/2; soft. Limestone (30%): very pale orange 10YR 8/2 and very light gray N8; biomicrite; calcarenitic; moderately hard; high intergranular, vuggy and moldic porosity.
960-970	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; friable; high intergranular and moldic porosity.
970-980	Limestone: very pale orange 10YR 8/2; micrite; calcarenitic; moderately hard; high intergranular porosity.
980-990	Limestone: very pale orange 10YR 8/2; micrite; calcarenitic; moderately soft; high intergranular porosity.
990-1000	Limestone: very pale orange 10YR 8/2; micrite; calcarenitic; moderately hard; high intergranular porosity.
1000-1030	Limestone: very pale orange 10YR 8/2 and white N9; biomicrite; calcarenitic; soft; high intergranular porosity.
1030-1040	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; soft; high intergranular porosity.
1040-1080	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; moderately hard; high intergranular porosity.
1080-1100	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; soft; high intergranular porosity.

MWH

LITHOLOGY

North Wellfield
3N - Replacement

Well Number	3N-R
Job Number	3220194.363802
Owner	City of Cape Coral

Depth (ft bls)	Description
0-10	Shell hash, light olive gray (5Y 6/1); bi-valves, minor limestone fragments with coarse grained quartz sand in matrix, trace organics near surface, very high porosity
10-20	Shell hash, yellowish gray (5Y 8/1); bi-valves, minor marl with coarse grained quartz sand in matrix, high porosity
20-28	Shell hash, yellowish gray (5Y 8/1) to light olive gray (5Y 6/1); bi-valves, thin lenses of clay, common coarse grained quartz sand, high porosity
28-35	Gritty clay, light olive gray (5Y 6/1); contains minor limestone fragments with quartz sand in matrix, poor apparent porosity and permeability
35-37	Clay, dark greenish gray (5GY 4/1); very soft, trace coarse-grained sub-angular quartz sand, very poor apparent porosity and permeability
37-45	Clay, dark greenish gray (5GY 4/1); dense, tacky, clean, very poor apparent porosity and permeability
45-85	Clay, dark greenish gray (5GY 4/1); very dense, tacky, clean, very poor apparent porosity and permeability
85-96	Marl, yellowish gray (5Y 8/1); abundant shell fragments, some coarse grained carbonate sand, trace very fine phosphatic sand, poor apparent porosity and permeability
96-103	Marly clay, very light gray (N8); abundant shell fragments, minor coarse quartz sand, trace fine phosphatic sand
103-123	Clay, dark greenish-gray (5GY 4/1) to greenish-black (5GY 2/1); soft, gritty, common phosphatic nodules and fine grained sand, some medium grained carbonate sand, small intervals of shell beds within formation, very poor apparent porosity and permeability
123-130	Clay, dark greenish-gray (5GY 4/1) to greenish-black (5GY 2/1); soft, gritty, abundant phosphatic nodules and fine grained sand, some medium grained carbonate sand, common shell fragments, very poor apparent porosity and permeability
130-138	Clay, dark greenish-gray (5GY 4/1) to greenish-black (5GY 2/1); gritty, some quartz sand, abundant phosphatic nodules and fine grained sand, very poor apparent porosity and permeability

