THE EFFECTS OF STREAM FLOW REGULATION ON THE ALLUVIAL AQUIFER NEAR MUSKOGEE OKLAHOMA AND THE SUITABILITY OF THE GROUND WATER FOR IRRIGATION

By

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CHAPTER I

INTRODUCTION

This study evaluates the ground water from the alluvial aquifer along the Arkansas River near Muskogee, Oklahoma to determine whether the hydrological relationship of the aquifer has been effected by the regulation of the Arkansas River and associated tributaries for the McClellan - Kerr Navigation system. Conditions which may be indicative of change include ground water levels and chemical changes. The efforts contained in this study compare historical pre-regulation public data with post-regulation public data, and limited proprietary data provided by Oklahoma Gas and Electric Company (OG&E). Changes in the relationship could have a direct impact upon agricultural land use of the overlying flood plain.

Location

The study area is located in 15N-19E, just east of the Arkansas River and west of Fort Gibson Oklahoma, Muskogee County. The area is adjacent to the confluence of the Neosho (Grand) River and the Verdigris River with the Arkansas River. (figure 1)

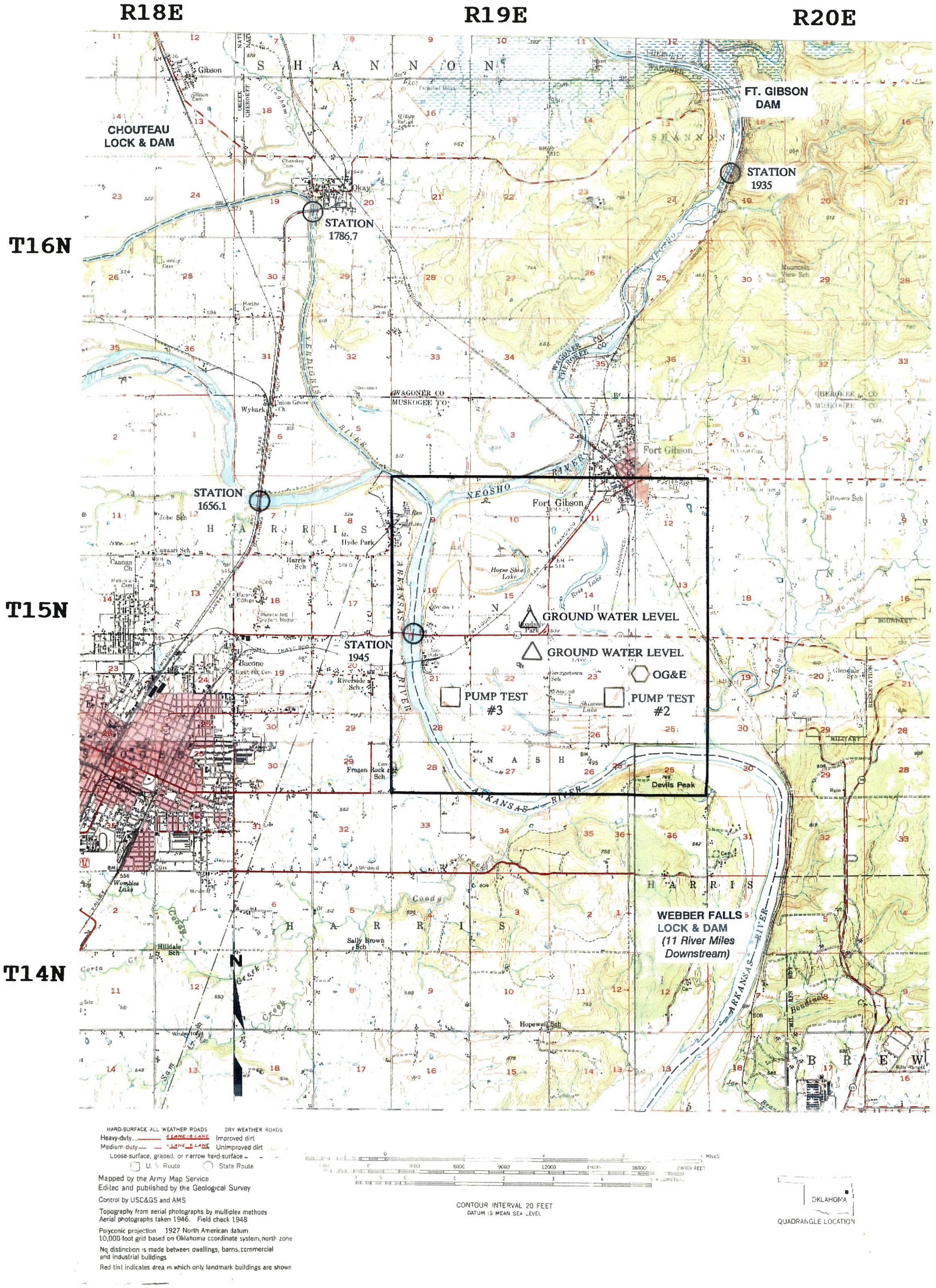

Figure 1. Location and reference map.

Background

Studies which preceded the regulation indicated that the ground water of the aquifer was recharged primarily from precipitation and was rated with a medium salinity hazard, a low sodium hazard class and was generally suitable for irrigation purposes. Since completion of the Webber Falls Lock and Dam downstream from the study area, the river stage of the Arkansas River has been maintained with sufficient depth to allow barge and tug boat navigation. This increased and constant level of the Arkansas River has created the potential for greater contribution of bank infiltration from the Arkansas River as a recharge source for the aquifer.

The water character of the Arkansas River has a high to very high salinity hazard and a sodium adsorption ratio (SAR) in the high to very high sodium hazard class. The Arkansas River water is generally not suitable for irrigation purposes.

Previous Studies

The principal studies relevant to this study are those of the USGS by Reed and Schoff (1951) which evaluated the aquifer of the flood plain for potential use as irrigation water, and Tanaka and Hollowell (1964) who studied the area as part of an evaluation of the Arkansas River alluvium from

Fort Smith to Muskogee prior to completion of the navigation system.

These studies provided important physical and chemical background data which preceded most flow regulation. These data are used for comparison to later studies and data, and the conclusions in the study.

Flow Characteristics and Regulation

The principal structures which regulate flow in the study area are the Fort Gibson Dam, located upstream on the Neosho River, and the Webber Falls Lock and Dam, located downstream on the Arkansas River. These projects were authorized by the River and Harbors Act of 1946 and various reauthorization acts and were constructed by the Corp of Engineers. Others structures with less direct influence include the Keystone Dam, upstream on the Arkansas River, and the Newt Graham Lock and Dam, upstream on the Verdigris River.

Additional projects at various upstream locations on tributaries to the Arkansas River were designed to reduce chloride contamination of the Arkansas River.

Arkansas River. The Webber Falls Lock and Dam is the last flow control structure upstream on the main stem of the Arkansas River portion of the McClellan-Kerr Navigation system. Impoundment began in November of 1970.

The principal effect of regulation of the Arkansas River on the aquifer is the creation of a reservoir in the Arkansas River channel raising the static water level and establishing a gradient into the aquifer. This reservoir extends upstream about 28 miles from the Webber Falls Lock and Dam or approximately 4 miles beyond the study area on the Arkansas River, 7 miles upstream into the Verdigris river channel and up to 8 miles upstream into the Neosho River channel.

Neosho River. The Fort Gibson Dam, started in 1942 had construction suspended until after World War II and was completed in September of 1953. This structure provides hydroelectric power, public water supply and flood control. Water storage assures adequate water supply year round for the Navigation channel downstream in the Arkansas River.

The main effect of regulation of the Neosho River on the aquifer is a reduction of Neosho water availability for mixing with the Arkansas River or possible infiltration of the Neosho water into the aquifer. Prior to restriction of the flow, the water was available to mix continuously with the waters of the Arkansas/Verdigris flow immediately adjacent to the study area.

The confluence of the Arkansas river with the Verdigris and Neosho rivers is shown in figure 2. In the photo, the water of the Neosho River can be distinguished from the Arkansas River by color. The darker Neosho River

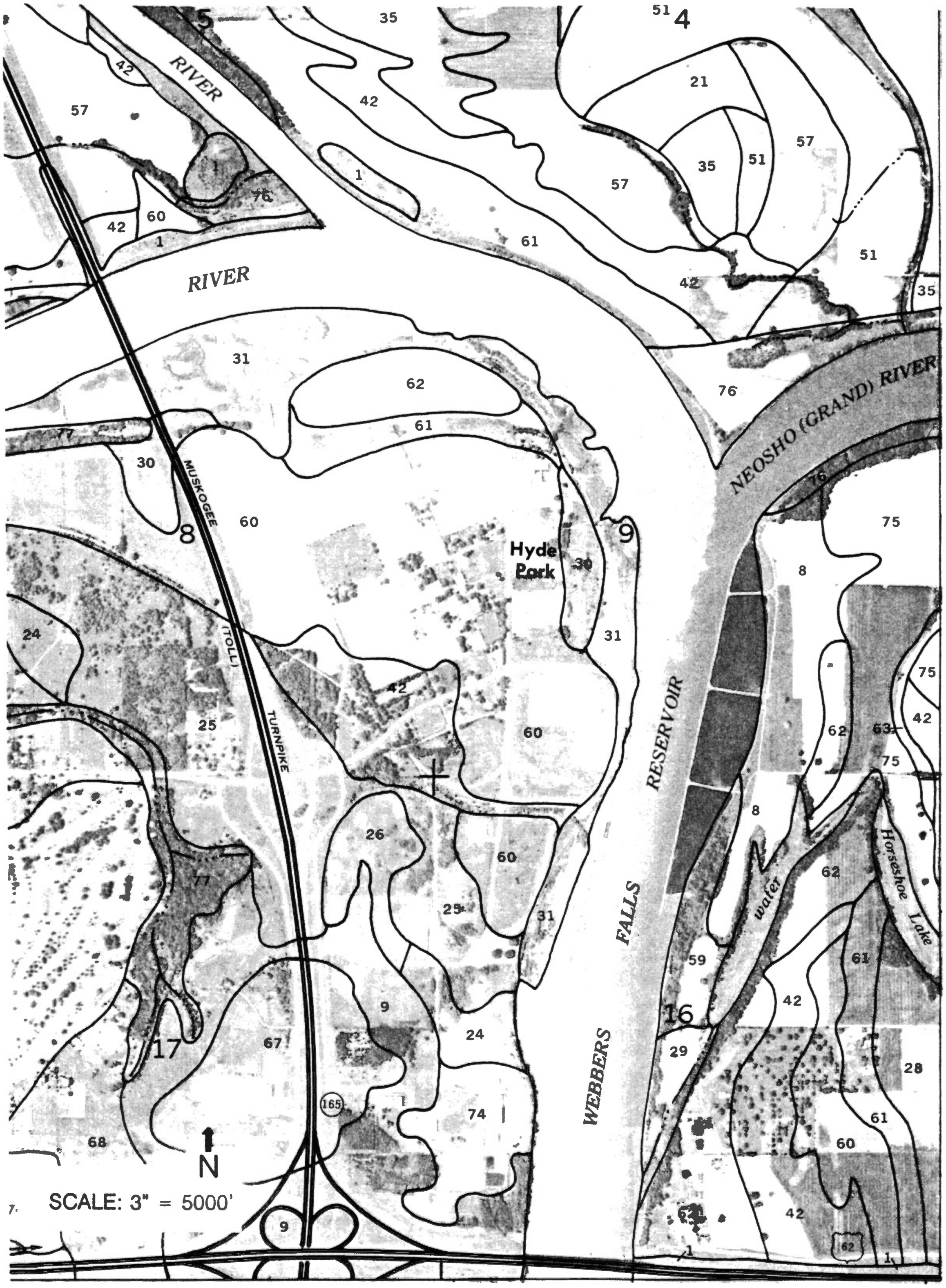

Figure 2. Confluence photo. Shows confluence of the Arkansas River, from the west, the Verdigris River, from the north, and the Neosho River from the east. (Soil Survey, Muskogee County, 1984)

is a result of low suspended sediment load which persists downstream for a least a mile at which point is passes beneath the bridges for US highway 62. The gauging station for the Arkansas River is located on the east bank of the river beside the highway 62 bridge. This photo illustrates a significant characteristic of the river flow as it passes station 1945 on the Arkansas River. During some Neosho flow conditions, the Arkansas River water is displaced and the character of the river water detected at station 1945 is not representative of true Arkansas River water but has characteristics of the Neosho River, or some combination of the Arkansas and Neosho Rivers. Comparisons of discharge rates of the Neosho River, to the chemical character of the river water as sampled at station 1945 shows a very close relationship of Neosho River flow rates and the chemical character of the Arkansas River.

Objectives.

The objectives of this study include, (1) the study of aquifer recharge sources, useful to establish relationship of ground water to potential surface sources of recharge and the effect of the recharge source to the chemical nature of the ground water, (2) evaluation of the chemical characteristics of surface water and the ground water to determine supporting evidence for recharge sources and possible causes of chemical variation in the ground water quality, (3) comparison of the physical level of the ground water before and after regulation to determine the nature of any changes which have occured, (4) comparison of chemical characteristics of the ground water before regulation to determine the nature of any changes which have occured, (5) the impact of any changes on agricultural use of the ground water.

Because expected changes in the chemical quality of the ground water did not reflect an impact as a result of infiltration by the Arkansas River type water, additional objectives developed include, (6) chemical conditions which could restrict Arkansas River water infiltration, (7) physical conditions which could restrict Arkansas River water infiltration, (8) the possible causes of the chemical changes in the ground water which were discovered.

Data Consideration

Data Sources

Existing records were used for stream flow and aquifer data.

Surface Water Records. Surface water records document the chemical character of the river water during a four year period from 1976 through 1979. These data permit an evaluation of the chemical characteristics of the river water after the creation of the Webber Falls Reservoir.

Ground Water Records. The records used for the study were obtained primarily from United States Geological Survey and the Oklahoma Water Resources Board. These records date from 1936 to 1988, although most of the data represent studies conducted in 1948 and 1958. Some proprietary data was provided by the Oklahoma Gas and Electric Company which operates an electrical generation station on the overlying flood plain. The OG&E data are from a water lease off the OG&E property and were data collected from 1980 - 1989. Additional wells monitor ground water on on OG&E property but data from them were not released for this study.

Data for ground water level were not widely available but the USGS and Oklahoma Water Resources Board did maintain records on two wells located in the study area within sections 22 15N-19E and 15 15N-19E from 1961 to 1980. Whereas this does not make it possible to evaluate the entire study area, it does make it possible to determine and illustrate general water level relationships in the area for ten years before and ten years after the Webber Falls Reservoir was established.

Climatological Data. Precipitation data for the area came from Department of Commerce records for the Muskogee station. This collection point is located north of Muskogee very near the study area just upstream from the confluence of the three rivers. These data were compared and contrasted against surface and ground water data to assess if any relationship among water level, water quality and precipitation. Precipitation data were presented as either "departure from normal" or "cumulative departure curves" to permit graphical comparisons and demonstrate the wet and dry cycles in the study area.

Soil Data. Information for soil, including groups and characteristics was obtained from the "Soil Survey for Muskogee County" (1984).

Data Character and Problems

Water data gathered by the various governmental organizations were collected for special projects and various purposes and may be discontinued because of new interest, new projects or lack of funding. Problems occur where data from different sources are merged. The data may not be continuous or necessarily measure consistent parameters. The values recorded may not be in equivalent forms, meet preferred standards of accuracy, expected relationships or balance. Data provided by OG&E, for example, did not provide a sodium analysis. OG&E assumes the difference in the cation sum from the sum of total anions represent the sodium value. Consequently, analysis presented in subsequent figures and tables for sodium in the

OG&E data were arrived by calculating sodium from the reported anion, cation difference.

Data for the Verdigris river were not compatible in time with data available for the Neosho River, Arkansas River and much of the ground water data. Therefore, because of variations in the availability and continuity of data, it is often necessary to convert some data and develop assumptions about gaps in data and speculate about trends.

CHAPTER II

GEOLOGICAL, HYDROLOGICAL & GEOCHEMICAL CONSIDERATIONS

Geological Considerations

The nature of the deposition of the alluvial material which forms the aquifer influences the distribution and continuity of the aquifer. This alluvium aquifer is presumed to have been deposited during earlier stream flows and should consist of point-bars, natural levees, backswamp, and channel fill material. Areas of point-bar deposition formed the aquifer and consist of coarse grained materials grading upward to finer sands. Frequent shifts in the stream course will establish new channels with the abandoned channels forming oxbow lakes in the flood plain. These oxbow lakes eventually became plugged with clays. The channel fill, backswamp deposits, and natural levee deposits are also predominantly clays. As a result of this depositional relationship, the sands and gravels may not be in lateral contact and a significant amount of clay is likely to be associated with the aquifer. Soil groups associated with the present day oxbow lakes and swales on the flood plain consist of soils with high percentages of clay with high to very high shrink swell capabilities and poor permeability. It is likely that previous oxbow lakes and channel fills had similar characteristics and clay type. These clays have a significant effect on the hydraulic properties and cation exchange potential of the alluvium. The classification of these high shrink/swell clay is "fine, montmorillonitic, thermic Vertic Hapludolls" (Soil Survey of Muskogee County, 1984).

The alluvium aquifer thins against bedrock and older terrace deposits eastward and is limited on the south and west by the Arkansas river channel. The Northern boundary is limited by the Neosho channel. Crossections in Appendix A illustrate the relationship of several sample descriptions from the aquifer. Each crossection indicates a high degree of continuity of porous material between the locations. This is particularly important to recognize in this study because of the limited well control for recent data.

Hydrological Considerations

The effects of any stream flow regulation on the aquifer should be seen in physical and/or chemical changes to the aquifer and ground water quality. Physical changes may be recognized in effects on the water movement and ground water level within the aquifer. Increased ground water levels can create problems of drainage for irrigation waters.

Historic flow stage of the Arkansas River, near station 1945, was approximately 471 feet above sea level, as determined from older topographic maps and photos. The creation of the Webber Falls Reservoir elevated the river stage to 490 feet above sea level.

Physical conditions.

Review of ground water levels (figure 3) prior to the regulation of the Arkansas River on the alluvium aquifer indicates an average "low" depth to groundwater of 25 to 30 feet below the surface. Two potential controls on ground water level are precipitation and river infiltration.

Precipitation Influence on Groundwater Level. Earlier studies have suggested that precipitation is the principle recharge source (Tanka and Hollowell, 1966, Reed and Schoff, 1951). Plots of historic precipitation and groundwater levels are compared in figures 3 and 4 respectively.

Together, figures 3 and 4 suggest a strong relationship of precipitation influence on ground water level. The dominance of precipitation on ground water levels, particularly during "wet" cycles influences recharge and discharge of the aquifer, and natural maintainance of the ground water quality.

River Infiltration Influence on Ground Water Level. Whereas precipitation is suggested as the principal source of ground water recharge, bank infiltration has been observed to influence level during high river flow stages with limited distance of bank infiltration. The limit on infiltration is a function of the relatively brief duration of the high stage (Tanaka and Hollowell, 1966)

One concern of this study involved the permanent increase in the river level which resulted from the creation of the Webber Falls Reservoir and could allow deep infiltration of Arkansas River water into the aquifer.

Physical evidence to support river infiltration is limited. Review of the ground water hydrograph, figure 3, shows a decline of the water level during the mid-1970's in conjunction with a decrease in precipitation. However, the decline in the level does not continue to decrease as the precipitation level continue to decrease, nor does it approach preregulation "low" levels of 25 - 30 feet below the datum of the land surface. It appears that the new ground water base level, approximately 15 feet below land the surface datum, corresponds to the regulated level of the Webber Falls Reservoir

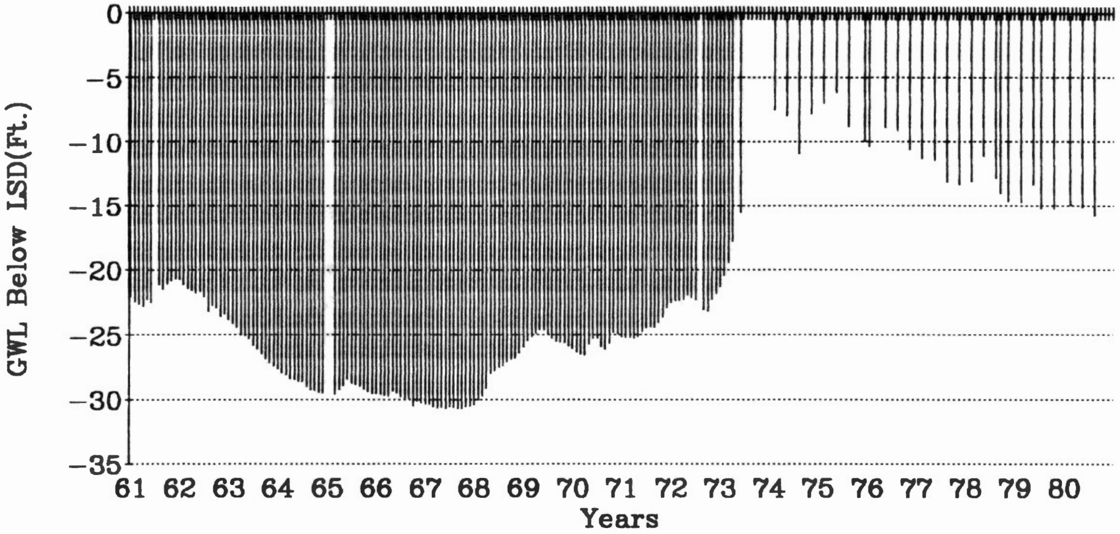

Figure 3. Ground water hydrograph, 1961 - 1980. Shows the ground water level 10 years prior to regulation and 10 years after regulation.

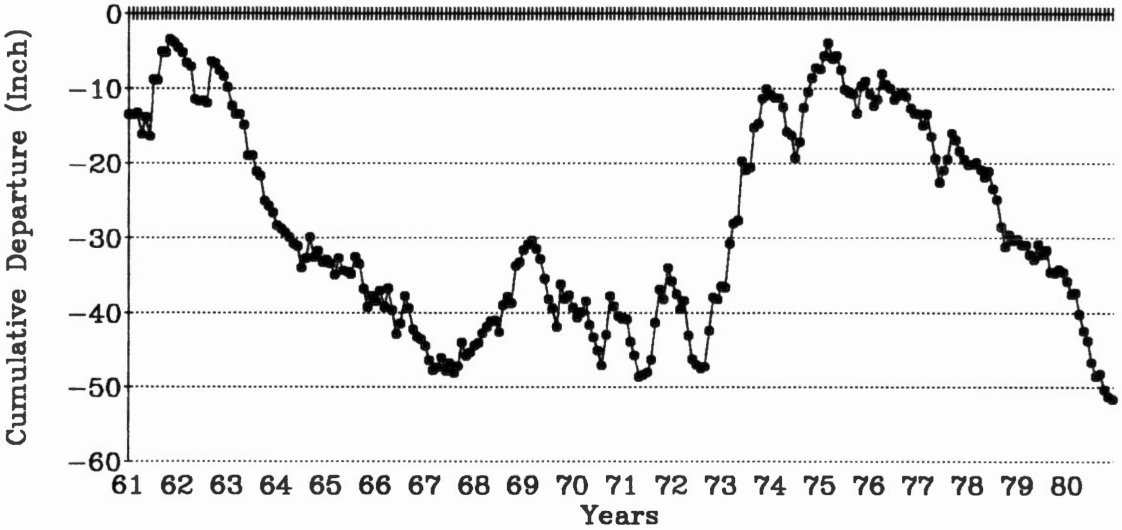

Figure 4. Muskogee precipitation cumulative departure curve. For period 1961 - 1980. Indicates cycles of wet and dry periods

This relationship suggest ground water level control by the river. However, timing of any infiltration by the river into the aquifer is obscured on the hydrographs by the strong relationship of precipitation with the ground water level.

Hydrologic calculations of expected rates of water movement into the aquifer from the river are not consistent with the groundwater hydrograph. A modified Darcy's equation (Bouwer, 1978), modified to estimate time required for a water level rise in the aquifer, is used to develop expectations for the effects of the Webber Falls Reservoir on the ground water level.

$$t = \frac{[\ H * LN(H/H - z) - z] * f}{K} \qquad \text{eq.1}$$

Where H is the change in stream level, f is the fillable porosity, z is the height of rise in the aquifer, and t is time, or how long the aquifer rise (z) would take. The formula requires assumptions that the aquifer is in hydraulic connection to the stream and is underlined by an impervious layer. For purposes of evaluating ranges of estimates, calculations varying aquifer rise (z) and fillable porosity (f) were developed. Time (t), in days, is estimated below. Variables kept constant for these calculations include the stream rise (H), of 20 feet and a hydraulic conductivity (K), using a fine sand, 16 feet per day.

