Table 1. Summary of Well and Aquifer Details

Well	WATER Measurable Test Draw-down?	Start-of-Test Level DTW btc ft	Elev. ft amsl	WELL Well Elev. ft amsl	Dist. "r" to Well	Screen Top/Bottom Depth	Elev	Radius in /ft	Length ft	Dist Aq. Top to Screen top	% Aquif. Screened	Borehole Radius in /ft	AQUIFER Top/Bottom Depth	Elev	BE* %	Nature of Aquifer	Thickness ft	Aquifer
SVR #7 (Pumping Well)	yes	165.21	2544.63	2709.84	0	280 350	2429.84 2359.84	4 0.33	70	100	21%	6.00 0.50	180 520	2529.84 2189.84	95%	Confined	340	Pierce Gulch Sand Aquifer
Big Gulch Stock Well	yes	152.13	2546.09	2698.22	845	180 180	2518.22 2518.22	2 0.17	0	0	<1%	3? 0.25?	180 520	2518.22 2178.22	96%	Confined	340	Pierce Gulch Sand Aquifer
M3-TW#2 Zone 3	dry	dry	dry	2766.01	3636	180 190	2586.01 2576.01	1 0.08	10	120	3%	4.00 0.33	60 360	2706.01 2406.01	dry	dry	300	Pierce Gulch Sand (dry)
M3-TW#2 Zone 2	yes	218.96	2547.05	2766.01	3636	230 250	2536.01 2516.01	1 0.08	20	170	7%	4.00 0.33	60 360	2706.01 2406.01	99%	Unconfined?	300	Pierce Gulch Sand Aquifer
M3-TW#2 Zone 1	yes	218.62	2547.39	2766.01	3636	270 320	2496.01 2446.01	1 0.08	50	210	17%	4.00 0.33	60 360	2706.01 2406.01	99%	Unconfined?	300	Pierce Gulch Sand Aquifer
M3-TW#4 Zone 4	no	dry	dry	2673	4489	61 71	2612 2602	1 0.08	10	na	na	4.00 0.33	180 200	2493 2473	na	na	20	dry sand
M3-TW#4 Zone 3	yes	134.96	2538	2673	4489	181 201	2492 2472	1 0.08	20	1	100%	4.00 0.33	180 200	2493 2473	85%	Confined	20	**unnamed fluvial sand aquifer**
M3-TW#4 Zone 2	yes	130.94	2542	2673	4489	325 556	2348 2117	1 0.08	231	25	89%	4.00 0.33	300 560	2373 2113	39%	Confined	260	Pierce Gulch Sand Aquifer
M3-TW#4 Zone 1	yes	130.23	2543	2673	4489	625 646	2048 2027	1 0.08	21	325	53%	4.00 0.33	300 560	2373 2113	33%	Confined	40	**may be part of PGSA**
Flack Corral 4-in	?	208.25	2551.98	2760.23	5974	? ?	? ?	2 0.17	?	?	?	3? 0.25?	210 330	2550 2430	?	?	120	?
Flack Corral 6-in	yes	215.01	2555.24	2770.25	6749	74 386	2696.25 2384.25	3 0.25	312	0	100%	3? 0.25?	220 340.25	2550.25 2430	95%	Unconfined?	120	Pierce Gulch Sand Aquifer
M3-TW#3 Zone 5	no	dry	dry	2786.63	8173	238 258	2548.63 2528.63	1 0.08	20	na	na	4.25 0.35	265 500	2521.63 2286.63	na	na	235	Pierce Gulch Sand (dry)
M3-TW#3 Zone 4	no	264.36	2522.27	2786.63	8173	334 354	2452.63 2432.63	1 0.08	20	69	9%	4.25 0.35	265 500	2521.63 2286.63	na	Unconfined?	235	Pierce Gulch Sand Aquifer
M3-TW#3 Zone 3	no	264.25	2522.38	2786.63	8173	369 379	2417.63 2407.63	1 0.08	10	104	4%	4.25 0.35	265 500	2521.63 2286.63	82%	Unconfined?	235	Pierce Gulch Sand Aquifer
M3-TW#3 Zone 2	no	264.09	2522.54	2786.63	8173	399 419	2387.63 2367.63	1 0.08	20	134	9%	4.25 0.35	265 500	2521.63 2286.63	na	Unconfined?	235	Pierce Gulch Sand Aquifer
M3-TW#3 Zone 1	no	263.98	2522.65	2786.63	8173	432 442	2354.63 2344.63	1 0.08	10	167	4%	4.25 0.35	265 500	2521.63 2286.63	81%	Unconfined?	235	Pierce Gulch Sand Aquifer
SVR #6	no	456.75	2358.88	2815.63	8189	560 730	2244 2084	4 0.33	170	103	<37%	4.00 0.33	457 >740	2358.63 <2064	84%	Unconfined?	>283	**Willow Creek Aquifer**
Little Gulch Stock Well	yes	176.02	2552.77	2728.79	9740	220 223	2508.79 2505.79	2 0.17	3	44	3%	3? 0.25?	176 288.79	2552.79 2440	99%	Unconfined?	112.79	Pierce Gulch Sand Aquifer
Kling-Irrigation well	no	96.66	2516.94	2613.6	9908	198 408	2415.6 2205.6	8 0.67	210	0	76%	11? 0.92?	300 575	2313.6 2038.6	45%	Confined	275	Pierce Gulch Sand Aquifer
M3-TW#1 Zone 5	no	92.03	2514.36	2606.39	10916	97 137	2260 2056	1 0.08	40	12	73%	4.00 0.33	85 140	2521.39 2466.39	93%	Confined?	55	**unnamed fluvial sand aquifer**
M3-TW#1 Zone 4	no	94.54	2511.85	2606.39	10916	353 383	2260 2056	1 0.08	30	0	13%	4.00 0.33	353 590	2253.39 2016.39	33%	Confined	237	Pierce Gulch Sand Aquifer
M3-TW#1 Zone 3	no	93.97	2512.42	2606.39	10916	395 425	2260 2056	1 0.08	30	42	13%	4.00 0.33	353 590	2253.39 2016.39	na	Confined	237	Pierce Gulch Sand Aquifer
M3-TW#1 Zone 2	no	91.57	2521.77	2606.39	10916	467 507	2260 2056	1 0.08	40	114	17%	4.00 0.33	353 590	2253.39 2016.39	27%	Confined	237	Pierce Gulch Sand Aquifer
M3-TW#1 Zone 1	no	91.54	2521.77	2606.39	10916	514 556	2260 2056	1 0.08	42	161	18%	4.00 0.33	353 590	2253.39 2016.39	na	Confined	237	Pierce Gulch Sand Aquifer
SVR #9	yes	197.22	2555.84	2753.06	11660	235 263	2518.06 2490.06	3 0.25	28	38	38%	6.00 0.50	197 270	2556.06 2483.06	99%	Unconfined?	73	Pierce Gulch Sand Aquifer
UWID State and Linder TW#1 (East) Zone 2 ("UWID State and Linder #1A" in HLI, 2007)	no	-14.67 (above ground)	2533.63	2518.96	22302	280 370	2238.96 2148.96	1 0.08	90	70	17%	4.00 0.33	210 735	2308.96 1784	20%	Confined	525	Pierce Gulch Sand Aquifer

NOTES: All wellheads surveyed by ISG during Aug 2007 except M3-TW #4 which has well elevation estimated based on TOPO. " BE" = Barometric Efficiency. "na" = Not Analyzed. Confined nature of aquifer based on comparisons of water levels with geology (interpreted from geophysics and geologic logs).

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Table 2. Summary of SVR #7 Test Aquifer Analyses

Well	Distance from SVR #7	Maximum Measured Drawdown		Calculated Transmissivity	Calculated Storativity	Theis	Cooper-Jacob	Recovery (Theis)	Neuman-Witherspoon	No WL Trend Correction	With WL Trend Correction	Well Loss Removed
		No Trend Adjustment	With Trend Adjustment	T (gpd/ft)	S (unitless)							
	ft	ft	ft									
Five-Well Composite - "Best-Fit"	varies	-	-	430,000	2.1E-03	x				x		
Five-Well Distance Drawdown	varies	-	-	380,000	7.0E-03	x				x		
SVR #7 (Well Loss Removed)	0	29.79	7.51	450,000	-	x				x		x
				380,000	-		x			x		
				520,000	-			x		x		
Big Gulch Stock Well	842	1.71	-	450,000	1.9E-03	x				x		
				500,000	1.2E-03		x			x		
				460,000	-			x		x		
M3-TW#2 Zone 2	3,636	0.17	0.05	240,000	9.1E-02	x				x		
				370,000	2.7E-02	x					x	
				Invalid	Invalid		x			x	x	
				Invalid	-			x		x	x	
M3-TW#2 Zone 1	3,636	0.17	0.08	350,000	6.2E-02	x				x		
				230,000	1.6E-01	x					x	
				Invalid	-			x		x	x	
M3-TW#4 Zone 3 (as upper part of PGSA)	4,489	0.15	0.08	Invalid	Invalid	x	x	x		x	x	
M3-TW#4 Zone 3 (as overlying, unnamed aquifer)		0.15	0.08	Invalid	Invalid				x			
M3-TW#4 Zone 2	4,489	0.67	0.60	570,000	3.0E-03	x				x		
				580,000	3.0E-03	x					x	
				"700,000?"	-			x		x		
				"840,000?"	-			x			x	
M3-TW#4 Zone 1 (as lower part of PGSA)	4,489	0.58	0.59	170,000	2.4E-03	x				x		
				160,000	2.2E-03	x					x	
				"690,000?"	-			x		x		
				"790,000?"	-			x			x	
M3-TW#4 Zone 1 (as underlying aquifer)				60,000	3.5E-04				x	x		
				60,000	3.5E-04				x		x	
Flack Corral 4-in	5,974	?	?	Invalid	Invalid	x	x	x		x	x	
Flack Corral 6-in	6,749	0.08	0.08	Invalid	Invalid	x	x	x		x	x	
M3-TW#3 Zones 1-4	8,173	none	none	-	-							
SVR #6 (Willow Creek Aquifer)	8,189	none	none	-	-							
Little Gulch Stock Well	9,740	0.08	0.14	180,000	1.3E-02	x				x		
				270,000	1.2E-02	x					x	
				Invalid	-			x		x		
				"670,000?"	-			x			x	
Kling-Irrigation well	9,908	none	none	-	-							
M3-TW#1 Zones 1-5	10,916	none	none	-	-							
SVR #9	11,660	0.09	0.15	250,000	8.7E-03	x				x		
				320,000	7.1E-03	x					x	
				Invalid	-			x		x		
				"780,000?"	-			x			x	
UWID State & Linder TW#1 Zone 2	22,302	none	none	-	-							

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Table 3. Well Loss and Well Efficiency Comparison

Pumping Time	Theoretical DD	Actual DD	Well Loss (difference)	Efficiency (ratio)	Means Well Loss	Means Efficiency
min	ft	ft	ft	%	22.92	14%
12	3.34	25.83	22.49	13%		
18	3.43	26.07	22.64	13%		
28	3.53	26.49	22.96	13%		
43	3.63	26.57	22.94	14%		
66	3.72	27.14	23.42	14%		
101	3.82	27.70	23.88	14%		
156	3.92	26.83	22.91	15%		
240	4.02	26.13	22.11	15%		

Figure 1. Well Location Map

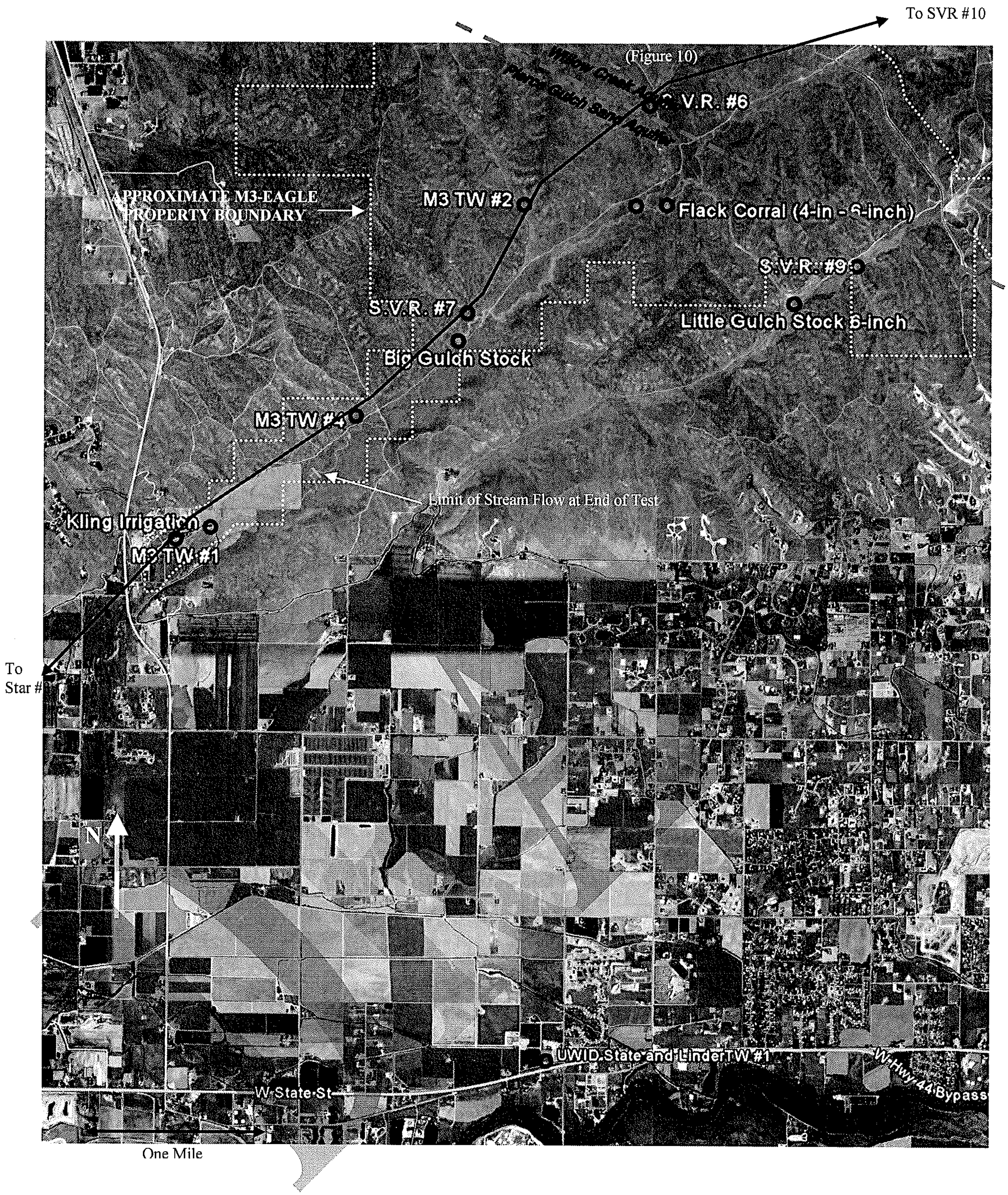


Figure 2. Composite Diagram for Well SVR #7 (the Pumping Well)