Depth (ft bls)	Description
138-141	Sandstone, light gray (N7) to greenish-gray (5GY 6/1), coarse grained quartz sand, moderately sorted, minor phosphatic sand, moderate apparent porosity and permeability
141-155	Clay, dark greenish gray (5GY 4/1); tacky, common quartz sand in matrix, minor shell fragments, minor fine phosphate nodules, very poor apparent porosity and permeability
155-160	Sandstone, light gray (N7), coarse grained quartz sand, well sorted, common fine phosphatic sand, good apparent porosity and permeability
160-165	Sandstone, light gray (N7), coarse grained quartz sand, well sorted, common fine phosphatic sand, minor shell fragments, good apparent porosity and permeability
165-175	Marl, light olive gray (5Y 6/1); common medium grain carbonate and fine grained phosphatic sand in matrix, minor shell fragments, poor apparent porosity and permeability
175-178	Marly limestone, yellowish gray (5Y 8/1); common carbonate and quartz sand in matrix, common shell fragments, common fine grained phosphatic sand, poor apparent porosity and permeability
178-183	Sandstone, grayish orange (10YR 7/4); medium to coarse grained carbonate sand, moderately sorted, abundant shell fragments, common fine grained phosphatic sand, moderate apparent porosity and permeability
183-190	Sandstone, grayish orange (10YR 7/4); primarily coarse grained quartz matrix, moderately sorted, abundant shell fragments, common fine grained phosphatic sand
190-192	Marly sandstone, greenish gray(5GY 6/1); abundant very fine phosphatic sand, coarse grained quartz sand, moderately sorted, moderate apparent porosity and permeability
192-210	Sandstone, very light gray (N8); medium to coarse grained quartz sand, moderately sorted, abundant very fine phosphatic sand, common shell fragments, good apparent porosity and permeability
210-215	Marly sandstone, very light gray (N8); medium to coarse grained quartz sand, moderately sorted, abundant very fine phosphatic sand, common shell fragments, moderated apparent porosity and permeability
215-220	Marl, light gray (N7); soft, abundant very fine phosphatic sand, some sandstone fragments (as above), minor coarse grained carbonate sand, trace shell fragments, poor apparent porosity and permeability
220-221	Limestone, olive gray (5Y 4/1); high induration, coarse grained quartz sand in matrix, common shell fragments, common fine grained phosphatic sand, trace casts and molds, good apparent porosity and permeability
221-225	Limestone, very pale orange (10YR 8/2) to grayish orange (10YR 7/4); medium to coarse grained quartz sand in matrix, moderately sorted, common fine phosphatic sand, minor shell fragments, good apparent porosity and permeability
225 – 383	Missing Cuttings

Depth (ft bls)	Description
383 – 390	Marl, light olive gray (5Y 6/1), soft, gritty, common fine grained phosphatic sand, some limestone and shell fragments, minor inter-bedded yellowish gray (5Y 8/1) marl lenses, poor apparent porosity and permeability
390-395	Marl, greenish gray (5GY 6/1), soft, gritty, common fine grained phosphatic sand, some limestone and shell fragments, minor medium grained carbonate sand, trace phosphate nodules, poor apparent porosity and permeability
396-415	Clay, light olive gray (5Y 6/1), tacky, dense, trace very fine grained phosphate sand, trace phosphate nodules, very poor apparent porosity and permeability
415-435	Clay, light olive gray (5Y 6/1), tacky, dense, gritty, minor medium grained carbonate sand, trace very fine grained phosphate sand, trace phosphate nodules, very poor apparent porosity and permeability
435-443	Marly clay, light olive gray (5Y 6/1), dense, gritty, fine to medium grained carbonate sand, very poor apparent porosity and permeability
443-463	Clay, light olive gray (5Y 6/1), dense, gritty, minor medium carbonate sand – well sorted, trace very coarse grained angular carbonate sand, very poor apparent porosity and permeability
463 – 468	Clay, olive gray (5Y 4/1), soft, sticky, clean, very poor apparent porosity and permeability
468-478	Clay, light olive gray (5Y 6/1), soft, sticky, abundant well sorted rounded phosphate granules, very poor apparent porosity and permeability
478-486	Clay, olive gray (5Y 4/1), soft, tacky, common well sorted rounded phosphate granules, very poor apparent porosity and permeability
486-493	Clay, olive black (5Y 2/1), soft, tacky, clean, very poor apparent porosity and permeability
493-529	Clay, light olive gray (5Y 6/1), soft, tacky, common well sorted rounded phosphate granules, very poor apparent porosity and permeability
529-543	Clay, yellowish gray (5Y 8/1), soft, tacky, common shell fragments (bryozoans), very poor apparent porosity and permeability
543-578	Limestone, sparse biomicrite, yellowish gray (5Y 8/1), poor induration, trace casts and molds, poor apparent porosity and permeability
578-588	Clay, olive gray (5Y 4/1), soft, tacky, very poor apparent porosity and permeability
588-603	Limestone, yellowish gray (5Y 8/1), biomicrite, moderate induration, minor casts and molds, trace shell fragments, moderate apparent porosity and permeability
603-615	Limestone, light gray (N7), sparse biomicrite, poor induration, trace casts and molds, trace vugs, trace shell fragments, good apparent porosity and permeability
615-623	Limestone, medium light gray (N6), biomicrite, moderate induration, minor coarse grained

