Results of the ECUA Sorrento Road Constant Discharge Aquifer Test Sand-and-Gravel Aquifer, Escambia County, Florida

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INTRODUCTION

In March and April 1999 the Escambia County Utilities Authority (ECUA) conducted a multi-well aquifer test at a site near the intersection of Bauer and Sorrento Roads in southwest Escambia County (section 21, township 3S, range 31W). The test was undertaken to determine local-scale aquifer hydraulic characteristics and to examine the feasibility of installing a permanent production well at the site. The Layne Christensen Company, Inc. performed site investigation activities, including aquifer test data collection and analysis, on behalf of ECUA. Results of the aquifer test are documented in Layne GeoSciences, Inc. (1999).

The purpose of this report is to provide additional documentation regarding the aquifer test, provide greater detail regarding the analysis and allow for distribution of the results. This type of information is especially important at this time of increasing water supply demands in northwest Florida. Aquifer testing provides the most realistic assessment of the hydraulic properties of the aquifer and forms the basis for determining the availability of ground water and the impact of withdrawals on existing users and the environment.

SITE HYDROGEOLOGY

The Sand-and-Gravel Aquifer consists primarily of fine to medium sand interbedded with varying amounts of clay. Due to the complex nature of the sediments, the lithology is highly variable both horizontally and vertically. The Sand-and-Gravel Aquifer includes the saturated sediments situated between the water table and the underlying, regionally extensive confining unit referred to as the Intermediate System. Beneath the Intermediate System lies the Upper Floridan Aquifer.

A test boring drilled to a depth of 321 ft fully penetrated the Sand-and-Gravel Aquifer. Cutting descriptions, natural gamma and normal electric logs indicate that the base of the aquifer is 200 ft below land surface (Figure 1). Given an estimated site elevation of 23 ft, the bottom of the Sand-and-Gravel Aquifer lies about 177 ft below sea level. The water table lies about one foot below land surface, resulting in a saturated thickness of 199 ft.

The lithologic log shows the aquifer to consist primarily of sand, with minor amounts of clay. Consistent with the lithologic log, the natural gamma log indicates minimal clay content from land surface to the aquifer base. The normal electric log shows the resistivity in the interval between 60 and 200 ft ranges between 200 and 300 ohms meter^2/meter (ohm-meters). Neither the lithologic nor the geophysical logs indicate any significant semi-confining unit. Accordingly, no attempt is made to differentiate the aquifer into surficial, low-permeability and main-producing zones.

The following drillers log was prepared by the Layne Christensen Company based on cuttings collected from the test boring.

Depth	Thickness	Description
0 – 5 ft	5 ft	Sand, tan, little clay
5 – 13 ft	8 ft	Sand, black
13 – 36 ft	25 ft	Sand, dark brown
36 – 37 ft	1 ft	Clay, brown
37 – 42 ft	6 ft	Sand with clay streak
42 – 56 ft	14 ft	Sand, coarse, brown
56 – 57 ft	1 ft	Clay
57 – 62 ft	5 ft	Sand, coarse, tan to white
62 – 69 ft	7 ft	Sand, coarse, tan
69 – 79 ft	10 ft	Sand with clay streak
79 – 101 ft	22 ft	Sand, coarse, tan
101 – 109 ft	8 ft	Sand, coarse, white, with shells
109 – 110 ft	1 ft	Clay, soft, white
110 – 121 ft	11 ft	Sand, coarse, white, with clay
121 – 207 ft	86 ft	Sand, medium, white
207 – 215 ft	8 ft	Clay, sandy, brown
215 – 221 ft	6 ft	Sand, medium, white
221 – 241 ft	20 ft	Sand, fine to medium, with clay
241 – 254 ft	13 ft	Sandy clay, gray to brown
254 – 261 ft	6 ft	Sand, fine to medium
261 – 281 ft	20 ft	Sandy clay, blue to gray
281 – 310 ft	29 ft	Clay, blue-gray, soft
310 – 321 ft	11 ft	Clay, blue-gray, hard

AQUIFER TEST

One 12-inch diameter test well (NWF_ID 7251) and four two-inch diameter observations wells were constructed at the test site. Figure 1 shows a cross-sectional view of the site. The test/production well was completed to a depth of 200 ft below land surface. Ten-inch diameter PVC wrapped well screen (0.035 inch slot size) was installed and gravel packed from 110 ft to 200 ft below land surface. Twelve-inch diameter steel casing extended from land surface to a depth of 110 ft.

