Appendix F - Aquifer Test Results

One of the methods for determining hydraulic connectivity is by performing an aquifer test to determine which monitoring wells respond to pumping and which do not.

A 24-hour aquifer test was conducted April 28-29, 2016. Well SL-6D was used as the pumped well and water levels were measured using pressure transducers in wells KE-21 KE-22, SL-1, SL-2, SL-3, SL-4I, and SL4D. Water levels were measured manually in wells SL-6D and SL-6S. Wells SL-5S and SL-5D experienced equipment failures and valid water-level data were not obtained.

The aquifer encountered by Well SL-6D was capable of producing an unexpectedly large flow of water. The test pump was the largest pump available (at 5.44 inches diameter) that would fit inside the 6-inch inside-diameter well casing. In order to assess the performance of the well and pump, especially with regard to the pumping of sand and silt, the test was conducted as a step-rate test, with initial rates of 200 gpm for the first 12 minutes of pumping, 300 gpm for the next 11 minutes of pumping, and then gradually increasing the rate to the maximum rate of the pump, which varied from 350 to 400 gpm for the duration of the test. According to flow meter readings and totalizer calculations, the average rate during final 18 hours of pumping was approximately 375 gpm. Water levels were measured manually in the pumped well with an electric water-level indicator, and water was discharged through a short discharge hose from which it flowed into the South Pond. Data collected at the pumped well is provided in Table F-1.

Table F-1. Aquifer test data.

Aquifer test data		Dates of test: 4/28-29/2016				
Pumped Well: SL-6D		Location: Westpark Drive and Big Bend Loop				
Well depth:	252 ft	Steel Casing Stickup: 2.5 ft				
Static Water level:	72.29 ft below MP					
Pump intake depth = 216 ft, pump bottom = 220 ft depth						
Pump start time: 11:15 am 4/28/16						
Pump stop time 11:15 am 4/29/16						
Measuring Point: Top of PVC casing = 0.27 ft above steel casing						

Minutes since pumping stopped	Minutes since pumping started	Depth to water below MP (ft)	Draw-down (ft)	Instan-taneous observed flow rate (gpm)	Flow meter reading (gallons)	Comments
	0	72.29	0	0	3764200	
	1	83.5	11.21	200		
	2	83.55	11.26			
	3	83.55	11.26			
	4	83.59	11.3			
	5	83.63	11.34			

Minutes since pumping stopped	Minutes since pumping started	Depth to water below MP (ft)	Draw-down (ft)	Instan-taneous observed flow rate (gpm)	Flow meter reading (gallons)	Comments
	6	83.7	11.41			
	7	83.7	11.41			
	8	83.72	11.43			
	10	83.79	11.5			
	11	83.85	11.56			
	12			300		increased flow to 300
	13	90.17	17.88			sand in water
	14	90.4	18.11			Clearing
	16	90.35	18.06			
	18	90.4	18.11			
	20	90.52	18.23			
	23	90.58	18.29			adj from 300 to 330
	25			330		
	26	93.86	21.57			
	27	93.81	21.52			water dirty- more sand
	28			350		
	30	96.76	24.47			fine sand
	32	97.7	25.41			
	34	98.42	26.13			
	35			375		
	36	99.82	27.53			water clear
	38	100.26	27.97	380		valve opened all the way
	39	101.36	29.07			more mechanical variation
	41	101.56	29.27			water temp = 33.9 degrees F
	42	102.13	29.84	385		
	45	102.43	30.14			
	49	102.6	30.31			
	55	103.04	30.75			flow meter check: 400 gal in 67.77 seconds (354 gpm)
	62	103.31	31.02		3783600	
	70	103.76	31.47			
	84	103.95	31.66	390		fluctuating between 360-420
	99	104.35	32.06			
	117	104.65	32.36	400		
	118				3803500	
	137	104.8	32.51			
	161	105	32.71			
	190	105.1	32.81		3829900	
	220	105.25	32.96			fluctuating between 380-400
	252	105.37	33.08	386		
	275	105.47	33.18	360		pumping rate declining