Depth (ft bls)	Description
	quartz sand, trace casts and molds, trace shell fragments, good apparent porosity and permeability
623-635	Limestone, light gray (N7), packed biomicrite, high induration, abundant casts and molds, vuggy, minor coarse grained quartz sand, minor shell fragments, excellent apparent porosity and permeability
635-643	Limestone, yellowish gray (5Y 8/1), packed biomicrite, high induration, abundant casts and molds, vuggy, common very coarse grained quartz sand, minor shell fragments, excellent apparent porosity and permeability
643 – 663	Limestone, yellowish gray (5Y 8/1) to very pale orange (10YR 8/2), packed biomicrite, good induration, abundant casts and molds, minor shell fragments, common very coarse grained quartz sand, trace very fine phosphate sand, excellent apparent porosity and permeability
663 – 675	Limestone, very light gray (N8), biomicrite, good induration, abundant casts and molds – well preserved, minor shell fragments, common very coarse grained quartz sand, excellent apparent porosity and permeability
675 – 686	Limestone, light gray (N7), biomicrite, good induration, abundant casts and molds – well preserved, minor vugs, minor shell fragments, minor very coarse grained quartz sand, excellent apparent porosity and permeability
686 – 690	Dolostone, pale yellowish brown (10YR 4/2), micrite, very high induration, minor vugs, trace fine phosphate sand, crystalline, low apparent porosity and permeability
690 – 698	Dolostone, olive gray (5Y 4/1), micrite, very high induration, minor vugs, crystalline, low apparent porosity and permeability
698 – 703	Limestone, very pale orange (10YR 8/2), biomicrite, high induration, vuggy, common coarse grained quartz sand, minor casts and molds, trace fine grained phosphate sand, good apparent porosity and permeability
703 – 710	Limestone, yellowish gray (5Y 8/1), sparse biomicrite, high induration, trace vugs, trace shell fragments, trace fine grained phosphate sand, good apparent porosity and permeability
710 – 715	Limestone, yellowish gray (5Y 8/1), biomicrite, moderate induration, common casts and molds, minor pinpoint vugs, trace shell fragments, trace fine grained phosphate sand, good apparent porosity and permeability
715 – 723	Limestone, yellowish gray (5Y 8/1), biomicrite, low induration, common casts and mold – well preserved, minor shell fragments, trace fine grained phosphate sand, trace coarse grained quartz sand, good apparent porosity and permeability
723-730	Limestone, yellowish gray (5Y 8/1), biomicrite, high induration, abundant casts and molds, minor vugs, minor fine grained phosphate sand, minor shell fragments, good apparent porosity and permeability
730-735	Limestone, very light gray (N8), biomicrite, moderate induration, abundant casts and molds, minor fine grained phosphate sand, minor shell fragments, good apparent porosity and permeability

