CDM

City of Clewiston

Water Treatment Plant Production Wells PW-1 and PW-2

April 2006

Completion Report

City of Clewiston

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April 2006

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Executive Summary

The City of Clewiston Water Treatment Plant (Clewiston WTP) will be a reverse-osmosis desalination facility that will treat brackish groundwater obtained from Upper Floridan Aquifer wells. Two test production wells (PW-1 and PW-2) were installed at the planned Clewiston WTP site, located in the Clewiston Public Works Complex on South Olympia Street and Arroyo Avenue, in order to obtain site-specific hydrogeologic data for the production wellfield. The water quality data were used for the design of the reverse–osmosis treatment system. Hydraulic data obtained from the test program were used for the final design of the production wellfield.

The test production wells were constructed of 16-inch diameter SDR-17 PVC casing set to approximately 700 feet below land surface (ft bls). The upper 200 feet of the casing was 17.4-inches in diameter to provide additional room for the pumps. The wells were completed with open hole to approximately 1,320 ft bls (PW-1) and 1,200 ft bls (PW-2).

The testing program included step-drawdown tests of each well and an aquifer performance test. The results of the testing program were highly favorable. Both wells can efficiently provide the target minimum capacity of 1,000 gallons per minute (gpm). The recommended wellfield design is a total of four wells (three primary wells and one back-up well). Each of the three primary production wells would provide approximately 900 gpm of water and would be used to supply one of the three reverse-osmosis desalination trains. This arrangement provides operational simplicity as one production well would be brought on line as each desalination train is brought on line.

The remaining two production wells (PW-3 and PW-4) are to be constructed at the Clewiston Sports Complex. It is recommended that wells PW-3 and PW-4 have the same construction of wells PW-1 and PW-2, with a final casing depth of approximately 700 ft bls and open hole to approximately 1,200 ft bls.

The chloride concentration of the production zone is approximately 1,300 milligrams per liter (mg/L), which is within the range of expected values. Most of the water production comes from between 700 and 800 ft bls. The production zone is underlain by strata containing lower-salinity water (measured chloride concentrations of 420 to 800 mg/L). The relatively low salinity strata are unproductive, but should act as a buffer against upwards migration of saline water.

Section 1 Introduction

The City of Clewiston will construct a reverse-osmosis desalination water treatment facility that will treat brackish feedwater from the Upper Floridan Aquifer. The Clewiston Water Treatment Plant (Clewiston WTP) will be constructed at the City of Clewiston Public Works Complex, which is located at the southeast corner of South Olympia Street and Arroyo Avenue. The location of the Public Works Complex is marked on an aerial photograph in **Figure 1-1**. The Clewiston WTP will have a capacity of 3.0 million gallons per day (mgd) of potable water, which will correspondingly require approximately 3.84 million gallons per day (mgd) (2,700 gpm) of brackish groundwater.

This report documents the construction and testing of the first two production wells, designated PW-1 and PW-2, at the Public Works Complex. The locations of wells PW-1 and PW-2 are shown on Figure 1-1. Wells PW-1 and PW-2 are the test wells for the project and will serve as production wells for the plant.

The main objective of the test well program was to obtain site-specific data on the hydrogeology and water quality in the production wellfield area. In particular, the depth of the main brackish-water production zone was identified and hydraulic and water quality data were obtained that were used to develop a groundwater solute-transport model. Data on current water quality and modeled changes in water quality over time are critical for the design of the reverse-osmosis desalination facility. Groundwater modeling will also be used towards determining the optimal location of subsequently installed production wells.

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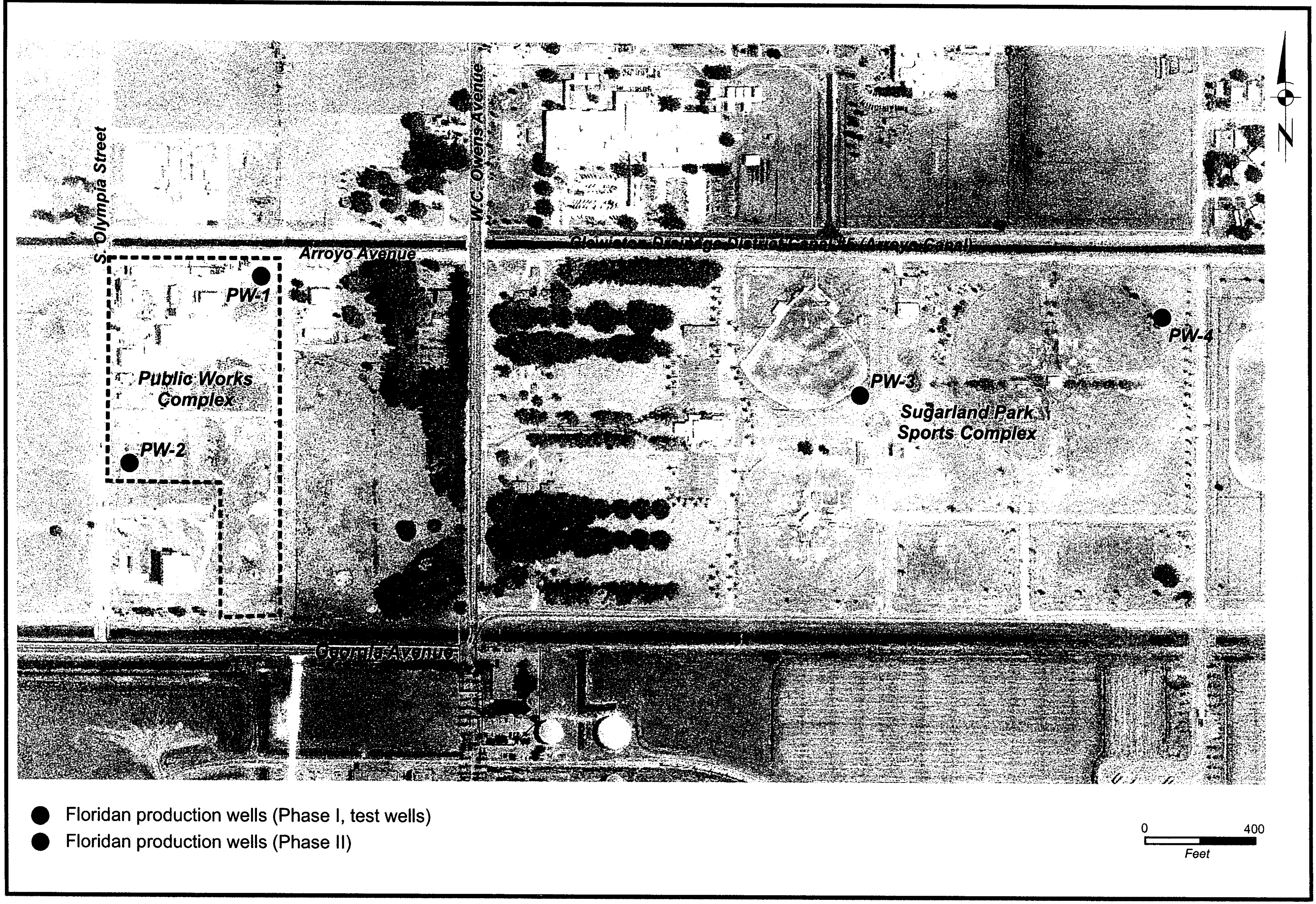

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Figure 1-1
City of Clewiston WTP
Aerial Photograph Showing Proposed Well Locations

Section 2
Test Production Well Construction

2.1 Well Construction Summary

Production wells PW-1 and PW-2 were designed by Camp Dresser & McKee Inc. (CDM) and installed by Southeast Drilling Services, Inc. (SDS) under contract with the City of Clewiston. Well construction and testing activities were observed and supervised by CDM. Wells PW-1 and PW-2 are located approximately 800 feet apart. Well construction began on April 27, 2005, and was completed on December 20, 2005.

The hydrogeology of the Floridan Aquifer System in the Clewiston area was largely unknown prior to the construction of wells PW-1 and PW-2. The nearest test wells are the South Florida Water Management District (SFWMD) South Bay (PBF-7) test well site, located approximately 14 miles east of the Clewiston WTP site, and the SFWMD L-2 Canal test well, which is located approximately 9.5 miles south of the Clewiston WTP site. The aquifer testing results for South Bay and L-2 Canal test wells are quite different. A productive zone is present at the South Bay site between approximately 1,200 and 1,450 feet below land surface (ft bls) (Lukasiewicz, et al., 2001). However, at the L-2 Canal test well site the available data indicates that the 1,200 to 1,450 ft bls zone is unproductive (Bennett, 2001). It was unknown whether the hydrogeology of the Clewiston WTP site would be more similar to that of the South Bay site or the L-2 Canal site.

The decision was made to set the final casing of the first production well (PW-1) at the top of the Floridan Aquifer System, so as to not risk casing off any of what may be limited productive strata. The final casing was thus set at 700 ft bls, rather than the initially planned 1,050 ft bls. This decision turned out to be correct in that the main brackish-water production zone in the Clewiston WTP vicinity was found to occur from approximately 700 to 800 ft bls.

