Results of the ECUA OLF4A
Constant Discharge Aquifer Test
Sand-and-Gravel Aquifer, Escambia County, Florida

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INTRODUCTION

In order to provide a better characterization of hydraulic properties of the Sand-and-Gravel Aquifer, an aquifer test was designed and conducted north of the City of Pensacola in the vicinity of Nine Mile Road, east of Hwy 29. The area surrounding the ECUA public supply well OLF4A was chosen as a suitable site for the test, based on the geographic distribution of other aquifer test data, ease of site access, site security, viable options for disposal of pumped water, and other factors.

CONCEPTUAL MODEL OF AQUIFER TEST SITE

The conceptual model of the Sand-and-Gravel Aquifer in Escambia County is a three-layer aquifer system with a water-table surficial zone, a leaky semi-confining low permeability zone, and a main producing zone. This model is discussed in detail in Roaza et al. (1991). Geophysical logs of the wells installed at the site indicate that, in general, the OLF4A site conforms to this three-layer conceptual model.

At the site, the Sand-and-Gravel Aquifer has a total thickness of about 281 feet. Based on the three-layer conceptual model, the aquifer was subdivided into a surficial zone (61 feet thick), a low permeability zone (38 feet thick), and a main producing zone (182 feet thick). The contacts between these hydrostratigraphic units were picked primarily on geophysical log interpretation. Delineation of zones based on the lithology of drilling cuttings was difficult due to the uniformly sandy nature of the cuttings. This vertical discretization was used for subsequent aquifer test analysis. For the purposes of analysis, unit thicknesses were assumed to be constant over the site.

There is a substantial thickness of unsaturated sediments above the surficial zone at the site. The water table lies at a depth of about 85 feet below land surface. Between land surface and the top of the saturated zone, three distinct lithologic intervals are present (Figure 1). From land surface to a depth of about 35 feet, sediments are predominantly sandy and, apparently, unsaturated. From 35 to about 75 feet below land surface, sediments have a more clayey composition. Below 75 feet, to the base of the aquifer, the sediments are predominantly sands with little clay and silt. All but the uppermost ten feet of this sandy sequence is saturated.

TEST DESIGN AND CONSTRUCTION

Four four-inch wells were installed into the main producing zone to provide monitoring of water levels during the test. Three of the wells were screened into essentially the same vertical interval as the OLF4A production well. OLF4A (NWF_ID 3433) has a screen length of 120 feet, which is about two thirds the thickness of the main producing zone at the site. MW01 (NWF_ID 3442), MW03 (NWF_ID 3444), and MW04 (NWF_ID 3415) were installed at radial distances of 100, 606, and 1,086 feet, respectively, from the production well. MW02 (NWF_ID 3443), which penetrated only the uppermost portion of the main producing zone, was installed at a radial distance of 102 feet from OLF4A. One existing surficial zone irrigation well (NWF_ID 3429), located 345 feet from the production well, was also used for water level monitoring. Figure 2 illustrates the general location and distribution of these wells at the site. Figure 3 shows the construction details of the four constructed wells, the irrigation well, and the production well. Table 1 gives detailed construction information for these wells. All wells constructed for the test were completed by gravel packing the screens and fully grouting the casings.

In addition to the wells discussed above, two distant wells were monitored during the test. Water levels in USGS #46 (NWF_ID 3335, 7,000 feet away) and in the ECUA Ensley production well (NWF_ID 3405, 4,500 feet away) were both manually monitored, but failed to show any significant declines during the test.

Table 1 -- OLF4A Aquifer Test Well Construction Details.

	Radial Distance from Production Well (feet)	Casing Depth (feet)	Total Depth (feet)	Static Water Level Above Sea Level (feet)
MW01	100	220	340	45.81
MW02	102	180	195	45.67
MW03	606	223	343	46.50
MW04	1,086	220	340	47.95
IRRIG	345	120	135	43.37
OLF4A	---	220	338	---

Pre-test activities included installing and adjusting automatic water level recorders in each of the four newly constructed wells and implementing a temporary piping system to remove water from the site during the test. Water was discharged into the drainage swale on the south side of Nine Mile Road and was piped a distance of about 450 feet before being released. This precaution was taken to prevent recharge of water to the surficial zone and interference with interpretation of test results. The water level recorders were sensitive to water level changes of one-hundredth of a foot, and were capable of reporting changes in water levels once every second. Discharge was measured with a eight-inch diameter, totalizing flow meter. Prior to the test, the meter was re-calibrated by the manufacturer to assure accurate discharge measurements. As requested, ECUA attempted to manage pumping in order to reduce transient effects on heads from nearby production wells in order to minimize extraneous "noise" prior to, and during the test.

TEST START-UP, OPERATION AND TERMINATION

On November 12, 1991 at 1:00:15 p.m. the OLF4A pump was engaged and the test begun. Pumping was constant at 2,500 gallons per minute (gpm) for the duration of the test. Water level data from all sites was collected by manually reading the water level recorders at five to ten second intervals initially, then at longer intervals through the first ten minutes of the test. After the first ten minutes each recorder was manually read on a regular basis to avoid data loss in the case of recorder failure. All recorders functioned throughout the test duration. The manually collected data supplemented data from the automatic water level recorders, which recorded data once every minute. Unlike the wells constructed for the test, the irrigation well was measured manually with a steel tape.

The intended duration of the test was 8,000 minutes, or about five-and-one-half days. On November 14, at approximately 8:35 p.m. (3,336 minutes) the test was unexpectedly terminated by a power failure. Preliminary examination of the data indicated that it was of sufficient quality and duration to meet the project's data needs and the test was not restarted.

WATER LEVEL DATA AND CORRECTIONS

Figure 4 shows the drawdown versus time curves for each of the five wells monitored at the site. Water level declines were observed in each of these wells. Due to the manner in which water level data was collected, two data corrections were necessary prior to test analysis. The first correction changed the data from clock time to time-into-test. The second correction was a linear function applied to the data to compensate for a small error introduced by the automatic water level recorder float system. As water levels decreased during the test, and the amount of steel tape on the float side of the recorder tape increased, the amount of freeboard on the float decreased. Essentially, recorders registered a slightly lower water level than they should have. Periodically during the test manual readings were taken in each well. Using these readings as calibration points, a linear correction formula was created for each well. It should be noted that the maximum errors occurred at the greatest values of drawdown, where the error has the least noticeable effect on the data curve, due to the log-log nature of the plots.