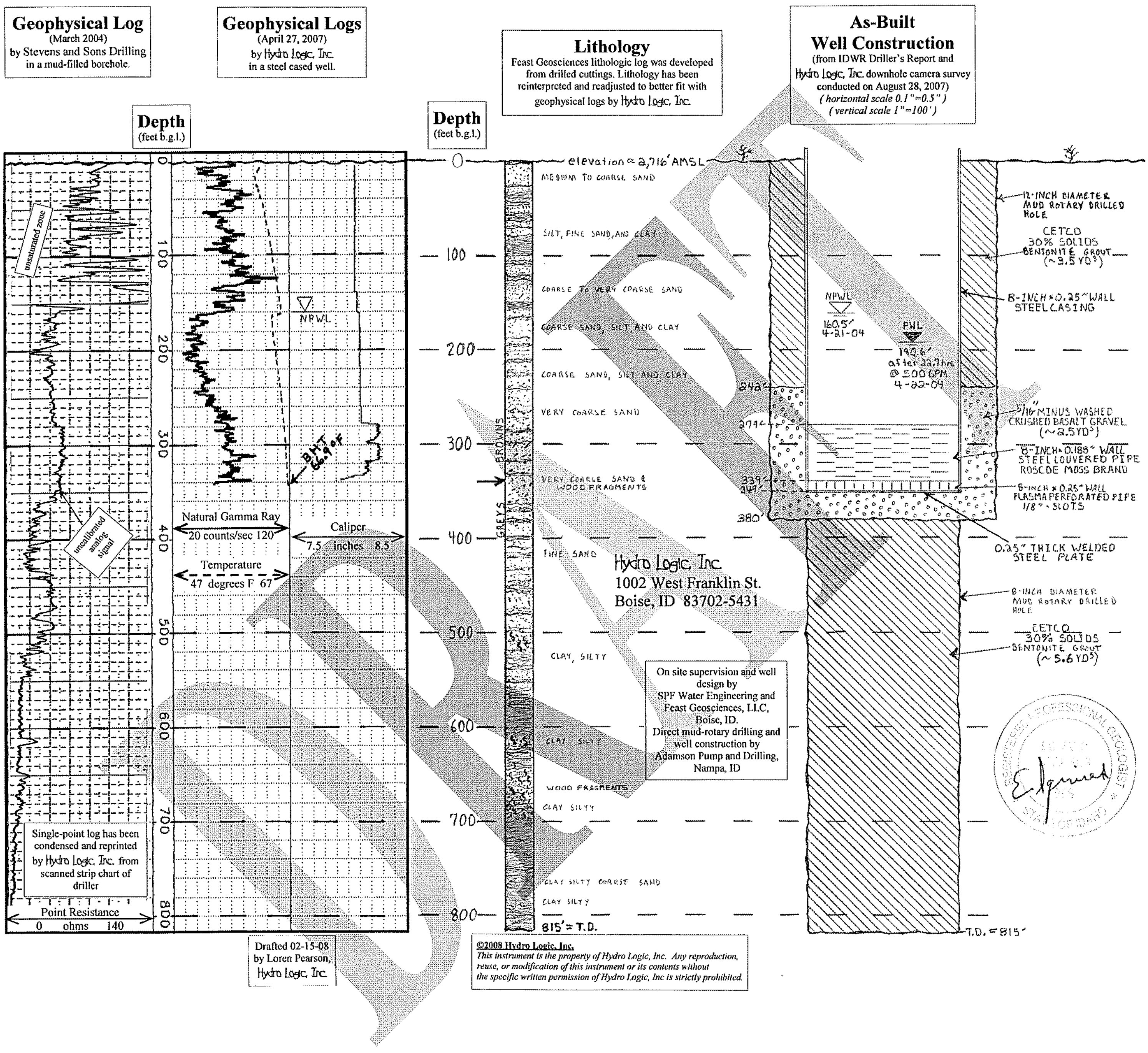


Figure 3. Composite Diagram for Well M3-TW #1

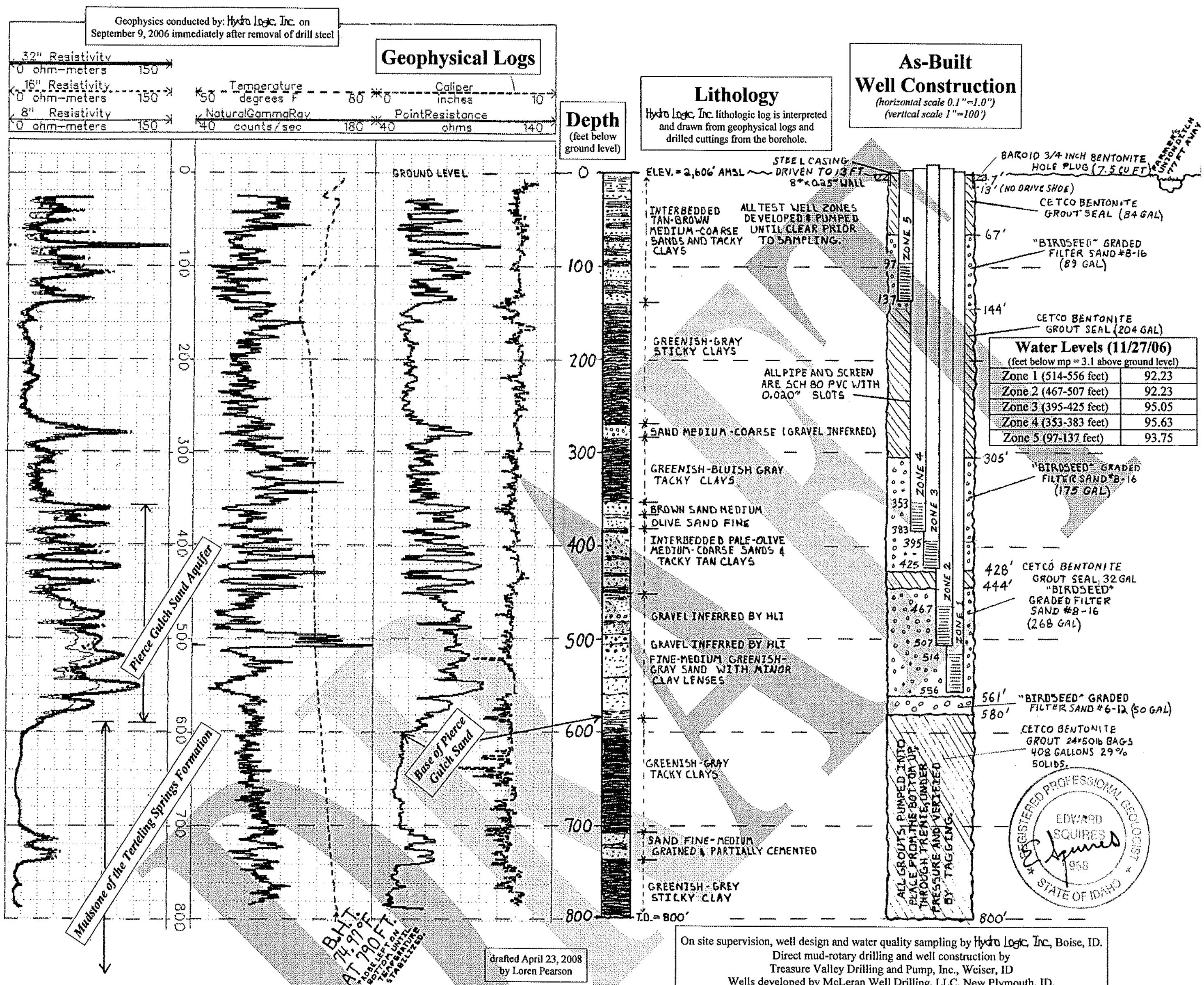


Figure 4. Composite Diagram for Well M3-TW #2

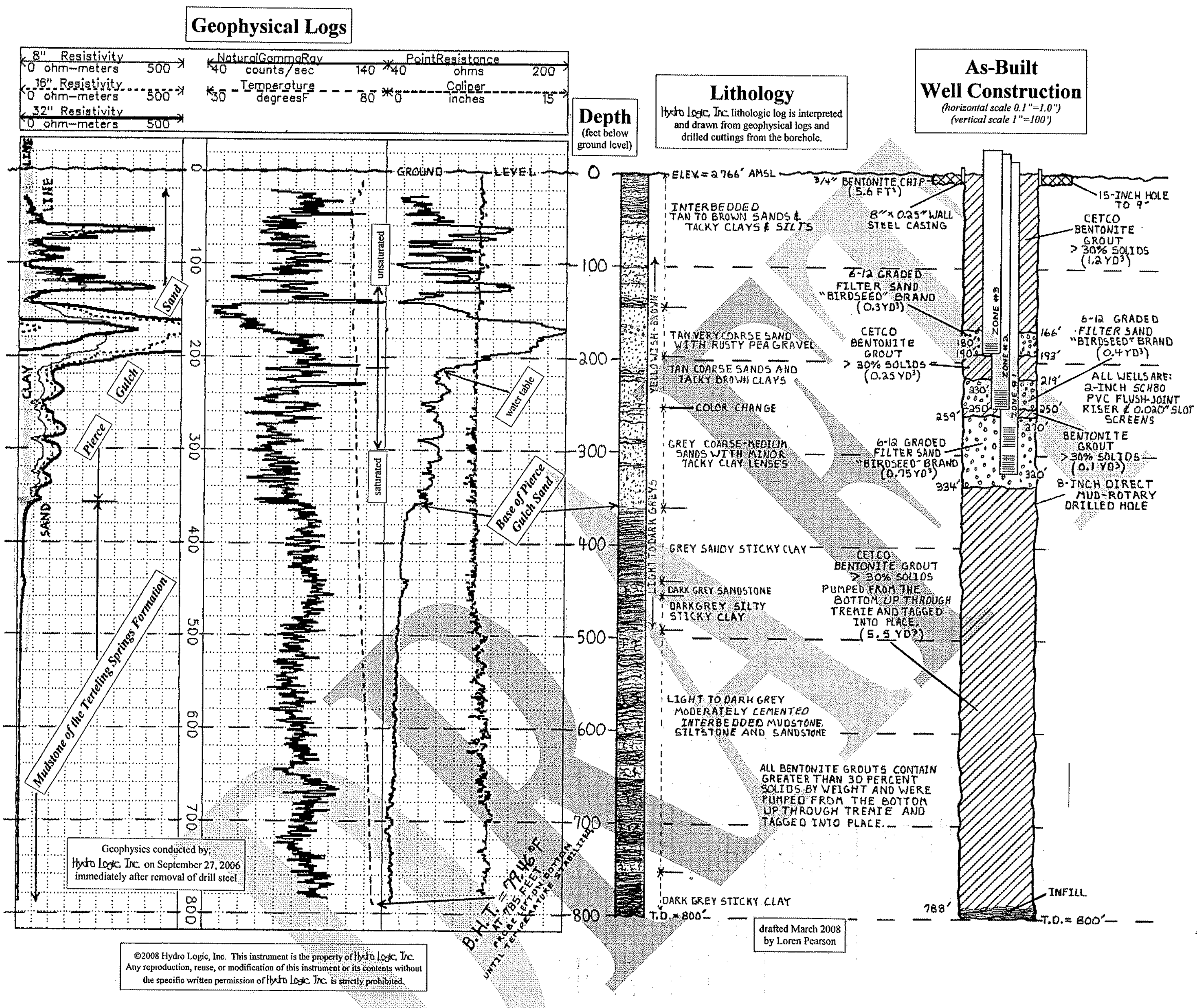


Figure 5. Composite Diagram for Well M3-TW #3

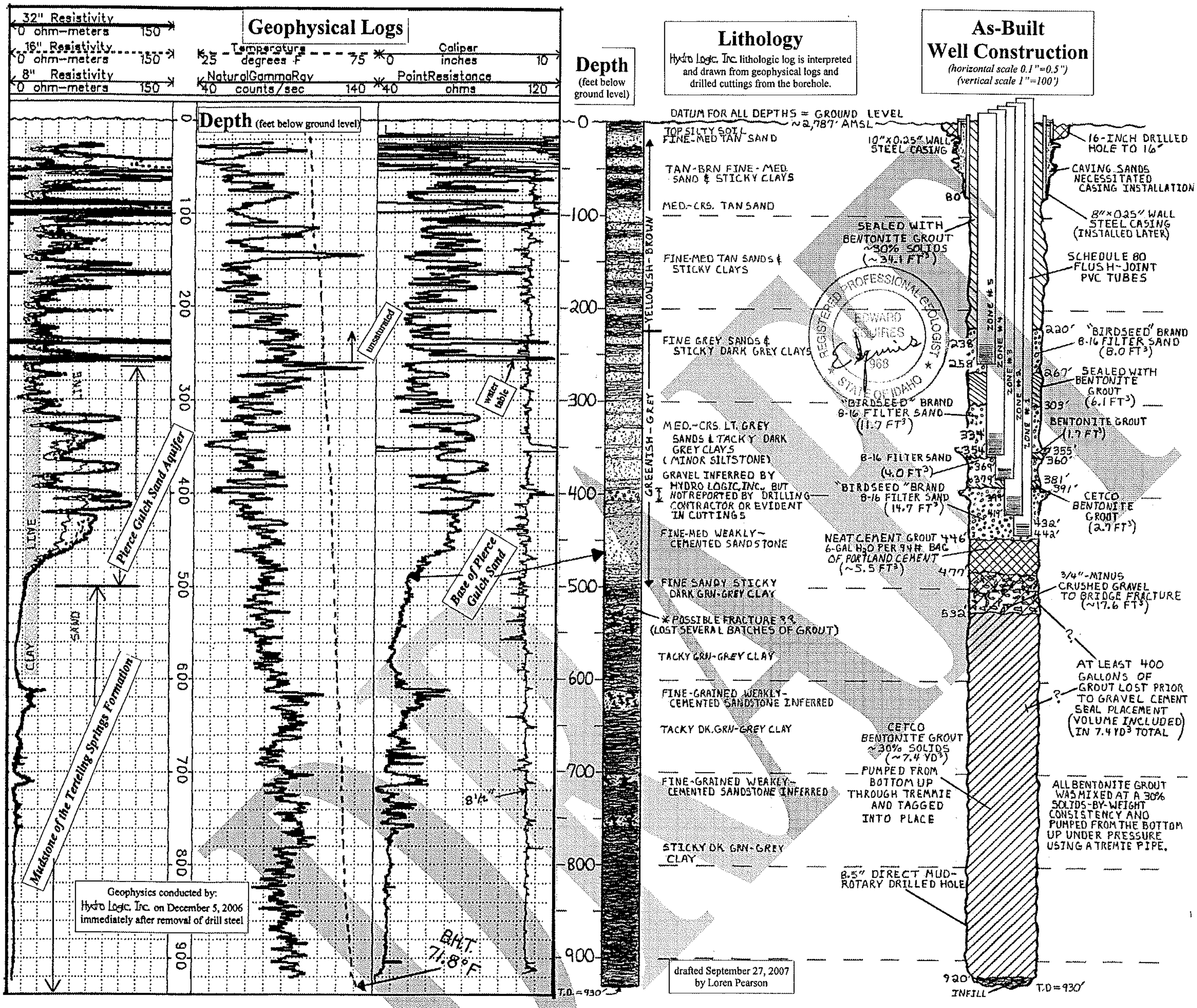


Figure 6. Composite Diagram for Well M3-TW #4

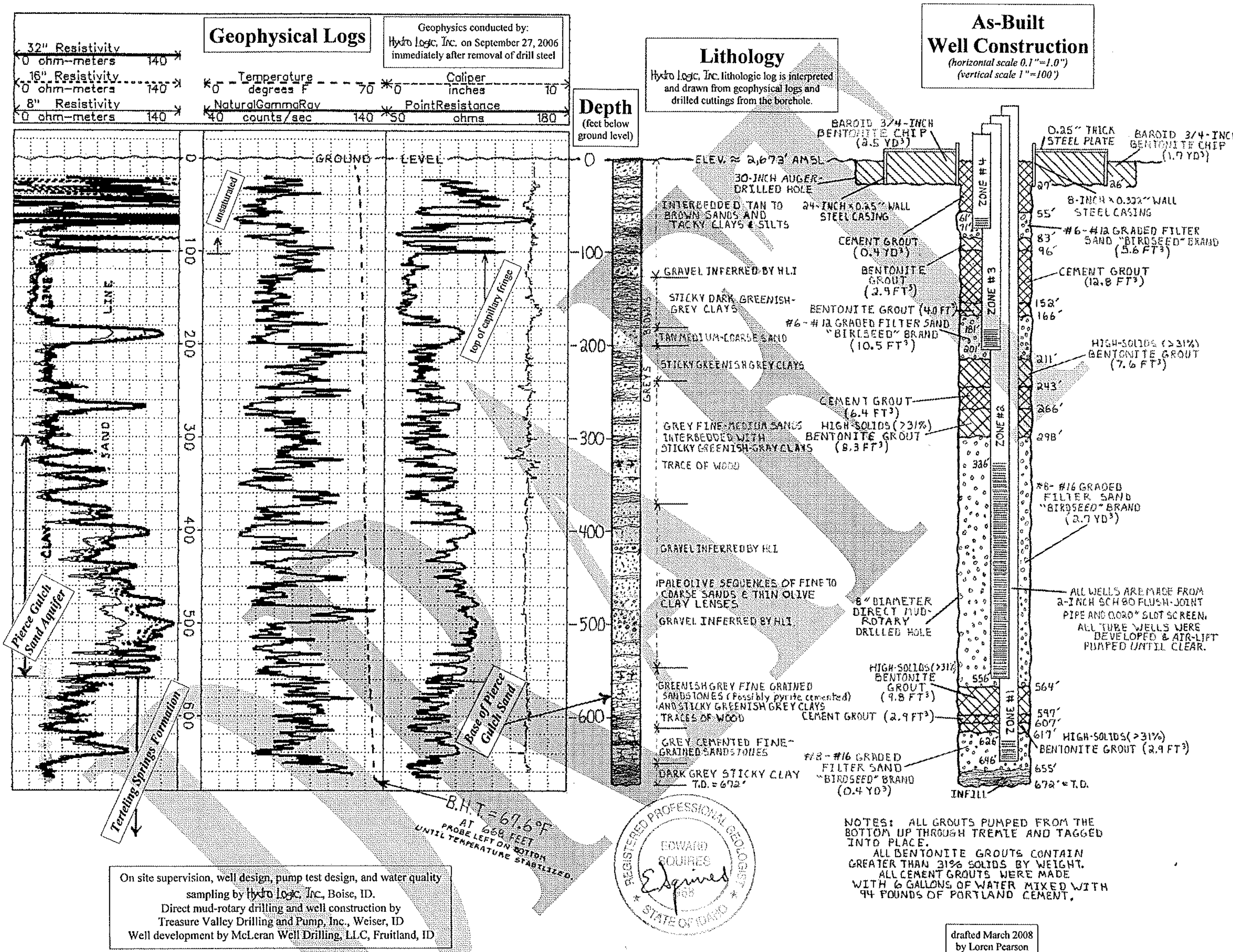


Figure 7. Composite Diagram for Well SVR #9

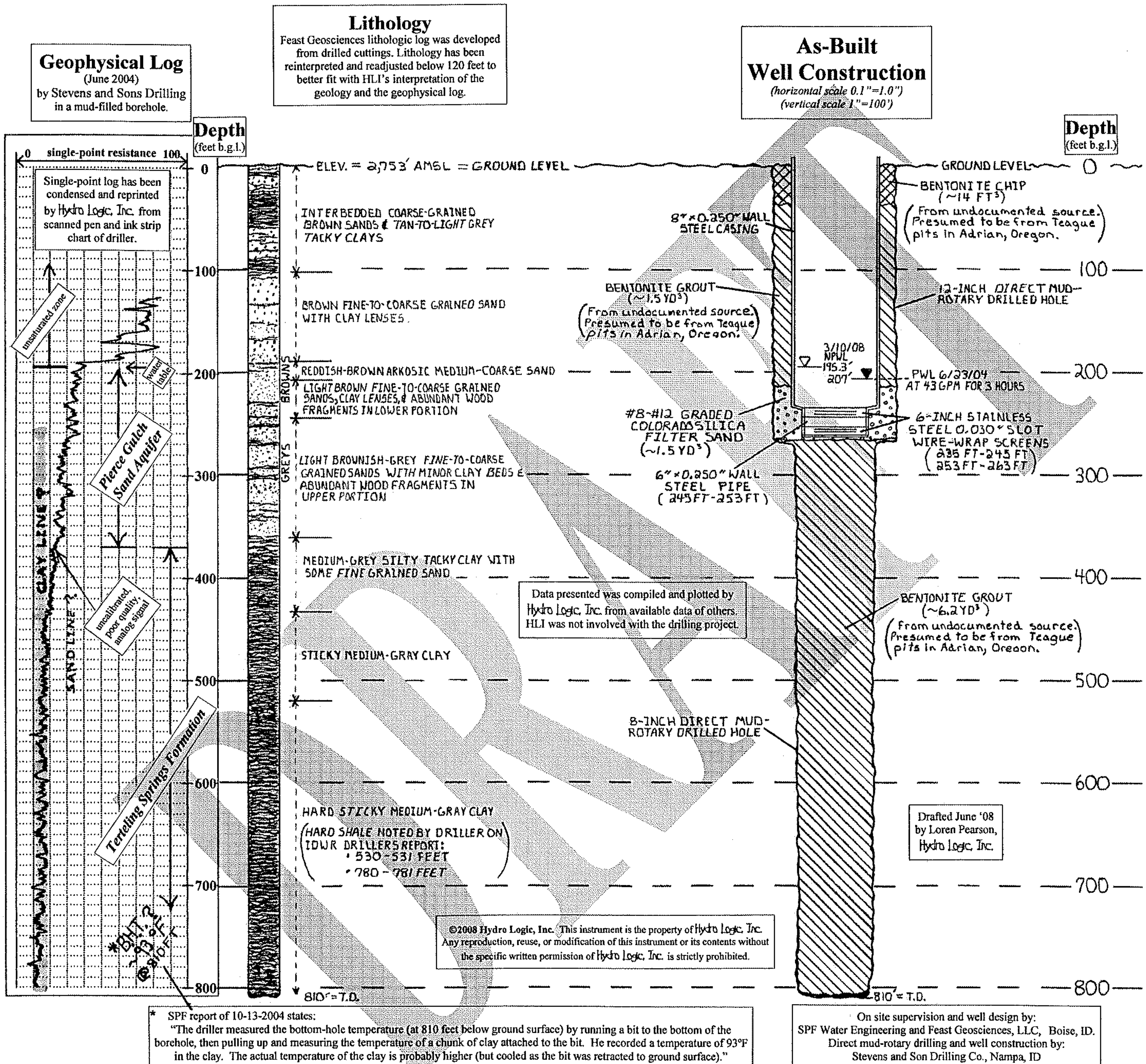


Figure 8. Composite Diagram for Well SVR #6

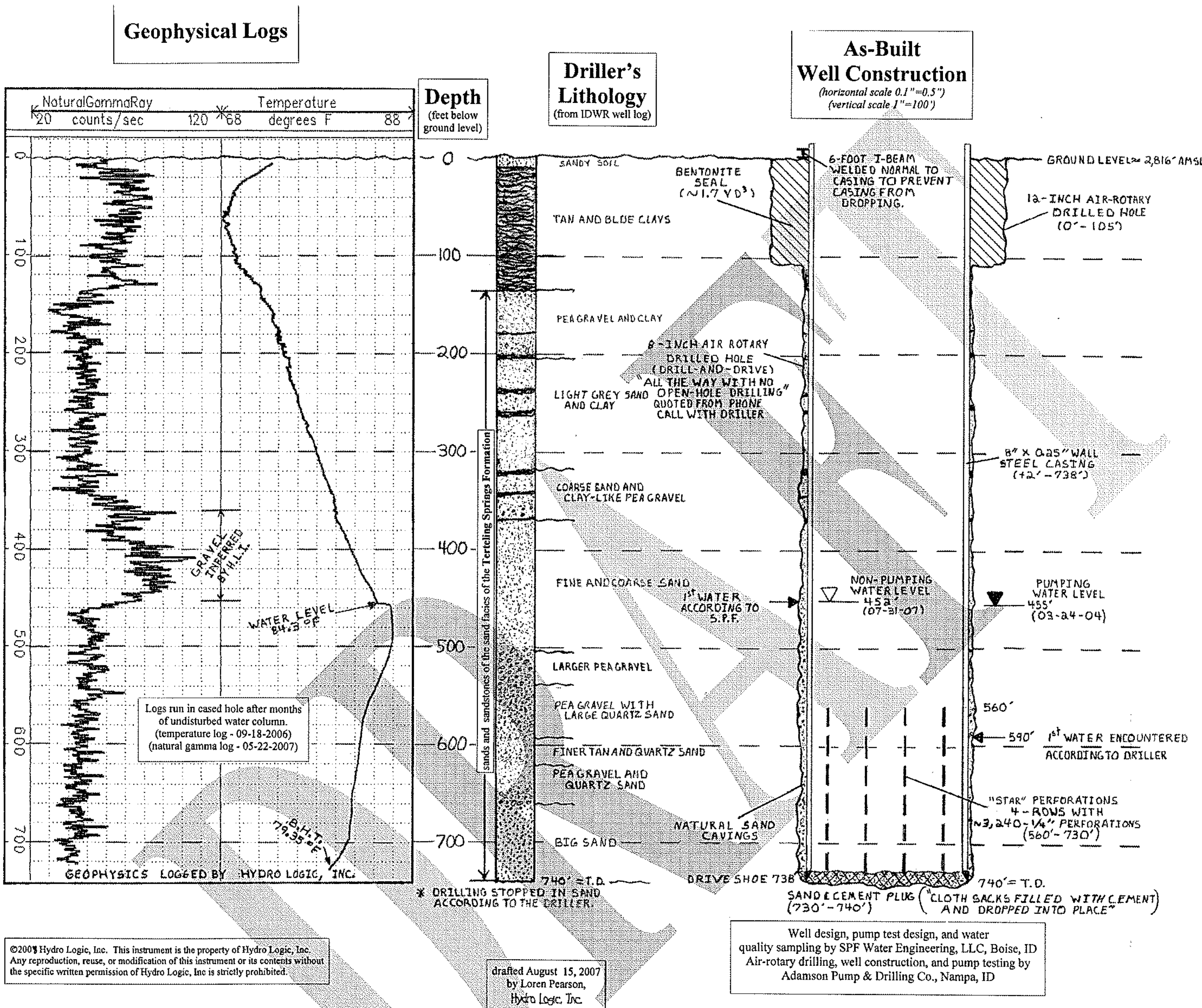


Figure 9. Composite Diagram for Well UWID State and Linder #1A

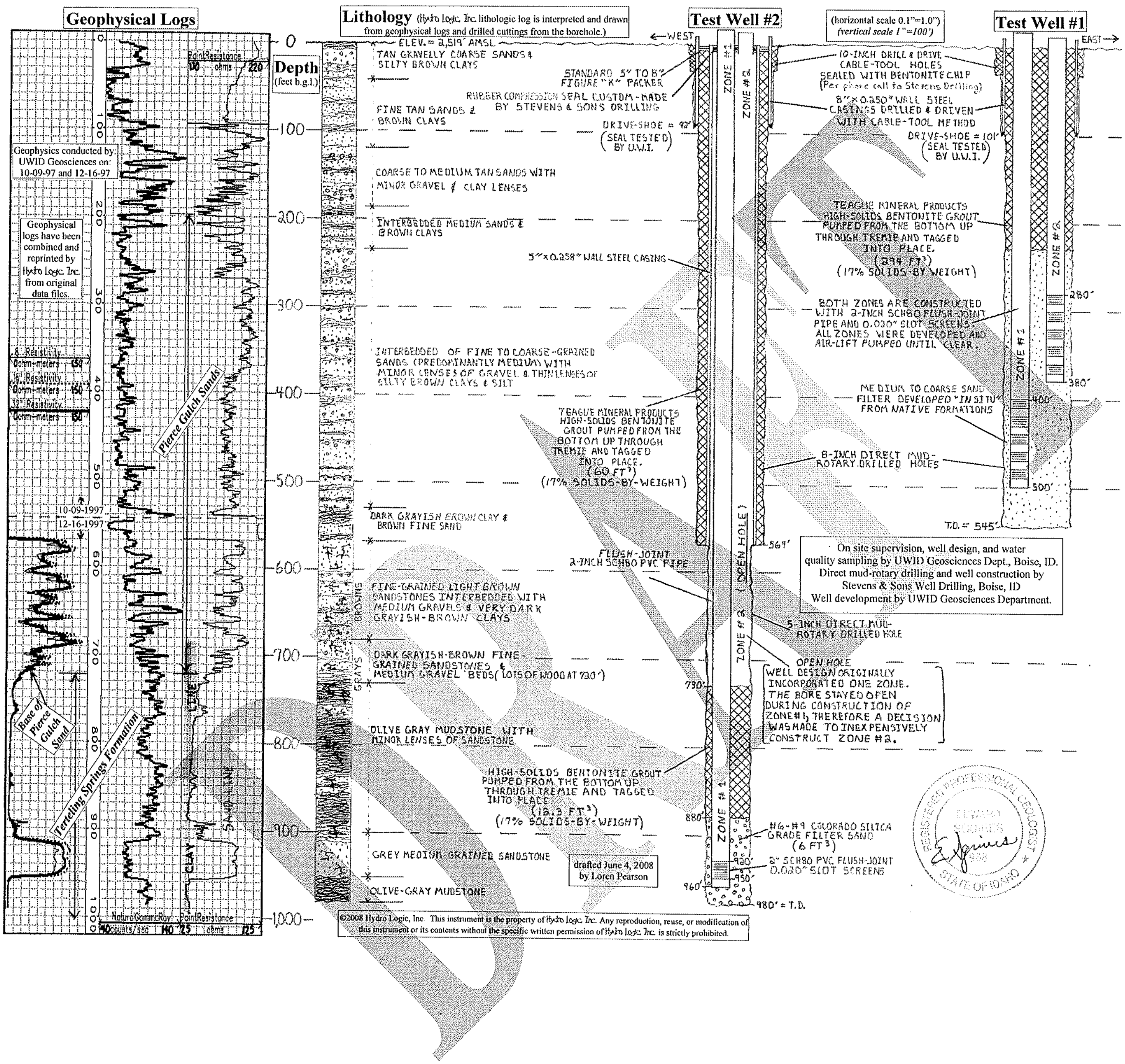
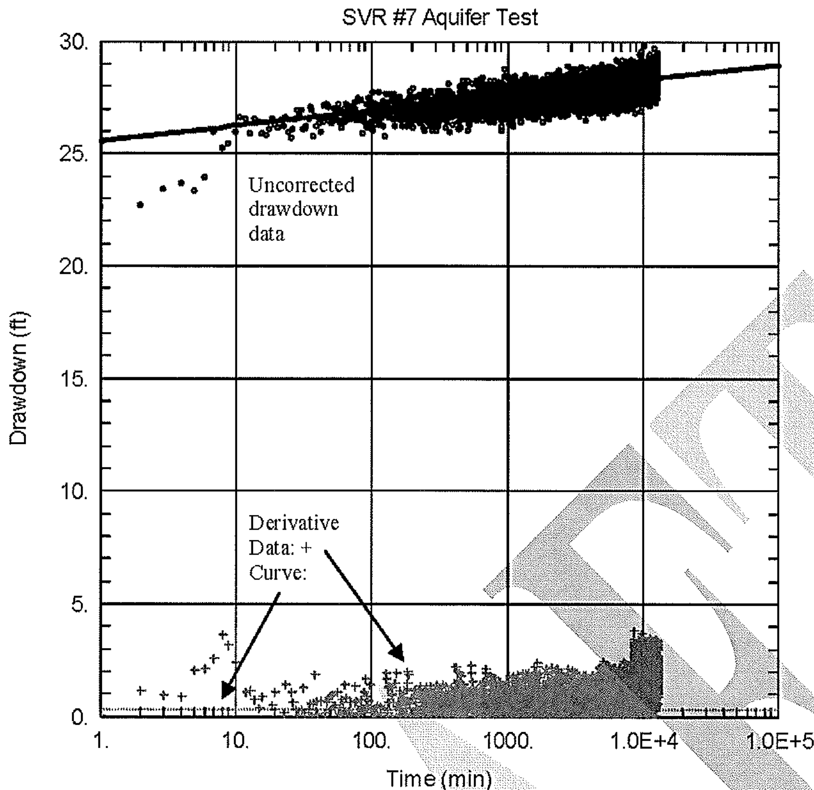


Figure 10. Southwest to Northeast Hydrogeologic Cross Section Beneath the M3 Site

[Insert figure here, rotated 90 degrees]

Figure 12. Cooper-Jacob Analysis for Well SVR #7



Screen = 279-349 ft
T=400,000 gpd/ft
S = Not Calculable
Kv/Kh=0.1
b = 340 ft
t_c < 1 min
r = 0.5ft
Q = 917gpm

Derivative analysis indicates method is valid for data after 20 min. Wide scatter of drawdown and derivative points the results of surging water levels in tight well casing.

Partial penetration correction corrections not applied. Analysis likely underestimates transmissivity value without PP correction.

$T = 264Q/\Delta s$ Where:

T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
Δs = Change in drawdown of water level over one log cycle of time, in feet (ft)

t_c = critical time where "u assumption" is met (where u = 0.05) such that method may be valid, is less than 1minute.

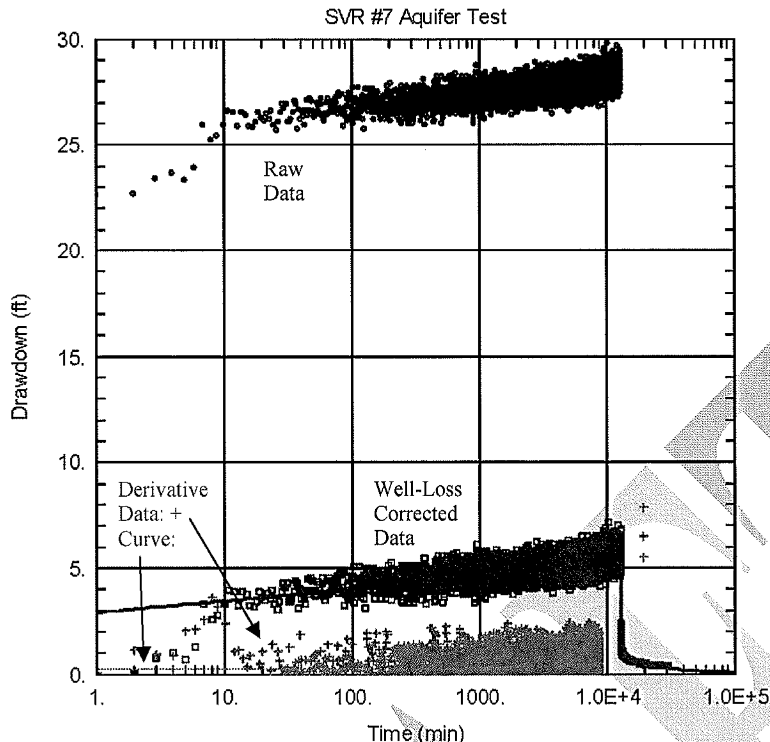
$u = 1.87r^2S/Tt$

t = time in days
r = effective radius of pumping well (ft)

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Based on the analytical method of Cooper and Jacob (1946).
No partial penetration corrections.

Figure 13. Theis Analysis for Well SVR #7



Screen = 279-349 ft
T=450,000 gpd/ft
S = Not Calculable
Kv/Kh=0.1
b = 340 ft
r = 0.5ft
Q = 917gpm

Derivative analysis indicates method is valid for data after 20 min. Wide scatter of drawdown and derivative points the results of surging water levels in tight well casing.

Well-loss correction of 23 feet applied derived from back-calculated theoretical-drawdown based on observation well analysis. See text for details.

Linear vertical (drawdown) scale used to allow better curve fit to data and less-exaggerated derivative data plot.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

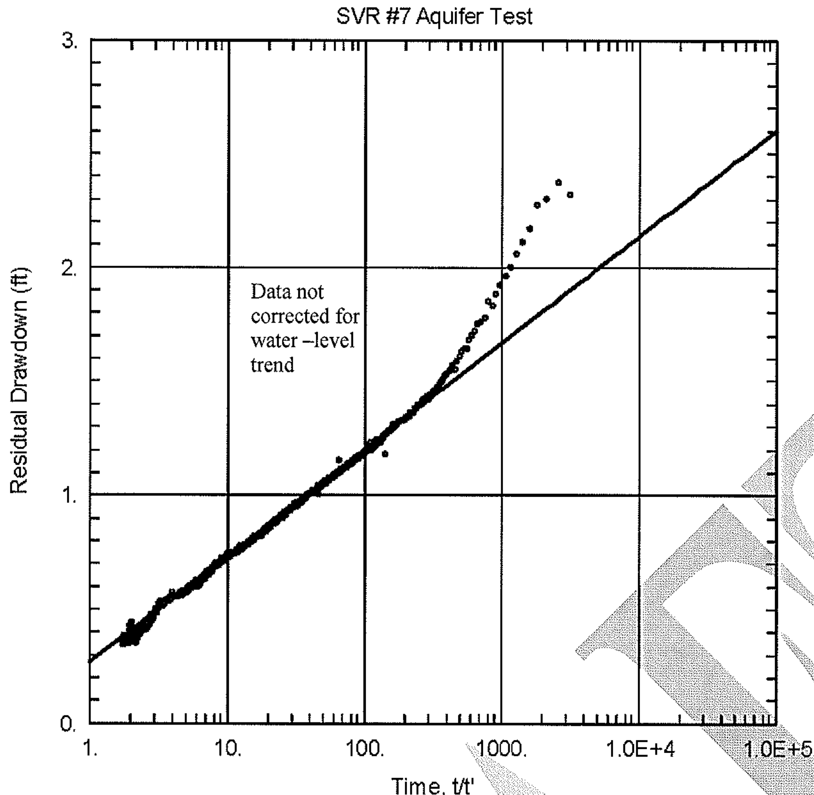
W(u) = $1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = effective radius of pumping well (ft)
t = time in days

Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details
b = aquifer thickness in feet (ft), estimated from geophysical and well logs in the area

Solid Line represents "type curve" where T and S best match observed drawdown. Variations from "smooth," semi-log curve the result of Aqtesolv® generating type curve based on variations in reported pumping rate.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 14. Theis Recovery Analysis for Well SVR #7



Screen = 279-349 ft
T=520,000 gpd/ft
S/S' =0.3
Kv/Kh=0.1
b = 340 ft
r = 0.5 ft
Q = 917gpm

S/S' less than 1 suggests "late" or "incomplete" recovery, often indicative of an aquifer no-flow boundary, as is present beneath the M3 site (see green line in Figure 1). However, seasonal (declining), regional, water- level trend over 11+ days of recovery may also be a cause of the apparent incomplete recovery.

$T = 264Q/\Delta s$ Where:

T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
Δs = Change in drawdown of water level over one log cycle of time, in feet (ft)

t = time since pumping started (minutes)
t' = time since pumping stopped (minutes)

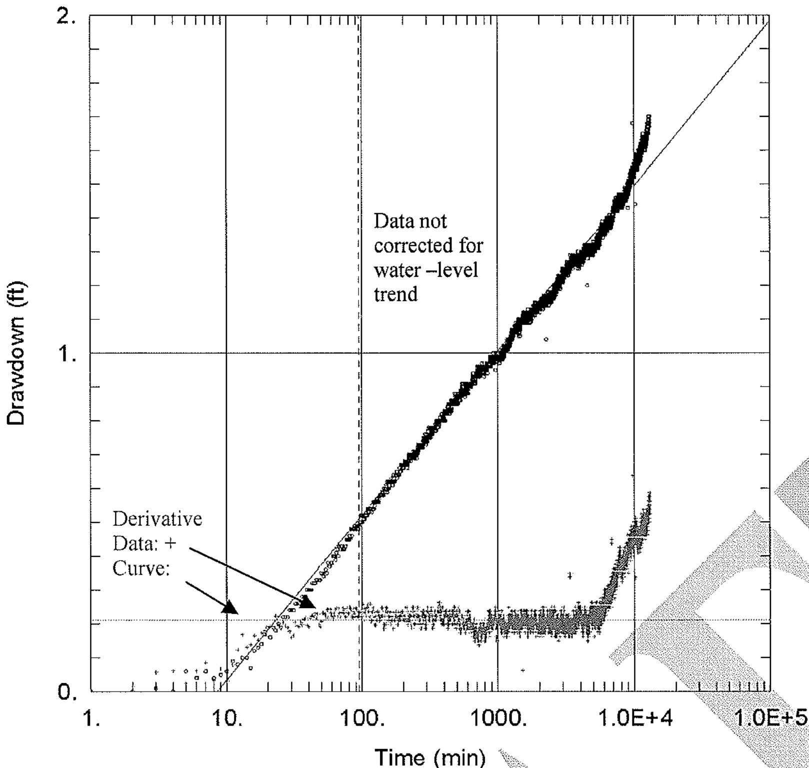
S/S' = storativity ratio (unitless) where:

S/S' < 1 indicates no-flow boundary ("late" recovery)
S/S' = 1indicates no recharge or discharge boundaries ("normal" recovery)
S/S' >1 indicates recharge boundary ("early" recovery)

Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details
b = aquifer thickness in feet (ft), calculated from geophysical log of well.
r = effective radius of pumping well (ft)

Based on the analytical method of Theis (1935).

Figure 15. Cooper-Jacob Analysis for the Big Gulch Stock Well



Screen = 180 ft (Open hole)
T=500,000 gpd/ft
S = 1.2x 10^{-3}
Kv/Kh=0.1
b = 340 ft
t_c = 95 min
r = 845 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data between 100 and 6,000 min. Rise in apparent drawdown and derivatives after 6,000 minutes caused by declining regional aquifer water level trend. Data are uncorrected for this trend.

Partial penetration corrections not needed.

T = 264Q/Δs Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
Δs = Change in drawdown of water level over one log cycle of time, in feet (ft)

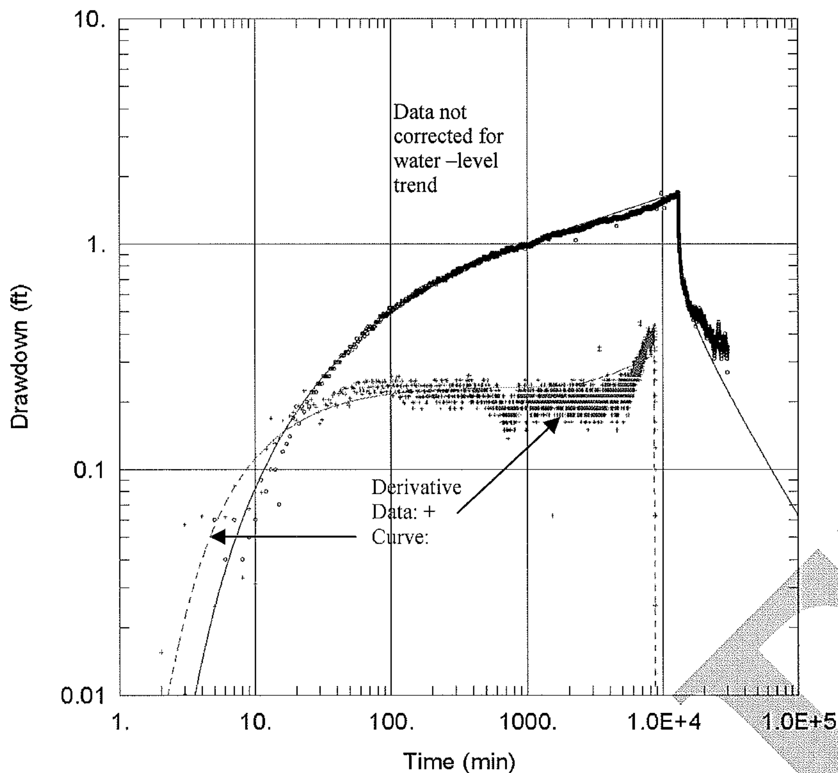
t_c = critical time where "u assumption" is met (where u = 0.05) such that method may be valid, is 95 minutes as shown by dashed vertical line.

$u = 1.87r^2S/Tt$
t = time in days
r = distance to pumping well (ft)

b = aquifer thickness in feet (ft), estimated from geophysical log of well SVR #7.

Based on the analytical method of Cooper and Jacob (1946).
No partial penetration corrections needed.

Figure 16. Theis Analysis for the Big Gulch Stock Well



Screen = 180 ft (Open hole)
T=450,000 gpd/ft
S = 1.8x 10^{-3}
Kv/Kh=0.1
b = 340 ft
r = 845 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data between 100 and 5,000 min. Rise in apparent drawdown and derivatives after 6,000 minutes caused by declining regional aquifer water level trend. Data are not corrected for this trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
- T = Transmissivity in gallons per day per foot (gpd/ft)
- Q = Pumping rate in gallons per minute (gpm) and
- *W(u)* = "well function" (defined below)

W(u) = $1.87r^2S/Tt$ Where:
- S = storativity (unitless)
- r = distance to pumping well (ft)
- t = time in days

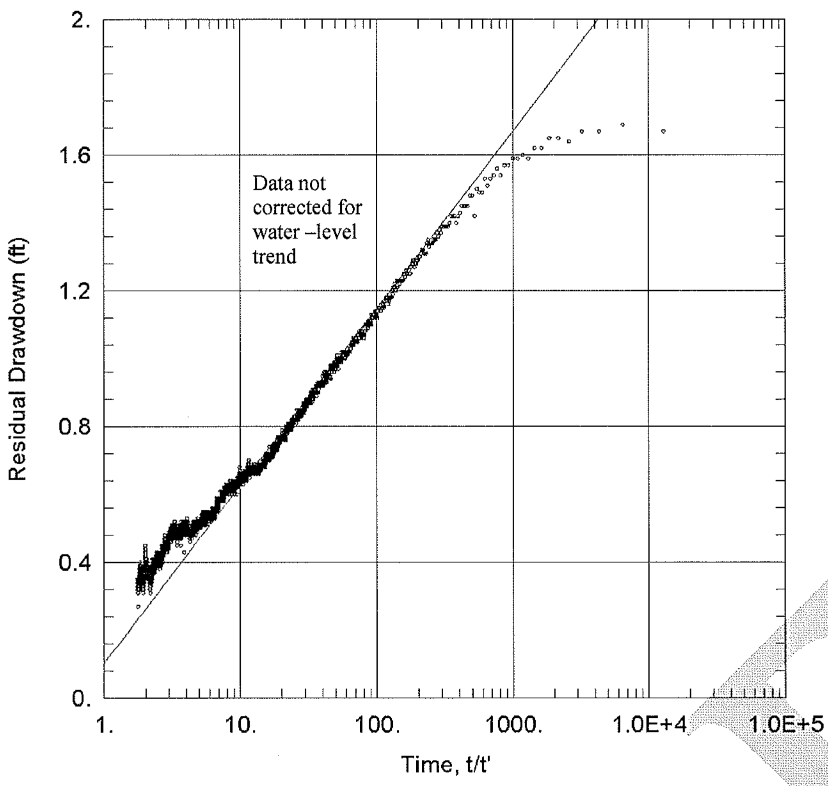
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), estimated from geophysical log of well SVR #7.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 17. Theis Recovery Analysis for the Big Gulch Stock Well



Screen = 180 ft (Open hole)
T=450,000 gpd/ft
S/S' =0.6
Kv/Kh=0.1
b = 340 ft
r = 845 ft
Q = 917gpm (at SVR #7)

S/S' less than 1 suggests "late" or "incomplete" recovery. However, seasonal (declining), regional, water-level trend over 11+ days of recovery is most probable cause of apparent incomplete recovery.

Partial penetration corrections not needed.

T = 264Q/Δs Where:
- T = Transmissivity in gallons per day per foot (gpd/ft)
- Q = Pumping rate in gallons per minute (gpm) and
- Δs = Change in drawdown of water level over one log cycle of time, in feet (ft)

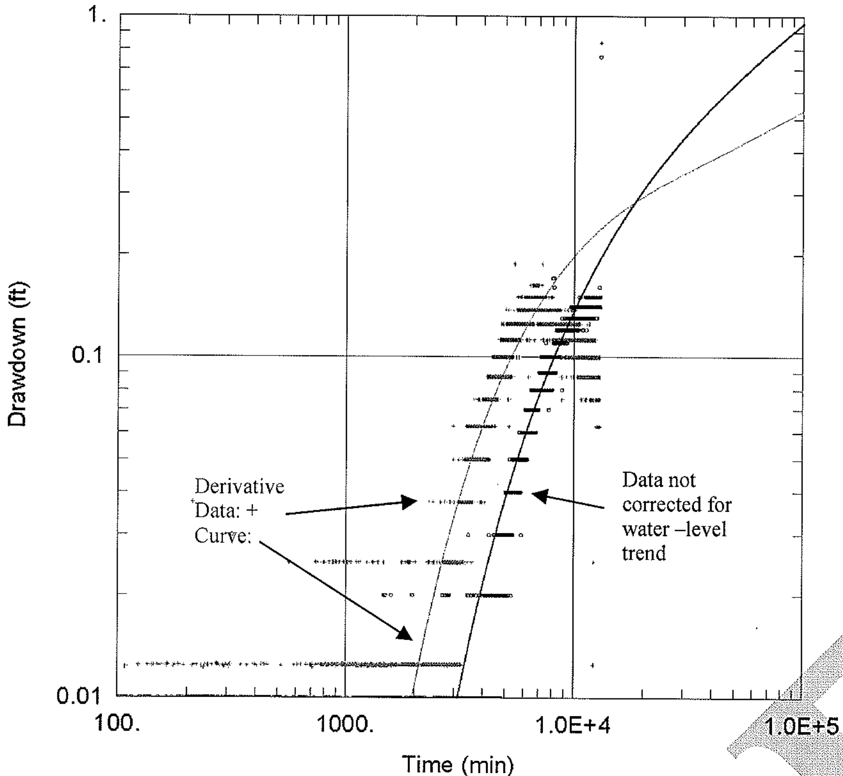
t = time since pumping started (minutes)
t' = time since pumping stopped (minutes)

S/S' = storativity ratio (unitless) where:
- S/S' < 1 indicates no-flow boundary ("late" recovery)
- S/S' = 1indicates no recharge or discharge boundaries ("normal" recovery)
- S/S' >1 indicates recharge boundary ("early" recovery)

Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details
b = aquifer thickness in feet (ft), estimated from geophysical log of well SVR #7.
r = distance to pumping well (ft)

Based on the analytical method of Theis (1935).

Figure 18. Theis Analysis for the M3-TW #2 Zone 2 – No Trend Correction



Screen = 230-250 ft
T=240,000 gpd/ft
S = 9.0x 10^{-2}
Kv/Kh=0.1
b = 300 ft
r = 3,636 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data between 2,000 and 7,000 min. Fall in apparent drawdown and derivatives after 6,000 minutes caused by end of rising regional aquifer water level trend. Data are uncorrected for this trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

W(u) = $1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

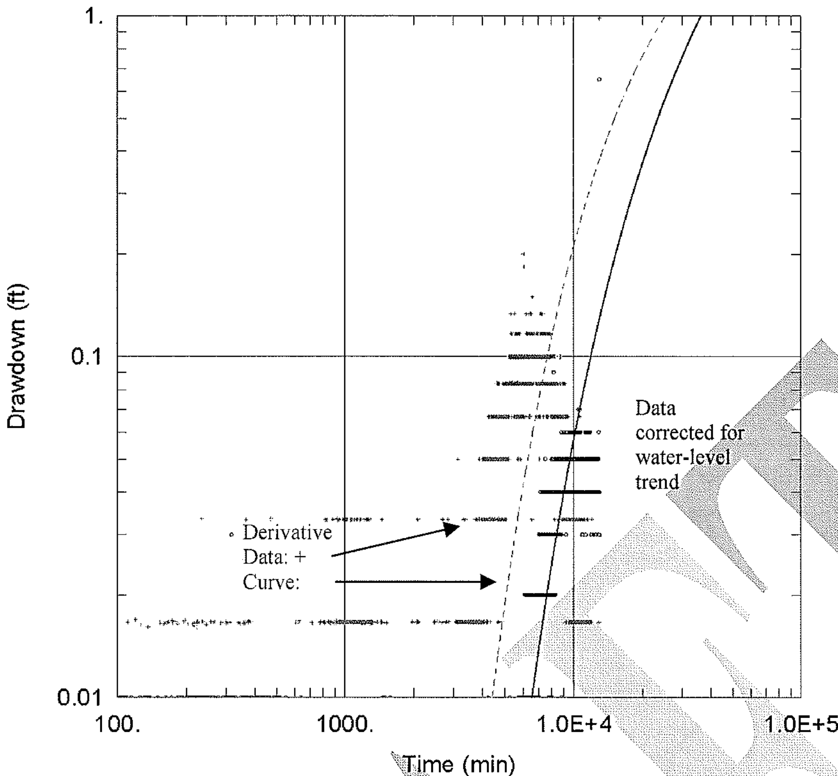
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 19. Theis Analysis for the M3-TW #2 Zone 2 – With Trend Correction



Screen = 230-250 ft
T=370,000 gpd/ft
S = 2.7x 10^{-2}
Kv/Kh=0.1
b = 300 ft
r = 3,636 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data between 2,000 and 5,000 min. Fall in apparent derivatives after 6,000 minutes may be caused in part by relatively large range for calculating derivative (0.4 log cycles) that extends beyond data collection period.

Partial penetration corrections not needed.