Construction summaries for wells PW-1 and PW-2 are provided in **Tables 2-1 and 2-2**, respectively. Well construction diagrams for wells PW-1 and PW-2 are provided in **Figures 2-1 and 2-2**, respectively. Well TP-1 is cased to 700 ft bls and is completed with an open hole to 1,320 ft bls. Well TP-2 is cased to 700 ft bls and is completed with an open hole to 1,200 ft bls.

Table 2-1: Production Well PW-1 Construction Summary

Date	Activity
April 27, 2005	Vibrated in 34-inch diameter pit casing to 39.5 feet below land surface (ft bls).
May 3, 2005	Drilled nominal 32-inch diameter borehole to approximately 150 feet bls.
May 4, 2005	Drilled nominal 32-inch diameter borehole to 210 feet bls and installed 26-inch diameter surface casing to 204.9 ft bls. Emplaced 265 sacks of neat cement.
May 5, 2005	Topped off cement.
May 11 to 16, 2005	Drilled nominal 8¾-inch diameter pilot hole to 800 ft bls.
May 16, 2005	Performed geophysical logging (gamma ray, caliper, dual induction).
May 23 to 31, 2005	Reamed nominal 25¾-inch diameter hole to 700 ft bls.

Table 2-1: Production Well PW-1 Construction Summary	
Date	**Activity**
May 31, 2005	Installed 200 feet of 17.4-inch and 500 feet of 16.0-inch diameter SDR-17 PVC casing for a total cased depth of 700 ft bls.
June 1, 2005	Installed cement stage 1; 20.5 yd^3 of 8% bentonite (gel) with neat tail. Tag depth = 417 feet bls.
June 2, 2005	Installed cement stage 2; 19.5 yd^3 of 8% bentonite (gel). Tag depth = 8.5 ft bls.
June 6, 2005	Installed cement stage 3; 4.5 yd^3 of 8% bentonite (gel). Cement returns at surface.
June 10, 2005	Began drilling out the cement plug in the casing using a 13-inch diameter bit.
June 10 to 11, 2005	Drilled to 740 ft bls using the mud-rotary method.
June 12 to 14, 2005	Switched over to reverse-air drilling method and cleaned out well.
June 15, 2005	Drilled to 840 ft bls.
June 16 to 19, 2005	Scheduled break.
June 20 to 26, 2005	Drilled nominal 13-inch diameter hole to 1,100 ft bls using the reverse-air rotary method.
June 27, 2005	Performed pumping test no. 1. Well produced approximately 1,300 gpm with 35 feet of drawdown. Water level was lowered to close to land surface.
June 28 to 29, 2005	Drilled 13-inch diameter hole to 1,240 ft bls using the reverse-air rotary method.
June 30 to July 10, 2005	Scheduled break and vacation.
July 11 to July 14, 2005	Drilled open hole to 1,420 ft bls.
July, 15, 2005	Performed pumping test no. 2.
July 16, 2005	Resume drilling to approximately 1,450 ft bls. Drill string broke leaving approximately 1,000 feet of pipe in hole.
July 17 to	Drillers fabricating tools and working on equipment to fish out drill string.
August 11, 2005	Drill pipe recovered from well.
August 15, 2005	Performed geophysical logging.
August 16, 2005	Back-plugged open hole to 1,320 ft bls with Portland cement
August 17, 2005	Performed step-drawdown test. Well ready for connection to the pilot plant

Table 2-2: Production Well PW-2 Construction Summary	
Date	**Activity**
April 27, 2005	Vibrated in 36-inch diameter pit casing to 39.5 feet below land surface (ft bls)
September 12 to 13, 2005	Drilled nominal 23-inch diameter borehole to 192 ft bls using the mud-rotary method.
September 14, 2005	Installed the 26-inch diameter surface casing to 185 ft bls and emplaced 14 yd^3 of neat cement.
September 20 to October 21, 2005	Drilled nominal 25¾-inch diameter hole to 705 ft bls.
October 21, 2005	Performed geophysical logging.
November 3, 2005	Installed final casing to 700 ft bls.
November 4, 2005	Installed cement stage 1; 12.5 yd^3 of 4% bentonite (gel) with 6 yd^3 neat cement tail.
November 5, 2005	Installed cement stage 2: 8.8 yd^3 of 4% bentonite (gel)
November 11 to 23, 2005	Drilling open hole to 1,200 ft bls.
November 23 to December 5, 2005	Drill string was stuck in hole, worked at its removal.
December 6, 2005	Performed geophysical logging.
December 12, 2005	Performed step drawdown test.
December 13 to 20, 2005	Performed aquifer performance test, and final SDI and sand test.

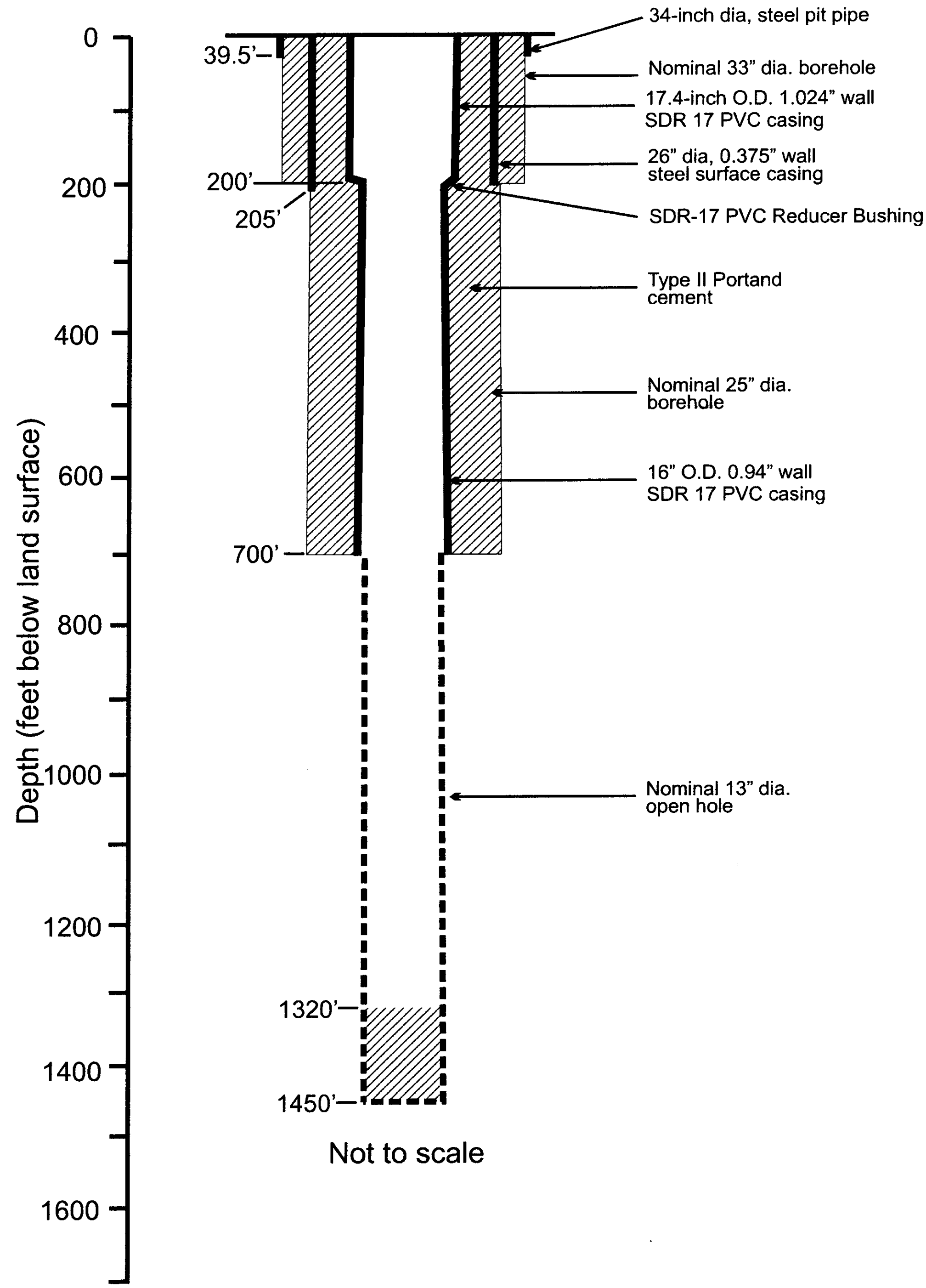

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Figure 2-1
Clewiston WTP
Production Well PW-1 As-Built Construction Diagram