Depth (ft bls)	Description
735 – 743	Limestone, light gray (N7), biomicrite, moderate induration, abundant casts and molds, minor fine grained phosphate sand, minor shell fragments, good apparent porosity and permeability
743-763	Limestone, yellowish gray (5Y 8/1), packed biomicrite, high induration, minor/common coarse grained sub-rounded carbonate sand, minor shell fragments, minor casts and molds, good apparent porosity and permeability
763 – 775	Limestone, yellowish gray (5Y 8/1), biomicrite, low induration, common shell fragments, minor casts and molds, trace quartz, carbonate, and phosphate sand, excellent porosity and permeability
775 – 779	Sandy limestone, light olive gray (5Y 6/1), biomicrite, moderate induration, common fine grained quartz sand, common medium grained sub-rounded carbonate sand, trace vugs, moderate apparent porosity and permeability
779 – 783	Sandy limestone, yellowish gray (5Y 8/1), biomicrite, moderate induration, common medium grained sub-rounded carbonate sand, minor fine grained quartz sand, trace casts and molds, trace vugs, moderate apparent porosity and permeability
783 – 790	Sandy limestone, yellowish gray (5Y 8/1), biomicrite, moderate induration, coarse grained rounded carbonate sand, vuggy, minor shell fragments, minor casts and molds, good intergranular porosity, overall excellent apparent porosity and permeability
790 – 813	Limestone, grayish orange (10YR 7/4), biomicrite, moderate induration, vuggy, abundant coarse grained sub-rounded carbonate sand, common casts and molds, excellent apparent porosity and permeability
813 – 817	Limestone, yellowish gray (5Y 8/1), packed oomicrite / sparse biomicrite, moderate induration, vuggy, abundant coarse grained angular to rounded carbonate sand, poorly sorted, trace shell fragments, excellent apparent porosity and permeability
817 – 823	Limestone, grayish orange (10YR 7/4), packed oomicrite / sparse biomicrite, moderate induration, vuggy, abundant coarse grained sub-angular to sub-rounded carbonate sand, poorly sorted, minor casts and molds, excellent apparent porosity and permeability
823 - 830	Limestone, grayish orange (10YR 7/4), biomicrite, poor induration, friable, abundant very coarse to medium grained sub-rounded carbonate sand, common pin point vugs, minor shell fragments, minor-trace coarse grained sub-angular quartz sand, excellent intergranular porosity, good apparent porosity and permeability
830 – 843	Sandy limestone, yellowish gray (5Y 8/1) to grayish orange (10YR 7/4), biomicrite, poor induration, friable, abundant very coarse to medium grained sub-rounded carbonate sand, common pin point vugs, trace shell fragments, minor coarse grained sub-angular quartz sand, excellent intergranular porosity, good apparent porosity and permeability
843 – 850	Limestone, yellowish gray (5Y 8/1), micrite, poor induration, friable, abundant medium grained rounded carbonate sand well sorted, homogeneous – clean, trace pin point vugs, good intergranular porosity, good apparent porosity and permeability
850 – 855	Limestone, yellowish gray (5Y 8/1), biomicrite, moderate induration, common medium

