Carter Lake
Lake Level and
Groundwater Study

September 1998

THE SCHEMMER ASSOCIATES INC.

ARCHITECTS · ENGINEERS · PLANNERS

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September 15, 1998

Carter Lake City Council
City Hall
950 Locust Street
Carter Lake, IA 51510

RE: Carter Lake
Lake Level and Groundwater Study
Carter Lake Iowa
TSA Project No. 379006

Dear Council Board Members:

At your request, we have reviewed and analyzed the Missouri River, Carter Lake and groundwater levels. We have concluded that the seasonal changes in the Missouri River will affect local groundwater and lake elevations. The clay liner in the lake helps insulate the lake from quick rises in groundwater levels. The disadvantage of the clay liner is that once the lake is high, it will stay high for long durations. Lowering the lake level should also lower groundwater levels in town but the lake would have to be significantly lowered to make much of a difference.

The attached report discusses in further detail our findings. Please review the report and feel free to call us with any questions you may have.

We are pleased to be of service to you on this project and look forward to assisting you in the future

Sincerely,

THE SCHEMMER ASSOCIATES INC.
Architects-Engineers-Planners

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Civil Engineer

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Groundwater Study

September 1998
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Prepared for:

The City of Carter Lake
950 Locust Street
Carter Lake, Iowa 51510

Prepared by:

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Table of Contents

1.0 Purpose

This study sought to evaluate the qualitative relationship between Missouri River, Carter Lake and groundwater elevations. The relationship between these items will aid in operation of the lake water level control pump station, methods to limit basement flooding south of the lake, and to understand how the Missouri River fluctuations may impact localized flooding. It has been suggested that the lake elevation is not directly related to groundwater but is primarily a function of storm water runoff and evaporation. Rainfall data from the Eppley Airport rain gauge was also used to evaluate the effect of rainfall on lake elevations.

2.0 Background

The City of Carter Lake, Iowa is located near an old oxbow of the Missouri River on the Iowa western border. The oxbow was isolated from the Missouri River main channel in the 1880s. Currently, the Missouri River levee separates the floodplain from the lake and several storm sewers empty into the lake. The storm sewer contributing area is 2,230 acres of urban development.

The water elevation of the lake has been a concern for numerous years dating back to the 1920s. Low lake levels restrict recreational boating and fishin g. High lake levels, however, cause localized flooding damage, bank erosion and may raise groundwater causing basements to flood in the City.

The City of Omaha currently has two systems in place for maintaining water surface elevations for the lake. One system uses an pump station at the lake to withdrawl water from Carter Lake. The lake water is forced into an 18 inch diameter pipe and routed into an 54-inch diameter Storz Expressway Force main that outlets at the Missouri River.

The second system uses a pump structure located in the Missouri River Barge Channel to withdrawl water from the River and pump it to Carter Lake. The river water is pumped into an 24 inch diameter pipe that is routed into the 54" diameter Storz Expressway Force Main. The water then backflows into the Storz Expressway Pump Station. From this location an 18 inch diameter pipe gravity flows to the Lake.

The same submersible pump is used interchangeably for both systems. The capacity of the pump when used to deliver water to the lake is approximately 2,100 gpm. Its capacity exceeds the average net evaporation loss (4.0 inches) for the worst typical month. This equates to 785 gpm. The pump, however, can not create a significant water level drop in the Lake elevation during the rainy season.

A new pump station is currently being constructed on the north shore of Carter Lake to lower high water levels. The system consists of a 9,000 gpm pump and 2,500 feet of 24" diameter piping. The system will withdraw water from Carter Lake and tap the Storz Expressway Pump Station force main. This is a similar configuration to the existing 18" line only with 12 times the capacity. The expected rate the lake can be lowered with this new system is 1.5 inches per day assuming no groundwater interactions and no additional precipitation. The system is expected to be operational by the end of 1998.

Several piezometer wells have been installed in the Carter Lake and Missouri River area. The wells and the lake level have been monitored sporadically by various groups for numerous years dating back to the 1950s. This study concentrated on the data collected between July 11, 1988 and December 14, 1990. The well locations are indicated on Figure One.

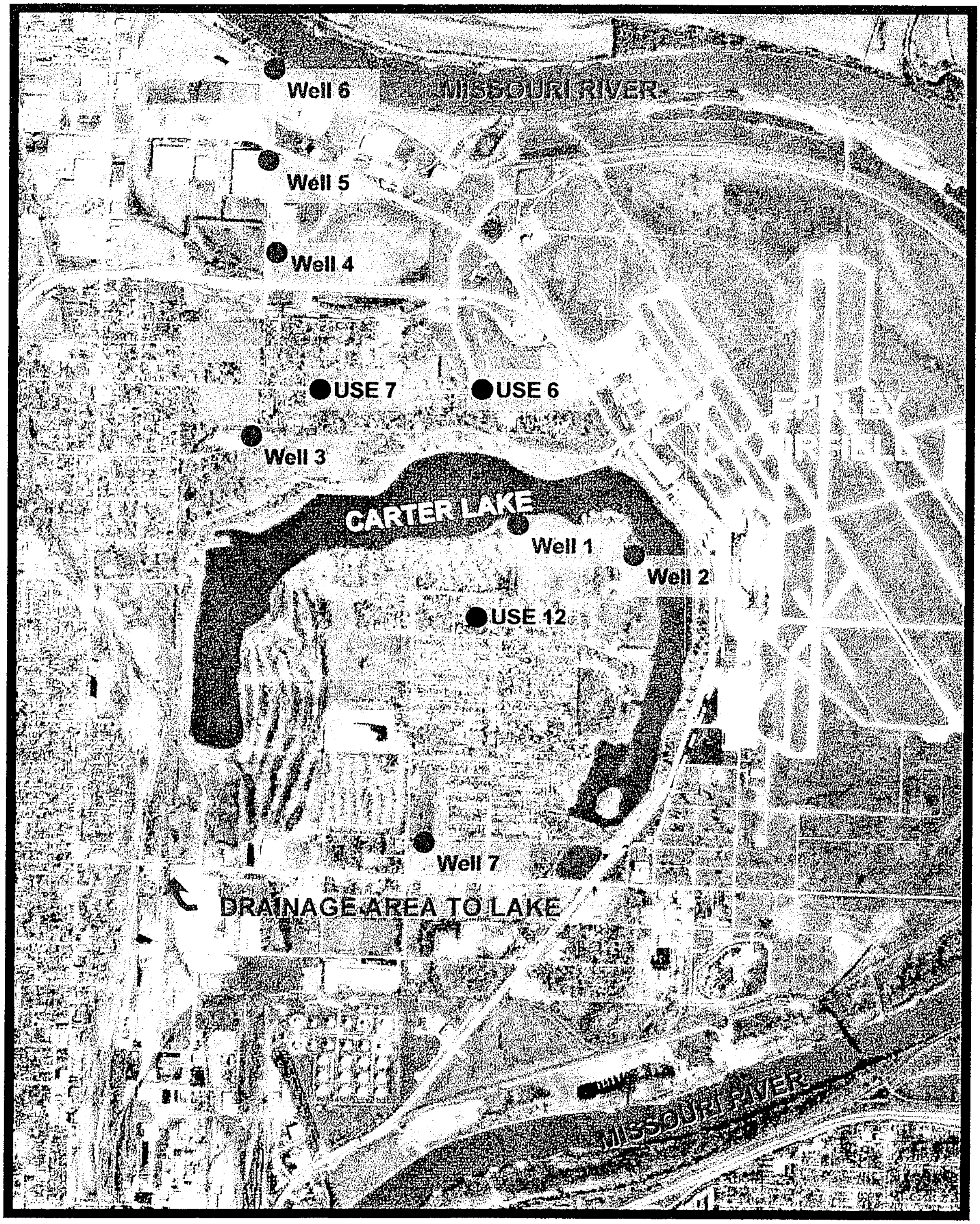


FIGURE ONE - SITE VICINITY

3.0 Collected Data

Groundwater elevations were measured in eight piezometer wells in the local area over the two-year time period studied. Figure One indicates the wells designation and location with respect to the Missouri River and Carter Lake. The groundwater measurements varied from nearly daily data to seasonal data. Also, during this time period, the Carter Lake and Missouri River surface water elevations were collected. Not all of the wells were measured on a sampling day, and the time of day of each measurement was also not recorded. Rainfall data from Eppley Airport was also compared to the sampling period. In order to see the net effect of rainfall, the culminated rainfall that fell between the groundwater measurement dates were used. The largest gap in the groundwater data is from July 31, 1989 to January 2, 1990. The individual collecting the data was ill during this period. The summarized data is listed in Appendix A. Figure Two is a graphical presentation of the data collected.

