ESTIMATES OF THE HORIZONTAL HYDRAULIC CONDUCTIVITY OF THE BISCAYNE AQUIFER AND UPPER TAMIAMI FORMATION FOR THE SNAPPER CREEK WELL FIELD IN MIAMI-DADE COUNTY, FLORIDA, 2010

By Leel Knowles, Jr., Louis C. Murray, Jr., and Rick M. Spechler

INTRODUCTION

Purpose and Scope: The purpose of this report is to describe the horizontal hydraulic conductivity and transmissivity of the Biscayne aquifer and upper Tamiami Formation located in the Snapper Creek well field of Miami-Dade County in south Florida (figure 1). Estimates of hydraulic conductivity and transmissivity were calculated from pnuematic slug-test data collected at 20 wells contained in the 6 well clusters shown in figure 1. Slug-test data were analyzed by the appropriate method, as described in the Data Analysis section, and results were tabularized along with the well construction data (table 1). This report also contains a brief description of the study area and slug-test methods.

Date of slug tests: March 3 - August 4, 2010
Personnel: Slug-test data collected and reviewed by Leel Knowles, Jr.;
slug-test data analyzed by Louis C. Murray, Jr.; and, report developed and written by Leel Knowles, Jr., and Rick M. Spechler.

Acknowledgments: The authors gracefully acknowledges the Miami-Dade County for its cooperation in the USGS water-science program, and extends a special thanks to the following individuals who provided program support or field assistance: Idia MacFarlane, Sonia Villamil, and Virginia Walsh.

HYDROGEOLOGIC SETTING

Two aquifer systems are present in the study area -- the Biscayne aquifer and the Floridan aquifer system (FAS). These two aquifer systems are separated by the clays, silts, sands and carbonates of the intermediate confining unit (ICU). The ICU contains beds of lower permeability that confine the water in the FAS.

The Biscayne aquifer, the principal source of water supply to Miami-Dade County, consists of highly permeable limestone with varying amounts of less-permeable sandstone, sand, and shell. Water in the Biscayne aquifer is under unconfined conditions, but can be locally semiconfined in flow zones separated by finer-grained materials. The water table fluctuates in direct and rapid response to variations in precipitation. Flow zones are characterized by connecting vugs or cavities. Between flow zones, vugs can still can be common, but are not necessarily connected; the limestone generally has matrix porosity and permeability. Most of the geologic formations comprising the Biscayne aquifer are of Pleistocene age, but locally, Pliocene-age rocks also are included in the aquifer. Most of the formations are thin and lens-like, and the entire sequence shown in figure 2 is not necessarily always present in one place. In the study area, the upper

5 feet (ft) consist generally of fill material and only the Miami Oolite and Fort Thompson Formation, which is the major water-producing unit of the aquifer are present. The base of the Biscayne aquifer at the study area is about 90 ft below land surface with the thickness of the aquifer averaging about 85 ft. With increasing depth, the sediments within the aquifer generally grade into less permeable clayey or silty sands of the Tamiami Formation.

MONITORING WELL CONSTRUCTION

A total of 23 observation wells tapping the Biscayne aquifer were drilled in the Snapper Creek well field during 2009-10. Hydraulic mud-rotary methods were used to construct wells comprised of 4.0-inch (in.) inner diameter (IND), schedule-40 polyvinyl chloride (PVC) casing and 5-15 ft of 0.02-in. slotted screen which penetrated the sandy upper parts of the Tamiami Formation. Wells drilled shallower than the Tamiami Formation have open holes drilled with 4-in. diameter boreholes. Borehole diameters for screened wells were 8 in. Well annulli were plugged with a bentonite-pellet seal and completed with grout to land surface. A coarse mixture of gravel and sand was tremied into the macroprous groundwater porous zones instead of grout when needed to prevent the grout from flowing into the highly permeable zones of adjacent monitor wells. Well construction, casing, and total depths at each location vary based on discretized flow-zone capture for high-resolution conceptual hydrogeologic model framework where concentrated flow occurred in the aquifer. A diagram of a cross section for a typical Biscayne aquifer monitor well is shown in figure 3.