$T = 114.6\,Q\,W(u)/s$ Where:
- T = Transmissivity in gallons per day per foot (gpd/ft)
- Q = Pumping rate in gallons per minute (gpm) and
- *W(u)* = "well function" (defined below)

W(u) = $1.87r^2S/Tt$ Where:
- S = storativity (unitless)
- r = distance to pumping well (ft)
- t = time in days

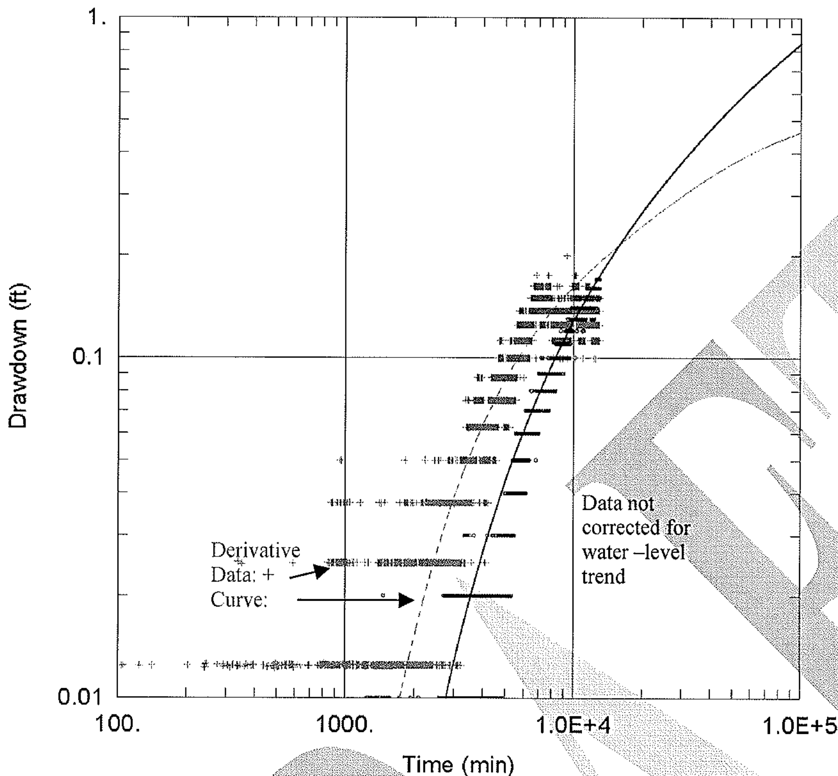
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 20. Theis Analysis for the M3-TW #2 Zone 1 – No Trend Correction



Screen = 270-320 ft
T=350,000 gpd/ft
S = 6.2x 10^{-2}
Kv/Kh=0.1
b = 300 ft
r = 3,636 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data between 2,000 and 7,000 min. Flattening in apparent drawdown and derivatives after 7,000 minutes caused by end of rising regional aquifer water level trend. Data are uncorrected for this trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

W(u) = $1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

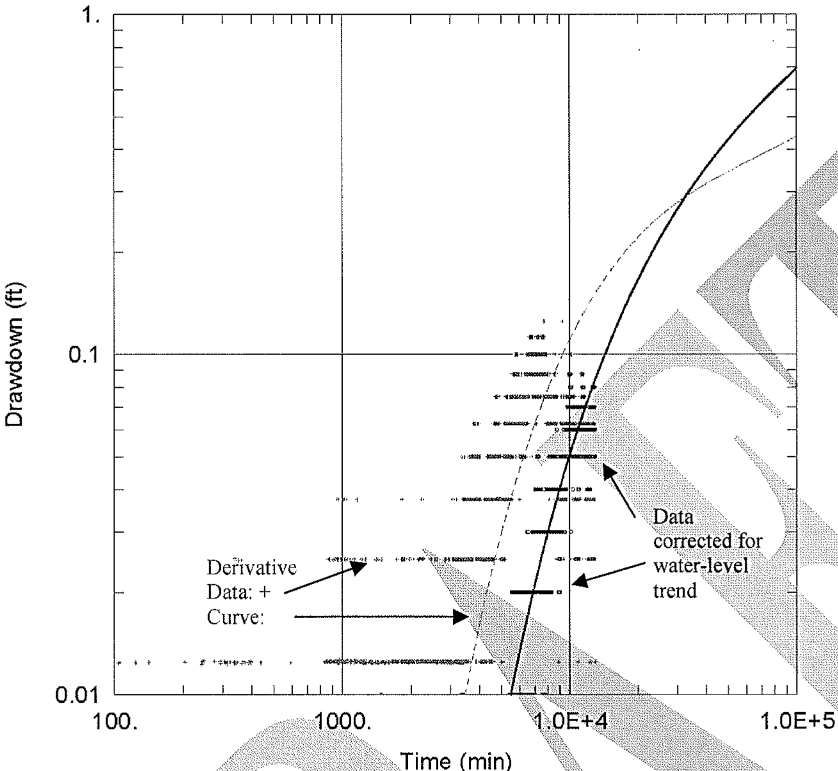
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 21. Theis Analysis for the M3-TW #2 Zone 1 – With Trend Correction



Screen = 270-320 ft
T=230,000 gpd/ft
S = 1.6x 10^{-1}
Kv/Kh=0.1
b = 300 ft
r = 3,636 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data for entire test. Data are corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

W(u) = $1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

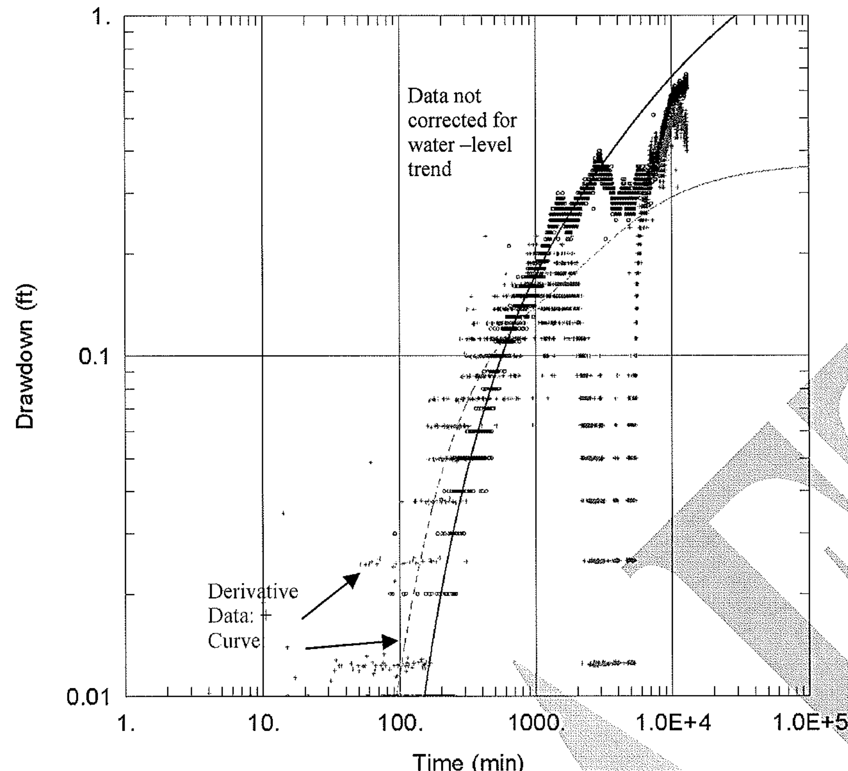
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 22. Theis Analysis for the M3-TW #4 Zone 2 – No Trend Correction



Screen = 325-556 ft
T=570,000 gpd/ft
S = 3.0x 10^{-3}
Kv/Kh=0.1
b = 260 ft
r = 4,489 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data from first 1,000 minutes of test. Afterward, incomplete barometric corrections and lack of water level trend corrections make analysis only approximate. Data are uncorrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
- T = Transmissivity in gallons per day per foot (gpd/ft)
- Q = Pumping rate in gallons per minute (gpm) and
- *W(u)* = "well function" (defined below)

W(u) = $1.87r^2S/Tt$ Where:
- S = storativity (unitless)
- r = distance to pumping well (ft)
- t = time in days

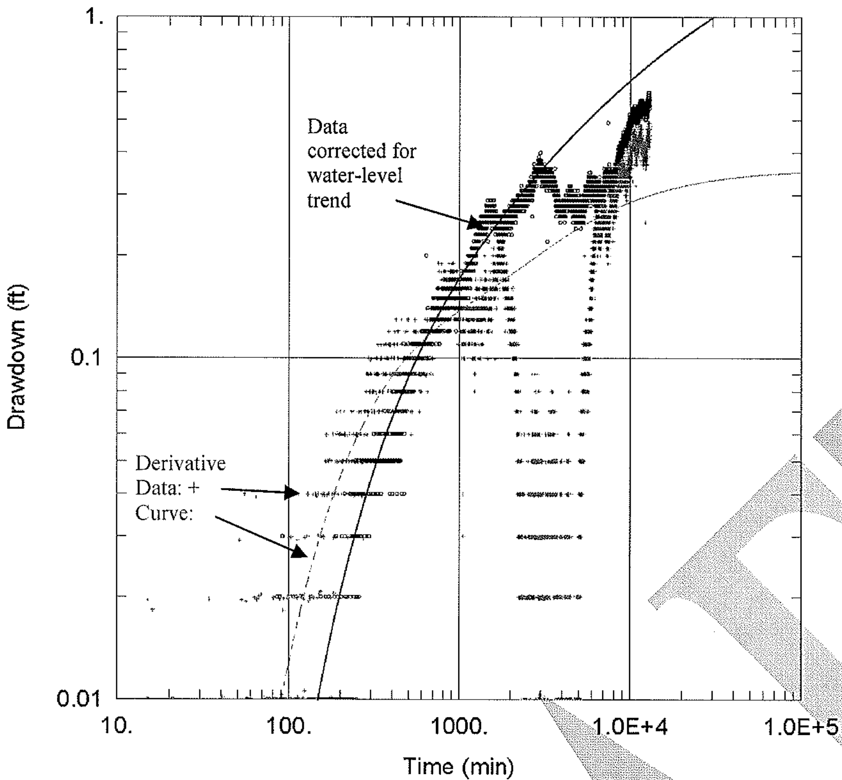
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 23. Theis Analysis for the M3-TW #4 Zone 2 – With Trend Correction



Screen = 325-556 ft
T=580,000 gpd/ft
S = 3.0x 10^{-3}
Kv/Kh=0.1
b = 260 ft
r = 4,489 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data from first 1,000 minutes of test. Afterward, incomplete barometric corrections and incomplete water level trend corrections make analysis only approximate. Data are corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

W(u) = $1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

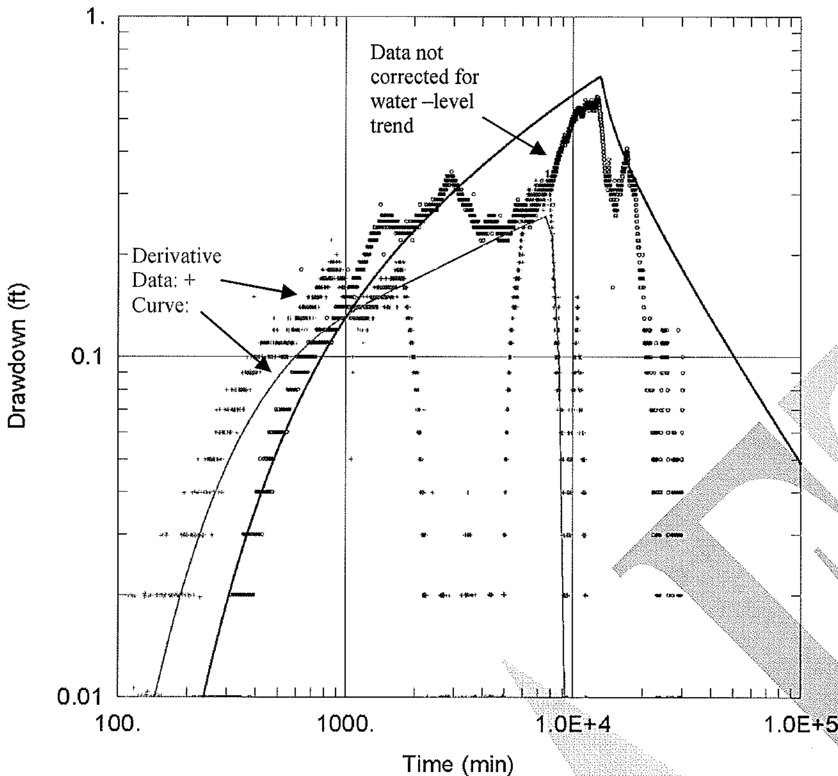
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 24. Neuman-Witherspoon Analysis for the M3-TW #4 Zone 1 – as an Aquifer Separate from the PGSA, No Trend Correction



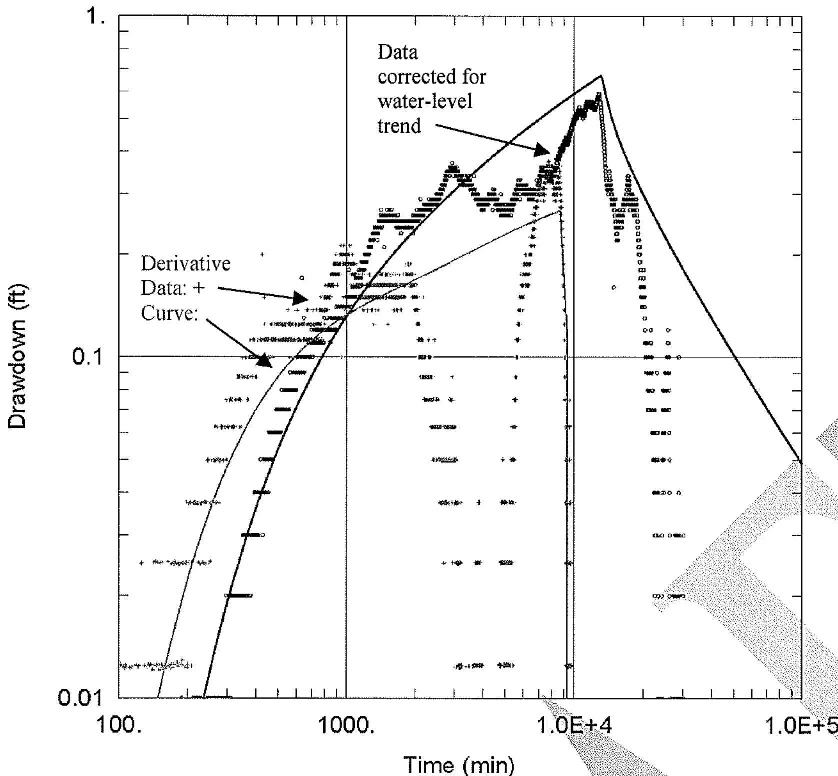
Screen = 625-646 ft
T_{PGSA}= 500,000 gpd/ft
S_{PGSA} = 2.3x 10^{-3}
Kv/Kh=0.1
b_{PGSA} = 260 ft
$T_{zone\ 1}$= 80,000 gpd/ft
$S_{zone\ 1}$ = 1 x 10^{-3}
$b_{zone\ 1}$ = 30 ft
$b_{aquitard}$ = 30 ft
r = 4,489 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates only fair match for method. After 200 minutes, incomplete barometric corrections and incomplete water level trend corrections make analysis only approximate. Data are not corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

Based on the analytical method of Neuman and Witherspoon (1972) derived from the original method of Theis (1935). Based on assumption of flow to the pumped aquifer, through a leaky aquitard, from a second aquifer. Flow through the aquitard is assumed to be vertical. See Appendix D for equations and illustrations.

Figure 25. Neuman-Witherspoon Analysis for the M3-TW #4 Zone 1 – As Aquifer Separate From PGSA, With Trend Correction



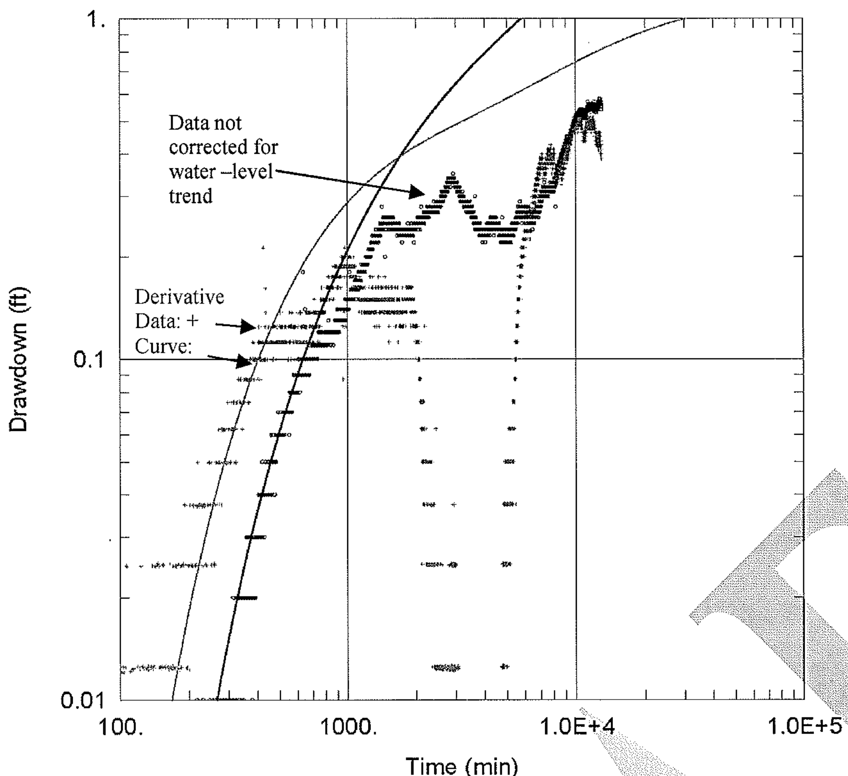
Screen = 625-646 ft
T_{PGSA}= 500,000 gpd/ft
S_{PGSA} = 2.3x 10^{-3}
Kv/Kh=0.1
b_{PGSA} = 260 ft
$T_{zone\ 1}$= 80,000 gpd/ft
$S_{zone\ 1}$ = 1 x 10^{-3}
$b_{zone\ 1}$ = 30 ft
$b_{aquitard}$ = 30 ft
r = 4,489 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates only fair match for method. After 300 minutes, incomplete barometric corrections and incomplete water level trend corrections make analysis only approximate. Data are not corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

Based on the analytical method of Neuman and Witherspoon (1972) derived from the original method of Theis (1935). Based on assumption of flow to the pumped aquifer, through a leaky aquitard, from a second aquifer. Flow through the aquitard is assumed to be vertical. See Appendix D for equations and illustrations.

Figure 26. Theis Analysis for the M3-TW #4 Zone 1 – As a part of the PGSA, No Trend Correction



Screen = 625-646 ft
T= 170,000 gpd/ft
S = 2.4x 10^{-1}
Kv/Kh=0.1
b = 260 ft
r = 4,489 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data from first 500 minutes of test. Afterward, incomplete barometric corrections and incomplete water level trend corrections make analysis only approximate. Data are not corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

W(u) = $1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

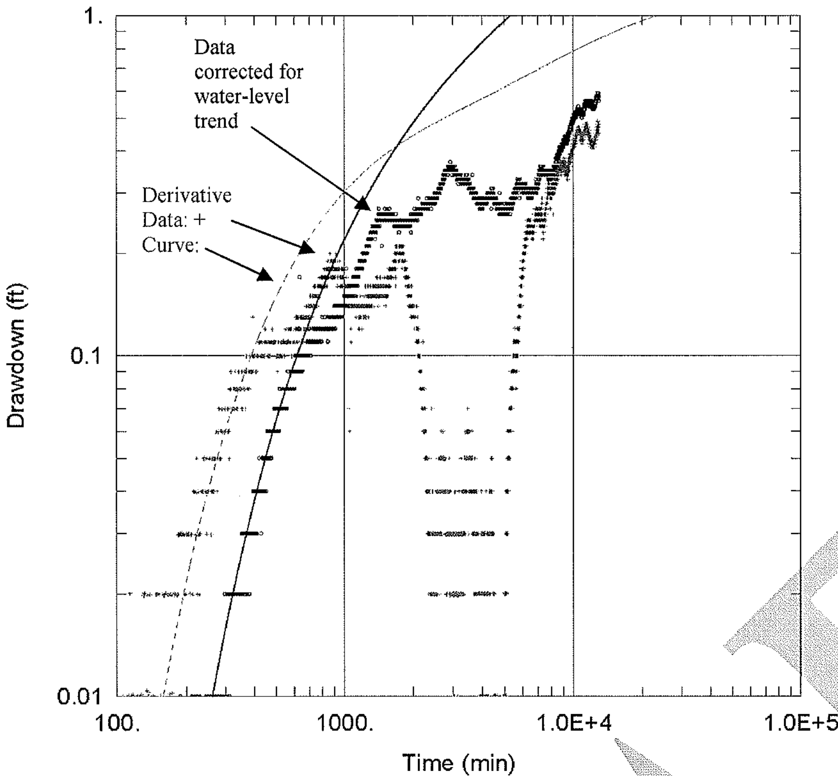
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 27. Theis Analysis for the M3-TW #4 Zone 1 – As a part of the PGSA, With Trend Correction



Screen = 625-646 ft
T= 160,000 gpd/ft
S = 2.4x 10^{-1}
Kv/Kh=0.1
b = 260 ft
r = 4,489 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is valid for data from first 500 minutes of test. Afterward, incomplete barometric corrections and incomplete water level trend corrections make analysis only approximate. Data are corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

W(u) = $1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

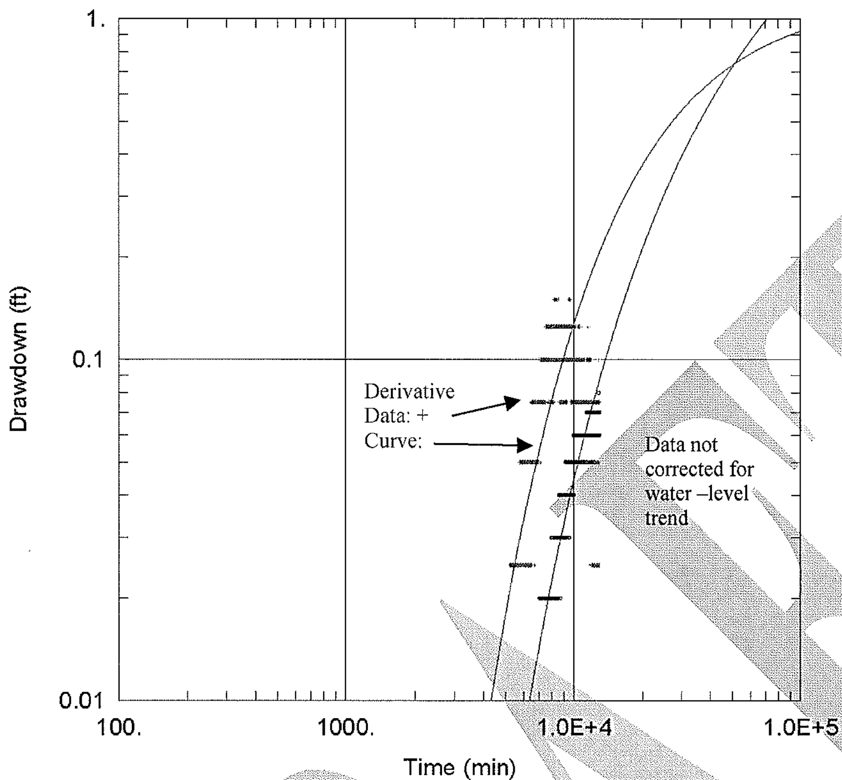
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 28. Theis Analysis for the Little Gulch Stock Well – No Trend Correction



Screen = 220-223 ft
T=180,000 gpd/ft
S = 1.3x 10^{-2}
Kv/Kh=0.1
b = 176 ft
r = 9,740 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is generally valid for data from first 8,000 minutes of test. However, small drawdown response and need to filter barometric effect make analysis only approximate. Data are not corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
- T = Transmissivity in gallons per day per foot (gpd/ft)
- Q = Pumping rate in gallons per minute (gpm) and
- *W(u)* = "well function" (defined below)

W(u) = $1.87r^2S/Tt$ Where:
- S = storativity (unitless)
- r = distance to pumping well (ft)
- t = time in days

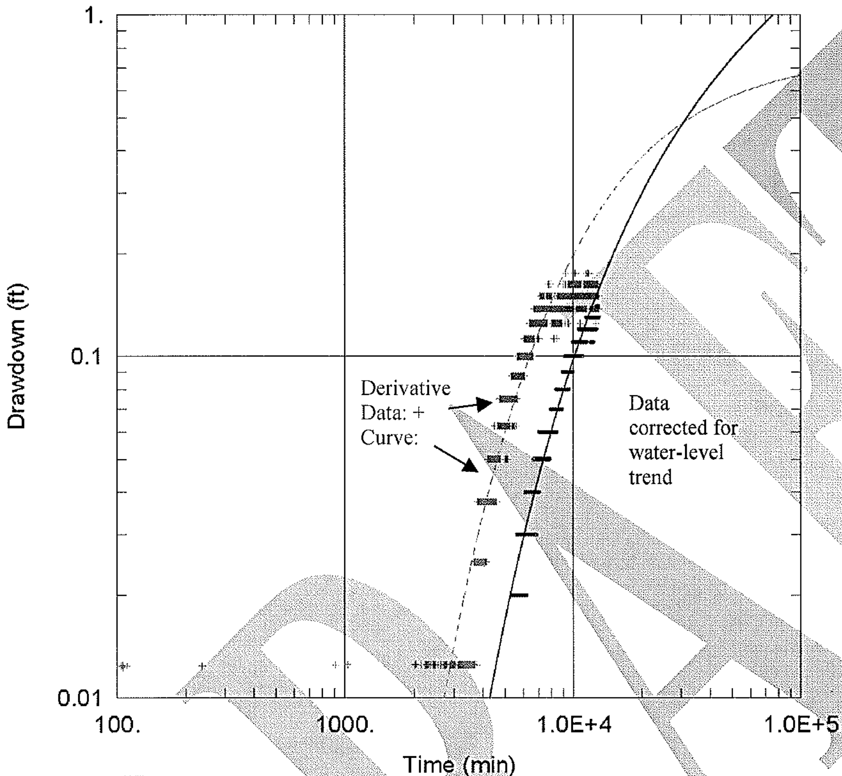
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 29. Theis Analysis for the Little Gulch Stock Well – With Trend Correction



Screen = 220-223 ft
T=270,000 gpd/ft
S = 1.1x 10^{-2}
Kv/Kh=0.1
b = 176 ft
r = 9,740 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is generally valid for data from first 8,000 minutes of test. Fit is better than analysis without trend correction. However, small drawdown response and need to filter barometric effect make analysis only approximate. Data are corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

W(u) = $1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

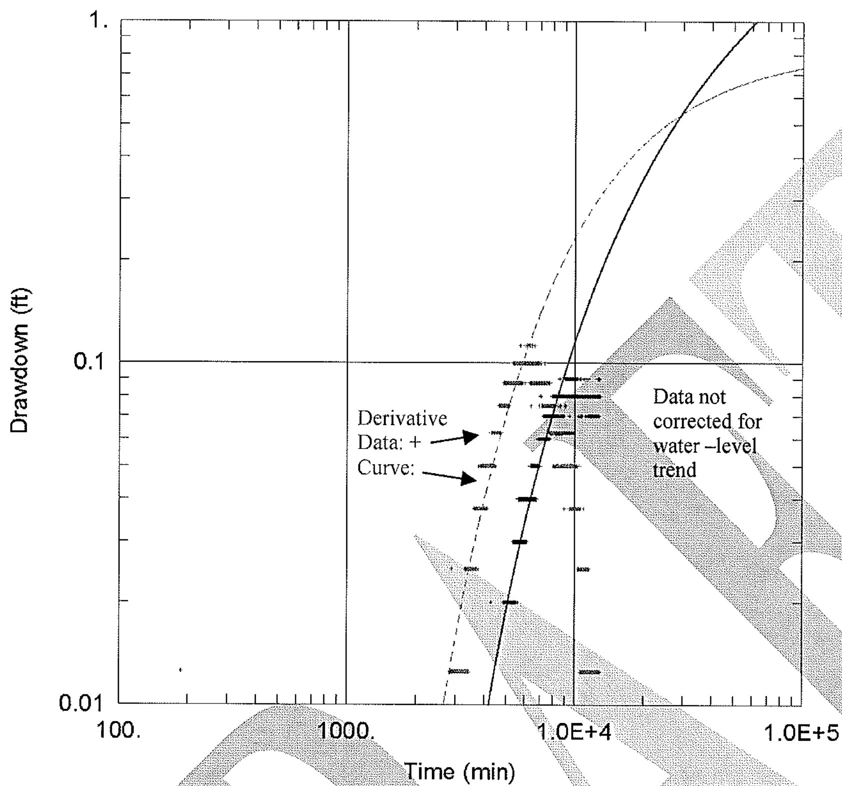
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 30. Theis Analysis for Well SVR #9– No Trend Correction



Screen = 235-263 ft
T = 250,000 gpd/ft
S = 8.7x 10^{-3}
Kv/Kh=0.1
b = 73 ft
r = 11,660 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is generally valid for data from first 6,000 minutes of test. However, small drawdown response and need to filter barometric effect make analysis only approximate. Data are not corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

W(u) = $1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

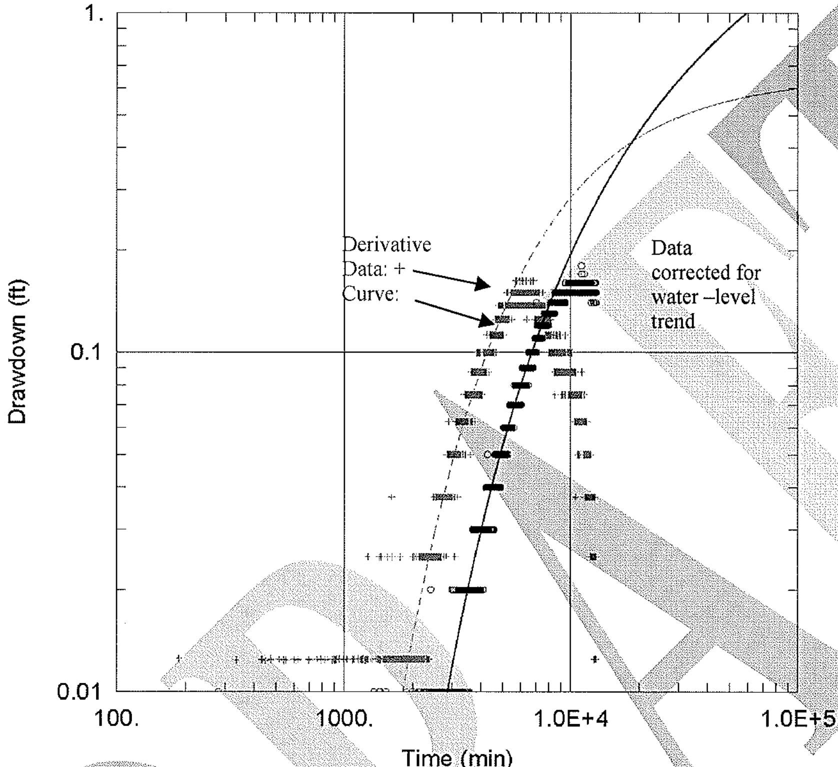
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 31. Theis Analysis for Well SVR #9 – With Trend Correction



Screen = 235-263 ft
T = 320,000 gpd/ft
S = 7.1x 10^{-3}
Kv/Kh=0.1
b = 73 ft
r = 11,660 ft
Q = 917gpm (at SVR #7)

Derivative analysis indicates method is generally valid for data from first 6,000 minutes of test. Fit is better than analysis without trend correction. However, small drawdown response and need to filter barometric effect make analysis only approximate. Data are corrected for seasonal aquifer water-level trend.

Partial penetration corrections not needed.

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

W(u) = $1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

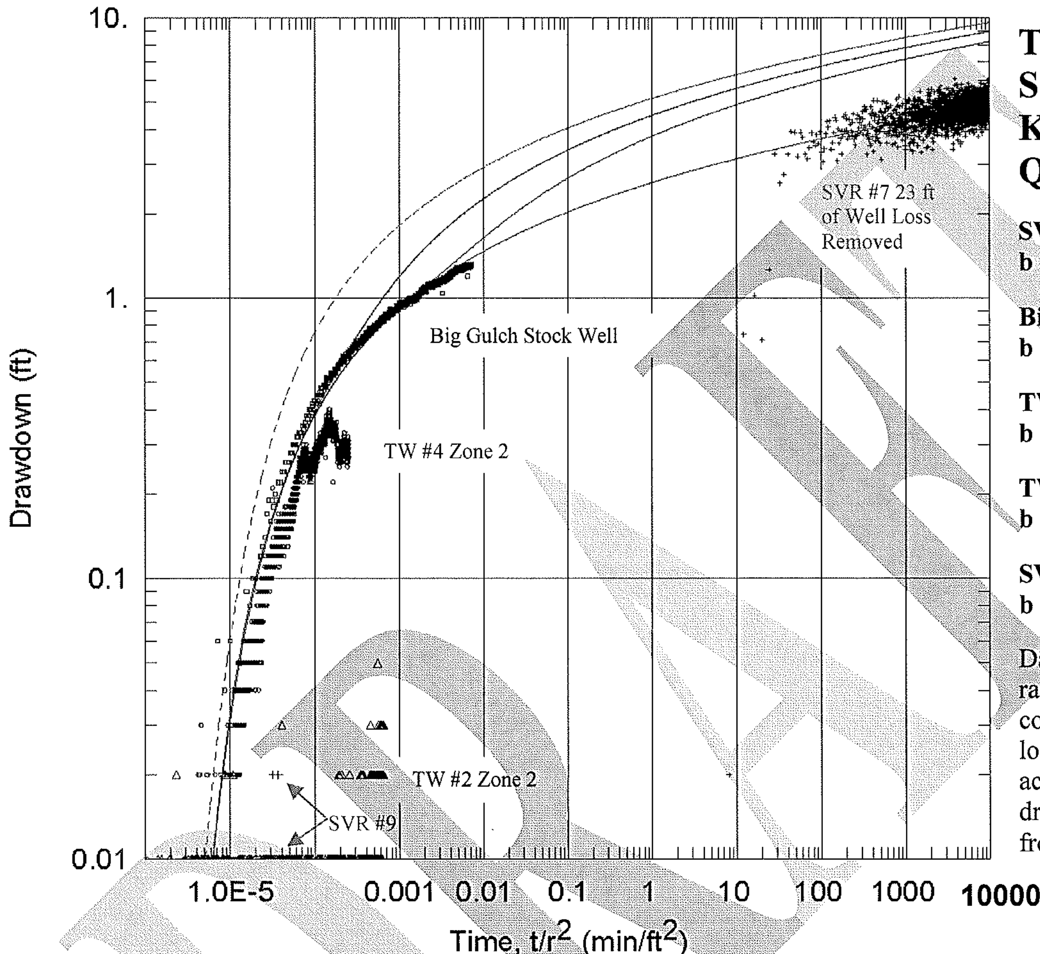
Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details

b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 32. Composite Theis Analysis for Five Observation Wells



$T_{composite}$ = 430,000 gpd/ft
$S_{composite}$ = 2.1x 10^{-3}
Kv/Kh=0.1
Q = 917gpm (at SVR #7)

SVR #7
b = 340 ft, r = 0.5 ft

Big Gulch stock well
b = 340 ft, r = 845 ft

TW #2 Zone 2
b = 300 ft, r = 3,636 ft

TW #4 Zone 2
b = 260 to 360 ft, r = 4,489 ft

SVR #9
b = 73 f, r = 11,660 ft

Data normalized by dividing time by radius squared. Pumping well data corrected by subtracting 23 feet of well loss (as calculated based on comparison of actual drawdown and theoretical drawdown calculated using data derived from analysis of Big Gulch well.)