TABLE 1

TIME VARIABLE ESTIMATES FOR RIVER INFILTRATION INTO AQUIFER

		(z) Aquifer Rise - (feet)		
		5	10	15
(f) fillable Porosity (%)	.1	.004	.024	.079
	.2	.009	.048	.159
	.3	.014	.072	.239
	.4	.301	.096	.318

Based upon these estimates, a rise in the aquifer to new river base level should have occurred quickly, within hours. Although the rate of reservoir impoundment to the regulated level was not instantaneous, the rate of rise in the aquifer should have been continuous with reservoir filling. Examination of the ground water hydrograph, figure 3, does not indicate any immediate increase after impoundment began in November of 1970. Increase in ground water level begins in late 1971 and early 1972 but is coincident with a precipitation event.

Evidence of recharge from the Neosho River is suggested by ground water level maps. Maps made from data collected by Reed and Schoff (1951), figure 5, of pre-Neosho regulation (Fort Gibson Dam) indicate higher ground water levels in the aquifer adjacent to the Neosho River.

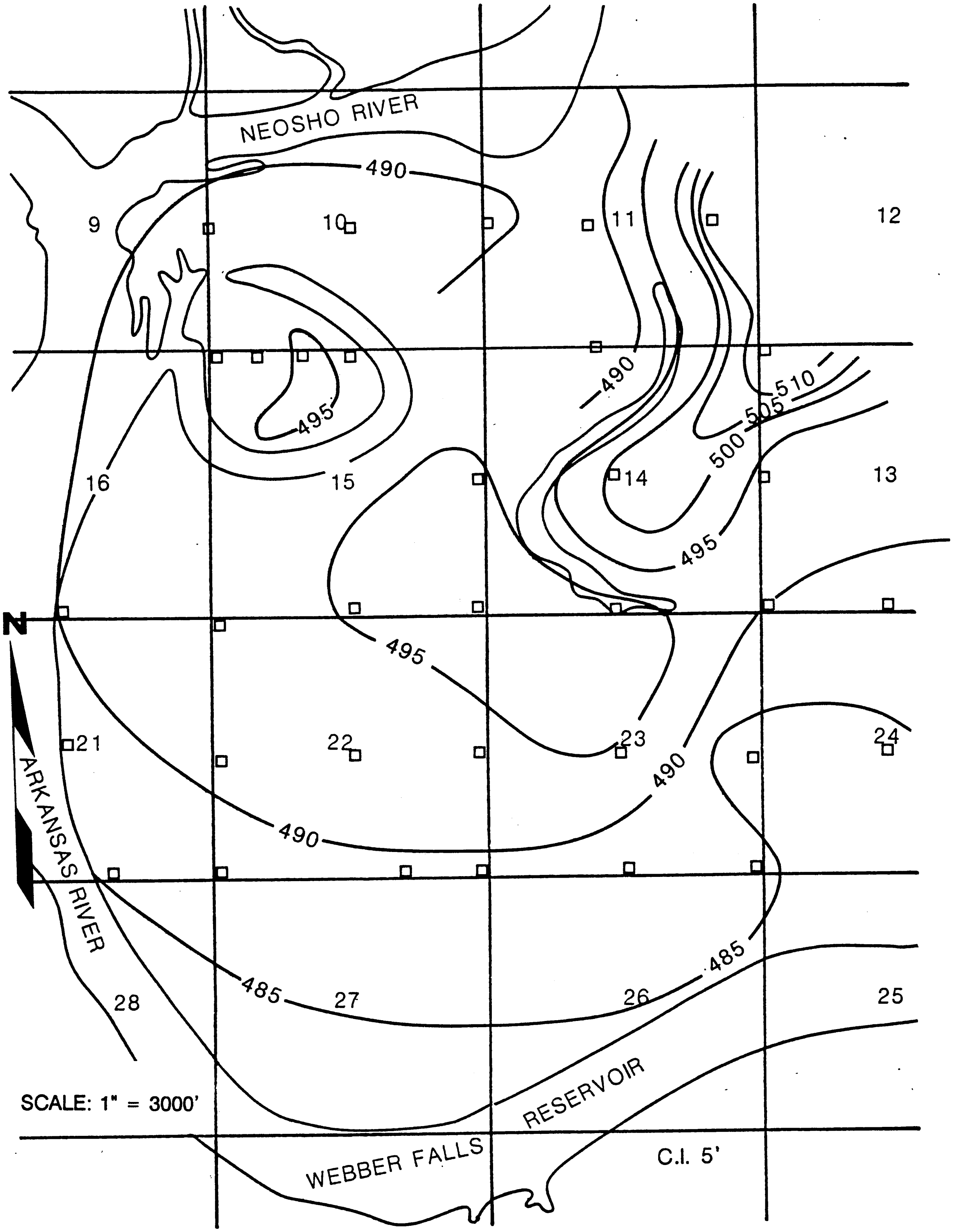

Figure 5. Ground water level map of 1948 data. Mapped by Reed and Schoff, pre-regulated Neosho River.

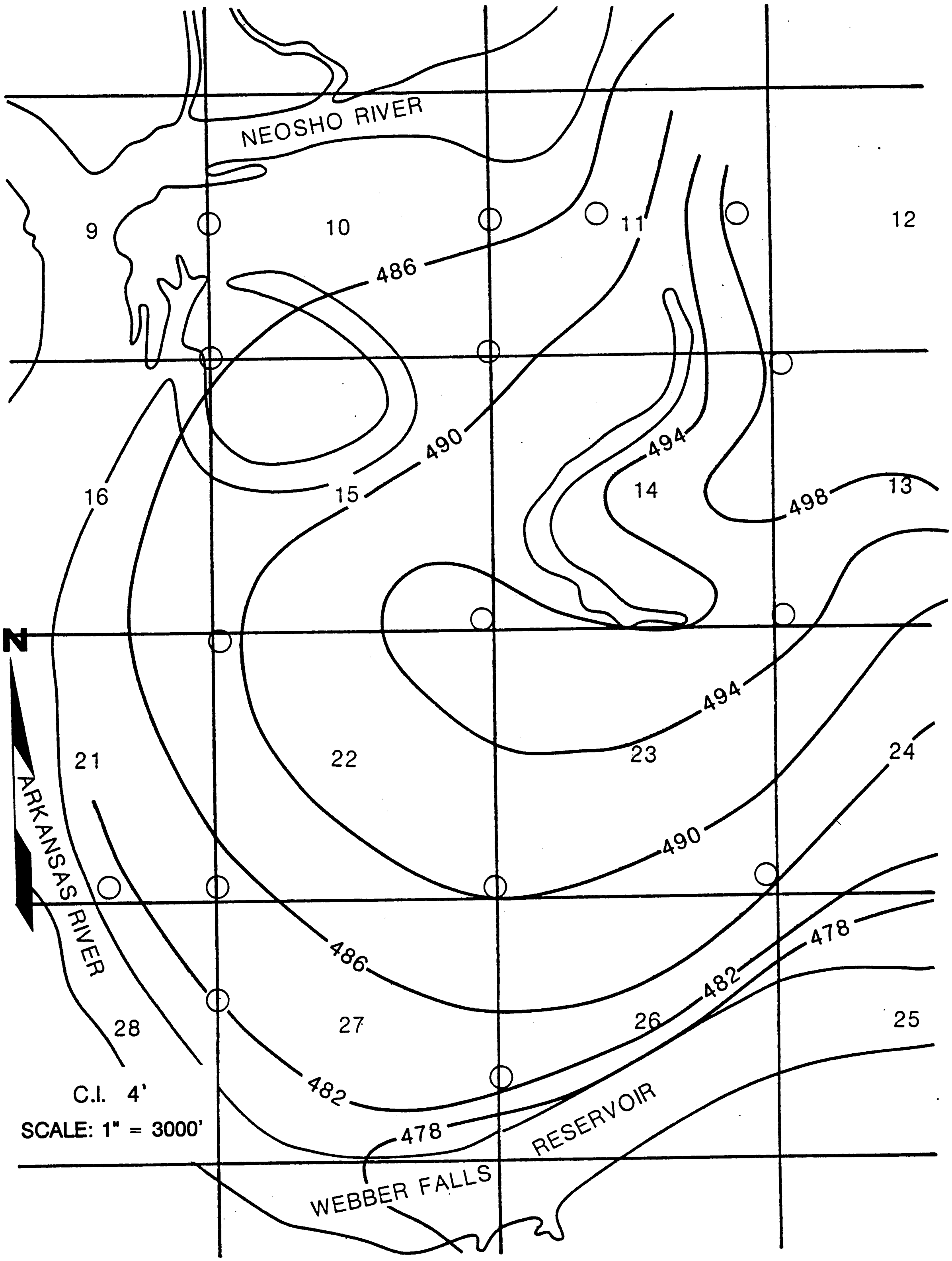

Figure 6. Ground water level map of 1958 data. Mapped by Tanaka and Hollowell, post-regulated Neosho River.

Post-Neosho regulation, 1958 data, as mapped by Tanaka and Hollowell (1966), figure 6, indicate a lowering in the ground water level adjacent to the Neosho River channel. The ground water level is similar throughout the remaining area.

It is possible that the calcium dominated water of the Neosho River water has greater infiltration potential than the sodium dominated Arkansas River water which may create hydraulic conductivity restrictions. This effect is discussed later in detail.

The overall apparent physical effect of regulation on the aquifer is a restriction of the discharge and recharge capability. This relationship is illustrated in figures 7 and 8, generalized schematic cross sections of the pre-regulation and post-regulation river/aquifer relationship. During pre-regulated conditions, the aquifer had a greater elevation or thickness range for discharge and recharge for the ground water. After regulation and creation of the Webber Falls Reservoir within the Arkansas River channel, the new elevated base level reduces the discharge range and recharge capability of the aquifer.

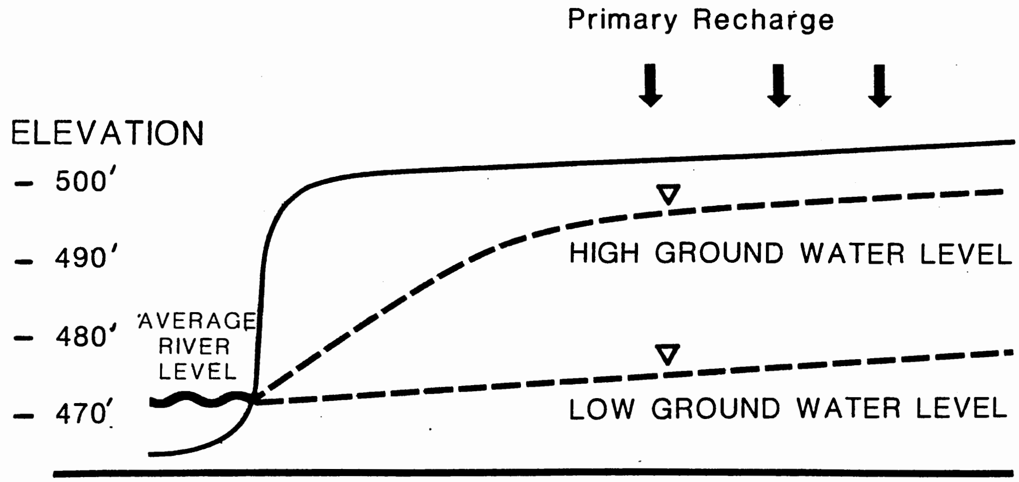

Figure 7. Generalized crossection, pre-regulation relationship of river and aquifer. Preregulated aquifer had higher capacity of discharge and recharge due to greater range of river base levels. Ground water quality could be naturally maintained.

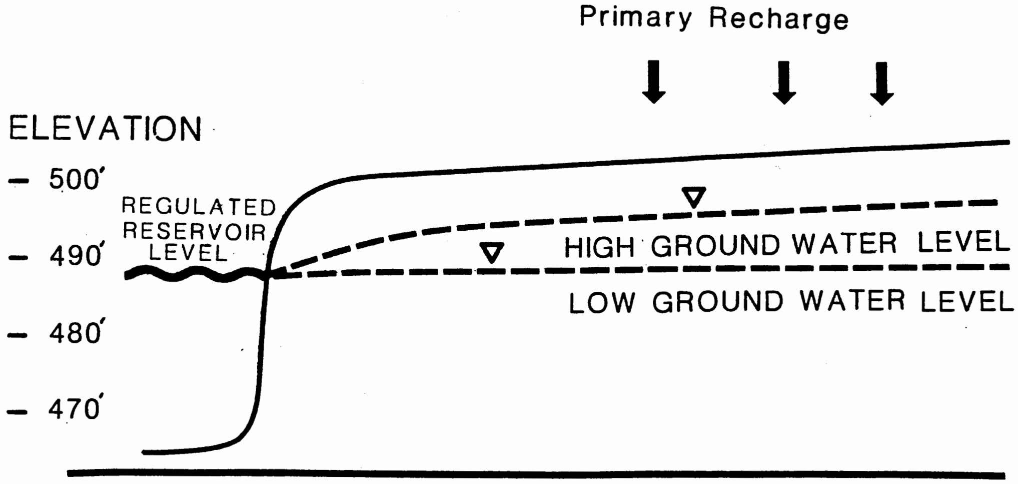

Figure 8. Generalized crossection illustrating regulated relationship of river and aquifer. Higher and constant reservoir/river base level restricts aquifer. Discharge and recharge capacity is reduced. Natural ground water maintenance limited.

Geochemical Considerations

The natural quality of the river water generally reflects the type of rock - water interactions involved. The course of Neosho River flow is over carbonate and cherty formations which contribute mostly carbonate elements. The Verdigris also flows over large areas of carbonate rock but is influenced by tributaries which contribute significant chloride elements to the character of the water. The Arkansas River is strongly affected by upstream deposits of salt and tributaries contributing sodium chloride elements. USGS analysis, as reported in Water-Resources Investigations 81-33, describe these three rivers as:

> The Arkansas River at station 1656.1 is of the sodium chloride type, unsuitable for public water supply and about half of the samples have a very high salinity hazard and high to very high sodium hazard.
>
> The Verdigris River at station 1786.7 was of the calcium carbonate/bicarbonate type for conductance equal to or less than 600 microohms which is just under half of the samples and chloride when conductance was above 600 and that the sodium cation would dominate if conductance was above 1000 microohms. As a result, the salinity hazard is rated as medium, with a low sodium hazard.
>
> The Neosho River at station 1935 was characterized as calcium carbonate/bicarbonate type. The salinity hazard is rated low or medium and the sodium hazard is considered low.

The quality of the ground water also reflects the type of rock the water is in contact with. Throughout discussions in the previous studies by Tanaka and Hollowell (1966), or Reed and Schoff (1951), no information is given on the lithology of any of the samples collected for studies of aquifer properties. Based upon the range of the separate sizes of the samples, which included coarse sands, gravels and in some cases, cobbles, it is within geologic reason to believe these larger particles have been derived from nearby sources. The most probable source is from the bluffs which have several hundred feet of relief (figure 2) adjacent to the Neosho River, upstream from the study area and carried to the area during flood flows of the Neosho River. The dominant rock units are Pennsylvannian and Mississippian carbonates.

Graphical Analysis

The analysis of all surface and ground water samples were evaluated using time vs concentration graphs and trilinear plots (piper plots) to compare and characterize the waters. Not all of the data were in a form acceptable for use in the evaluation. Some conversions and calculations were required. As indicated earlier, the OG&E data did not include sodium values and it was necessary to calculate the sodium by the difference between the reported anion and cation values. Further, because the alkalinity was provided in CaCO3, it was converted to bicarbonate by multiplying the CaCO3 values by the equivalent weights of the HCO3/CaCO3 ratio (61/50.044) of 1.2192.

The Arkansas River data required conversion because bicarbonate values were not provided. Again, this was accomplished by calculating the difference between the reported anions and cations.

The Neosho River data had incomplete bicarbonate data for 1978 and 1979. This was resolved by calculating the difference between anion and cation balance. These difference calculations were allowed to overlapped periods of reported bicarbonate values to verify the accuracy of the estimates. The calculations provided estimated values which were representative of the reported values. (Average HCO3 reported = 104.24 mg/l vs average HCO3 calculated = 103.45 mg/l)

Piper plots of the data were generated through the use of WATEVAL, a program developed to analyze and plot the inorganic constituents detected in the water. The Piper method is a version of a trilinear plot introduced by Arthur Piper (1944). Trilinear plots usually utilize three components, two ion triangles and a central diamond.
Most current applications using the "Piper" trilinear plot uses a scale which represents the "percent of total milliequvalent per liter". This scale breaks the sides of the triangle into 100 parts. The diamond is not divided into scales since the ion triangles have accounted for 100% of the constituents. Regardless of the scaling method selected, the diamond can be subdivided into five areas which represent specific water characteristics. If a point plots within the upper corner of the diamond, the water character represents "permanent Hardness" (non carbonate hardness),

the lower corner represents "alkali carbonate", the right corner is "saline", and the left corner is "temporary hardness"(carbonate hardness). The central fields are an area of no particular dominance. Concentrations, in TDS of the water are represented by circles which vary in diameter depending upon a concentration scale which is developed for the set of samples.

The Neosho River Piper Plot. The data for 1976 through 1979 have a very close grouping within the temporary hardness (carbonate hardness) area of the piper diamond (figure 9). Data were also evaluated for water years 1962 and 1963 to compare the water quality for changes. The groupings are nearly identical indicating very little change in the Neosho River water chemistry between 1963 and 1976.

Arkansas River Piper Plot. The analysis for 1976 to 1979 data from the Arkansas River plot with a greater distribution of data. Values range from carbonate hardness to saline in the piper diamond (figure 10). This distribution of the data is consistent with the relationship of the Arkansas and Neosho river flow previously discussed. The Neosho River often commingles or displaces the Arkansas River flow at the gauging station on the Arkansas River. Therefore, the plot represents a combination of the Neosho River water, represented by the carbonate hardness values, and normal Arkansas River water chemistry, which is saline in nature.

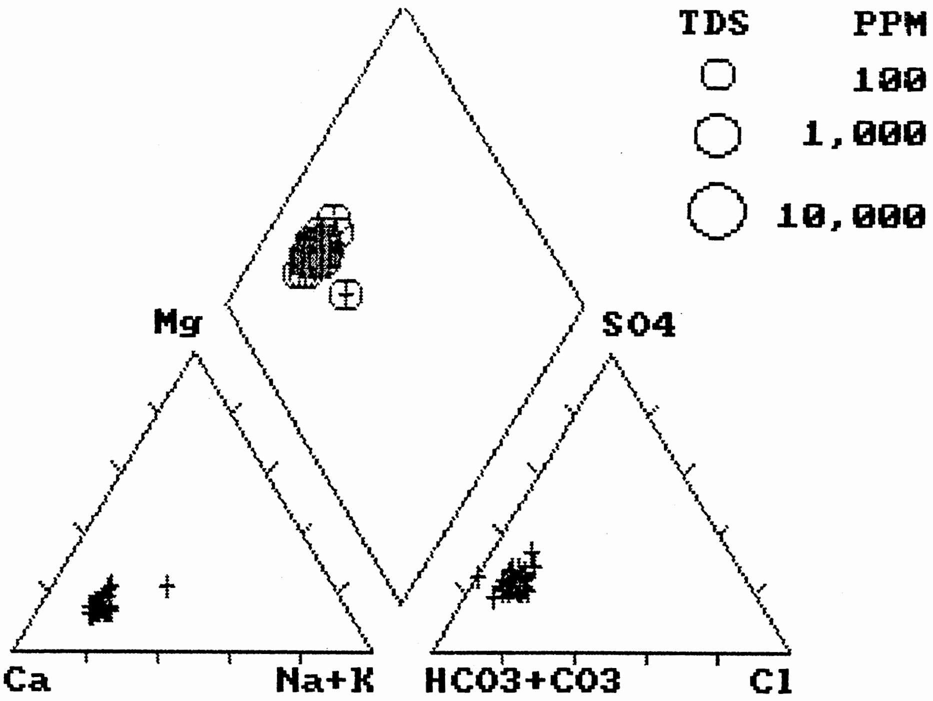

Figure 9. Neosho River piper plot, 1976-1979. Close data grouping in the carbonate hardness area of the piper plot.

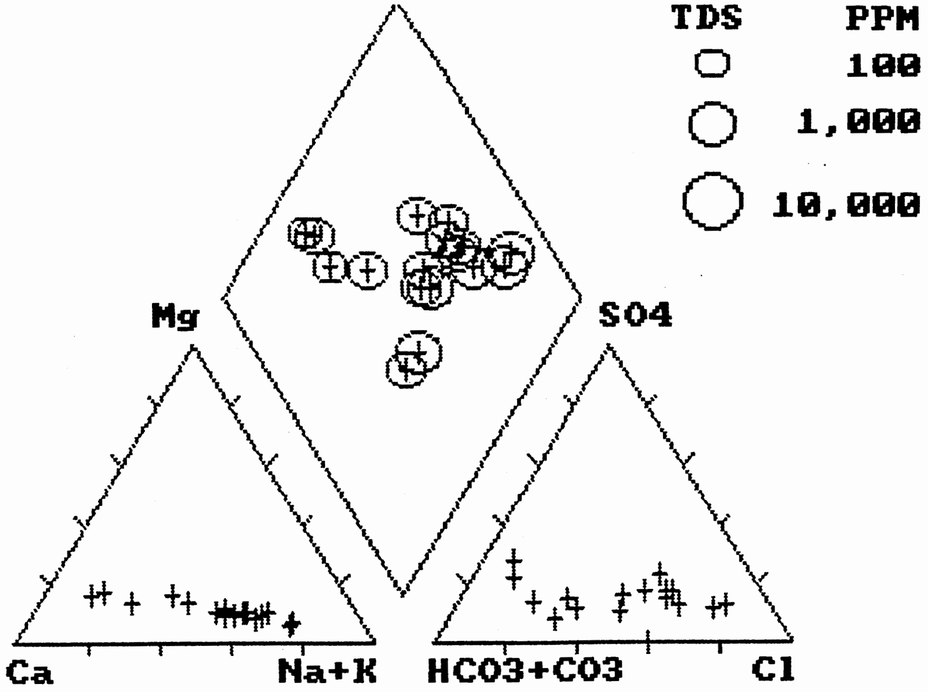

Figure 10. Arkansas River piper plot, 1976- 1979. Data spread includes carbonate hardness from Neosho water mix but dominant concentration indicates the Arkansas River is saline.

Ground Water Piper Plots. The ground water analysis is presented in three sets of plots. Figure 11 is the piper plot of the ground water analysis of 1948 data collected by Reed and Schoff (1951), found in Table V of Appendix C. The data indicate that these samples have characteristics typical of carbonate hardness. Figure 12 is the piper plot of ground water analysis of 1958 samples collected by Tanaka and Hollowell, (1951), (Table V, Appendix C). The 1958 data also plot within the carbonate hardness area of the piper diamond. This suggests that no significant change in the chemistry of the aquifer ground water occurred in those ten years.

The OG&E ground water data represent a period of approximately ten years, 1980 through 1989, (Table VI, Appendix C). The plot of this data, figure 13, resulted in a considerable distribution of the samples on the plot. However, the greatest concentration of samples is situated within the carbonate hardness area of the piper diamond. The spread indicates a trend in the change of the aquifer water chemistry towards the permanent hardness (non carbonate) area of the piper diamond. The piper plot indicates this is a result of increasing levels of sulfate occurring in the ground water samples. The piper plot also indicates an increase in sodium without a corresponding increase in chloride. The latter would occur if the sodium increase were a result of sodium chloride in the Arkansas River water.

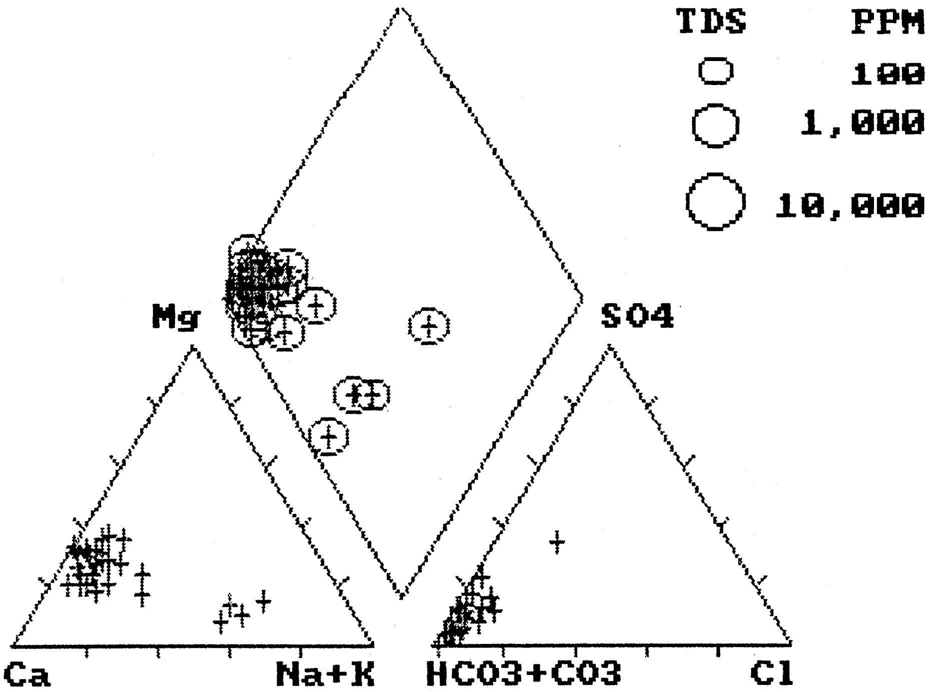

Figure 11. Piper plot, 1948 USGS ground water. Samples indicate carbonate hardness character.