INSTRUMENTATION AND EQUIPMENT LIST

- Win-Situ 5 software
- Lap-top personal computer (PC)
- Submersible pressure transducer (0-10 psi range)
- Pneumatic slug assembly, valve assembly with gauge, and compression coupling assemblies for 2-in. and 4-in. well casings
- Air compressor (with a regulator) or hand pump
- Socket wrench or short screwdriver, and teflon tape
- Pipe wrenchs (optional, but handy to loosen assemblies if overtighten)
- Commercial spreadsheet package with USGS-approved aquifer analysis programs
- Instruction sheet
- Carrying case

TEST METHODS

All 4-in wells were developed by the drilling company after well construction. The depth of each well was measured prior to testing. At each well, the static water level was measured using an electric tape immediately prior to the start and finish of each test. To measure rapid changes in water level, the well was equipped with a submersible pressure transducer which was inserted through the access hole in the top of the pneumatic slug assembly fastened securely to the top of the casing. The transducer, which was connected to the laptop PC, generally was placed about 10 ft below the static water level. The Win-Situ 5 program was designed to collect water-level data at a 250 mHz linear time-rate, or 4 samples per second which was the maximum rate allowable.

A log sampling rate was first attempted, but the rate was found to be inadequate during analysis (Dan-Der-Kamp model) because of the relatively long-lived, oscillatory response data which is indicative of highly permeable formations. The linear frequency provided a longer and higher sampling rate needed for the model to converge on a valid solution.

Each rising-head test began with the valve assembly closed and air pumped into the well casing to a presssure equivalent from 3 ft (36 inches) to 3.5 ft (42 inches) of water displacement. After each test program file was created and activated on the PC, the test was initiated (5 or more seconds later) by releasing the air (by quickly opening the guage valve) causing the water level to change rapidly within the well. Water-level data were collected by the PC and periodically verified with a graphing subprogram of Win-Situ 5 until the level had returned to or near its original static level. Three tests were made on each well for repeatability.

DATA ANALYSIS

Water-level data from the field tests were copied to a spreadsheet program developed by the USGS (Halford and Kuniansky, 2002) using: 1) The Bouwer and Rice (1976) method for unconfined aquifers with an exponential decay response, and 2) The Van der Kamp (1976) method for highly permeable formations, or those with an oscillatory response. The Van der Kamp method was used on a majority of the wells in this study. Both methods are acceptable to use for partially penetrating wells. Results from the multiple tests were averaged to obtain a mean estimate of horizontal hydraulic conductivity and transmissivity for each well (table 1). Well-construction details, including open-hole information, and individual test results for each well, are listed in table 1. Pictures of the wells contained at each of the 6 well clusters are shown in figures 4-9.

For the test data reports, water-level data were depth-to-water values referenced from the water level inside the well to the measuring point on the top of casing. (Appendices 1-20.)

RESULTS

Overall for the 60 tests performed at 20 well locations within well field, values of horizontal hydraulic conductivity (K) estimated range from 40 to 10,000 feet per day (ft/d) with a median and mean of 4,000 ft/d. Results are interesting when grouped by flow zones/formation (descending depth) and calculating the geometric mean of K for each grouping:

Flow zone	**Geometric mean of tests for K, in ft/d**
Upper	8,000
Middle	6,000
Lower	4,000
Tamiami Formation	900

Horizontal K trends lower with depth (as expected) and the geometric mean of the aquifer matrix is 800 ft/d, the lowest of the grouping, which might also be expected. Individual test results using the spreadsheet analysis package are listed in Appendices 1-20.

Variability in the horizontal K increases with depth at the Snapper Creek well field site. Only two wells tapped the upper flow zone in the test, but had similar results (within 30 percent of each other), ranging only from 7,000 to 10,000 ft/d; whereas, the lower flow zone horizontal K ranges from 2,000 to 9,000 ft/d for 6 wells, and the Tamiami Formation horizontal K ranges from 100 to 4,000 ft/d for 5 wells. The three matrix wells had the highest variability in horizontal K of all the wells with values ranging from 40 to 6,000 ft/d, and with the deepest of the three matrix wells having the highest horizontal K.

The 90-percent recovery time for each well (analyzed using the Bower and Rice method) ranges from 9 - 36 seconds with a mean of 22 seconds (Appendices 1-20).

CONCLUSIONS

The pneumatic slug tests conducted provide estimates of the horizontal hydraulic K of the Biscayne aquifer and upper Tamiami Formation in the immediate vicinity of the 20 wells tested at the Snapper Creek well field in Kendall, Florida. Horizontal hydraulic K estimates range from 40 to 10,000 ft/d. Horizontal hydraulic K for the Biscayne aquifer at the site trends lower with depth ranging from a geometric mean of 8,000 ft/d for the upper flow zone to 6,000 ft/d for the middle flow zone to 4,000 ft/d for the lower flow zone to 900 ft/d for the Tamiami Formation (top of the underlying confining unit). Variability in horizontal hydraulic K increases with depth at the Snapper Creek well field; although the matrix wells exhibited the largest variability in K.

REFERENCES

Bouwer, Herman, 1989, The Bouwer and Rice slug test - an update, Ground Water, 27(3), p. 304.