The shallow observation well (NWF_ID 7340) was completed to a depth of 20 ft. Well screen with a slot size of 0.010 inch was installed from 15 to 20 ft below land surface. Three deep observations wells (MW-1 North [NWF_ID 7339], MW-1 West [NWF_ID 7341] and MW-2 West [NWF_ID 7342]) were each completed to a depth of 200 ft and cased to a depth of 110 ft. Well screen with a slot size of 0.010 inch was installed from 110 to 200 ft below land surface.

Layne Christensen made the following radial distance determinations; shallow well – 60 ft from production well, MW-1 North – 86 ft, MW-1 West – 230 ft and MW-2 West – 1,000 ft. For purposes of this analysis, the radial distance to MW-2 West was re-measured and determined to be 1,130 ft. The distance was measured by comparing well locations, as determined with a differential global positioning system (GPS) unit. The subsequent analysis was performed using this radial distance and not the originally determined 1,000 ft.

The static water level in all three deep observation wells was approximately 16 ft below land surface or about seven ft above sea level. The static water level in the shallow well was about one foot below land surface, or about 22 ft above sea level. The resultant hydraulic gradient between the water table and the top of the production screen is 0.14 ft/ft.

For the multi-well aquifer test, a submersible pump was installed in the production well and the observation wells were equipped with digital water level recorders. The planned 72-hour test was begun on March 29, 1999. Discharge water was piped approximately 150 ft south to the drainage swale along Sorrento Road and open discharged. From there it open channel flowed to the west away from the site. Due to pump failure, the test was prematurely terminated at 2,000 minutes. Further, data collection in MW-1 North and MW-1 West stopped at 200 and 720 minutes, respectively, due to the water level declining below the pressure transducer. 2,000 minutes of drawdown data were collected in MW-2 West.

The 72-hour test was re-started on April 6, 1999 and run for 4,200 minutes. The production well was pumped at a rate of 1,205 gallons per minute (gpm). At the end of the 4,200 minutes of pumping the production well had a specific capacity of 17 gpm per foot of drawdown.

During the second test the pressure transducers in MW-1 North and MW-1 West were initially set too deep. They did not begin recording data until the water level had dropped a sufficient, but unknown, distance. Data collection did not start until 28 minutes (MW-1 West) and 48 minutes (MW-1 North), respectively, had elapsed. Accordingly, data from these wells were not analyzable. Data were collected for the duration of the test in MW-2 West. No recovery data were obtained from the second test in any of the three deep observation wells. The MW-2 West drawdown data (test two) are the best available data collected during the two tests and the two recovery periods. During the test water levels in the shallow observation well were observed to recover slightly.

TEST ANALYSIS

Data from MW-2 West were analyzed by the District in July and August 1999 utilizing Aqtesolv^{tm} for Windows^{tm} software. Aqtesolv^{tm} is proprietary software produced by HydroSOLVE, Inc. MW-2 West data were analyzed using both the Hantush and Jacob (1955) and Moench (1985) analytical models. Type curves were generated by the software and manually matched to the observed time/drawdown data. Type curves were generated for numerous combinations of parameters in order to obtain the best curve match with the observed data. No automated data analysis was performed.

For purposes of flow system characterization two alternate conceptualizations are possible. First, the test/production and observation wells can be viewed as partially penetrating a thick, sand aquifer with no internal confinement. Under this assumption, pumping would produce both vertical and horizontal flow components above the screen. The aquifer could be thus analyzed using a partially penetrating, unconfined analytical model. This option was rejected because of the significant head difference between the upper and basal portions of the aquifer. Second, the test/production and observation wells can be viewed as fully penetrating a thinner aquifer overlain by an aquitard. In this instance, flow would be strictly horizontal in the pumped aquifer and strictly vertical in the aquitard. This conceptual model was adopted. The test data were analyzed with two models that implement this conceptualization.