Composite plot for five wells with time normalized by distance such that data would plot on similar curves in a uniform, homogeneous aquifer. The pumping well (SVR #7), nearest observation well ("Big Gulch") and observation well to west (TW #4) plot on curve. Wells to the east of the pumping well (TW #2 and SVR #9) where the Pierce Gulch Sand Aquifer becomes unconfined, show a delayed response caused by thinner aquifer (lower transmissivity) and unconfined conditions (larger storativity).

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

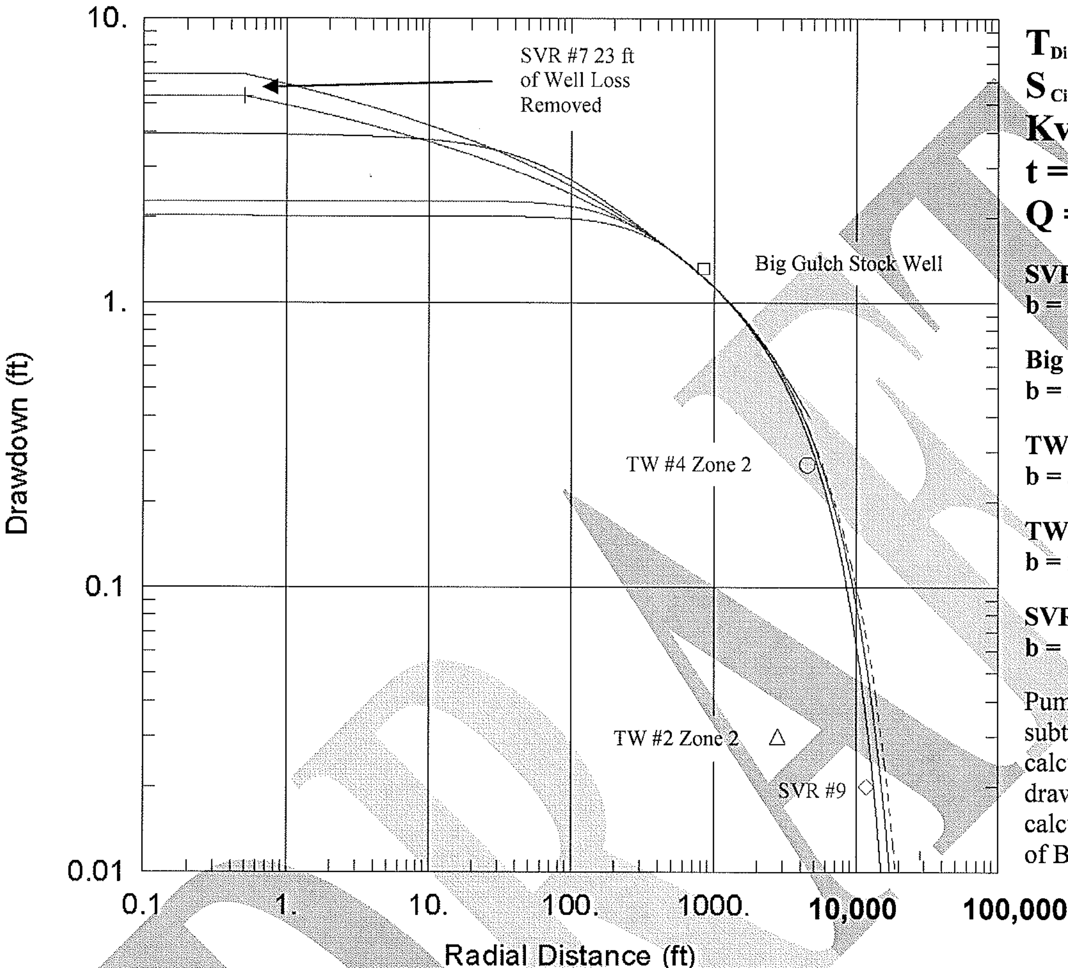
W(u) = $1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details
b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 33. Theis Distance Drawdown Analysis



$T_{Dist\text{-}Drawdwon}$ = 380,000 gpd/ft
$S_{Cist.\text{-}Drawdwon}$ = 7.0x 10^{-3}
Kv/Kh=0.1
t = 5,000 min
Q = 917gpm (at SVR #7)

SVR #7
b = 340 ft, r = 0.5 ft

Big Gulch stock well
b = 340 ft, r = 845 ft

TW #2 Zone 2
b = 300 ft, r = 3,636 ft

TW #4 Zone 2
b = 260 to 360 ft, r = 4,489 ft

SVR #9
b = 73 f, r = 11,660 ft

Pumping well data corrected by subtracting 23 feet of well loss (as calculated based on comparison of actual drawdown and theoretical drawdown calculated using data derived from analysis of Big Gulch well.)

Distance Drawdown plot at 5,000 into test. The pumping well (SVR #7), nearest observation well ("Big Gulch") and observation well to west (TW #4) plot on curve. Wells to the east of the pumping well (TW #2 and SVR #9) where the Pierce Gulch Sand Aquifer becomes unconfined, show a different response caused by thinner aquifer (lower transmissivity) and unconfined conditions (larger storativity).

T = 114.6 Q W(u)/s Where:
T = Transmissivity in gallons per day per foot (gpd/ft)
Q = Pumping rate in gallons per minute (gpm) and
W(u) = "well function" (defined below)

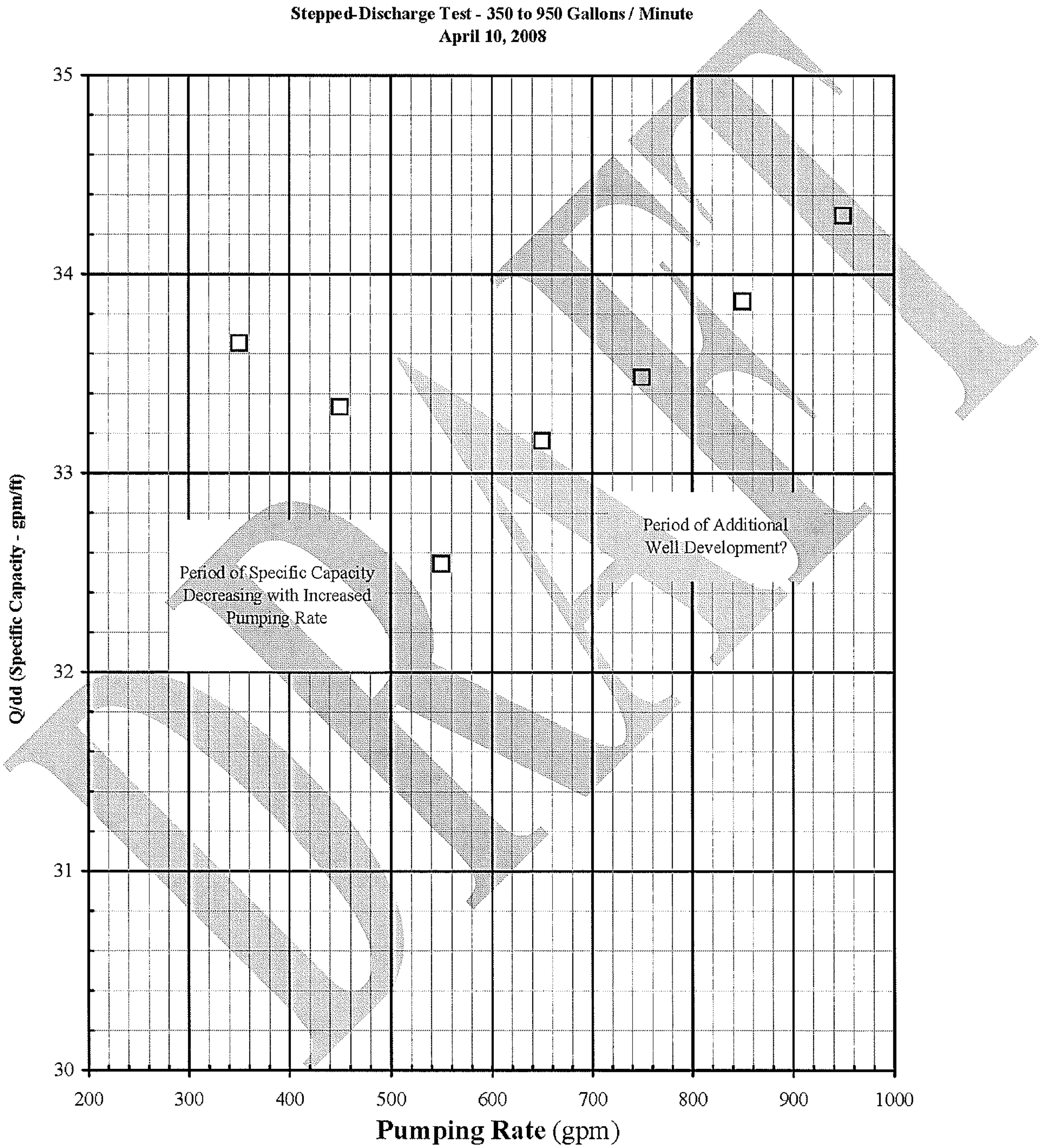
W(u) = $1.87r^2S/Tt$ Where:
S = storativity (unitless)
r = distance to pumping well (ft)
t = time in days

Kv/Kh = Bulk vertical to horizontal ratio of hydraulic conductivity (unitless), see text for details
b = aquifer thickness in feet (ft), calculated from geophysical log of well.

Solid Line represents "type curve" where T and S best match observed drawdown.

Based on the analytical method of Theis (1935) with partial penetration corrections of Hantush (1961a and b).

Figure 34. Specific Capacity at Various Pumping Rates During the Step-Discharge Test



APPENDICIES

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Appendix A - Well Driller's Reports for Wells without Additional Information

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Appendix B – Barometric Efficiency Analyses

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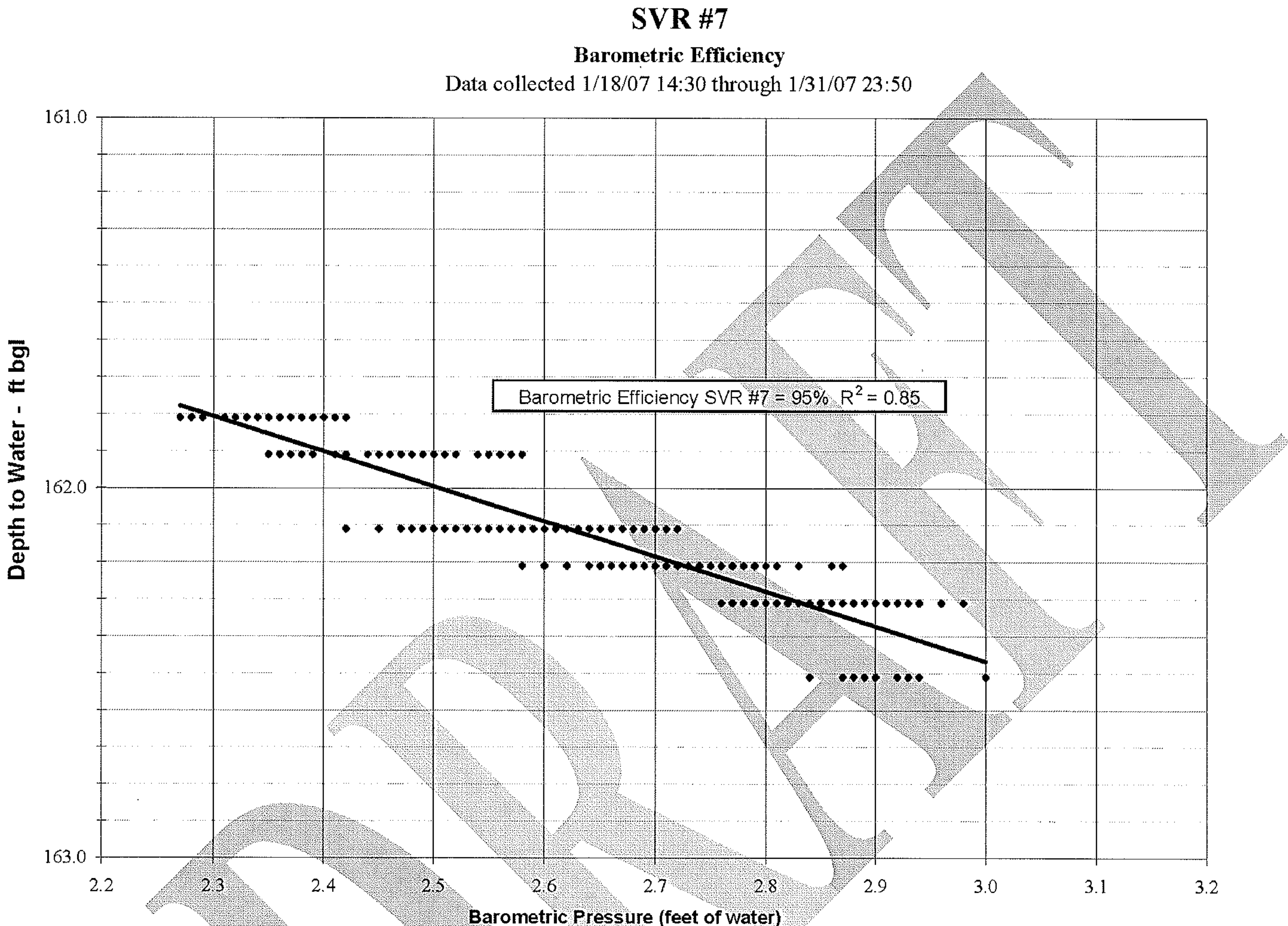
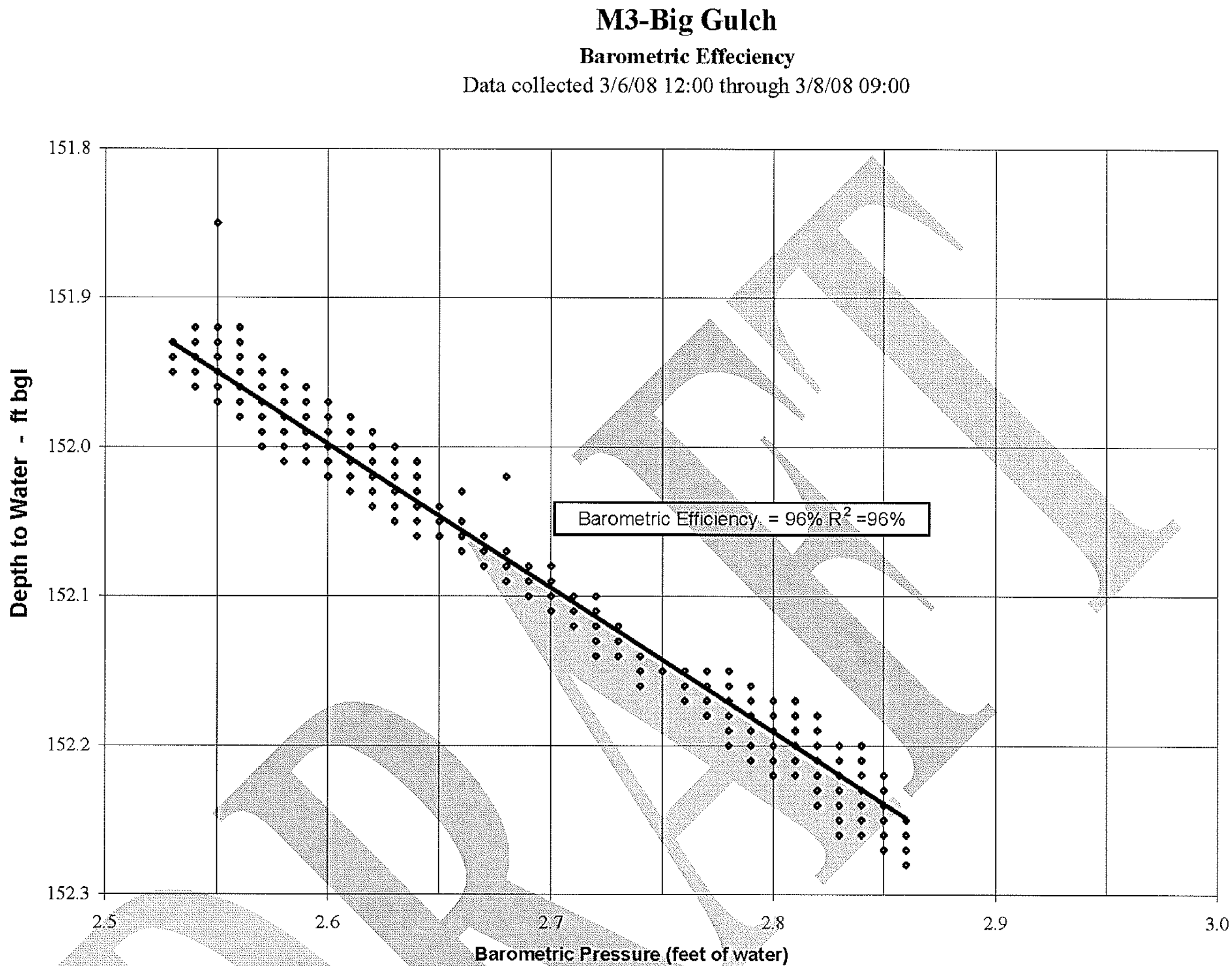
Figure B-1. Barometric Efficiency Plot for SVR #7



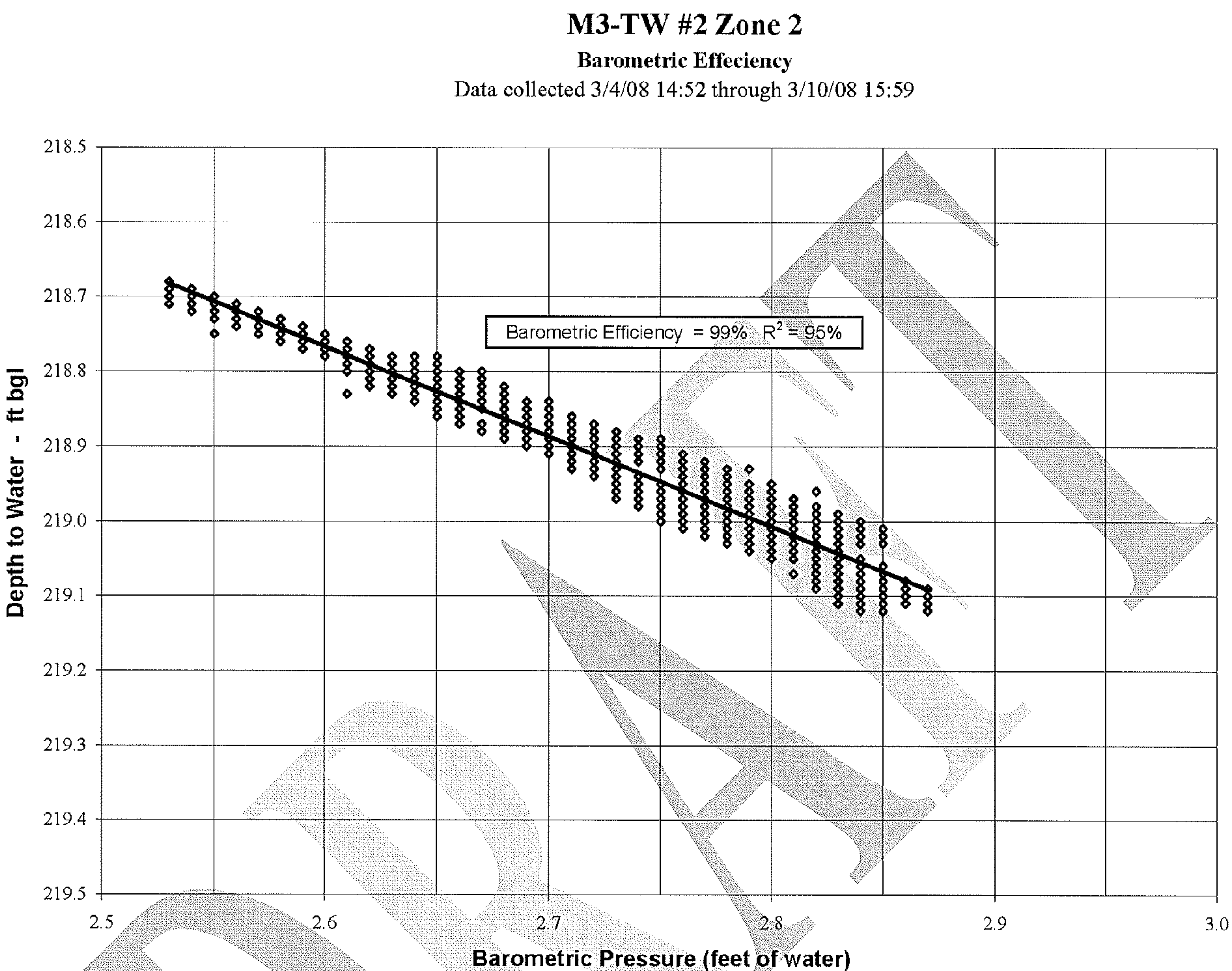
Distance from Pumping Well SVR #7 = 0 ft
Screen Depth = 280 to 350 ft

Figure B-2. Barometric Efficiency Plot for Big Gulch Stock Well



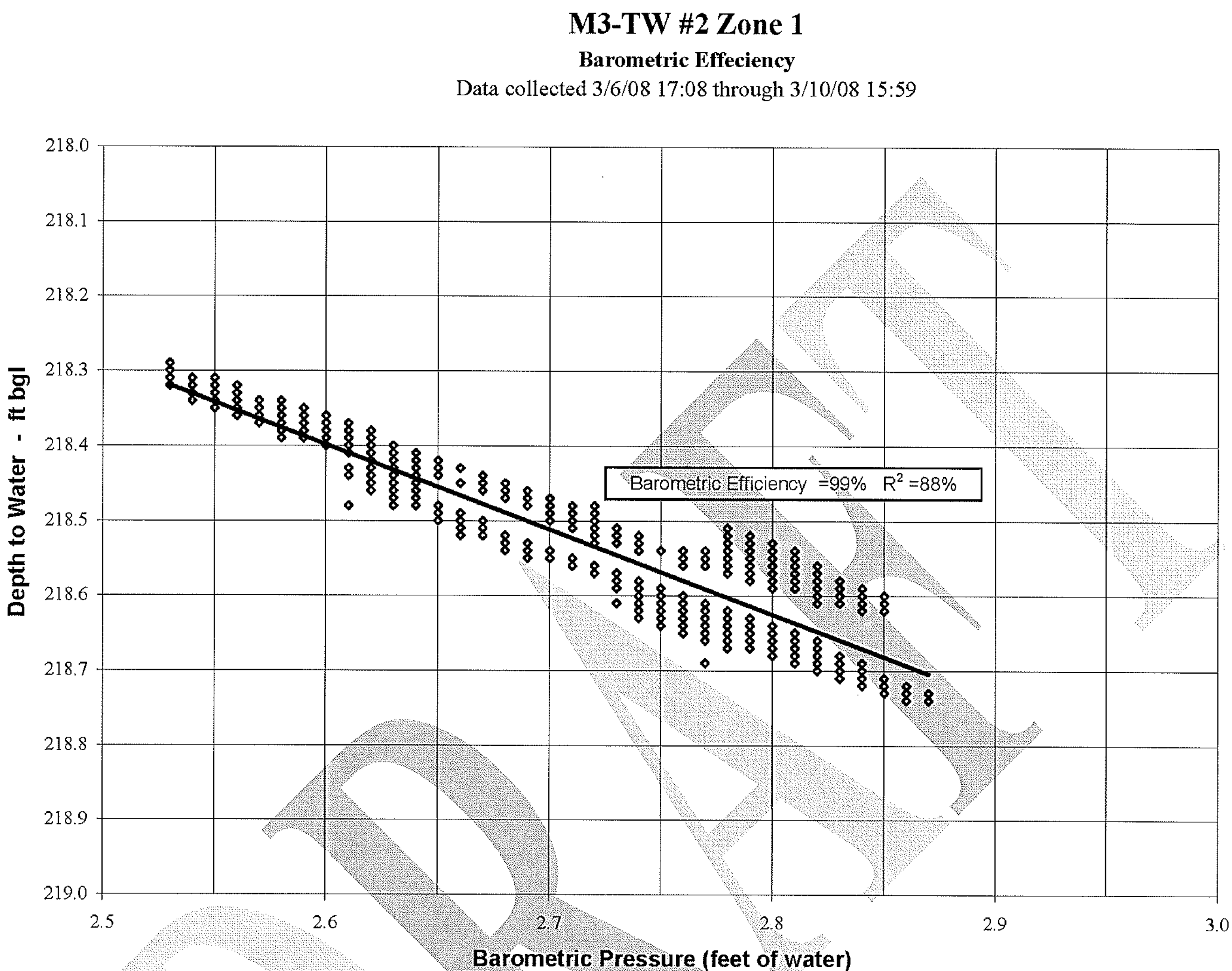
Distance from Pumping Well SVR #7 = 845 ft
Screen Depth = 180 to 180 ft ("open hole," no well screen)

Figure B-3. Barometric Efficiency Plot for TW #2 Zone 2



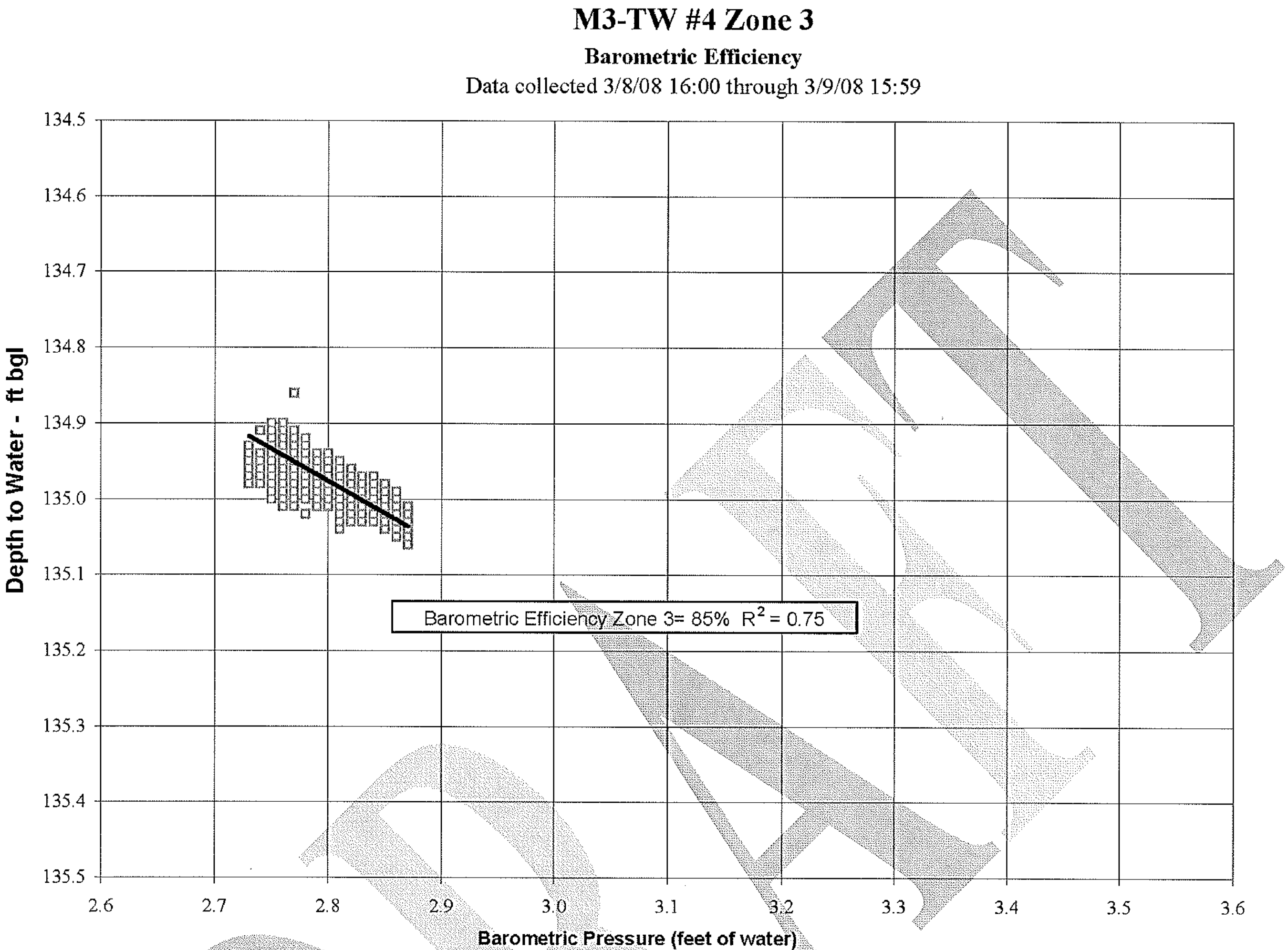
Distance from Pumping Well SVR #7 = 3,636 ft
Screen Depth = 230 to 250 ft

Figure B-4. Barometric Efficiency Plot for TW #2 Zone 1



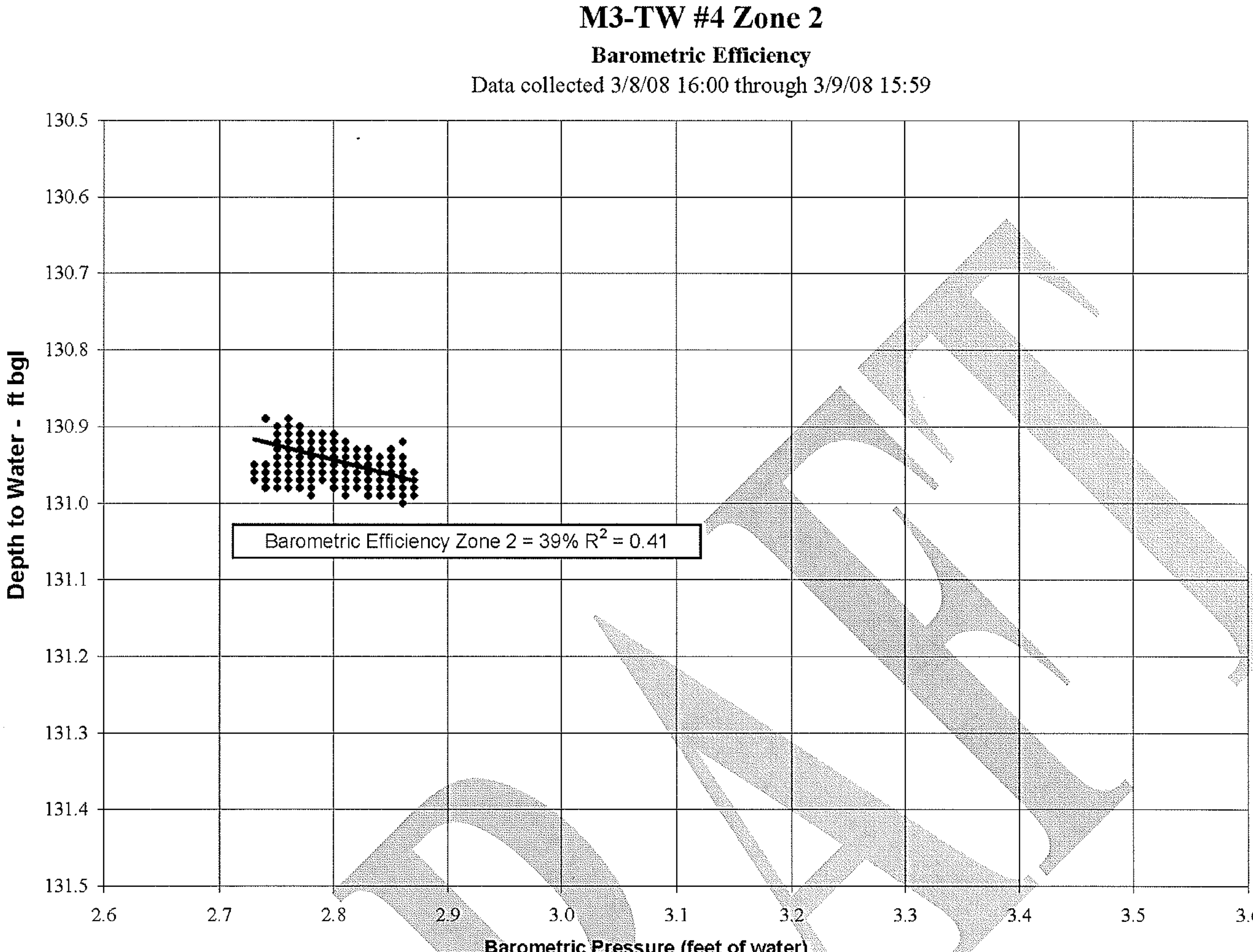
Distance from Pumping Well SVR #7 = 3,636 ft
Screen Depth = 270 to 320 ft