Bouwer, Herman and R.C. Rice, 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells, Water Resources Research, Vol. 12, No. 3, pp. 423-428.

Butler, James J., 1988, The Design, Performance, and Analysis of Slug Tests: Lewis Publishers, Boca Raton, FL, 252 p.

Halford, K.J., and E.L. Kuniansky, 2002. Documentation of spreadsheets for the analysis of aquifer-test and slug-test data. U.S. Geological Survey Open-File Report 02-197, Carson City, Nevada, 51 p.

Rupp, D.E., J.S. Selker, and J. Simunek, 2001, Ground Water, 39(2), p. 308.

Van der Kamp, Garth, 1976, Determining aquifer transmissivity by means of well response tests: the underdamped case: Water Resources Research, v. 12(1), 71–77 p.

Table 1: Well locations, and construction details used to estimate the horizontal conductivity of the Biscayne aquifer and the upper Tamiami Formation for the Snapper Creek well field, Kendall-Miami, Florida [FT, feet; BLS; below land surface, IND, inside diameter; K, horizontal hydraulic conductivity; FT/D, feet per day; N/A, not available]

Table 1: Well locations, and constructio	CLUSTER ID - USGS BASE NUMBER AND DISTANCE RELATION TO WELL HOUSE 23	USGS NUMBER	USGS STATION ID	LATITUDE[a]	LONGITUDE[a]	MEASURED WELL DEPTH, IN FT BLS	BOTTOM OF CASING, IN FT BLS	OPEN-HOLE INTERVAL, IN FT	OPEN-HOLE INTERVAL TYPE	WELL CASING IND, IN INCHES	DATE OF TEST	INDIVIDUAL TESTS FOR K, IN FT/D	MEAN K, IN FT/D
1	**G-3877 South 450 m**	G-3877	254150080215501	25° 41' 50.85" N	80° 21' 55.0" W	92.6	88.0	4.6	Tamiami Formation	4.0	3/4/2010	100 100 100	100
2		G-3902	254150080215502	25° 41' 50.85" N	80° 21' 55.1" W	73.7	68.0	5.7	Lower Flow Zone	4.0	8/4/2010	8600 8400 8900	9000
3		G-3903	254150080215503	25° 41' 50.85" N	80° 21' 55.2" W	20.0	6.0	14.0	Upper Flow Zone	4.0	N/A[b]	N/A	N/A
4	**G-3878 South 130 m**	G-3878	254151080214301	25° 41' 51.75" N	80° 21' 43.25" W	81.1	74.0	7.1	Lower Flow Zone	4.0	8/4/2010	7600 7600 7500	8000
5		G-3904	254151080214302	25° 41' 51.75" N	80° 21' 43.26" W	73.4	63.0	10.4	Middle Flow Zone	4.0	8/4/2010	3900 3900 3900	4000
6		G-3905	254151080214303	25° 41' 51.75" N	80° 21' 43.27" W	33.9	29.5	4.4	Matrix	4.0	8/4/2010	2000 2000 2100	2000
7		G-3906	254151080214304	25° 41' 51.75" N	80° 21' 43.28" W	14.4	5.0	9.4	Upper Flow Zone	4.0	N/A[b]	N/A	N/A
8	**G-3879 South 35 m**	G-3879	254153080213901	25° 41' 53.5" N	80° 21' 39.95" W	94.5	84.0	10.5	Tamiami Formation	4.0	8/3/2010	4500 4500 4200	4000
9		G-3907	254153080213902	25° 41' 53.65" N	80° 21' 39.96" W	72.5	63.0	9.5	Lower Flow Zone	4.0	8/3/2010	2100 2000 2000	2000
10		G-3908	254153080213903	25° 41' 53.65" N	80° 21' 39.97" W	56.6	45.0	11.6	Middle Flow Zone	4.0	8/3/2010	660 660 680	700
11		G-3909	254153080213904	25° 41' 53.65" N	80° 21' 39.98" W	38.4	35.0	3.4	Matrix	4.0	3/3/2010	40 40 40	40
12	**G-3880 North 35 m**	G-3880	254154080213704	25° 41' 54.65" N	80° 21' 37.6" W	14.0	8.0	6.0	Upper Flow Zone	4.0	8/4/2010[c]	poor result poor result poor result	N/A
13		G-3910	254154080213702	25° 41' 54.65" N	80° 21' 37.8" W	80.7	65.0	15.7	Lower Flow Zone	4.0	3/31/2010	2500 2800 2900	3000
14		G-3911	254154080213703	25° 41' 54.65" N	80° 21' 37.9" W	62.9	60.0	2.9	Middle Flow Zone	4.0	3/31/2010	8600 8600 8600	9000
15		G-3912	254154080213701	25° 41' 54.65" N	80° 21' 37.7" W	88.6	82.0	6.6	Tamiami Formation	4.0	3/31/2010	3500 3500 3600	4000
16	**G-3881 North 130 m**	G-3881	254155080243501	25° 41' 55.9" N	80° 21' 35.0" W	95.8	81.0	14.8	Tamiami Formation	4.0	3/31/2010	1000 1000 930	1000
17		G-3913	254155080243502	25° 41' 55.9" N	80° 21' 35.1" W	75.1	63.5	11.6	Lower Flow Zone	4.0	3/31/2010	3100 3300 3300	3000
18		G-3914	254155080243503	25° 41' 55.9" N	80° 21' 35.2" W	60.8	53.0	7.8	Matrix	4.0	3/31/2010	6400 6400 6300	6000
19		G-3915	254155080243504	25° 41' 55.9" N	80° 21' 35.3" W	17.1	8.0	9.1	Upper Flow Zone	4.0	3/31/2010	9500 9900 9900	10000
20	**G-3882 North 450 m**	G-3882	254158080212201	25° 41' 58.45" N	80° 21' 22.3" W	91.1	81.0	10.1	Tamiami Formation	4.0	3/30/2010	390 420 440	400
21		G-3916	254158080212202	25° 41' 58.45" N	80° 21' 22.4" W	77.7	68.5	9.2	Lower Flow Zone	4.0	3/30/2010	5800 4700 poor result	5000
22		G-3917	254158080212203	25° 41' 58.45" N	80° 21' 22.5" W	44.3	36.5	7.8	Middle Flow Zone	4.0	3/30/2010	5300 5500 5300	5000
23		G-3918	254158080212204	25° 41' 58.45" N	80° 21' 22.6" W	18.5	8.0	10.5	Upper Flow Zone	4.0	3/30/2010	7000 6800 6600	7000