Hantush and Jacob (1955)

The Hantush and Jacob (1955) solution simulates the transient response to pumping of an aquifer overlain by a leaky aquitard that is, in turn, overlain by a constant head source bed. This model assumes that all wells in the pumped aquifer are fully penetrating. In addition the model assumes the following:

- no release of water from storage in the aquitard.
- aquifer is overlain by aquitard having uniform hydraulic conductivity (k') and thickness (b').
- aquifer and aquitard are of infinite areal extent.
- aquifer is homogeneous, isotropic and of uniform thickness.
- aquitard is overlain by constant head source bed.
- well discharge is constant.
- well is of infinitesimal diameter.
- flow of water through aquitard is vertical.
- flow of water through aquifer is horizontal.
- initial potentiometric surface of the aquifer and the water table are horizontal and extend infinitely in the radial direction.
- water is released instantaneously from storage with decline in hydraulic head.

Figure 2 shows the Hantush and Jacob type curve which best represents the aquifer plotted with the observed data where:

$$u = \frac{r^2 S}{4Tt} \quad \text{and}$$

W(u,r/B) is the Hantush well function and

B is the Hantush leakage parameter $= \sqrt{\dfrac{Tb'}{k'}}$ and

T = kb.

The terms are defined as:

b' = aquitard thickness (ft)
b = aquifer thickness (ft)
k' = vertical hydraulic conductivity of the aquitard (ft/d)
k = horizontal hydraulic conductivity of the aquifer (ft/d)

r	=	radial distance from the pumping well to the observation well (ft)
S	=	aquifer storativity (dimensionless)
t	=	time (d)
T	=	aquifer transmissivity (ft^2/d)

The Hantush and Jacob analytical solution assumes the existence of an overlying semi-confining unit. Further, the solution assumes strictly vertical flow through the aquitard and strictly horizontal flow through the aquifer. Lithologic and geophysical data show a primarily sand lithology over the entire thickness of the Sand-and-Gravel Aquifer. An explicitly differentiable aquitard is not evident. The vertical head gradient of 0.14 across the upper, unscreened portion of the aquifer indicates impedance to vertical flow and, hence, some degree of "confinement."

For the purposes of aquifer test analysis, the pumped aquifer was assumed to equate to the screened interval (90-ft thick). Given that no assumption regarding b' was made, no hydraulic parameters derivative of b' were determined. The following hydraulic properties were calculated:

Hydraulic Property	MW-2 West
r/B (dimensionless)	0.22
B (ft)	5,100 (rounded)
T of the 90-ft thick pumped aquifer (ft^2/d)	6,200 (rounded)
k of the 90-ft thick pumped aquifer (ft/d)	69
S of the 90-ft thick pumped aquifer (dimensionless)	0.0005
k'/b' (1/d)	0.00024

Reed (1980) offers a test of the adequacy of the contrast between k and k' to support the assumption of strictly vertical flow in an aquitard, namely:

$$k > 100b(k'/b')$$

Based on values obtained from this test, the above relationship (i.e. 69 > 1.8) holds. Therefore, the assumption of vertical flow in the (assumed) aquitard is appropriate, supporting use of the Hantush and Jacob method in the absence of a lithologically differentiable aquitard.

If it is assumed that the entire thickness of saturated sediments lying above the top of the test screen is the semi-confining unit, the site k' is about 0.026 ft/d. If b' is assumed to be 50 ft, k' calculates to 0.012 ft/d.

Moench (1985)

The Moench (1985) model simulates the transient response of a leaky, confined, isotropic aquifer to pumping. It differs from the Hantush and Jacob model in that it does account for the influence of storage in the confining unit on aquifer drawdown. This model further assumes:

-pumping well fully penetrates aquifer.

-aquifer is overlain by aquitard having uniform hydraulic conductivity (k'), thickness (b') and storage (S').
-aquifer and aquitard are of infinite areal extent.
-aquifer is homogeneous, isotropic and of uniform thickness.
-aquitard is overlain by constant head source bed.
-flow of water through aquitard is vertical.
-flow of water through aquifer is horizontal.
-initial potentiometric surface of the aquifer and the water table are horizontal and extend infinitely in the radial direction.
-water is released instantaneously from storage with decline in hydraulic head.

