Layne-Western *a division of Layne Christensen Company*

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May 1, 2007

Mr. Brad Harris
Layne-Western
4601 North 252nd Street
Valley, NE 68064

RE: Aquifer Test Analysis, Carter Lake, Iowa

Dear Mr. Harris:

The community of Carter Lake, Iowa plans to pump groundwater from an alluvial aquifer to maintain a desired level of a lake near Kiwanis Park. Layne Christensen Company (Layne) was retained by Carter Lake to provide an estimate of the connection between the aquifer. Specifically, Layne was tasked with estimating the percentage of well water obtained from induced infiltration of the lake. The objective of this analysis is to provide a recommendation on future well spacing that will reduce the account of water that is re-circulated from the lake to the well. To develop these recommendations, Layne conducted field activities which consisted of:

- Rehabilitation of the pumping well;
- Installation of a three (3), two (2) inch diameter observation wells; and
- Implementation of a seven (7) day aquifer test.

The data obtained from the aquifer test were evaluated by Layne's geohydrologist to determine the hydraulic properties of the aquifer at the Site. The objective of the aquifer test analysis is to estimate the site specific hydraulic properties of the aquifer, which are defined below:

- Transmissivity (T) - is the volume of water flowing through a cross-sectional area of an aquifer whose height is the entire thickness of the aquifer and whose width was one (1) foot, under a unit hydraulic gradient (1 ft/1 ft).
- Hydraulic conductivity – defined as the transmissivity divided by the aquifer thickness, or the volume of water flowing through a one (1) foot by one (1) foot. cross-sectional area of an aquifer under a unit hydraulic gradient, in a given amount of time (usually a day).
- Storage coefficient (S) - is the volume of water released from an aquifer per one (1) foot surface area per one (1) foot change in head

The calculated Site specific aquifer properties were then used to estimate the distance from the pumping well to the line source of recharge, defined as the estimated distance where the pumped water is being primarily supplied by induced infiltration of the recharge boundary. The following letter report describes the work performed at the Site to achieve the project objectives described above.

TEST WELL CONSTRUCTION/SITE GEOLOGY

An existing supply well (82-1), originally installed by Layne in 1983, was used by Layne field staff to conduct the aquifer test. The existing well construction was documented to consist of an 18-inch diameter screen and casing. The well was installed with 20 feet of stainless steel screen, placed from 73 to 93 feet below ground surface (bgs).

Three (3) two (2)-inch diameter observation wells were installed to monitoring changes in the water level of the aquifer induced by pumping the test well. The wells were installed 50, 150, and 450 feet from the test well, in a perpendicular line towards the recharge boundary (Lake). The observation wells were installed towards the lake, in a line perpendicular to the recharge boundary. Boring log and well completion details are presented in Appendix A. Based on the three (3) boring logs available, the Site geology consisted of alluvial sediments, as described below:

- 0 – 7 feet – Silty clay
- 7 – 15 feet – Fine sand
- 15 – 20 feet – Blue clay
- 20 – 43 feet – Fine sand
- 43 – 58 feet – Gravel and coarse sand
- 58 – 60 feet – Blue clay
- 60 – 93 feet – Fine to coarse sand, with some small gravel
- 93 feet – Bedrock (Limestone).

Depth to water was measured in the test well and the observation wells at approximately 15 feet below ground surface (bgs). Depth to water was consistent thought the Site.

CONSTANT RATE TEST

A seven (7) day aquifer test was performed at well 82-1 from April 4 to April 11, 2007. Changes in the potentiometric surface were monitored at the pumping well and at the three (3) observation wells, and water level measurements were collected using electronic pressure transducers/data loggers and an electronic water level indicator. The test well was pumped at a constant discharge rate of approximately 1,070 gallons per minute (gpm) for the duration of the test. Several methods were used to estimate the hydraulic properties of the aquifer at the Site. The first method used was the Cooper-Jacob (1946) distance drawdown/time drawdown method, which is described in detail in *Analysis and Evaluation of Pumping Test Data* (Kruseman and de Ridder, 1994). This method is applicable for confined or unconfined aquifers and was developed with the following assumptions:

1. The aquifer is confined;
2. The aquifer has a seemingly infinite areal extent;
3. The aquifer is homogeneous, isotropic, and of uniform thickness over the area influenced by the test;
4. Prior to pumping, the potentiometric surface of the aquifer is nearly horizontal;
5. The aquifer is pumped at a constant discharge rate;
6. The well penetrates the entire thickness of the aquifer and receives water by horizontal flow; and
7. Drawdown data is corrected for the dewatering of the aquifer (unconfined systems only).

The first step in analyzing the pump test data was to construct the semi-logarithmic plot of drawdown versus distance, presented as Figure 1. A best fit line was matched to the observed drawdown data using manual techniques. The slope of the best fit line was use to calculate the Site specific hydraulic aquifer parameters per the Cooper-Jacob method (1946). The slope of the straight line obtained from the distance drawdown plot typically remains unchanged due to the presence of a recharge boundary (Driscoll, 1989), and the transmissivity value calculated from this method should be close to the true value of the aquifer. However, near the presence of a recharge boundary, the straight line is displaced upward and the storage coefficient will be higher than the correct value (Driscoll, 1989).

Next, semi-logarithmic time drawdown plots were generated for all three observation wells, presented as Figure 2. After the semi-logarithmic drawdown plots were generated, a best fit line was matched to the observed drawdown data using manual techniques. The impact of the recharge boundary could be seen in the plot of all three wells, as the drawdown response deviates from the theoretical response in a confined aquifer after approximately 10 minutes of pumping. Near a recharge boundary, the slope of the time drawdown curve becomes flatter and transmissivity values calculated, using the Cooper Jacob method, will yield a transmissivity that is higher than the true aquifer value. Therefore, only the early time portion of the curve, where the presence of the recharge boundary was not observed, was used to estimate the aquifer properties. As shown of Figure 2, both OW 50 and OW 150 are impacted approximately the same by the recharge boundary, as the slope of their best fit lines are similar. However the drawdown observed at OW 450 appears to have been impacted more by the recharge boundary, as the slope of the best fit line is less. This appears consistent with the physical locations of the observation wells, as OW 450 is located closer to the Lake than the other wells.

A second method of aquifer test analysis was performed using the Moench, 1985 curve matching technique, which accounts for the presence of a recharge boundary. This solution was developed with all of the assumptions listed for the Cooper Jacob solution, however the Moench 1985 technique also assumes a constant-head source which supplies leakage across an overlying aquitard. The aquifer parameter values calculated using the Moench technique were used to check the aquifer parameters calculated using the Cooper Jacob time drawdown technique.

Calculations to estimate the aquifer parameters were performed manually and using the aquifer test analysis software AQTESOLV™. Detailed calculations are presented in Appendix B and the results of the analysis are summarized in the table below.