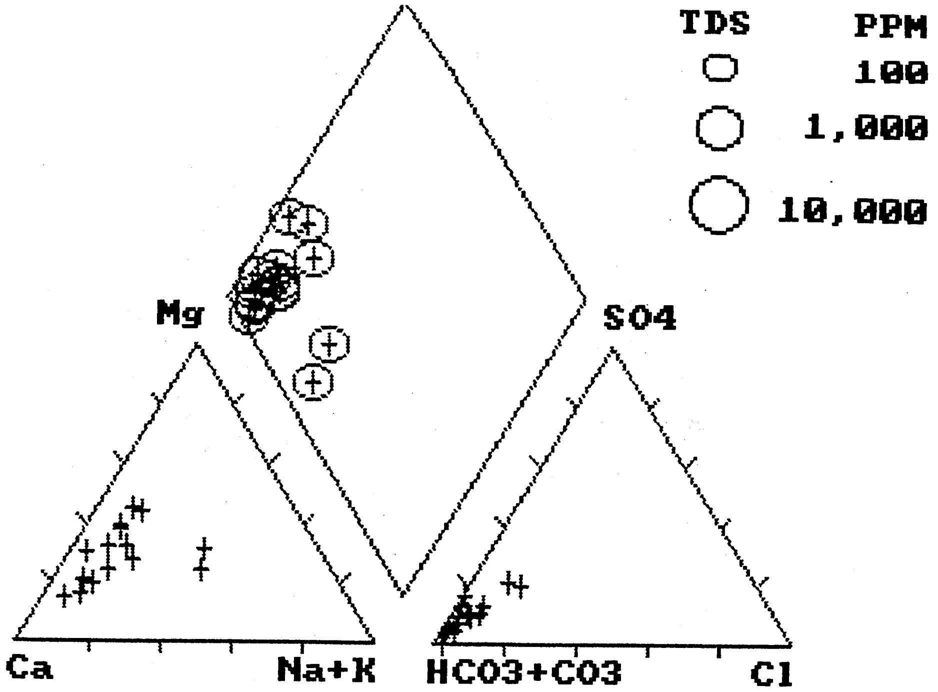

Figure 12. Piper plot, 1958 USGS ground water. Post Neosho regulated data does not indicate change from carbonate hardness character.

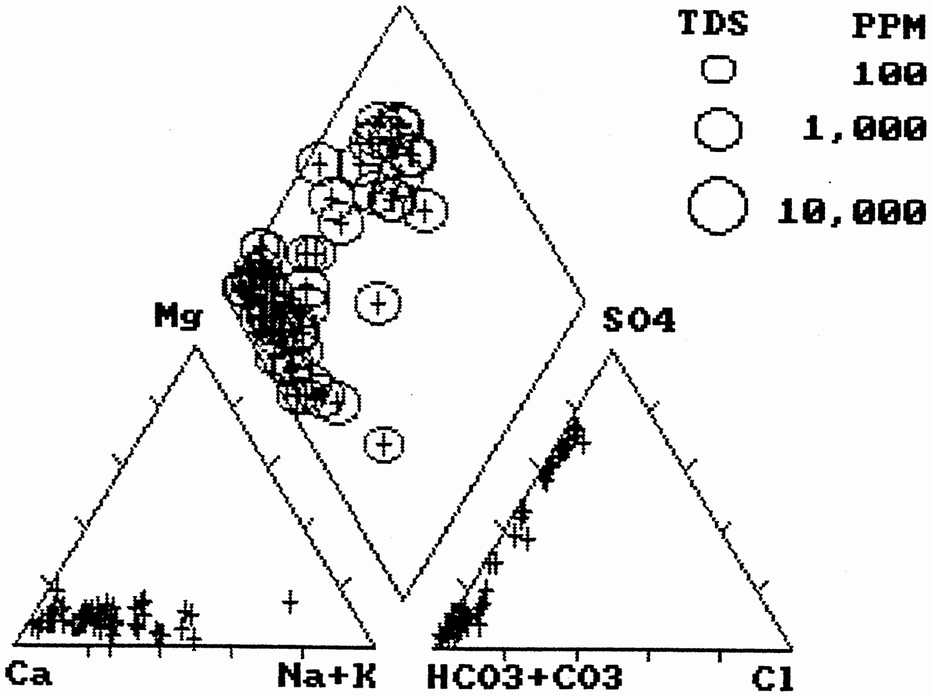

Figure 13. Piper plot, OG&E ground water data. For period 1980-1989. Dominant data grouping still indicates carbonate hardness character. Significant increase in sulfate and sodium apparent.

The following comparisons of the stream water and ground water analysis demonstrate additional relationships between the surface waters and ground waters. Specific elements were reviewed for indication of impact of the Webber Falls Reservoir water on the ground water of the aquifer.

Chloride

The chloride ion generally is not effected by retardation and may be considered a good indicator for any infiltration of the Arkansas River water.

River Water Chloride. The chloride ions found in the Arkansas River and tributaries are presumed to occur naturally from halite exposures upstream. Figure 15 illustrates the range of chloride values for the Arkansas River during 1976 through 1979. The wide range of Arkansas River chloride values can be attributed to commingling with or dilution by the Neosho River. A comparison to figure 14, a plot of the discharge or flow rate of the Neosho River, illustrates the Neosho River flow and chloride concentration relationship during most of the period. High chloride values can be expected during low flow periods with the Neosho river. The Verdigris river, for which correlative period discharge data were not available, may also influence the correlation during portions of the period.

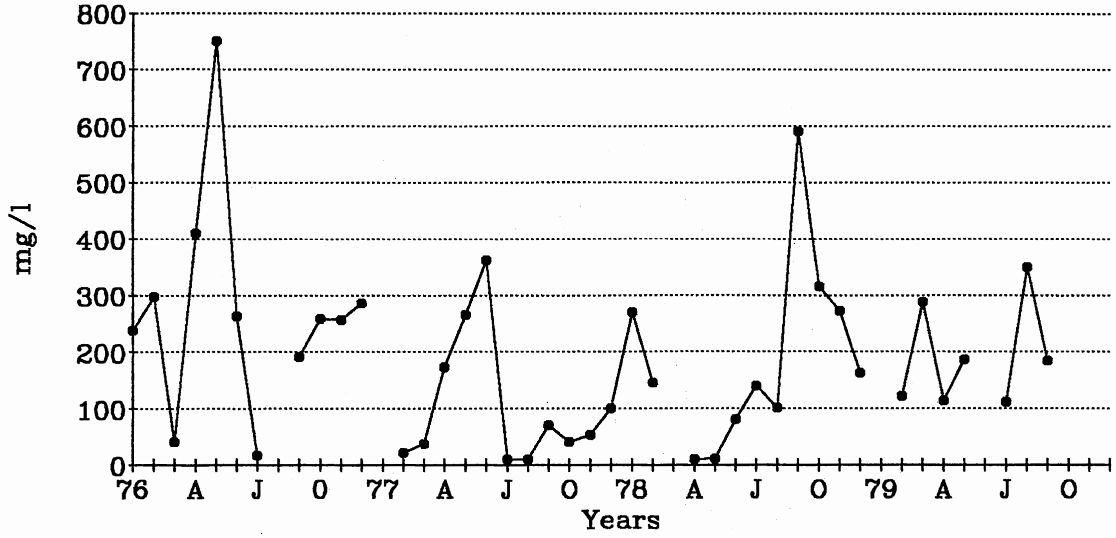

Figure 14. Chloride content, Arkansas River, 1976 - 1979. Wide variation in values are a result of mix with Neosho River water. High values are more representative of Arkansas River water.

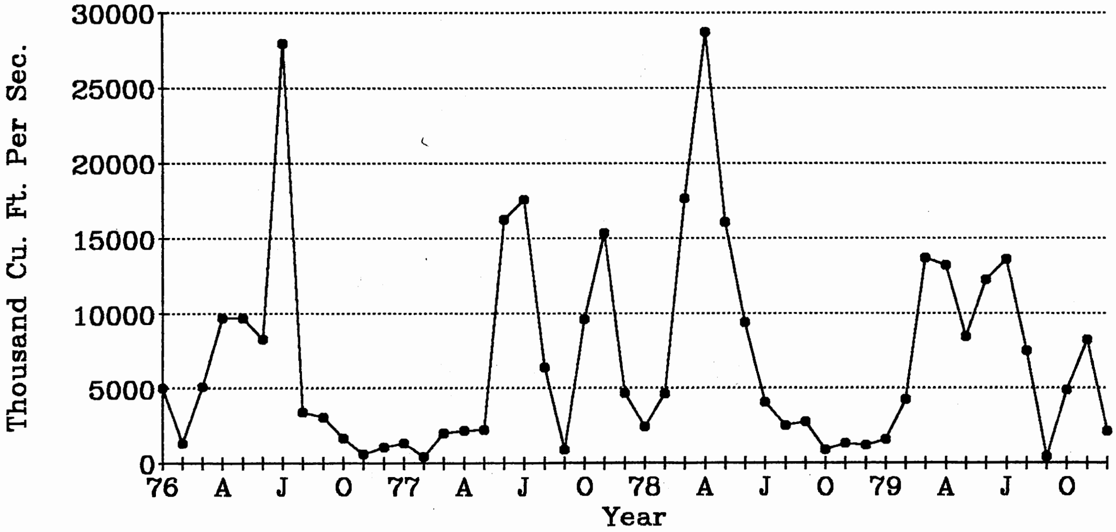

Figure 15. Discharge rate, Neosho River, 1976-1979. High flow rates of Neosho River influence water quality as recorded for the Arkansas River.

Ground Water Chloride. Chloride analysis for ground water records reveal a much lower and more consistent range of values.

The analysis for ground water is presented in two groups in separate figures. The first group, figure 16, represents data from USGS sources from 1936 to 1988 from wells in different locations within the aquifer (see figure 53 for location map). The chloride values average 13.49 mg/l. Although individual samples are periodically elevated to values greater than 50 mg/l, these aquifer samples do not approach the higher values of the Arkansas River which has an average value of 190.51 mg/l. This average for the Arkansas River water does not correct for Neosho River flow and averages the total record. The actual chloride values of normal Arkansas River water are probably significantly higher.

The second group, figure 17, is data provided by OG&E for samples from 1980 to 1989. The average value for the OG&E chloride data is 8.9 mg/l. Infiltration of the Arkansas River water into the aquifer is not suggested for this period of record which extends nearly 20 years after the Webber Falls Reservoir was created.

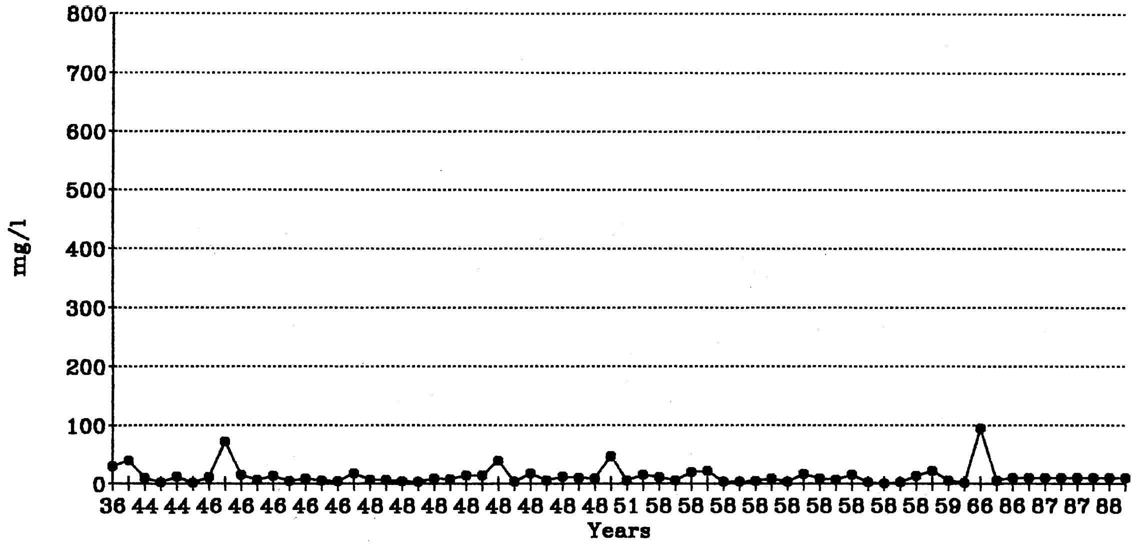

Figure 16. Chloride levels, USGS data ground water samples, 1936 - 1988. Values have little variation and do not show evidence of Arkansas River water infiltration.

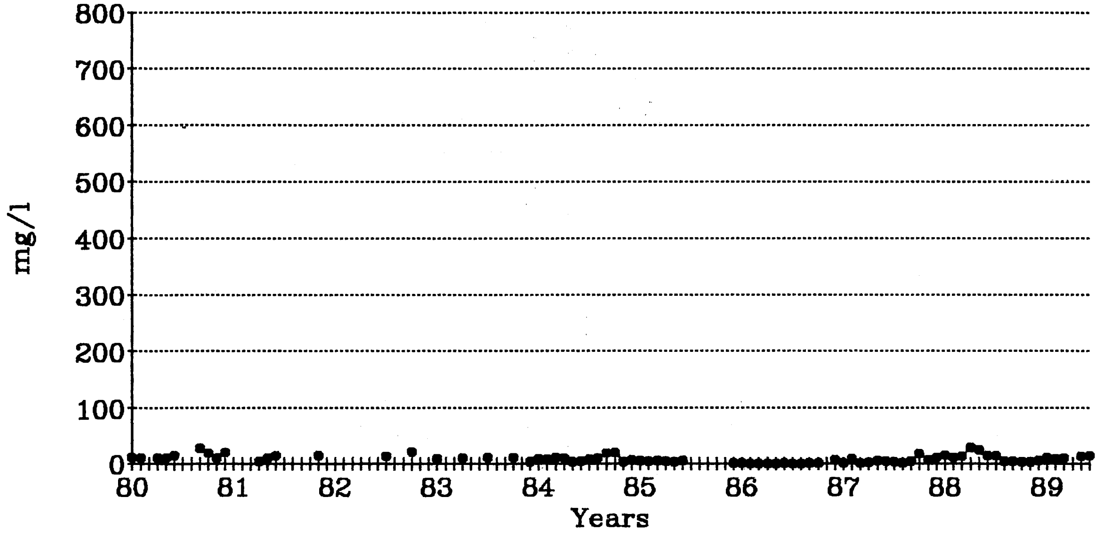

Figure 17. Chloride level, OG&E data, 1980 - 1989. Values are consistent with historic ground water chloride values and do not show evidence of influence of high Arkansas River water infiltration.

Chloride:Conductivity Ratio. Ratios of the chloride ion to the conductivity were developed to determine the relationship of chloride to the conductivity of the waters studied. The ground water data, figures 18 and 19, illustrate chloride:conductivity ratios in the .01-.05 range. The Arkansas River ratios, figure 17, average a magnitude higher than the ground water, or up to 0.4. Because of regular commingling with the Neosho River which has lower values, the recorded values do not reflect continuous Arkansas River water and are represented by periodic peaks. Based upon visual comparison of the higher Chloride:Conductivity ratios of the Arkansas River and lower ratios of the ground water data, the analysis of the chloride:conductivity does not support infiltration of the Webber Falls Reservoir water into the aquifer.

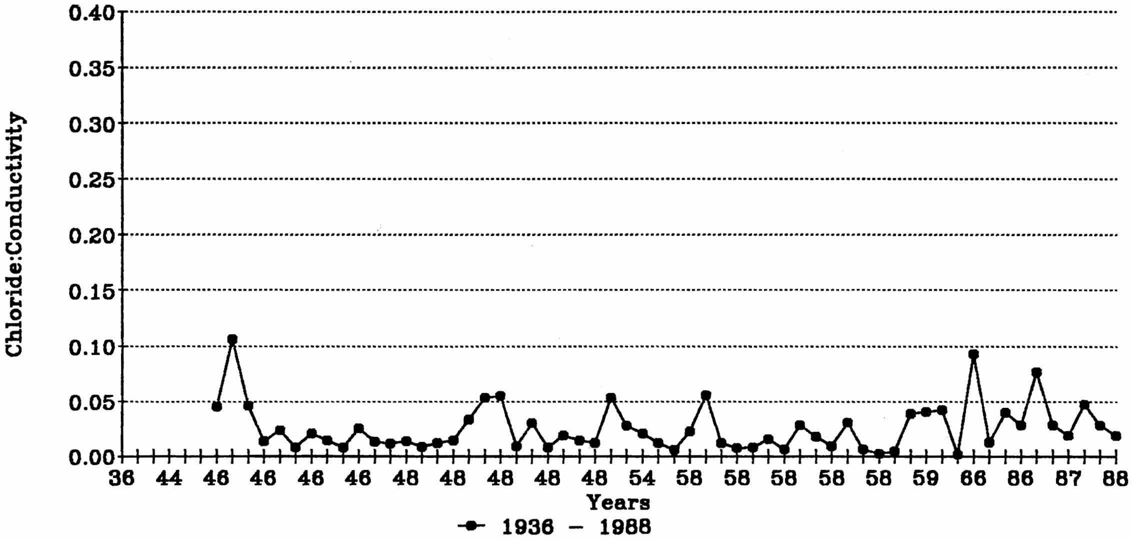

Figure 18. Chloride:Conductivity ratio, USGS ground water data, 1936 -1988.

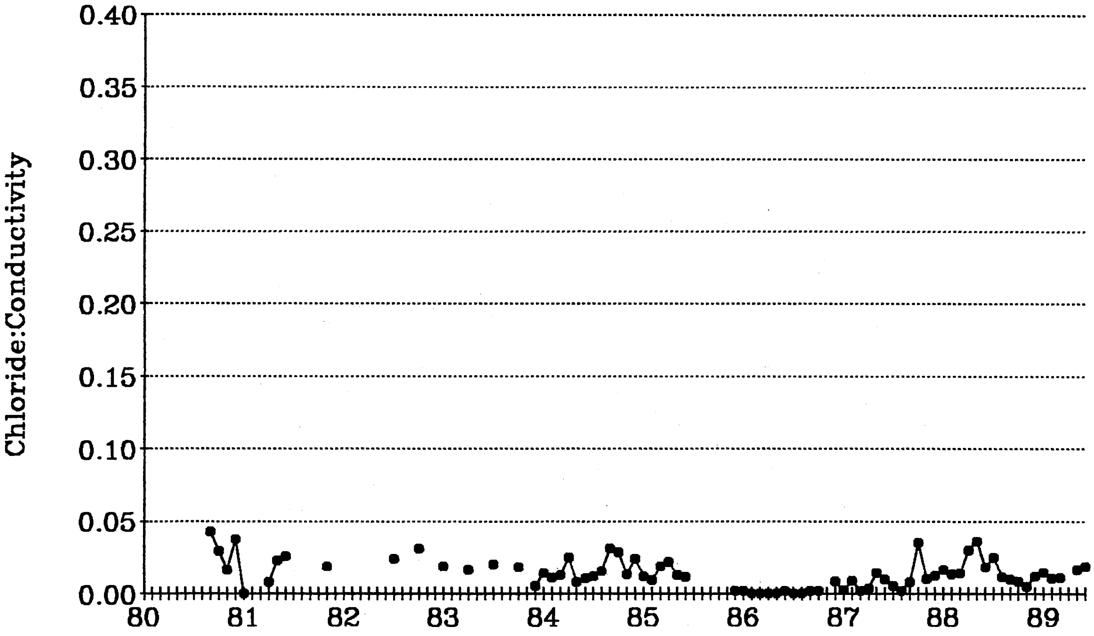

Figure 19. Chloride:Conductivity ratio, OG&E data, 1980 - 1989.

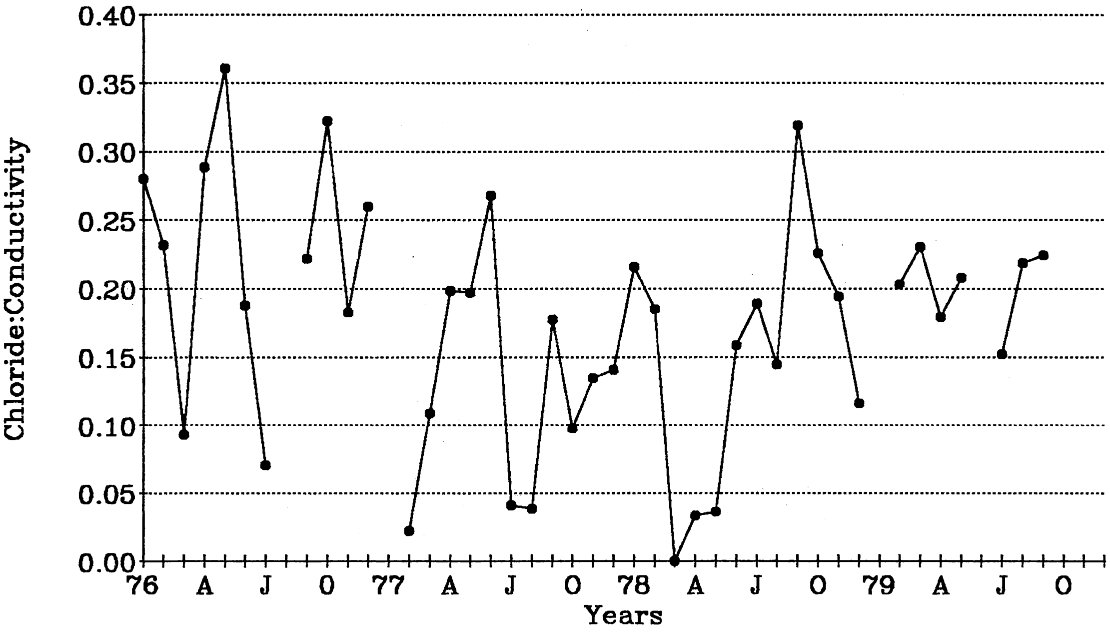

Figure 20. Chloride:Conductivity ratio, Arkansas River, 1976-1979.

Sulfate

Sulfate values for the Arkansas River, figure 21, are generally above 50 mg/l and less than 100 mg/l for the period 1976 to 1979. The variable range is again a result of the influence of the high flow periods of Neosho River flow at the Arkansas River gauging station. Sulfate values for the Neosho River, figure 22, are about one-half of the Arkansas river values or less than 50 mg/l.

Values for the USGS ground water samples taken over a 50 year period, figure 23, generally fall under 50 mg/l values. Review of the OG&E data, figure 26, indicates background sulfate values consistent with the other ground water data, about 50 mg/l, but does indicate very high periodic increases in sulfate levels.

The 1980 - 1989 OG&E background values are consistent with pre-regulation values and the elevated occurrences are significantly higher than could be contributed by the Webber Falls Reservoir. The analysis of sulfate values of the ground water do not suggest infiltration by river water.