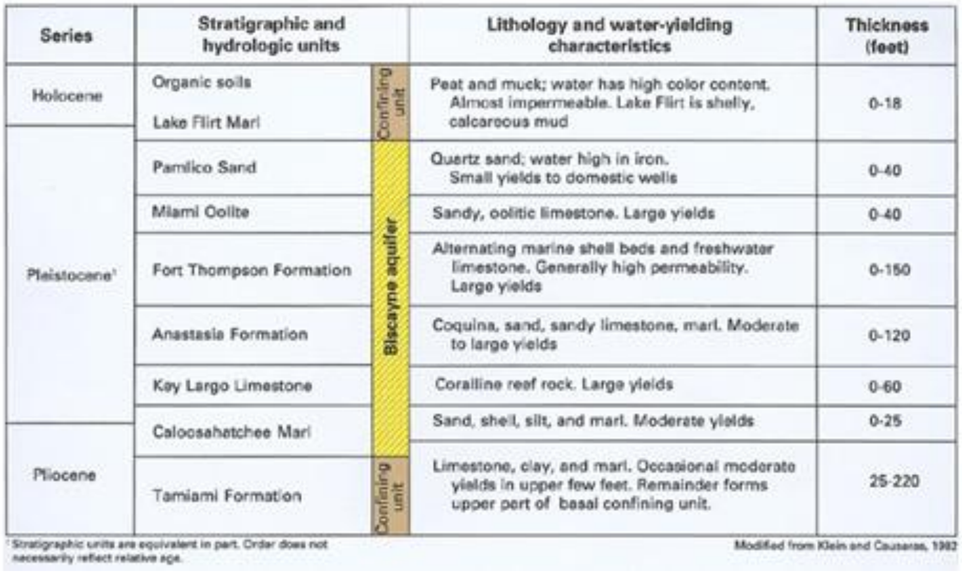
---

[a] North American Datum of 1983

[b] Water level below casing bottom during test, therefore, not tested

[c] Poor water displacement during test (likely 'bad' well), therefore, not analyzed

Figure 1. Location of study area and well clusters in the Snapper Creek well field.