Figure B-5. Barometric Efficiency Plot for TW #4 Zone 3



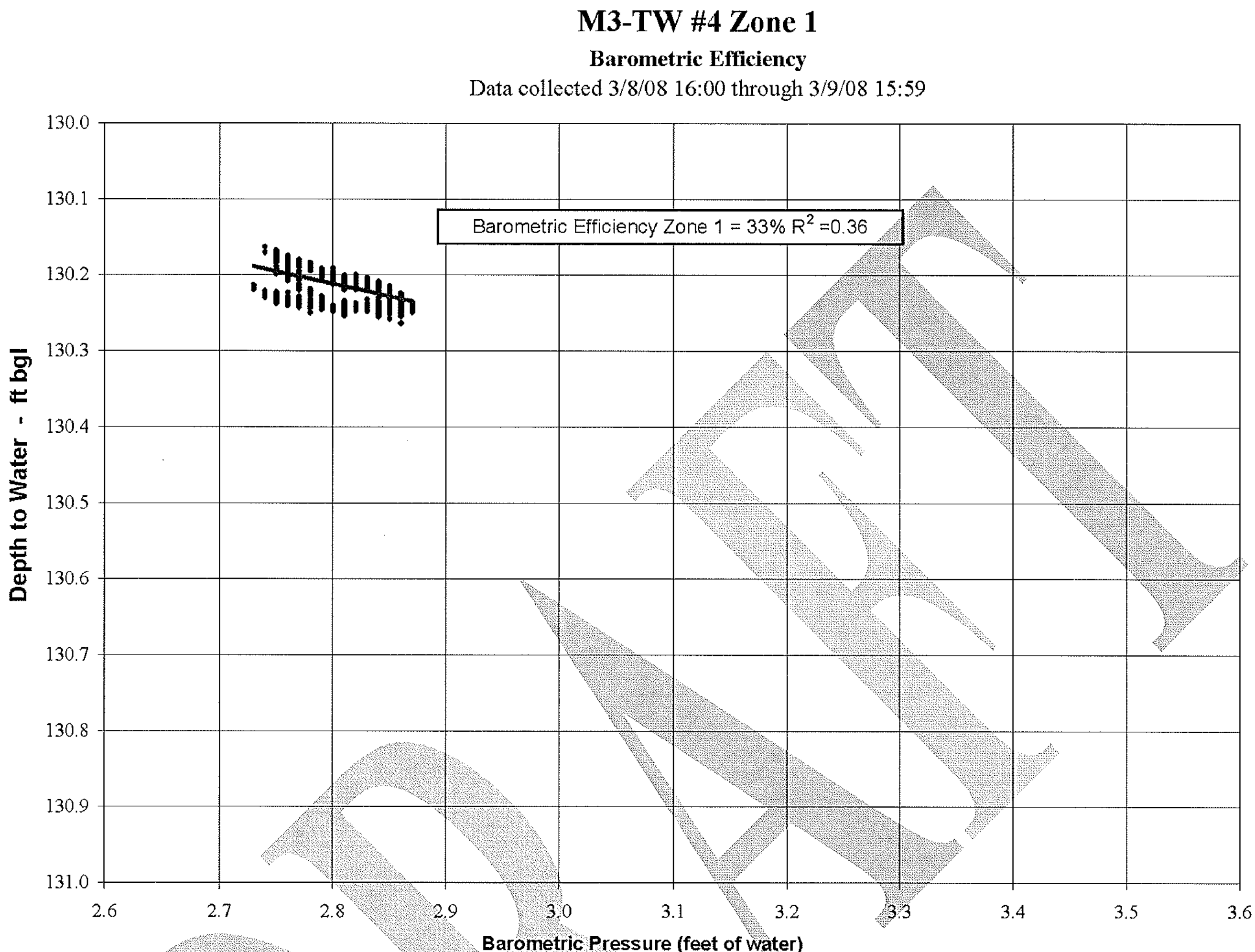
Distance from Pumping Well SVR #7 = 4,489 ft
Screen Depth = 181 to 201 ft

Figure B-6. Barometric Efficiency Plot for TW #4 Zone 2



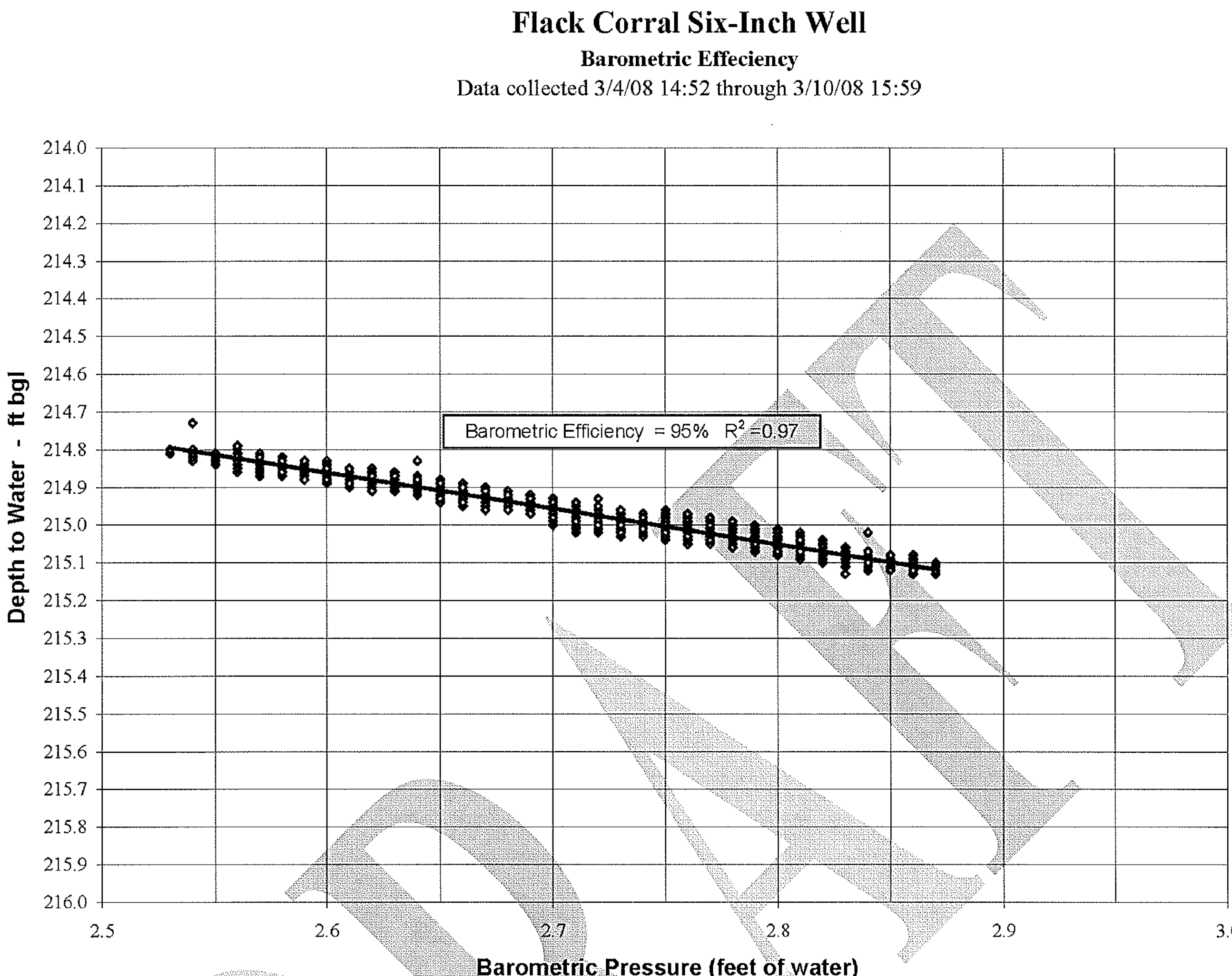
Distance from Pumping Well SVR #7 = 4,489 ft
Screen Depth = 325 to 556 ft

Figure B-7. Barometric Efficiency Plot for TW #4 Zone 1



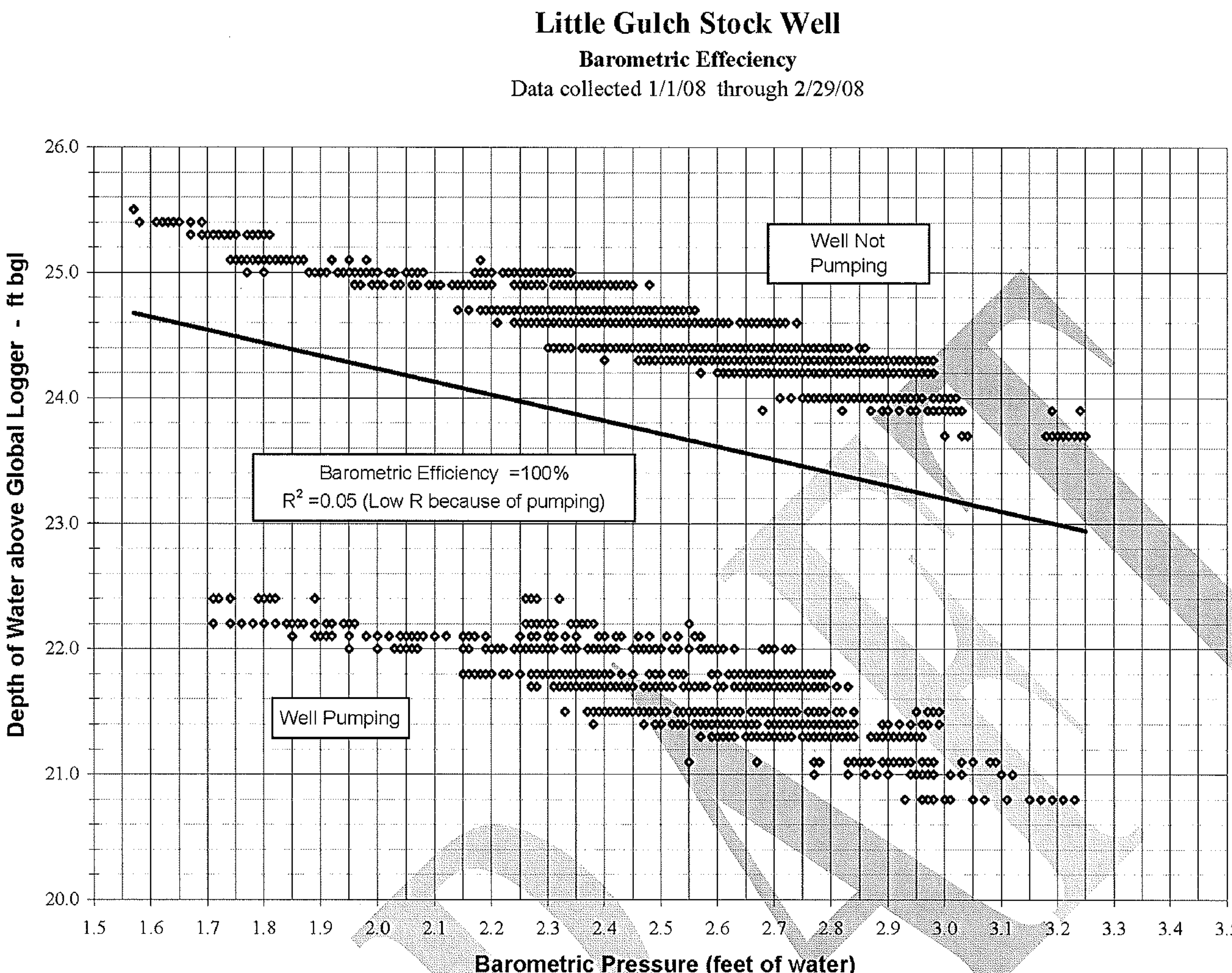
Distance from Pumping Well SVR #7 = 4,489 ft
Screen Depth = 625 to 646 ft

Figure B-8. Barometric Efficiency Plot for Flack Corral 6-Inch Well



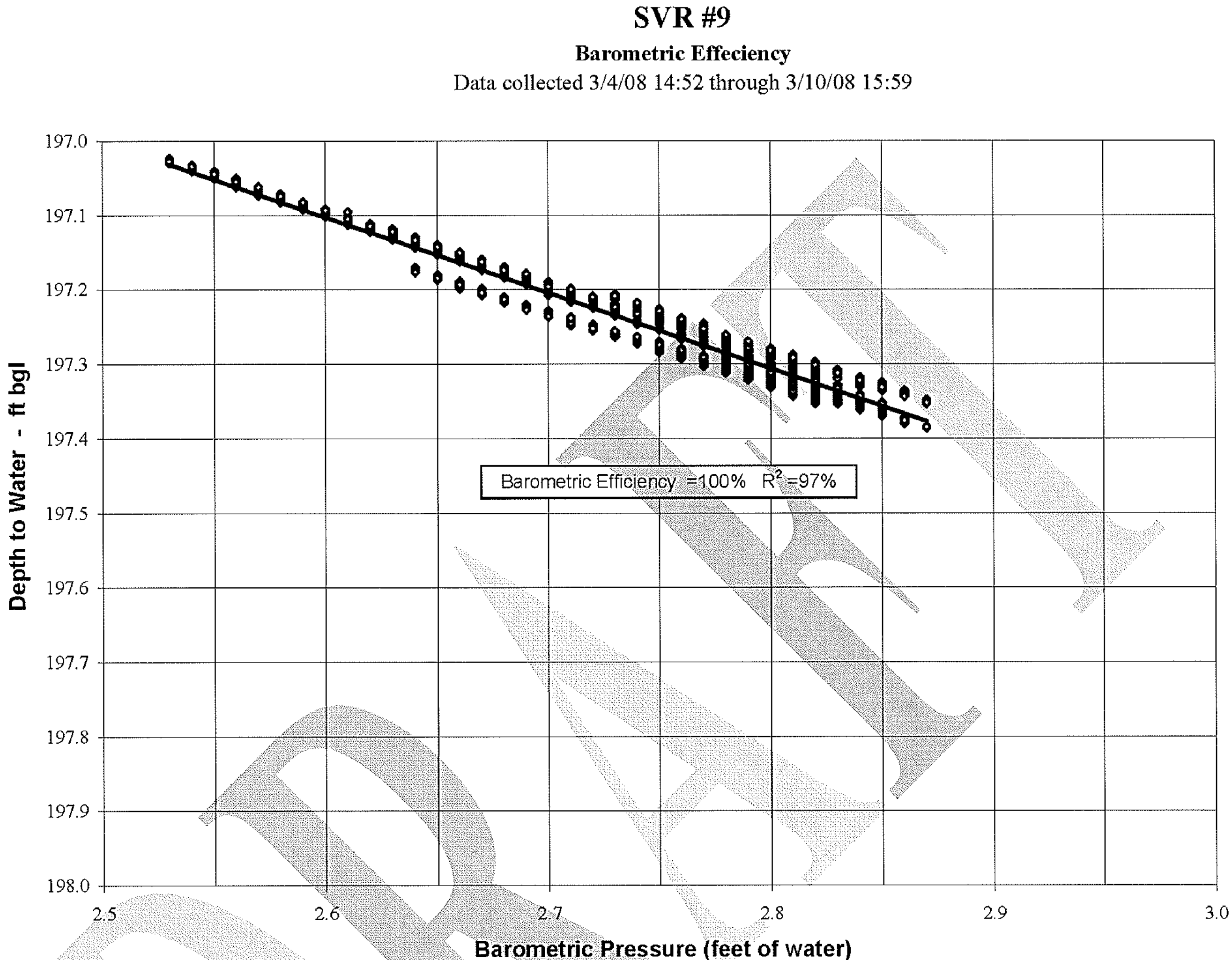
Distance from Pumping Well SVR #7 = 6,749 ft
Screen Depth = 74 to 386 ft

Figure B-9. Barometric Efficiency Plot for Little Gulch Stock Well



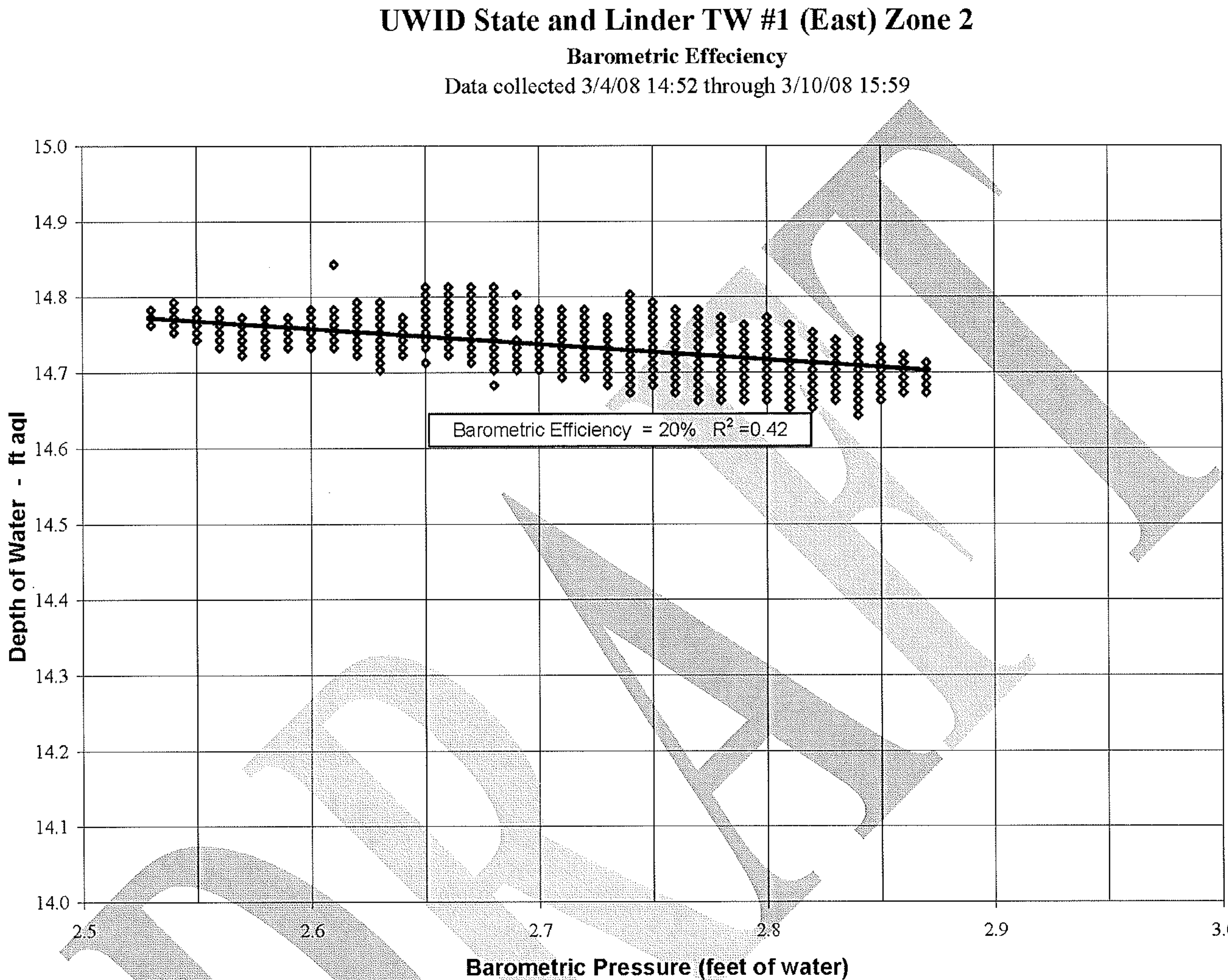
Distance from Pumping Well SVR #7 = 9,740 ft
Screen Depth = 220 to 223 ft

Figure B-10. Barometric Efficiency Plot for SVR #9



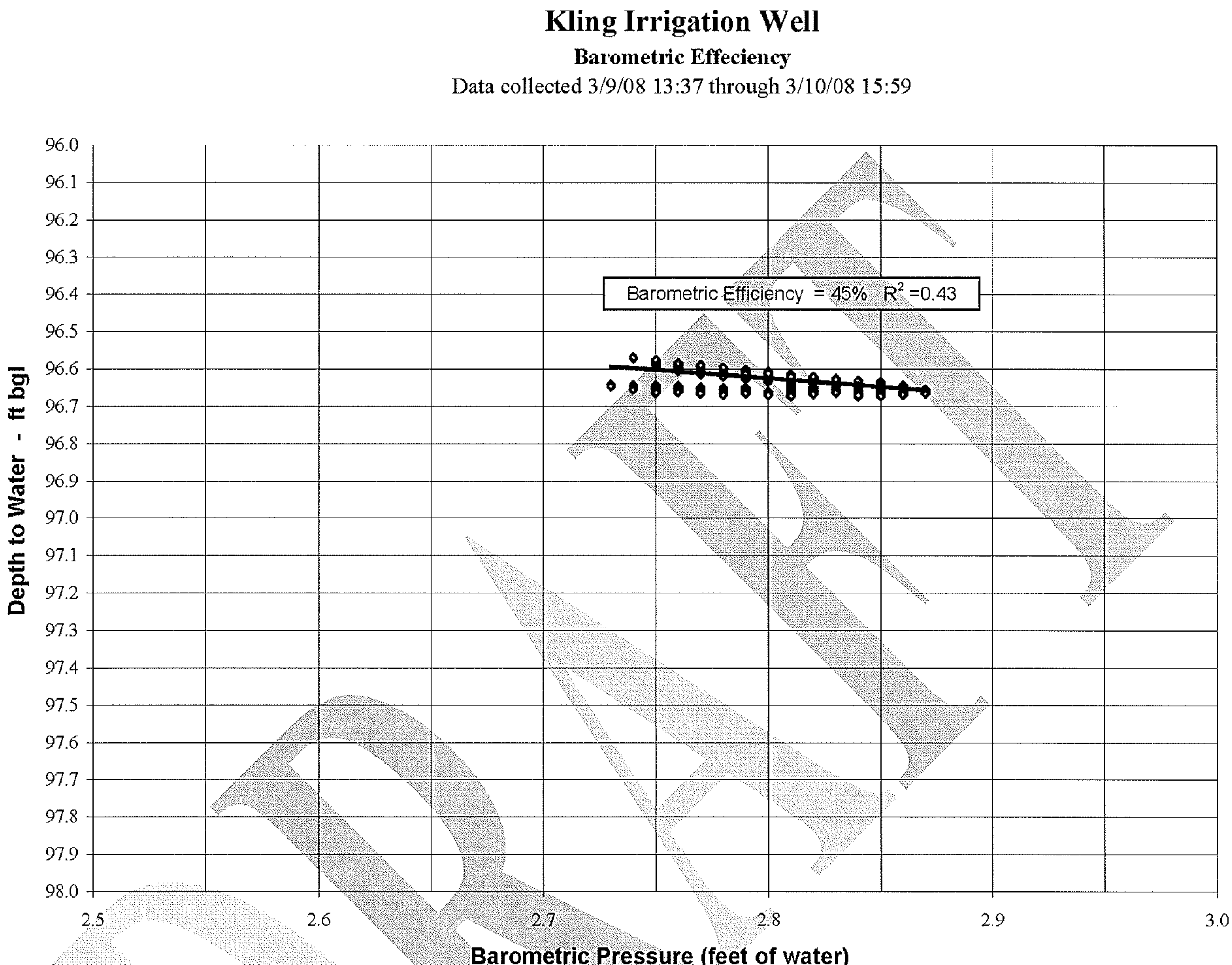
Distance from Pumping Well SVR #7 = 11.660 ft
Screen Depth = 235 to 263 ft

Figure B-11. Barometric Efficiency Plot for UWID State and Linder TW #1 Zone 2



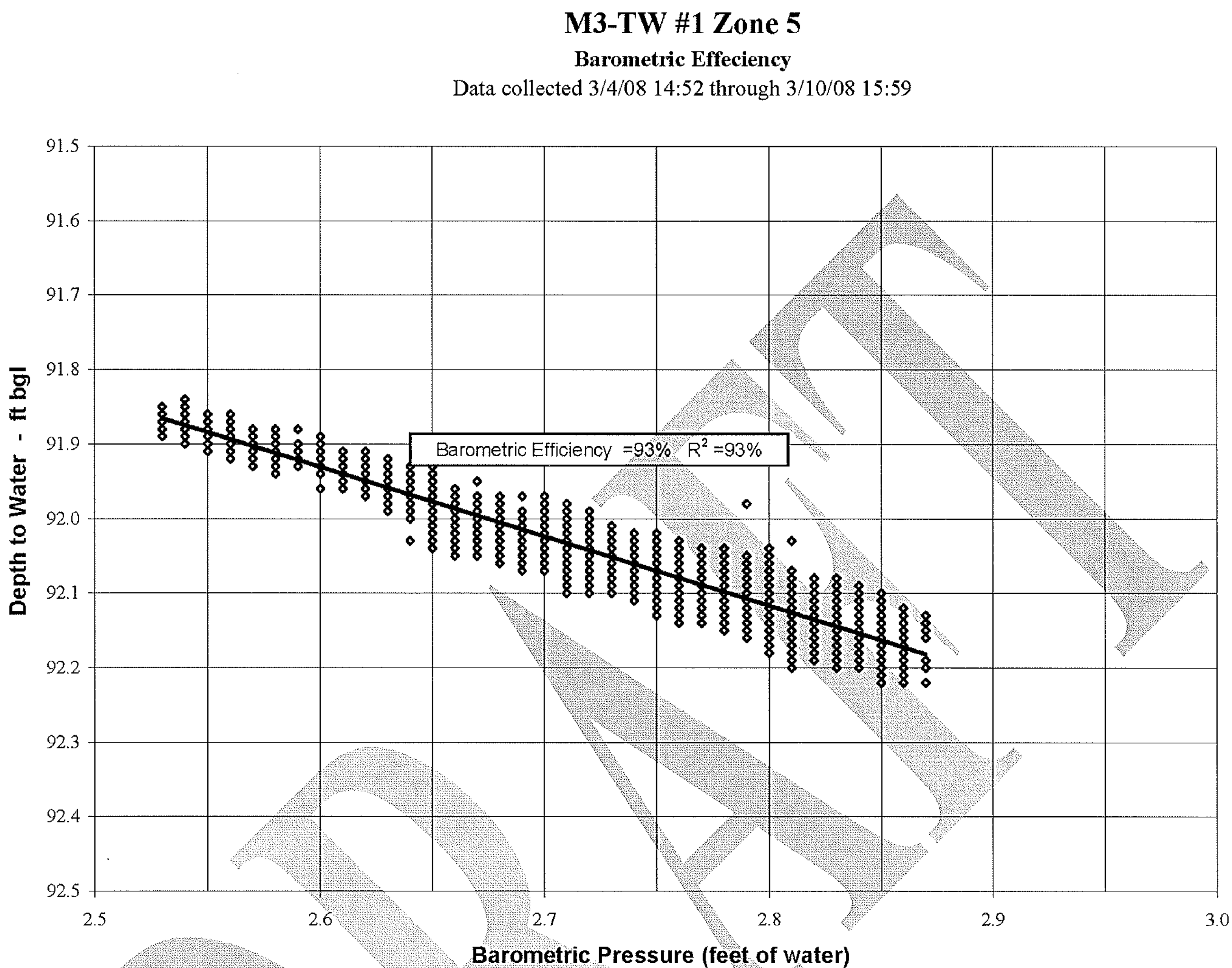
Distance from Pumping Well SVR #7 = 22,302 ft
Screen Depth = 280 to 370 ft

Figure B-12. Barometric Efficiency Plot for the Kling Irrigation Well



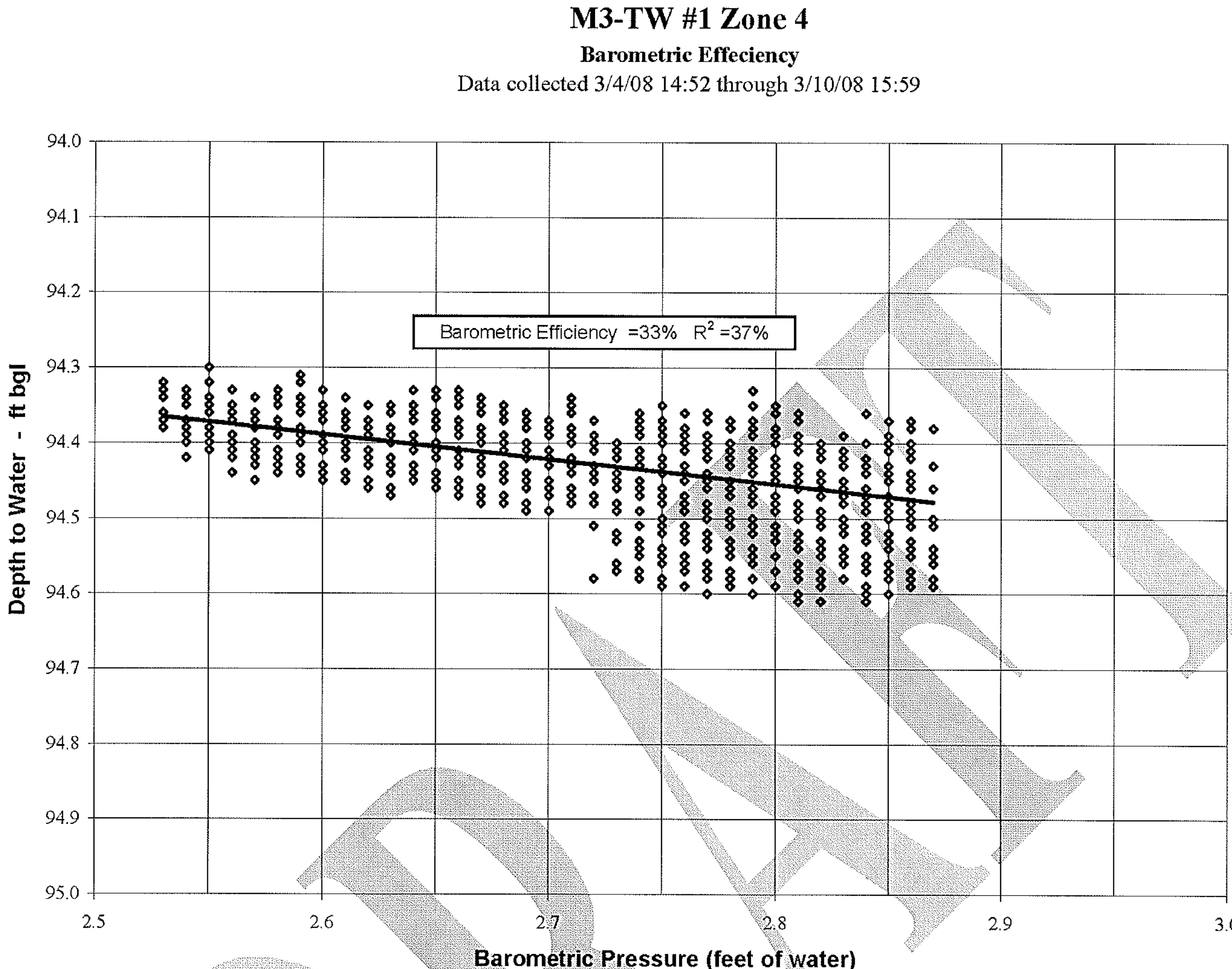
Distance from Pumping Well SVR #7 = 9,908 ft
Screen Depth = 198 to 408 ft

Figure B-13. Barometric Efficiency Plot for TW #1 Zone 5



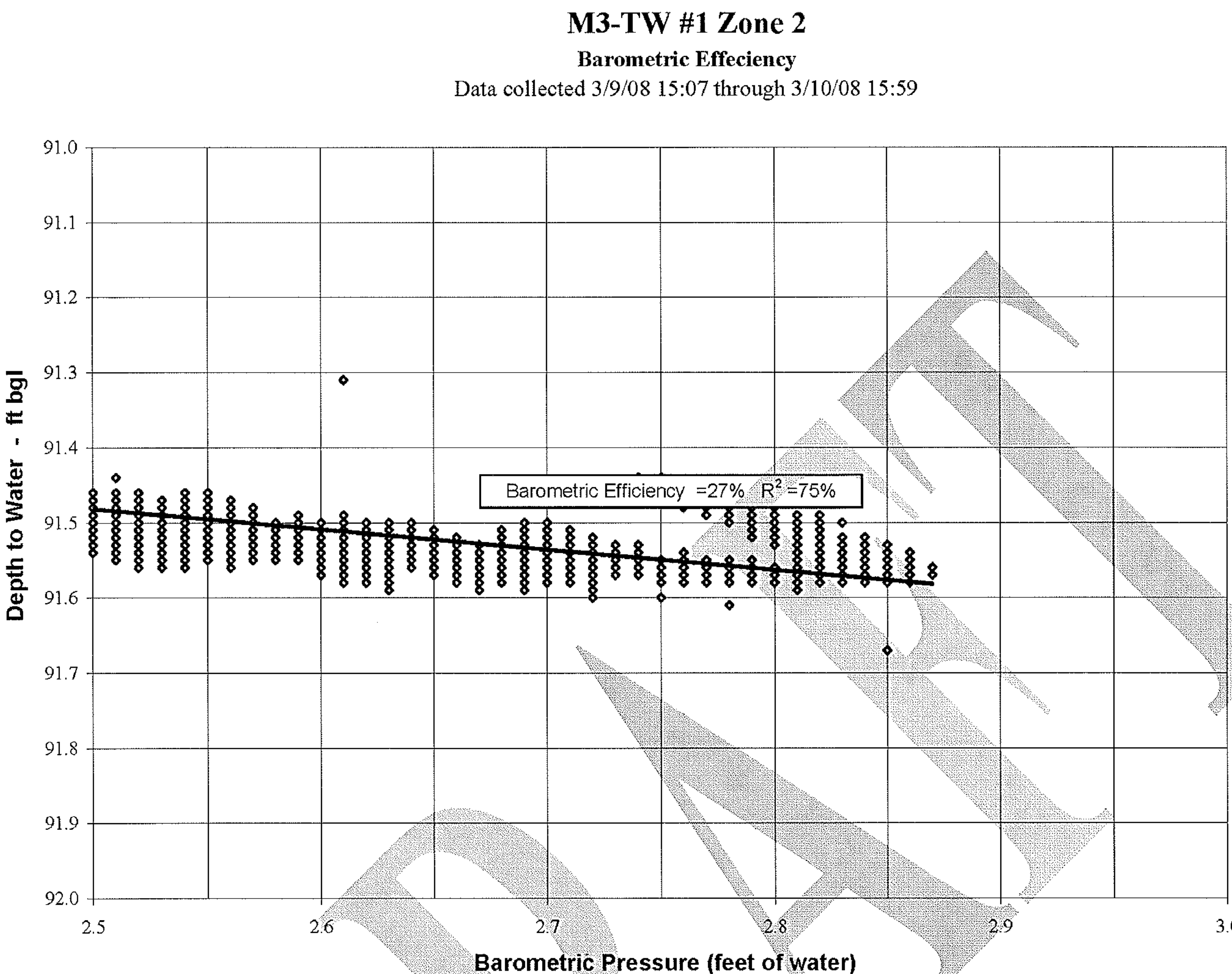
Distance from Pumping Well SVR #7 = 10,916 ft
Screen Depth = 97 to 137 ft