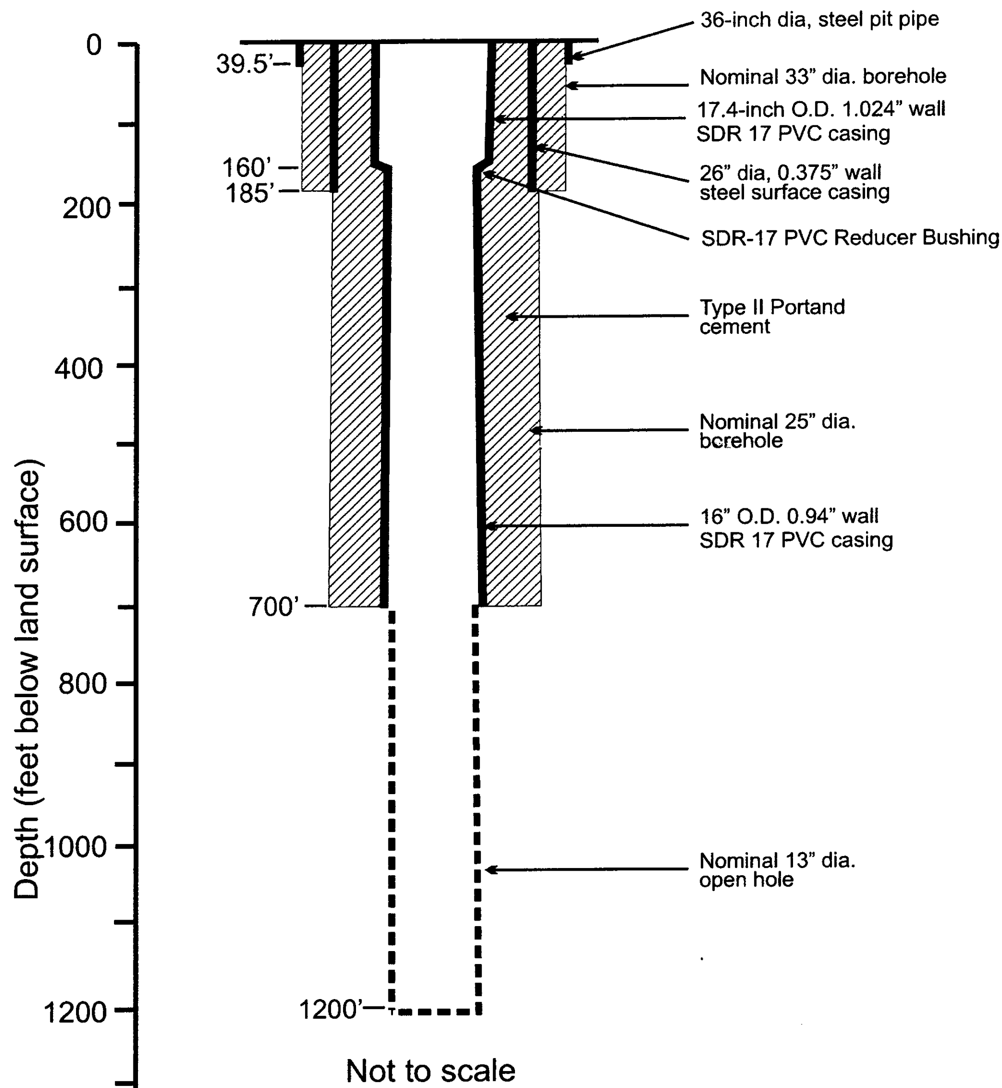

Figure 2-2
Clewiston WTP
Production Well PW-2 As-Built Construction Diagram

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2.2 Drilling Methods

The 34-inch diameter pit pipe for wells PW-1 and PW-2 were vibrated in approximately 39.5 ft bls, respectively, to case off the unconsolidated surficial muck, marls, and sands. The nominal 33-inch diameter borehole for the surface casings, and nominal 11-inch diameter pilot hole and 25-inch diameter reamed hole for the final production casing, were drilled using the mud rotary method. All drilling below the production casing was performed using the reverse-air rotary method.

2.3 Casing

The pit pipe is composed of 34-inch diameter, 0.375-inch wall steel. The surface casings are composed of 26-inch diameter, 0.375-inch wall steel with butt-welded joints and were set at approximately 205 ft bls in well PW-1 and 185 ft bls in well PW-2. The surface casings were set a minimum of 5 feet into the clay that underlies the Surficial Aquifer System. The production casings for both wells consist of Certa-Lok™ SDR-17 PVC casing. The upper 200 feet of casing in well TP-1 and upper 160 feet of casing in well TP-2 are 17.4-inches in diameter (1.024-inch minimum wall) to provide extra room for the pump. The 17.4-inch casing is connected using a reducer bushing to the 16-inch outer diameter (0.941-inch minimum wall) casing. The use of a smaller diameter casing was allowed in that it would provide a larger annular space for cementing and would not significantly impact well performance.

Section 3
Geology and Hydrogeology

The geology and hydrogeology at the Clewiston WTP site were evaluated from well cuttings and geophysical logs. Samples of the cuttings from wells PW-1 and PW-2 were collected at 10 feet intervals and major lithological changes and described in the field for color, composition, fossils, apparent porosity and permeability, and hardness. Limestone samples were compositionally and texturally described using the limestone classification system of Dunham (1962). The cutting samples for well PW-1 were subsequently re-examined and described by a CDM geologist using a stereomicroscope. A lithologic column for well PW-1 is provided in **Figure 3-1**. Lithologic logs for wells TP-1 and TP-2 are included in **Appendix A**.

3.1 Surficial Aquifer System

The Surficial Aquifer System in Florida is defined as the "permeable hydrogeologic unit contiguous with land surface that is comprised principally of unconsolidated clastic deposits" (Southeastern Geological Society Ad Hoc Committee, 1986). The Surficial Aquifer System comprises all materials from the water table to the top of the Intermediate Confining Unit. The base of the Surficial Aquifer System is marked by a significant decrease in the average hydraulic conductivity relative to the Surficial Aquifer System strata.

The Surficial Aquifer System at the Clewiston WTP extends from land surface to approximately 170 to 196 ft bls. The upper part of the Surficial Aquifer System consists of approximately 25 feet of sand, followed by approximately 40 feet of shell and shelly limestone. The Surficial Aquifer System consists mostly of sandstones and sandy limestones from 65 196 ft bls to its base. Trace phosphate sand grains are present from approximately 105 to 150 ft bls. Phosphate is more abundant (1-2%) below 150 ft bls.

Use of the Surficial Aquifer System is uncommon in eastern Hendry County and western Palm Beach County and because the aquifer has high color and surface water is readily available. The Surficial Aquifer System also locally has high salinities, which are apparently due to relict seawater trapped in the aquifer from inundation during Pleistocene sea level high stands.

3.2 Intermediate Confining Unit

The Intermediate Confining Unit is defined as "including all rocks that lie between and collectively retard the exchange of water between the overlying Surficial Aquifer System and the underlying Floridan Aquifer System" (Southeastern Geological Society Ad Hoc Committee, 1986). In eastern Hendry County and western Palm Beach County, the boundary between the Surficial Aquifer System and Intermediate Confining Unit essentially coincides with the top of the Hawthorn Group.