Series	Stratigraphic and hydrologic units		Lithology and water-yielding characteristics	Thickness (feet)
Holocene	Organic soils Lake Flirt Marl	Confining unit	Peat and muck; water has high color content. Almost impermeable. Lake Flirt is shelly, calcareous mud	0-18
Pleistocene[1]	Pamlico Sand	Biscayne aquifer	Quartz sand; water high in iron. Small yields to domestic wells	0-40
	Miami Oolite		Sandy, oolitic limestone. Large yields	0-40
	Fort Thompson Formation		Alternating marine shell beds and freshwater limestone. Generally high permeability. Large yields	0-150
	Anastasia Formation		Coquina, sand, sandy limestone, marl. Moderate to large yields	0-120
	Key Largo Limestone		Coralline reef rock. Large yields	0-60
Pliocene	Caloosahatchee Marl		Sand, shell, silt, and marl. Moderate yields	0-25
	Tamiami Formation	Confining unit	Limestone, clay, and marl. Occasional moderate yields in upper few feet. Remainder forms upper part of basal confining unit.	25-220

[1] Stratigraphic units are equivalent in part. Order does not necessarily reflect relative age.

Modified from Klein and Causaras, 1982

Figure 2. Stratigraphic and hydrologic section for the Biscayne aquifer in southeastern Florida.

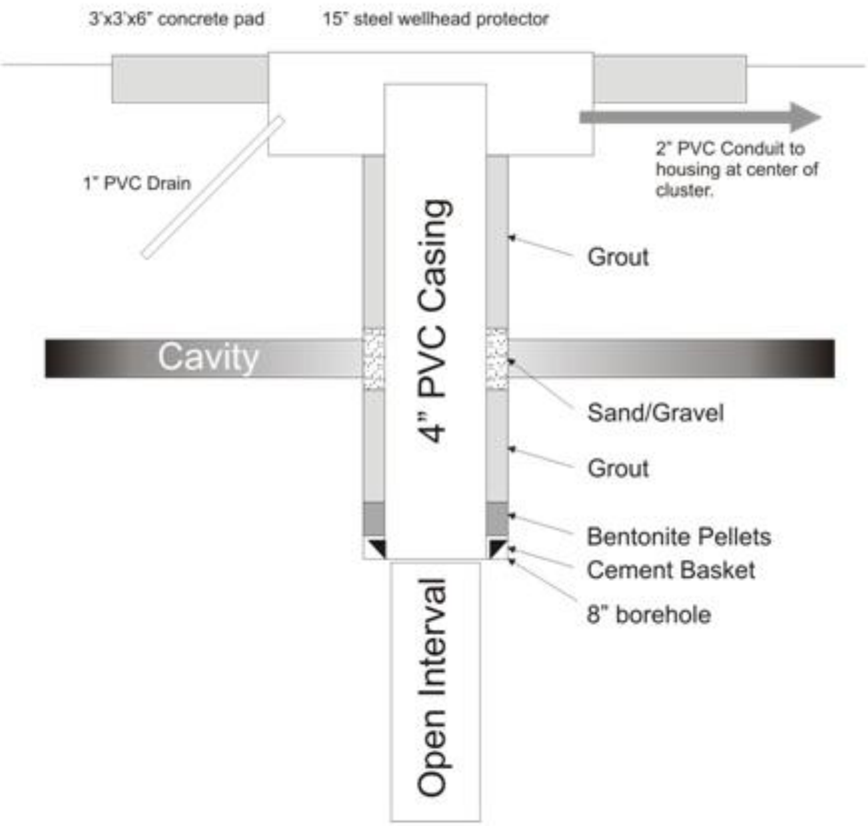


Figure 3. Cross section of a monitor well at Snapper Creek well field. Drawing not to scale.