Figure B-14. Barometric Efficiency Plot for TW #1 Zone 4



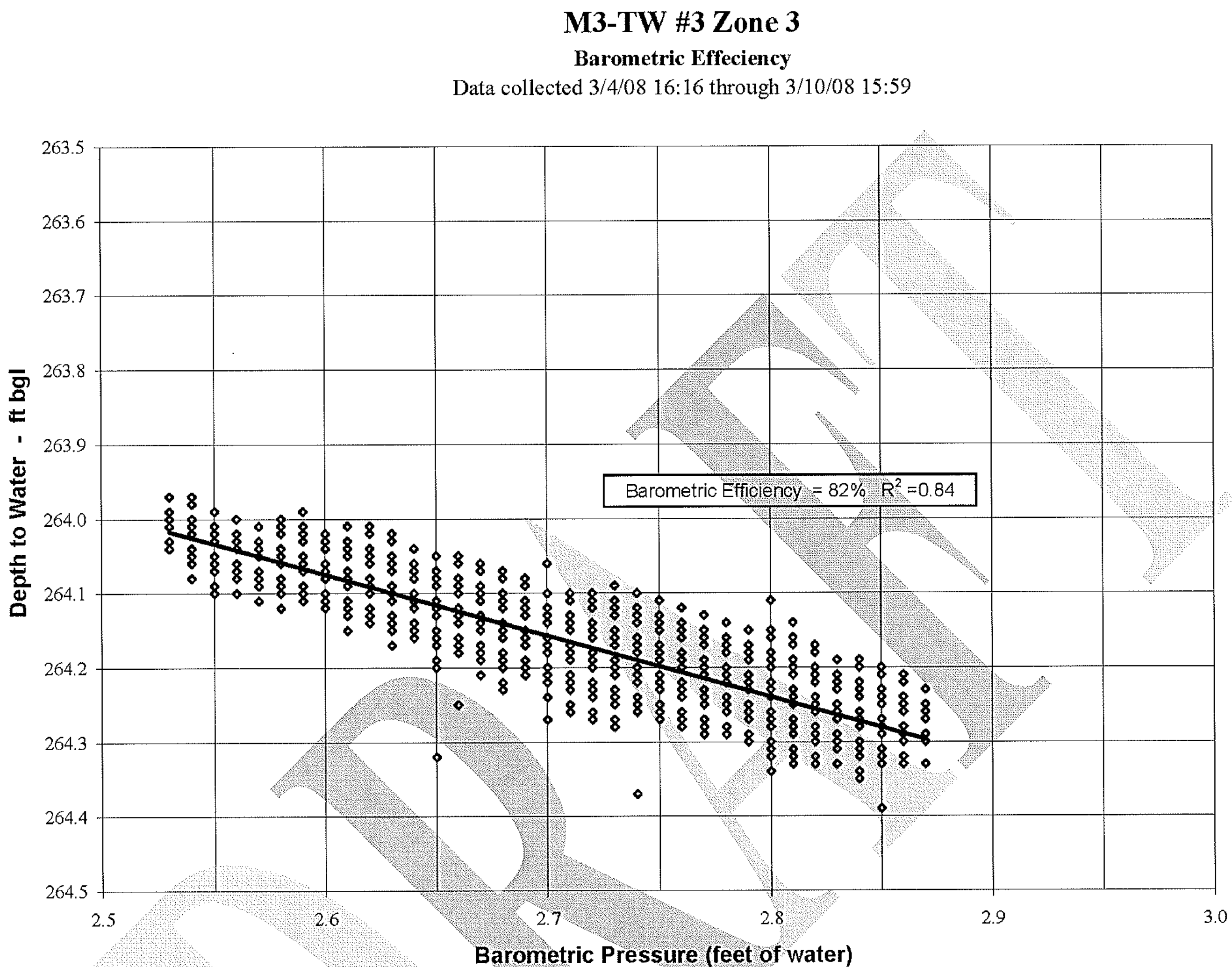
Distance from Pumping Well SVR #7 = 10,916 ft
Screen Depth = 253 to 383 ft

Figure B-15. Barometric Efficiency Plot for TW #1 Zone 2



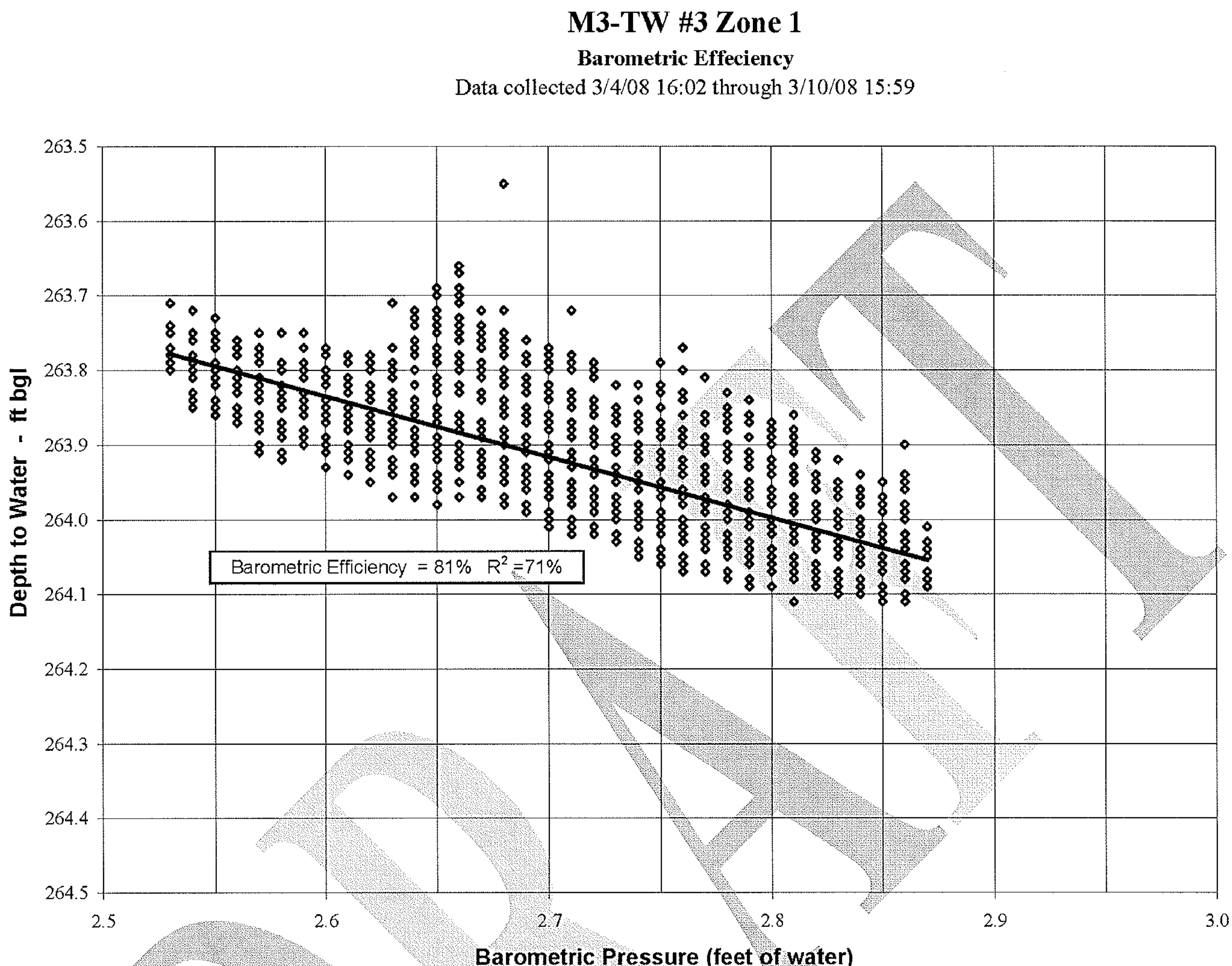
Distance from Pumping Well SVR #7 = 10,916 ft
Screen Depth = 467 to 507 ft

Figure B-16. Barometric Efficiency Plot for TW #3 Zone 3



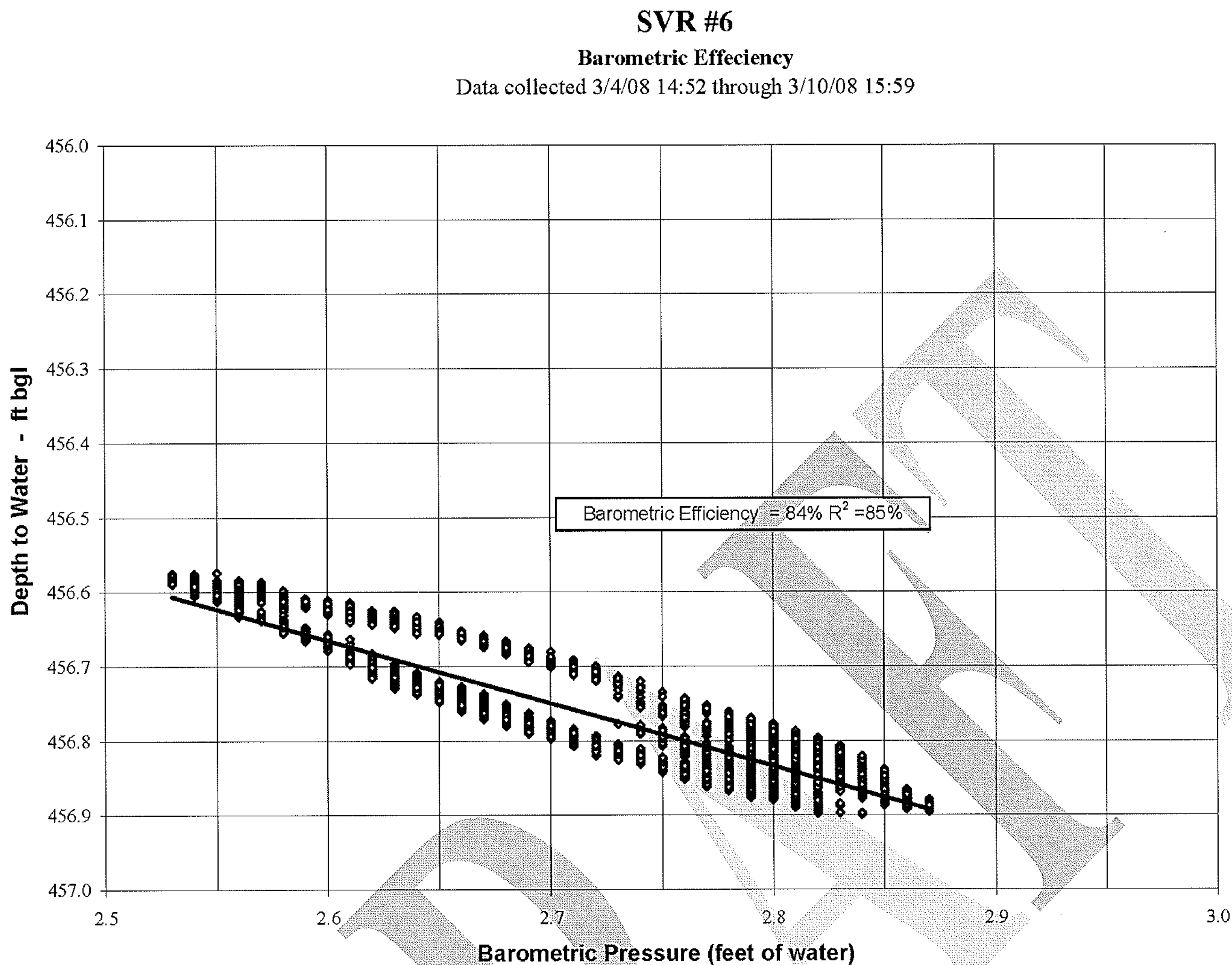
Distance from Pumping Well SVR #7 = 8,173 ft
Screen Depth = 369 to 379 ft

Figure B-17. Barometric Efficiency Plot for TW #3 Zone 1



Distance from Pumping Well SVR #7 = 8,173 ft
Screen Depth = 432 to 442 ft

Figure B-18. Barometric Efficiency Plot for SVR #6



In Willow Creek Aquifer - NOT in Pierce Gulch Sand Aquifer
Distance from Pumping Well SVR #7 = 8,189 ft
Screen Depth = 560 to 730 ft

Appendix C – Actual and BE-Corrected Water Levels

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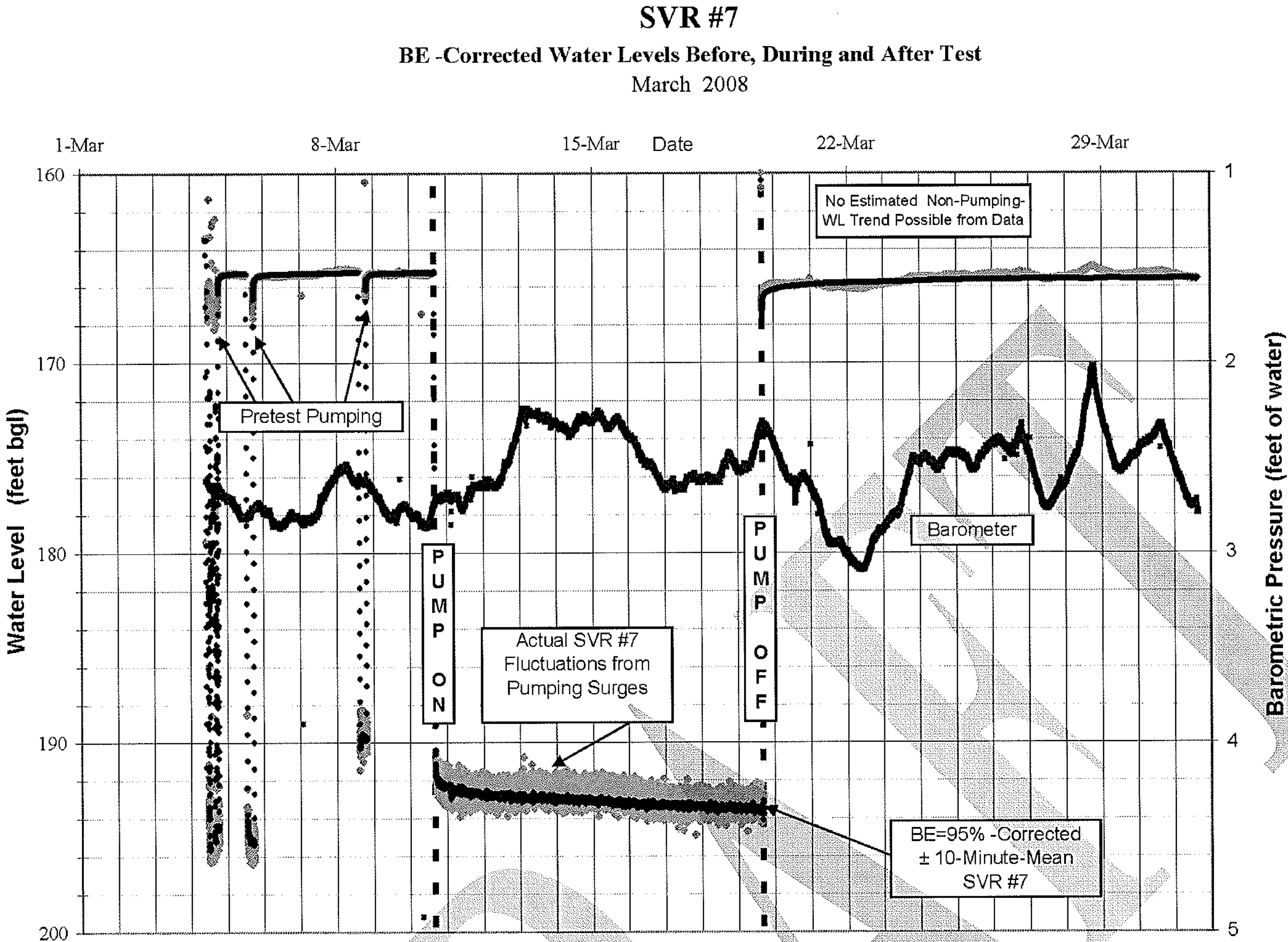
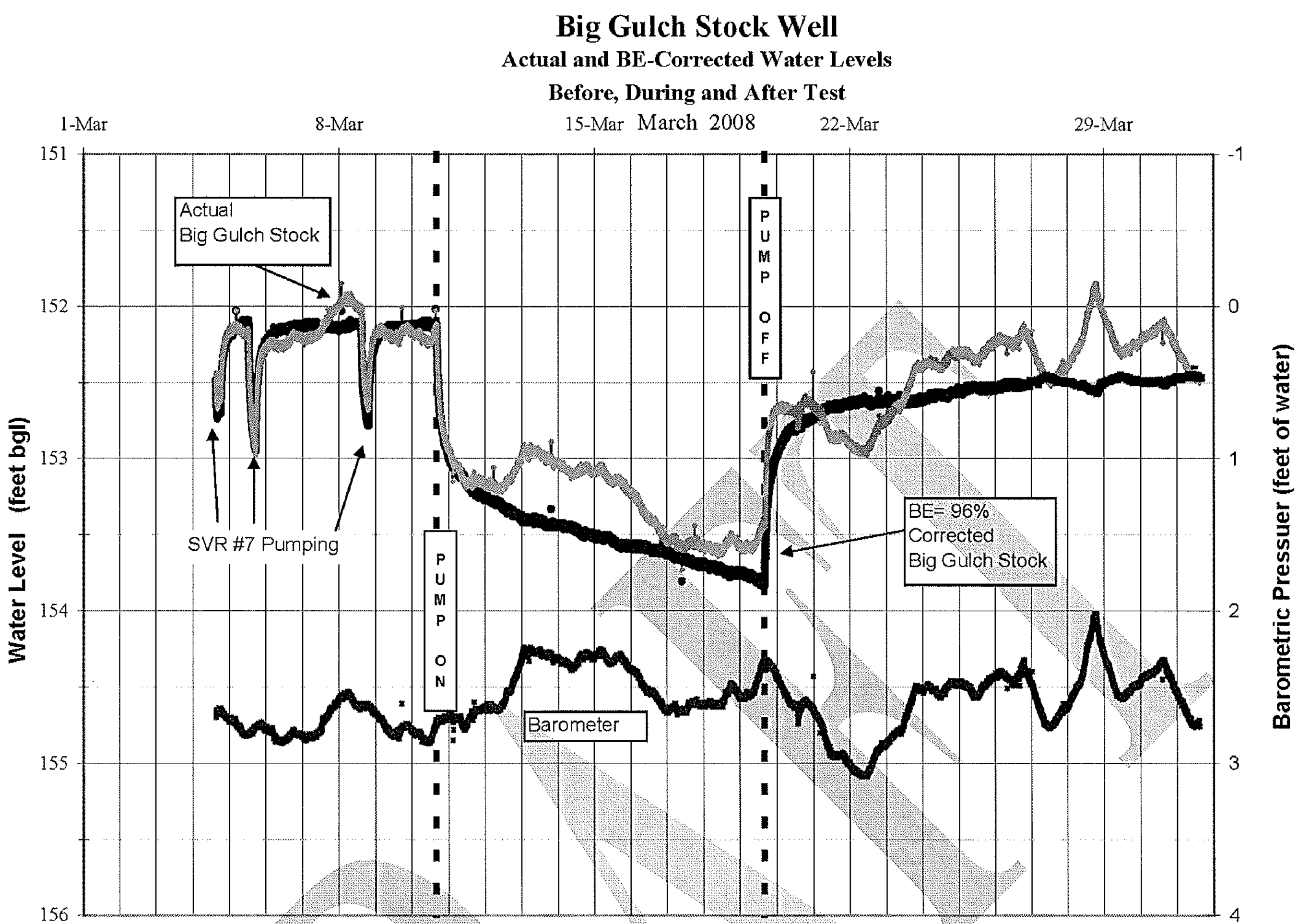
Figure C-1. Actual and BE-Corrected Water Levels for SVR #7



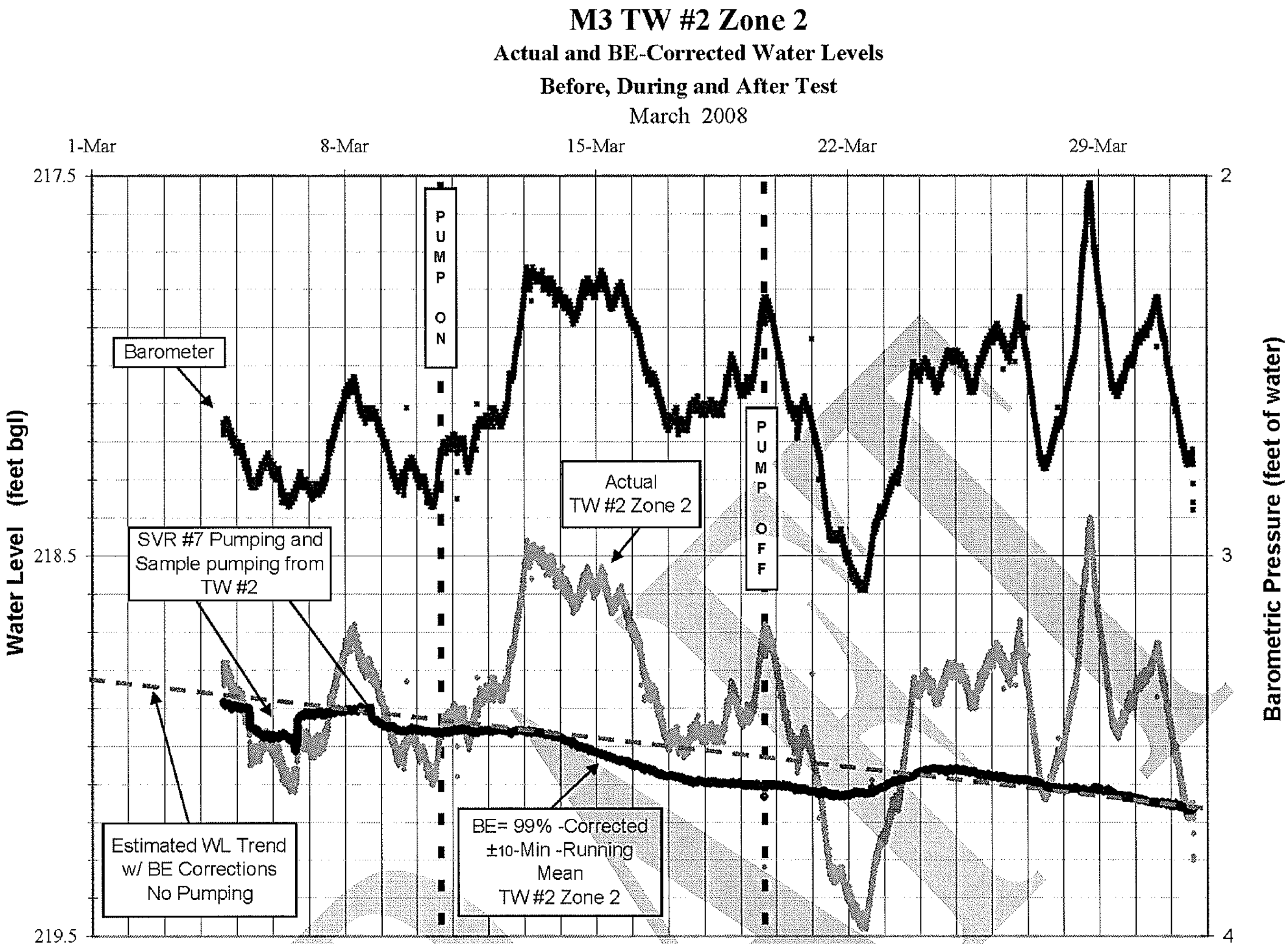
Distance from Pumping Well SVR #7 = 0 ft
Screen Depth = 280 to 350 ft

Figure C-2. Actual and BE-Corrected Water Levels for Big Gulch Stock Well



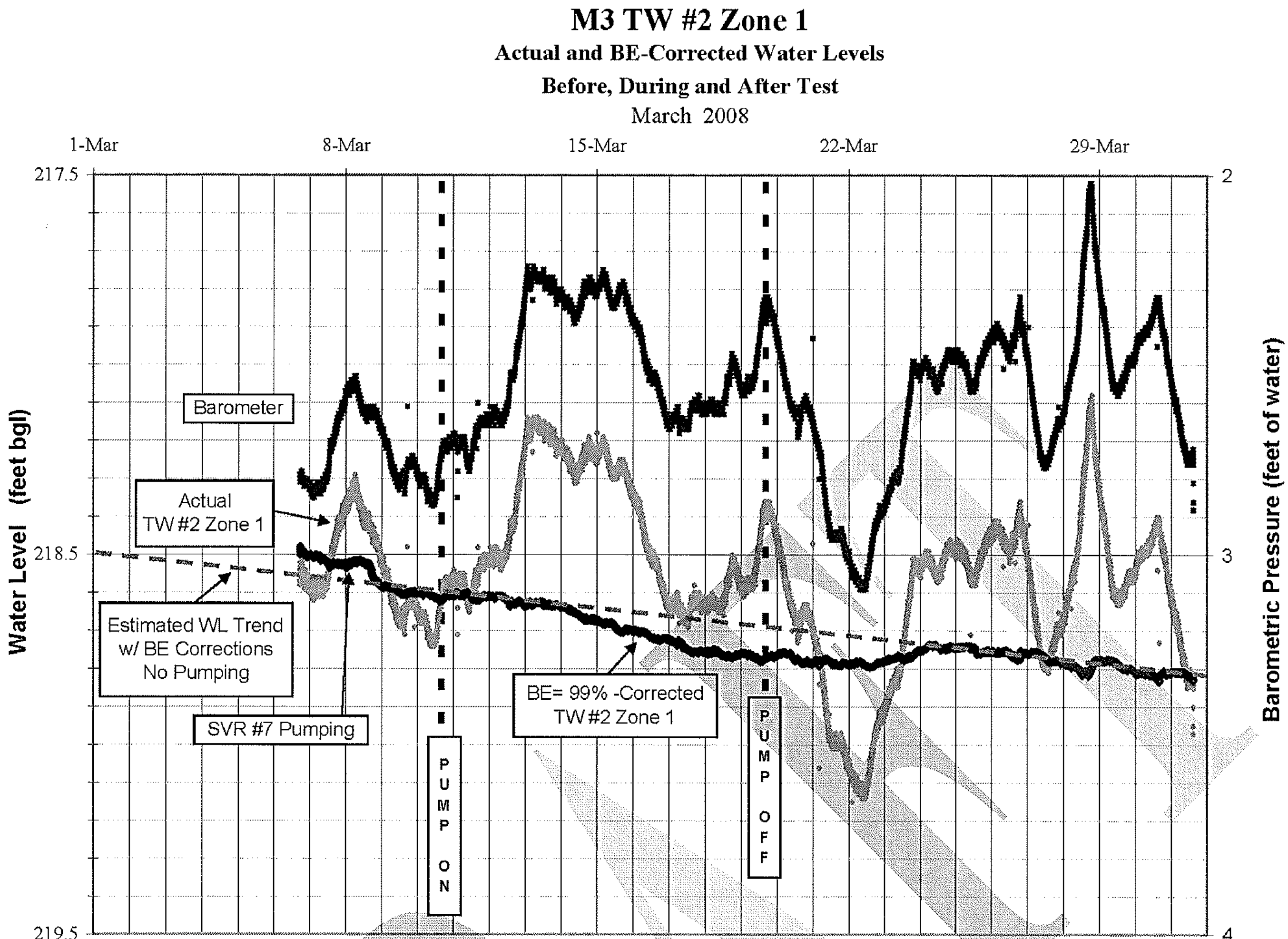
Distance from Pumping Well SVR #7 = 845 ft
Screen Depth = 180 to 180 ft ("open hole," no well screen)

Figure C-3. Actual and BE-Corrected Water Levels for TW #2 Zone 2



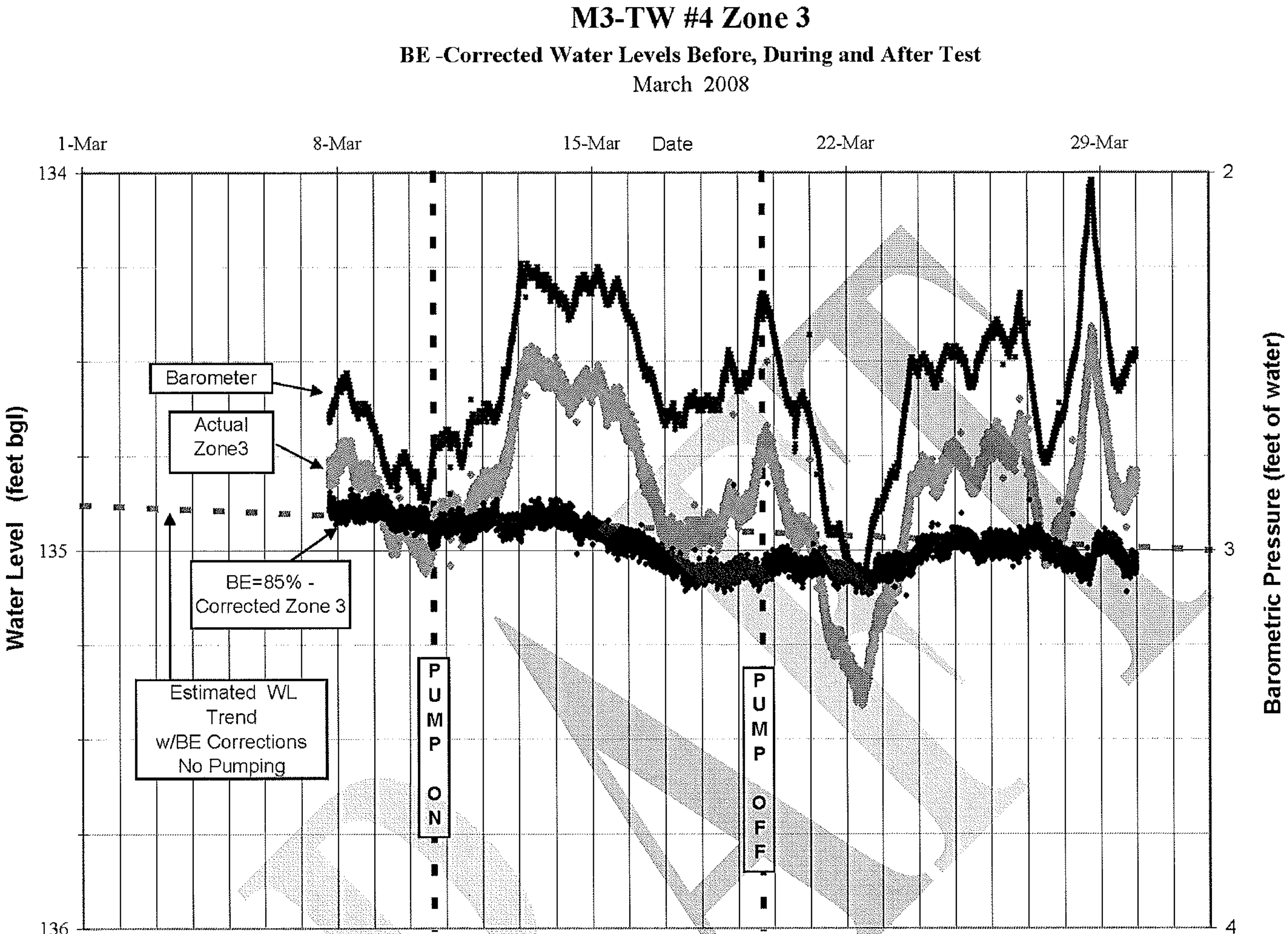
Distance from Pumping Well SVR #7 = 3,636 ft
Screen Depth = 230 to 250 ft

Figure C-4. Actual and BE-Corrected Water Levels for TW #2 Zone 1



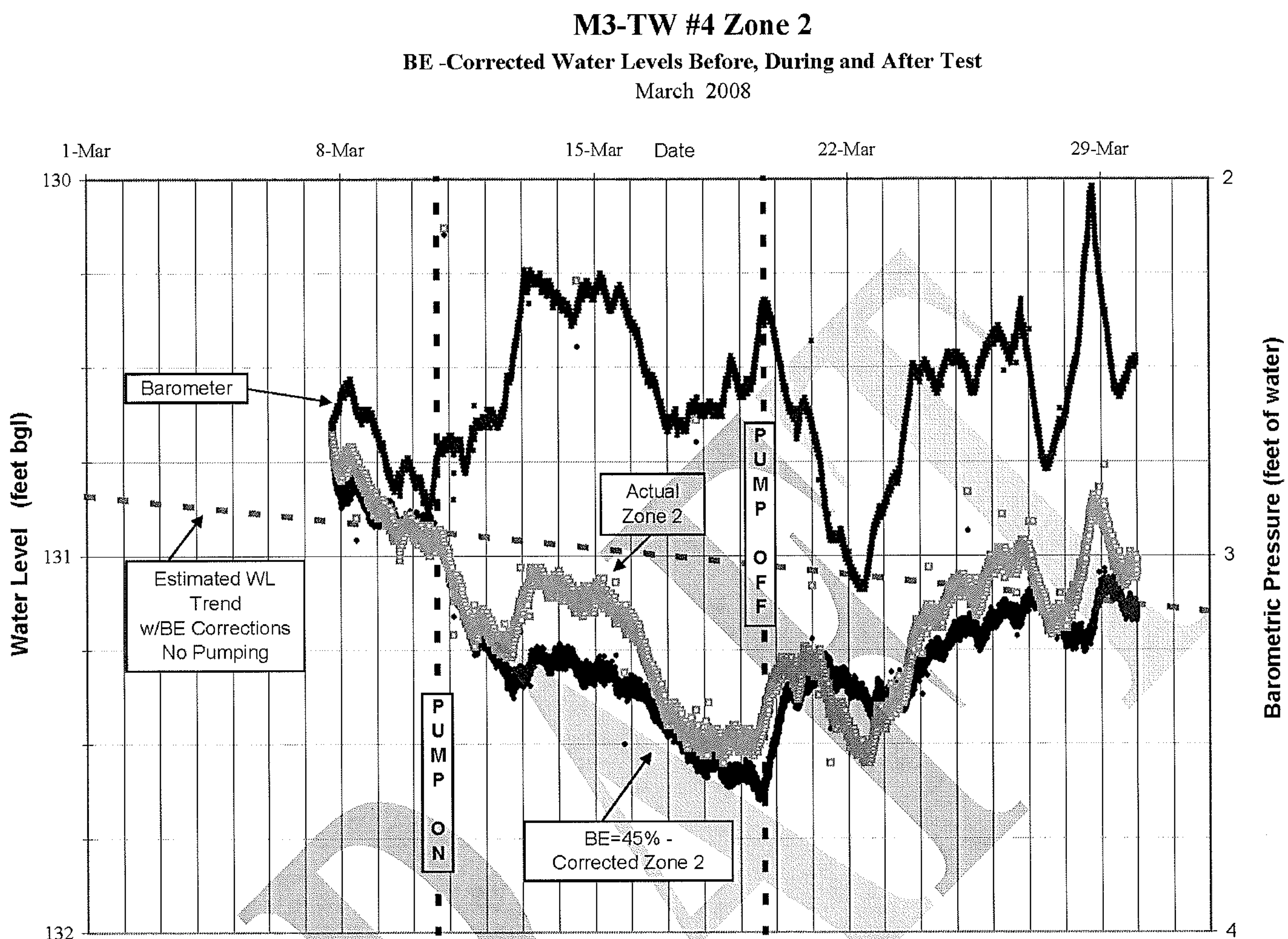
Distance from Pumping Well SVR #7 = 3,636 ft
Screen Depth = 270 to 320 ft