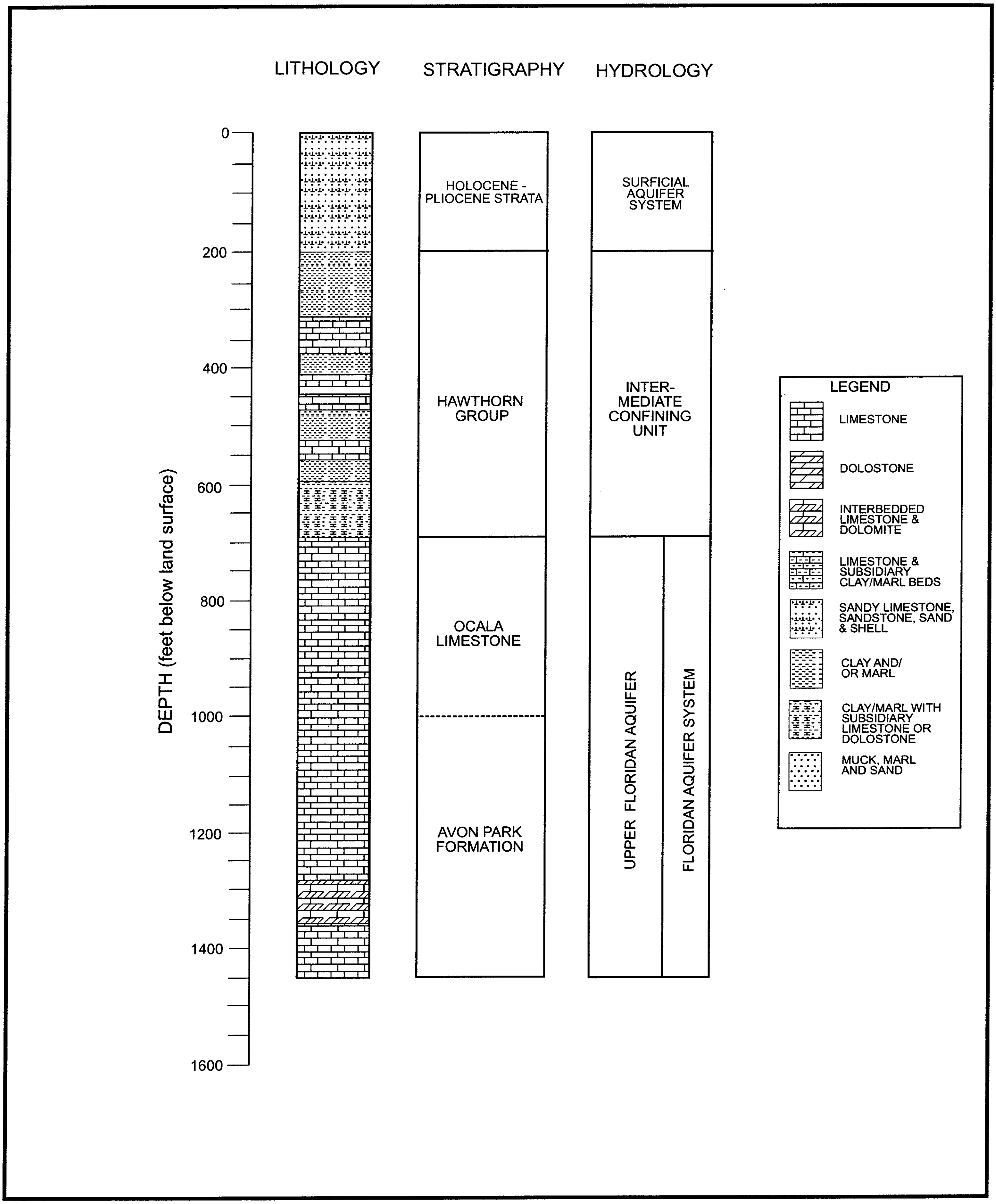

Figure 3-1
Clewiston WTP
Production Well PW-1 Hydrogeology

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The lithology of the Intermediate Confining Unit, which consists of the Hawthorn Group strata, is variable and includes clay, marl, fine-grained sand, siltstone, and limestone (Reese, 1994). The Intermediate Confining Unit strata tend to have high phosphate concentrations, which result in relatively high responses on gamma ray logs. The Hawthorn Group is largely of Miocene age.

The base of the Intermediate Confining Unit at the Clewiston WTP site occurs at approximately 680 ft bls, at which depth there is pronounced down-hole decrease in activity on the gamma ray geophysical log reflecting a decrease in phosphate and clay concentration. Resistivity also increases below 670 ft bls, which also marks down-hole transition to relatively clean (low clay) limestones of the Floridan Aquifer System.

3.3 Floridan Aquifer System

The Floridan Aquifer System is one of the most productive aquifers in the United States and underlies all of Florida and parts of Georgia and South Carolina for a total area of about 100,000 square miles. The Floridan Aquifer System consists of an extensive sequence of thickly bedded Tertiary-aged limestones, and less abundantly dolomites, that are connected to varying degrees. The system in eastern Hendry County consists of the Ocala Limestone, Avon Park Formation, and Oldsmar Formation. The base of the Floridan Aquifer System is generally placed at the top of the uppermost evaporite (anhydrite) bed in the Cedar Keys Formation, which occurs at approximately 3,500 ft bls in the project site area (Miller, 1986). The Floridan Aquifer System in southern Peninsular Florida is divided into the Upper Floridan Aquifer, Middle Confining Unit, and Lower Floridan Aquifer. Only the Upper Floridan Aquifer was penetrated by the Clewiston WTP production wells.

It is difficult to identify the boundaries between the Ocala Limestone, Avon Park Formation and Oldsmar Formation, as the Eocene-aged formations are chronostratigraphic (age-defined) units rather than rock-stratigraphic units (Miller, 1986). Typically, formation boundaries are placed at the nearest lithological change to the chronostratigraphic boundary, as determined from biostratigraphic (fossil) data. Reese and Memberg (2000) abandoned the traditional formation names and included all strata between the Hawthorn Group and Cedar Keys Formation in an informal "Eocene Group." Nevertheless, the traditional formation boundaries were used in this investigation.

There is no consensus on the stratigraphic nomenclature for the interbedded clays, marls, limestones, and phosphorites between the marls and clays of the upper Hawthorn Group and the underlying relatively pure Eocene-aged limestones. The early Miocene and Oligocene-aged strata in some studies have been referred to as the Tampa Limestone and Suwannee Limestone, respectively (e.g., Meyers, 1989). However, the Tampa Limestone is generally no longer recognized in South Florida. Miller (1986), and Reese and Memberg (2000), both reported that the Suwannee Limestone are present only in westernmost Palm Beach County. The Suwannee Limestone was not identified in the SFWMD L-2 Canal Test well (Bennett, 2001). The Suwannee Limestone was not positively identified at the Clewiston WTP site. The

Ocala Limestone appears to be present from 680 ft bls to approximately 1,000 ft bls. The limestones commonly consists of microfossiliferous peloidal limestones that would be classified as peloid bioclast wackestones, packstones, and grainstones, with reference to the limestone classification system of Dunham (1962). Bioclasts are rounded, sand-sized fossil fragments that are typically deposited as a carbonate sand. The fossils consist mostly of mollusk fragments. The large discoidal foraminifera typical of the Ocala Limestone are present and are most common below approximately 850 ft bls.

The centimeter-sized echinoid *Neolaganum dali* was found by Vernon (1951) to be very abundant in the upper 50 feet of the Avon Park Formation in Florida peninsula wells. The top of the Avon Park Formation is placed at approximately 1,000 ft bls in well PW-1 based on the common occurrence of *Neolaganum dali* echinoids in the cutting sample from 1,000 to 1,010 ft bls in well PW-1 and from 1,020 to 1,050 ft bls in well PW-2. The Avon Park limestones consist mostly of peloid bioclast grainstones, and to a lesser degree packstones, which were deposited as carbonate sand. The distinctive cone-shaped benthic foraminifera belonging to the genus *Dictyoconus* are characteristic of the Avon Park Formation, whereas the Ocala Limestone contains a distinctly different foraminifera fauna. Subsidiary dolostone (< 20%) is present from 1,280 to 1,360 ft bls. The Avon Park Formation extends downwards through the total depth of well PW-1 (1,450 ft bls).

Section 4
Well Testing Procedures and Results

The first test production well (PW-1) served as the exploratory well for the project. The objective of the testing program was to obtain site specific data on the hydraulic (potential well yields) and water quality of potential production zone strata. The testing program included the following elements: pumping and packer testing performed on well PW-1, geophysical logging, step-drawdown tests on the completed well, and an aquifer performance test. Water samples collected from the completed wells were analyzed for Florida primary and secondary drinking water standards and reverse-osmosis design parameters.

4.1 Reverse-Air Drilling Water Quality Data

During reverse-air drilling, water is pumped upwards from the drill bit, through the drill string, to land surface. An open circulation system was used in which the pumped water was discharged to a nearby canal, rather than being pumped back down the well. In open circulation systems, the reverse-air discharge water should be approximately representative of the water being produced from the bottom of the hole. However, there may be some mixing with water produced higher in the well, so the reverse-air discharge water may not be completely representative of bottom hole water quality. Nevertheless, the reverse-air discharge data provides valuable information on salinity trends within the penetrated aquifer.

The reverse-air discharge samples were analyzed in house by CDM for chloride concentration. The chloride data for wells PW-1 are summarized in **Table 4-1.**

Table 4-1: Reverse-Air Discharge Water Quality Data

Depth (ft)	Chloride (mg/L)	Specific Conductance (us/cm)
800	1,580	-
840	1,600	-
920	915	-
960	800	-
1,000	800	-
1,040	750	-
1,080	715	-
1,120	580	-
1,160	625	-
1,200	600	-
1,240	420	2005
1,260	480	2391
1,280	480	2081
1,300	480	2262
1,320	540	2424
1,340	540	2476
1,360	620	2602
1,380	620	2741
1,400	660	2950
1,420	680	3000

The reverse-air discharge data show that chloride concentration, and thus salinity, are highest near the top of the aquifer and decrease with depth to approximately 1,300 ft bls. Chloride concentration increases with depth below 1,300 ft bls. Normally brackish water aquifers are density stratified with salinity increasing with depth. However, a zone of fresher water in the Upper Floridan Aquifer appears to be widespread in the southern Lake Okeechobee area (e.g., Bennett, 2001; Lukasiewicz, et al., 2001).

4.2. Single-Well Constant-Rate Pumping Tests

Two constant-rate pumping tests were performed on test production well PW-1 in order to obtain information on potential well yields with depth. Pumping Test #1 was performed after drilling to 1,100 ft bls. The well produced 1,300 gpm with approximately 35.5 feet of drawdown. The corresponding specific capacity is 37.1 gpm/ft. Static water level is located 34 to 35 ft above land surface, so water level was drawdown to approximately land surface during the test.

Pumping Test #2 was performed after drilling to 1,420 ft bls. The well produced approximately 1,600 gpm with 53 feet of drawdown for a specific capacity of 30 gpm/ft. The water produced during Pumping Test #2 had a chloride concentration of 1,200 to 1,220 mg/L, despite the fact that the open hole interval penetrated over 500 feet of strata containing water with a chloride concentration of less than 1,000 mg/L. Comparison of the results of Pumping Tests #1 and #2 indicate that nearly all of the water production comes from above 1,100 ft bls.