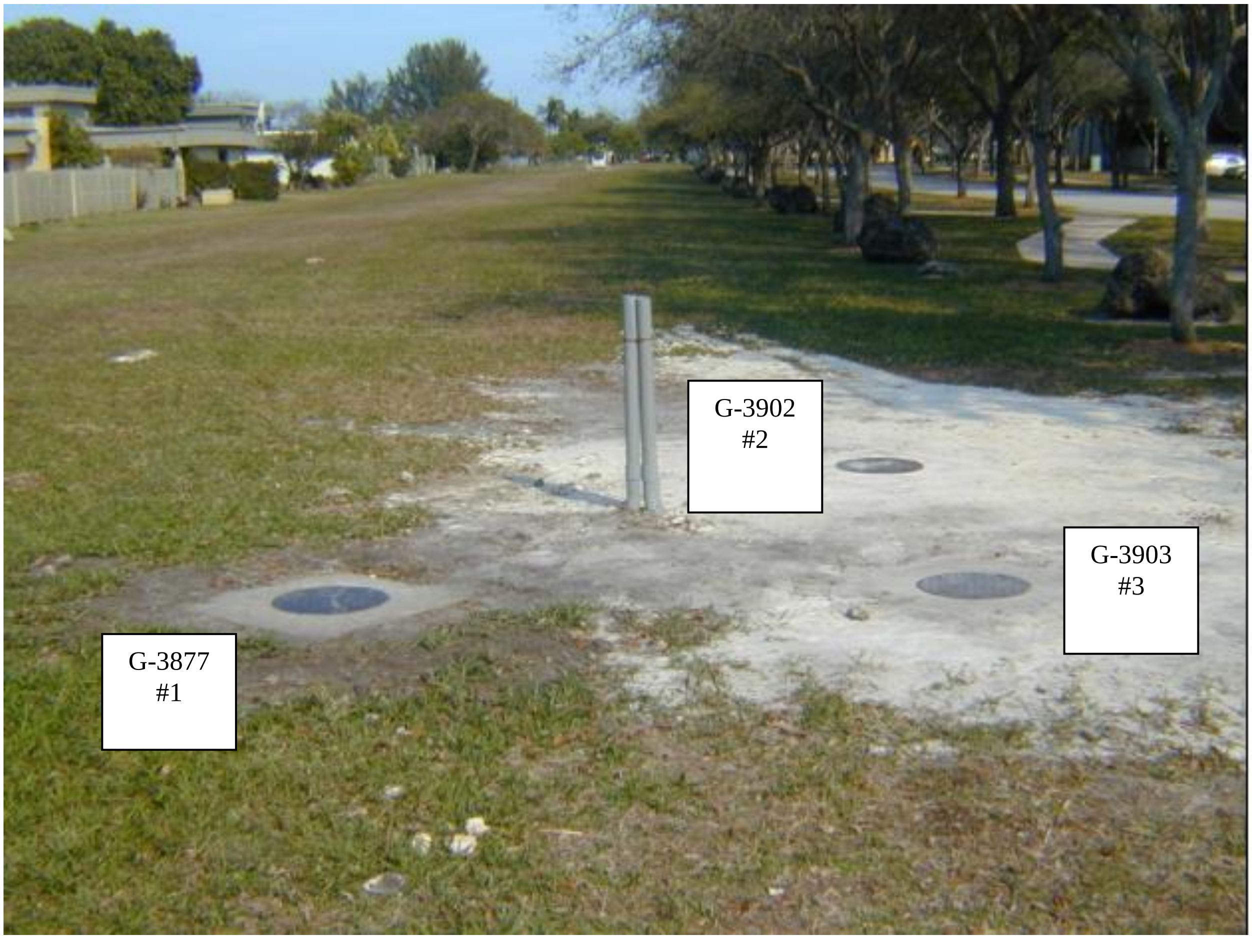


Figure 4. Well Cluster G-3877 South 450 m.

Figure 5. Well Cluster G-3878 South 130 m.