Table 1

Summary of Aquifer Parameters

Analysis Technique	Transmissivity (ft^2/day)	Storage Coefficient (dimensionless)
Distance Drawdown	21,700	0.4
OW 50 – Time Drawdown	17,800	0.001
OW 150 – Time Drawdown	30,400	0.001
OW 450 – Time Drawdown	65,000	0.0007

A representative transmissivity of the aquifer was estimated by averaging the value obtained from the distance drawdown analysis and the time drawdown analysis of OW 50 and OW 150. The time drawdown curve of well OW 450 appears to have been influenced by the recharge boundary and produced very high estimates of transmissivity. In summary, the results of the analysis indicate that an approximate transmissivity of the aquifer is 21,500 square feet per day (ft^2/day) or 160,800 gallons per day per foot (gpd/ft). Based on the boring log the aquifer thickness at the site, below the clay confining unit, is approximately 30 feet, which yields a hydraulic conductivity of approximately 715 feet per day (ft/day). This value appears reasonable given the sand and gravel formation reported and is indicative of a highly productive aquifer. The storage coefficient of the aquifer was estimated to range from 0.0007 to 0.001, which indicates that the aquifer is under confined or leaky confined conditions.

PERCENTAGE OF WATER OBTAINED FROM RECHARGE SOURCE

Once site specific aquifer parameters were estimated, an analytical model was developed to estimate the percentage of water obtained from the recharge boundary. The percentage of water diverted from a source of recharge depends on the hydraulic properties of the aquifer, which were previously calculated, the distance of the pumping well to the line source of recharge, and the time of pumping.

The first step in estimating the percentage of water obtained from a recharge boundary is to estimate the location of the line source of recharge relative to the pumping well. To estimate this value, the following equation was solved (Rorabaugh, 1948):

$$s = \frac{528Q \log\left[\left(\frac{2a - r_p}{r_p}\right)\right]}{T}$$

where:

s = drawdown in observation well (feet)
Q = pumping rate (gpm)
a = distance from pumping well to recharge boundary (ft)
T = aquifer transmissivity (gpd/ft)
r_p = distance from pump well to observation well (feet)

This equation is valid for the case where the observation well is in a perpendicular line with the recharge boundary and the observation well is on the boundary side of the pumping well. This is the field situation for the pumping test conducted at the Site. Using the aquifer parameters previously calculated, the distance to the line source of recharge was estimated as 400 ft from the pumping well, in the direction towards the lake. Calculations are provided in Appendix B.

Time to Reach Equilibrium

The time to reach equilibrium near a line source of recharge was estimated using the following equation (Foley, et. al., 1953):

$$t_e = \frac{a^2 S}{112 T \varepsilon \log\left(\frac{2a}{r}\right)^2}$$

Where:

t_e = time required to reach approximate equilibrium (years);

a = distance from pumped well to line source of recharge (feet);

r = distance from pumped well to observation point (feet);

S = coefficient of storage (dimensionless);

T = coefficient of transmissivity (gpd/ft);

ε = deviation from absolute equilibrium (generally assumed to be 0.05).

Based on this method the estimated time to reach equilibrium near the pumping well is approximately 10 to 15 minutes, depending on the value of the storage coefficient yield used in the equation. The equilibrium method only estimates the time to reach equilibrium on the boundary side of the pumping well and should not be applied to conclusions regarding the expansion of the cone of depression along the landward side of the pumping well. Calculations are presented in Appendix C.

Percentage of Water Derived from Source of Recharge

The percentage of pumped water being diverted from a source of recharge depends upon the hydraulic properties of the aquifer, the distance from the pumping well to the recharge boundary, and the time of pumping. Theis (1941) derived a graphical method to estimate the percentage of water pumped by a well that is obtained from a source of recharge. To use the Theis method, the value of the function f must be calculated using the equation listed below:

$$f = \frac{2693a^2S}{Tt}$$

where:

S = aquifer storage coefficient (dimensionless)
a = distance from pumping well to recharge boundary (ft)
T = aquifer transmissivity (gpd/ft)
t = time to reach equilibrium (min)

Once the value of the function f is calculated, the percentage of water obtained from the recharge source can be obtained from the chart presented below.

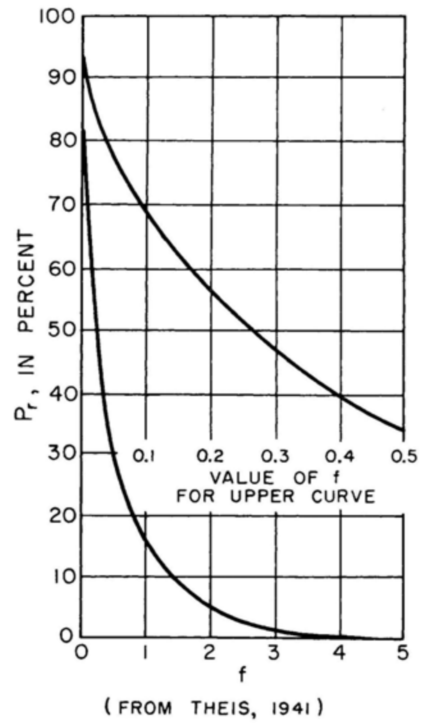


Figure 13. Graph for determination of percentage of pumped water being diverted from a source of recharge

The chart above gives the value of P_r for a given value of the function f. The quantity $(100 – P_r)$ represents the percentage of pumped water taken from storage within the aquifer. Based on the Theis method, it is estimated that approximately 45 percent of the water obtained from well 82-1 was obtained through induced infiltration of the recharge boundary. Calculations are presented in Appendix C.

The method presented above is valid for what hydrogeologists term steady state conditions, which occurs when drawdown in the aquifer exhibits only negligible change over a long period of time. Steady state conditions were observed in the furthest observation well, OW 450, between 1,000 minutes and 10,000 minutes, indicating that at this distance from the well steady state conditions are observed after approximately one (1) day of pumping. Pumping for a period of less than one day will likely yield more water from the aquifer and less from the recharge boundary.

SUMMARY AND CONCLUSIONS

Layne rehabilitated an existing production well, installed three (3) observation wells, and conducted an aquifer test at a location near Kiwanis Park, near Carter Lake, Iowa. The objective of these activities was to estimate the percentage of well water obtained from induced infiltration of the lake. The objective of this analysis is to provide a recommendation on future well spacing that will reduce the account of water that is re-circulated from the lake to the well.

Based on the results of the aquifer test, it was concluded that the aquifer transmissivity is approximately 21,500 ft^2/day and the aquifer storage coefficient ranges from 0.0007 to 0.001, which indicates semi-confined conditions. Based on the analysis performed, the distance from the pumping well to the line source of recharge was estimated at 400 feet, in the direction toward the lake. For the pumping rate at which the test was performed (1,070 gpm), the percentage of water obtained from induced infiltration of the lake was estimated as 45 percent. This estimate is appropriate for steady state conditions, which based on the results of the test, occurred after approximately one day of pumping. Pumping for periods shorter than one day will result in obtaining a lower percentage of water from the recharge boundary and a higher percentage of water from the aquifer.