Minutes since pumping stopped	Minutes since pumping started	Depth to water below MP (ft)	Draw-down (ft)	Instan-taneous observed flow rate (gpm)	Flow meter reading (gallons)	Comments
	297	105.51	33.22	350		
	320	105.58	33.29	360		
	350	105.6	33.31	375		370-380 consistently
	380	105.61	33.32			
	410	105.73	33.44			
	463	105.74	33.45			
	532	105.94	33.65			
	601	106.11	33.82			
	675	106.2	33.91			
	787	106.3	34.01			
	908	106.52	34.23			
	1026	106.6	34.31			
	1159	106.71	34.42			
	1283	106.78	34.49	372		
	1410				4271100	
	1424	106.8	34.51	372		
	1440			0	4282100	pump off - 24 hr avg 360 gpm
0.07	1440.07	100	27.71			
1.42	1441.42	73.7	1.41			
2	1442	73.57	1.28			
3	1443	73.37	1.08			
4	1444	73.22	0.93			
5	1445	73.15	0.86			
6.25	1446.25	73.17	0.88			
7	1447	73.08	0.79			
8	1448	73.04	0.75			
9	1449	73.02	0.73			
10	1450	73.01	0.72			
11	1451	72.98	0.69			
12	1452	72.95	0.66			
13	1453	72.88	0.59			
14	1454	72.88	0.59			
15	1455	72.87	0.58			
16	1456	72.87	0.58			
18	1458	72.83	0.54			
20	1460	72.8	0.51			
22	1462	72.8	0.51			
25	1465	72.75	0.46			
28	1468	72.77	0.48			

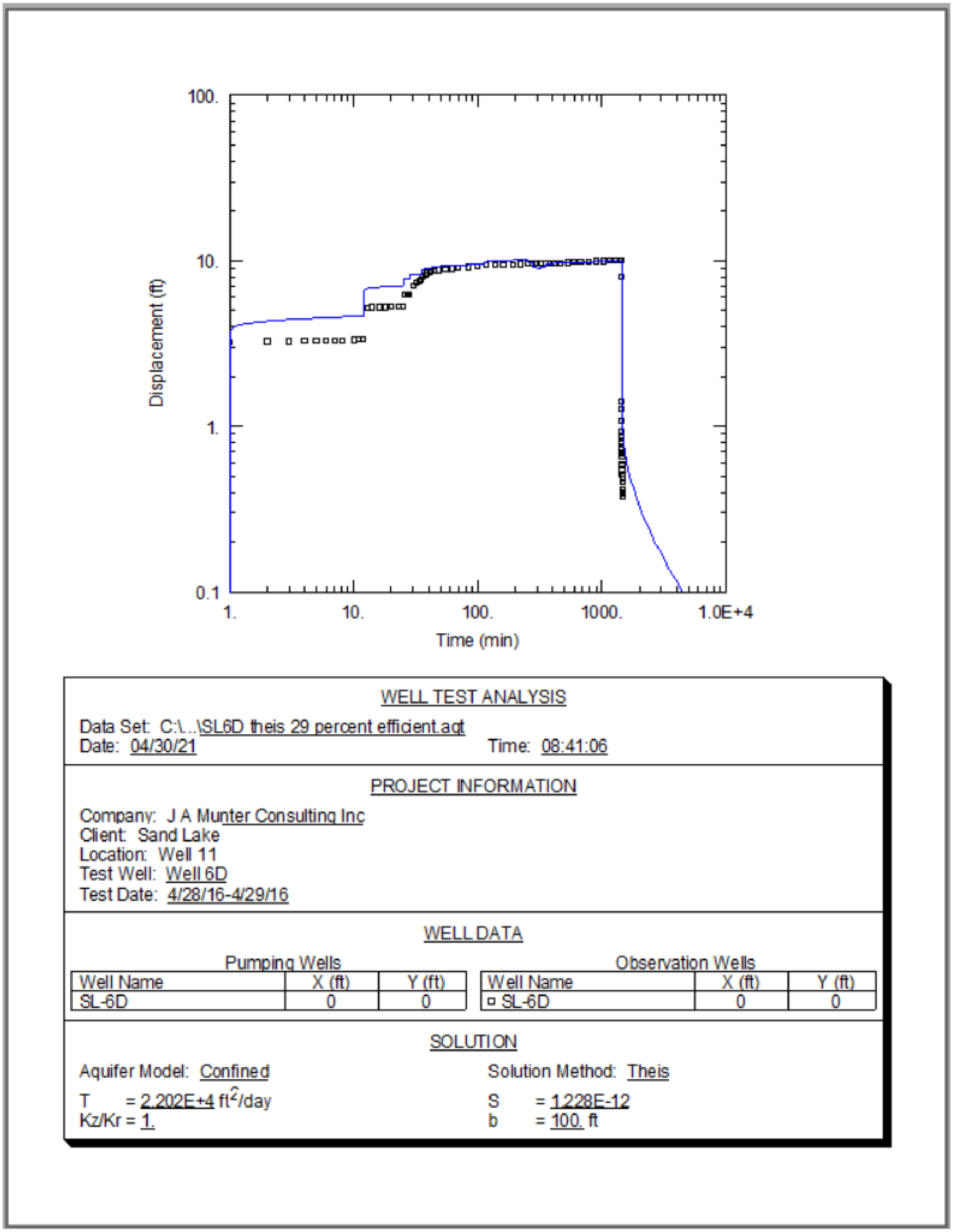
Minutes since pumping stopped	Minutes since pumping started	Depth to water below MP (ft)	Draw-down (ft)	Instan-taneous observed flow rate (gpm)	Flow meter reading (gallons)	Comments
36	1476	72.71	0.42			
37	1477	72.69	0.4			
38	1478	72.68	0.39			
41	1481	72.68	0.39			
45	1485	72.67	0.38			