Figure 3 shows the Moench type curve which best represent the aquifer plotted with the observed data where the solution for dimensionless head in Laplace transform space is as follows:

$$\bar{h}_D = \frac{2K_0(r_D x)}{p\{pW_D[K_0(x) + xS_w K_1(x)] + xK_1(x)\}}$$

where:

$$x = (p + \bar{q}_D)^{1/2}$$

$$\bar{q}_D = \gamma^2 m \tanh(m)$$

$$m = \frac{(\sigma p)^{1/2}}{\gamma}$$

$$\gamma = r_w \sqrt{\frac{k'}{kbb'}}$$

$$\sigma = \frac{S'_s b'}{S_s b}$$

$$r_D = \frac{r}{r_w}$$

$$W_D = \frac{\pi r_c^2}{2\pi r_w^2 S_s b}$$

The Hantush leakage and storage parameters, B and β, are related to σ and γ as follows (Moench, 1985):

$$r/B = \gamma\ r_D$$

$$\beta = \frac{\gamma}{4}(\sigma)^{1/2} r_D$$

where:

B is the Hantush leakage parameter = $\sqrt{\frac{Tb'}{k'}}$ and

β is the Hantush storage parameter = $\frac{r}{4}\sqrt{\frac{k'S'}{b'TS}}$ and

T = kb.

The terms are defined as:

b'	=	aquitard thickness (ft)
b	=	aquifer thickness (ft)
k'	=	vertical hydraulic conductivity of the aquitard (ft/d)
k	=	horizontal hydraulic conductivity of the aquifer (ft/d)
K_0	=	modified Bessel function of second kind, zero order
K_1	=	modified Bessel function of second kind, first order
p	=	Laplace transform variable
r	=	radial distance from the pumping well to the observation well (ft)
r_c	=	well casing radius (ft)
r_w	=	well radius (ft)
S	=	aquifer storativity (dimensionless)
S'	=	aquitard storativity (dimensionless)
S_s	=	specific storage of aquifer in leaky system (1/ft)
S'_s	=	specific storage of aquitard in leaky system (1/ft)
S_w	=	wellbore skin (dimensionless)
T	=	aquifer transmissivity (ft^2/d)

Application of the Moench solution is constrained in the same manner as is the Hantush and Jacob method, namely, there is no explicit value for b'. Accordingly, no parameters derivative of b' were calculated. If it is assumed that the entire thickness of saturated sediments lying above the top of the test screen is the semi-confining unit, the site k' is about 0.028 ft/d. If b' is assumed to be 50 ft, k' calculates to 0.013 ft/d. The analytical results were insensitive to β, implying that storage in the confining unit has a negligible impact on aquifer drawdown.

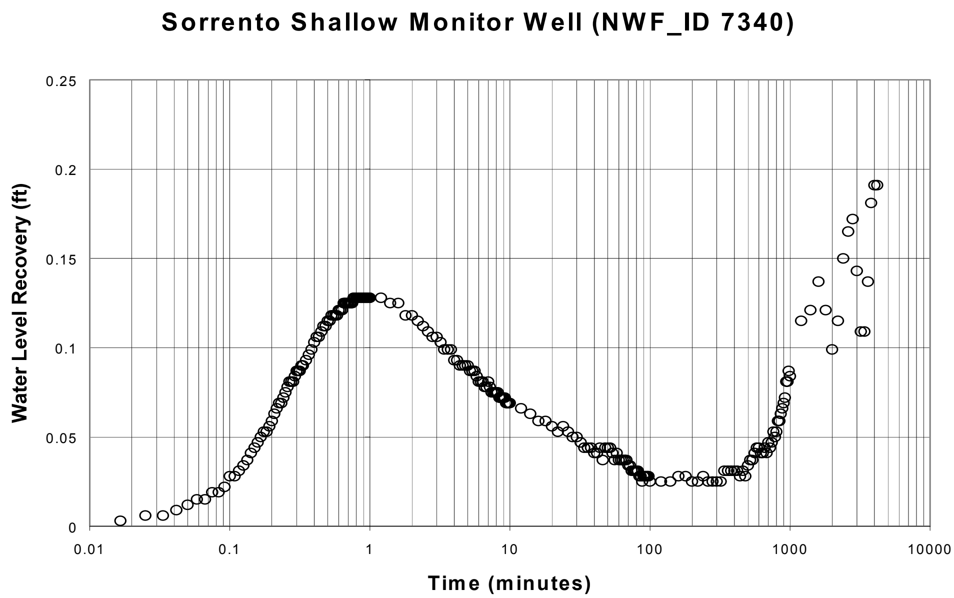
Hydraulic Property	MW-2 West
r/B (dimensionless)	0.23
B (ft)	4,900 (rounded)
T of the 90-ft thick pumped aquifer (ft^2/d)	6,100 (rounded)
k of the 90-ft thick pumped aquifer (ft/d)	68
S of the 90-ft thick pumped aquifer (dimensionless)	0.0005
k'/b' (1/d)	0.00025