Depth (ft bls)	Description
	grained rounded carbonate sand poorly sorted, common casts and molds, trace pin point vugs, trace shell fragments, good apparent porosity and permeability
855 – 870	Limestone, yellowish gray (5Y 8/1), sparse biomicrite, high induration, common medium grained sub-rounded carbonate sand, trace pin point vugs, trace shell fragments, good apparent porosity and permeability
870 – 873	Limestone, very pale orange (10YR 8/2), sparse biomicrite, high induration, common medium grained sub-rounded carbonate sand, trace pin point vugs, trace casts and molds, good apparent porosity and permeability
873 - 875	Limestone, yellowish gray (5Y 8/1), sparse biomicrite, high induration, common medium grained sub-rounded carbonate sand, minor vugs, minor casts and molds, good apparent porosity and permeability
875 – 883	Limestone, grayish orange (10YR 7/4), high induration, pel-biomicrite, abundant very coarse to medium grained carbonate sand poorly sorted, common casts and molds, trace shell fragments, good intergranular porosity, good apparent porosity and permeability
783 – 790	Sandy limestone, yellowish gray (5Y 8/1), biomicrite, moderate induration, coarse grained rounded carbonate sand, vuggy, minor shell fragments, minor casts and molds, good intergranular porosity, overall excellent apparent porosity and permeability
790 – 813	Limestone, grayish orange (10YR 7/4), biomicrite, moderate induration, vuggy, abundant coarse grained sub-rounded carbonate sand, common casts and molds, excellent apparent porosity and permeability
813 – 817	Limestone, yellowish gray (5Y 8/1), packed oomicrite / sparse biomicrite, moderate induration, vuggy, abundant coarse grained angular to rounded carbonate sand, poorly sorted, trace shell fragments, excellent apparent porosity and permeability
817 – 823	Limestone, grayish orange (10YR 7/4), packed oomicrite / sparse biomicrite, moderate induration, vuggy, abundant coarse grained sub-angular to sub-rounded carbonate sand, poorly sorted, minor casts and molds, excellent apparent porosity and permeability
823 - 830	Limestone, grayish orange (10YR 7/4), biomicrite, poor induration, friable, abundant very coarse to medium grained sub-rounded carbonate sand, common pin point vugs, minor shell fragments, minor-trace coarse grained sub-angular quartz sand, excellent intergranular porosity, good apparent porosity and permeability
830 – 843	Sandy limestone, yellowish gray (5Y 8/1) to grayish orange (10YR 7/4), biomicrite, poor induration, friable, abundant very coarse to medium grained sub-rounded carbonate sand, common pin point vugs, trace shell fragments, minor coarse grained sub-angular quartz sand, excellent intergranular porosity, good apparent porosity and permeability
843 – 850	Limestone, yellowish gray (5Y 8/1), micrite, poor induration, friable, abundant medium grained rounded carbonate sand well sorted, homogeneous – clean, trace pin point vugs, good intergranular porosity, good apparent porosity and permeability
850 – 855	Limestone, yellowish gray (5Y 8/1), biomicrite, moderate induration, common medium grained rounded carbonate sand poorly sorted, common casts and molds, trace pin point vugs, trace shell fragments, good apparent porosity and permeability

Depth (ft bls)	Description
855 – 870	Limestone, yellowish gray (5Y 8/1), sparse biomicrite, high induration, common medium grained sub-rounded carbonate sand, trace pin point vugs, trace shell fragments, good apparent porosity and permeability
870 – 873	Limestone, very pale orange (10YR 8/2), sparse biomicrite, high induration, common medium grained sub-rounded carbonate sand, trace pin point vugs, trace casts and molds, good apparent porosity and permeability
873 - 875	Limestone, yellowish gray (5Y 8/1), sparse biomicrite, high induration, common medium grained sub-rounded carbonate sand, minor vugs, minor casts and molds, good apparent porosity and permeability
875 – 883	Limestone, grayish orange (10YR 7/4), high induration, pel-biomicrite, abundant very coarse to medium grained carbonate sand poorly sorted, common casts and molds, trace shell fragments, good intergranular porosity, good apparent porosity and permeability