To offer some perspective of the test results, typical river bank filtration systems such as the Platte South and Platte West well fields in Omaha, NE, obtain between 75 to 95 percent of their pumped water from induced infiltration of the recharge source. These systems pump water from an alluvial aquifer near a recharge boundary (Platte River), similar to what Carter Lake proposes. Given those typical river bank filtration system design numbers, the estimated value of 45 percent for Carter Lake is a number that appears favorable for the project.

If additional wells are planned to keep the lake filled, it is recommended that the new wells be located further south of the existing well. For example, if a new well is located 200 feet south of the existing well (600 feet from the line source of recharge), the estimated percentage of water obtained from infiltration of the lake will be reduced to approximately 30 percent. Locating a new well 200 feet further south (800 feet from the line source of recharge), results in an estimated 15 percent of water being obtained from induced infiltration.

Once project specifics are determined, such as number of wells and well flow rates, Layne would be happy to assist with re-running these calculations to estimate the percentage of flow obtained from induced infiltration of the lake. Layne appreciates the opportunity to work with Carter Lake on this important project. Your questions are appreciated and expected.

Sincerely,

Luca DeAngelis, P.E., R.G.

Geohydrologist

Layne Western

a division of Layne Christensen Company

REFERENCES:

Cooper, H. H., and Jacob, C.E., 1946. A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well Field History. Amer. Geophys. Union, Vol. 27, pp.526-534.

Kruseman, G.P., and de Ridder, N.A, 1994. Analysis and Evaluation of Pumping Test Data. International Institute for Land Reclamation and Improvement. The Netherlands.

Moench, A.F., 1985. Transient flow to a large-diameter well in an aquifer with storative semiconfining layers, Water Resources Research, vol. 21, no. 8, pp. 1121-1131.

Rorabaugh, M.I., 1948. Ground-water resources of the northeastern part of the Louisville area, Kentucky. City of Louisville, Louisville Water Company.

Theis, C.V., 1941. The Effect of a Well on the Flow of a Nearby Stream. Trans. Amer. Geophys. Union pt.3.

FIGURES

Figure 1
Distance Drawdown
Q = 1,070 gpm
Carter Lake, Nebraska

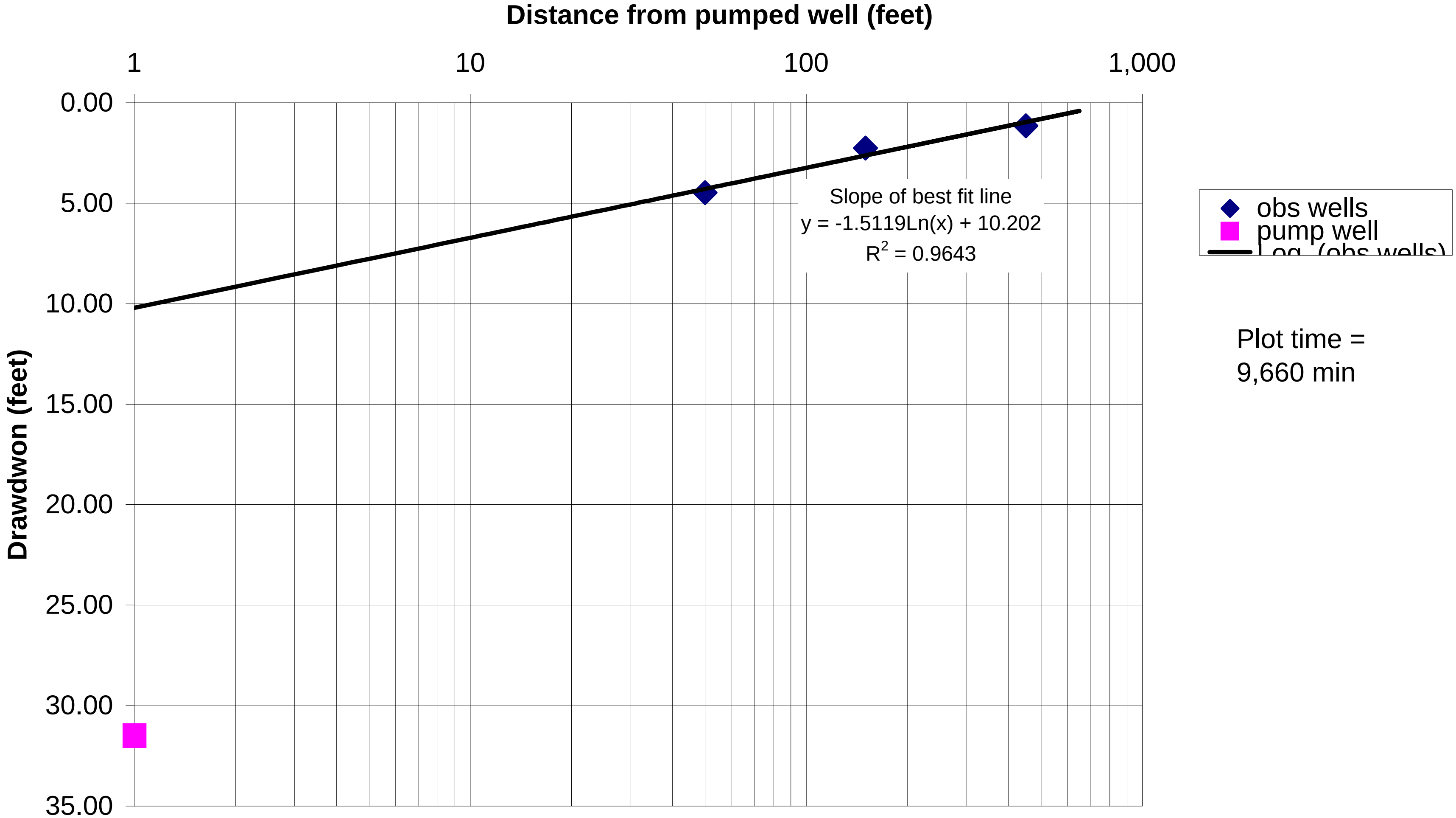
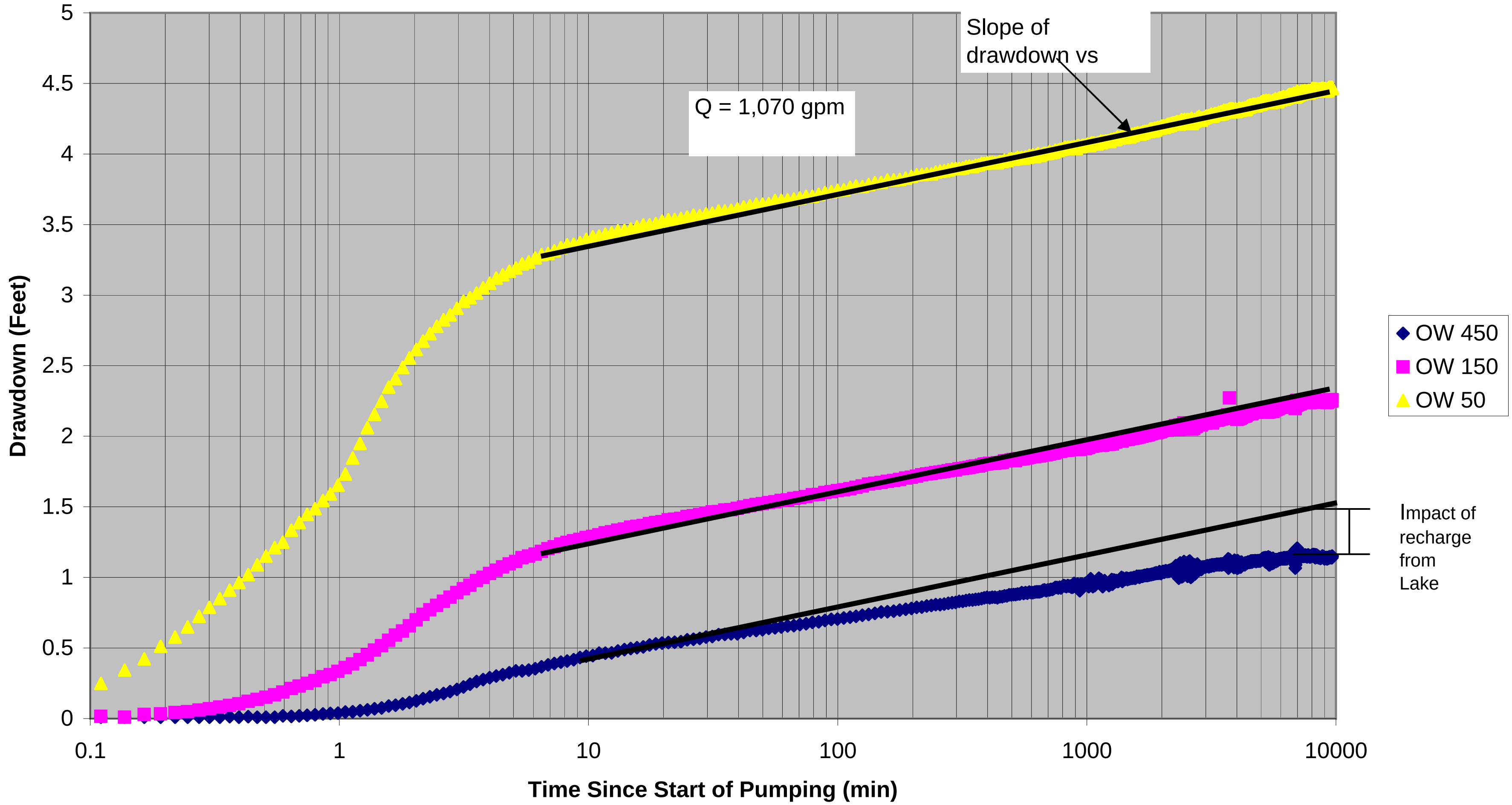