REFERENCES

Layne GeoSciences, Inc., 1999. Report on Bauer and Sorrento Roads Test Well and Ground Water Survey, report prepared for the Escambia County Utilities Authority.

Moench, A.F., 1985. Transient Flow to a Large-Diameter Well in an Aquifer with Storative Semiconfining Layers, Water Resources Research, vol. 21, no. 8, pp. 1121-1131.

Reed, J.E., 1980. Type Curves for Selected Problems of Flow to Wells in Confined Aquifers, Techniques of Water-Resources Investigations of the USGS, Book Three, Applications of Hydraulics, Chapter B3.



DRAWDOWN DATA FOR ECUA SORRENTO ROAD AQUIFER TEST
MW-2 WEST (NWF_ID 7342)

Elapsed Time (Minutes)	*Drawdown (Feet)*
2	0.01
2.2	0.014
2.4	0.014
2.6	0.014
2.8	0.014
3	0.017
3.2	0.017
3.4	0.017
3.6	0.02
3.8	0.02
4	0.023
4.2	0.023
4.4	0.023
4.6	0.026
4.8	0.029
5	0.029
5.2	0.029
5.4	0.029
5.6	0.033
5.8	0.033
6	0.036
6.2	0.033
6.4	0.036
6.6	0.039
6.8	0.039
7	0.042
7.2	0.042
7.4	0.046
7.6	0.049
7.8	0.049
8	0.049
8.2	0.049
8.4	0.055
8.6	0.055
8.8	0.058
9	0.058
9.2	0.061
9.4	0.061
9.6	0.065
10	0.071
12	0.09
14	0.116
16	0.147
18	0.179
20	0.217
24	0.297
26	0.342

Elapsed Time (Minutes)	*Drawdown (Feet)*
28	0.386
30	0.434
32	0.476
34	0.52
36	0.575
38	0.619
40	0.671
42	0.718
44	0.77
46	0.818
48	0.865
50	0.913
52	0.964
54	1.012
56	1.06
58	1.111
60	1.159
62	1.207
64	1.255
66	1.303
68	1.351
70	1.389
72	1.437
74	1.485
76	1.529
78	1.577
80	1.622
82	1.667
84	1.711
86	1.753
88	1.791
90	1.839
92	1.877
94	1.919
96	1.96
98	1.999
100	2.04
140	2.752
160	3.052
180	3.326
200	3.575
220	3.802
240	4.006
260	4.2
280	4.379
300	4.548
340	4.841

Elapsed Time (Minutes)	*Drawdown (Feet)*
360	4.975
380	5.106
400	5.227
420	5.342
440	5.454
460	5.553
480	5.651
500	5.744
520	5.833
540	5.916
560	5.996
580	6.075
600	6.155
620	6.235
640	6.311
660	6.385
680	6.458
700	6.522
720	6.592
740	6.652
760	6.71
780	6.77
800	6.831
820	6.882
840	6.936
860	6.987
880	7.035
900	7.083
920	7.13
940	7.175
960	7.22
980	7.261
1000	7.306
1200	7.672
1400	7.971
1600	8.28
1800	8.487
2000	8.637
2200	8.758
2400	8.866
2600	8.965
2800	9.07
3000	9.182
3200	9.229
3400	9.274
3800	9.35
4200	9.443