The pump was shut down after 24 hours of pumping. The water level recovered extremely fast, recovering 96% of drawdown within two minutes. This is an indication of a highly inefficient well. Although well inefficiency is usually attributed to head loss that occurs as water flows through the well openings or screen into the well, another possible cause of such a high degree of inefficiency is the high rate of turbulent flow through the narrow annulus between the well pump motor and the well casing. The well pump motor is below the intake ports of the pump. This turbulent flow resulted in head loss between the water column in the bottom of the well (and in the adjacent aquifer) and the water level measured at the water surface (which is what was measured in Table F-1). In order to further evaluate well efficiency, a step-drawdown analysis was conducted using the method of Todd (1980). This analysis concluded that the well was only 29% efficient. This means that the water levels measured above the pump were not accurately reflecting the water levels in the aquifer immediately outside of the well screen. The exact distribution of the source of the inefficiency between the well intake openings and the turbulent flow past the pump is not known, however this is unimportant to the interpretion of the test results; only the cumulative well loss is important. In the analysis below, a correction factor based on the total well efficiency of 29% is applied to the drawdown data in order to analyze the test results.

The only data deemed suitable for a standard time-drawdown analysis to calculated aquifer coefficients were data from the pumped well. Aquifer test data were analyzed using software by AQTESOLV^{tm} (Duffield, 2007).

Such an analysis normally assumes that a pumping well is 100 percent efficient, meaning that the water levels measured in the well accurately reflect water levels in the aquifer immediately outside the well screen. In this case, the analysis was conducted using drawdown data multiplied by a factor of 0.29 to compensate for the low efficiency of the well/pump arrangement.

Figure F-1 shows the results of the aquifer test analysis, indicating that the transmissivity of the aquifer at the site is approximately 22,000 ft^2/day using the method of Theis (1935). It is not possible to calculate a valid value of aquifer storativity when only data from the pumped well are available.