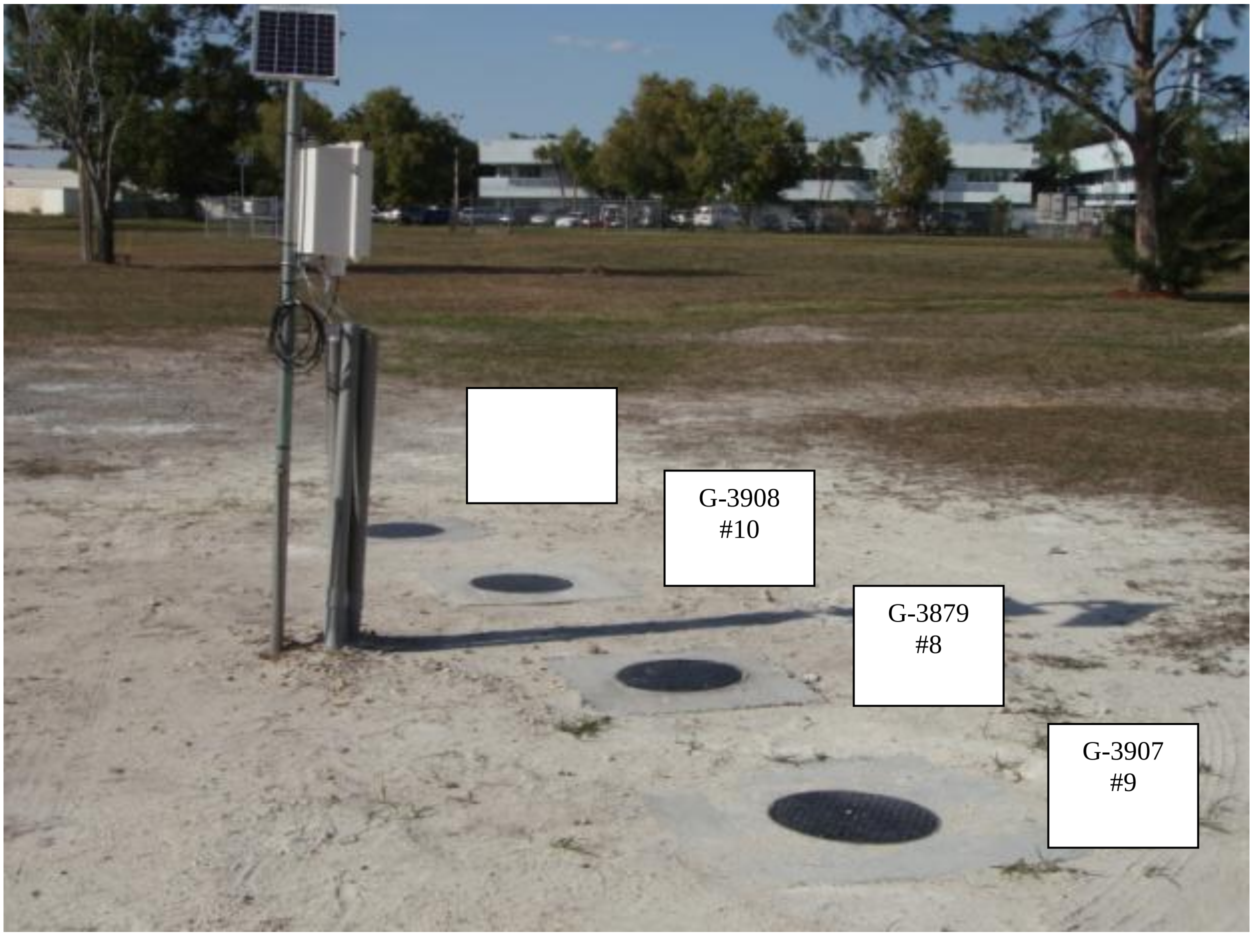


Figure 6. Well Cluster G-3879 South 35 m.

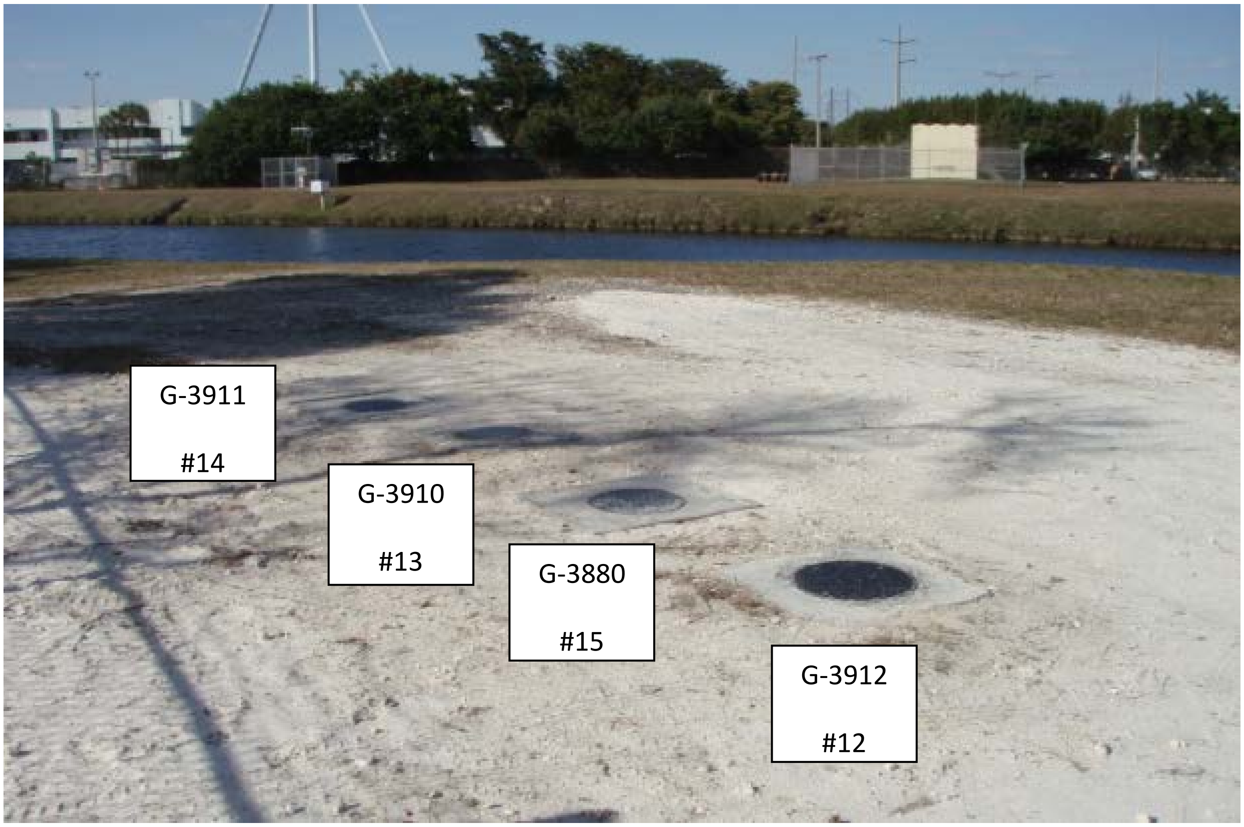


Figure 7. Well Cluster G-3880 North 35 m.