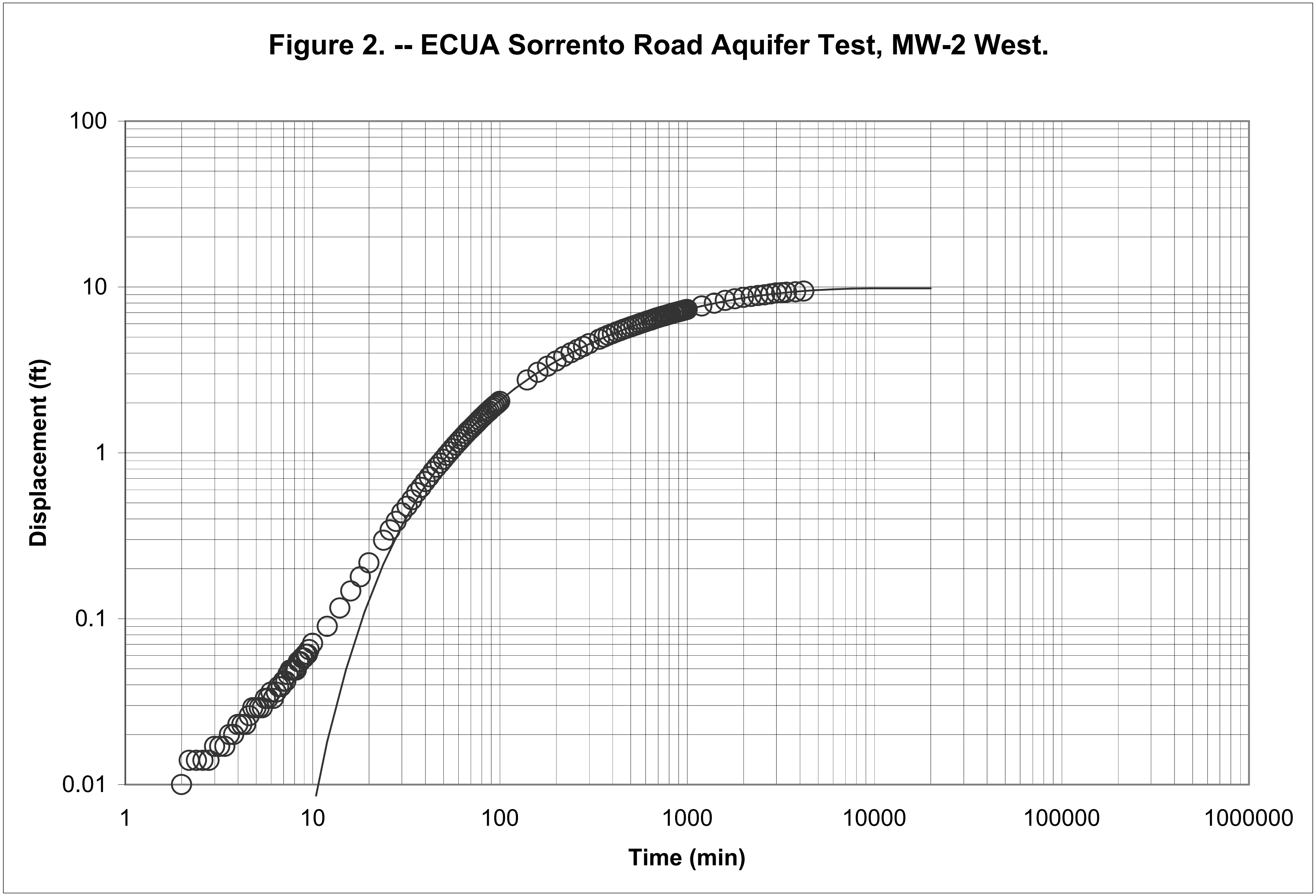