Figure 2
Drawdown Response in Observation Wells
(Lin-Log Scale)
Carter Lake, Nebraska



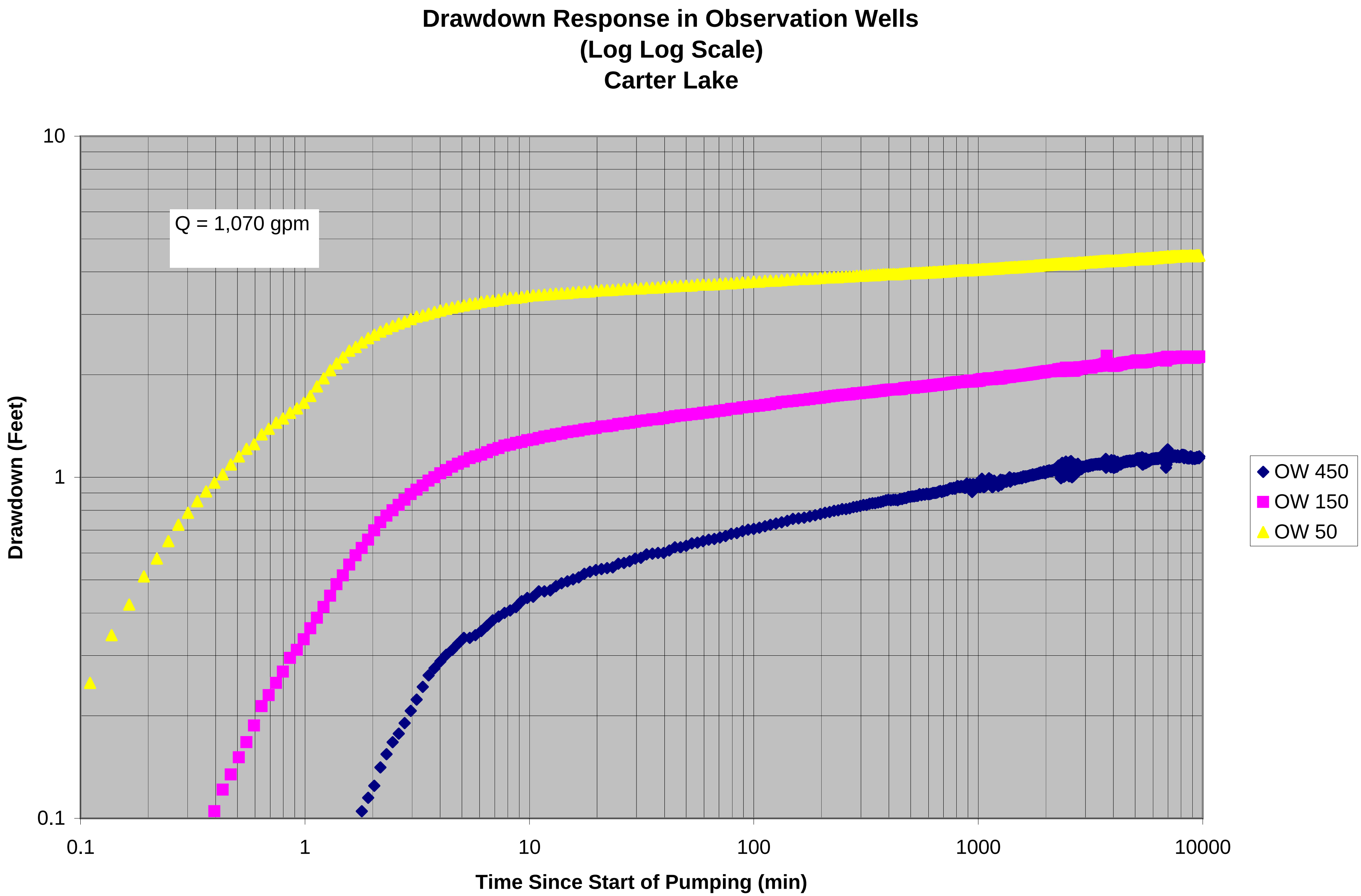
APPENDIX A

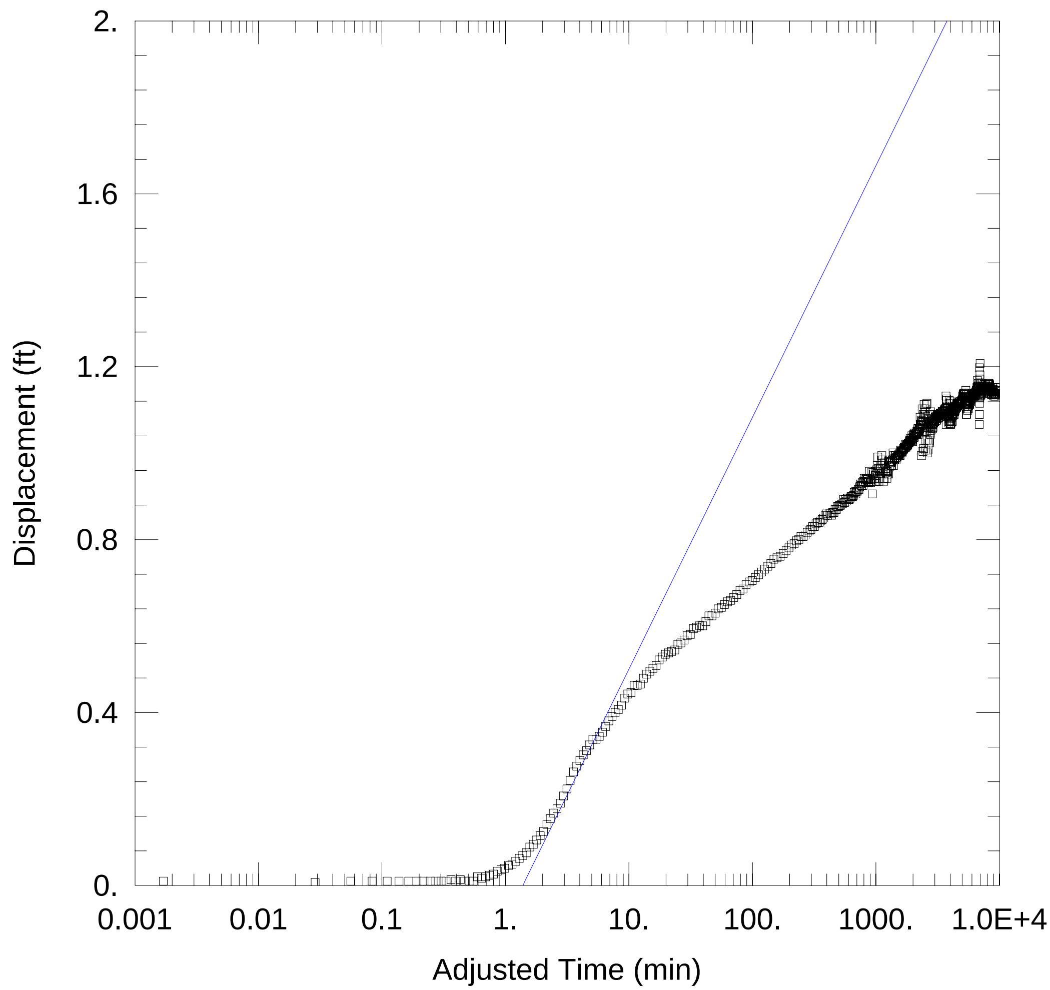
BORING LOGS/

WELL COMPLETION DIAGRAMS

APPENDIX B

AQUIFER TEST CALCULATIONS


Drawdown Response in Observation Wells
(Log Log Scale)
Carter Lake
Q = 1,070 gpm
Drawdown (Feet)
10
1
0.1
0.1
1
10
100
1000
10000
Time Since Start of Pumping (min)
OW 450
OW 150
OW 50



WELL TEST ANALYSIS

Data Set: H:\Common\Hydrology\Omaha\Omaha Office\Carter Lake\storage_OW450.aqt
Date: 04/30/07 Time: 14:48:59

PROJECT INFORMATION

Company: Layne
Client: Nex Gen BioFuels
Location: Council Bluffs Site
Test Well: TW-1 Pump Test
Test Date: 3/27/2007

AQUIFER DATA

Saturated Thickness: 78. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
TW1	0	0