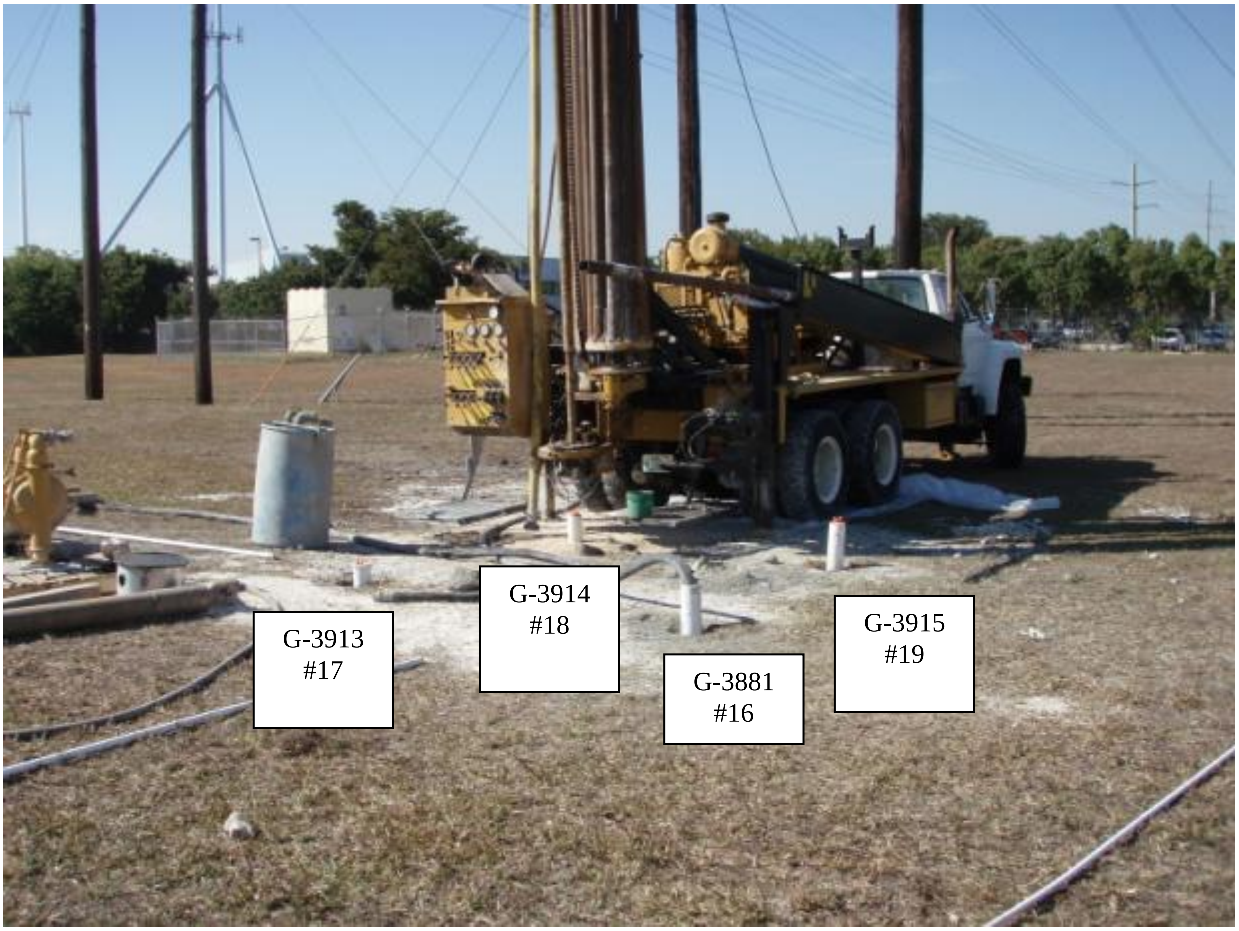


Figure 8. Well Cluster G-3881 North 130 m.

Figure 9. Well Cluster G-3882 North 450 m.