As mentioned previously, the water level of Carter Lake can be artificially controlled by pumping water into or out of the lake. The City of Omaha operated the pumping stations and no records were kept of the amount or how often water was either pumped into or withdrawn from the lake. It was thought a small amount of water was pumped into the lake during this time period. In June of 1988, utility trenches were dewatered for construction puposes at the nearby Eppley Airport. The dewatering lowered the groundwater water approximately 1.7 feet for nearly the entire month.

4.0 Rainfall Influence

Graphically the data was broken into individual areas to observe possible correlations. Figures Two through Four compare the data sets to lake and river levels. Figure Two and Three displays the rainfall, river and lake levels over the time period. The magnitude of the change in river levels of six feet or more was not duplicated by the lake. Also, sharp peaks in the river elevations appear to coincide to precipitation events. Again the magnitude of the change in river elevation were not duplicated in the lake levels due to the precipitation.

Carter Lake Groundwater Study
Observed Water Levels

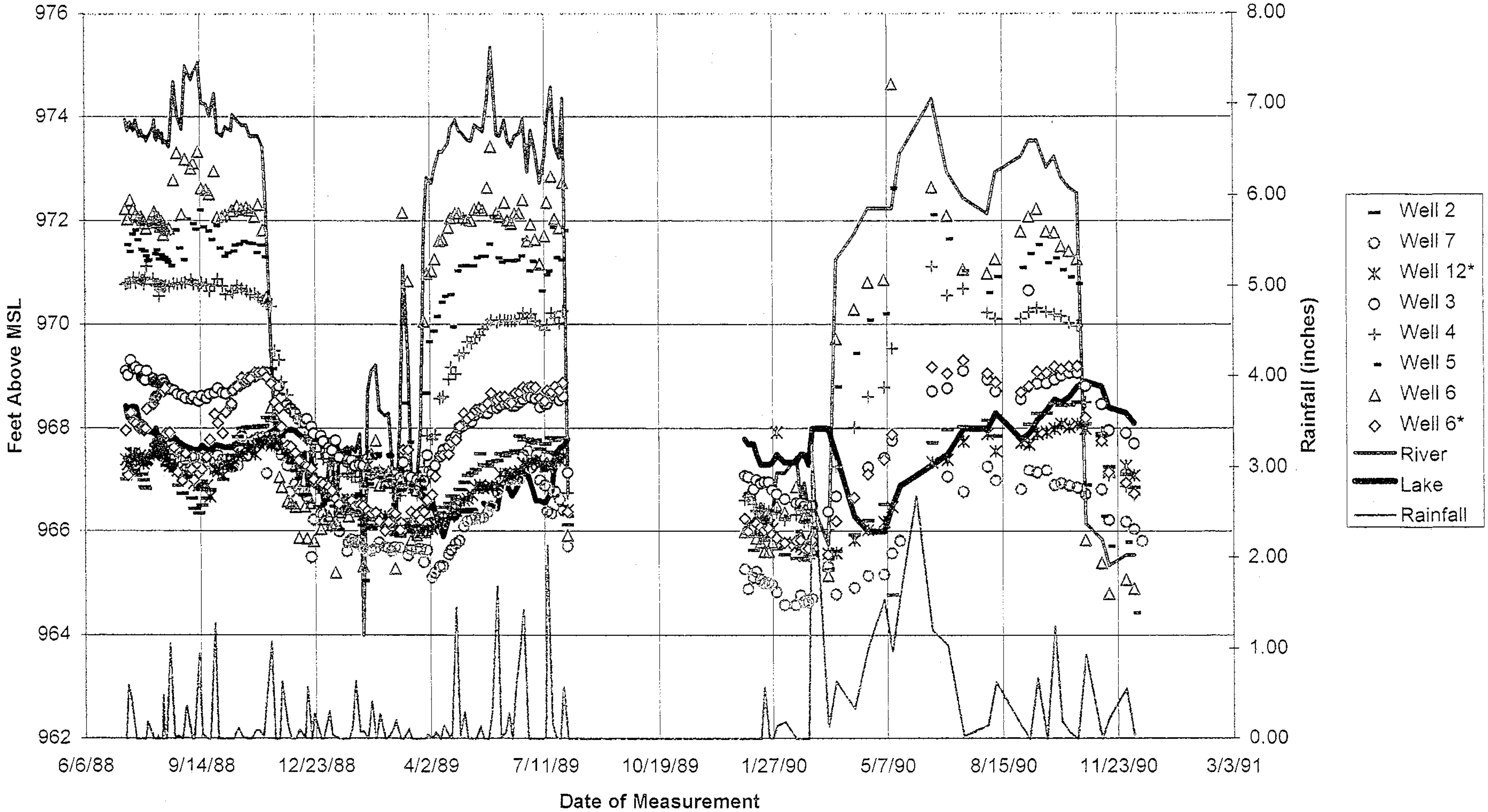


Figure Two

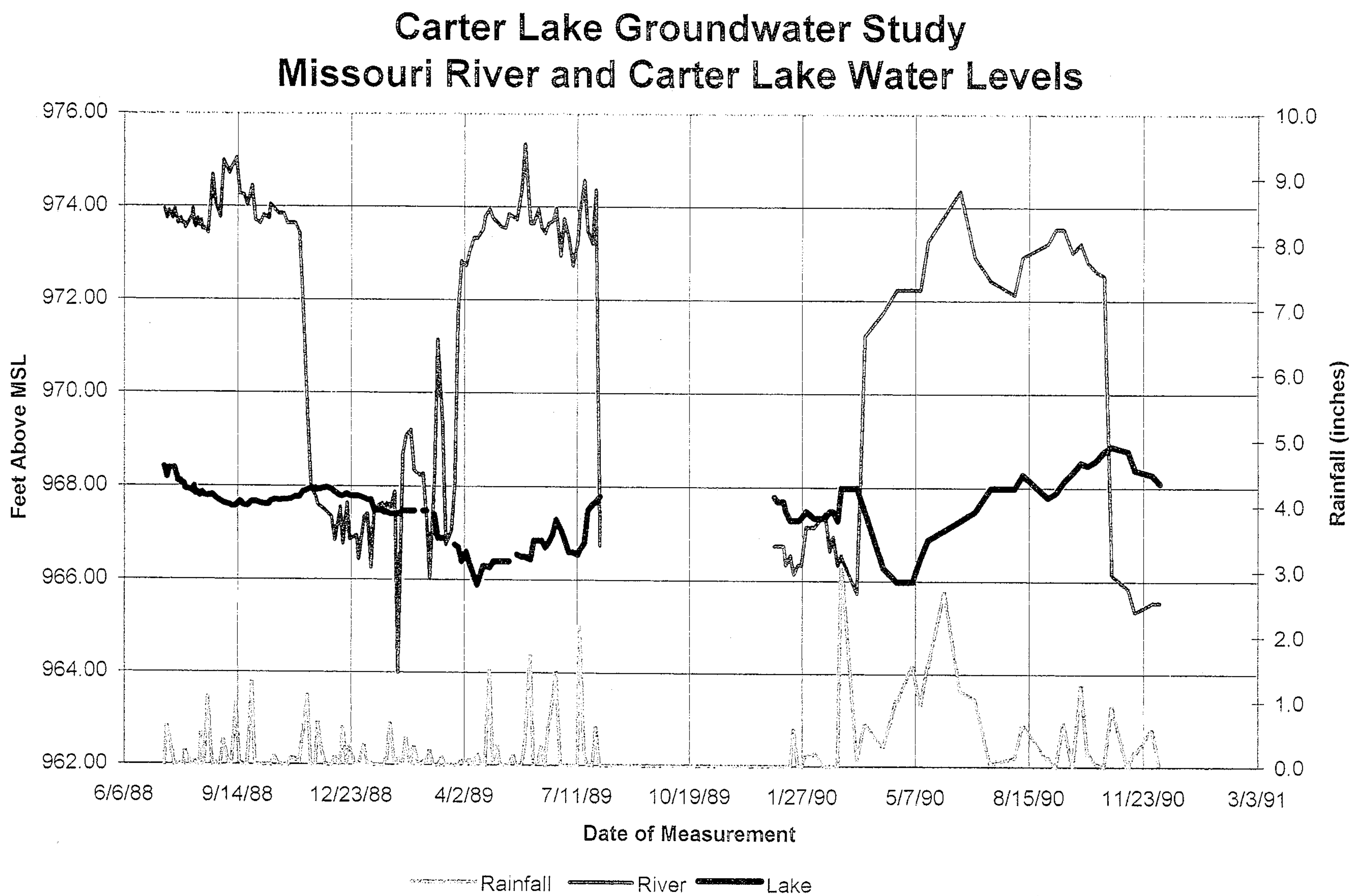


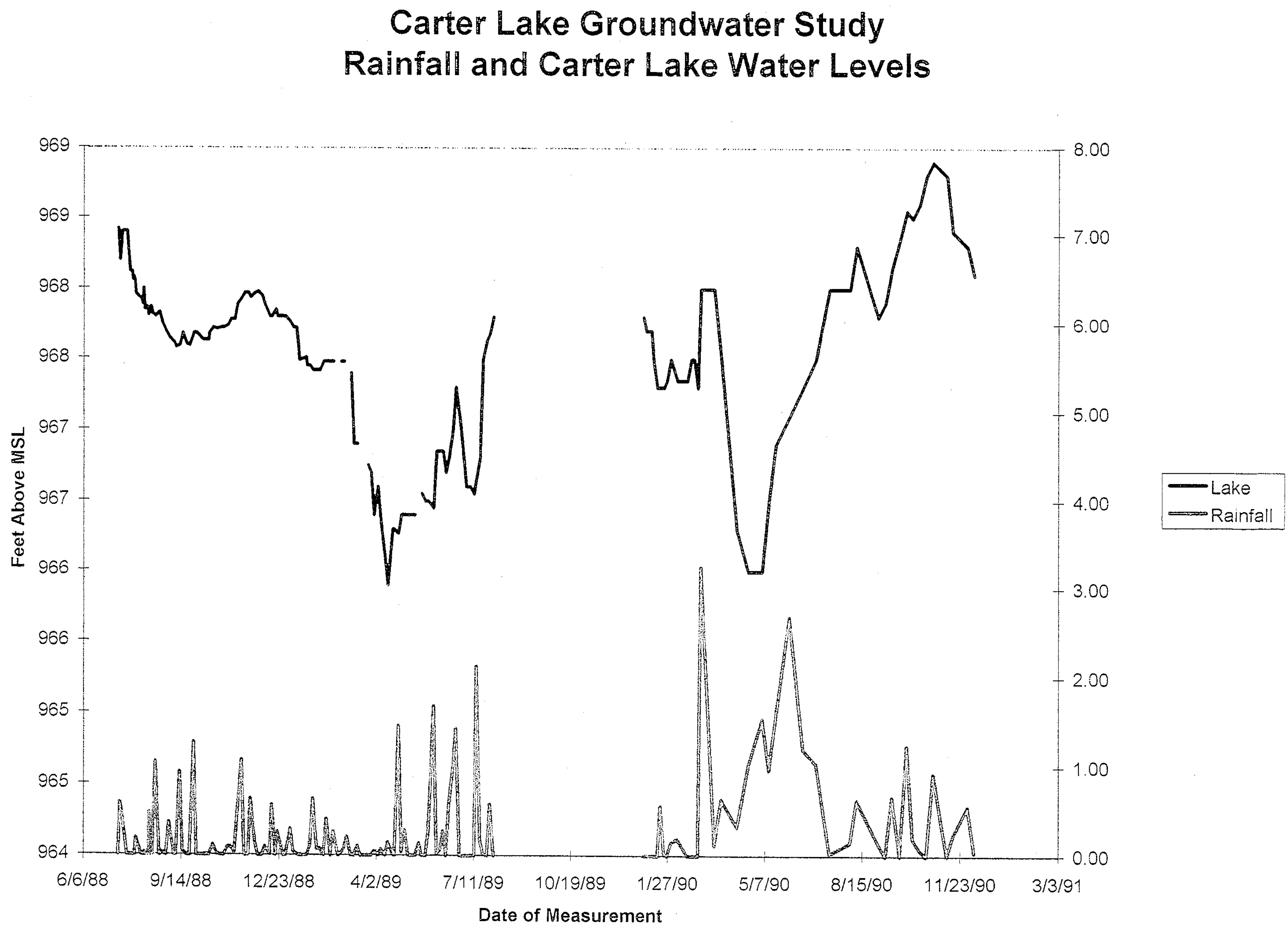
Figure Three

Figure Four compares rainfall to lake levels. A general relationship is noticed in 1990 with sharp rainfall peaks roughly coinciding with peak lake elevations but several small discrepancies are noticeable. The large drop in elevation in April/May appears to counter the rainfall data. Some loss would be expected by evaporation, but April and May are not the large evaporative months. The rainfall in September of 1988 is comparable to the rainfall in September of 1990, but the lake elevation trend is in opposite directions for the corresponding times. It appears the lake is influenced by rainfall events, but rainfall alone is not a direct indicator of anticipated lake levels. A more elaborate analysis of runoff volumes and evaporation losses could be performed to attempt to show a more direct correlation. At the level of this study, a more elaborate and costly method was determined unnecessary to accomplish the study purpose.