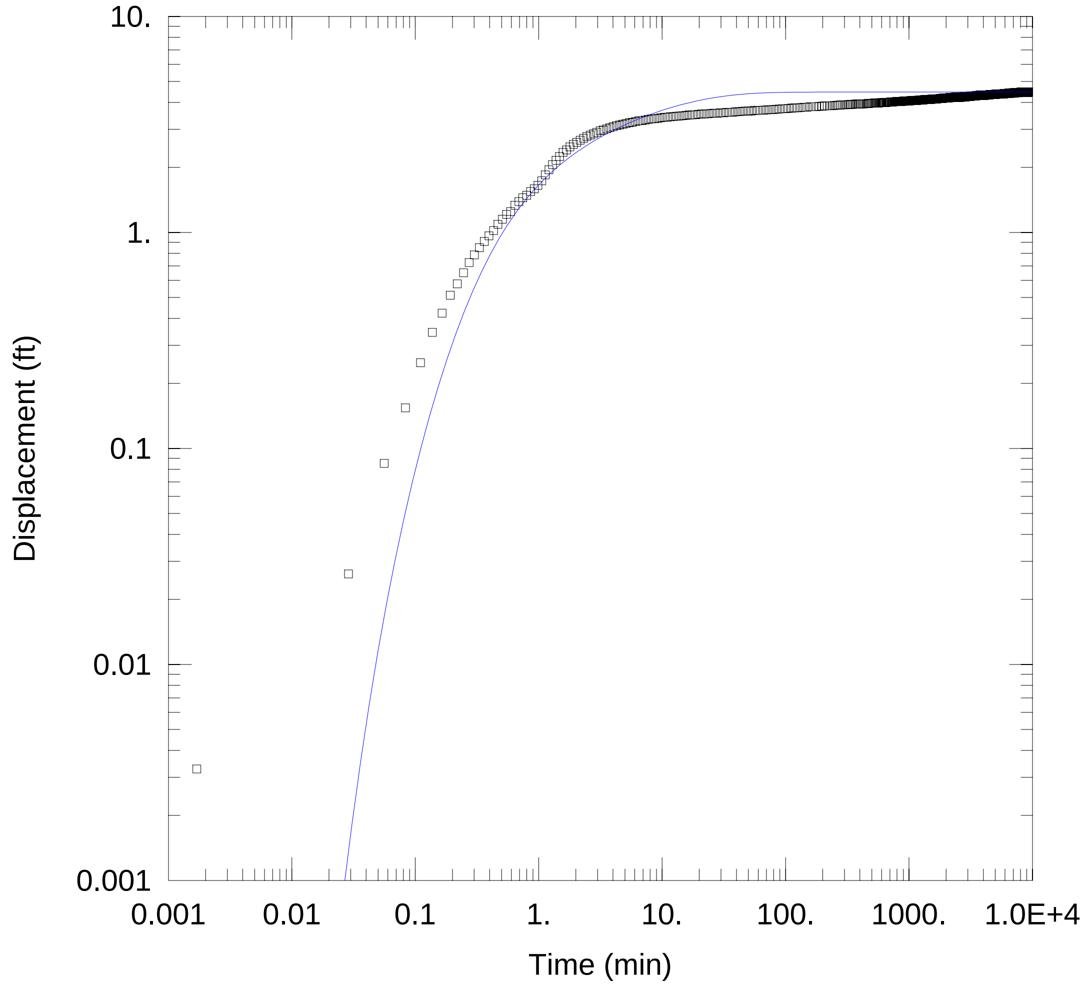
Observation Wells

Well Name	X (ft)	Y (ft)
□ OW450	450	0

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 6.481E+4 ft^2/day S = 0.000691



WELL TEST ANALYSIS

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Date: 04/30/07 Time: 14:54:31

PROJECT INFORMATION

Company: Layne
Client: Carter Lake
Location: Carter Lake, IA
Test Well: TW-1 Pump Test
Test Date: 3/24/2007

AQUIFER DATA

Saturated Thickness: 78. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
TW1	0	0

Observation Wells

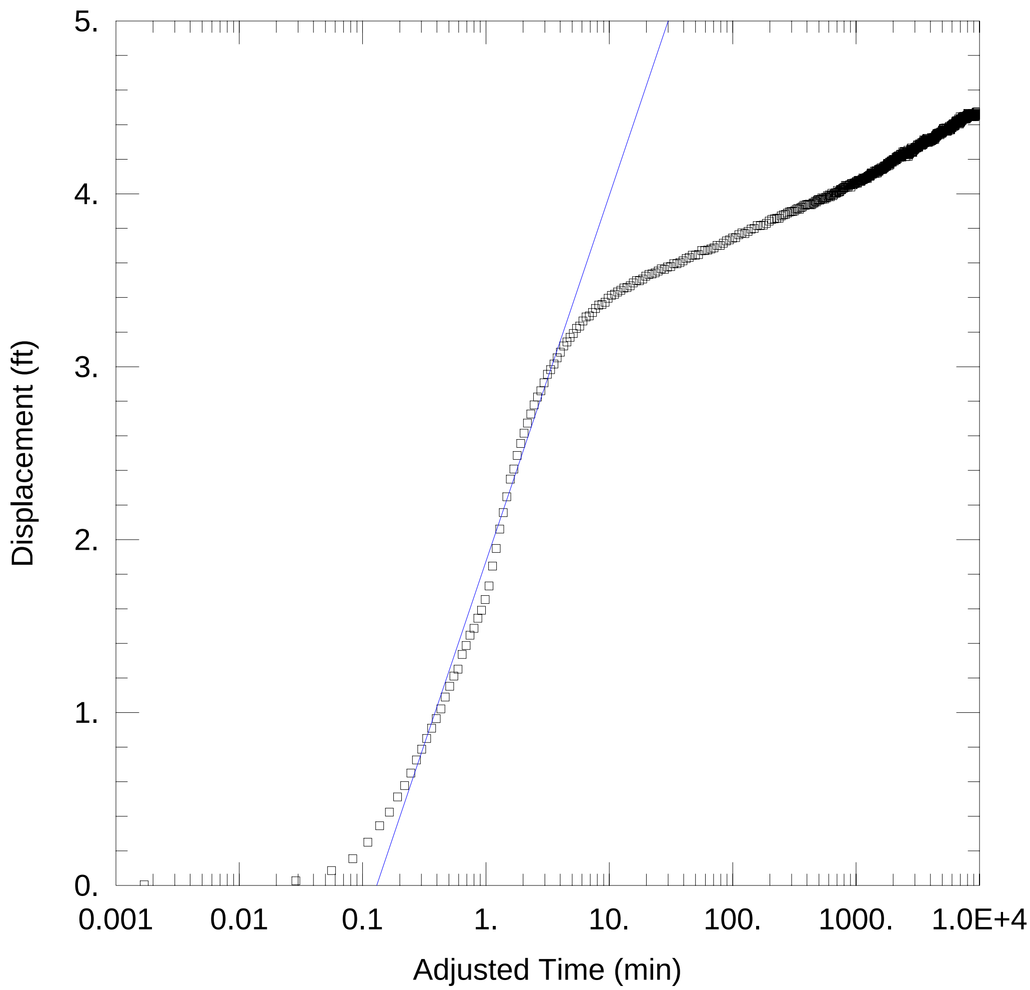
Well Name	X (ft)	Y (ft)
□ OW50	50	0

SOLUTION

Aquifer Model: Leaky
Solution Method: Moench (Case 3)

T = 1.783E+4 ft^2/day
r/B' = 0.1
r/B" = 0.
Sw = 0.

S = 0.001451
ß' = 0.008368
ß" = 0.
r(w) = 1. ft



WELL TEST ANALYSIS

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Date: 04/30/07 Time: 14:48:06

PROJECT INFORMATION

Company: Layne
Client: Carter Lake
Location: Carter Lake, IA
Test Well: TW-1 Pump Test
Test Date: 3/24/2007

AQUIFER DATA

Saturated Thickness: 78. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
TW1	0	0