Figure C-5. Actual and BE-Corrected Water Levels for TW #4 Zone 3



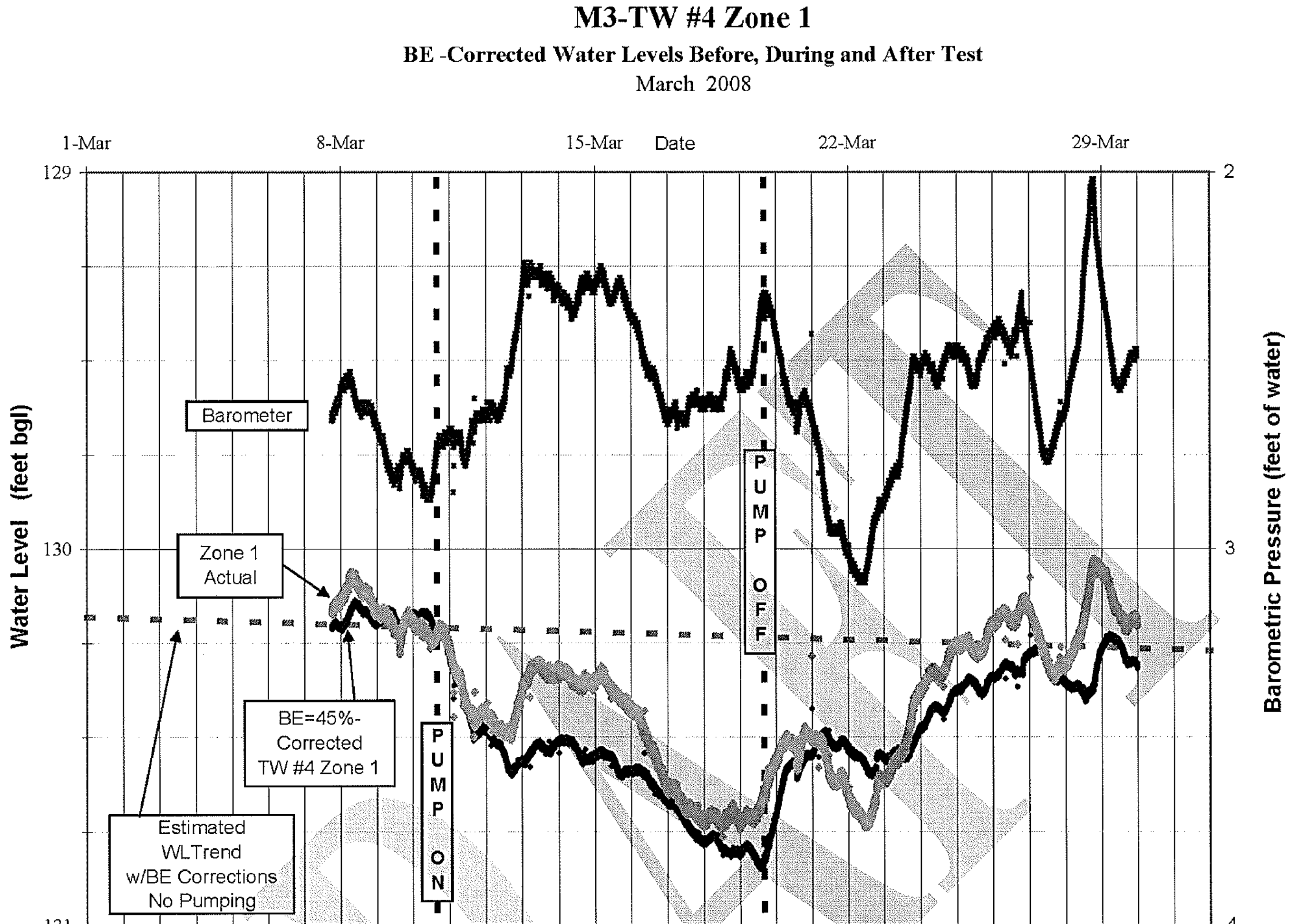
Distance from Pumping Well SVR #7 = 4,489 ft
Screen Depth = 181 to 201 ft

Figure C-6. Actual and BE-Corrected Water Levels for TW #4 Zone 2



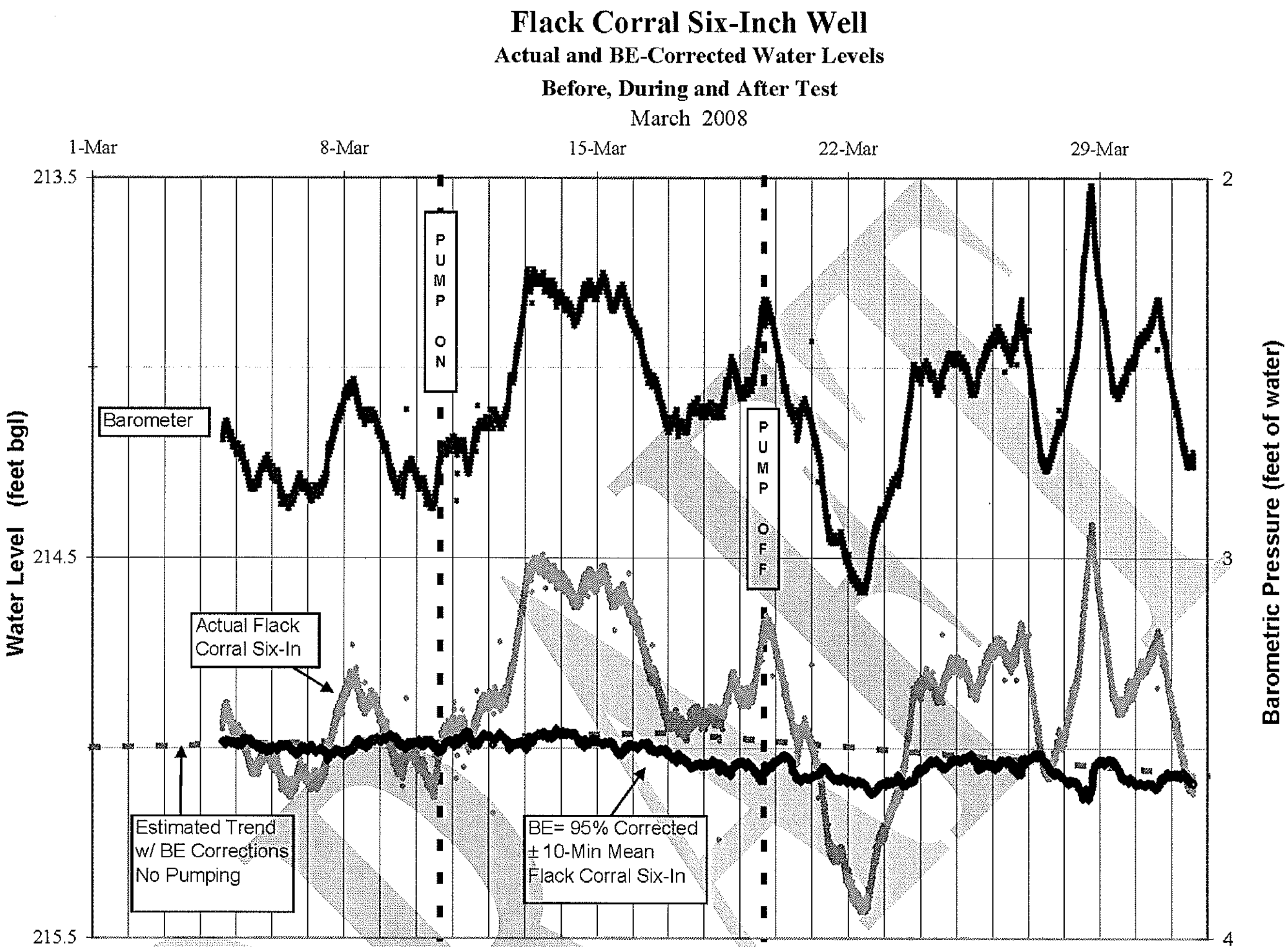
Distance from Pumping Well SVR #7 = 4,489 ft
Screen Depth = 325 to 556 ft

Figure C-7. Actual and BE-Corrected Water Levels for TW #4 Zone 1



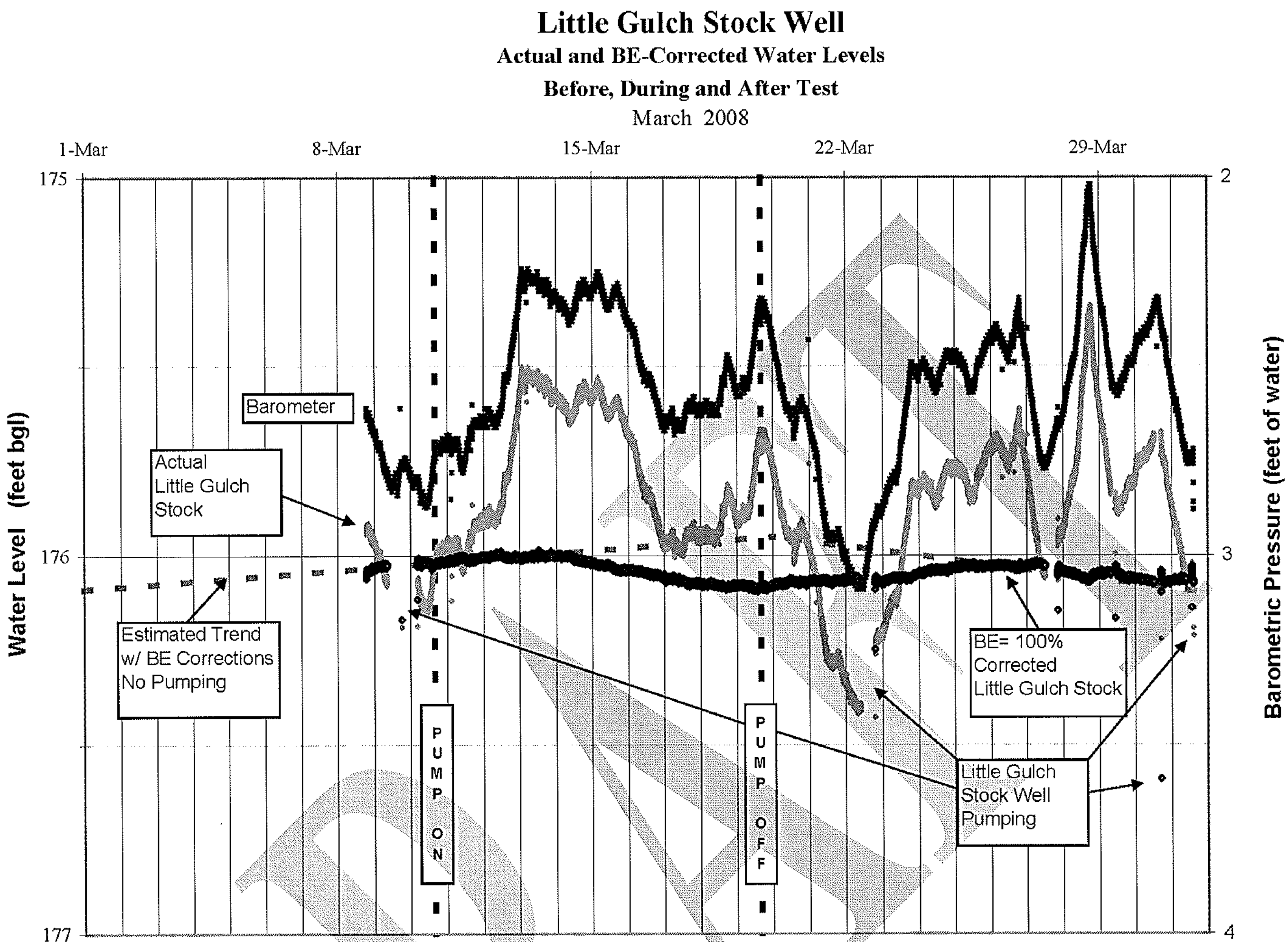
Distance from Pumping Well SVR #7 = 4,489 ft
Screen Depth = 625 to 646 ft

Figure C-8. Actual and BE-Corrected Water Levels for Flack Corral 6-Inch Well



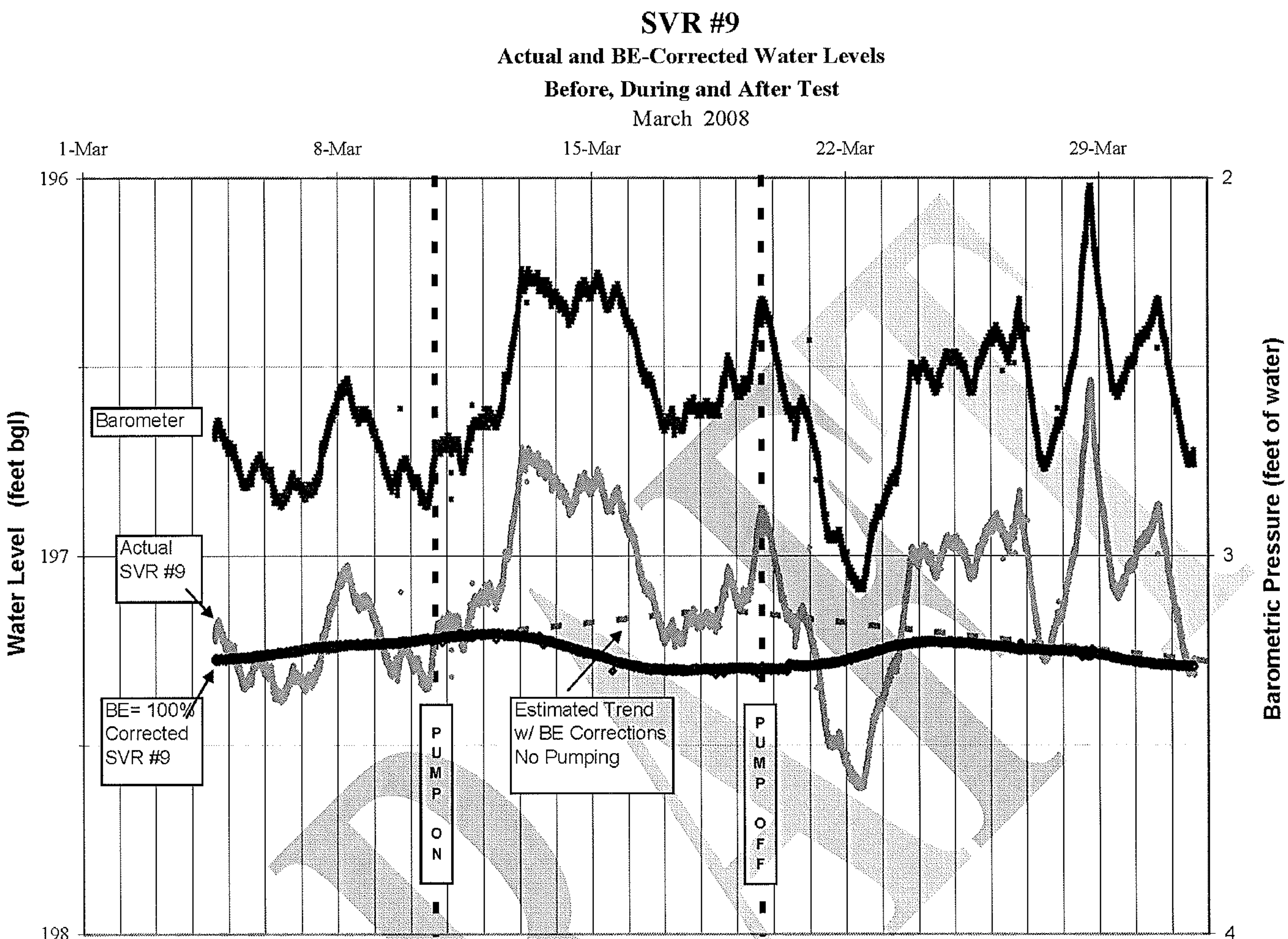
Distance from Pumping Well SVR #7 = 6,749 ft
Screen Depth = 74 to 386 ft

Figure C-9. Actual and BE-Corrected Water Levels for Little Gulch Stock Well



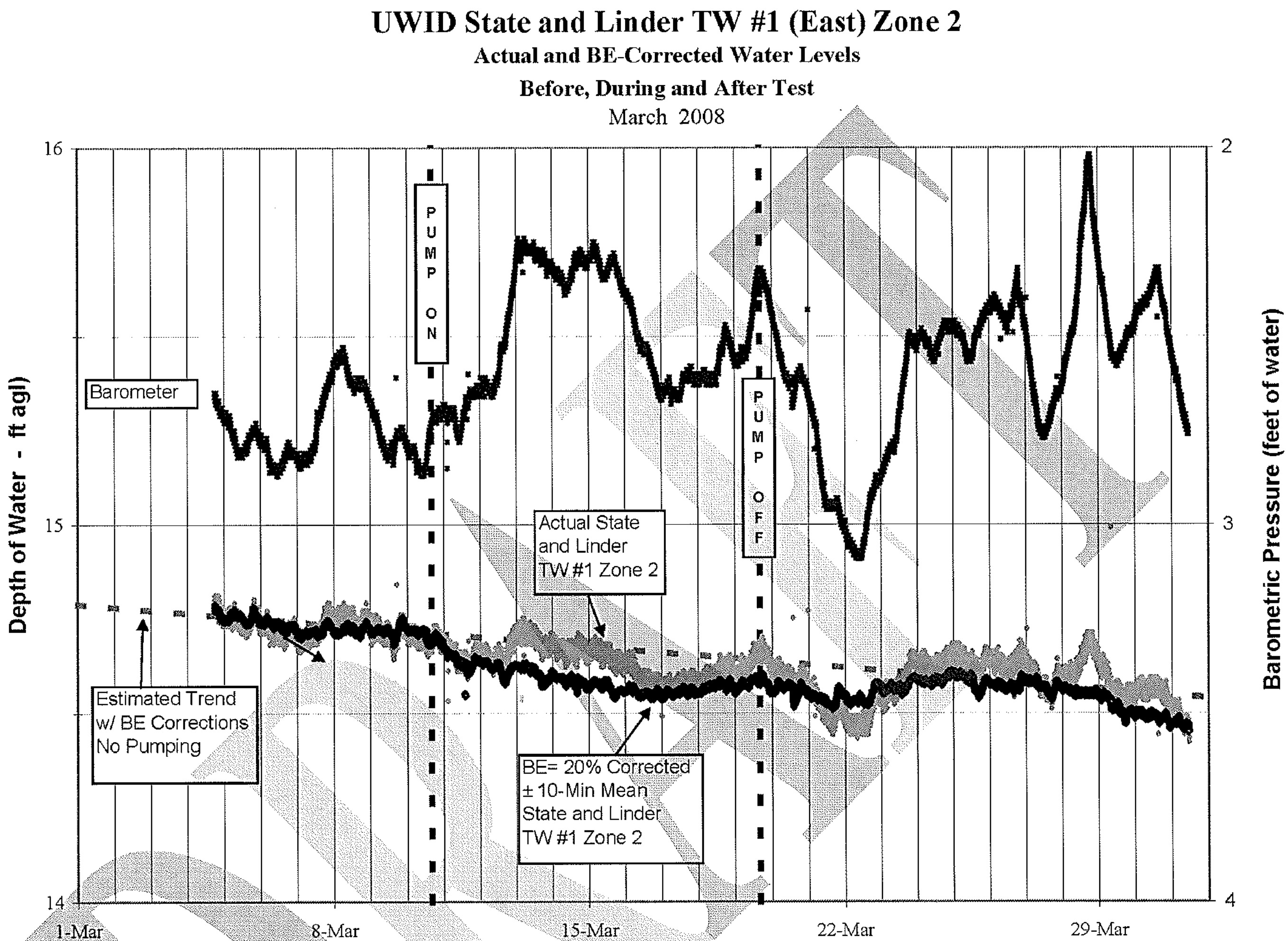
Distance from Pumping Well SVR #7 = 9,740 ft
Screen Depth = 220 to 223 ft

Figure C-10. Actual and BE-Corrected Water Levels for SVR #9



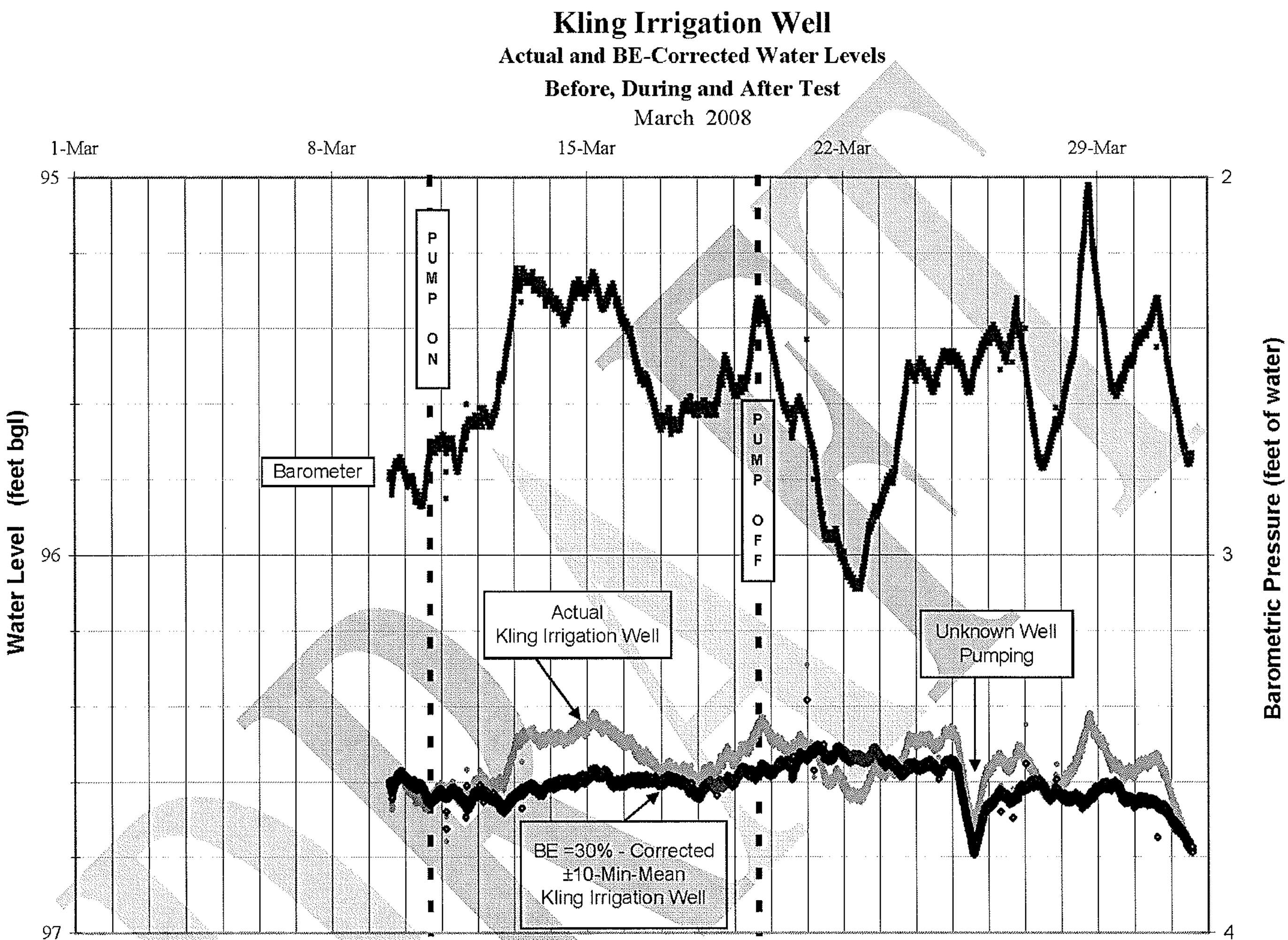
Distance from Pumping Well SVR #7 = 11,660 ft
Screen Depth = 235 to 263 ft

Figure C-11. Actual and BE-Corrected Water Levels for UWID State and Linder TW #1 Zone 2



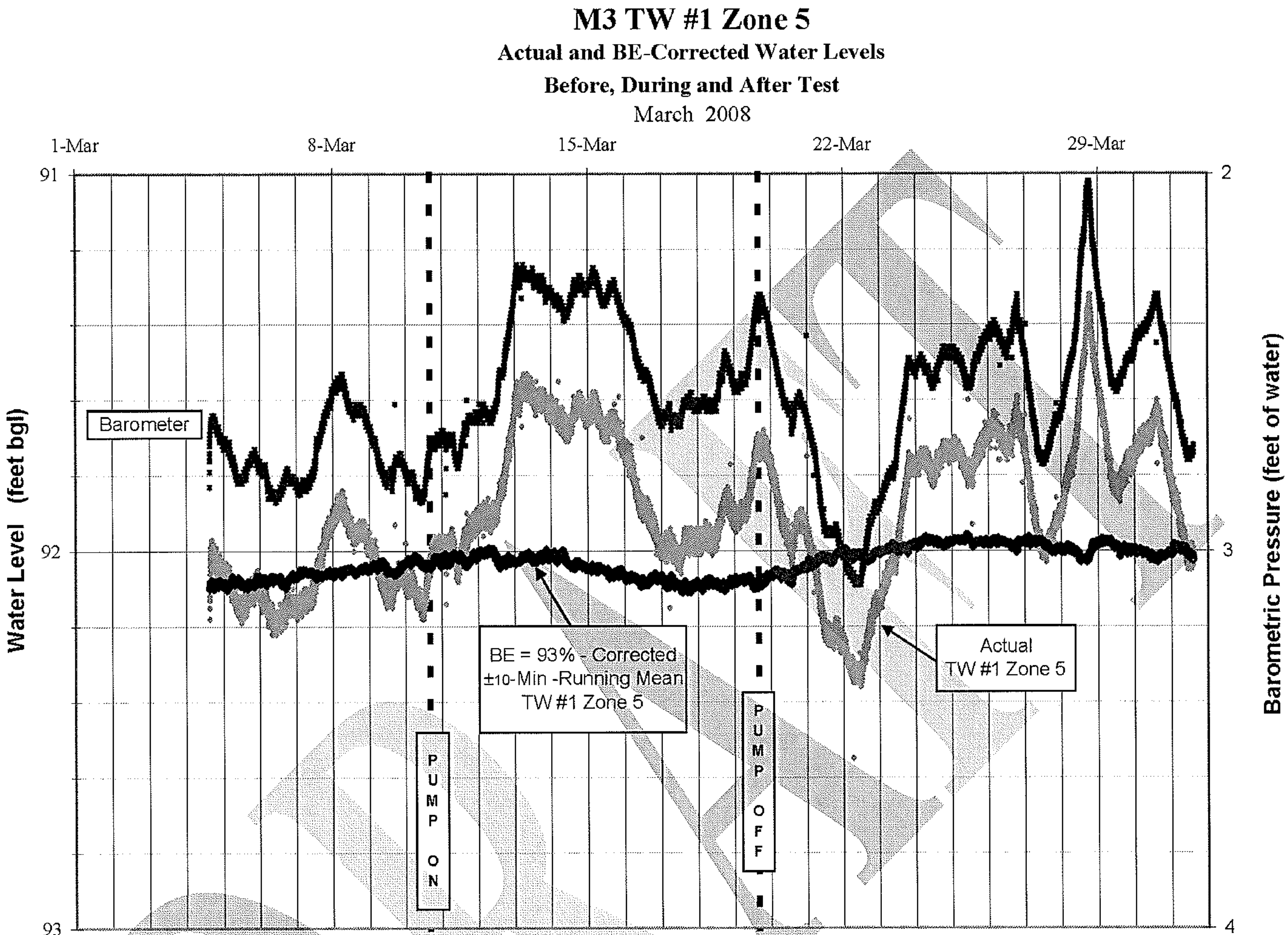
Distance from Pumping Well SVR #7 = 22,302 ft
Screen Depth = 280 to 370 ft

Figure C-12. Actual and BE-Corrected Water Levels for the Kling Irrigation Well



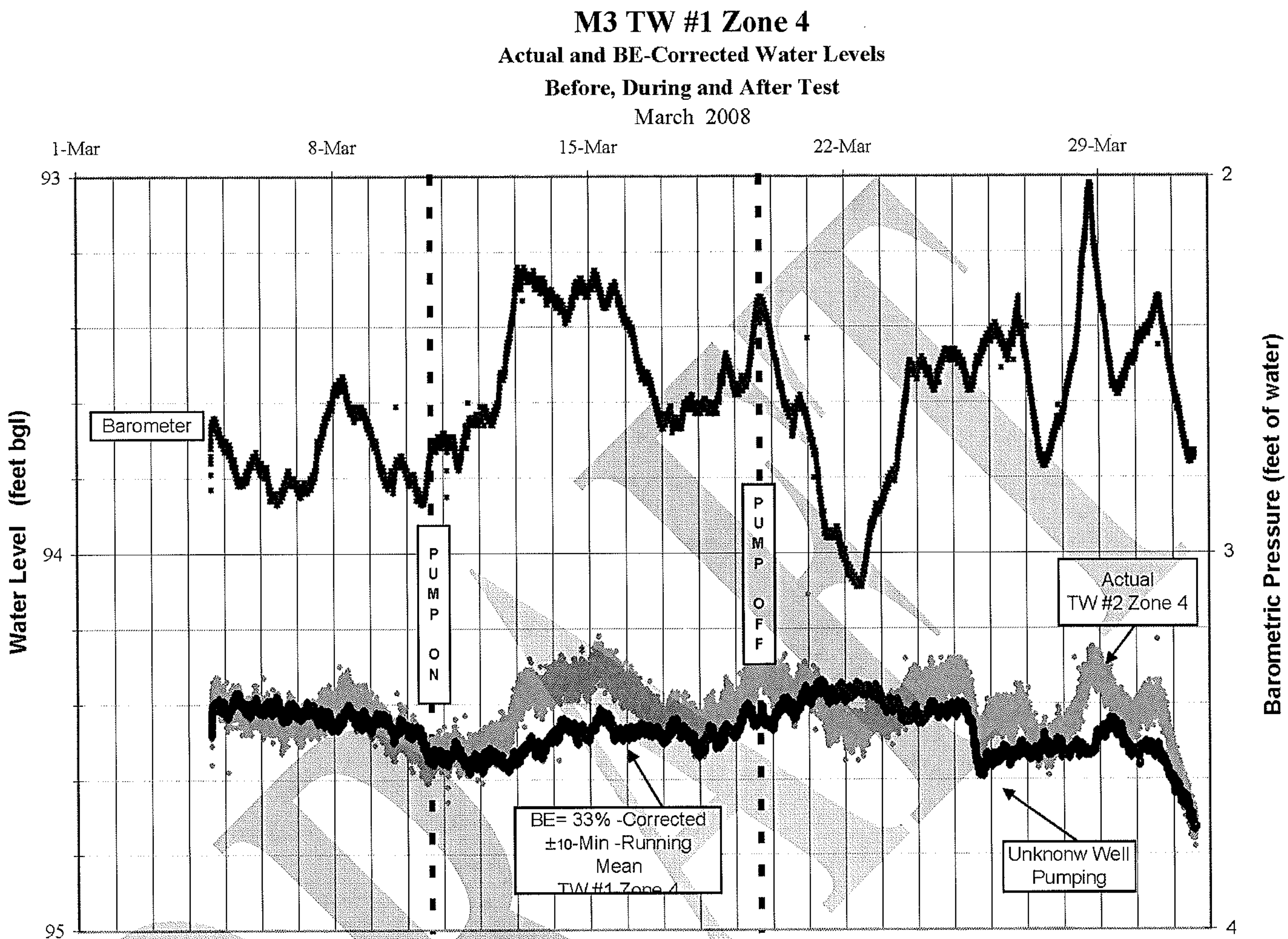
Distance from Pumping Well SVR #7 = 9,908 ft
Screen Depth = 198 to 408 ft

Figure C-13. Actual and BE-Corrected Water Levels for TW #1 Zone 5



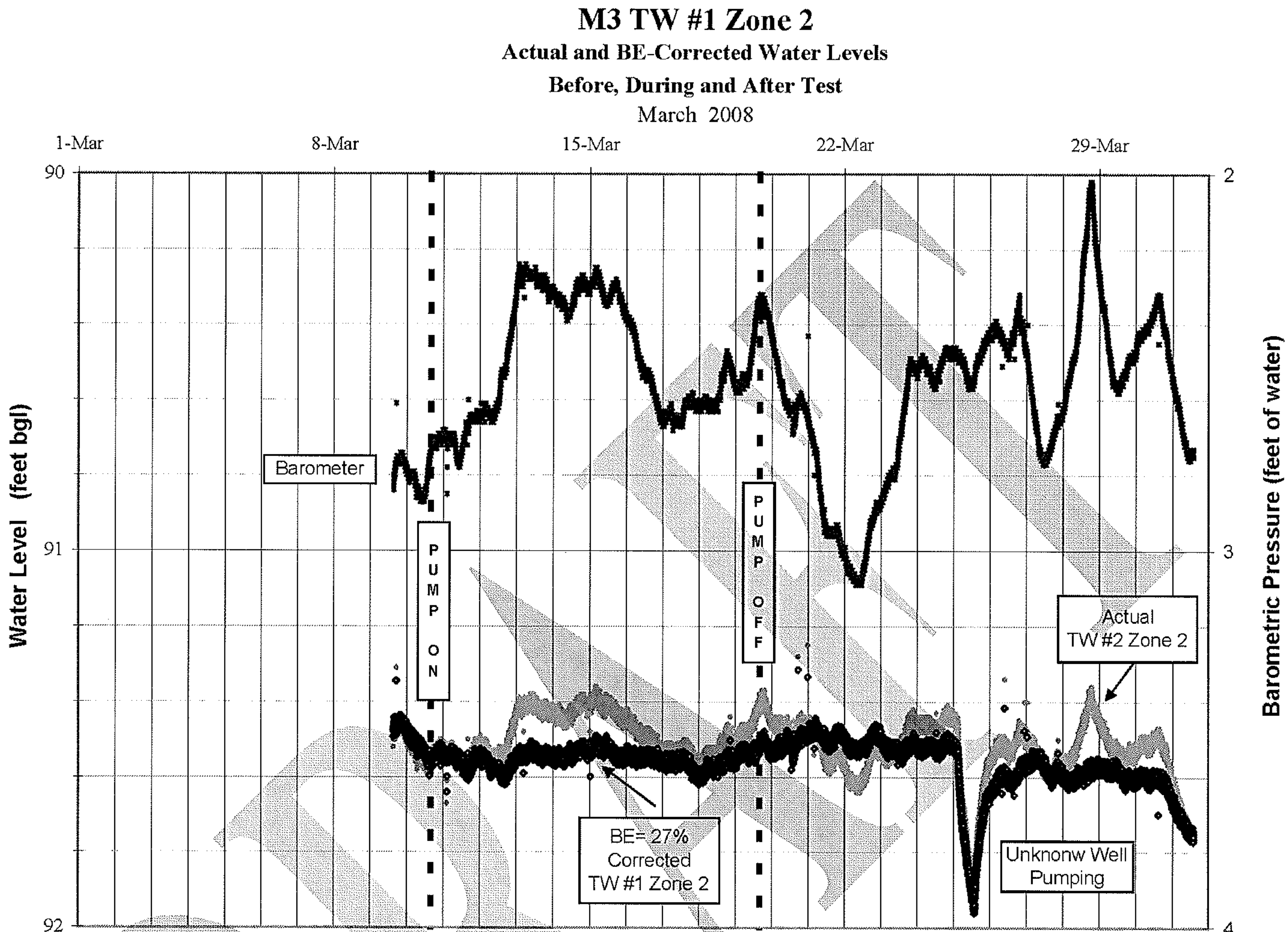
Distance from Pumping Well SVR #7 = 10,916 ft
Screen Depth = 97 to 137 ft