5.0 Groundwater Influence

Figures Five through Seven display groundwater elevations and adjacent surface water elevations. Figure Four shows the Missouri River level and groundwater elevations measured in wells located north of the Lake for the period of study. It is expected these wells would be strongly influenced by river elevations and it appears they are. The wells that are closer to the river indicate a direct correlation to the river fluctuations. As the locations of the well move away from the river the fluctuations become dampened and tend to average out. The dominant observation on Figure Four is the large effects the change in water levels from navigation season versus the non-navigation river level have on groundwater. Groundwater levels near the river drop over six feet and all of the wells north of the lake to some degree reflect this cyclic trend. The summer groundwater flow direction appears to be southerly. The groundwater flow direction in wells four, five and six, however, reverse and start flowing toward the river during the winter months. The groundwater elevations close to the river reflect short term fluctuations while the more distant wells reflect long term averages.

Figure Six indicates the groundwater elevations adjacent to Carter Lake. Wells two and six* are separated by Carter Lake. If Carter Lake is hydraulically connected to the groundwater flow, then it would be expected that wells two and six* would behave differently depending on the elevation of Carter Lake. If Carter Lake is hydraulically separate from groundwater then wells two and six* should behave similar as if Carter



Carter Lake Groundwater Study
Rainfall and Carter Lake Water Levels
969
969
968
968
967
967
966
966
965
965
964
Feet Above MSL
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
6/6/88
9/14/88
12/23/88
4/2/89
7/11/89
10/19/89
1/27/90
5/7/90
8/15/90
11/23/90
3/3/91
Date of Measurement
Lake
Rainfall