ANALYSIS OF AQUIFER TEST RESULTS

The primary goal of the aquifer test analysis is to determine, as accurately as possible, the most representative values of the relevant hydraulic properties of the Sand-and-Gravel Aquifer at this site (main producing zone transmissivity [T], storativity [S], and vertical to horizontal anisotropy ratio [kz/kr], and the vertical hydraulic conductivity [k'] of the low permeability zone). The analysis was accomplished through use of an analytical model of the behavior of water levels in the vicinity of a pumped well. A number of these models are available for aquifer test analysis; each is subject to its own set of assumptions and incorporates different factors into its solution. If the correct model for the conditions at the site is supplied with the correct information concerning aquifer geometry and well construction, type curves can be produced that match the observed data. Using a technique known as the "match-point" method, the desired aquifer properties can then be determined.

Hantush (1964) provides an analytical solution for drawdown in the vicinity of a pumped well that partially penetrates a leaky, confined aquifer. Utilization of a leaky aquifer analytical solution is supported by the fact that the surficial zone well readily drew down in response to pumpage of the underlying main producing zone (Figure 4). The surficial zone irrigation well began to drawdown at about 10 minutes into the test. The solution of Hantush is subject to a number of assumptions, which are summarized as follows.

(1) Constant discharge (Q) from production well.

(2) Production well has an infinitely small diameter and is partially penetrating.

(3) Production aquifer is anisotropic with respect to hydraulic conductivity.

(4) Aquifer is overlain by a confining unit having uniform thickness (b') and vertical hydraulic conductivity (k').

(5) Confining bed is overlain by an infinite, constant head source bed.

(6) No release of water from storage within the confining bed.

(7) Vertical flow only within the confining bed.

(8) Vertical flow gradients in the pumped aquifer result solely from partial penetration, not from leakage into the aquifer.

(9) The aquifer is infinite in areal extent and no drawdown occurs at infinity.

(10) Drawdown at the start of test is everywhere zero.

The general solution for drawdown (s) in an observation well in the pumped aquifer is given by:

$$s = Q/4pkrb \cdot [W(ur,r/Br) + f(ur,x,r/Br,d/b,l/b,d'/b,l'/b)] \quad (1)$$

where:

Q is the pumped well discharge, (481,283 ft^3/d).

W(ur, r/Br) is the well function for a leaky, confined aquifer with fully penetrating wells.

f(ur, x, r/Br, d/b, l/b, d'/b, l'/b) is a function that corrects W for partial penetration.

ur is $r^2S/4krbt$, (dimensionless). (2)

Br is $(krbb'/k')^{1/2}$, (ft). (3)

x is $(kz/kr)^{1/2} \cdot (r/b)$, (dimensionless).

S is the pumped aquifer storage coefficient, (dimensionless).

r is the radial distance from the production well to an observation well, (ft).

b is the pumped aquifer thickness, (182 ft).

b' is the confining unit thickness, (38 ft).

k' is the confining unit vertical hydraulic conductivity, (ft/d).

kr is the pumped aquifer horizontal hydraulic conductivity, (ft/d).

kz is the pumped aquifer vertical hydraulic conductivity, (ft/d).

d is the distance from the top of the aquifer to the top of the production well screen, (ft).

l is the distance from the top of the aquifer to the bottom of the production well screen, (ft).

d' is the distance from the top of the aquifer to the top of the observation well screen, (ft).

l' is the distance from the top of the aquifer to the bottom of the observation well screen, (ft).

t is time, (d).