4.3 Step-Drawdown Tests

Step-drawdown tests were performed on the completed wells PW-1 and PW-2. The test for well PW-1 consisted of three, two-hour constant-rate steps at progressively greater pumping rates using a centrifugal pump. The step-drawdown test on well PW-2 consisted of 2-steps. For well PW-2, drawdown data for a higher pumping was obtained a separate test. Flow rates were measured using a totalizing flowmeter and pressure (heads), and thus drawdowns, were measured using an In Situ, Inc. miniTroll Pro pressure datalogging system. Chloride concentrations were measured in-house using the argentometric method. The results of the step-drawdown tests are summarized in **Table 4-2.**

Table 4-2: Step-Drawdown Test Results

Step No.	Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)	Chloride Concentration (mg/L)
Well PW-1				
1	700	18.4	38.1	1,200
2	1,000	28.2	35.4	1,140
3	1,400	39.2	35.7	1,160
Well PW-2				
1	800	21.9	36.5	-
2	1,050	42.2	24.9	-
3*	1,300	42.6	30.8	1,150

* Recorded during aquifer performance test

The results of step-drawdown tests were highly favorable. The production wells could produce 1,000 gpm of water without drawing the potentiometric surface below land surface.

4.4 Water Quality Data

Water samples were collected from both wells PW-1 and PW-2 at the end of step-drawdown tests and analyzed for Florida primary and secondary drinking water standards and reverse-osmosis parameters. The concentrations of all organic parameters were below detection limits. Split samples were collected and analyzed by different laboratories for some of the more critical parameters for the design of the reverse-osmosis desalination facility. The results of the analyses for reverse-osmosis parameters in well PW-1 are summarized in **Table 4-3**.

Table 4-3: Summary of Water Quality Data

Parameter	Well PW-1		
	STL (8/17/05)	Southern Analytical (9/7/05)	Southern Analytical (10/6/05)
Ammonium (NH4) (mg/L)	-	-	0.42
Barium (mg/L)	-	0.028	-
Cadmium (µg/L)	-	<0.001	-
Calcium (mg/L)	130	-	120
Chloride (mg/L)	1,300	1,200	-
Color (pcu)	-	<5	-
Specific Conductance (µmhos/cm)	-	-	5,010
Copper (µg/L)	-	<0.005	-
Dissolved organic carbon (mg/L)	-	-	<1
Fluoride (mg/L)	-	<0.03	-
Hydrogen sulfide (mg/L)	-	-	0.5?
Iron (mg/L)	-	0.25	-
Lead (µg/L)	-	<0.001	-
Magnesium (mg/L)	110	-	120
Manganese (µg/L)	-	<0.01	-
Mercury (µg/L)	-	<0.0001	-
Nitrate & Nitrite (mg/L)	-	<0.05	-
Orthophosphate (mg/L)	-	-	0.25
pH (stnd units)	8.68	8.05	-
Silica (iotal) (mg/L)	-	-	13
Potassium (mg/L)	-	-	29
Sodium (mg/L)	770	660	-
Strontium (mg/L)	-	-	16
Sulfate (mg/L)	490	570	-
Sulfide (mg/L)	2.9 2.9 (Dupl.)	-	-
Temperature (°C)	-	-	-
TDS (mg/L)	2,700	2,600	-
Total alkalinity (mg/L)	94	-	88
Alkalinity – bicarb. as $CaCO_3$ (mg/L)	-	-	88
Alkalinity – carb. as $CaCO_3$ (mg/L)	-	-	<2
Total hardness as $CaCO_3$ (mg/L)	-	-	790
Total organic carbon (mg/L)	-	-	<1
Turbidity (NTU)	-	-	0.15
Zinc (mg/L)	-	<0.016	-
UV254 Absorbance (cm-1)	-	-	0.31

4.5 Sand and SDI Testing

Production well PW-1 and PW-2 were tested for sand and silt density index (SDI) while the wells were being pumped at a minimum of 1,000 gpm. The sand concentration was measured using a Rossum Sand Test. Only a few grains of sand were produced and the well met the acceptance criteria of less than 1 mg/L. Silt Density Index (SDI) was measured using standard equipment by recording the time required to filter 500 mL of water through a 0.45 µm filter at the start and after 5, 10, 15, and 20 minutes of pumping at a pressure of 30 psi. The time for the initial and 15 minute samples were 35 and 46 seconds, respectively. SDI is calculated as follows:

$$SDI = 100 * (T_i - T_f) / T_t$$

Where T_i = initial time, T_f = final time, and T_t = the total time of test in minutes. The calculated SDI values for the PW-1 and PW-2 test are 2.6 and 1.6, respectively, which meet the acceptance of criteria of 3 or less. Sand production was negligible in both wells.

4.6 Aquifer Performance Testing

A constant-rate aquifer performance test (APT) was performed to obtain site specific data on aquifer hydraulic parameters. Well PW-2 was pumped and well PW-1 was used as an observation well. The APT was performed by pumping well PW-2 at an average rate of approximately 964 gpm using a centrifugal pump. Pressure was monitored using a pressure transducer and Hermit 3000 datalogger. The pump failed after two days of pumping, which prevented collection of recovery data. A water sample collected near the end of the APT had a chloride concentration of 1,140 mg/L, which was very close to the concentration recorded at the end of the step-drawdown test. The specific conductance of the APT-1 sample was 3,815 µmhos/cm.

A log-log plot of the drawdown data for test APT is provided in **Figure 4-1**. The data were interpreted using the Hantush and Jacob (1955) method for a leaky confined aquifer. The distance between well PW-1 and PW-2 was calculated to be 801 feet using well locations determined using a global positioning system (GPS) and approximately 790 feet using a tape measure. A distance of 800 feet was used in the test analysis calculations. The calculated values for aquifer hydraulic parameters are summarized below:

Transmissivity = 12,800 ft^2/day
Storage coefficient = 4.3 X 10^{-4}
Leakance = 8.0 X 10^{-4} day^{-1}

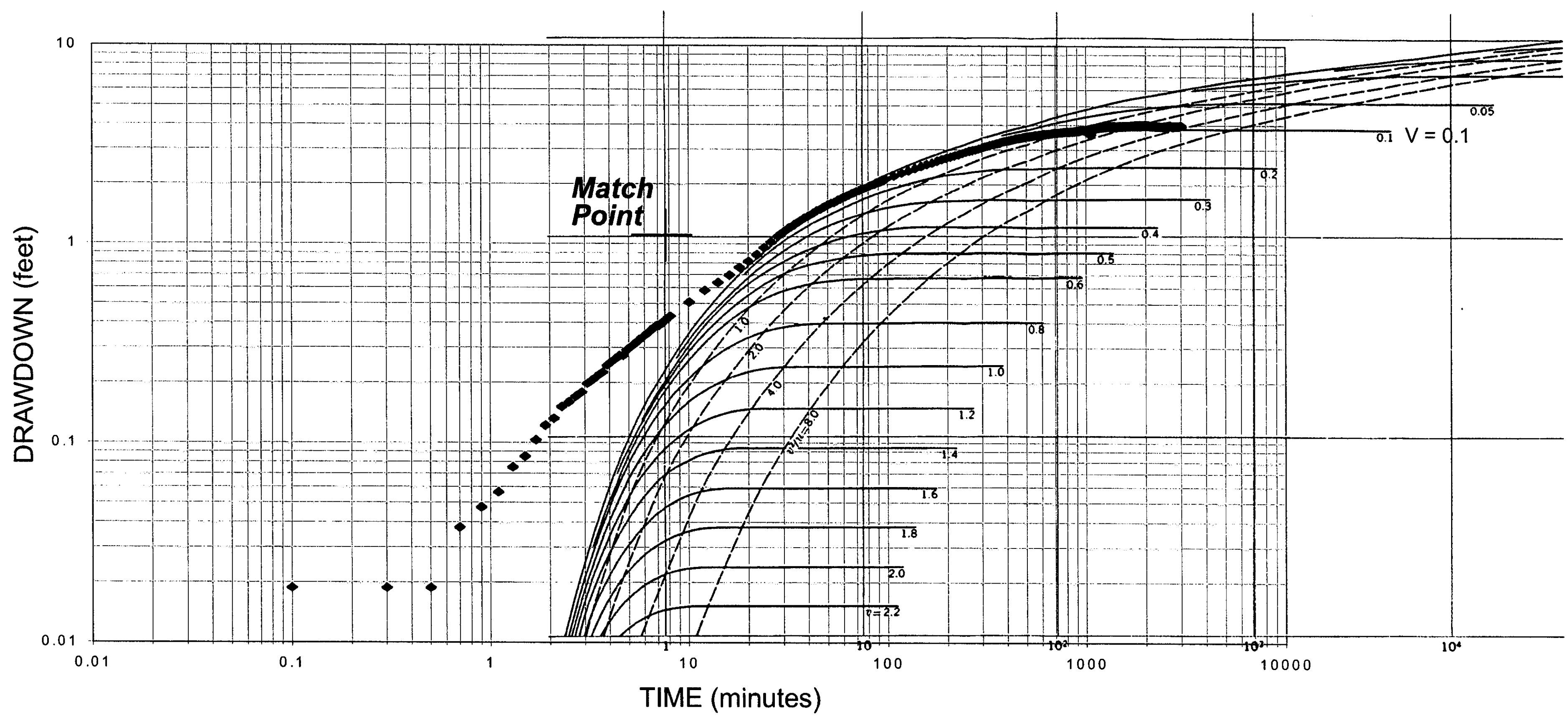
4.7 Geophysical Logging

Geophysical logging was performed by MV Geophysical and Advanced Borehole Services (ABS) under contract with SDS. A schedule of the geophysical logs run on wells PW-1 and PW-2 is provided in **Table 4-4**.