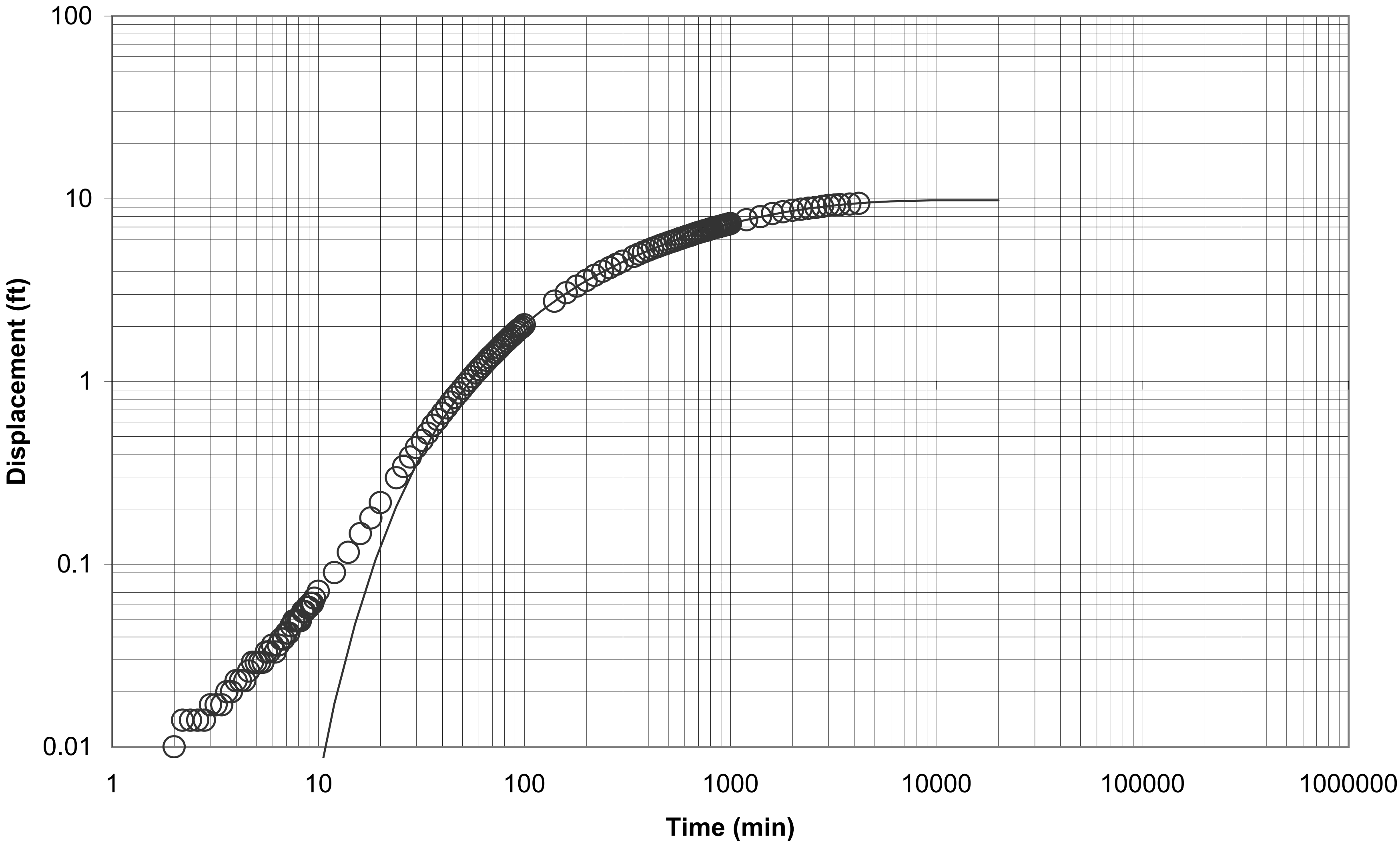