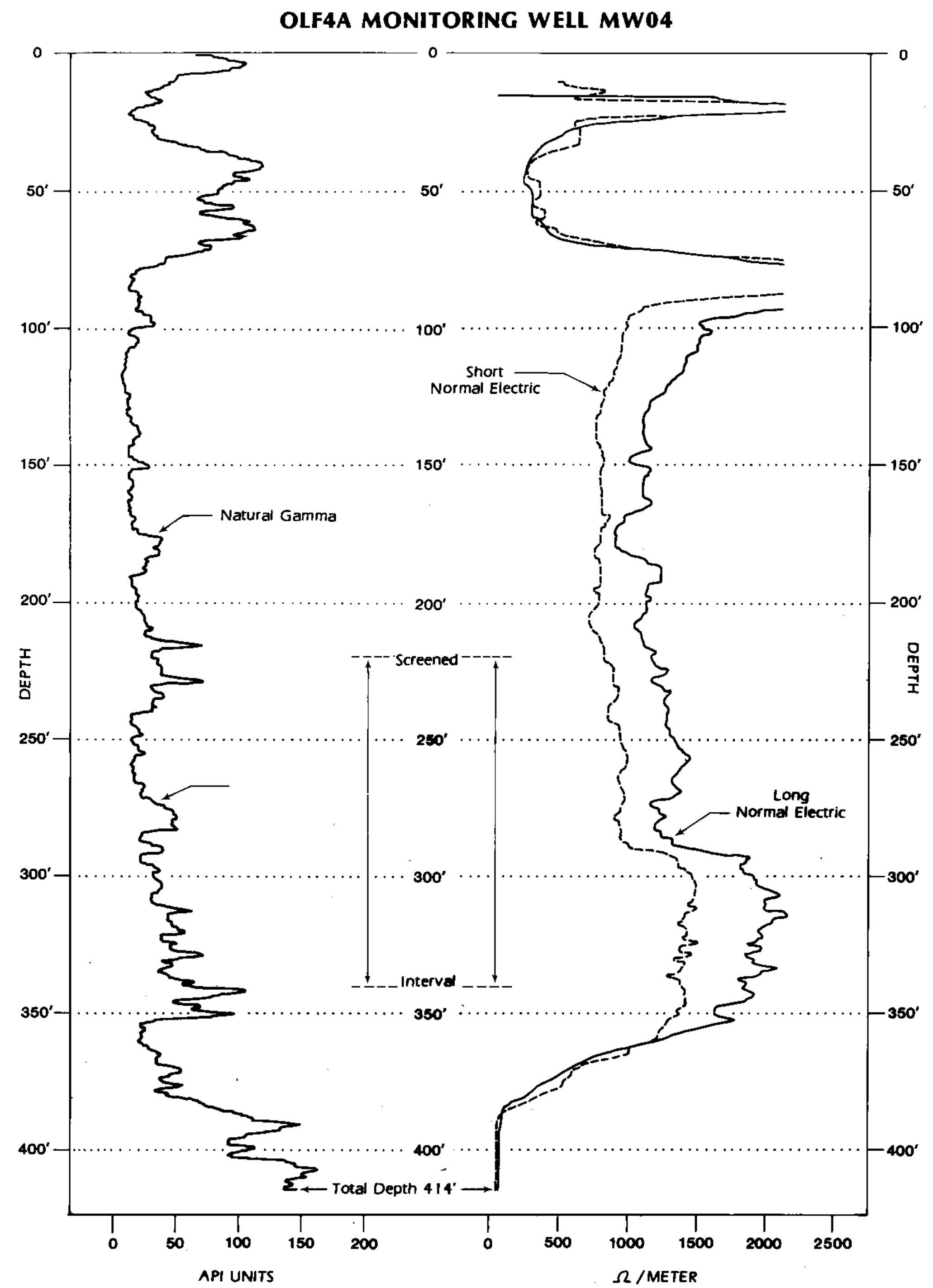
Reed (1980) presents a FORTRAN program (Table 6.1) that computes type curves for the solution of Hantush (1964). Using type curves generated by this program, the type curve matching procedure was applied to the drawdown data obtained from MW01, MW02, and MW03 (Figures 5 through 7). In this case, application of the type curve method involved a trial-and-error variation of r/Br and kz/kr, until a pair of values which gave an acceptable type curve match for both MW01 and MW02 was determined. Because MW01 and MW02 have essentially the same value of r, and assuming constant values of Br and kz/kr, it was possible to determine a pair of values of r/Br and kz/kr that yielded type curves that matched both data curves (Figures 5 and 6) reasonably well. Aquifer properties determined with the match point data found in Figures 5 through 7 and with equations 1, 2, and 3 are found in Table 2.

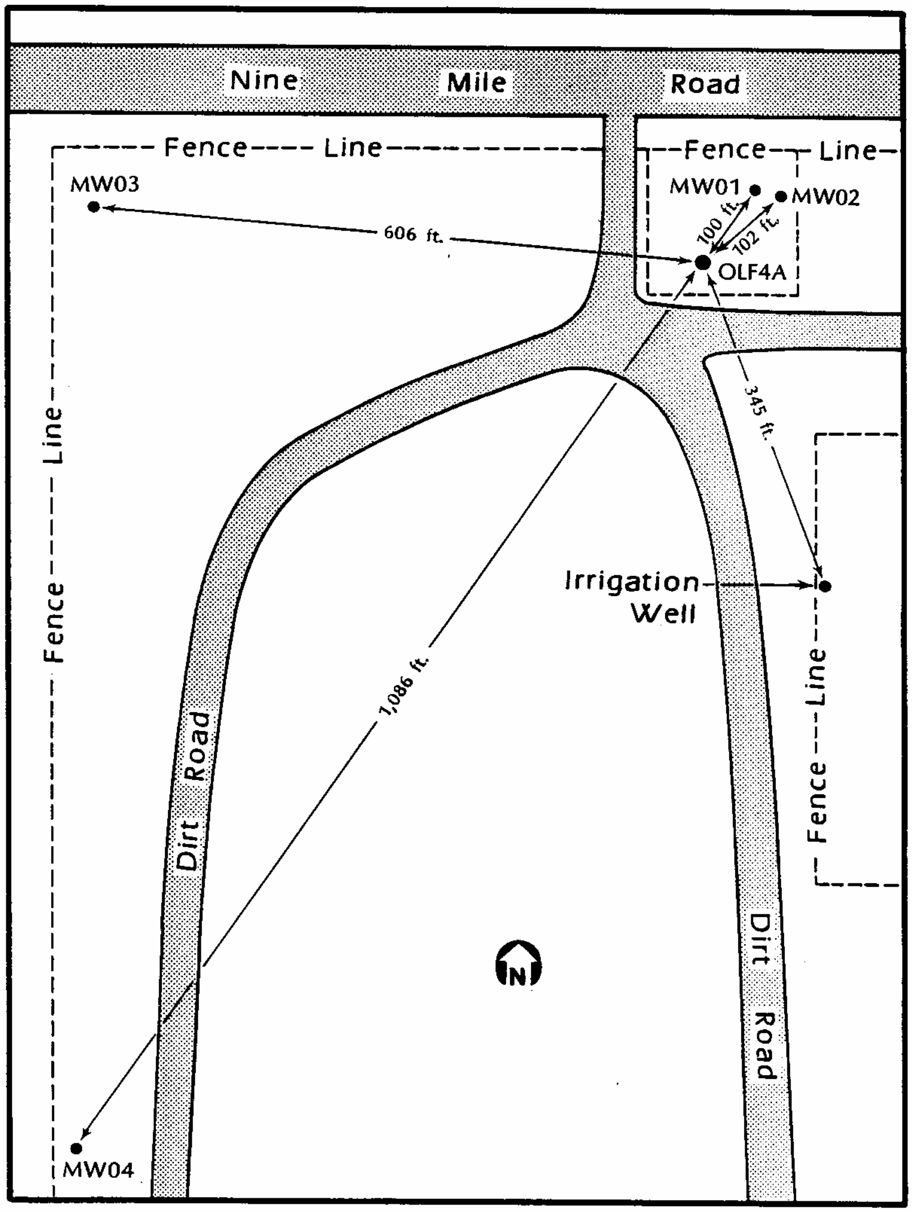
The hydraulic properties, as determined by the aquifer test analysis, are typical of what would be expected for a sand and gravel aquifer. The horizontal hydraulic conductivity is in the range given by Freeze and Cherry (1979) for clean, unconsolidated sands. The ratio of horizontal to vertical hydraulic conductivity of 10 is not unexpected. The vertical hydraulic conductivity of the low permeability zone is high, being about 1/20th of the vertical hydraulic conductivity of the main producing zone. The k' values are in the range given by Freeze and Cherry (1979) for silty sands. S values are typical of a confined aquifer.