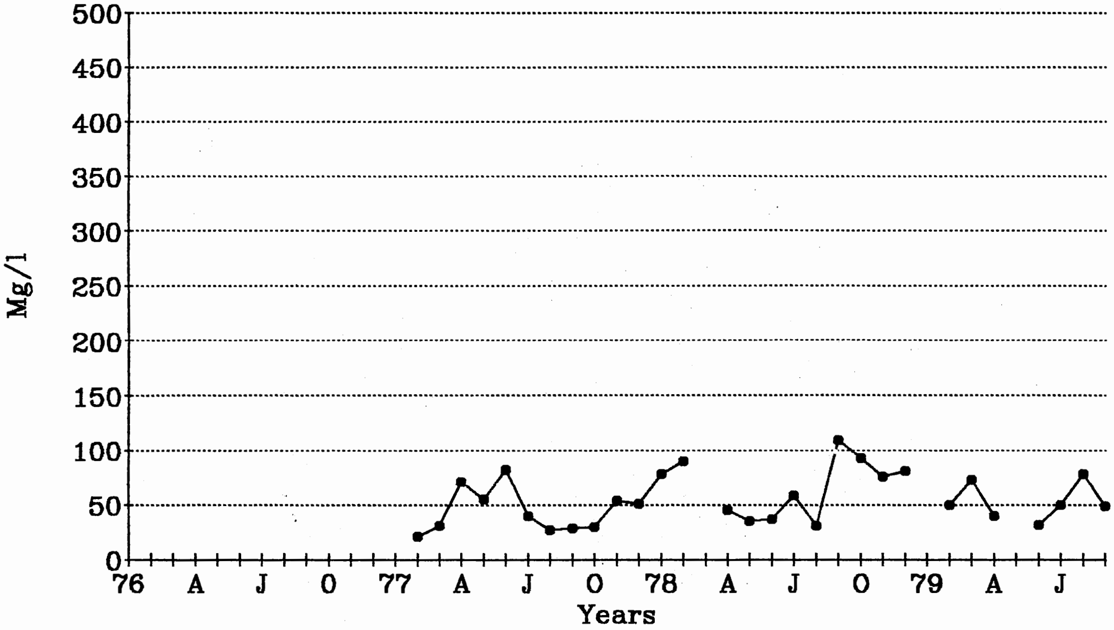

Figure 21. Sulfate levels, Arkansas River, 1976-79.

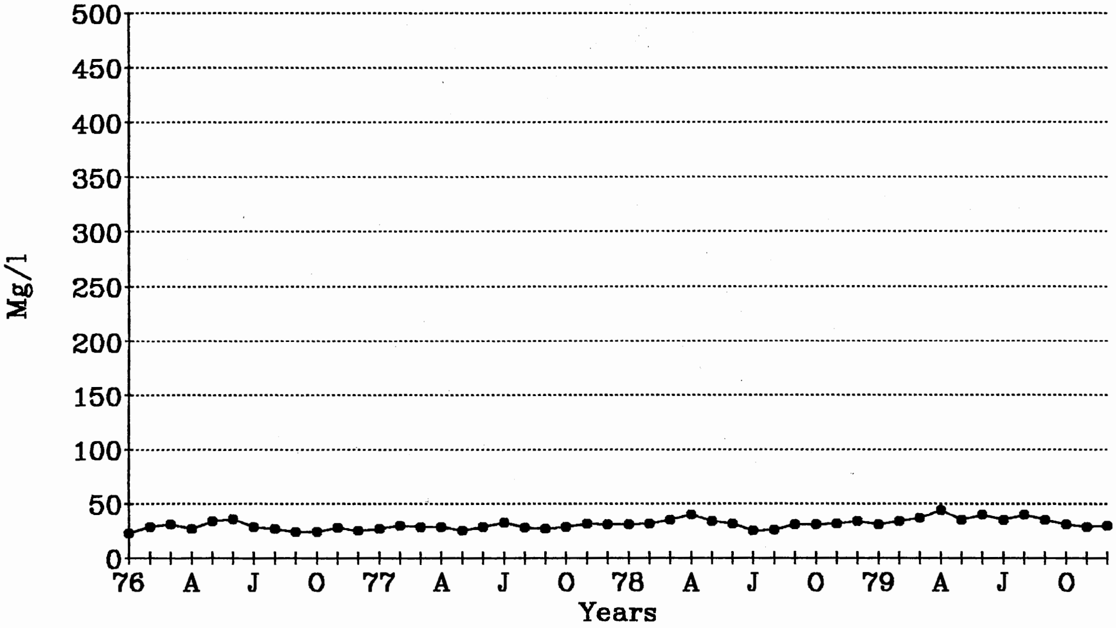

Figure 22. Sulfate levels, Neosho River, 1976-79.

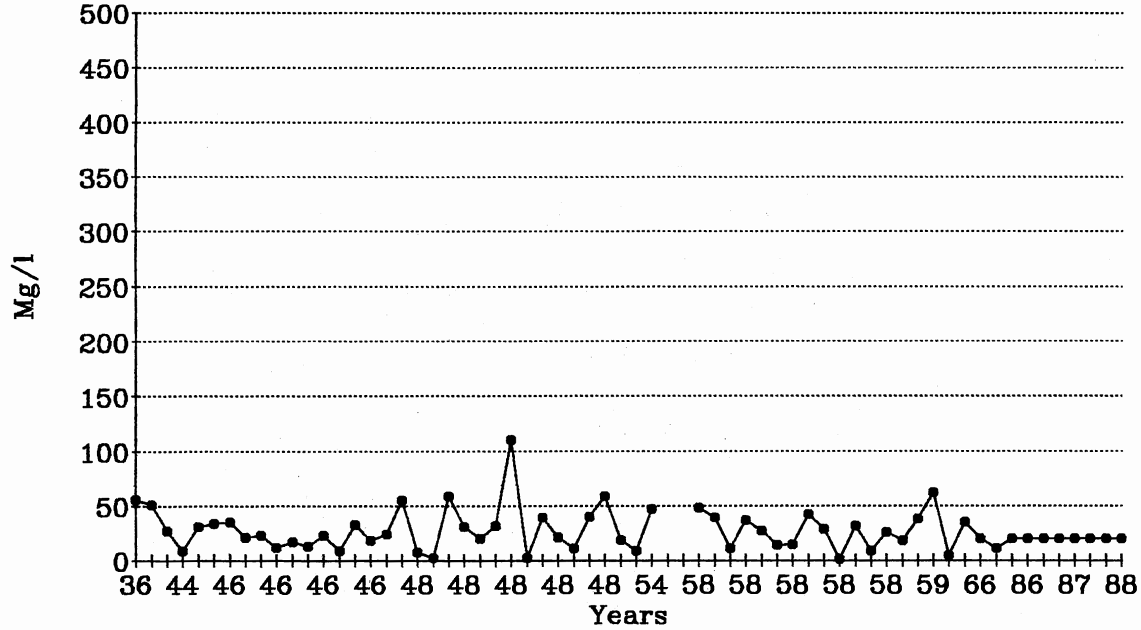

Figure 23. Sulfate levels, USGS ground water data, 1936-88.

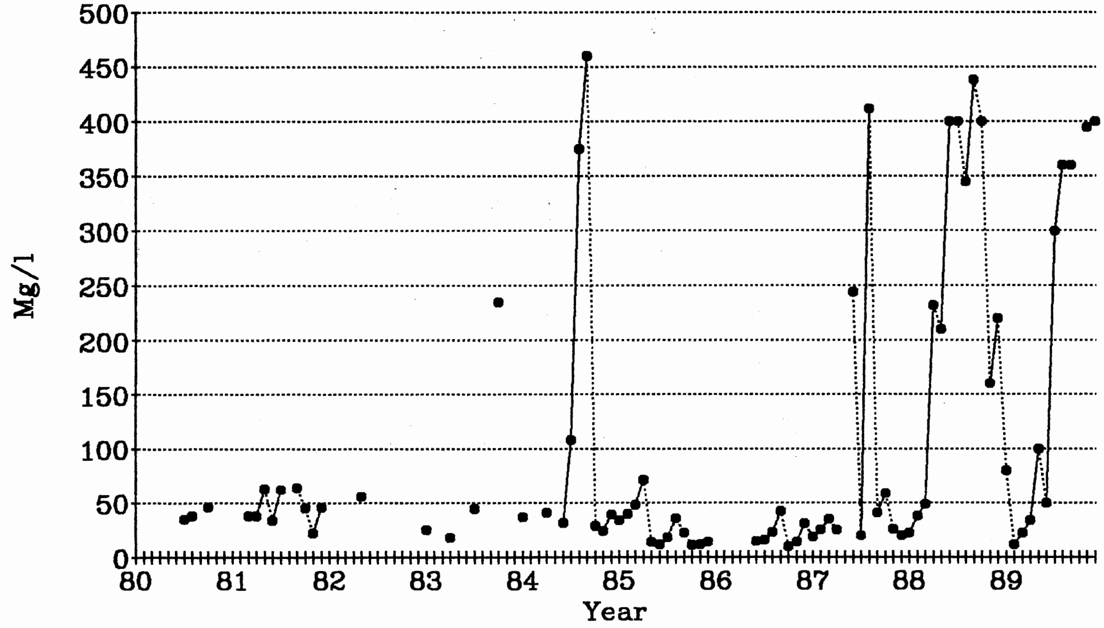

Figure 24. Sulfate levels, OG&E data, 1980-89

Geochemical Effects on Hydrology

Geochemical conditions can affect the physical characteristics of the aquifer as well the chemical nature of the ground water. These physical characteristics include permeability, hydraulic conductivity and transmissivity. The lack of physical or chemical evidence for Arkansas River/Webber Falls Reservoir water infiltration may be related to geochemical reactions.

Cation exchange reactions may occur when a dominant cation becomes bound to another particle it comes in contact with. Usually, in natural water chemistry, divalent calcium or magnesium are the dominant cations and will enter any exchange reactions. If sodium dominates the cations, the effect of sodium exchange onto clay particles may cause the clay particles to become dispersed which can result in a decrease in permeability (Bouwer, 1978). The data indicates that sodium is a dominant cation of the Arkansas River (figure 25). It is possible, upon infiltration of the Arkansas River water during high river stages, that sodium in the Arkansas River water may infiltrate into the adjacent aquifer and undergo cation exchange with the clays. The clay will disperse and migrate through the pore spaces of the coarser aquifer and separate in such a way as to plug the pores and reduce the transmissivity of the aquifer. The depth of this effect into the aquifer may be limited to a few hundred feet but can result in significant reduction of the hydraulic conductivity of the river into the aquifer. This would have an effect of creating a geochemical barrier to any significant infiltration from the Arkansas River.

Evidence for this type of ion exchange effects on hydraulic conductivity reduction can be interpreted from Schoff and Reeds work in 1948. In test well number 29, located 1/4 of a mile from the Arkansas River, their study reported:

> Locally the sand and gravel may be so mixed that they possess only a relatively low permeability, or they may contain silt or clay that reduces the permeability. Test hole 29 is an example of such a situation. In it, silt and very fine sand were found beginning at the surface and grading down into medium-grained sand. Coarse sand and fine gravel were encountered at about 23 feet and continued to the bedrock at 47 feet, with much fine gravel-pea size and somewhat larger-coming from depths of 40 to 45 feet. With 29 feet of saturated material, most of it gravelly, it seemed that the hole should yield water freely, but the attempt to obtain a sample of water failed utterly. At the end of an hour of jetting practically the only water coming from the hole was the water put into it from the driller's tank truck, whereas the other holes sampled by this method began to produce with a steady pulse after a few minutes and furnished relatively clear water after about 30 minutes. Two facts from the record of the drilling pointed to the explanation: (1) No loss of drilling fluid occurred, although the drilling mud consisted only of the silts and sands washed from the hole, and (2) the hole showed little tendency to cave in. Furthermore, the water rose very slowly after the bit was pulled from the hole, instead of coming almost at once to the static level. These circumstances suggest that silt and clay were mixed with the sand and gravel, passing unnoticed into the slush pit and leaving the false impression that clean sand and gravel were present.

Additional evidence in Schoff and Reeds work can be interpreted in comparing the results of three aquifer tests.

These tests sought to determine various parameters of the aquifer. Only two of the three test were successful and provide comparison of the aquifer properties (see figure 1). Test one, on well P-2, located in section 23-15N-19E indicated that the well had an approximate specific capacity of nearly 50 gallons per minute per foot of drawdown. The other aquifer test on well P-3, located in section 21-15N-19E about a third of a mile from the Arkansas River, was selected specifically to evaluate the hydraulic connection of the aquifer to the river. The specific capacity of P-3 was less than 20 gallons per minute per foot of drawdown. Observation wells associated with this test indicated a .26 foot greater drawdown in the observation well nearest the river than in the observation well farthest from the river and could indicate a reduction in the transmissivity of the aquifer near the river. After the aquifer test, the greatest net decline in water level occurred in the observation well nearest the river and the least decline was in the observation well farthest from the river, suggesting little bank infiltration or recharge from the river.

Figure 25 illustrates the average calcium, magnesium and sodium levels found in the Arkansas River during 1976 - 1979. These values are not adjusted for effects of Neosho River flow. As indicated by the figure, the Arkansas River has adequate sodium levels to effect this type of cation exchange reactions.

Figure 26, illustrates the average calcium, magnesium and sodium values for the Neosho River. Figures 27 and 28 illustrate the average calcium, magnesium and sodium found in the ground water of the study area in the USGS records and the OG&E data.

The pre-regulated relationship of the aquifer and river allowed for periodic opportunities for reversal of cation exchange reactions when the calcium dominated ground water discharged into the river during high aquifer levels and low river stages.

Establishment of a higher static level of the river by creation of the Webber Falls Reservoir has reduce the gradient from the aquifer to the river and has limited the previous discharge/recharge capability of the aquifer. Without this discharge/recharge capability, cation exchange reactions may become permanent, restricting significant infiltration of the Arkansas River water into the aquifer and limiting the discharge of ground water from the aquifer to the river except at very high ground water levels.

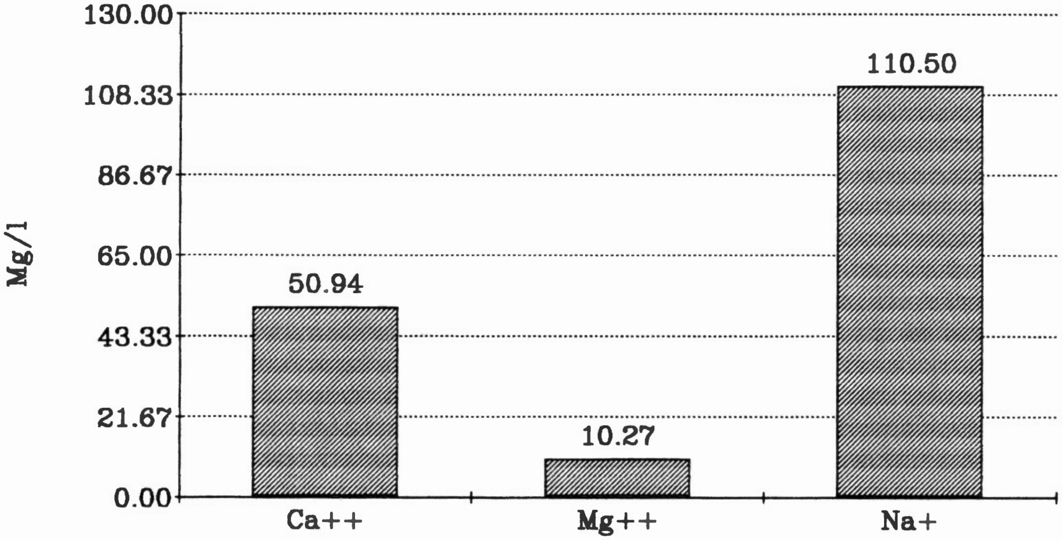

Figure 25. Calcium vs magnesium vs sodium, Arkansas River 1976 - 79. Relationship of average values. Despite effects of Neosho River water on the average values, the sodium percentage is still nearly 50%.

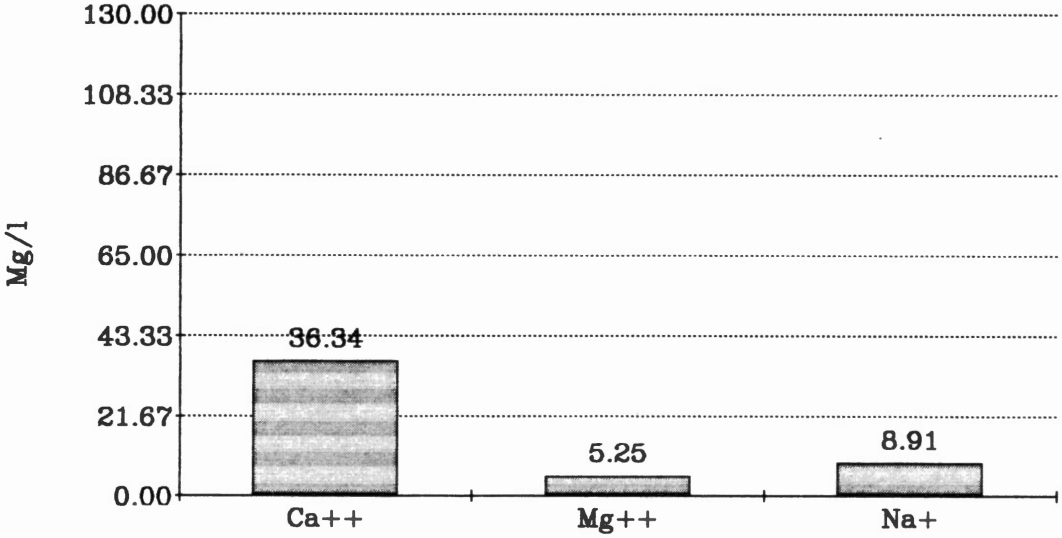

Figure 26. Calcium vs magnesium vs sodium values, Neosho River 1976 - 79. Average values.

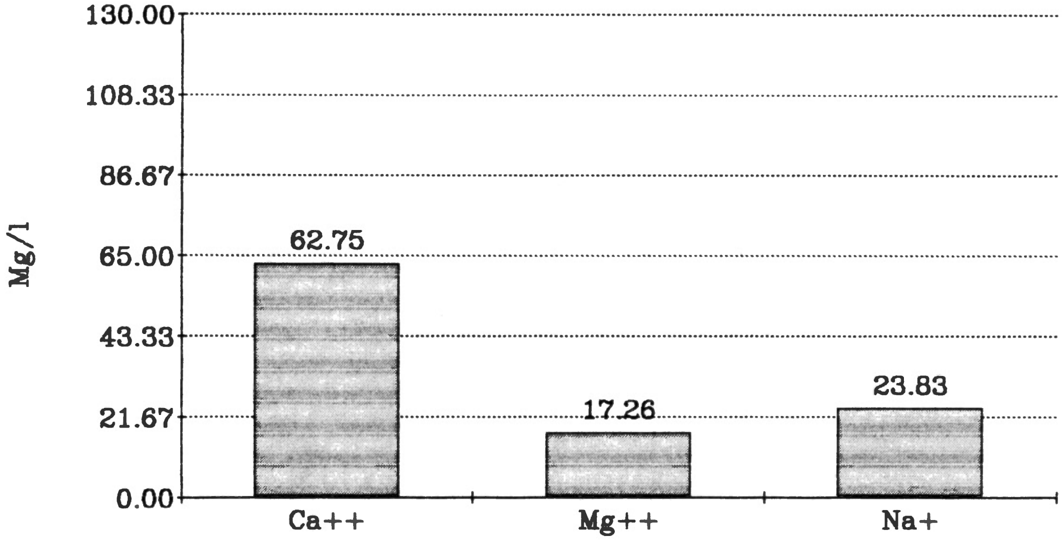

Figure 27. Calcium vs magnesium vs sodium, USGS ground water samples, 1936 - 1988. Average values.

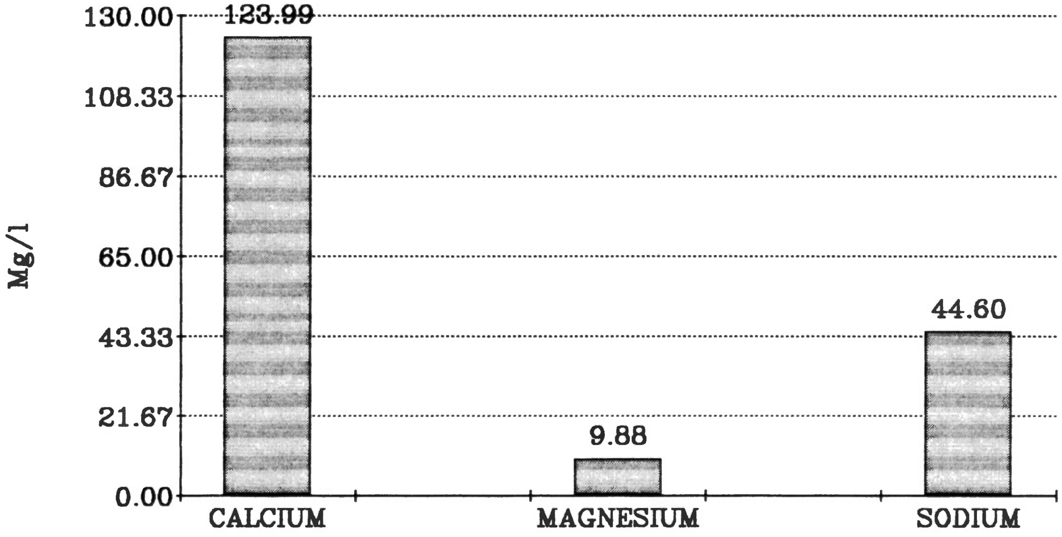

Figure 28. Calcium vs magnesium vs sodium, OG&E ground water samples, 1980 - 1989. Average values.

CHAPTER III

AGRICULTURAL AND IRRIGATION CONSIDERATIONS

Agricultural Activity

The study area has had active agricultural activity for decades. Currently, the southern and eastern portion of the flood plain, overlying the aquifer, is currently farmed for soybeans, alfalfa, and wheat. The areas in the western portion are developed by commercial nurseries which grow ornamental trees,including pears, crabapple, ash, locust, and maples.

Soil

The soil of the flood plain is variable. The dominant soil types are those of the "Servern-Kiomatia-Roebuck which is described as a "Deep, nearly level to moderately sloping, well drained or somewhat poorly drained soils that have a loamy, sandy, or clayey surface layer and loamy or sandy underlying layers or a clayey subsoil on flood plains" (Soil Conservation Service, 1984). Significant areas of the flood plain have high clay content soils with high to very high shrink/swell potential. These soils can cause serious problems for soil tilth and may require soil amendments to enhance productivity. Figure 29, shows the distribution of these soils in the study area.

These soils are described with (Soil Survey Muskogee County, 1984):

	DEPTH (IN)	CLAY %	DRAINAGE/IRRIGATION
OSAGE (51)	0-16	35-40	percs slowly
	16-68	35-60	
ROEBUCK (57 & 59)	0-22	40-60	slow intake,
	22-70		percs slowly

It is apparent from figure 29 that these potential problem areas are in the western areas where agricultural activity is dominated by crops of alfalfa, soybeans and wheat. These activities are carried out by individual farmers and information regarding agricultural practices are difficult to obtain. The soils of the western portion of the study area appear to have characteristics which do not pose unusual management problems.

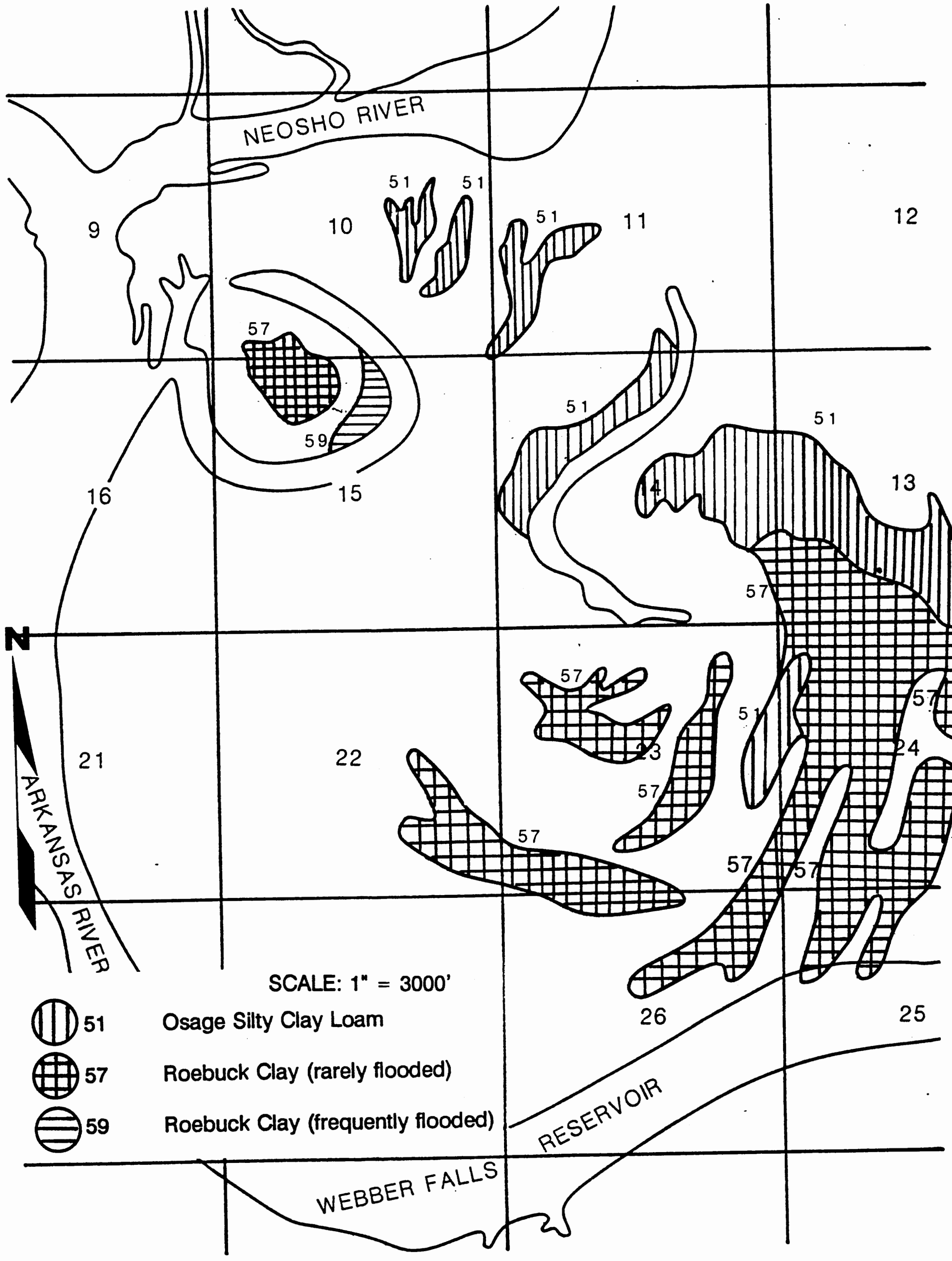

Figure 29. Location map of high shrink swell soils. (From Soil Survey Muskogee County, Oklahoma, 1984)

Irrigation Water Consideration

Water used for irrigation can be evaluated for various factors but the most common natural chemical considerations concern the levels of salinity and potential sodium hazard.