Table 4-4: Schedule of Geophysical Logging

Construction Phase	Depths (ft bls)	Geophysical Logs
Well TP-1		
Production casing pilot hole	0 – 800	X-Y caliper, gamma ray, dual induction
Reamed open hole	0 – 1,450	X-Y caliper, gamma ray, sonic, static & dynamic flowmeter. Borehole video survey (casing).
Completed well	0 – 1,320	
Well TP-2		
Production casing pilot hole	0 – 705	X-Y caliper, gamma ray, dual induction
Reamed open hole	0 – 1,200	X-Y caliper, gamma ray, dual induction. Borehole video survey (casing).

The geophysical logging program for the exploratory well (PW-1) was designed to locate and characterize potentially productive strata, which can assist in determining the optimal production zone depths. The flowmeter log is of particular importance in that it can provide a continuous measure of the flow rate (velocity) in the well with depth. The fluid flow (volume/time) at a given depth is approximately equal to the product of the flow velocity and borehole cross-sectional area. The fluid flow log for the upper part of the production well PW-1 open hole (**Figure 4-2**) shows that nearly all of the flow entered the well from between 708 and 775 ft bls. The strata from 775 to 1,420 ft bls is much less the transmissive than the 708 to 775 ft bls flow zone.



Distance: 800 feet
Pumping rate: 964 gpm

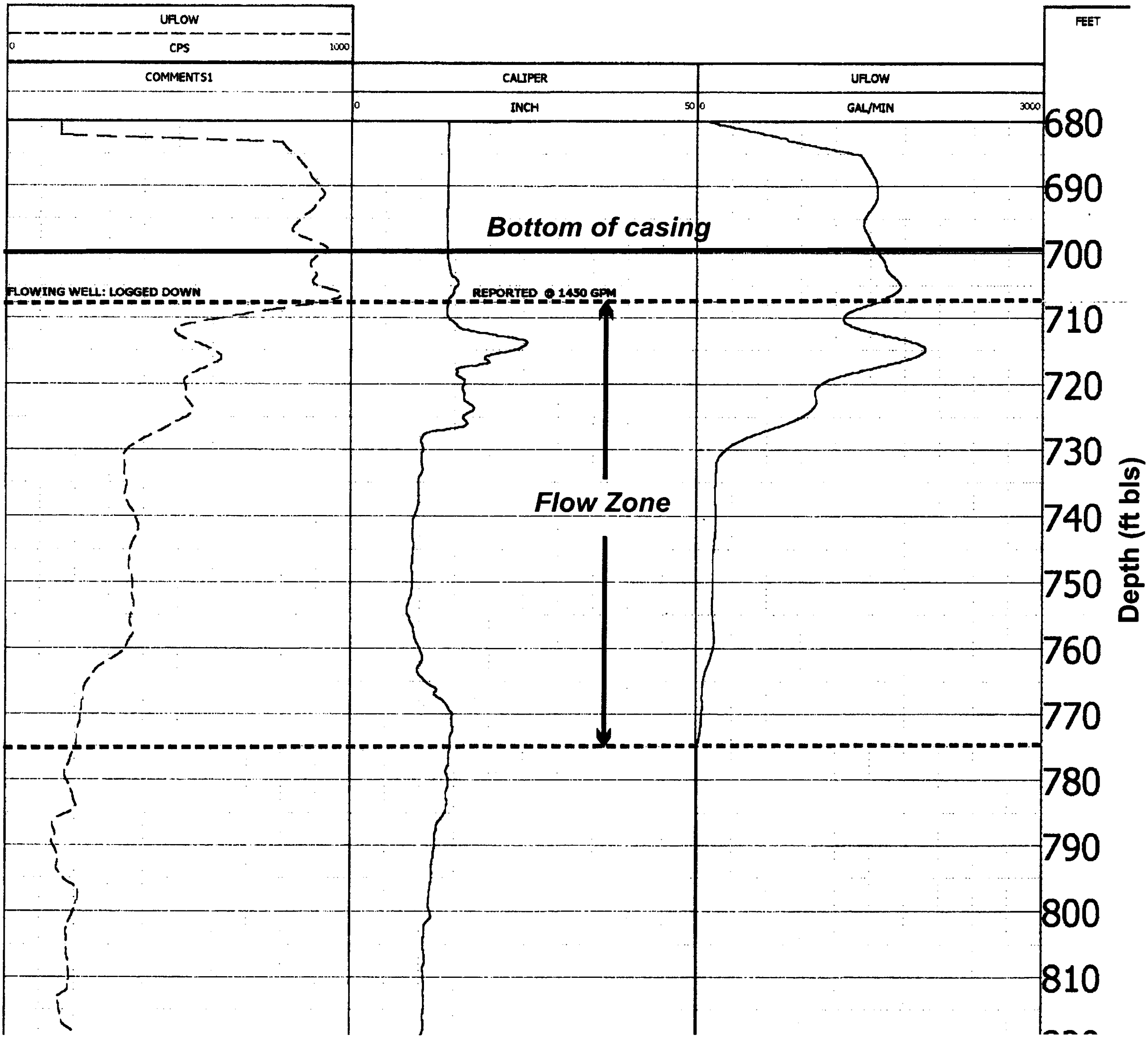
Transmissivity: 12,800 ft^2/day
Storage coefficient: 4.3 X 10^{-4}
Leakance: 8.0 X 10^{-4} day^{-1}

Data analyzed using the Hanutush and Jacob (1955) method.

CDM

Figure 4-1
City of Clewiston WTP
Aquifer Performance Test Results

Production Well PW-1 Flowmeter Log
Run by ABS on 8/15/05



Note: Flowmeter log shows that 95+% of the water entered the well between 708 and 775 ft bls.

CDM

Figure 4-2
Clewiston WTP
Production Well PW-1 Flowmeter Log

Section 5
Conclusions and Recommendation

The results of the testing of production wells PW-1 and PW-2 indicate that the Upper Floridan Aquifer has a high transmissivity and is suitable for a brackish water source for the Clewiston WTP. The Upper Floridan Aquifer is artesian, with static water levels approximately 34.5 ft above land surface. Production wells PW-1 and PW-2 could produce over 1,000 gpm of water without drawing water levels below land surface. It is recommended that the raw water for the Clewiston WTP be provided by three production wells with a capacity of approximately 900 gpm and one back-up well. There will be one primary production well for each reverse-osmosis desalination train, which would simplify plant and wellfield operations.

The remaining two production wells (PW-3 and PW-4) are to be constructed at the Clewiston Sports Complex at locations marked on Figure 1-1. It is recommended that wells PW-3 and PW-4 have the same construction of wells PW-1 and PW-2, with a final casing depth of approximately 700 ft bls and open hole to approximately 1,300 ft bls.

The testing results show that nearly all of the water produced in the production wells PW-1 and PW-2 is produced in the upper 75 feet of open hole interval, from 700 to 775 ft bls. The strata from 775 to 1,420 ft bls is relatively unproductive. Salinity within the upper part of the Upper Floridan Aquifer decreases with depth. The production zone has an average chloride concentration of approximately 1,300 mg/L, whereas samples collected from the underlying strata had chloride concentrations as low as 400 to 500 mg/L. Having strata containing relatively low salinity water below the production zone is favorable in that it provides a buffer between the production zone and deeper more saline waters.