Figure Four

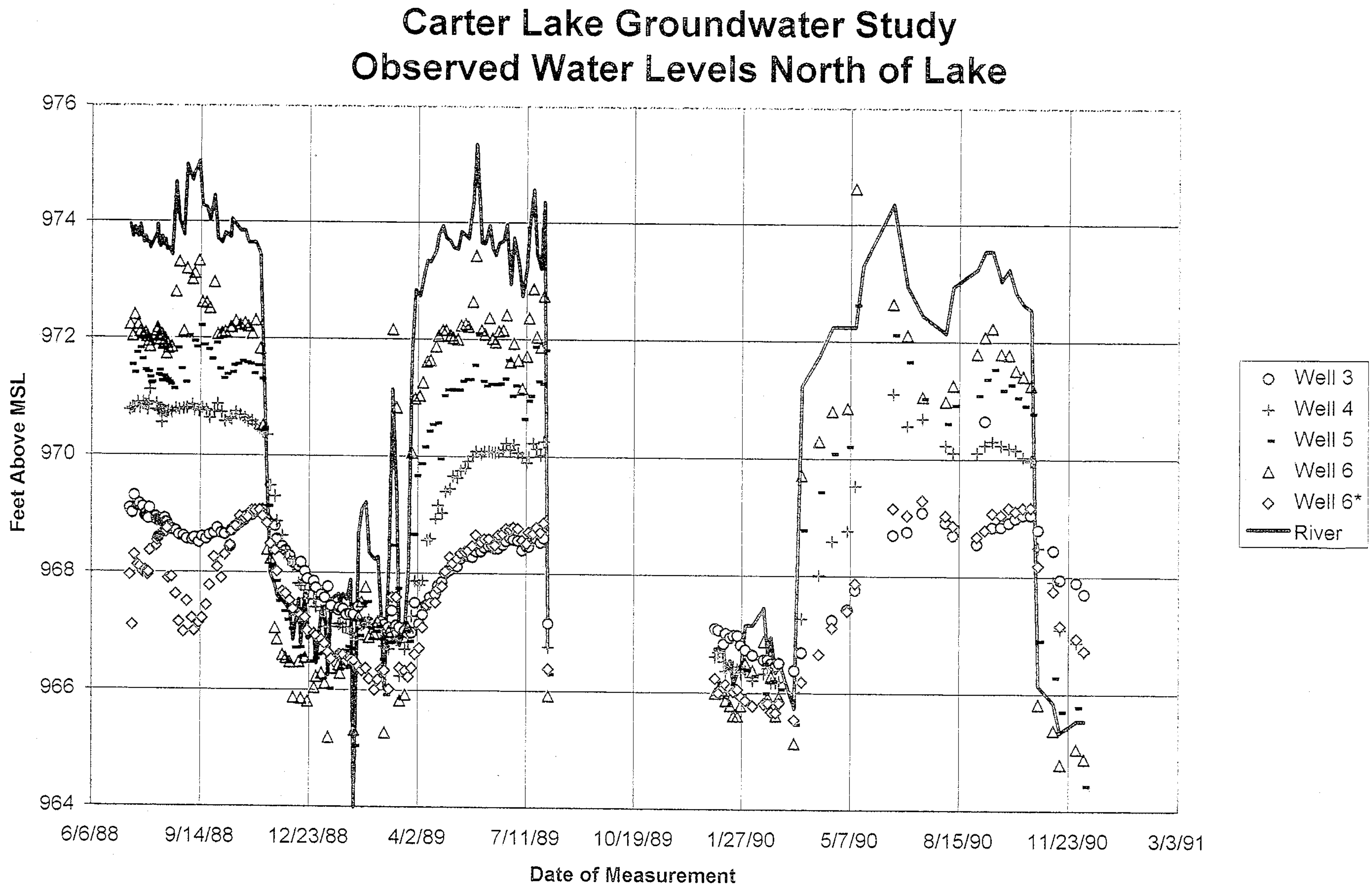

Carter Lake Groundwater Study
Observed Water Levels North of Lake
976
974
972
970
968
966
964
Feet Above MSL
6/6/88
9/14/88
12/23/88
4/2/89
7/11/89
10/19/89
1/27/90
5/7/90
8/15/90
11/23/90
3/3/91
Date of Measurement
Well 3
Well 4
Well 5
Well 6
Well 6*
River

Figure Five

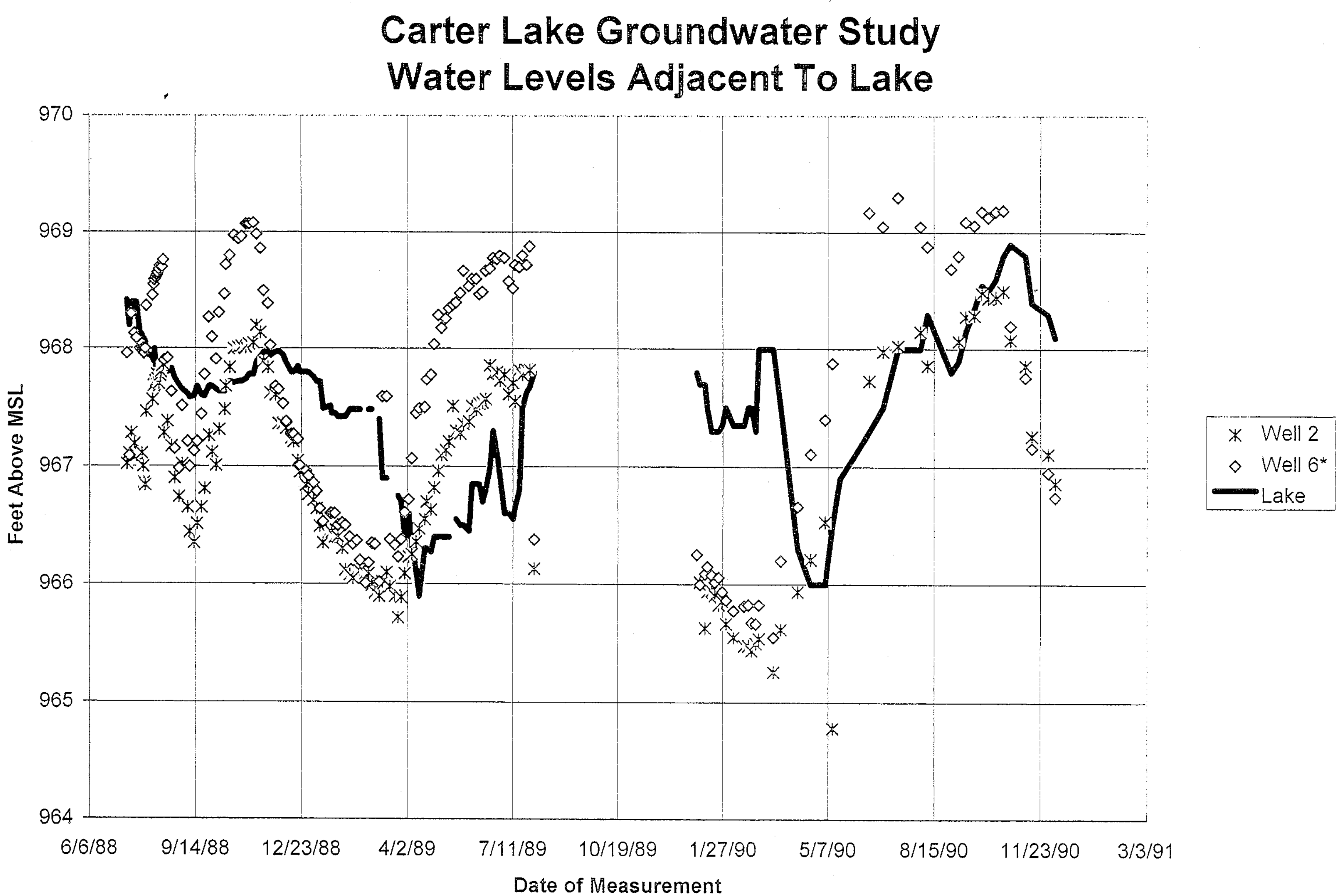

Carter Lake Groundwater Study
Water Levels Adjacent To Lake
970
969
968
967
966
965
964
Feet Above MSL
6/6/88
9/14/88
12/23/88
4/2/89
7/11/89
10/19/89
1/27/90
5/7/90
8/15/90
11/23/90
3/3/91
Date of Measurement
Well 2
Well 6*
Lake