Irrigation in the study area is supplemental and generally confined to the summer. Greenleaf Nursery reports that they average one inch of irrigation per week, depending upon precipitation. Currently two types of irrigation are practiced in the area. Drip irrigation is the dominant method used by the Grand River Nursery, in the north and west portion of the study area, whereas Greenleaf uses conventional spray in the south portion.

For any type of irrigation, some water must continue to move past the root zone to carry away any excess salts. Normally, precipitation will provide this need. If the area is arid, or precipitation becomes inadequate, then irrigation must provide the water volume to accomplish this need. The U.S. Salinity Laboratory (1954), refers to this as the "leaching requirement". In general, the amount of leaching required is the ratio of depth of drainage volume to the depth of irrigation water applied.

Increases in the electrical conductivity of the ground water, especially during the cyclic drought periods, may make the drip method inappropriate if the salinity within the root zone becomes excessive. Depending upon the severity, a change of crop type(s) to a less salt sensitive variety, may be an alternative approach to continue the drip method.

Salinity and Conductivity

Salinity is most often expressed in terms of electrical conductivity and is directly related to the total dissolved solids of the water. Figure 30 illustrates this relationship with the total dissolved solids and conductivity of the OG&E data. Conductivity is particularly useful because it can be determined readily. Although most water used for irrigation is typically less saline than that considered harmful, the salinity of soil solutions are typically greater. The considered level of acceptable conductivity for irrigation water is 750 micromhos/cm. Some salt sensitive crops could be affected at this level. The U.S. Department of Agriculture reported ranges of soil solutions as much 10 times as high as found in irrigation water.

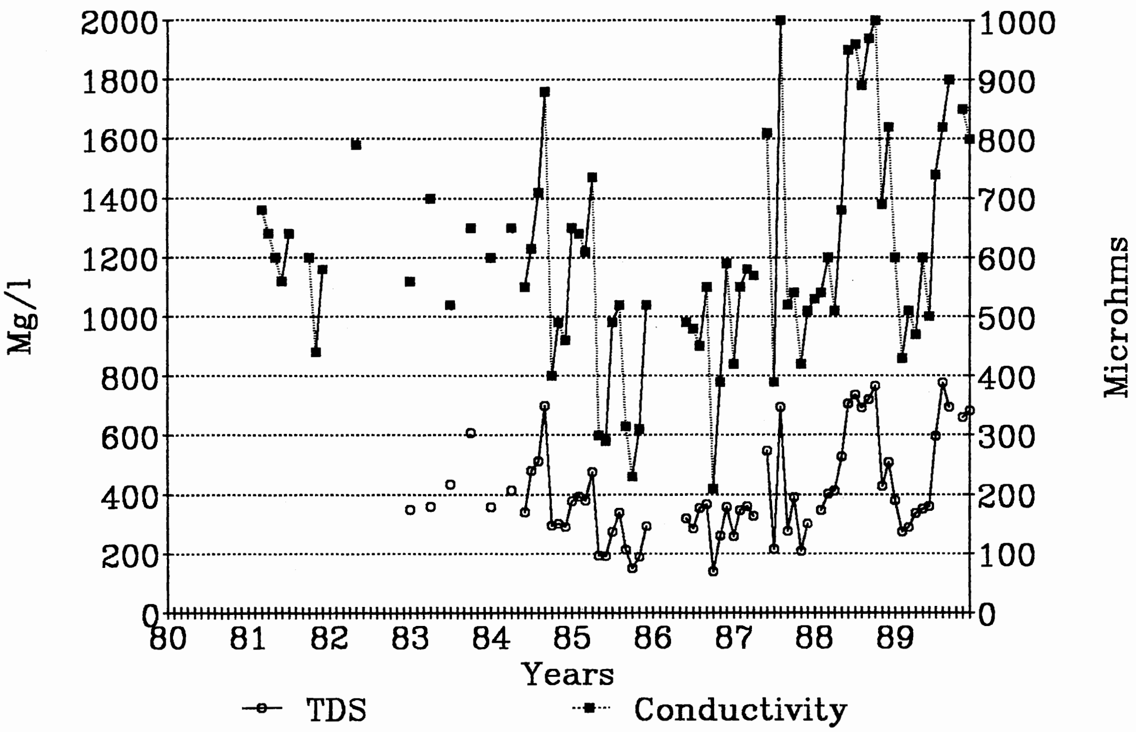

Figure 30. OG&E conductivity and total dissolved solids. OG&E data, 1980 - 89.

The increase is a result of concentration of the solids from water loss through evaporation and root uptake of water by plants. As a result, water which may appear acceptable for irrigation may contribute to saline conditions, especially if drainage is poor, from to soil conditions or elevated water tables. Water with conductivities greater than 750 micromhos/cm. are useable but special management maybe required.

The electrical conductivities of the Arkansas river vary from approximately 700 to over 2000 micromhos/cm (figure 31). These values are obtained for the period 1976 thru 1979 with the lower values a result of high Neosho

River flows mixing with the Arkansas River water at the gauging station.

Figures 32 and 33 exhibit the conductivities for the USGS ground water data and OG&E data, respectively. The OG&E data indicate higher conductivities are developing in the ground water than has been recorded in the USGS ground water data.

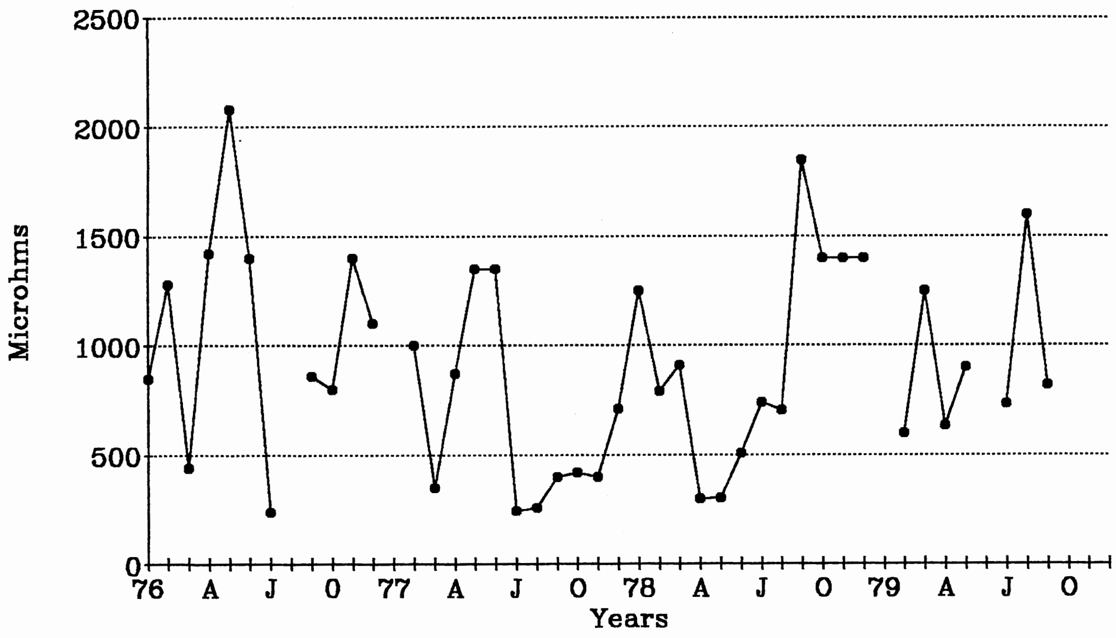

Figure 31. Conductivity, Arkansas River, 1976-1979.

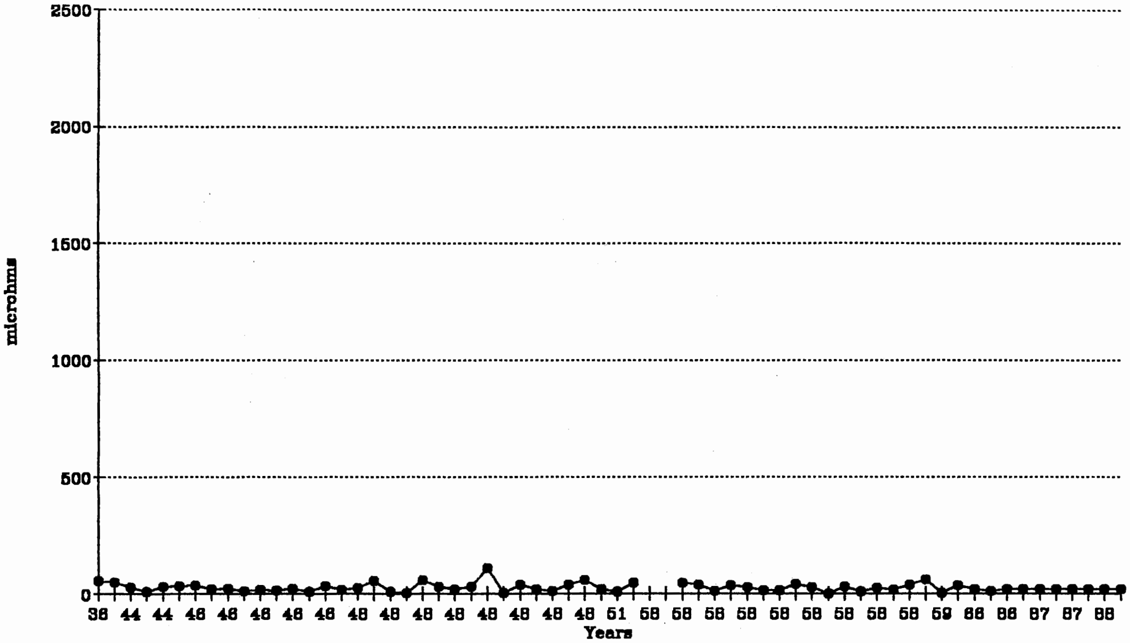

Figure 32. Conductivity, USGS ground water samples, 1936 - 88.

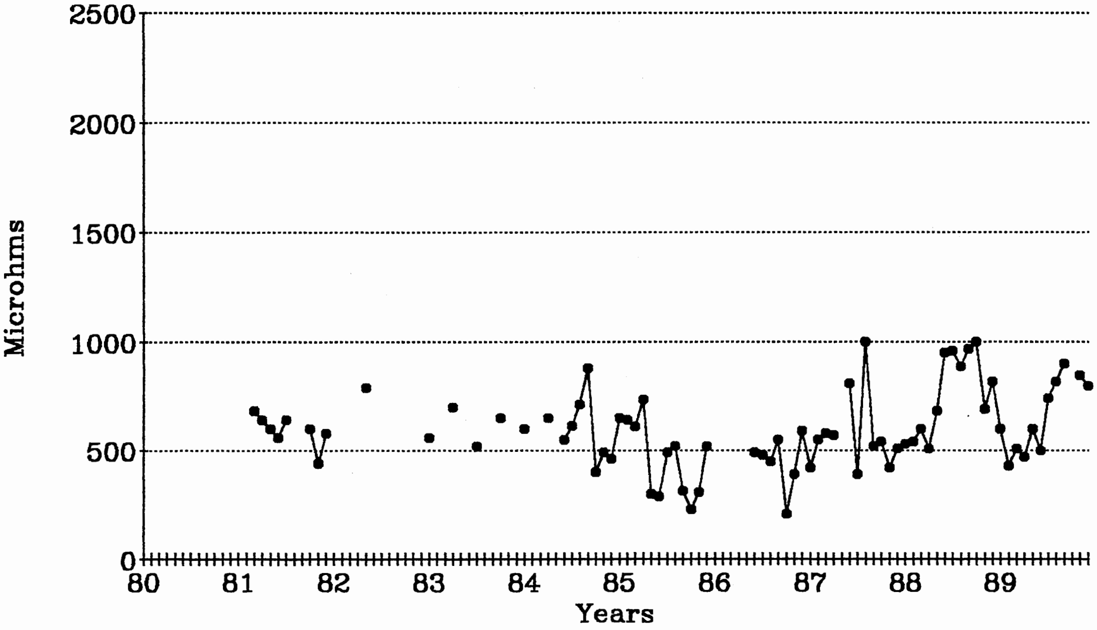

Figure 33. Conductivity values, OG&E data, 1980-89

Sulfate

Sulfate values for the aquifer are periodically elevated relative to the historic USGS ground water data. (figure 23 versus figure 34)

Examination of the sulfate values of the OG&E ground water data, figure 33, compared to the total dissolved solids values in figure 35 clearly indicate that sulfate is the primary cause of the increasse in total dissolved solids/conductivity.

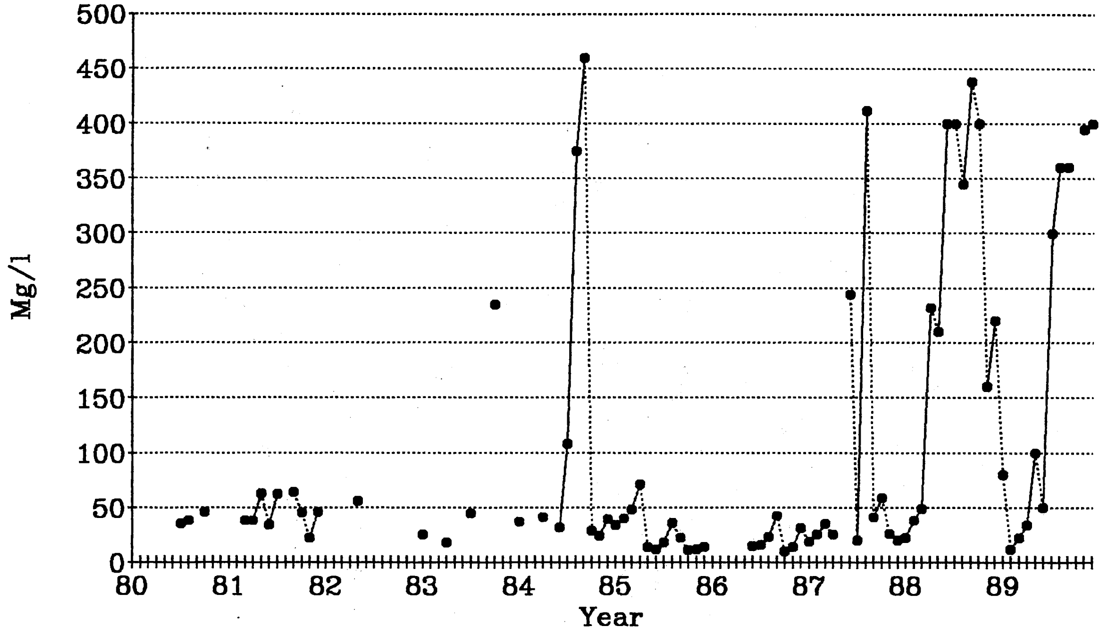

Figure 34. Sulfate levels, OG&E data, 1980-89.

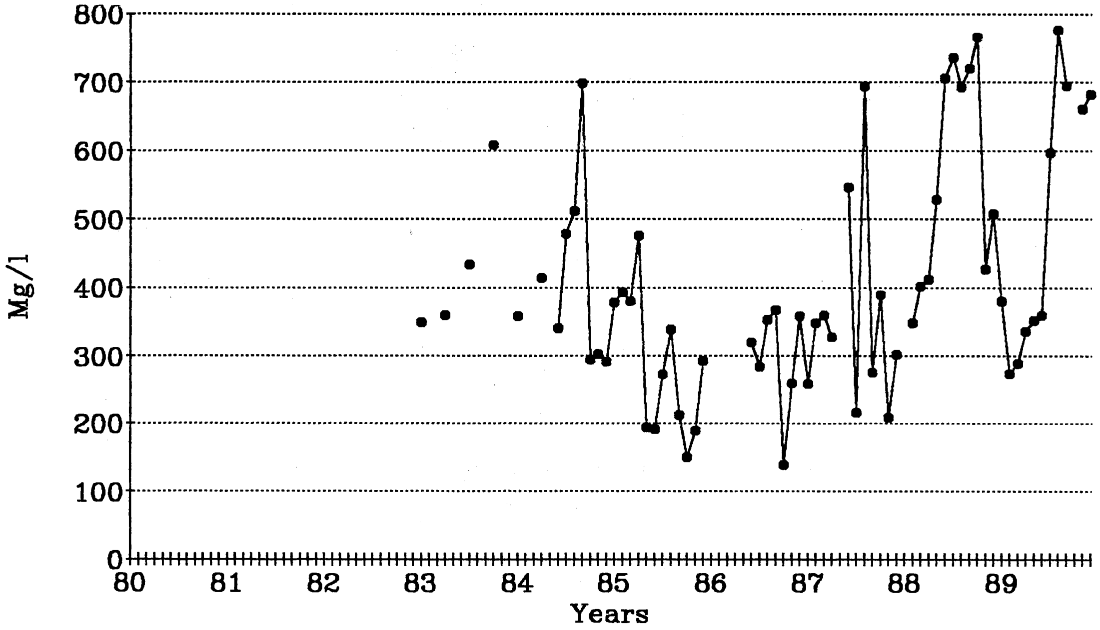

Figure 35. Total dissolved solids, OG&E data, 1980-89.

Sources of Sulfate

Coal stock piles from the OG&E facility represent one potential source of sulfate. This source, is however, can be discounted because the coal is a Wyoming "low sulfur" variety and the stock pile is not on the gradient with the OG&E ground water control data.

Another source could be induced infiltration from the Arkansas River by pumping irrigation wells. The typical sulfate levels of the Arkansas River, figure 36, are much lower than the levels reached in the OG&E data, figure 37. Additionally, increases in chloride values, as a result of induced river infiltration, are not observed.

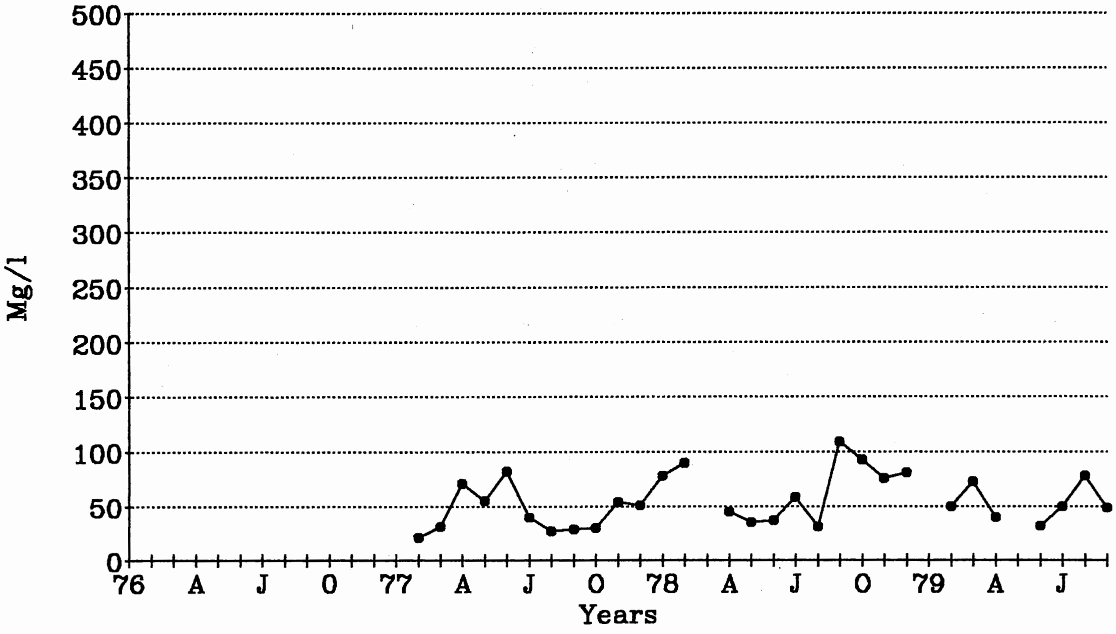

Figure 36. Sulfate levels, Arkansas River, 1976-79.

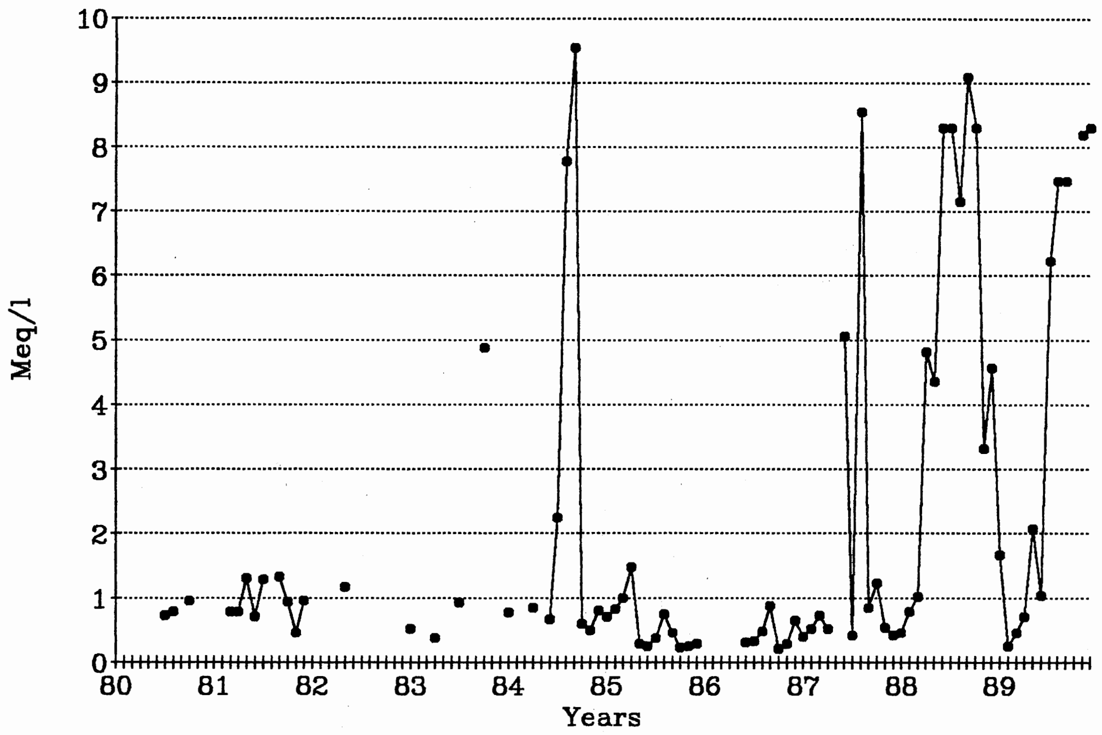

Figure 37. Sulfate levels, OG&E data, 1980-89.

The occurrence of the elevated sulfate values are generally seasonal, coincident with the growing season and reduced periods of precipitation. The initial occurrence of elevated sulfate began in the summer of 1983 but was more pronounced in the summer of 1984. It reoccurs in the summer of 1987 and each summer thereafter. This relationship suggest an association with the infiltration of irrigation water.