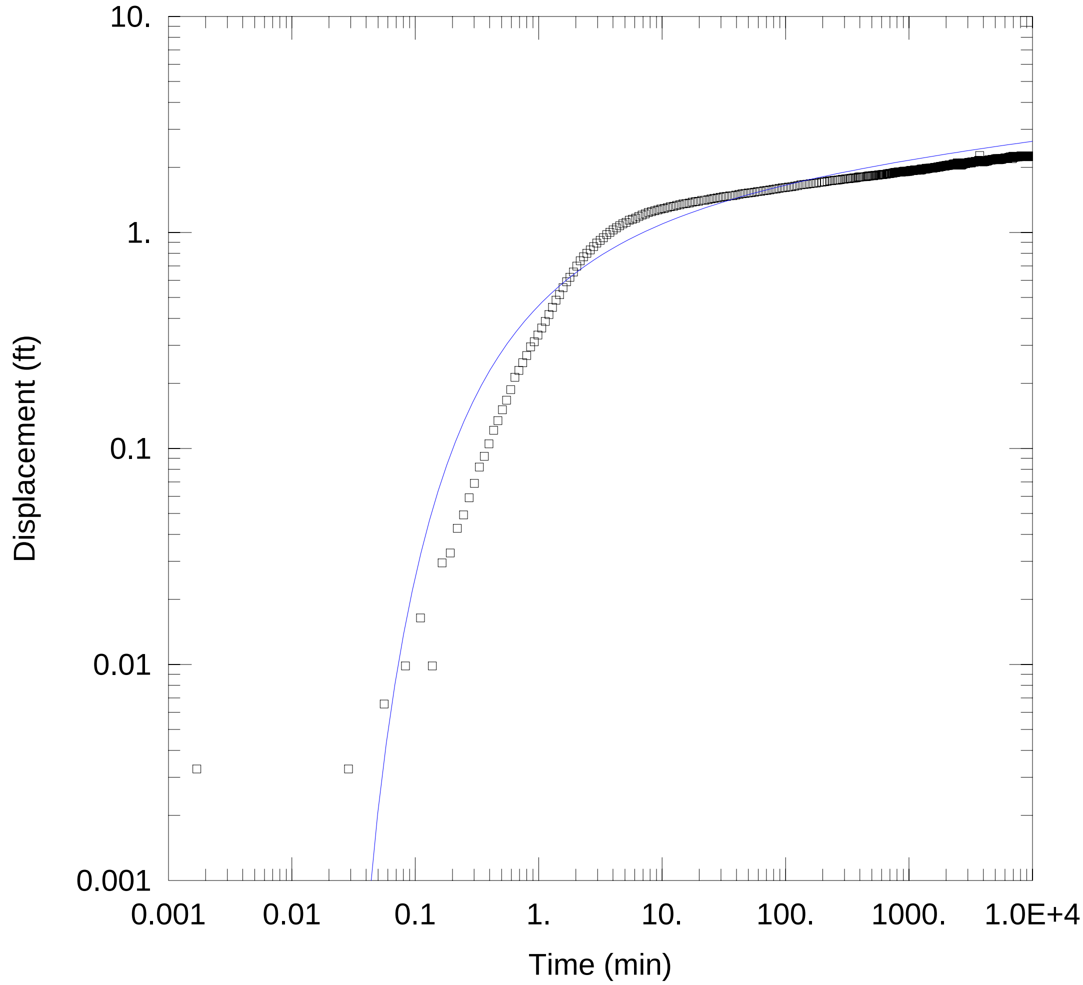
Observation Wells

Well Name	X (ft)	Y (ft)
□ OW50	50	0

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 1.783E+4 ft^2/day S = 0.001451



WELL TEST ANALYSIS

Data Set: H:\Common\Hydrology\Omaha\Omaha Office\Carter Lake\OW150.aqt
Date: 04/30/07 Time: 14:52:17

PROJECT INFORMATION

Company: Layne
Client: Nex Gen BioFuels
Location: Council Bluffs Site
Test Well: TW-1 Pump Test
Test Date: 3/27/2007

AQUIFER DATA

Saturated Thickness: 78. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
TW1	0	0

Observation Wells

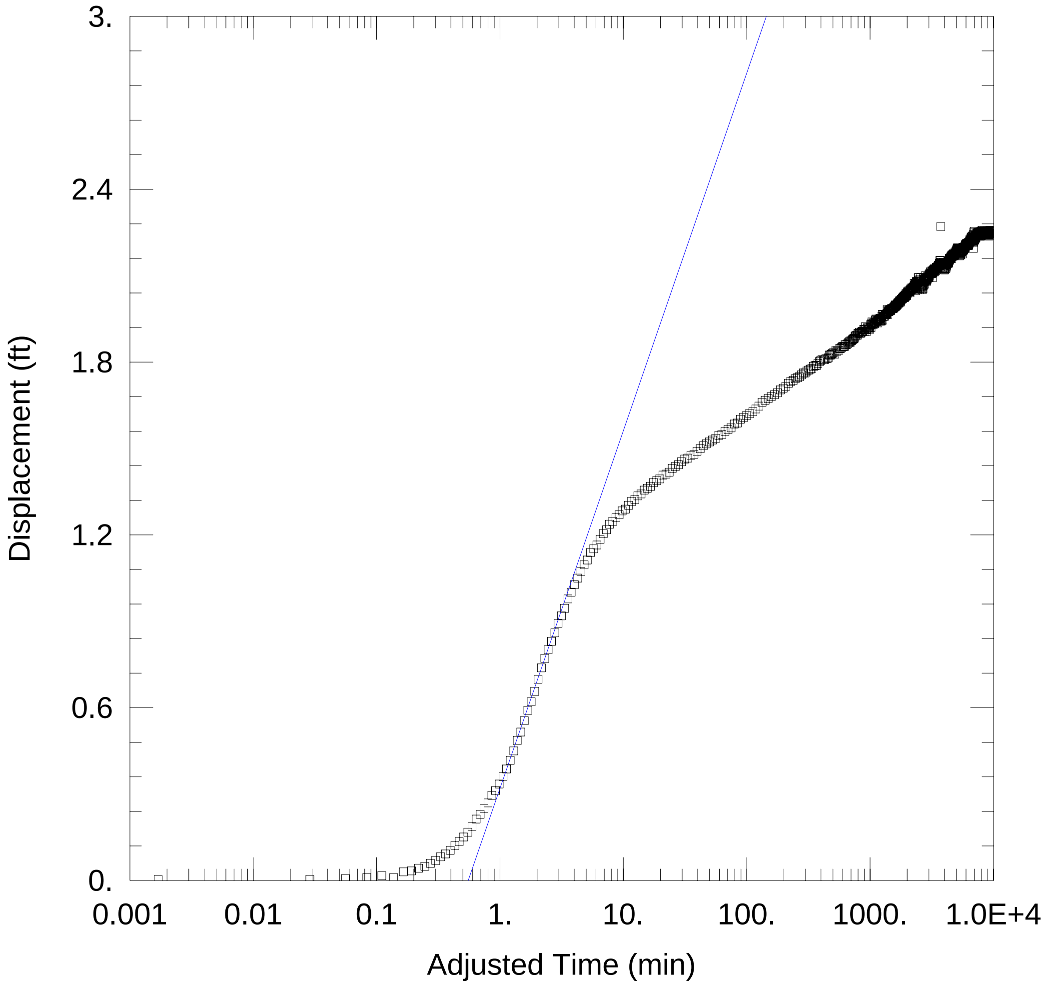
Well Name	X (ft)	Y (ft)
□ OW150	150	0

SOLUTION

Aquifer Model: Leaky Solution Method: Moench (Case 3)

T = 4.007E+4 ft^2/day
r/B' = 0.001079
r/B" = 0.
Sw = 0.