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Appendix A

Lithologic Logs

GEOLOGIST LOG
CITY OF CLEWISTON WATER TREATMENT PLANT
PRODUCTION WELL PW-1

SITE LOCATION: City of Clewiston Public Works Complex, 1200 South Olympia Street, Clewiston, Florida

SAMPLE TYPE: Grab (cuttings)

PROJECT NUMBER: 27335 45302 (CDM)

SAMPLE DESCRIPTION BY: KM, RGM

DEPTH INTERVAL (FEET)	THICK-NESS (FEET)	SAMPLE DESCRIPTION
0 – 25	25	SAND, pale yellowish brown (10 YR 6/2), quartz, fine to medium-grained, very well sorted, < 5% shell fragments (mollusks).
25 – 65	40	SHELLY LIMESTONE TO SHELL, yellowish gray (5 Y 8/1), very poorly lithified limestone, grainstone, ~ 90 % mollusk fragments, very high apparent macroporosity, 1-2 % very coarse, hard phosphate (black), ~ 5 % sandy limestone matrix (moderate macroporosity).
65-105	40	INTERBEDDED SANDSTONE AND SAND, light olive gray (5Y 6/1), fine to medium-grained, soft, poorly to moderately well sorted, low to moderate apparent macroporosity, minor (< 2%) shell fragments- poorly sorted sand (opaque), coarse to very coarse grained, subrounded to subangular.
105-130	25	SANDY LIMESTONE TO SANDSTONE, light olive gray (5Y 6/1), soft, grainstone, moderate vuggy and intergranular macroporosity, ~ 5 % mollusk fragments, trace very fine phosphate.
130-150	20	SANDY LIMESTONE TO SANDSTONE, light olive gray (5Y 6/1), soft, grainstone, moderate vuggy and intergranular macroporosity, ~ 5-10 % mollusk fragments, trace very fine phosphate.
150-180	30	SANDY LIMESTONE, light olive gray (5Y 6/1), soft, grainstone, moderate vuggy and intergranular macroporosity, ~ 5-10 % mollusk fragments, 1-2 % fine to medium grained phosphate.
180-196	16	SANDY LIMESTONE, light olive gray (5Y 6/1), soft, grainstone, moderate vuggy and intergranular macroporosity, ~ 5-10 % mollusk fragments, 1-2 % medium to coarse grained phosphate.
196-210	14	CLAY, dark greenish gray (5 GY 4/1), soft, plastically deformable, phosphatic silt present.
210 – 280	70	CLAY, dark, greenish gray (5 GY 4/1), soft, plastically deformable, phosphatic silt.
280 - 313	33	CLAY, dark, greenish gray (5 GY 4/1), soft, plastically deformable, phosphatic silt, 1-2% fossil fragments (mollusks).
313 – 374	61	LIMESTONE, light olive gray (5Y 6/1), fossil grainstone, soft, abundant shell fragments (mollusks), very high apparent macroporosity, trace very fine-grained phosphate.
374 – 406	32	CLAY, dark greenish gray (5 GY 4/1), soft, silty, ~ 1% very fine-grained phosphate.
406 – 417	11	LIMESTONE, light olive gray (5 Y 6/1), fossil grainstone, soft, moderate macroporosity, trace fine-grained phosphate. Fossils include mollusks and forams.
417 – 443	26	CLAY, dark, greenish gray (5 GY 4/1), soft, plastically deformable, ~ 1% fine-grained phosphate..
443 - 473	30	LIMESTONE, light olive gray (5 Y 6/1), fossil grainstone, soft, moderate macroporosity, trace fine-grained phosphate. Fossils include mollusks and forams.
473 - 525	52	CLAY, dark, greenish gray (5 GY 4/1), soft, plastically deformable, ~ 1-2% fine-grained phosphate.
525 – 555	30	LIMESTONE, light olive gray (5 Y 6/1), fossil grainstone, soft, 1-2% fine-grained phosphate. Fossils include mollusk fragments.

GEOLOGIST LOG
CITY OF CLEWISTON WATER TREATMENT PLANT
PRODUCTION WELL PW-1

SITE LOCATION: City of Clewiston Public Works Complex,
1200 South Olympia Street, Clewiston, Florida

SAMPLE TYPE: Grab (cuttings)

PROJECT NUMBER: 27335 45302 (CDM)

SAMPLE DESCRIPTION BY: KM, RGM

DEPTH INTERVAL (FEET)	THICK-NESS (FEET)	SAMPLE DESCRIPTION
555 – 596	41	CLAY, dark, greenish gray (5 GY 4/1), soft, plastically deformable, 1-2% coarse-grained phosphate.
596 – 625	29	LIMESTONE, light olive gray (5 Y 6/1), fossil packstone, marly, soft, 2% coarse-grained phosphate. Fossils fragments are abundant, mostly mollusks.
625 – 648	23	LIMESTONE, light olive gray (5 Y 6/1), fossil quartz packstone to wackestone, soft, low macroporosity and apparent permeability. Abundant (5-10%) phosphate, mostly round fine sand-sized grains, some larger grains. Fossils include mollusk and echinoderm fragments.
648 – 670	32	LIMESTONE, greenish gray (5 GY 6/1), fossil quartz packstone, similar to above, soft, 20-30% shell fragments, abundant fine-grained phosphate.
670 – 698	28	DOLSOTONE (80%), dark greenish gray (5 GY 4/1), micro-sucrosic, finely crystalline (< 0.123 mm), very low visible macroporosity and apparent permeability. LIMESTONE (18%) similar to above. PHOSPHATE (2%) granule-size rounded grains.
698 – 720	22	LIMESTONE (90-95%), very pale orange (10 YR 8/2), fossil peloid (bioclast) grainstone, soft, low visible macroporosity and apparent permeability. Limestone consists of coarse fossil fragments (mollusks) in a fine-grained carbonate sand matrix. DOLOSTONE (5-10%), same as above, may be cuttings that fell into hole from above.
720 – 770	50	LIMESTONE, very pale orange (10 YR 8/2). 50% - bioclast wackestone/grainstone, similar to above. 50% - fossil mudstone/wackestone, micritic fragments with some surfaces molds of fossils. Fossils are mostly mollusk fragments. Minor dolostone fragments, similar to 670-698 ft.
770 – 800	30	Coarse cuttings than above LIMESTONE, very pale orange (10 YR 8/2), fossil peloid grainstone, less commonly packstone and wackestone, soft. Large fossils fragments in carbonate sand matrix. Moderate macroporosity and apparent permeability. Fossils include mollusks and bryozoans. Minor phosphatic limestone and dolostone fragments, which may have fallen into the hole from above.
800 – 810	10	LIMESTONE, very pale orange (10 YR 8/2), peloid fossil grainstone (coquina). Predominantly coarse fossil fragments. May have a very high porosity and permeability.
810 - 850	40	LIMESTONE, very pale orange (10 YR 8/2), fossil peloid grainstone, very soft, low macroporosity and apparent permeability. Limestone consists of large fossil fragments (mollusks) in a very fine-grained peloidal carbonate sand matrix.
850 – 950	50	LIMESTONE, very pale orange (10 YR 8/2), bioclast grainstone, with a coarser carbonate sand matrix than above. Soft, poorly indurated, moderate to high intergranular porosity and apparent permeability. Fossils include mollusks and large discoidal foraminifera (*Lepidocyclina* and *Operculinoides*).

GEOLOGIST LOG
CITY OF CLEWISTON WATER TREATMENT PLANT
PRODUCTION WELL PW-1

SITE LOCATION: City of Clewiston Public Works Complex, 1200 South Olympia Street, Clewiston, Florida

SAMPLE TYPE: Grab (cuttings)

PROJECT NUMBER: 27335 45302 (CDM)

SAMPLE DESCRIPTION BY: KM, RGM

DEPTH INTERVAL (FEET)	THICK-NESS (FEET)	SAMPLE DESCRIPTION
950 – 970	20	LIMESTONE, very pale orange (10 YR 8/2), fossil peloid grainstone to packstone, finer grained and less porous and permeable than above. Larger fossils include mollusks, discoidal foraminifera, and echinoids.
970 – 1000	30	LIMESTONE, very pale orange (10 YR 8/2), fossil peloid grainstone to packstone, medium to hard (harder than above), low porosity and apparent permeability. Large fossil fragments in a carbonate sand matrix.
1000 – 1020	20	LIMESTONE, very pale orange (10 YR 8/2), bioclast grainstone, large fossils in carbonate sand matrix. Sample consists mostly of fossil fragments. Common 1 cm sized echnoid (*Neolaganum dali*). May have a high porosity and permeability
1020 - 1040	20	LIMESTONE, very pale orange (10 YR 8/2), bioclast grainstone, similar to above except for presence of some harder, larger cuttings.
1040 - 1100	60	LIMESTONE, very pale orange (10 YR 8/2), peloid bioclast grainstone, fine-grained, soft, moderate intergranular porosity and apparent permeability. Trace (< 1%) dictyoconid foraminifera and echinoids. Typical Avon Park Formation lithology.
1100 – 1110	10	LIMESTONE, very pale orange (10 YR 8/2), same as above except for some moderately hard cuttings.
1100 – 1240	90	LIMESTONE, very pale orange (10 YR 8/2), bioclast/peloid grainstone, soft, poorly indurated, moderate porosity, low to moderate permeability. Fossils include mollusks, echinoids (trace) and dictyoconid foraminifera (1%).
1240 – 1250	10	LIMESTONE, very pale orange (10 YR 8/2), bioclast/peloid grainstone, very fine-grained, soft, poorly indurated, moderate to high porosity, moderate permeability. Fossils include mollusks, echinoids (trace) and dictyoconid foraminifera (<1%).
1250 – 1260	10	LIMESTONE, very pale orange (10 YR 8/2), fossil (bioclast) packstone to wackestone, moderately hard, low porosity and apparent permeability. Fossils include mollusks and minor dicyoconid foraminifera (*Dictyoconus cookei*).
1260 – 1270	10	LIMESTONE, very pale orange (10 YR 8/2), bioclast/peloid grainstone, similar to 1240 to 1250 ft. Trace dictyoconid and large biconvex (*Lepidocyclina*?) foraminifera.
1270 – 1280	10	LIMESTONE, very pale orange (10 YR 8/2), mixed lithologies, bioclast/peloid grainstone, similar to above, and fossil packestone to wackestone, similar to 1250 to 1260.
1280 – 1290	10	LIMESTONE (80%), very pale orange (10 YR 8/2) fossil bioclast/peloid wackestone, packestone, and grainstones, similar to above. DOLOSTONE (20%), pale yellowish brown (10 YR 6/2 to 5/2), very finely crystalline, microsucrosic, high moldic and intercrystalline porosity, moderate apparent permeability. Replacement of a bioclastic limestone.
1290 – 1360	70	LIMESTONE (>95%), very pale orange (10 YR 8/2), bioclast/peloid grainstone, subsidiary packstone and/or wackestone. Soft to moderately hard. Overall low to moderate porosity (intergranular) and low to moderate apparent permeability. DOLOSTONE (<5%), similar to 1280 to 1290, except less porous.