Figure Six

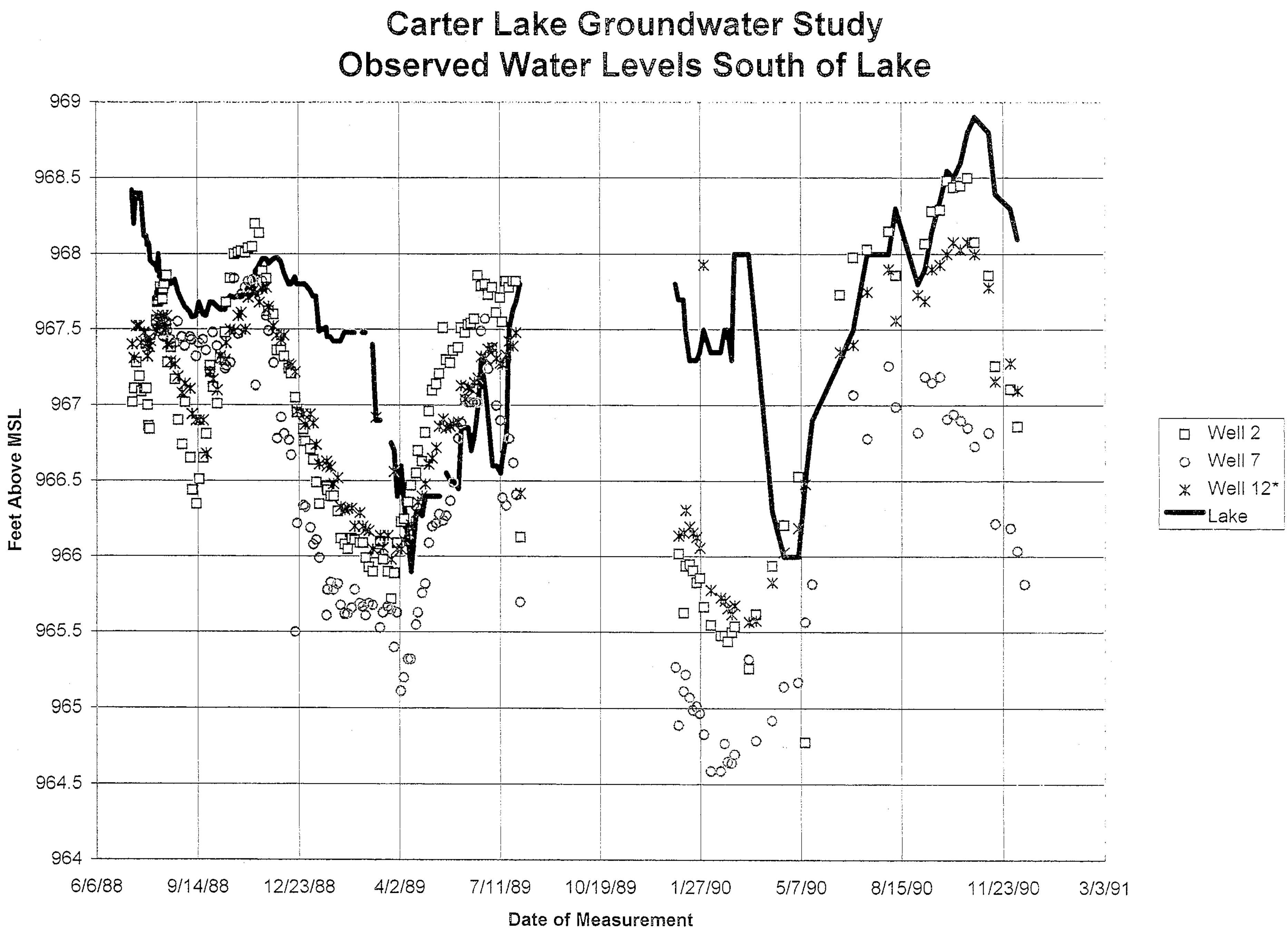


Figure Seven

Lake was not separating the two. From Figure Six, it appears groundwater changes north of the lake are parallel to changes south of the lake without a direct reflection in Carter Lake. In other words, wells two and six* are more strongly connected than well two or well six* are to the lake. From Figure Seven the lake does appear to be influenced by groundwater south of the lake but with a short lag time. If the lake was totally independent of groundwater then the lake elevation would not be located as close in elevation and tend to follow groundwater trends for the bulk of the period.

It also is noticed the lake poorly follows the groundwater decreases and will stay one to two feet higher in elevation for up to four months. This pattern is not surprising. Several communities with lakes in a major river valley have observed the same pattern. Generally, the lake will rise within a day or two following a rise in the river and will take several months for the lake to drain back down. The Village of Cedar Creek, Nebraska in the Platte River Valley has experienced this phenomenon and is located within 200 feet of the Platte River. Also, Base Lake at Offutt Air Force Base located in the Missouri River Valley is also believed to behave in this similar manner. What is surmised, but not well documented, is that the layer of fine material that covers the bottom of the lake will seal when the lake is higher than the adjacent groundwater. The fine material conversely is separated or "lifted" when the adjacent groundwater is higher than the lake level and groundwater can more easily enter the lake. It is believed the fine material layer does act as a barrier to groundwater flow in all cases. But, the amount of resistance is variable depending on the direction of flow. The effect of this phenomenon is that once the lake level rises it will remain high for extended durations with only a slow amount of seepage back into the groundwater. When the lake is higher than groundwater, then wells two and six* would be expected to fluctuate somewhat independent of the lake.

Borings taken by the Corps of Engineers in the late 1950s found a layer of clay lining the lake which varied from 3 to 19 feet thick. This clay lining was naturally deposited from frequent Missouri River flooding events prior to construction of the 1952 flood levee. Dredging operations over the years have lessened the thickness and may have penetrated the clay liner in a few areas. The thinner the clay liner the more apt the lake is to fluctuate with the river rises and behave similar to other river valley lakes.

Figure Seven shows the data from the three wells south of the lake, rainfall, and lake elevations over the study period. The rainfall peak on March 16, 1990 showed a strong correlation to lake level rises without showing a groundwater rise. This pattern is typical for the small rises and falls in the lake level. The long term trend however is to gravitate toward the groundwater elevations rather than diverging. It appears rainfall would dominate short term changes with groundwater governing the long term trends.

The cause effect relationship is difficult to determine with the several variables involved. It is anticipated that maintaining Carter Lake during the summer at an elevation higher than the adjacent groundwater would tend to marginally raise the local groundwater levels. The clay liner would retard the effects of the higher lake level but hydrostatic pressures would eventually seek to lower the lake and raise groundwater. It is expected that the groundwater flow rate in the sandy aquifer is much higher than the lake seepage rate indicating that the additional seepage from the lake would only marginally raise the groundwater levels in town.

Lowering the lake below the adjacent groundwater levels may have a more notable effect. It appears the lake is more likely to receive groundwater flows than to supplement groundwater flows. Dewatering the lake would likely lower the water table but the lag time is likely to be on the order of weeks. It is expected the area of groundwater lowering would be limited due to the presence of the Missouri River as the predominate source of groundwater. Withdrawals from the lake would likely be more cost effective than attempting to install numerous well points depending on the exact area desired to be dewatered. Lowering the lake several feet below groundwater, however, may not be conducive to recreation.

Another method used to seek interrelationships with large data sets is to use a covariance coefficient. The covariance coefficient varies from one to negative one. A coefficient of one indicates a strong linear relationship between the two data sets with zero indicating a lack of correlation. A negative one indicates a negative or opposite correlation such as when one data set rises the other falls. Table One summarizes the covariant coefficients calculated between the data sets. No attempt to lag or adjust the data due to spacial distances were made. It can be noted that Well 12* has the highest correlation to the Carter Lake levels. Well 12* is located south of the lake and a near the residential portion of the City. The groundwater at Well 12* to more strongly related to the lake than Well 2 which is located adjacent to the lake. Well 12* appears to be related to the lake through possible sand seams or that the clay liner is punctured at some location that relates to Well 12*. This further supports the argument that Carter Lake is influenced by groundwater. This method is not with out flaws. This method does not show a cause effect relationship only that the data sets change similarly to each other. The rainfall data also shows no correlation to river levels, groundwater or lake levels. As mentioned previously, a more sophisticated model using estimated runoff volumes and evaporation losses would likely show a greater correlation.