Figure 2. -- ECUA Sorrento Road Aquifer Test, MW-2 West.
100
10
1
0.1
0.01
Displacement (ft)
1
10
100
1000
10000
100000
1000000
Time (min)

Figure 3. -- ECUA Sorrento Road Aquifer Test, MW-2 West.



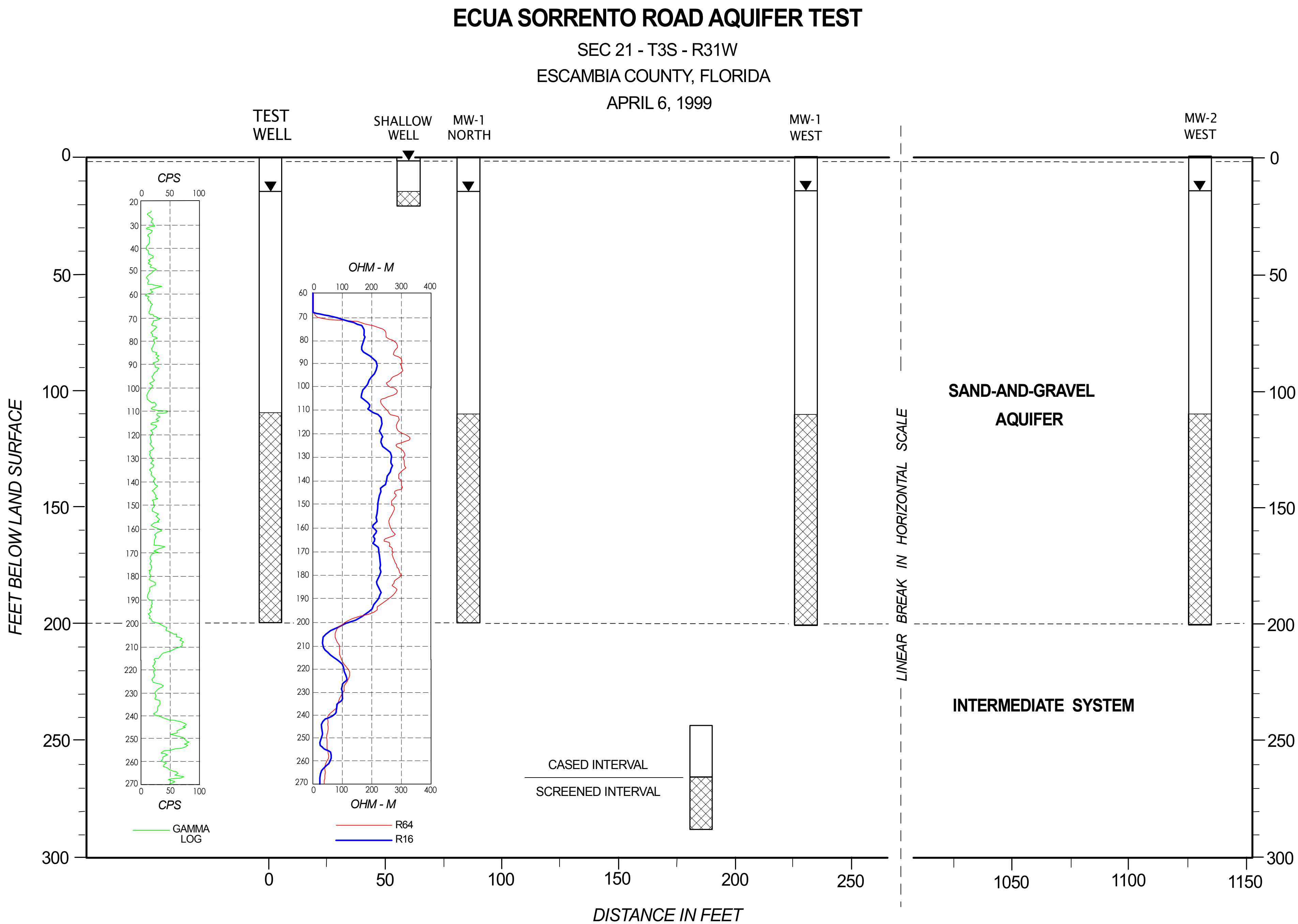


FIGURE 1. WELL CONSTRUCTION AND GENERALIZED HYDROSTRATIGRAPHY AT THE AQUIFER TEST SITE.