The response of the aquifer at this site has direct implications for understanding contaminant transport processes in the Sand-and-Gravel Aquifer in Escambia County. It is important to be aware that stress induced by pumpage can, under hydrogeologic conditions similar to those present here, be transmitted to the top of the aquifer in a relatively short period of time. In turn, this creates, or increases, a downward hydraulic gradient into the main producing zone. This gradient, together with the relatively high vertical hydraulic conductivity of the low permeability zone (0.22 ft/d to 0.26 ft/d), will facilitate the transport of contaminants from the uppermost parts of the aquifer into the portion tapped by production wells. The combination of hydraulic conditions observed here is probably typical of much of southern Escambia County and points out the vulnerability of the main producing zone to contamination from land surface.

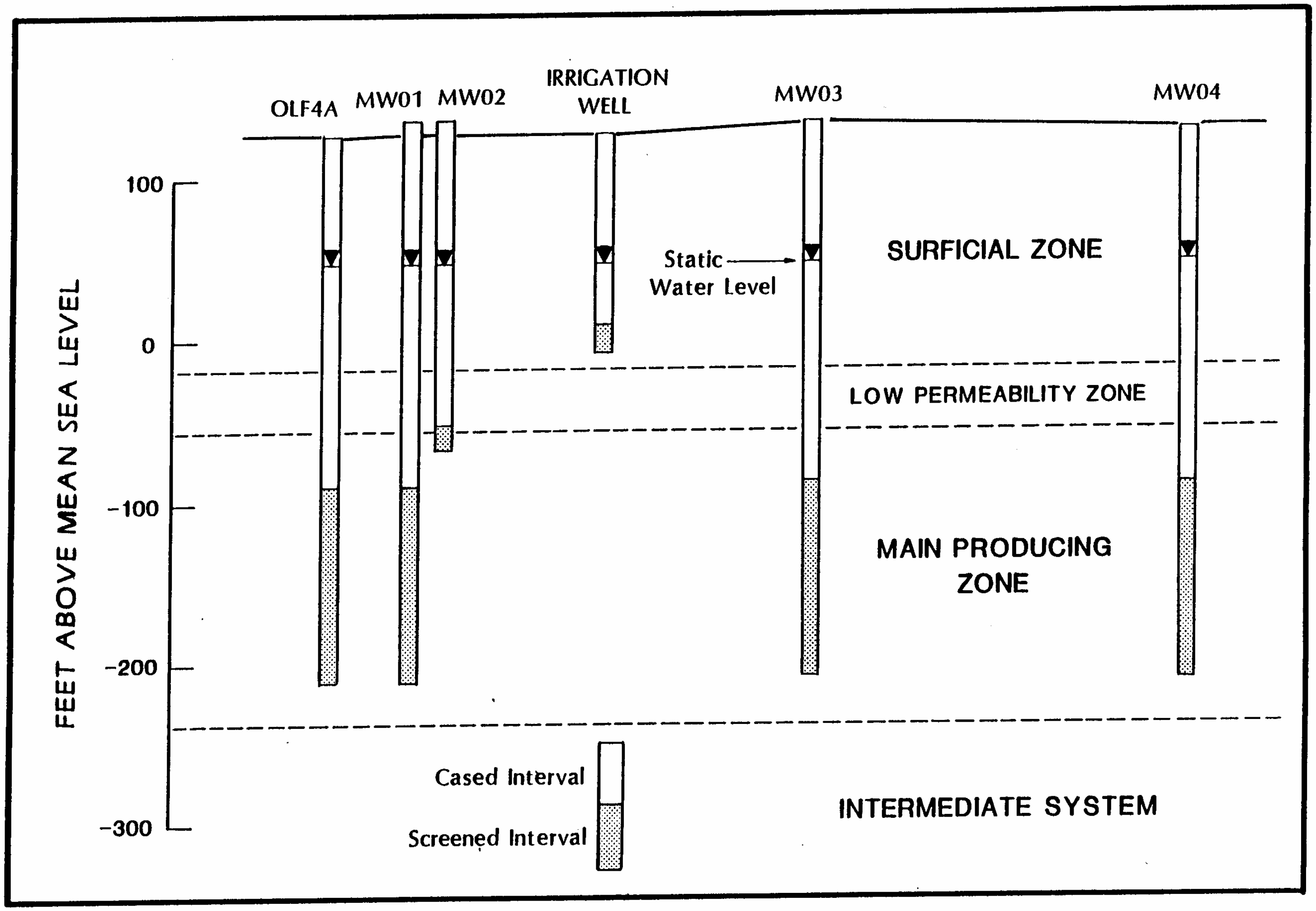
Table 2 -- Aquifer Hydraulic Properties at OLF4A Test Site.