	Well 7	Well 12*	Well 3	Well 4	Well 5	Well 6	Well 6*	River	Lake	Rainfall
Well 2	0.84	0.89	0.87	0.74	0.58	0.49	0.91	0.51	0.35	0.03
Well 7	1.00	0.81	0.89	0.86	0.69	0.61	0.82	0.62	0.31	0.03
Well 12*	0.81	1.00	0.87	0.72	0.52	0.43	0.81	0.43	0.55	-0.03
Well 3	0.89	0.87	1.00	0.90	0.76	0.68	0.87	0.69	0.37	-0.01
Well 4	0.86	0.72	0.90	1.00	0.93	0.88	0.85	0.89	0.14	0.04
Well 5	0.69	0.52	0.76	0.93	1.00	0.98	0.79	0.99	-0.12	0.08
Well 6	0.61	0.43	0.68	0.88	0.98	1.00	0.73	0.99	-0.21	0.07
Well 6*	0.82	0.81	0.87	0.85	0.79	0.73	1.00	0.73	0.11	0.08
River	0.62	0.43	0.69	0.89	0.99	0.99	0.73	1.00	-0.21	0.09
Lake	0.31	0.55	0.37	0.14	-0.12	-0.21	0.11	-0.21	1.00	-0.11

Table One - Correlation Coefficients

6.0 Summary

Groundwater in the vicinity of Carter Lake is dominated by seasonal Missouri River elevations. The Missouri River short peaks in stage due to rain storms were weakly observed in the groundwater elevations as monitoring points moved further from the river. Carter Lake is sufficiently remote from the Missouri River that the daily river peaks were not reflected in groundwater elevations. The groundwater elevations near Carter Lake did show a strong seasonal relationship to changes in Missouri River elevations. The long term average of the lake is to gravitate toward groundwater elevations near the lake. The lake is covered with a natural clay liner deposited by the Missouri River. The clay liner further retards groundwater movement into and out of the lake. The lake appears to rise more readily than it decreases with changing groundwater levels. Major rainfall events influenced the Missouri River and Carter Lake elevations. The impact of runoff on river elevations were larger than the impact of runoff on lake levels. It appears the Missouri River, Carter Lake and groundwater are all part of the same hydrologic unit and changes in one influences the others. The magnitude of the response vary with the Missouri River having the largest response and Carter Lake having the least response to changes in precipitation, seasonal fluctuations and groundwater influence.

The new pump station will greatly help reduce the time the lake remains at high levels. Flood damages should be reduced along the shoreline and to a lessor degree decrease groundwater elevations in town. During periods of high groundwater and high lake levels, some shoreline and basement flooding should be expected until the pump is able to remove runoff and groundwater inflows. The piezometer wells could be used in conjunction with rainfall data to help warn the population of Carter Lake of the anticipated duration and severity or flood of if special temporary dewatering measures are necessary.

Appendix A
Data Summary

Recorded Water Elevations (ft.)
Carter Lake Piezometer Study
Project No. 379006

* = USE location

Date	Culmative time days	Location										Rainfall over Period inches
		Well 2 ft msl	Well 7 ft msl	Well 12* ft msl	Well 3 ft msl	Well 4 ft msl	Well 5 ft msl	Well 6 ft msl	Well 6* ft msl	River ft msl	Lake ft msl	
7/11/88	0	966.78		967.40	967.96	970.99	971.57	972.2	967.96	973.85		0.00
7/13/88	2	967.02		967.40	969.10	970.78	971.54	972.24	967.96	973.95	968.42	0.00
7/15/88	4	967.11		967.31	969.02	970.81	971.41	972.04	967.09	973.75	968.20	0.59
7/18/88	7	967.28		967.52	969.31	970.82	971.75	972.41	968.30	973.91	968.40	0.46
7/20/88	9	967.19		967.52	969.14	970.91	971.83	972.24	968.13	973.75	968.40	0.18
7/23/88	12	967.09		967.41	969.17	970.81	971.64	972.12	968.09	973.95	968.4	0.00
7/25/88	14	967.11		967.48	969.12	970.91	971.46	972.07	968.00	973.65	968.12	0.00
7/26/88	15	967.11		967.40	968.97	970.86	971.42	972.10	968.04	973.75	968.12	0.00
7/27/88	16	967.00		967.32	969.00	970.86	971.42	972.03	968.00	973.65	968.06	0.00
7/28/88	17	966.86		967.40	968.95	970.78	971.33	972.03	967.96	973.65	968.08	0.00
7/29/88	18	966.84		967.38	968.92	970.91	971.23	971.96	968.00	973.65	968.06	0.00
8/4/88	24	967.46		967.42	969.10	971.13	971.25	971.86	968.37	973.55	967.96	0.19
8/5/88	25	967.56		967.49	968.95	970.89	971.37	972.13	968.46	973.81	967.92	0.00
8/6/88	26	967.68		967.59	968.89	970.78	971.45	972.18	968.55	973.95	967.89	0.00
8/7/88	27	967.69		967.55	968.59	970.77	971.35	972.04	968.59	973.62	968.00	0.00
8/8/88	28	967.72		967.52	968.91	970.75	971.27	971.98	968.61	973.57	967.85	0.03
8/9/88	29	967.78		967.54	968.89	970.76	971.35	972.07	968.63	973.65	967.85	0.00
8/10/88	30	967.74	967.55	967.56	968.87	970.56	971.35	972.07	968.65	973.75	967.87	0.00
8/11/88	31	967.70	967.45	967.56	968.87	970.76	971.31	971.90	968.68	973.62	967.86	0.00
8/12/88	32	967.77	967.49	967.59	968.89	970.76	971.27	971.94	968.71	973.60	967.81	0.00
8/13/88	33	967.80	967.54	967.53	968.93	970.75	971.29	971.99	968.71	973.70	967.83	0.48
8/14/88	34	967.85	967.53	967.50	968.86	970.74	971.25	971.74	968.70	973.52	967.87	0.00
8/15/88	35	967.86	967.49	967.59	968.85	970.74	971.25	971.92	968.76	973.55	967.86	0.00
8/18/88	38	967.28	967.43	967.40	968.79	970.76	971.21	971.84	967.90	973.55	967.82	0.00
8/22/88	42	967.38	967.41	967.29	968.75	970.74	971.14	971.86	967.92	973.44	967.80	1.05
8/25/88	45	967.17	967.55	967.27	968.72	970.80	971.83	972.80	967.63	974.68	967.83	0.00
8/29/88	49	966.90	967.45	967.19	968.65	970.78	971.48	973.32	967.15	974.03	967.75	0.03
9/1/88	52	966.74	967.39	967.08	968.63	970.80	971.25	972.13	966.98	973.78	967.69	0.00
9/6/88	57	967.02	967.45	967.14	968.58	970.82	972.04	973.20	967.51	974.99	967.65	0.37
9/8/88	59	966.65	967.43	967.11	968.56	970.87	971.95	973.02	967.21	974.72	967.61	0.00
9/12/88	63	966.44	967.32	966.94	968.60	970.78	971.85	973.13	967.00	974.85	967.58	0.00
9/15/88	66	966.35	967.41	966.90	968.52	970.76	972.22	973.34	967.13	975.05	967.59	0.94
9/19/88	70	966.51	967.43	966.90	968.62	970.82	971.89	972.63	967.21	974.28	967.68	0.05
9/22/88	73	966.65	967.36	966.90	968.58	970.78	971.81	972.61	967.44	974.25	967.60	0.00
9/26/88	77	966.81	967.22	966.68	968.65	970.65	971.65	972.52	967.78	974.03	967.59	0.00
9/29/88	80	967.26	967.48	967.22	968.68	970.76	971.92	972.97	968.27	974.45	967.68	1.27
10/3/88	84	967.12	967.39	967.17	968.77	970.89	971.48	972.08	968.10	973.71	967.68	0.00
10/6/88	87	967.01	967.30	967.10	968.68	970.75	971.32	972.10	967.91	973.65	967.65	0.00
10/11/88	92	967.31	967.24	967.32	968.66	970.59	971.39	972.12	968.31	973.82	967.63	0.00
10/12/88	93	967.48	967.26	967.30	968.45	970.65	971.42	972.20	968.47	973.75	967.63	0.00
10/16/88	97	967.68	967.28	967.41	968.72	970.63	971.54	972.20	968.72	974.05	967.68	0.00
10/20/88	101	967.84	967.84	967.50	968.79	970.76	971.56	972.30	968.80	973.95	967.72	0.12
10/24/88	105	968.00	967.47	967.49	968.85	970.70	971.61	972.24	968.97	973.85	967.71	0.02
10/27/88	108	968.01	967.73	967.59	968.90	970.65	971.59	972.27	968.94	973.85	967.72	0.00
10/31/88	112	968.02	967.78	967.61	968.97	970.59	971.57	972.21	968.96	973.65	967.72	0.00
11/3/88	115	968.01	967.82	967.50	968.99	970.60	971.40	972.09	969.07	973.65	967.74	0.09
11/7/88	119	968.04	967.83	967.71	969.04	970.53	971.54	972.32	969.07	973.65	967.78	0.09
11/10/88	122	968.05	967.13	967.75	969.04	970.46	971.31	971.83	969.08	973.45	967.78	0.03
11/14/88	126	968.20	967.76	967.74	969.07	970.40	970.48	970.53	968.98	971.93	967.89	0.49
11/17/88	129	968.14	967.82	967.68	968.90	970.36	969.14	968.40	968.86	969.45	967.93	1.07
11/21/88	133	967.89	967.59	967.77	968.83	969.49	968.11	968.25	968.50	967.98	967.97	0.00
11/23/88	135	967.84	967.49	967.78	968.81	969.31	967.85	967.05	968.39	967.78	967.97	0.00
11/28/88	140	967.62	967.28	967.65	968.58	968.89	967.51	966.86	968.03	967.61	967.94	0.64
12/1/88	143	967.60	966.78	967.52	968.45	968.64	967.33	966.59	967.68	967.52	967.97	0.14
12/5/88	147	967.36	966.92	967.46	968.38	968.38	967.18	966.54	967.65	967.45	967.98	0.00
12/8/88	150	967.36	966.81	967.43	968.29	968.23	967.03	966.47	967.53	967.34	967.95	0.00
12/13/88	155	967.32	966.77	967.46	968.18	968.13	966.71	965.87	967.38	966.85	967.88	0.10
12/15/88	157	967.24	966.67	967.27	968.11	967.82	966.72	966.48	967.27	967.55	967.80	0.01
12/19/88	161	967.21	965.50	967.26	968.18	967.78	966.57	965.86	967.27	966.78	967.80	0.57