MWH

LITHOLOGY

W-2C NORTH WELLFIELD

Well Number	230-R
Job Number	3220194
Owner	City of Cape Coral

DEPTH (ft bls)	DESCRIPTION
0-10	Shell hash, ~80%, white (N9) to very pale orange (5Y 8/1), unconsolidated, ~20% quartz sand, light olive gray (5Y 6/1), very fine to medium, angular to sub-angular, trace organics, very high porosity.
10-20	Sandstone, ~80%, light olive gray (5Y 6/1), medium to fine grained, calcareous, well indurated, common very fine phosphatic sand in quartz sand matrix, ~15% limestone, yellowish gray (5Y 8/1), moderate induration, biomicrite, high porosity, ~5% calcareous silt, light olive gray (5Y 6/1), soft, sticky.
20-40	Silt, light olive gray (5Y 5/2), soft, sticky, occasional shell fragments.
40-90	Clay and silt, dusky yellow green (5GY 5/2) to mottled with grayish olive green (5GY 3/2), slightly calcareous, stiff, sticky, occasional shells, low effective porosity.
90-110	Clay and silt as above with ~20% limestone, yellowish gray (5Y 8/1), fossiliferous biomicrite, friable, low effective porosity.
110-130	Limestone, yellowish gray (5Y 8/1), fossiliferous biomicrite, friable, moderate effective porosity, clay and silt as above ~20%. Low effective porosity.
130-140	Same as above except ~10% clay.
140-150	Limestone, yellowish gray (5Y 8/1) to light olive gray (5Y 5/2), packed fossiliferous biomicrite, abundant very fine to fine black phosphatic sand, ~5% clay, dusky yellow green (5GY 5/2), stiff, sticky.
150-160	Limestone as above except common very fine to fine black phosphatic sand.
160-180	Silt, yellowish gray (5Y8/1), soft, sticky, ~60%, clay, dusky yellow green (5GY 5/2) to greenish gray (5GY 6/1), mottled, stiff, sticky, ~20%, limestone fragments as above, ~ 20%, common fine phosphatic sand, low effective porosity.
180-190	Silt as above ~50%, soft, sticky, low effective porosity, Limestone, medium gray (N5), ~50% sorted biosparite, very well indurated, copious microphosphatic sand, common shell fragments, white (N7) to yellowish gray (5Y 8/1)
190-210	Clay and silt, dusky yellowish green, (5GY 5/2), soft, silky, sticky, common shell fragments, low effective porosity. Increasing from common to abundant very fine phosphatic sand with depth.
210-240	Marl, yellowish gray (5Y 8/1) to pale olive (10Y 6/2), soft, sticky, calcareous, abundant fine phosphatic sand, ~10-20% limestone, yellowish gray (5Y 8/1), sparse biomicrite, moderate induration, low effective porosity.
240-260	Marl as above except ~25 to 35% limestone as above
260-300	Silt, pale olive, 10 Y 6/2, calcareous, soft, silky, sticky, abundant very fine phospatic sand, low effective porosity, occasionial limestone fragments as above.
300-340	Silt, dusky yellow green (5GY 5/2) to light olive gray (5Y 5/2), soft, sticky, ~ 10-20% clasts of dolomitized limestone light olive gray (5Y 5/2), microcrystalline, very well indurated, low porosity.
340-350	Sample not collected by DDC.