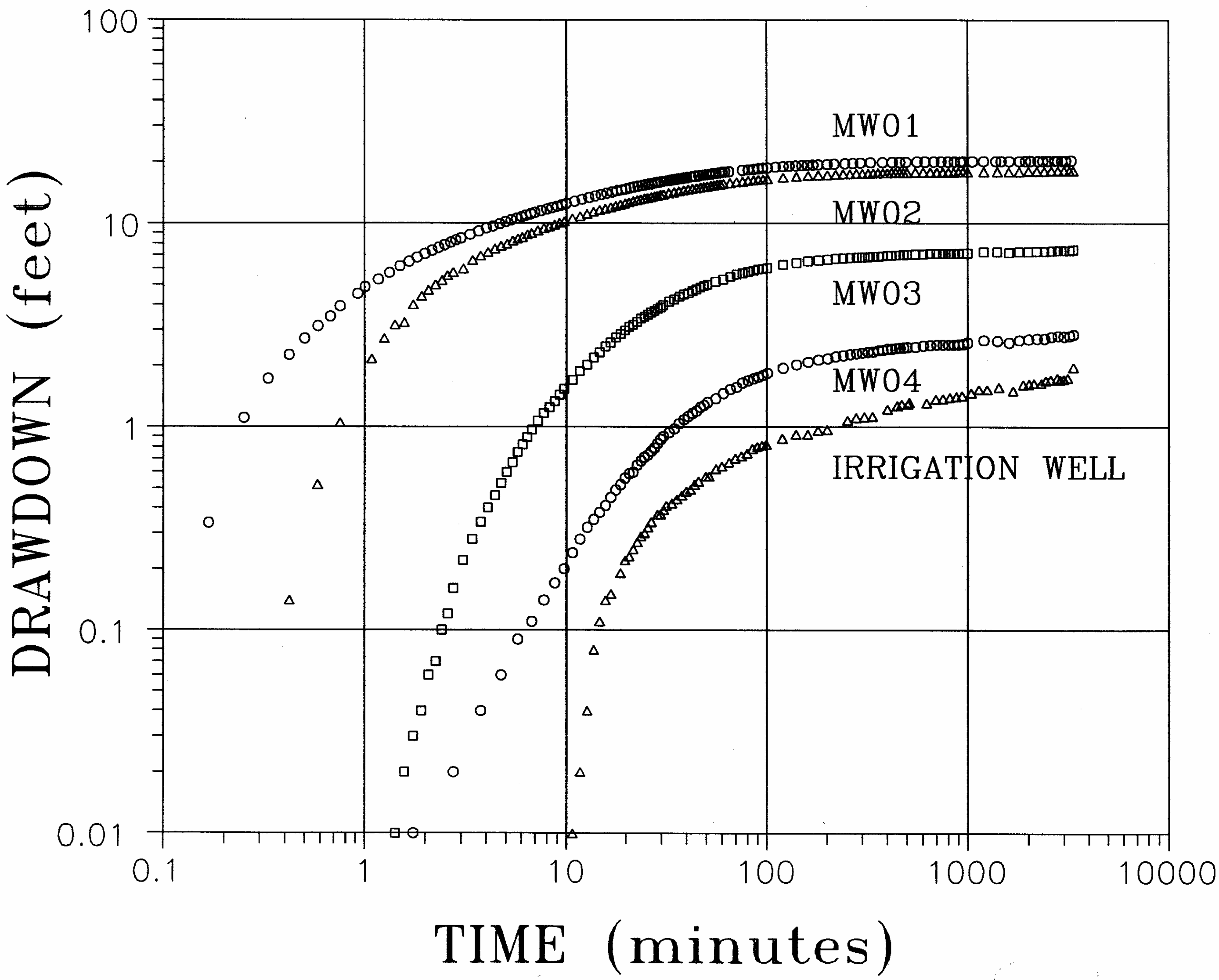
Hydraulic Property	MW01	MW02	MW03
k_z/k_r (dimensionless)	0.10	0.10	0.10
B_r (ft)	1,250	1,280	1,350
T (ft^2/d)	10,640	9,580	11,270
S for MPZ (dimensionless)	0.00071	0.00044	0.00048
k' (ft/d)	0.26	0.22	0.23
k_z (ft/d)	5.9	5.3	6.2
k_r (ft/d)	59	53	62