Recorded Water Elevations (ft.)
Carter Lake Piezometer Study
Project No. 379006

* = USE location

	Culmative	Location										Rainfall
Date	time	Well 2	Well 7	Well 12*	Well 3	Well 4	Well 5	Well 6	Well 6*	River	Lake	over Period
12/21/88	163	967.05	966.22	967.22	968.03	967.70	966.97	966.55	967.23	967.65	967.85	0.00
12/27/88	169	966.95	966.34	966.96	967.90	967.55	966.47	965.81	967.01	966.87	967.80	0.27
12/29/88	171	966.84	966.33	966.94	967.86	967.54	966.53	966.04	966.96	966.95	967.80	0.00
1/3/89	176	966.76	966.19	966.87	967.75	967.41	966.60	966.23	966.92	966.45	967.80	0.00
1/6/89	179	966.71	966.08	966.94	967.63	967.34	966.62	966.29	966.86	967.34	967.76	0.30
1/9/89	182	966.64	966.11	966.88	967.58	967.34	966.66	966.12	966.79	967.42	967.72	0.04
1/12/89	185	966.49	965.99	966.74	967.77	967.07	966.02	965.20	966.64	966.26	967.72	0.02
1/19/89	192	966.35	965.61	966.61	967.44	967.07	966.58	966.37	966.53	967.54	967.49	0.00
1/20/89	193	966.46	965.78	966.63	967.36	967.12	966.55	966.43	966.60	967.65	967.51	0.00
1/23/89	196	966.44	965.83	966.60	967.41	967.13	966.44	966.29	966.60	967.45	967.45	0.00
1/26/89	199	966.40	965.78	966.59	967.38	967.06	966.66	966.45	966.60	967.65	967.45	0.10
1/30/89	203	966.40	965.82	966.48	967.28	967.06	966.73	966.46	966.50	967.55	967.42	0.64
2/2/89	206	966.30	965.68	966.52	967.30	966.96	966.70	966.50	966.52	967.89	967.42	0.07
2/6/89	210	966.12	965.62	966.33	967.29	966.94	965.05	965.32	966.50	964.00	967.42	0.08
2/9/89	213	966.08	965.62	966.31	967.42	966.85	966.92	967.27	966.40	968.71	967.48	0.00
2/13/89	217	966.05	965.66	966.32	967.11	967.10	967.48	967.51	966.34	969.10	967.48	0.41
2/16/89	220	966.12	965.78	966.32	967.14	967.15	967.51	967.77	966.37	969.22	967.48	0.00
2/21/89	225	966.11	965.69	966.20	967.15	967.19	967.05	966.90	966.20	968.35	967.48	0.27
2/24/89	228	966.09	965.67	966.29	967.05	967.11	966.99	966.95	966.01	968.25		0.00
2/27/89	231	966.09	965.61	966.20	966.95	967.05	967.08	967.17	966.18	968.29	967.48	0.03
3/2/89	234	965.99	965.69	966.18	967.16	967.00	966.52	966.27	966.35	967.34	967.48	0.08
3/6/89	238	965.93	965.68	966.17	967.11	966.75	965.92	965.28	966.34	966.05		0.21
3/9/89	241	965.90		966.05	967.06	966.70	966.81	967.00	966.02	968.24	967.40	0.00
3/13/89	245	966.02	965.53	966.92	967.35	966.87	968.48	972.17	967.59	971.15	966.90	0.00
3/16/89	248	966.10	965.63	966.14	967.10	966.85	967.74	970.84	967.59	969.42	966.90	0.11
3/21/89	253	965.98	965.67	966.06	967.06	966.25	966.32	965.83	966.38	966.76		0.00
3/24/89	256	965.90	965.65	966.14	967.01	966.70	967.00	965.93	966.33	967.05		0.00
3/27/89	259	965.72	965.40	965.98	966.97	966.82	966.83	967.07	966.23	968.05	966.75	0.00
3/30/89	262	965.89	965.63	966.56	966.98	967.26	968.67	970.06	966.38	971.80	966.70	0.00
4/3/89	266	966.09	965.11	966.05	967.49	967.87	969.67	970.99	966.61	972.85	966.40	0.05
4/6/89	269	966.23	965.20	966.05	967.13	967.80	969.87	971.04	966.72	972.75	966.60	0.01
4/10/89	273	966.25	965.32	966.11	967.29	967.88	970.16	971.27	967.07	973.05	966.35	0.07
4/13/89	276	966.36	965.32	966.16	967.46	968.57	970.44	971.63	967.45	973.35	966.10	0.00
4/18/89	281	966.47	965.55	966.21	967.59	968.60	970.55	971.65	967.49	973.34	965.90	0.15
4/20/89	283	966.55	965.63	966.29	967.65	968.94	970.58	971.88	967.50	973.52	966.30	0.02
4/24/89	287	966.70	965.76	966.36	967.79	969.17	969.96	972.06	967.74	973.80	966.30	0.00
4/27/89	290	966.63	965.82	966.40	967.86	969.04	971.04	972.16	967.78	973.95	966.27	1.46
5/1/89	294	966.82	966.09	966.48	968.01	969.40	971.14	972.16	968.04	973.75	966.40	0.04
5/4/89	297	966.96	966.20	966.61	968.06	969.45	971.15	972.07	968.29	973.68	966.40	0.29
5/8/89	301	967.10	966.22	966.65	968.15	969.67	971.14	972.03	968.18	973.58	966.40	0.01
5/11/89	304	967.14	966.28	966.72	968.13	969.64	971.14	972.01	968.26	973.55	966.40	0.00
5/15/89	308	967.21	966.24	966.86	968.26	969.76	971.29	972.24	968.35	973.85	966.40	0.00
5/18/89	311	967.51	966.27	966.91	968.33	969.80	971.32	972.27	968.38	973.79		0.14
5/22/89	315	967.30	966.37	966.85	968.31	969.92	971.32	972.22	968.40	973.73	966.55	0.00
5/25/89	318	967.28	966.49	966.86	968.29	970.01	971.56	972.65	968.48	974.35	966.50	0.00
5/30/89	323	967.36	966.78	966.88	968.39	970.09	972.10	973.44	968.67	975.35	966.50	0.29
6/2/89	326	967.38	966.88	966.89	968.39	970.05	971.29	972.16	968.54	973.66	966.45	1.68
6/6/89	330	967.51	967.04	967.13	968.45	970.09	971.21	972.09	968.60	973.65	966.85	0.02
6/9/89	333	967.48	967.02	967.04	968.48	970.09	971.24	972.37	968.60	973.95	966.85	0.07
6/12/89	336	967.53	967.02	967.12	968.50	970.07	971.24	972.02	968.47	973.55	966.85	0.28
6/15/89	339	967.54	967.02	967.11	968.44	970.07	971.23	971.96	968.49	973.45	966.70	0.00
6/19/89	343	967.57	967.02	967.15	968.44	970.08	971.25	972.15	968.67	973.65	966.80	0.57
6/22/89	346	967.86	967.49	967.18	968.50	970.12	971.33	972.16	968.69	973.70	967.00	1.00
6/26/89	350	967.79	967.57	967.32	968.56	970.23	971.65	972.42	968.78	973.97	967.30	1.43
6/29/89	353	967.80	967.24	967.31	968.62	970.13	971.04	971.62	968.77	972.96	967.10	0.00
7/3/89	357	967.73	967.38	967.37	968.59	970.21	971.22	971.94	968.80	973.75	966.90	0.00
7/7/89	361	967.78	967.00	967.38	968.57	970.07	971.08	971.65	968.78	973.35	966.60	0.00
7/11/89	365	967.61	966.90	967.31	968.41	969.99	970.65	971.17	968.58	972.75	966.60	0.00
7/13/89	367	967.71	966.39	967.28	968.47	969.90	970.96	971.72	968.52	973.26	966.55	0.00
7/17/89	371	967.55	966.34	967.27	968.47	970.00	971.04	972.37	968.72	973.90	966.65	2.13