Figure C-14. Actual and BE-Corrected Water Levels for TW #1 Zone 4



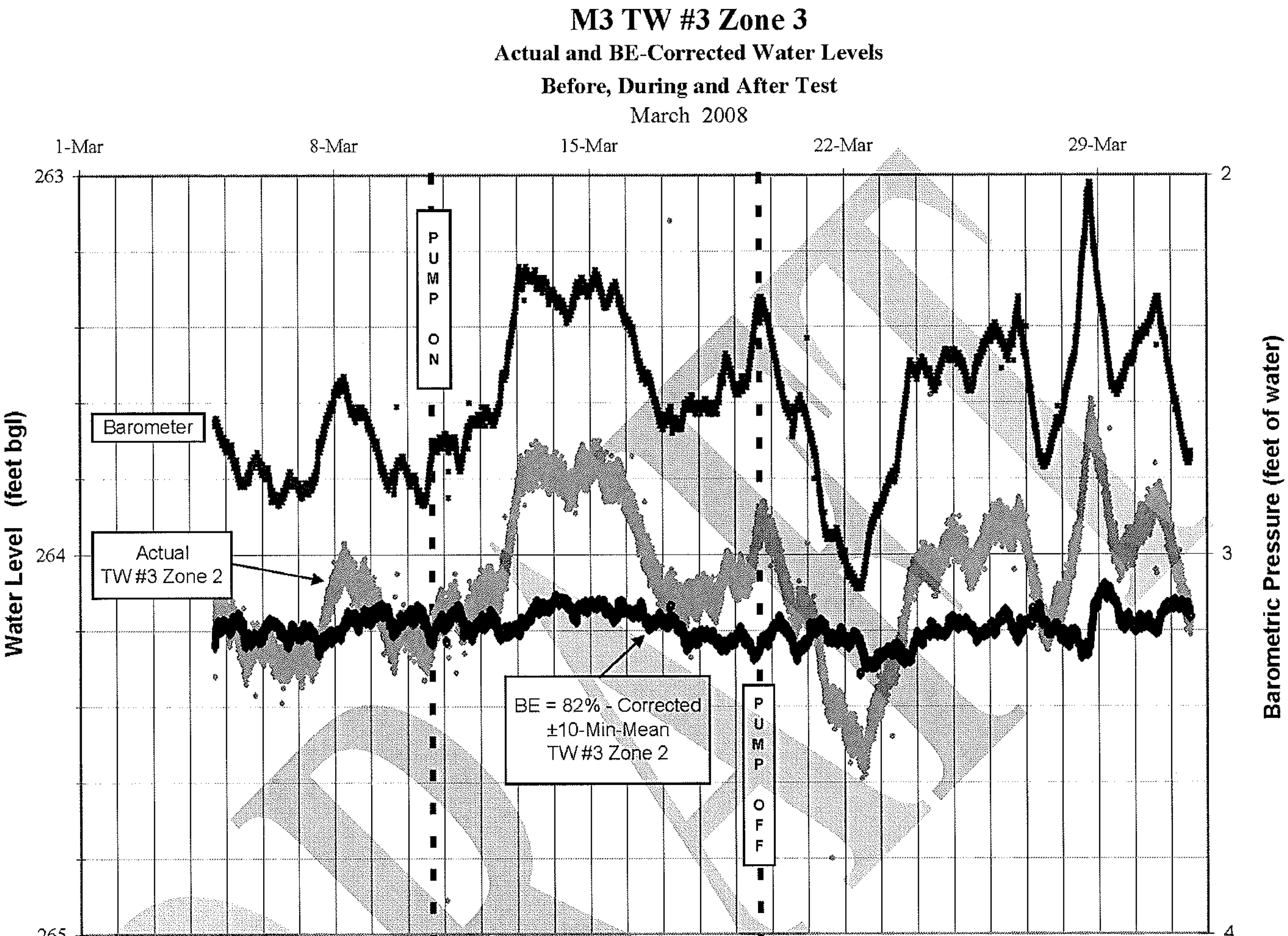
Distance from Pumping Well SVR #7 = 10,916 ft
Screen Depth = 253 to 383 ft

Figure C-15. Actual and BE-Corrected Water Levels for TW #1 Zone 2



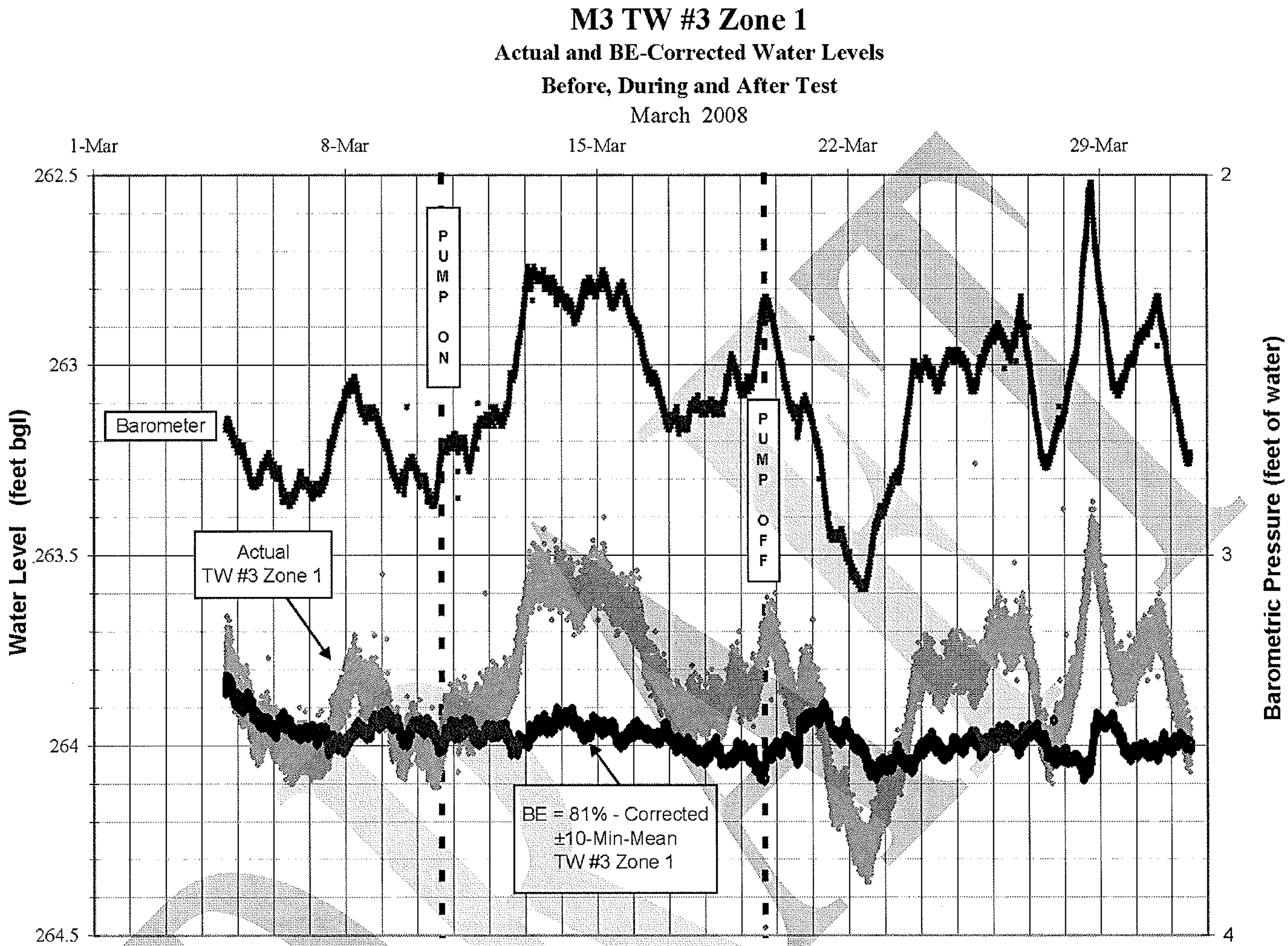
Distance from Pumping Well SVR #7 = 10,916 ft
Screen Depth = 467 to 507 ft

Figure C-16. Actual and BE-Corrected Water Levels for TW #3 Zone 3



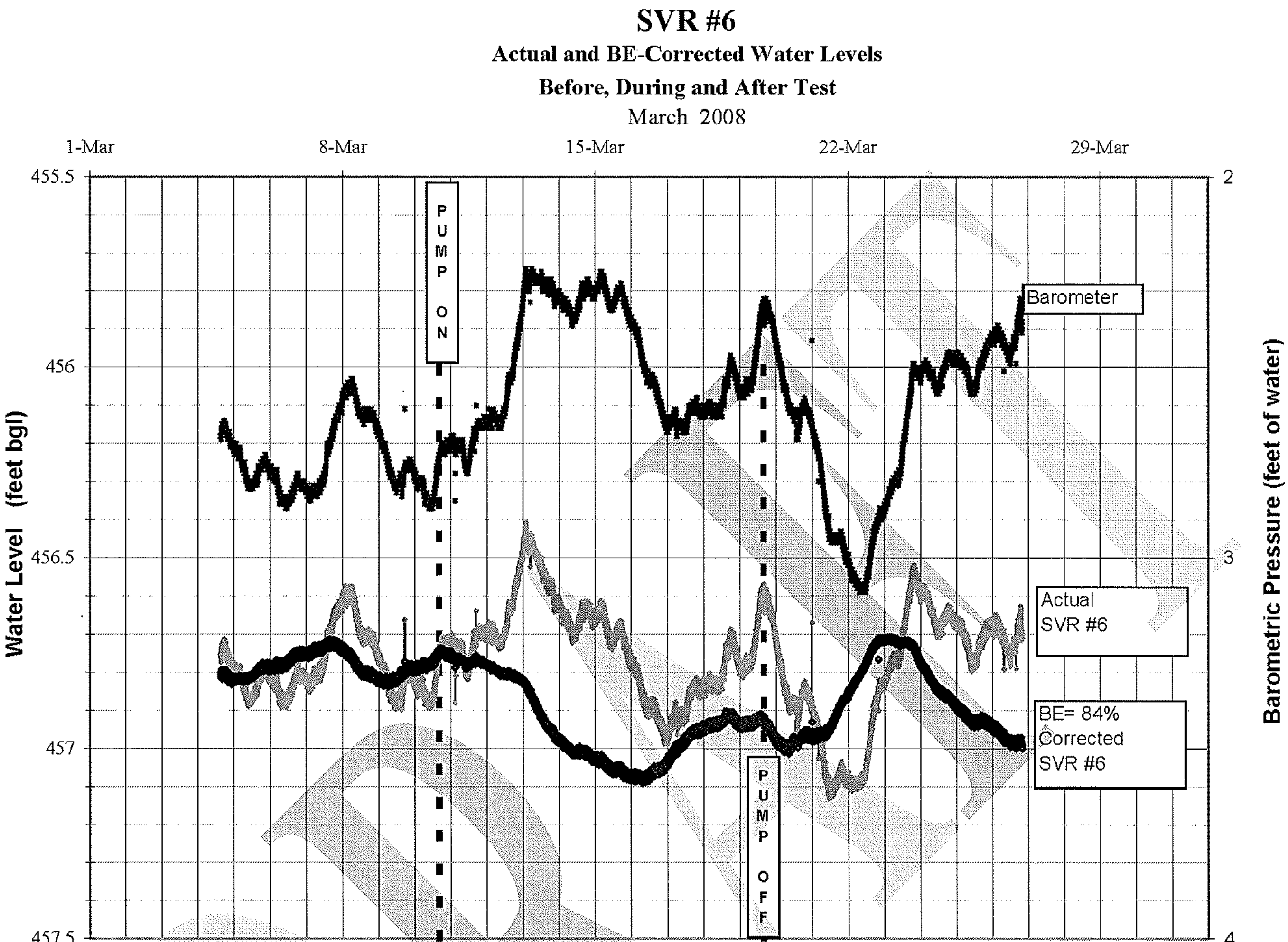
Distance from Pumping Well SVR #7 = 8,173 ft
Screen Depth = 369 to 379 ft

Figure C-17. Actual and BE-Corrected Water Levels for TW #3 Zone 1



Distance from Pumping Well SVR #7 = 8,173 ft
Screen Depth = 432 to 442 ft

Figure C-18. Actual and BE-Corrected Water Levels for SVR #6



In Willow Creek Aquifer - NOT in Pierce Gulch Sand Aquifer
Distance from Pumping Well SVR #7 = 8,189 ft
Screen Depth = 560 to 730 ft

Appendix D – Additional Information on the Analytical Methods Used in this Report

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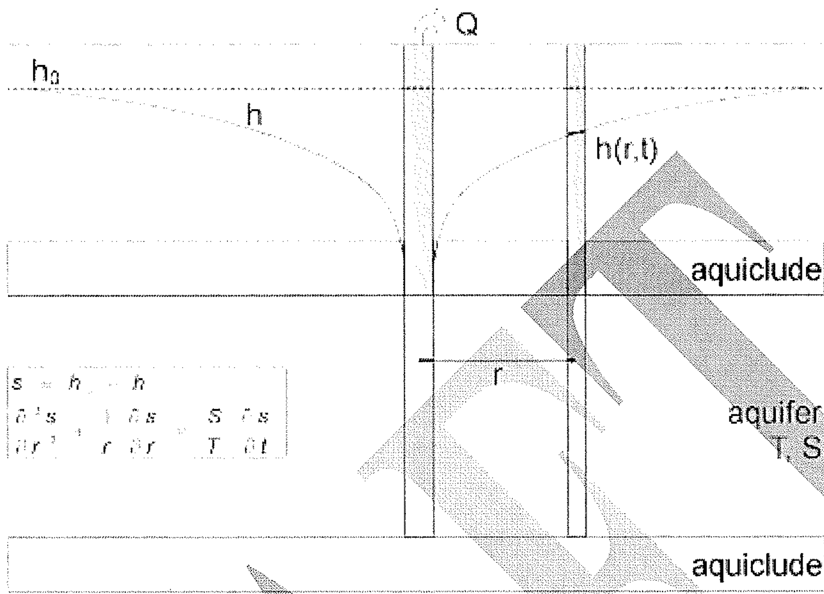
Details on the Method of Cooper, H.H. and C.E. Jacob, 1946. (From Aqtesolv®)
Schematic Diagram:



Assumptions:

- aquifer has infinite areal extent
- aquifer is homogeneous, isotropic and of uniform thickness
- pumping well is fully penetrating
- flow to pumping well is horizontal
- aquifer is confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic
- diameter of pumping well is very small so that storage in the well can be
- values of u are small (i.e., r is small and t is large)

Equations:

For large values of time, Cooper and Jacob (1946) proposed the following equation for displacement in a confined aquifer in response to pumping:

$$s = \frac{2.303Q}{4\pi T}\log\left(\frac{2.25Tt}{r^2S}\right)$$

$$s_D = \frac{4\pi T}{Q}s$$

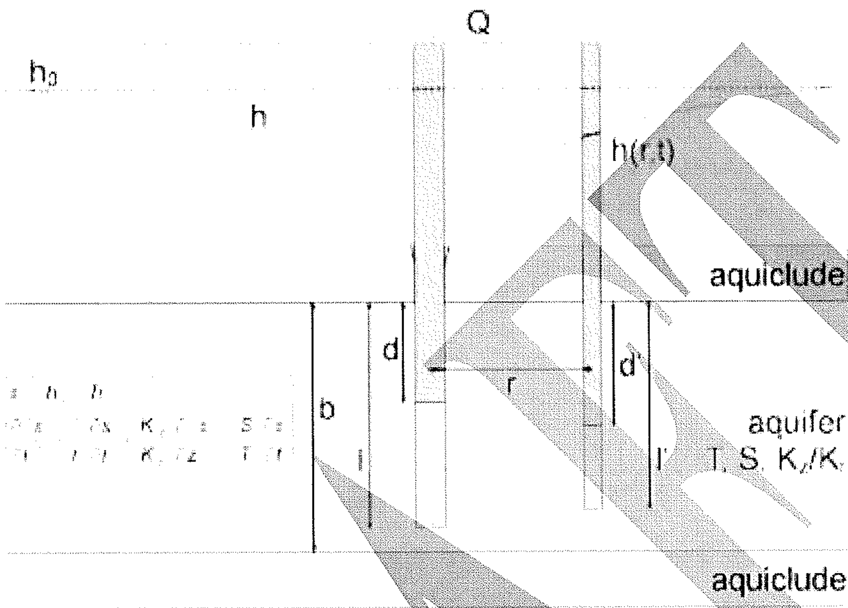
$$t_D = \frac{Tt}{r^2S}$$

where

- Q is pumping rate $[L^3/T]$
- r is radial distance [L]
- t is time [T]
- s is drawdown [L]
- S is storativity [dimensionless]
- T is transmissivity $[L^2/T]$

Details on the Method of Hantush, M.S. 1961a and b (From Aqtesolv®)

Schematic Diagram:



Assumptions:

- aquifer has infinite areal extent
- aquifer is homogeneous and of uniform thickness
- pumping well is fully or partially penetrating
- flow to pumping well is horizontal when pumping well is fully penetrating
- aquifer is confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic head
- diameter of pumping well is very small so that storage in the well can be neglected

Equations:

Hantush (1961a, b) derived equations for the effects of partial penetration in a confined aquifer. For a piezometer, the partial penetration correction is as follows:

$$s = \frac{Q}{4\pi T}\left(w(u) + \frac{2b}{\pi(l-d)} \sum_{n=1}^{\infty} \frac{1}{n} \left[\sin\left(\frac{n\pi l}{b}\right) - \sin\left(\frac{n\pi d}{b}\right)\right] \cos\left(\frac{n\pi z}{b}\right)\ w\left(u, \sqrt{\frac{K_z}{K_r}}\frac{n\pi r}{b}\right)\right)$$

For an observation well, the following partial penetration correction applies:

$$s = \frac{Q}{4\pi T}\left(w(u) + \frac{2b^2}{\pi^2 (l-d)(l'-d')} \sum_{n=1}^{\infty} \frac{1}{n^2} \left[\sin\left(\frac{n\pi l}{b}\right) - \sin\left(\frac{n\pi d}{b}\right)\right] \left[\sin\left(\frac{n\pi l'}{b}\right) - \sin\left(\frac{n\pi d'}{b}\right)\right] w\left(u, \sqrt{\frac{K_z}{K_r}}\frac{n\pi r}{b}\right)\right)$$

where

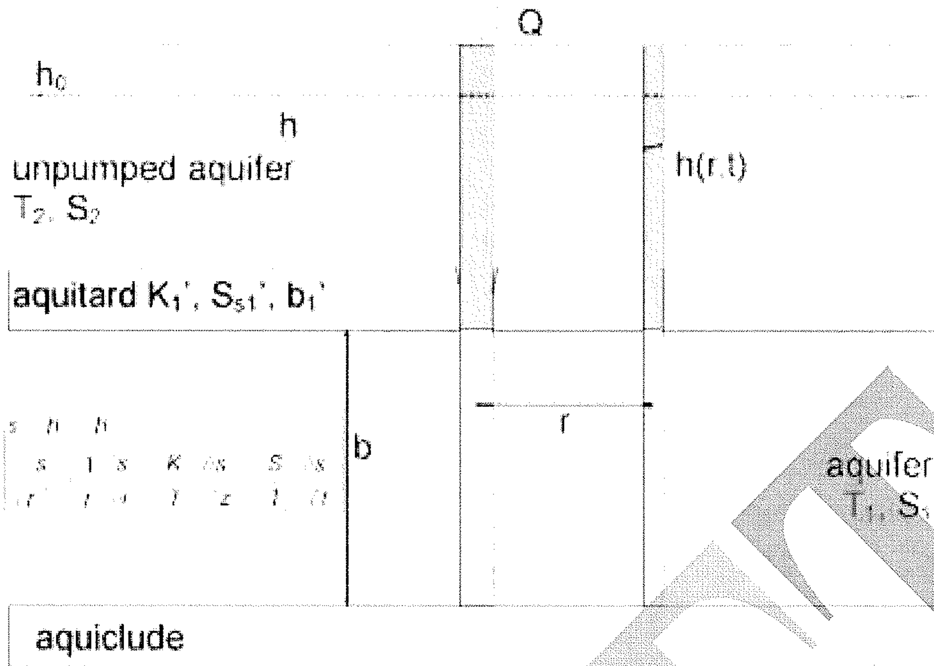
- b is aquifer thickness [L]
- d is depth to top of pumping well screen [L]
- d' is depth to top of observation well screen [L]
- l is depth to bottom of pumping well screen [L]
- l' is depth to bottom of observation well screen [L]
- K_z/K_r is vertical to horizontal hydraulic conductivity anisotropy [dimensionless]
- w(u,ß) is the Hantush-Jacob well function for leaky confined aquifers
- z is depth to piezometer opening [L]

At large distances, the effect of partial penetration becomes negligible when

$$r > 1.5b/\sqrt{K_z/K_r}$$

Details on the Method of Neuman, S.P., and Witherspoon, P. 1972. (From Aqtesolv®)

Schematic Diagram:



Assumptions:

- aquifer has infinite areal extent
- aquifer is homogeneous, isotropic and of uniform thickness
- pumping well is fully penetrating
- flow to pumping well is horizontal
- aquifer is leaky confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic head
- diameter of pumping well is very small so that storage in the well can be neglected
- confining bed(s) has infinite areal extent, uniform vertical hydraulic conductivity, storage coefficient and thickness
- flow is vertical in the aquitard(s)l

Equations:

$$s_1 = \frac{Q}{4\pi T}\int_0^\infty (1-e^{-y t_D})([1+G(y)]J_0(\omega_1(y))+[1-G(y)]J_0(\omega_2(y)))\frac{dy}{y}$$

$$s_1' = \frac{Q}{4\pi T}\frac{2}{\pi}\sum_0^\infty \frac{1}{n}\sin\frac{n\pi z}{b_1'}\int_0^\infty [1-e^{-n\pi t_D} + \frac{e^{-n\pi t_D} - e^{-y t_D}}{1-y^2/(n^2\pi^2)}]([\frac{2(r/B_{21})^2(-1)^n y}{F(y)\sin y} - G(y) - 1]J_0(\omega_1(y))$$

$$-[\frac{2(r/B_{21})^2(-1)}{F(y)\sin y} - G(y)+1]J_0(\omega_2(y)))\frac{dy}{y}$$

$$s_2 = \frac{Q}{4\pi T}\int_0^\infty (1-e^{-y t_D})\frac{2(r/B_{21})^2}{F(y)}[J_0(\omega_1(y)) - J_0(\omega_2(y))]\frac{dy}{\sin y}$$

$$t_{D1} = \frac{T_1 t}{r^2 S_1}$$

$$\bar{t}_{D1} = t_{D1}(r/B_{11})^4/(4\beta_{11})^2$$

$$r/B_{ij} = r\sqrt{K_j'/T_i b_j'}$$

$$\beta_{ij} = \frac{r}{4b_i}\sqrt{\frac{K_j' S_{sj}'}{K_i S_{si}}}$$

$$G(y) = M(y)/F(y)$$

$$\omega_1^2(y) = \frac{1}{2}[N(y)+F(y)]$$

$$\omega_2^2(y) = \frac{1}{2}[N(y)-F(y)]$$

$$F^2(y) = M^2(y) + \left[\frac{2(r/B_{11})(r/B_{21})y}{\sin y}\right]^2$$

$$M(y) = \left[\frac{(r/B_{11})^4}{(4\beta_{11})^2} - \frac{(r/B_{21})^4}{(4\beta_{21})^2}\right]y^2 - \left[(r/B_{11})^2 - (r/B_{21})^2\right]y\cot y$$

$$N(y) = \left[\frac{(r/B_{11})^4}{(4\beta_{11})^2} + \frac{(r/B_{21})^4}{(4\beta_{21})^2}\right]y^2 - \left[(r/B_{11})^2 + (r/B_{21})^2\right]y\cot y$$

$$s_D = \frac{4\pi T}{Q}s$$

$$t_D = \frac{Tt}{r^2 S}$$

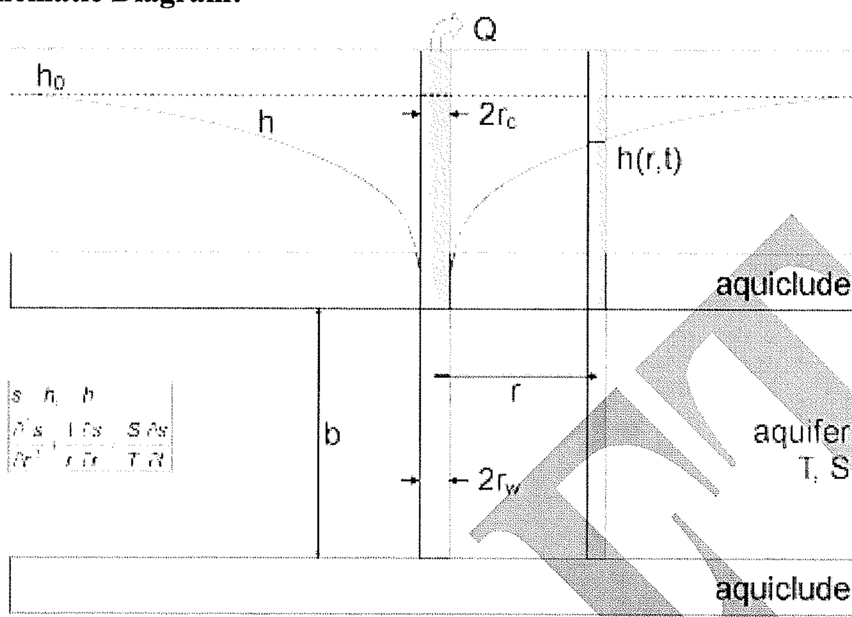
where

- b_i is thickness of aquifer i [L]
- b_j' is thickness of aquitard j [L]
- J_0 is Bessel function of first kind, zero order
- K_i is horizontal hydraulic conductivity in aquifer i [L/T]
- K_j' is vertical hydraulic conductivity in aquitard j [L/T]
- Q is pumping rate [L^3/T]
- r is radial distance [L]
- s_1 is drawdown in the pumped aquifer [L]

- s'_1 is drawdown in the aquitard [L]
- s_2 is drawdown in the unpumped aquifer [L]
- S, S_1 is storativity in the pumped aquifer [dimensionless]
- t is time [T]
- T, T_1 is transmissivity in the pumped aquifer [L^2/T]

Details on the Method of Papadopulos, I.S. and H.H. Cooper, 1967. (From Aqtesolv®)

Schematic Diagram:



Assumptions:

- aquifer has infinite areal extent
- aquifer is homogeneous, isotropic and of uniform thickness
- pumping well is fully penetrating
- flow to pumping well is horizontal
- aquifer is confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic head

Equations:

Papadopulos and Cooper (1967) derived a solution for a finite-diameter pumping well with wellbore storage in a confined aquifer as follows:

$$s = \frac{Q}{4\pi T} F(u, \alpha, r_D)$$

$$F = \frac{8\alpha}{\pi} \int_0^{\infty} \frac{(1 - e^{-\beta^2 r_D^2 / 4u})[J_0(\beta r_D) A(\beta) - Y_0(\beta r_D) B(\beta)]}{([A(\beta)]^2 - [B(\beta)]^2)\beta^2} d\beta$$

$$A(\beta) = \beta Y_0(\beta) - 2\alpha Y_1(\beta)$$

$$B(\beta) = \beta J_0(\beta) - 2\alpha J_1(\beta)$$

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

$$\alpha = \frac{r_w^2 S}{r_c^2}$$

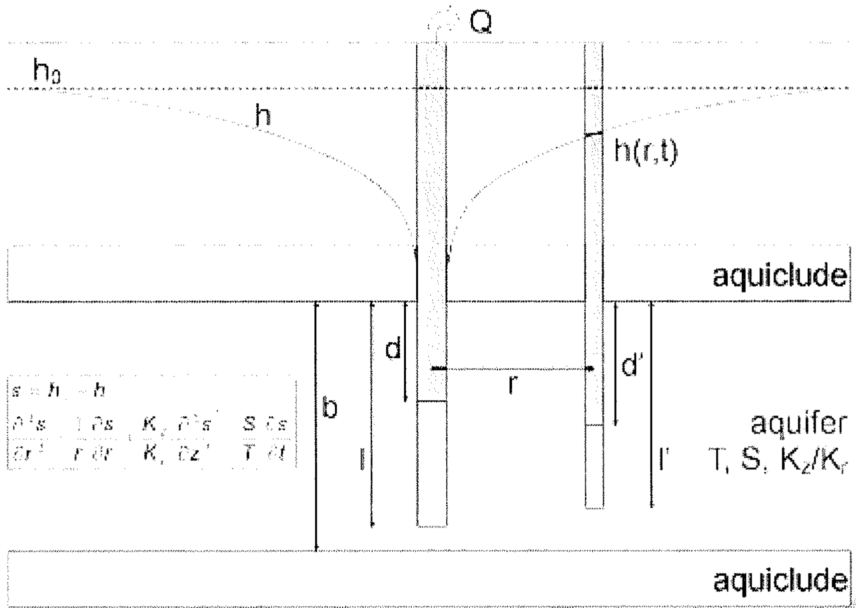
$$r_D = \frac{r}{r_w}$$

where

- J_i is Bessel function of first kind, order i
- Q is pumping rate $[L^3/T]$
- r is radial distance [L]
- r_c is casing radius [L]
- r_w is well radius [L]
- s is drawdown [L]
- S is storativity [dimensionless]
- t is time [T]
- T is transmissivity $[L^2/T]$
- Y_i is Bessel function of second kind, order i

Details on the Method of Theis, C.V., 1935. (Pumping) (From Aqtesolv®)

Schematic Diagram:



Assumptions:

- aquifer has infinite areal extent
- aquifer is homogeneous and of uniform thickness
- pumping well is fully or partially penetrating
- flow to pumping well is horizontal when pumping well is fully penetrating
- aquifer is confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic head
- diameter of pumping well is very small so that storage in the well can be neglected

Equations:

$$s = \frac{Q}{4\pi T}\int_u^{\infty}\frac{e^{-y}}{y}dy$$

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

where

- Q is pumping rate [L^3/T]
- r is radial distance [L]
- s is drawdown [L]
- S is storativity [dimensionless]
- t is time [T]
- T is transmissivity [L^2/T]

Hydrogeologists commonly refer to the exponential integral in the drawdown equation as the Theis well function, abbreviated as w(u). Therefore, we can write the Theis drawdown equation ir compact notation as follows:

$$s = \frac{Q}{4\pi T} w(u)$$

Hantush (1961a, b) derived equations for the effects of partial penetration in a confined aquifer. For a piezometer, the partial penetration correction is as follows:

$$s = \frac{Q}{4\pi T}\left(w(u) + \frac{2b}{\pi(l-d)}\sum_{n=1}^{\infty}\frac{1}{n}[\sin(\frac{n\pi l}{b}) - \sin(\frac{n\pi d}{b})]\cdot\cos(\frac{n\pi z}{b})\cdot w(u, \sqrt{\frac{K_z}{K_r}}\frac{n\pi r}{b})\right)$$

For an observation well, the following partial penetration correction applies:

$$s = \frac{Q}{4\pi T}\left(w(u) + \frac{2b^2}{\pi^2(l-d)(l'-d')}\sum_{n=1}^{\infty}\frac{1}{n^2}[\sin(\frac{n\pi l}{b}) - \sin(\frac{n\pi d}{b})]\cdot[\sin(\frac{n\pi l'}{b}) - \sin(\frac{n\pi d'}{b})]\cdot w(u, \sqrt{\frac{K_z}{K_r}}\frac{n\pi r}{b})\right)$$

where

- b is aquifer thickness [L]
- d is depth to top of pumping well screen [L]
- d' is depth to top of observation well screen [L]
- l is depth to bottom of pumping well screen [L]
- l' is depth to bottom of observation well screen [L]
- K_z/K_r is vertical to horizontal hydraulic conductivity anisotropy [dimensionless]
- w(u,β) is the Hantush-Jacob well function for leaky confined aquifers
- z is depth to piezometer opening [L]

At large distances, the effect of partial penetration becomes negligible when

$$r > 1.5\, b / \sqrt{K_z / K_r}$$

Details on the Method of Theis, C.V., 1935. (Straight-Line Recovery) (From Aqtesolv®)

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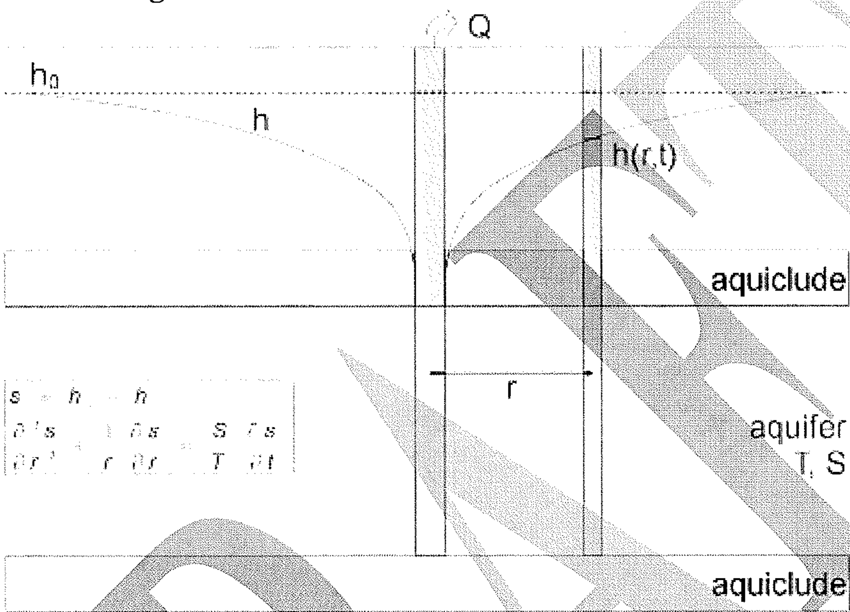

Assumptions:

- aquifer has infinite areal extent
- aquifer is homogeneous, isotropic and of uniform thickness
- pumping well is fully penetrating
- flow to pumping well is horizontal
- aquifer is confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic head
- diameter of pumping well is very small so that storage in the well can be neglected
- values of u are small (i.e., r is small and t is large)

Equations:

$$s' = \frac{Q}{4\pi T}\left[\ln(t/t') - \ln(S/S')\right]$$

where

- Q is pumping rate [L^3/T]
- s' is residual drawdown [L]
- S is storativity during pumping [dimensionless]
- S' is storativity during recovery [dimensionless]
- t is time since pumping began [T]
- t' is time since pumping stopped [T]
- T is transmissivity[L^2/T]