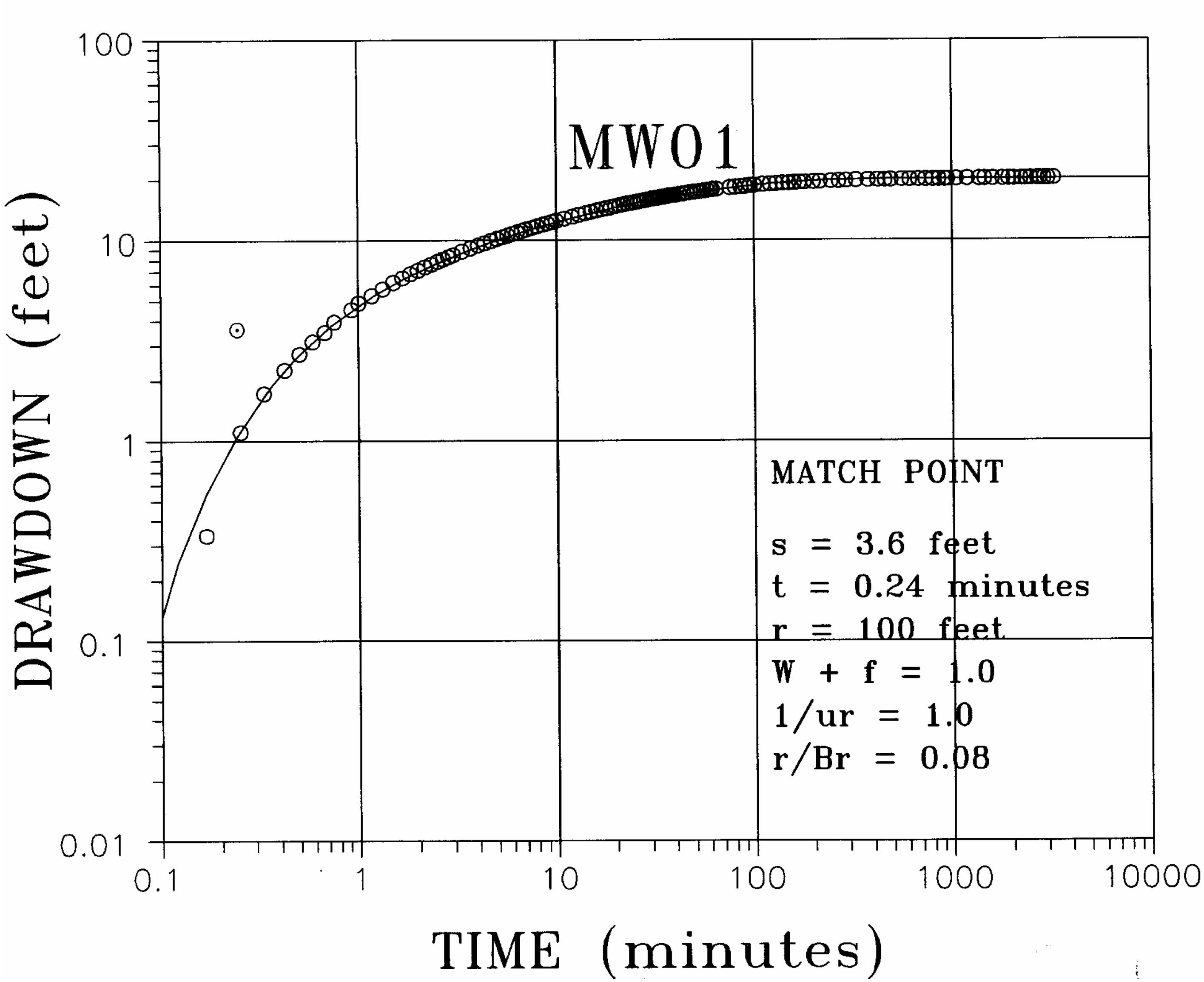

OLF4A MONITORING WELL MW04
DEPTH
0
50'
100'
150'
200'
250'
300'
350'
400'
Natural Gamma
Short
Normal Electric
Long
Normal Electric
Screened
Interval
Total Depth 414'
0
50
100
150
200
API UNITS
0
500
1000
1500
2000
2500
Ω /METER