The most likely source of sulfate is from some form of soil amendment practice. This could include application of calcium sulfate (gypsum - CaSO4 2H2O) which is used on clayey soils to improve soil permeability, or agricultural sulfur, used to increase the acidity for certain crops.

Sulfur. Application of agricultural sulfur, in significant quantities to impact the ground water, does not seem necessary. The pH range of the soil should be adequate or require only minimal, local applications, to adjust the soil reactivity. Crops raised in the study area should find the pH adequate.

TABLE II

CROP AND pH REQUIREMENT
(Brady, 1990)

CROP	pH
Pears	6.75
Crab Apple	6.75
Ash	6.75
Locust	7.5
Maples	6.75
Soybeans	5 - 7
Alfalfa	6 - 7
Wheat	5 - 7

Most of the Ornamentals prefer a neutral to slightly acidic range (6.75- 7.5). However, wheat and soybeans prefer a moderately acid environment (5 - 6).

Calcium Sulfate. The application of gypsum is the most likely source of the sulfate. Discussions with area agricultural supply houses do not suggest high current usage of gypsum. However, comments were made that significant amounts were sold "years" ago.

The reaction of calcium sulfate with the soil can be complex. When applied and irrigated into the soil, calcium from the calcium sulfate may replace the sodium associated with the high shrink/swell clays through a series of cation exchanges. The sodium is then available for movement with the soil solution. Some of the sodium exchanged for the calcium may be retained on other clays as it migrates through the vadose zone. Because sodium has a lower ionic reaction preference, it is more likely to appear in the ground water. If no additional calcium exchange sites are available, some of the remaining calcium from the calcium sulfate may precipitate within the soil and some will reach the ground water. Elevated levels of calcium and sodium could be expected. Figure 39, sodium values for the OG&E data, and figure 41, calcium values for the OG&E data, indicate high, intermittent levels during the early portion of the period of OG&E period of record.

The sulfate values do not show a corresponding increase for the early period of record. The sulfate from the calcium sulfate may have been retained within the soil separately. This could occur if low oxygen, or anaerobic conditions existed, and the sulfate was used as an oxygen source for decomposable organics. This environment would convert the sulfate to sulfide, which has a significantly lower solubility, and prevent the sulfate from entering the ground water. Only when oxygen levels improved could the sulfide be reconverted to sulfate and available for migration, or recombined with precipitated calcium to form calcium sulfate.

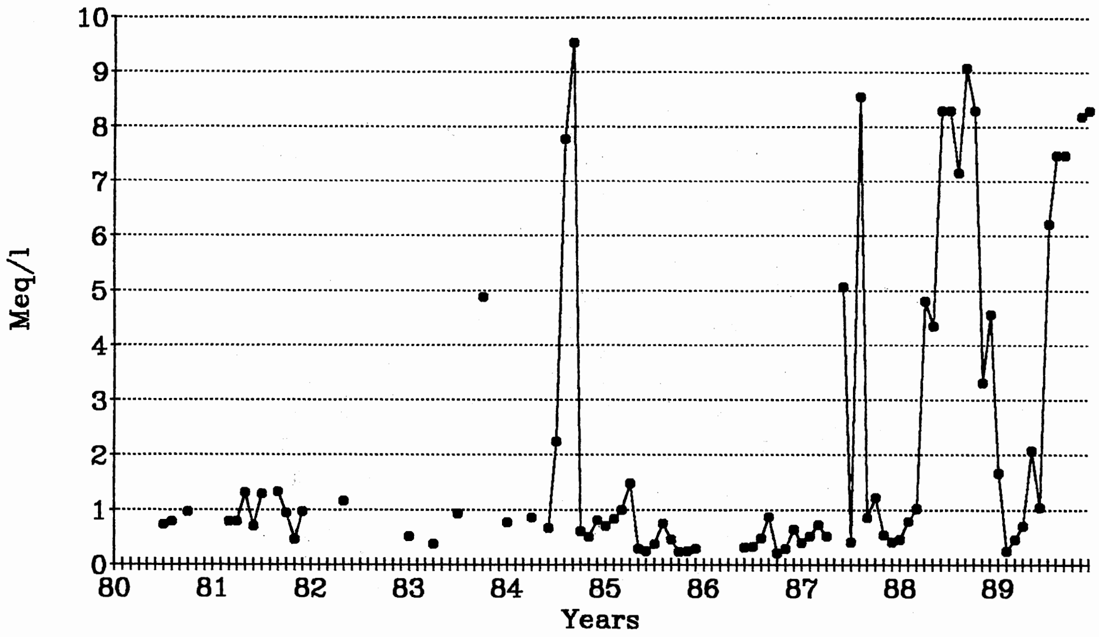

Figure 38. Sulfate levels, OG&E data, 1980-89.

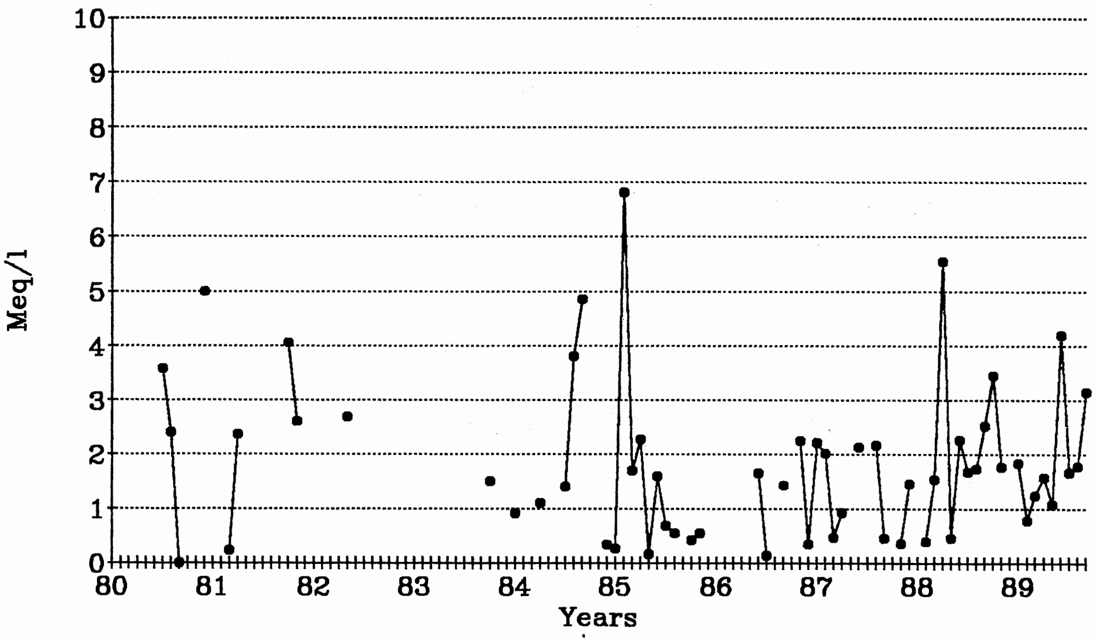

Figure 39. Sodium levels, OG&E data, 1980-89.

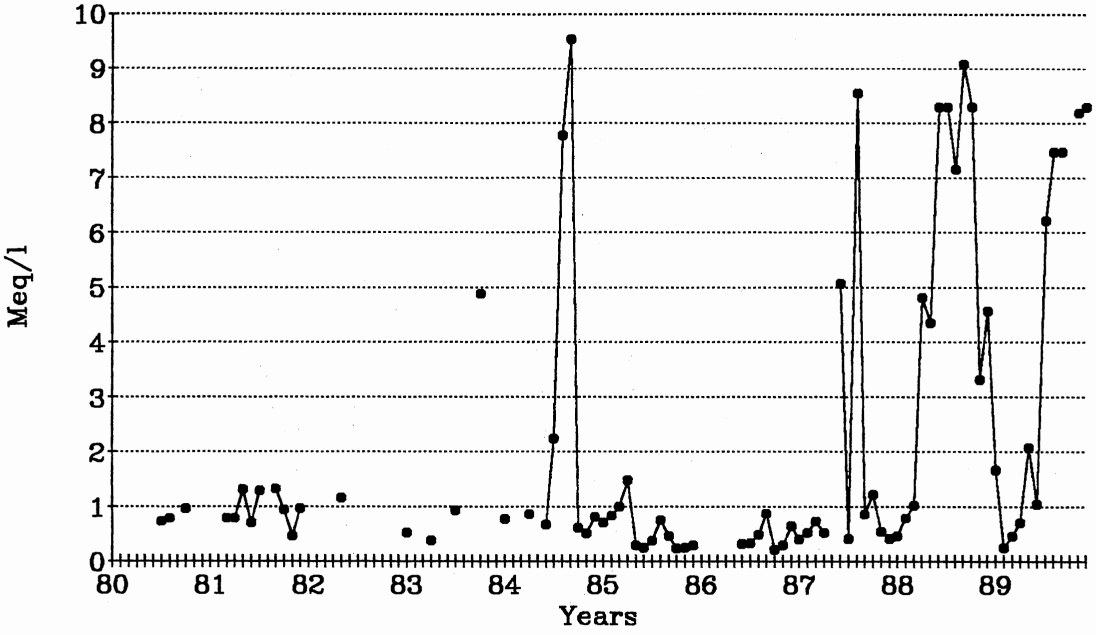

Figure 40. Sulfate levels, OG&E data, 1980-89.

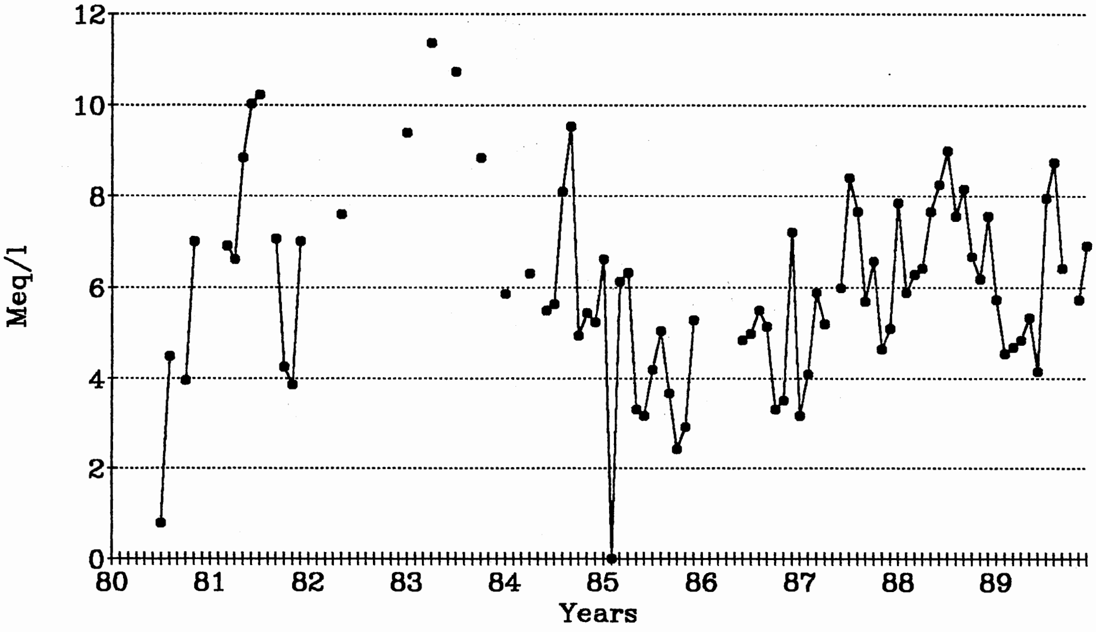

Figure 41. Calcium levels, OG&E data, 1980-89.

The principal mechanism which could control the oxygen condition of the aquifer is the ground water level. Ground water levels were not provided with the OG&E data. However, figures 3 and 4 indicate that during wet precipitation periods, the ground water level could expect to be high.

The "precipitation cumulative departure curve" for the period 1980 - 1989, included in figure 42, indicates that the elevated sulfate levels occur during a general cycle of precipitation increase.

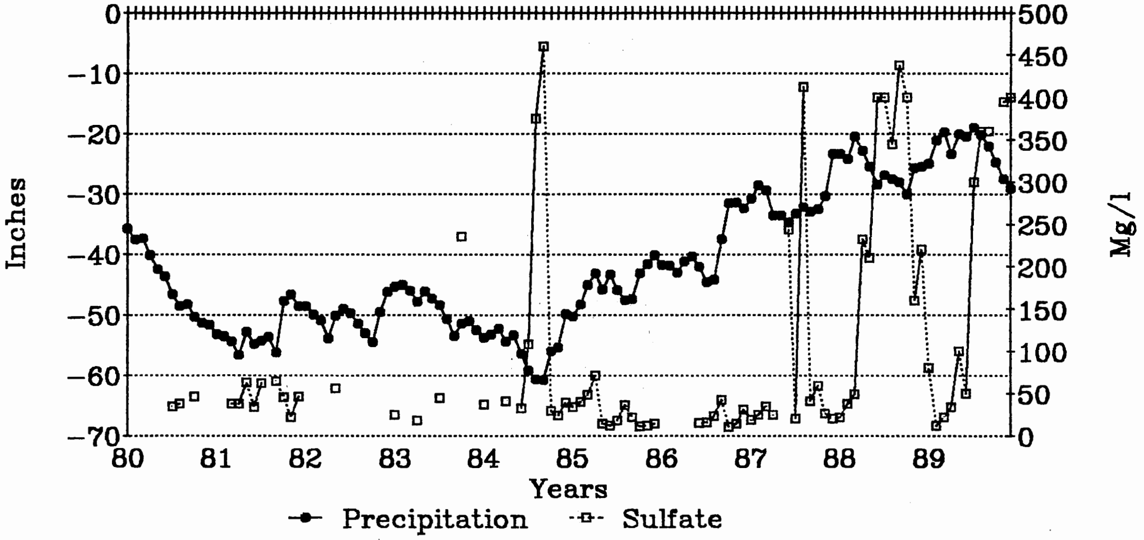

Figure 42. Muskogee precipitation cumulative departure curve, 1980 - 89 and OG&E sulfate levels. Elevated occurrences of sulfate coincide with periods of lower precipitation.

However, occurrences of the sulfate increases develop during seasonal decreases in precipitation and the period of the increases are controlled by the duration of the decreased precipitation. This suggests irrigation related activity. Figure 39, OG&E calcium levels, and figure 40 OG&E sodium levels indicate fluctuations of these elements related with the increases in sulfate. This is consistent with irrigation efforts that have reached and carried the previously accumulated calcium sulfate to the ground water.

Sodium

Excessive sodium levels can contribute to the total salinity problem of the water but the most common effect occurs on the permeability of the aquifer or soils when sodium dominates the available cations as already discussed. The OG&E ground water piper diagram data (figure 13) indicates increases in sodium associated with the increases in the sulfate content.

Potential sources for the sodium include infiltration from the Arkansas River water, or a by-product of agricultural activity. Because the sodium level is not associated with a corresponding increase in chloride in the aquifer, Arkansas River water is not a likely source. Agricultural practices are more likely.

As previously discussed, this association of sodium with sulfate is a consistent relationship for effects of ion exchange of calcium from the calcium sulfate (Gypsum - CASO4 2H2O) for the sodium of the high shrink/swell clays within the aquifer or surface soils.

Sodium Adsorption Ratio. The relative content of sodium in water or soil is usually expressed as the sodium adsorption ratio (SAR). The formula for calculating the SAR is (in meq/l):

$$SAR = Na/((Ca + Mg)/2)^{1/2} \qquad \text{Eq \#2}$$

An SAR of four can be harmful to sensitive crops, but depending upon soil types and concentration of the soil solution, a range of 8 to 18 is considered useable. In some reports, particularl reports prior to 1953, the relationship of sodium to other cations are expressed as "percentage sodium". Percent sodium values should be less than 50 for acceptable levels.

The effect of high sodium (SAR value) on suitability of irrigation water is often plotted against the salinity as a measure of electrical conductivity of the water. The plot is divided into sixteen areas of varying degrees of salinity and/or sodium hazard.

S1 & C1 = Low hazard
S1 & C2 = Medium hazard
S3 & C3 = High hazard
S4 & C4 = Very High hazard

From figures 43, data for the USGS samples, and figure 44, data for the OG&E samples, the level of salinity and sodium hazard, or irrigation characteristics for the ground waters, do not exceed the medium salinity or low sodium hazard. These can be compared to figure 45, the plot of the Arkansas River water irrigation characteristics and figure 46, the Neosho River water irrigation characteristics.

The plot of the conductivity and sodium adsorption ratio indicate a only a slight increase in risk over historic ground water samples.

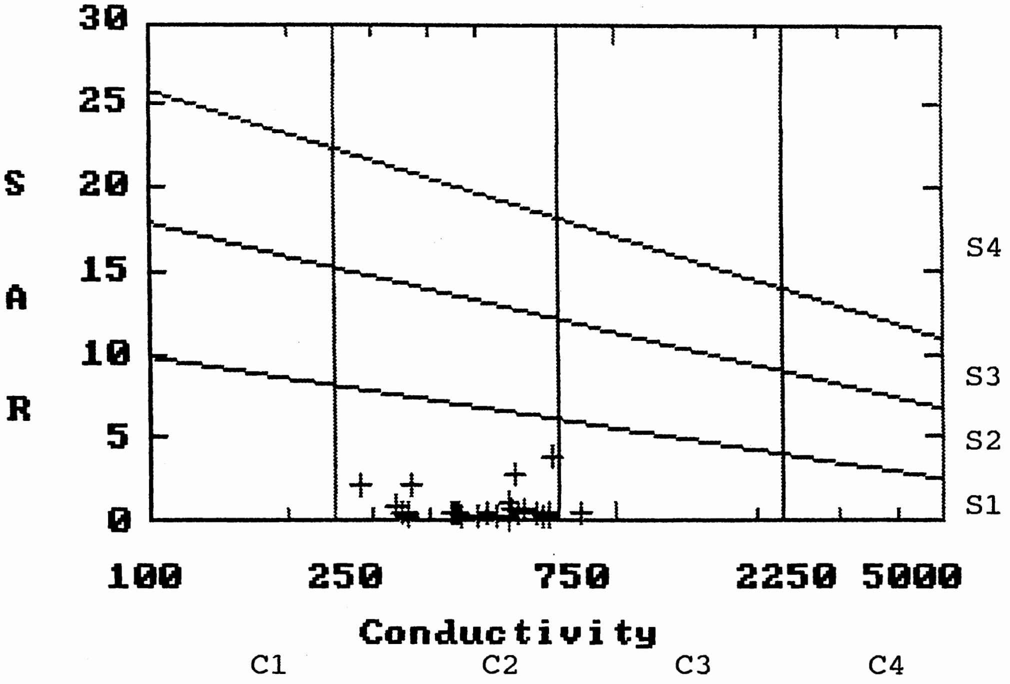

Figure 43. Sodium Adsorption Ratio vs conductivity, USGS, 1936-88 ground water data.

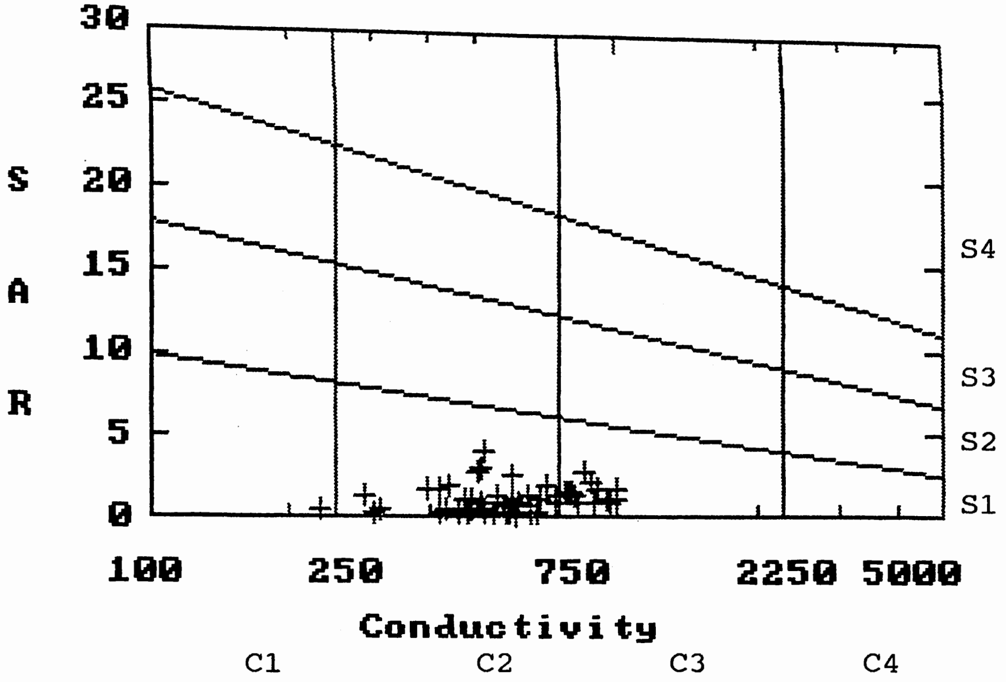

Figure 44. Sodium Adsorption Ratio vs conductivity, OG&E data, 1980-1989.

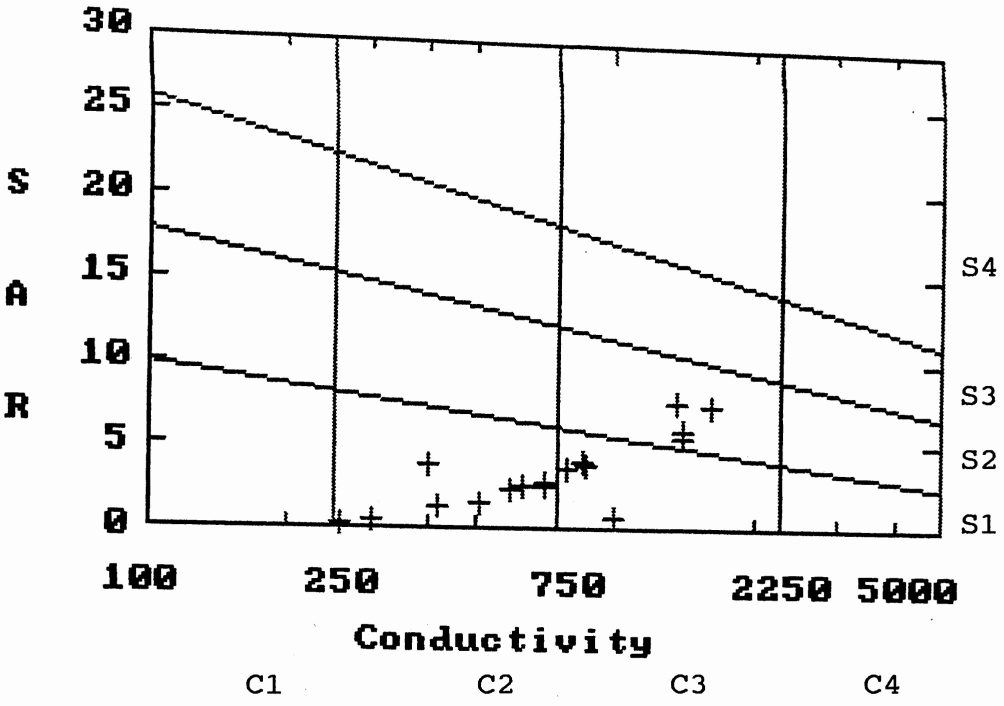

Figure 45. Sodium Adsorption Ratio vs Conductivity, Arkansas River, 1976-79.

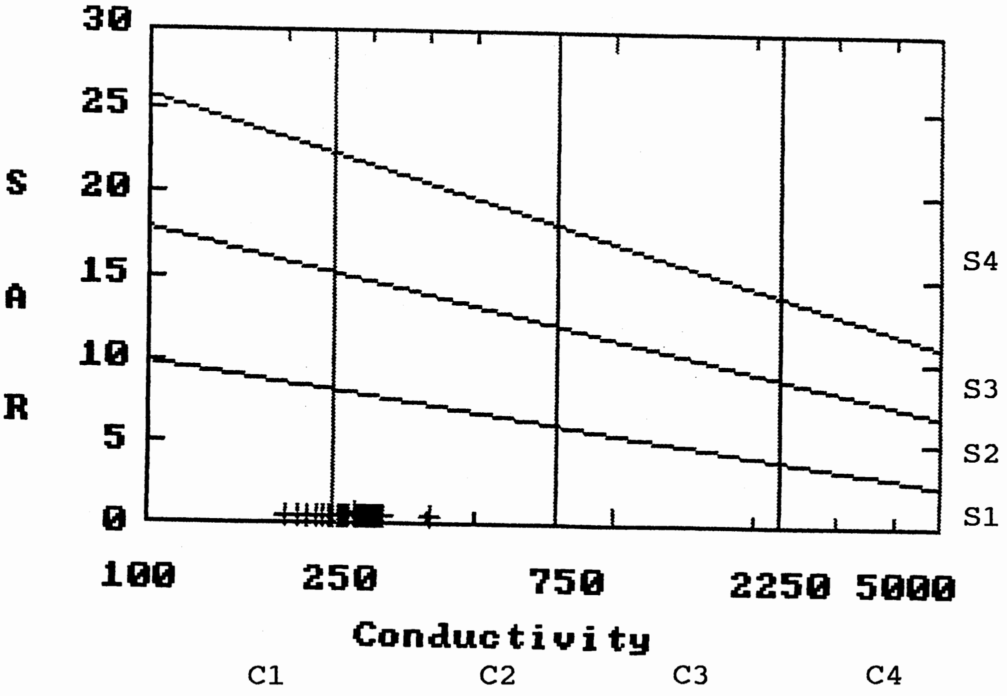

Figure 46. Sodium Adsorption Ratio vs Conductivity, Neosho River, 1976 - 79.