S = 0.0008071
ß' = 0.08128
ß" = 0.
r(w) = 0.5 ft



WELL TEST ANALYSIS

Data Set: H:\Common\Hydrology\Omaha\Omaha Office\Carter Lake\storage_OW150.aqt
Date: 04/30/07 Time: 14:51:08

PROJECT INFORMATION

Company: Layne
Client: Nex Gen BioFuels
Location: Council Bluffs Site
Test Well: TW-1 Pump Test
Test Date: 3/27/2007

AQUIFER DATA

Saturated Thickness: 78. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
TW1	0	0

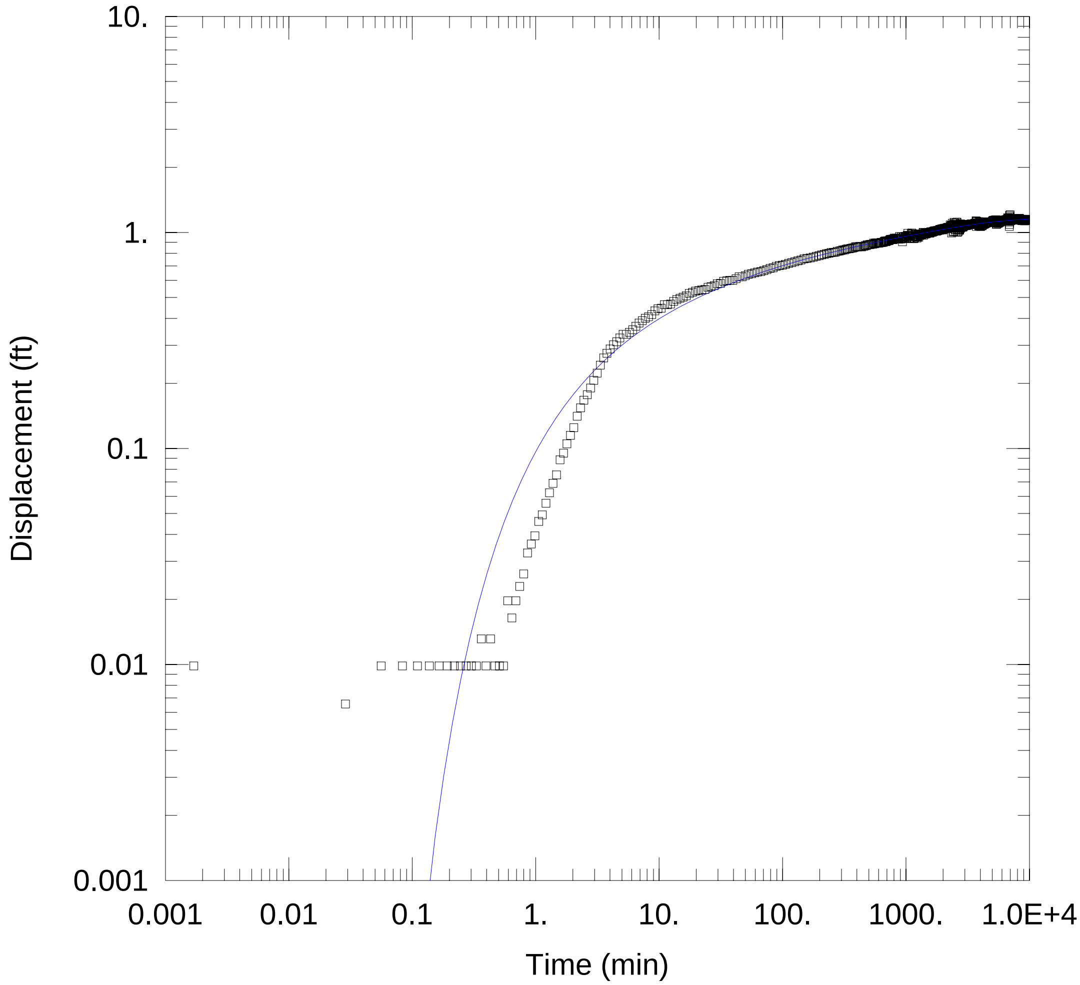
Observation Wells

Well Name	X (ft)	Y (ft)
□ OW150	150	0

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 3.039E+4 ft^2/day S = 0.001167



WELL TEST ANALYSIS

Data Set: H:\Common\Hydrology\Omaha\Omaha Office\Carter Lake\OW450.aqt
Date: 04/30/07 Time: 14:50:41

PROJECT INFORMATION

Company: Layne
Client: Nex Gen BioFuels
Location: Council Bluffs Site
Test Well: TW-1 Pump Test
Test Date: 3/27/2007

AQUIFER DATA

Saturated Thickness: 78. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
TW1	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ OW450	450	0

SOLUTION

Aquifer Model: Leaky
Solution Method: Moench (Case 3)

T = 8.312E+4 ft^2/day
S = 0.0005551
r/B' = 0.05858
ß' = 0.06748
r/B" = 0.
ß" = 0.
Sw = 0.
r(w) = 0.5 ft

Distance Drawdown
Data Analysis
Carter Lake, Iowa Aquifer Test

Carter Lake Distance Drawdown Analysis

	Test Data Distance from Pumped Well (feet)	Observed Drawdown (feet)
For time= 9660 min	50	4.47
	150	2.26
	450	1.15
From Chart	10	6.72
	100	3.24

Calculate T

$$T = \frac{2.3Q}{2\pi\Delta s}$$

	gpm	ft3/day
Q	1070	205989.3
	feet	
Δs	3.48	
	ft2/day	
T	21,667.75	

Calculate S

$$S = \frac{2.25\,Tt}{r_o^2}$$

ro (feet)	900
t(day)	6.7
S	0.4032609

APPENDIX C

LAKE/AQUIFER CONNECTION CALCULATIONS

CALCULATION - use near recharge source

Time to reach equilibrium near recharge source

$$t_e = \frac{a^2 S}{112 T \varepsilon \log\left(\frac{2a}{r}\right)^2}$$

Value	
	t_e = time required to reach approximate equilibrium (years);
400	a = distance from pumped well to line source of recharge (feet);
1	r = distance from pumped well to observation point (feet);
0.001	S = coefficient of storage (dimensionless);
160,000	T = coefficient of transmissivity (gpd/ft);
0.05	ε = deviation from absolute equilibrium (generally assumed to be 0.05).

Calculate time

3.08E-05 years

0.01 days