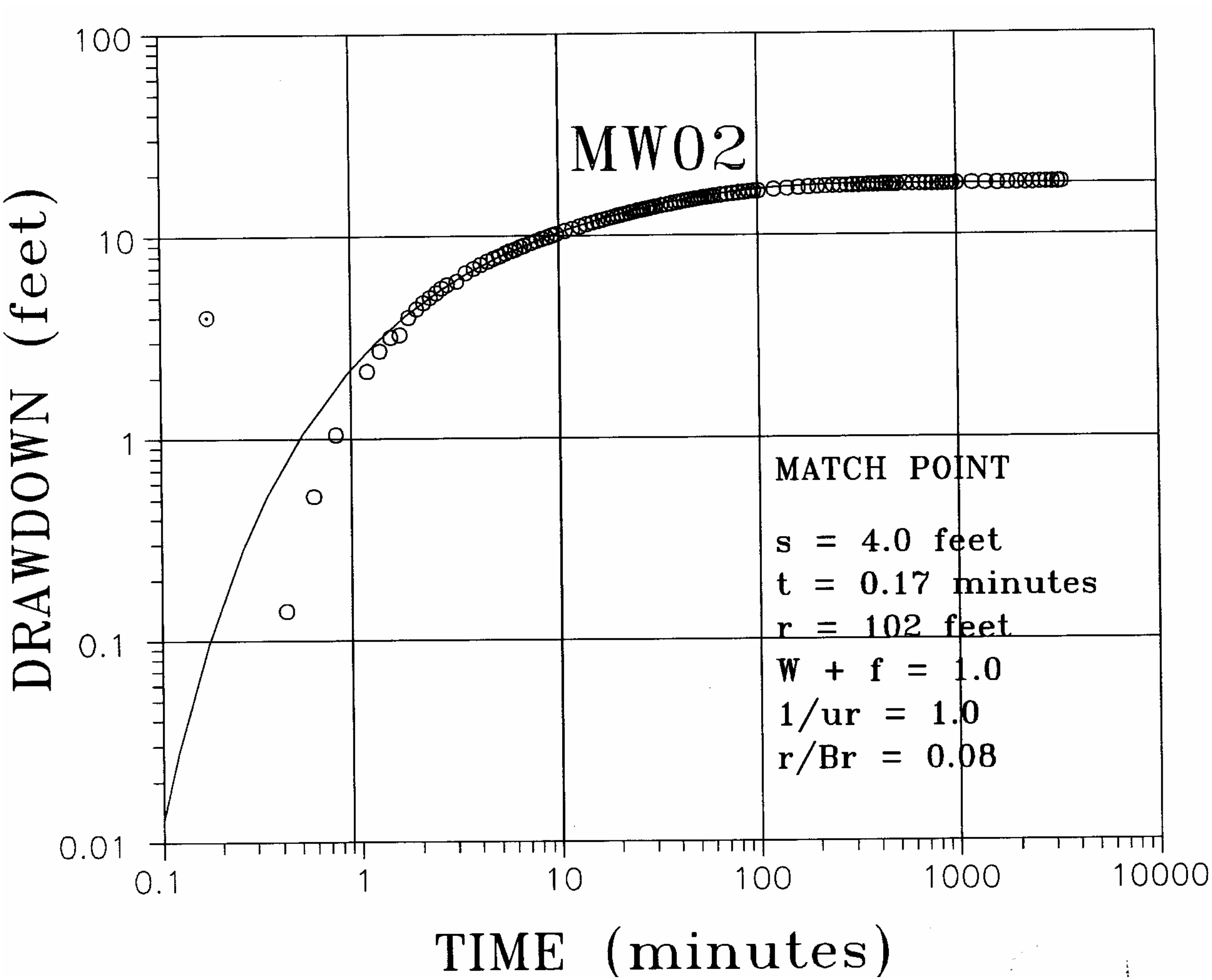


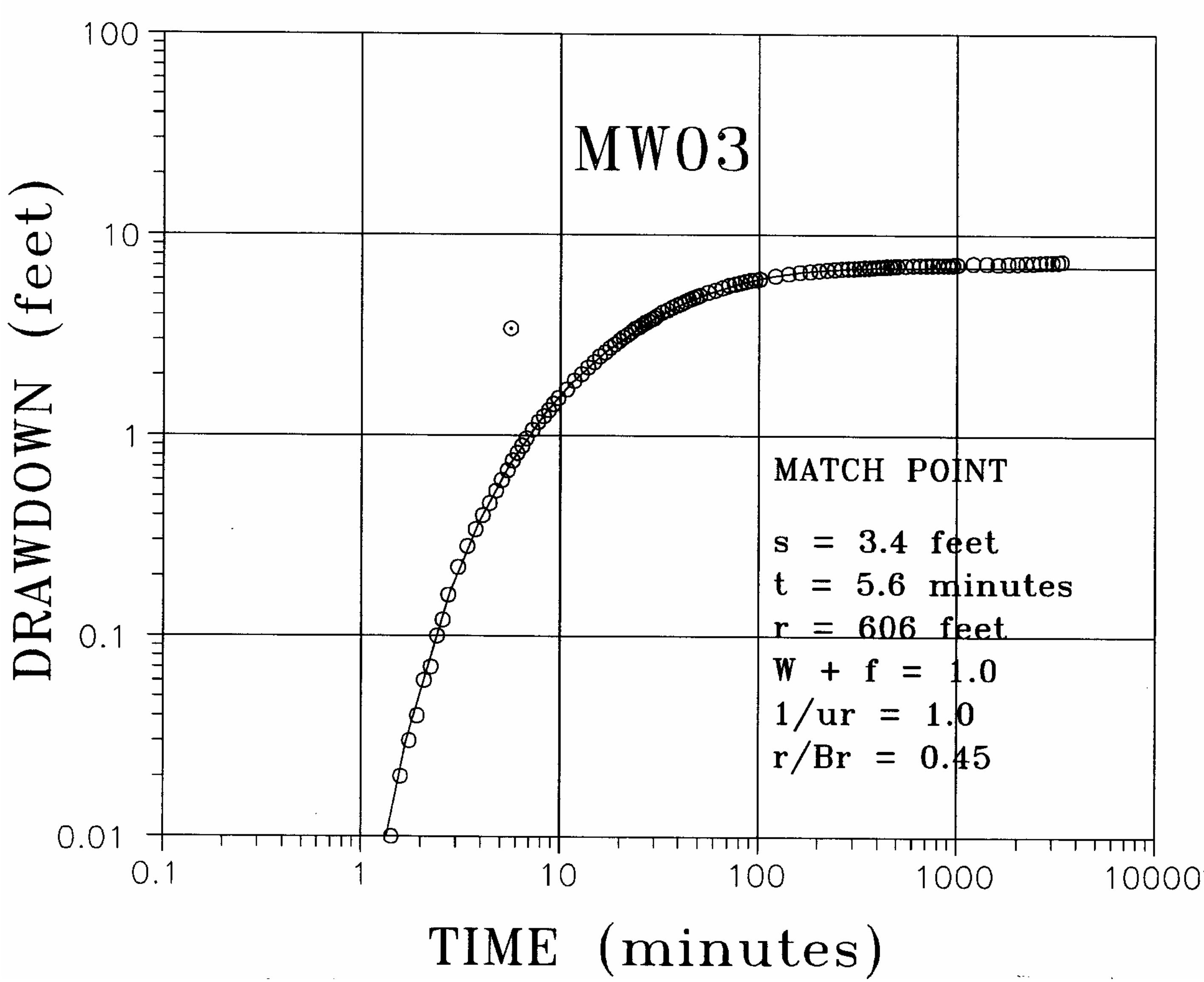
Nine Mile Road
Fence Line
Fence Line
MW03
MW01
MW02
606 ft.
100 ft.
102 ft.
OLF4A
345 ft.
Fence Line
Irrigation Well
Fence Line
1,086 ft.
Dirt Road
Dirt Road
N
MW04


OLF4A
MW01
MW02
IRRIGATION WELL
MW03
MW04
FEET ABOVE MEAN SEA LEVEL
100
0
-100
-200
-300
Static Water Level
SURFICIAL ZONE
LOW PERMEABILITY ZONE
MAIN PRODUCING ZONE
INTERMEDIATE SYSTEM
Cased Interval
Screened Interval


DRAWDOWN (feet)
100
10
1
0.1
0.01
0.1
1
10
100
1000
10000
TIME (minutes)
MW01
MW02
MW03
MW04
IRRIGATION WELL


MW01
DRAWDOWN (feet)
TIME (minutes)
100
10
1
0.1
0.01
0.1
1
10
100
1000
10000
MATCH POINT
s = 3.6 feet
t = 0.24 minutes
r = 100 feet
W + f = 1.0
1/ur = 1.0
r/Br = 0.08


MW02
DRAWDOWN (feet)
TIME (minutes)
100
10
1
0.1
0.01
0.1
1
10
100
1000
10000
MATCH POINT
s = 4.0 feet
t = 0.17 minutes
r = 102 feet
W + f = 1.0
1/ur = 1.0
r/Br = 0.08


MW03
DRAWDOWN (feet)
100
10
1
0.1
0.01
0.1
1
10
100
1000
10000
TIME (minutes)
MATCH POINT
s = 3.4 feet
t = 5.6 minutes
r = 606 feet
W + f = 1.0
1/ur = 1.0
r/Br = 0.45