CHAPTER IV

SUMMARY AND CONCLUSIONS

The Arkansas River, and associated tributaries, were regulated for flood control and creation of navigable water for the McClellan-Kerr Navigation System. This study evaluated the impact of this stream flow regulation on an alluvium aquifer adjacent to the Arkansas River, near Muskogee Oklahoma, with particular attention to the effect on the use of the ground water for irrigation. The regulation of the Arkansas River in the study area was created by the Webber Falls Reservoir which increased the base level of the river from an average low flow level of 470 feet above sea level to a constant level of 490 feet above sea level. Effects evaluated include changes in the physical and chemical character of the aquifer and ground water.

The study supported previous conclusions by Reed and Schoff (1951), and Tanaka and Hollowell (1966), that precipitation was the primary recharge source for the aquifer. Variations in the Precipitation Cumulative Departure Curve for the Muskogee area correspond with changes in ground water levels. Wet cycles in precipitation are associated with high ground water levels and drought cycles are associated with low ground water levels. Supplemental recharge is possible from the Neosho River. Ground water levels mapped by Reed and Schoff(1951), prior to Neosho River regulation, indicated high ground water levels immediately adjacent to the Neosho River channel. Tanaka and Hollowell data, recorded after upstream regulation on the Neosho River, by the Fort Gibson Dam, indicated a decrease in the ground water level near the channel.

Physical evidence of Arkansas River infiltration is limited to an apparent new ground water base level corresponding to the new regulated elevation of the Webber Falls Reservoir. Preregulated low ground water levels were as much as 25 to 30 feet below the land surface. Regulated ground water levels only dropped to approximately 15 feet below the surface. This level corresponds closely to the regulated level of the Webber Falls Reservoir and suggest ground water level control by river infiltration. However, this level probably represents restricted ground water discharge into the river because of the new river/reservoir base level.

The effect on the chemical character of the ground water was particularly important because the Arkansas River has a high chloride and sodium content and is not suitable for irrigation use. The stream data for the Arkansas River are recorded at a station which is immediately downstream from the mouth of the Neosho River. Records obtained for the station represent the Arkansas River but are influenced by the characteristics of the Neosho River water during high flows of Neosho River.

The study did not find chemical evidence of infiltration of Arkansas River water into the aquifer. Support for this conclusion was based upon evaluation of chloride levels in the aquifer. Because chloride is mobile under most conditions, and the Arkansas River has a high chloride level, it was assumed that chloride would be a reliable indicator if Arkansas River water had infiltrated the aquifer. Chloride levels did not increase during any period of record for the ground water nor did any evaluation of other chloride relationships of the surface waters and ground waters suggest movement of the Arkansas River water into the aquifer. The range of values for chloride of the Arkansas River for the period 1976 to 1979 were as high as 750 mg/l and as low as 10 mg/l. The 10 mg/l is coincident with the average Neosho River chloride level. The average level for chloride, as recorded by the station was 190 mg/l. The ground water chloride level averaged 9 mg/l.

The apparent absence of infiltration may be explained by cation exchange reactions from the excessive sodium of the Arkansas River water with the clays in the aquifer as the Arkansas River water begins initial infiltration. The resultant swelling and dispersion of the clays create a reduction in the hydraulic conductivity near the river channel, effectively restricting or eliminating deep infiltration of the Arkansas River water into the aquifer. Reed and Schoff's drilling observations and aquifer test support this. While drilling a test hole one half a mile from the Arkansas River channel, the hole failed to fill immediately with water despite the fact that the aquifer consisted of over forty feet of sand and gravel. Separate pump test near the Arkansas River channel also suggested low transmissivity. The specific capacity of a test well near the Arkansas River channel had half the specific capacity of test wells further from the channel. Additionally, the observation well closest to the river had greater drawdown than the observation well furthest from the river. These characteristics suggest little infiltration or recharge from the Arkansas River.

Changes in the discharge capacity of the aquifer, because of the higher regulated base level of the Arkansas River/Webber Falls Reservoir, has limited the ability of the aquifer to naturally maintain the quality of the ground water. When the pre-regulated stream channel was in low flow it was possible for much of the ground water to discharge into the river. Any high levels of chemicals which entered the aquifer were discharged with the ground water and the aquifer was recharged by precipitation. The natural discharge/recharge cycle helped maintained the ground water quality.

Post-regulation ground water data, provided by OG&E, indicated that the level of the total dissolved solids and electrical conductivity of the aquifer increased relative to values recorded by previous studies of the USGS. These changes were primarily a result of occurrences of significant increases in sulfate levels. Background sulfate levels in the aquifer averaged approximately 50 mg/l. Levels of sulfate increased to values in excess of 400 mg/l. These elevated sulfate occurrences were seasonal and associated with decreases in precipitation. The probable sources of sulfate, related primarily to agriculture, included sulfur, to control the pH of the soil, or calcium sulfate, to improve permeability of high clay content soils. Soil pH conditions and review of current crops did not indicate a need for significant use of agricultural sulfur. The flood plain overlying the aquifer does have soils with large areas of high to very high shrink/swell potential. Agricultural use of these areas are certain to have used calcium sulfate to improve soil permeability. Discussions with area Extension offices and farm supply sources did not indicate a significant current use of gypsum (calcium sulfate) in the county. Discussions indicated that significant amounts had been used.

The duration of the increased sulfate levels were coincident with the duration of the seasonal decrease in precipitation. This suggest infiltration control of irrigation water . Supporting evidence of calcium sulfate as the source of the sulfate includes occurrences of elevated levels of calcium and sodium in the ground water.

The sodium resulted from the exchange of calcium, from the calcium sulfate, for the sodium of the high shrink/swell montmorillic clays. The calcium in the ground water was a result of excess calcium from the calcium sulfate not retained in the soil.

A common method of evaluation of irrigation water quality is a plot of the electrical conductivity against the sodium adsorption ratio. The plot of the Arkansas River data, as recorded downstream from the mouth of the Neosho River, indicated a high salinity hazard and a medium sodium hazard. The OG&E ground water data indicated a high salinity hazard but a low sodium hazard. This is an increase in the ground water conductivity hazard over pre-regulated USGS data.

The water in this area is currently being used for irrigation purposes without any reported problems. Figure 47, a plot of the cumulative departure values for precipitation from 1948 through 1990, illustrate the wet and dry cycles in the Muskogee area. Projection of the precipitation data indicate that decreases in precipitation should be expected during the next several years. Increased demands on the aquifer for irrigation water, the subsequent increased irrigation infiltration returns, combined with continued aquifer discharge restrictions, will accelerate degradation of the water quality of the aquifer. Long term agricultural land use of this area could seriously impact the suitability of the ground water use for irrigation.

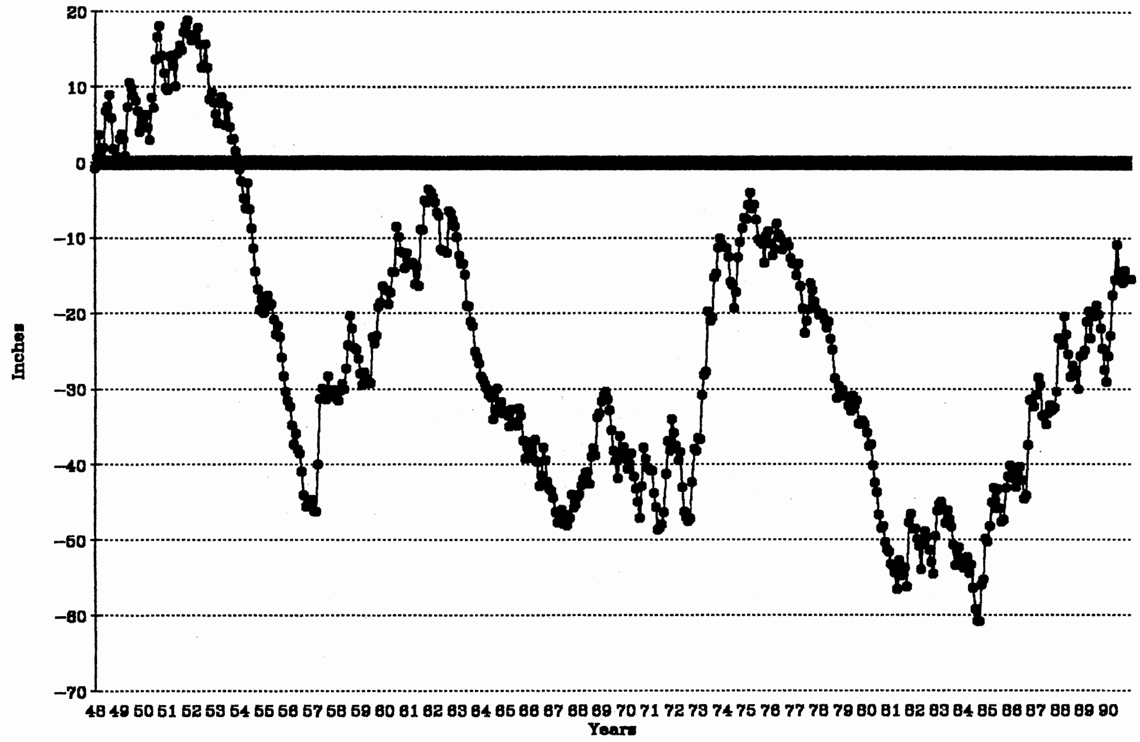

Figure 47. Muskogee precipitation cumulative departure curve for, 1948-1990. Cycles of drought are indicated.

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BIBLIOGRAPHY

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APPENDIXES

APPENDIX A

CROSS SECTIONS

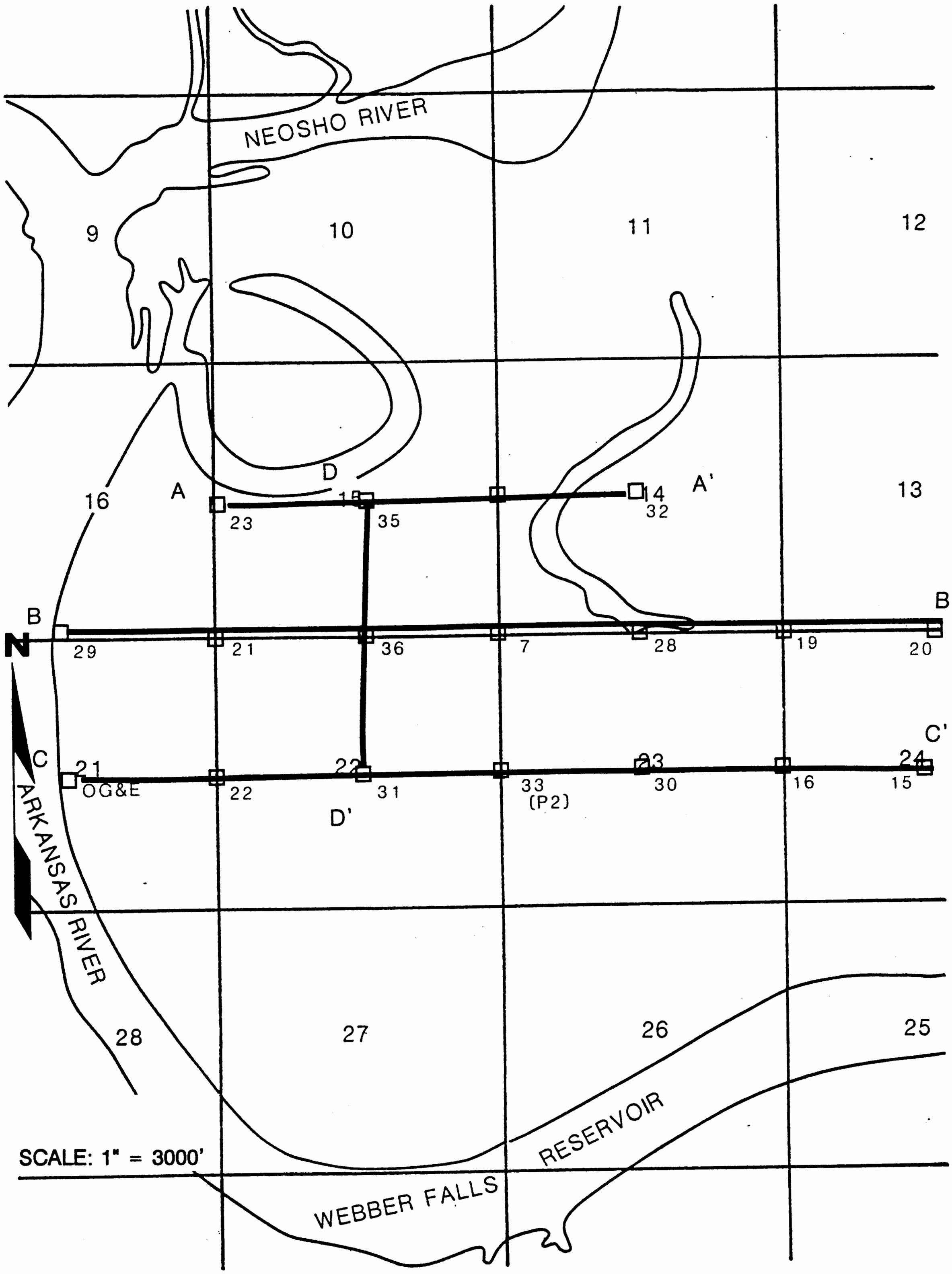

Figure 48. Cross section reference map.