GEOLOGIST LOG
CITY OF CLEWISTON WATER TREATMENT PLANT
PRODUCTION WELL PW-1

SITE LOCATION: City of Clewiston Public Works Complex, 1200 South Olympia Street, Clewiston, Florida

SAMPLE TYPE: Grab (cuttings)

PROJECT NUMBER: 27335 45302 (CDM)

SAMPLE DESCRIPTION BY: KM, RGM

DEPTH INTERVAL (FEET)	THICK-NESS (FEET)	SAMPLE DESCRIPTION
1360 – 1410	50	LIMESTONE, very pale orange (10 YR 8/2), bioclast/peloid grainstone, very fine to fine-grained, soft, moderate porosity (intergranular), low to moderate permeability. Fossils include bivalves, trace echinoids and foraminifera (dictyoconid).
1410 – 1420	10	LIMESTONE, very pale orange (10 YR 8/2), bioclast/peloid grainstone, similar to above except dictyoconid foraminifera are common (2-3%).

GEOLOGIST LOG
CITY OF CLEWISTON WATER TREATMENT PLANT
PRODUCTION WELL PW-2

SITE LOCATION: City of Clewiston Public Works Complex, 1200 South Olympia Street, Clewiston, Florida

SAMPLE TYPE: Grab (cuttings)

PROJECT NUMBER: 27335 45302 (CDM)

SAMPLE DESCRIPTION BY: KM, RGM

DEPTH INTERVAL (FEET)	THICK-NESS (FEET)	SAMPLE DESCRIPTION
0 – 20	20	SAND, yellowish gray (5 Y 7/1), quartz, fine, well rounded, well sorted, mollusk fragments.
20 – 40	20	SAND, light olive gray (5 Y 5/2), quartz, fine, well rounded, moderately well sorted, mollusk fragments, silt, very fine phosphate.
40 – 60	20	SHELL, yellowish gray (5 Y 8/1) to light olive gray (5 Y 5/2), mollusks, mostly bivalves, to ¼ inch across, silty, sandy.
60 – 90	30	SILT, light olive gray (5 Y 5/2), soft, bivalve fragments to ¼ inch across, very fine quartz sand, medium grained phosphate.
90 – 130	40	LIMESTONE, yellowish gray (5 Y 7/2), grainstone to wackestone, moderately hard, moderately intergranular macroporosity, very sandy, mollusks, silt.
130 – 160	30	LIMESTONE, yellowish gray (5 Y 7/2), grainstone, soft to moderately hard, moderate intergranular macroporosity, mollusks, fine quartz sand, silt, trace of very fine phosphate.
160 – 170	10	SANDSTONE, light olive gray (5 Y 5/2), medium grained, well rounded quartz sand, moderately well sorted, carbonate cement, mollusks, silt.
170 – 180	10	CLAY, light olive gray (5 Y 5/2), soft, sticky, silty, fine sand, mollusks, very fine phosphate
180 – 200	10	CLAY, dark greenish gray (5GY 4/1), soft, silty, mollusks.
200 – 220	20	MARL, medium greenish gray (5GY 5/1), soft, silty.
220 – 300	80	MARL, dark greenish gray (5GY 4/1 to 5 Y 4/1), soft (plastic), silty, minor light-colored shell fragments.
300.– 340	40	SAND, olive gray (5 Y 4/1), very fine-grained quartz and silt, very fossiliferous (abundant mollusk fragments), soft, un-indurated, minor phosphate (≤ 1%).
340 – 400	60	SILTY, SANDY MARL, dark greenish gray (5GY 4/1 to 5 Y 4/1). soft, un-indurated, minor mollusk fragments, minor phosphate (≤ 1%).
400 – 540	140	SILTY, SANDY MARL, same as above, except more fossiliferous and silt to sand-sized phosphate grains (2-4%).
540 – 600	60	SILTY, SANDY MARL, light olive gray (5 Y 6/1), common fossil and limestone fragments, soft, un-indurated, very low apparent permeability.
600 – 680	80	CALCAREOUS SANDSTONE to SANDY LIMESTONE, very light olive gray (5 Y 7/1), rock is composed mostly of silt to fine sand-sized quartz and carbonate grains, and less abundant phosphate (1-2%), Soft, low apparent permeability. Fossils include mollusks.
680 – 700	20	LIMESTONE, very pale yellowish brown (10 YR 7/2), fossil wackestone to packstone, soft, low apparent porosity and permeability. Fossils include mollusks and foraminifera. Non-phosphatic.
700 – 760	60	NO SAMPLES recovered.
760 – 780	20	LIMESTONE, very pale orange (10 YR 8/2 to 7/2), bioclast grainstone; cuttings consists mostly of disaggregated fine- to granule-sized rounded fossil fragments. Soft, high porosity and apparent permeability. Fossils include mollusks and large discoidal foraminifera (*Lepidocyclina*).
780 – 790	10	MARLY LIMESTONE, very pale orange (10 YR 8/2). Sample consists of silt- and sand-sized fossil fragments in a marl matrix. Soft, very low apparent permeability.

GEOLOGIST LOG
CITY OF CLEWISTON WATER TREATMENT PLANT
PRODUCTION WELL PW-2

SITE LOCATION: City of Clewiston Public Works Complex, 1200 South Olympia Street, Clewiston, Florida

SAMPLE TYPE: Grab (cuttings)

PROJECT NUMBER: 27335 45302 (CDM)

SAMPLE DESCRIPTION BY: KM, RGM

DEPTH INTERVAL (FEET)	THICK-NESS (FEET)	SAMPLE DESCRIPTION
790 – 820	30	LIMESTONE, very pale yellowish brown (10 YR 7/2), fossil wackestone to grainstone. Moderate porosity and apparent permeability. Sample consists of wackestone to grainstone fragments and abundant large fossil fragments including large discoidal foraminifera (*Lepidocyclina*), bryozoan fragments, and echinoid spines.
820 – 860	40	LIMESTONE, very pale yellowish brown (10 YR 7/2), peloid/bioclast grainstone and/or packstone. Grains are silt to very fine sand sized. Soft, moderate porosity, low apparent permeability. Common large fossils and fragments including large discoidal foraminifera (*Lepidocyclina*).
860 – 900	40	LIMESTONE, very pale orange (10 YR 8/2), bioclast grainstone, medium-grained, moderate hardness, high porosity, moderate to high apparent permeability. Fossils include mollusks.
900 – 930	30	LIMESTONE, very pale orange (10 YR 8/2 to 7/2), bioclast/peloid grainstone. Limestone consists of relatively large fossils in a very fine-grained peloid/bioclast sand matrix. Very soft (mostly disaggregated), high porosity, low to moderate apparent permeability. Fossils include mollusks and foraminifera.
930 – 940	10	LIMESTONE, dolosotone, and marl. LIMESTONE, same as above. Dolostone, pale yellowish brown (10 YR 6/2 to 5 Y 6/2), microsucrosic, hard, low porosity and apparent permeability.
940 – 960	20	LIMESTONE, same as above, except somewhat coarse and better indurated.
960 -1020	60	LIMESTONE, very pale yellowish brown (10 YR 7/2), bioclast/peloid grainstone. Sample consists sand- and granule-sized fossils is a very fine- to slit-sized carbonate sand (grainstone/packstone) matrix. Soft, moderate porosity and low to moderate apparanet permeability. Fossils include foraminifera, bivalves, and echinoids.
1020 - 1050	30	LIMESTONE, very pale yellowish brown (10 YR 7/2), bioclast/peloid grainstone. Sample consists mostly of disaggregated sand- and granule-sized fossils, some of which have adhering very fine- to silt-sized peloid grainstone. Common 1 cm-sized echnoids (*Neolaganum dali*). Soft, moderate to high porosity and permeability
1050 - 1200	150	LIMESTONE, very pale yellowish brown (10 YR 7/2), similar to above except fewer echnoids and somewhat better lithified. Minor (≤ 1%) dictyoconid foraminifera.