MONITORING WELL MW01–303157087152201

ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)	ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)
0.167	0.336	36.00	16.45
0.25	1.11	37.00	16.54
0.33	1.73	38.00	16.62
0.42	2.26	39.00	16.69
0.50	2.72	40.00	16.76
0.583	3.13	42.00	16.89
0.67	3.49	44.00	17.02
0.75	3.92	46.00	17.12
0.92	4.52	48.00	17.24
1.00	4.87	50.00	17.32
1.167	5.31	52.00	17.42
1.33	5.73	54.00	17.51
1.50	6.17	56.00	17.59
1.67	6.50	58.00	17.67
1.83	6.81	60.00	17.77
2.00	7.09	61.75	17.83
2.167	7.37	64.75	17.91
2.33	7.60	75.75	18.19
2.50	7.84	80.75	18.33
2.67	8.06	85.75	18.42
2.83	8.26	90.75	18.54
3.00	8.44	95.75	18.64
3.33	8.81	100.75	18.72
3.67	9.13	110.75	18.86
4.00	9.44	120.75	18.97
4.33	9.67	129.75	19.06
4.67	9.93	139.75	19.13
5.00	10.17	149.75	19.19
5.33	10.37	159.75	19.25
5.67	10.56	169.75	19.32
6.00	10.76	179.75	19.37
6.33	10.96	199.75	19.45
6.67	11.12	216.75	19.50
7.00	11.29	245.75	19.60
7.50	11.51	269.75	19.66
8.00	11.73	293.75	19.72
8.50	11.94	330.75	19.81
9.00	12.13	379.75	19.85
9.50	12.31	423.75	19.88
10.00	12.48	460.75	19.89
11.00	12.79	493.75	19.92
12.00	13.08	560.75	19.98
13.00	13.35	613.75	20.00
14.00	13.59	677.75	20.02
15.00	13.80	736.75	20.03
16.00	14.01	798.75	20.03
17.00	14.23	857.75	20.04
18.00	14.40	919.75	20.04
19.00	14.55	950.75	20.08
20.00	14.72	1054.75	20.12
21.00	14.88	1196.75	20.16
22.00	15.04	1376.75	20.16
23.00	15.18	1466.75	20.14
24.00	15.30	1605.75	20.14
25.00	15.42	1808.75	20.16
26.00	15.53	1937.75	20.17
27.00	15.65	2054.75	20.18
28.00	15.76	2235.75	20.18
29.00	15.85	2358.75	20.18
30.00	15.97	2503.75	20.21
31.00	16.05	2698.75	20.24
32.00	16.14	2789.75	20.24
33.00	16.23	2925.75	20.23
34.00	16.32	3062.75	20.23
35.00	16.39	3264.75	20.27

MONITORING WELL MW02--303157087152202

ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)	ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)
4.200000E-001	1.400000E-001	44.75	14.85
5.800000E-001	5.200000E-001	46.75	14.96
7.500000E-001	1.05	48.75	15.06
1.08	2.16	50.75	15.16
1.25	2.72	52.75	15.25
1.42	3.18	54.75	15.33
1.58	3.27	56.75	15.42
1.75	3.98	58.75	15.49
1.92	4.38	60.75	15.57
2.08	4.7	65.75	15.75
2.25	4.99	70.75	15.89
2.42	5.26	75.75	16.01
2.58	5.54	80.75	16.14
2.75	5.75	85.75	16.25
3.08	5.98	90.75	16.34
3.42	6.57	95.75	16.43
3.75	6.91	100.75	16.5
4.08	7.21	120.75	16.75
4.42	7.5	140.75	16.93
4.75	7.74	160.75	17.07
5.08	7.94	180.75	17.16
5.42	8.2	200.75	17.27
5.75	8.41	220.75	17.33
6.08	8.55	240.75	17.39
6.42	8.79	260.75	17.44
6.75	8.96	280.75	17.47
7.25	9.2	300.75	17.49
7.75	9.43	320.75	17.52
8.25	9.65	340.75	17.55
8.75	9.82	360.75	17.58
9.25	10.04	380.75	17.62
9.75	10.2	400.75	17.62
10.75	10.54	420.75	17.66
11.75	10.81	440.75	17.66
12.75	11.09	460.75	17.67
13.75	11.35	480.75	17.7
14.75	11.57	500.75	17.7
15.75	11.78	550.75	17.74
16.75	11.97	600.75	17.77
17.75	12.16	650.75	17.78
18.75	12.34	700.75	17.79
19.75	12.51	750.75	17.79
20.75	12.66	800.75	17.79
21.75	12.8	850.75	17.79
22.75	12.95	900.75	17.8
23.75	13.06	950.75	17.82
24.75	13.2	1000.75	17.83
25.75	13.31	1200.75	17.91
26.75	13.43	1400.75	17.91
27.75	13.54	1600.75	17.86
28.75	13.65	1800.75	17.91
29.75	13.75	2000.75	17.95
30.75	13.85	2200.75	17.96
32.75	14.02	2400.75	17.96
34.75	14.16	2600.75	18.02
36.75	14.32	2800.75	18.05
38.75	14.47	3000.75	18.02
40.75	14.61	3200.75	18.05
42.75	14.74	3335.75	18.07

MONITORING WELL MW03–303157087152901

ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)	ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)
1.42	0.01	46.75	4.85
1.58	0.02	48.75	4.92
1.75	0.03	50.75	5.00
1.92	0.04	55.75	5.18
2.08	0.06	60.75	5.32
2.25	0.07	65.75	5.46
2.42	0.10	70.75	5.61
2.58	0.12	75.75	5.69
2.75	0.16	80.75	5.78
3.08	0.22	85.75	5.88
3.42	0.28	90.75	5.95
3.75	0.34	95.75	6.00
4.08	0.40	100.75	6.04
4.42	0.46	120.75	6.26
4.75	0.53	140.75	6.40
5.08	0.60	160.75	6.53
5.42	0.67	180.75	6.59
5.75	0.75	200.75	6.66
6.08	0.82	220.75	6.71
6.42	0.89	240.75	6.75
6.75	0.97	260.75	6.79
7.25	1.07	280.75	6.82
7.75	1.17	300.75	6.83
8.25	1.25	320.75	6.86
8.75	1.34	340.75	6.89
9.25	1.44	360.75	6.90
9.75	1.54	380.75	6.92
10.75	1.70	400.75	6.95
11.75	1.88	420.75	6.95
12.75	2.03	440.75	6.99
13.75	2.19	460.75	6.99
14.75	2.33	480.75	7.01
15.75	2.49	500.75	7.03
16.75	2.61	550.75	7.05
17.75	2.75	600.75	7.08
18.75	2.86	650.75	7.09
19.75	2.98	700.75	7.10
20.75	3.10	750.75	7.10
21.75	3.19	800.75	7.11
22.75	3.30	850.75	7.11
23.75	3.42	900.75	7.12
24.75	3.48	950.75	7.13
25.75	3.58	1000.75	7.15
26.75	3.66	1200.75	7.23
27.75	3.73	1400.75	7.24
28.75	3.81	1600.75	7.19
29.75	3.87	1800.75	7.23
30.75	3.96	2000.75	7.26
32.75	4.13	2200.75	7.28
34.75	4.23	2400.75	7.28
36.75	4.36	2600.75	7.33
38.75	4.47	2800.75	7.37
40.75	4.55	3000.75	7.37
42.75	4.66	3200.75	7.37
44.75	4.76	3336.75	7.41