Recorded Water Elevations (ft.)
Carter Lake Piezometer Study
Project No. 379006

* = USE location

Date	Culmative time	Location										Rainfall
		Well 2	Well 7	Well 12*	Well 3	Well 4	Well 5	Well 6	Well 6*	River	Lake	over Period
7/20/89	374	967.82	966.78	967.33	968.59	970.23	971.88	972.87	968.70	974.57	966.80	0.18
7/24/89	378	967.78	966.62	967.42	968.60	970.14	971.29	972.05	968.80	973.47	967.50	0.02
7/27/89	381	967.82	966.41	967.39	968.54	970.03	971.25	971.87	968.72	973.22	967.63	0.00
7/31/89	385	967.82	965.70	967.48	968.61	970.26	971.82	972.75	968.88	974.36	967.68	0.58
1/2/90	540	966.13	965.27	966.42	967.15	966.75	966.29	965.92	966.38	966.75	967.80	0.00
1/5/90	543		964.89		967.09	966.61	966.19	965.99	966.25	966.75	967.80	0.00
1/10/90	548	966.02	965.11	966.14	967.06	966.69	966.11	966.06	966.00	966.75	967.70	0.00
1/12/90	550	965.63	965.22	966.16	966.83	966.53	965.94	966.00	966.09	966.75	967.70	0.00
1/16/90	554	965.94	965.07	966.31	967.01	966.37	966.12	965.87	966.15	966.35	967.50	0.00
1/19/90	557	965.95	964.99	966.20	966.94	966.45	966.14	965.79	966.08	966.55	967.30	0.00
1/23/90	561	965.91	965.01	966.16	966.97	966.45	966.03	965.61	966.02	966.15	967.30	0.57
1/26/90	564	965.83	964.97	966.13	966.97	966.40	965.93	965.61	966.06	966.35	967.30	0.02
1/30/90	568	965.86	964.83	966.06	966.81	966.34	965.97	965.79	965.94	966.35	967.35	0.00
2/6/90	575	965.67	964.59	967.93	966.73	966.37	966.39	966.51	965.87	967.15	967.50	0.15
2/16/90	585	965.55	964.59	965.78	966.64	966.22	966.29	966.37	965.78	967.15	967.35	0.19
2/20/90	589	965.48	964.77	965.73	966.56	966.33	966.00	966.87	965.82	967.45	967.35	0.00
2/23/90	592	965.48	964.65	965.71	966.56	966.42	966.19	965.93	965.83	966.65	967.50	0.00
2/27/90	596	965.44	964.64	965.66	966.50	966.18	966.21	966.29	965.68	966.95	967.50	0.00
3/2/90	599	965.50	964.70	965.62	966.46	966.18	965.89	965.62	965.67	966.35	967.30	0.00
3/16/90	613	965.54	965.32	965.68	966.51	966.20	966.07	965.94	965.83	966.55	968.00	3.25
3/23/90	620	965.26	964.79	965.57	966.39	966.03	965.47	965.15	965.55	965.75	968.00	0.12
4/8/90	636	965.62	964.92	965.58	966.69	967.27	968.79	969.72	966.20	971.25	967.50	0.64
4/20/90	648	965.94	965.14	965.83		968.02	969.44	970.30	966.66	971.75	966.30	0.33
5/4/90	662	966.21	965.17	966.03	967.25	968.60	970.09	970.82	967.11	972.25	966.00	1.02
5/11/90	669	966.53	965.57	966.19	967.43	968.78	970.21	970.87	967.40	972.25	966.00	1.54
5/18/90	676	964.78	965.82	966.48	967.77	969.54	972.63	974.62	967.88	972.25	966.50	0.97
6/1/90	690									973.30	966.90	1.57
6/15/90	704									973.83	967.10	2.68
6/28/90	717	967.73	967.07	967.35	968.71	971.12	972.12	972.65	969.17	974.35	967.30	1.20
7/12/90	731	967.98	966.78	967.40	968.77	970.57	971.66	972.11	969.05	972.95	967.50	1.04
8/2/90	752	968.03	967.26	967.75	969.10	970.70	971.04	971.07	969.30	972.45	968.00	0.03
8/9/90	759	968.15	966.99	967.90	968.93	970.24	970.62	970.99	969.05	972.15	968.00	0.15
8/31/90	781	967.86	966.82	967.56	968.71	970.12	970.93	971.27	968.88	972.95	968.30	0.63
9/7/90	788		967.19	967.73	968.56	970.12	971.10	971.80	968.69	973.25	967.80	0.14
9/14/90	795	968.07	967.15	967.69	970.66	970.25	971.37	972.09	968.80	973.55	967.90	0.00
9/22/90	803	968.28	967.19	967.90	968.85	970.32	971.54	972.24	969.09	973.55	968.15	0.67
9/29/90	810	968.29	966.91	967.93	968.86	970.25	971.19	971.80	969.06	973.05	968.35	0.00
10/5/90	816	968.48	966.94	968.00	968.93	970.20	971.28	971.79	969.18	973.25	968.55	1.24
10/12/90	823	968.44	966.90	968.08	969.01	970.17	971.06	971.52	969.13	972.85	968.50	0.20
10/19/90	830	968.45	966.85	968.03	969.06	970.04	970.92	971.42	969.18	972.65	968.60	0.07
10/26/90	837	968.50	966.73	968.08	969.06	969.98	970.79	971.27	969.19	972.55	968.80	0.00
11/9/90	851	968.08	966.82	968.00	968.81	968.50	966.91	965.83	968.20	966.15	968.90	0.93
11/15/90	857	967.86	966.22	967.78	968.46	967.92	966.29	965.39	967.76	965.85	968.80	0.00
11/30/90	872	967.26	966.19	967.16	967.96	967.10	965.71	964.80	967.16	965.35	968.40	0.23
12/7/90	879	967.11	966.04	967.28	967.91	966.88	965.79	965.07	966.95	965.55	968.30	0.56
12/14/90	886	966.86	965.82	967.10	967.71	966.72	964.44	964.90	966.74	965.55	968.10	0.04
Average		967.00	966.40	966.99	968.15	969.07	969.52	969.97	967.68	971.25	967.50	0.26
Standard Deviation		0.82	0.92	0.63	0.81	1.68	2.33	2.85	1.05	3.18	0.63	0.50

Appendix B
Previous Studies