WELL TEST ANALYSIS

Data Set: C:\...\SL6D theis 29 percent efficient.aqt
Date: 04/30/21 Time: 08:41:06

PROJECT INFORMATION

Company: J A Munter Consulting Inc
Client: Sand Lake
Location: Well 11
Test Well: Well 6D
Test Date: 4/28/16-4/29/16

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
SL-6D	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ SL-6D	0	0

SOLUTION

Aquifer Model: Confined
Solution Method: Theis

T = 2.202E+4 ft^2/day
S = 1.228E-12
Kz/Kr = 1.
b = 100. ft

Figure F-1. Time-drawdown plot and results of aquifer test analysis. (See Attachment F-1 for printable version of this figure).

Positive water-level responses to the start-up and cessation of pumping were observed in the following wells: SL-2, KE-22, SL-4D, and SL-4I (see Appendix E). All four of these wells also experienced water-level fluctuations of approximately 0.1 to 0.2 feet in response to tides. All of the responses to pumping were relatively small - less than approximately 0.5 ft

No drawdown responses were observed in wells SL-1, KE-21, or SL-6S. However well KE-21 showed a water level rise of approximately 0.15 ft between April 28 and April 30 that was likely caused by an increase in pond elevation and the immediately surrounding water table created by the discharge of pumped water into the pond (see Appendix E).

The drawdowns observed in the responding monitoring wells were not considered large enough to warrant a standard quantitative time-drawdown analysis, especially considering the complication of tidal influences on observed water levels. However, the approximate expected response in the wells was evaluated by comparing the responses observed to calculations using the model of Theis (1935). Table F-2 shows the results of Theis model calculations compared to observed drawdown. The approximate observed drawdowns shown in Table C-2 were estimated from the data plots shown in Appendix E and visually adjusted for the estimated effects of tidal fluctuations. Fortuitously, the time of the relative maximum of water levels caused by the tidal fluctuations coincided closely with both the start of pumping and the end of pumping.

Table F-2. Comparison of simulated vs measured and visually-estimated drawdowns in monitoring wells

Well	Aquifer zone tapped	Distance from pumped well, r (ft)	Approximate observed tidally-corrected drawdown after 24 hours of pumping (ft)	Calculated drawdown (ft)	
				Storativity, $S = 10^{-4}$	Storativity, $S = 10^{-5}$
KE-22	upper zone	1000	0.5	0.22	0.28
SL-2	middle zone	1500	0.4	0.20	0.26
SL-4I	upper zone	2050	0.35	0.19	0.25
SL-4D	lower zone	2050	0.35	0.19	0.25

Notes:
Other parameters used for the Theis (1935) simulations were:
Pumping rate = 375 gpm
Transmissivity = 22,000 ft^2/day

The results shown in Table F-2 are somewhat surprising considering the large variation in depth and location of the monitoring wells and the aquifer zones tapped by the wells. The productions well, SL-6D, is inferred to tap the upper zone. The responses observed in wells tapping the upper, middle and lower aquifer zones provides a strong indication that the zones are hydraulically interconnected - at least in the vicinity of the test area. Potential interconnections of these aquifer zones is illustrated in Cross Sections A-A' and B-B' (Figures 7 and 8)

The results of the aquifer test show that at least some of the individual aquifer zones tapped possess some degree of hydraulic continuity with other zones in the area sufficient to respond to short-term hydraulic stresses. At the SL-6S/SL-6D well site, the confining unit separating the shallow and deeper aquifer is concluded to function as an effective barrier to short-term hydraulic stresses between the aquifers at that location.

REFERENCES CITED

Duffield, Glen M., 2007, AQTESOLV^{tm} for Windows^{tm}, Version 4.50 Professional, HydroSOLVE, Inc., copyright 1996-2007.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage: Trans. Amer. Geophys. Union, 2, pp 519-524.

Todd, David Keith, 1980, Groundwater Hydrology, John Wiley & Sons, New York, Chichester, Brisbane and Toronto