DEPTH (ft bls)	DESCRIPTION
350-360	Limestone, yellowish gray (5Y 7/2), micrite, friable, moderate effective porosity, ~ 20% silt as above.
360-380	Marl and silt, yellowish gray (5Y 7/2) to light olive gray (5Y 5/2), mottled, soft, sticky, ~ 10-20% limestone as above.
380-400	Marly limestone, white (N9) to yellowish gray (5Y 8/1), micrite, very friable, low to moderate effective porosity,
400-420	Same as above except ~10-20% silt, light olive gray (5Y 5/2), common fine phospatic sand.
420-430	Limestone, yellowish gray (5Y 8/1), to medium light gray, poorly washed biosparite, moderate to well indurated, moderate porosity.
430-442	Limestone, yellowish gray (5Y 8/1) to light gray (N7), fossiliferous biomicrite, moderate induration, low porosity, minor pinpoint vugs, trace very fine black phosphatic sand.
442-455	Limestone, light gray (N7) to greenish gray (5GY 6/1), sparse biomicrite, moderately friable, moderate porosity, common very fine phosphatic sand.
455-462	Limestone, yellowish gray (5Y 8/1) to light gray (N7), sparse biomicrite, good induration, fair porosity, common very fine phosphatic sand, trace (<1%) clay, olive gray (5Y 4/1) soft, sticky, low effective porosity.
462-464	Clay, greenish gray (5GY 6/1), soft, sticky, low effective porosity.
464-473	Limestone: silty, yellowish gray; (5Y 8/1), micrite, soft, very friable, low effective porosity, common very fine phosphatic sand, trace clay as above.
473-482	Dolosilt, yellowish gray (5Y 8/1), soft, sticky, ~10% limestone, yellowish gray, (5Y 8/1), micrite, very friable, trace green clay as above.
482-484	Limestone, white (N9) to yellowish gray (5Y 8/1), biomicrite, moderate induration, moderate porosity, common very fine phospatic sand.
484-490	Dolosilt, (no strong acid reaction), yellowish gray, (5Y 8/1), soft sticky, ~10% limestone, pale olive (10Y 6/2), micrite, very friable, ~5% dolostone, dusky yellow, (5Y 6/4), microcrystalline, well indurated. Overall low effective porosity.
490-500	Dolosilt, yellowish gray (5Y 8/1), soft, sticky, ~10% dolostone, dusky yellow (5Y 6/4), microcrystalline, well indurated, ~5% limestone, very pale orange (10YR 8/2), micrite, very friable, clay ~5%, greenish gray, (5GY 6/1), soft, sticky.
500-502	Limestone: white (N9) to yellowish gray (5Y 8/1); biomicrite; moderately hard; moderate moldic porosity; trace very fine grained phosphate; Marl (8%): soft; moderate plasticity.
502-505	Limestone: white (N9) to yellowish gray (5Y 8/1); biomicrite; hard; moderate moldic porosity; trace very fine grained phosphate; Marl (10%): soft; moderate plasticity.
505-510	Limestone: light gray (N7), micrite; hard; moldic porosity; Marl (1%): moderately soft; low plasticity.
510-515	Limestone, light gray (N7), biomicrite, moderately hard; high moldic porosity.
515-520	Limestone: yellowish gray 5Y 8/1, biomicrite; hard; moderately high vuggy and moldic porosity; moderate yellowish green 10 GY 6/4 staining; very fine grained phosphate (3%).
520-525	Clay: dusky yellow green 5 GY 5/2; moderately stiff; low plasticity; low permeability.
525-550	Limestone: yellowish gray 5Y 8/1 to grayish orange 10 YR 7/4, micrite; hard; moderately vuggy and moldic porosity.
550-555	Clay: yellowish gray 5Y 8/1; soft; moderately high plasticity; friable limestone (20%).
555-580	Limestone: yellowish gray 5Y 8/1 to grayish orange 10 YR 7/4, micrite; hard to friable; moderately high vuggy porosity; pelitic.
580-610	Limestone: yellowish gray 5Y 8/1 to grayish orange 10 YR 7/4, micrite; hard to friable; moderately high vuggy and moldic porosity.
610-635	Limestone: yellowish gray 5Y 8/1, micrite; hard to friable; moderately high vuggy and moldic porosity; hard, olive gray 5Y 4/1 sparite.
635-645	Clay: olive gray 5Y 4/1; moderately soft; high plasticity; low permeability.
645-650	Limestone: yellowish gray 5Y 8/1 to grayish orange 10 YR 7/4, micrite; friable; moderately high vuggy porosity; phosphate (2%).

DEPTH (ft bls)	DESCRIPTION
650-660	Limestone: yellowish gray 5Y 8/1 to light olive gray 5Y 5/2, micrite; hard to friable; moderately high vuggy and moldic porosity; thinly laminated.
660-690	Limestone: yellowish gray 5Y 8/1, micrite; hard to friable; high vuggy and moldic porosity; hard, olive gray 5Y 4/1 sparite.
690-712	Limestone: yellowish gray 5Y 7/2 to grayish orange 10YR 7/4; micrite; hard to friable; high vuggy porosity.
712-713	Clay: pale yellowish brown 10 YR 6/2; moderately stiff; moderately high plasticity; low porosity.