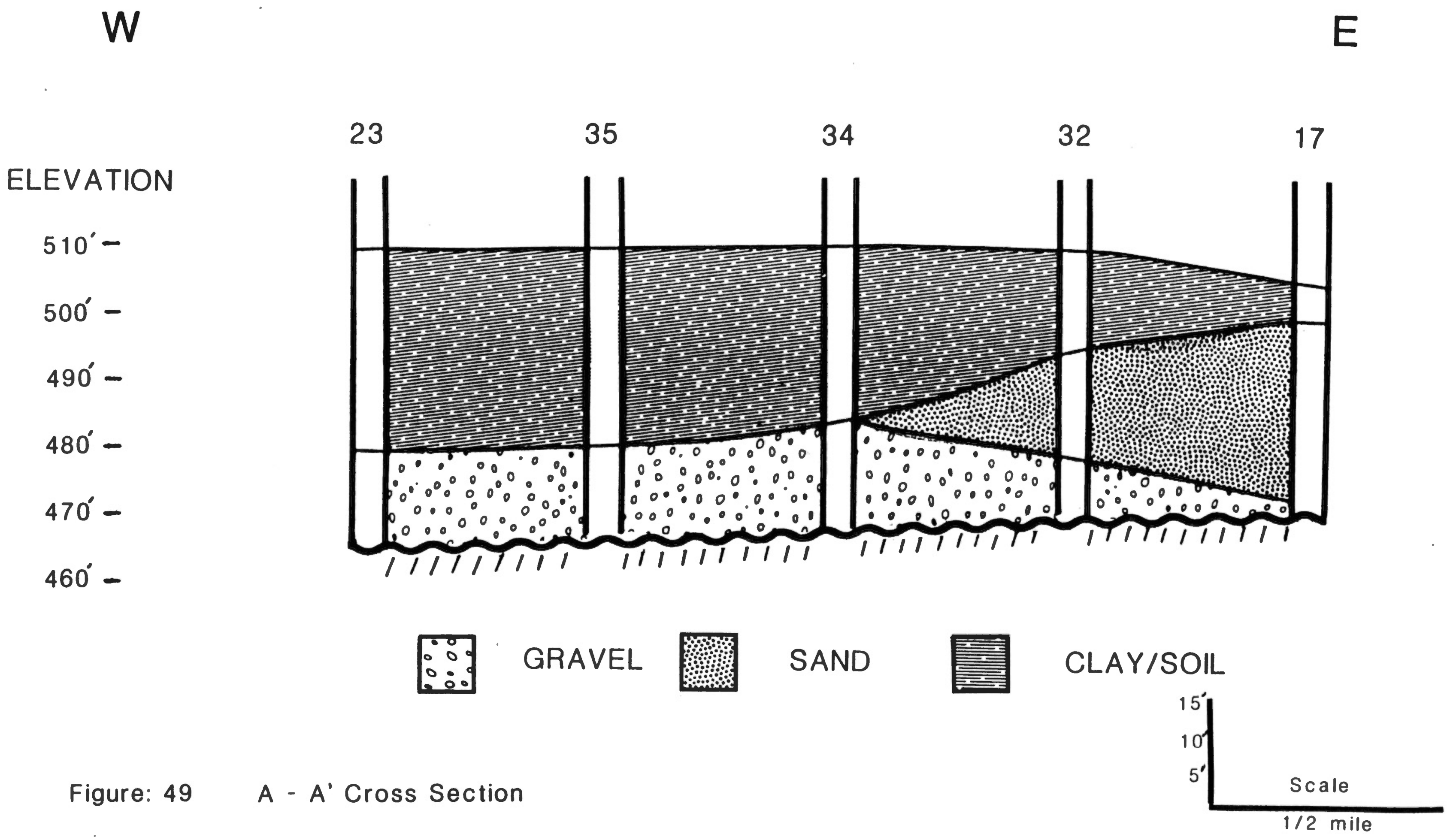

Figure: 49 A - A' Cross Section

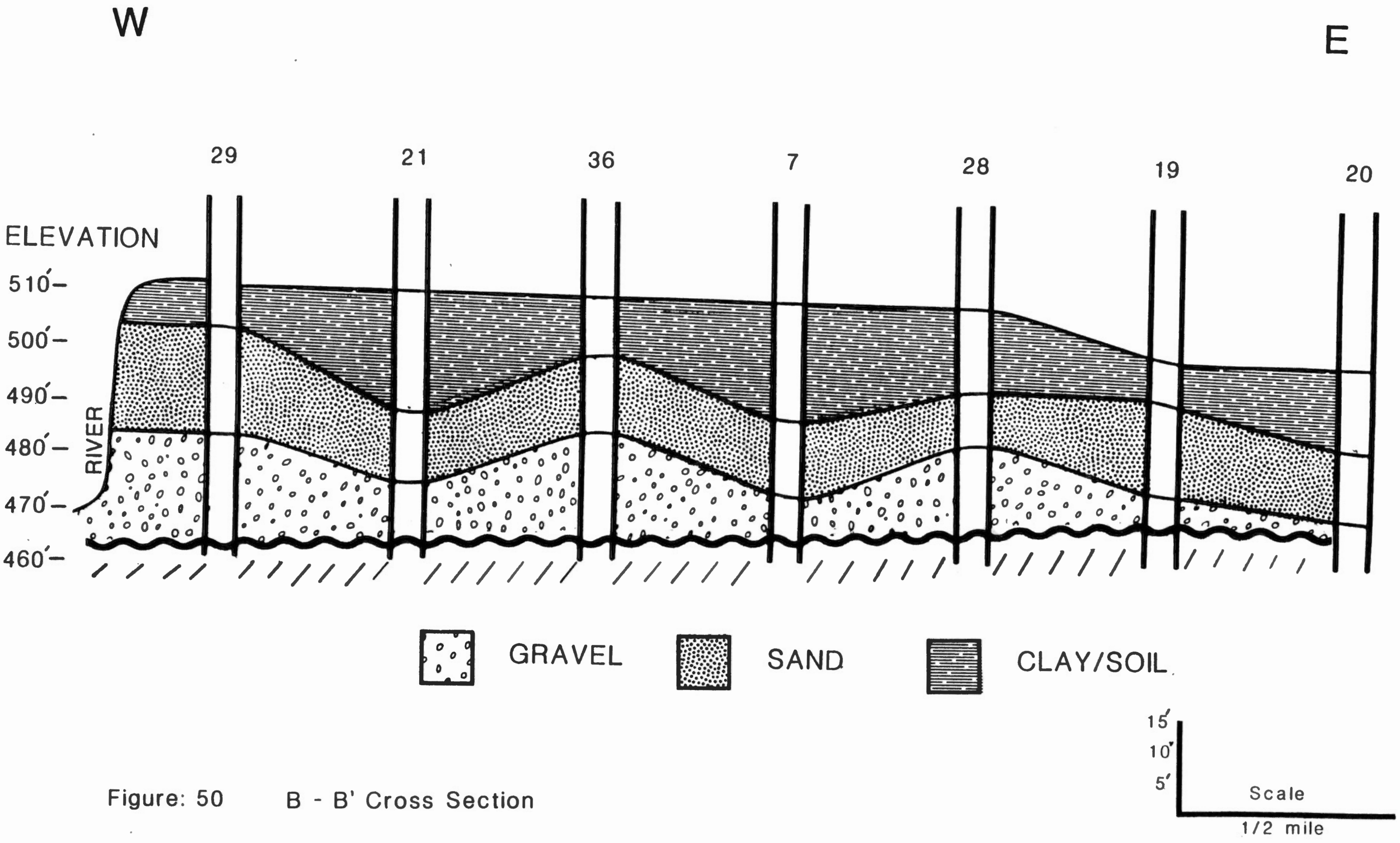

Figure: 50 B - B' Cross Section

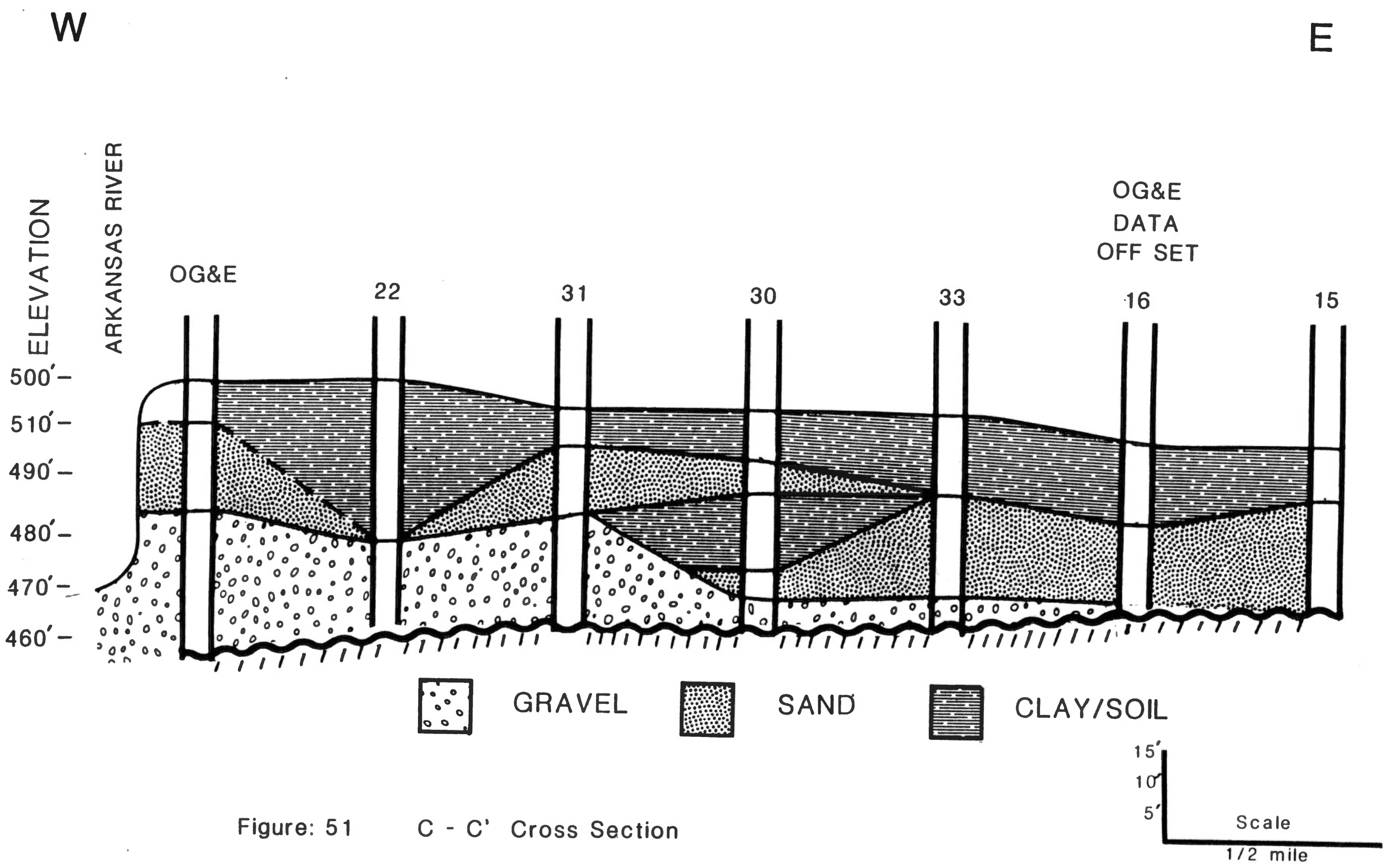

Figure: 51 C - C' Cross Section

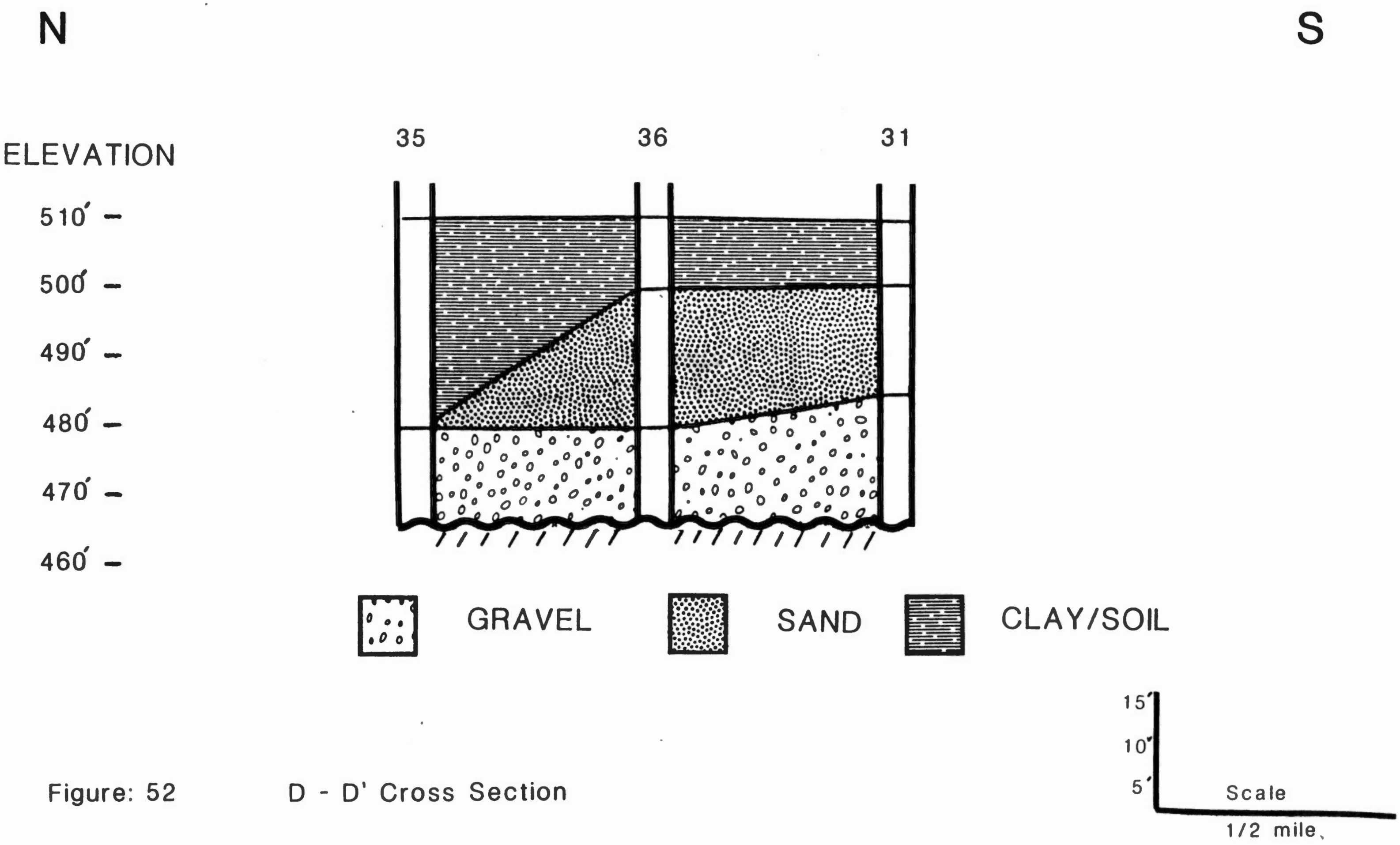

Figure: 52 D - D' Cross Section

APPENDIX B

CROSS SECTION SOIL
SAMPLE DESCRIPTION

Logs of Test Holes and Wells
(From Reed and Schoff)

TEST HOLE 7

115 feet south and 22 feet west of NE corner, sec. 22 T. 15N R. 19E.

Elevation 507.2

	Thickness	Depth
Clay, red brown	10	10
Clay, brown	5	15
Clay, red-brown,sandy	8	23
Sand, brown, fine	6	29
Sand, brown, medium, some coarse grains	3	32
Sand, brown, coarse	1	33
Sand, brown, coarse and med. to fine gravel	8	41
Sand, brown, fine to medium	1	42
Shale, black	3	45

TEST HOLE 15

NW1/4NW1/4SE1/4 sec. 24, T.15N R. 19E

Elevation 497.0

Clay, brown	12	12
Sand, brown, fine	9	21
Sand, gray-brown, fine	7	28
Sandstone, hard some blsck shale	8	36

TEST HOLE 16

0.43 mile north of SE corner sec. 23, T.15N R. 19E

Elevation 498.1

Road gravel and clay	3	3
Clay, brown, some gray clay	11	14
Clay, brown	2	16
Clay, gray, some gravel	2	18
Sand, brown, fine	7	25
Sand, fine, to medium	5	30
Sand, fine to medium, some gravel and sandstone cuttings	1.5	31.5

TEST HOLE 17

38 feet south of NW corner SW1/4 sec. 13, T.15N R. 19E

Elevation 501.7

Road gravel and brown clay	5	5
Silt and fine brown sand	20.5	25.5
Sand, fine to medium, with a few pebbles	7.5	33
Shale, black	6	39

TEST HOLE 19

45 feet south and 93 feet east of NW corner sec. 24, T. 15N. R.19E.

Elevation 498.7

Clay	3	3
Sand, very fine	18	21
Sand, medium, with some gravel	10	31

Shale, gray	2.5	33.5

TEST HOLE 20

100 feet north of SW corner SE1/4 sec.13, T.15N R.19E

Elevation 498.1	Thickness	Depth
Clay, brown and gray	14	14
Sand, very fine	15	29
Shale black	1	30

TEST HOLE 21

105 feet south of NW corner sec. 22, T.15N R.19E
Elevation 506.9

Road gravel	1.5	1.5
Clay, brown, some pebbles	14.5	16
Clay, gray, some pebbles	6.5	22.5
Sand, fine	10	32.5
Sand, fine to coarse	2	34.5
Gravel, fine to coarse	7	41.5
Shale, black	3.5	45

TEST HOLE 22

NW corner SW1/4 sec. 22, T.15N R. 19E
Elevation 510.4

Loam, red, fine sandy	5	5
Clay, brown, with some fine sand	8.5	13.5
Sand, fine, and gravel, very tight	1.5	15
Clay, gray	6	21
Clay, gray, with some sand	9	30
Sand, fine	3	33
Sand, coarse, and gravel	13.5	46.5
Shale, gray	2	48.5

TEST HOLE 23

SW corner NW1/4 sec. 15, T.15N R.19E
Elevation 511.1

Clay, brown and gray, trace of sand at 11 ft.	21	21
Clay, gray	6	27
Sand, coarse and gravel	2	29

Lost circulation repeatedly at 29.25; drove sucker rod to refusal at 45.9 feet, probably top of shale.

TEST HOLE 28

SW corner SE1/4 sec. 14, T.15N R.19E
Elevation 506.0

Road gravel and clay	5	5
Clay	7	13
Sand, very fine	9	21
Sand, fine to coarse	5	26
Sand, medium to coarse, and fine gravel	12	38.5
Shale, black	2.5	41

TEST HOLE 29

SW corner SE1/4 sec. 16, T.15N, R.19E

Elevation 509.7	Thickness	Depth
Silt, dark gray	.5	.5
Silt, brown and fine sand with flakes of black shale	3.5	4
Sand, fine to medium, with flakes of black shale	17	21
Sand, medium and fine gravel	14	35
Sand, medium and gravel, coarse	5	40
Sand, coarse, and gravel, fine	6	46
Gravel, fine, and sand	1	47
Shale	1	48

Note: Hardly lost circulation during drilling, which indicates poor permeability of material, possible clay mixed with sand and gravel.

TEST HOLE 30

82 feet south and 12 feet west of NE corner SW1/4 sec. 22, T.15N R.19E.

Elevation 506.7

Clay, dark gray and brown	10	10
Silt	5	15
Clay, brown	6	21
Clay, dark gray	10	31
Sand, medium	7	38
Sand and gravel	6	44
Shale	1	45

TEST HOLE 31

About 267 feet west of center of sec. 22 T. 15N R. 19E.

Elevation 508.1

Clay, brown	7	7
Silt	12	19
Clay, gray and brown	6	25
Gravel, fine, and sand with flakes of black shale near bottom	18.5	43.5
Shale, black	4.5	48

TEST HOLE 32

At center sec. 14 T.15N R.19E

Elevation 504.0

Clay, dark gray	8	8
Clay, brown	6	14
Silt and sand	11	25.5
Sand, medium	10	35.5
Shale	2	37.5

TEST HOLE 33

Center of sec. 23, T.15N R.19E.

Elevation 507.4	Thickness	Depth
Clay	10	10
Sand, very fine	8	18

Sand, some gravel	3	21
Sand, medium	11.5	32.5
Sand, medium, and gravel	5	37.5

Lost circulation at 37.5 feet; frove sucker rod to 42.66 feet, probably through gavel to shale.

TEST HOLE 34

About 200 feet north and 30 feet west of SE corner NE1/4 sec. 15 T. 15N R. 19E.

Elevation 507.3	Thickness	Depth
Clay, dark gray	14	14
Clay and very fine sand	7	21
Clay, brown, and some fine sand	6	27
Sand, coarse, and gravel	3	30
Shale	1	31

TEST HOLE 35

Center of sec. 15, T. 15N, R.19E

Elevation 510.7

Silt and clay	5	5
Clay, gray and brown	5	10
Clay, dark gray	7	17
Clay, brown	4	21
Clay, dark gray	10.5	31.5
Sand, coarse, and gravel	3	34.5

Lost circualtion at 34.5 feet; drove sucker rod to 43.5 feet, probably through sand and gravel to top of shale.

TEST HOLE 36

90 feet east and 30 feet north of SW corner SE1/4 sec. 15 T. 15N R. 19E.

Elevation 510.6

Soil, silt and clay	3	3
Clay, brown	5	8
Sand, very fine	23.5	31.5
Sand, medium to coarse, and gravel	12.5	44
Shale	1	45

OG&E RIVER BANK STATION

SE1/4, SE1/4, NW 1/4, sec. 21, T.15N R, 19E

Elevation 507.1

Loam, brown, sandy	24	24
Water, sand, and gravel	23.4	47.4
Sandstone	.6	48

Struck log at 29 feet.

APPENDIX C

DISCUSSION OF SOURCES AND TABLES OF WATER QUALITY DATA

DISCUSSION OF WATER QUALITY

DATA SOURCES

Surface Water Sources. The physical and chemical data used for this study was taken from United States Geological Survey and Oklahoma Water Resources publications.

Since the aquifer of interest was located near to or adjacent to the waters of three different rivers, efforts were taken to evaluate each river to determine if any correlation of the ground waters of the aquifer to any of these rivers.

To accomplish this, the data was evaluated from sampling stations closest to the thesis area but still upstream for each river and a station downstream from the confluence of the three rivers and adjacent to the aquifer. These surface stations are:

Station 1655.9 - Arkansas River, upstream from confluence
of Arkansas, Verdigris, and Neosho Rivers.
Approximate location section 7-15N-19E, Muskogee Co., HW 16, North of Muskogee.
Water years October 1961 - September 1963 (discontinued).
The data from this station was too incomplete to be useful.

Station 16561 - Arkansas River, as above.
Water years 1957, 1962 to 1963.

Station 1786.7 - Verdigris River, near Okay Oklahoma, Wagoner Co., Approximate location section 19, 20-16N-19E.

Water years November 1959, October 1962 - September 1963 (discontinued).

Station 17862 - Verdigris River, upstream from the Okay station located at the Newt Graham Lock and Dam, Water year 1972 to 1976, only chemical data for water year 1976 collected. This data incomplete.

Station 1935 - Neosho River, downstream from Fort Gibson Dam. Approximate location, 19-16N-19E, Wagoner Co.

Water years October 1951 - to Present.

Discharge data for this station has been compiled to allow evaluation of flow rates in the Neosho River as they may effect chemical quality of the Arkansas River adjacent to the aquifer.

Station 1945 - Arkansas River, downstream from confluence of Arkansas, Verdigris, and Neosho Rivers. Section 21-15N-19E, Muskogee Co., U.S. 62 East of Muskogee.

Water years 1957, 1962-63, 1976 to 1979.

Discharge data for this station has been compiled to allow evaluation of chemical data in the Arkansas River, downstream, adjacent to the study area.

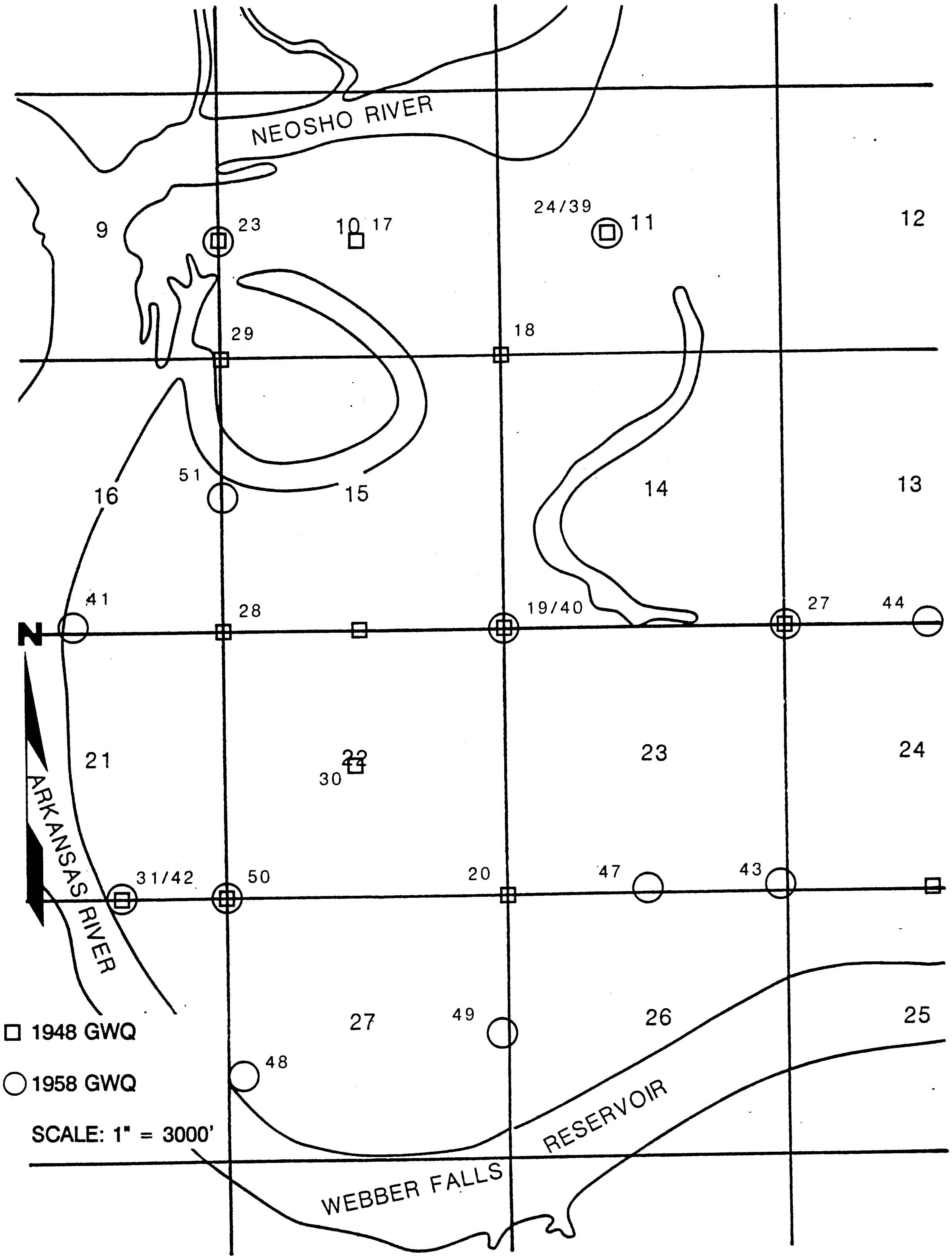

Figure 53. Location map for 1948 and 1958 ground water quality samples.

TABLE III

ARKANSAS RIVER WATER QUALITY

STATION 1945 (mg/l)	SiO2	Ca++	Mg++	Na+	K+	HCO3-	CO3--	SO4--	Cl-	Dissolved Solids	Hardness (CaCO3)	Calculated SAR	Cond. (mmhos-25C	pH (Units)	Temp. (C)
January 1976		75	13	140	5.3				238	648	208	3.94	850	8.1	6.5
February		77	14	140	5.4				297	823	200	3.87	1280	8.7	12
March		67	9	20	3.7				41	274	140	0.61	440	7.7	12.5
April		72	16	180	4.4				410	849	240	5.02	1420	8.2	14
May		80	23	486	6.7				751	1644	308	12.37	2080	8.1	18
June		64	14	169	5.1				263	681	250	5.01	1400	9	27
July		32	4.7	10	3.3				17	170	88	0.44	240		26
August															
September		54	11	100	5.6				191	541		3.25	860	8.9	28
October		63	16	160	5.8				258	716	206	4.68	800	7.8	15.5
November		60	12	162	5.3				256	664	185	5.01	1400	7.9	6
December		61	13	160	9.2				286	706	208	4.87	1100	8.2	6
January 1977															
February		35	5.2	15	3.1			21	22	175	98	0.63	1000	8.8	8
March		4	2.8	10	2			31	38	183	117	0.94	349	7.7	16
April		52	11	112	4.5			71	173	476	162	3.70	871	8.2	21
May		49	13		0.9			55	266	657	165	0.00	1350	7.5	24
June		55	12	238	8.5			82	362	845	193	7.61	1350	8.1	29.5
July		34	4.9	10	3.6			40	10	152	110	0.43	245	7.5	27.5
August		34	4.9	5	3.6			27	10	152	98	0.21	259	7	26
September		38	6.6	94	4			29	71	272	126	3.72	400	7.4	25
October		37	7.7	30	3.1			30	41	256	127	1.18	420	8.8	19
November								54	54				400	7.6	8
December		45	8.8	72	4.8			51	100		150	2.58	710	7.3	6
January 1978								78	270				1250	7.7	2
February		49	10	103	5.1			90	146		154	3.52	790	8.1	1
March													910	8.3	10.5
April		43	7.2	10	2.9			45	10		140	0.37	300	8.1	13
May								35	11				303	7.8	17

TABLE III (continued)

STATION 1945 (mg/l)	SiO2	Ca++	Mg++	Na+	K+	HCO3-	CO3--	SO4--	Cl-	Dissolved Solids	Hardness (CaCO3)	Calculated SAR	Cond. (mmhos-25C	pH (Units)	Temp. (C)
June		40	7.6	40	3			37	81		141	1.53	510	7.3	23
July								59	140				740	7.9	30.5
August		45	7	73	3.2			31	102		142	2.68	705	8.4	32
September								109	591				1850	8.7	29
October		69	18	210	6.9			93	316		242	5.84	1400	8.7	19
November								76	272				1400	8.4	17
December		70	16	195	7.2			81	163		242	5.49	1400	8.3	5
January 1979															
February		45	7.8	65	4.1			50	122		153	2.36	600	7.9	6.5
March								73	288				1250	7.9	11
April		40	7.3	65	3.9			40	114			2.49	635	7.7	18.5
May									187				900	7.9	20.5
June		35	5	14	3.2			32			118	0.59		7.9	25
July								50	112				735	7.3	27
August		55	10	227	5.5			78	350		181	7.42	1600	8.6	29.5
September								49	184				820	8.4	23.5
October															
November															
December															

TABLE IV

NEOSHO RIVER WATER QUALITY

STATION 1935 mg/l	SiO2	Ca++	Mg++	Na+	K+	HCO3-	HCO3- (calc)	CO3--	SO4--	Cl-	Dissolved Solids	Hardness (CaCO3)	Reported SAR	Cond. (mmhos-25C)	pH (Units)	Temp. (C)	Discharge (cfs)
January 1976	1.1	31	4.6	7.8	2.7	110	96.03		23	7.5	138	96	0.3	220	8.1	8	5037
February	0.1	39	5.8	8.3	2.6	118	115.98		29	9.9	153	120	0.3	280	8.4	8	1313
March	0.5	38	6.7	9.9	2.5	114	117.27		31	11	165	120	0.4	287	7.6	12	5091
April	2.7	33	6.7	7.8	2.6	103	101.56		27	11	156	110	0.3	240	7.5	15	9710
May	1.9	38	6.1	9.4	2.6	118	113.59		34	8.4	194	120	0.4	406	7.8	19	9733
June	4.2	40	5.9	9.1	2.5	113	112.59		36	10	208	120	0.4	290	7.8	25	8292
July	5.4	32	4.3	9.7	2.8	93	93.96		29	8.1	143	98	0.4	240		24	27950
August	4.9	29	6.2	7.1	2.7	90	90.00		27	8.1	117	98	0.3	200	8.3	27	3398
September	4.4	34	4.5	7.1	2.9	97	101.53		24	7.5	143	100	0.3	230	8.2	20	3062
October	2.7	32	4.3	7.5	2.8	94	94.64		24	8	140	98	0.3	210	8.1	15	1632
November	1.5	35	4.5	7	2.7	100	97.16		28	8.7	146	110	0.3	240	8.1	6	588
December	1.1	33	4	7.8	2.9	101	92.61		25	9.8	147	99	0.3	230	8.2	6	1071
January 1977	1.1	42	4.7	8.1	2.9	105	114.55		27	14	144	120	0.3	250	8.1	1.5	1291
February	0.9	34	4.8	9.4	2.6	100	93.78		30	12	135	100	0.4	245	8.4	5.5	416
March	0.5	32	4.4	8.7	2.6	98	85.09		29	12	145	98	0.4	295	7.7	15	1998
April	1.3	34	4.5	9.8	2.8	96	94.60		29	12	144	27	0.2	261	7.4	18	2180
May	2.5	16	4.6	11	3.1	99	46.86		25	13	165	59	0.6	280	7.6	23	2210
June	2.4	36	4.7	9.4	2.9	100	98.91		29	13	201	110	0.4	265	7.4	26.5	16240
July	5.2	33	4.6	8.7	3.4	94	88.88		33	9.2	155	100	0.4	240	7	28	17580
August	7.1	32	4.7	8	4	95	91.69		28	8.7	148	99	0.4	265	7.4	25	6429
September	7.8	32	4.8	7.3	3.8	95	92.81		27	8	144	100	0.3	240	7.5	23	899
October	7.5	34	5	7.8	4.5	110	97.83		29	8.5	142	110	0.3	245	7.9		9633
November	8.4	36	6	7.4	4.2	110	104.75		32	8.1	154	110	0.3	285	8.2	14	15340
December	8.8	37	5.9	8.8	3.8	110	111.59		31	8.5	163	120	0.4	280	7.8	5.5	4680
January 1978	8.8	39	5.8	8.1	4	110	114.80		31	8.8	164	120	0.3	265	8.3	4	2410
February	0.3	39	5.7	9.8	4.2	110	115.48		32	10	166	120	0.4	285	8.2	2.5	4637
March	7.5	41	6.2	9.6	4.2	110	114.57		35	13	162	130	0.4	290	8.1	9	17640
April	7.4	44	6.7	8.8	3.8	120	123.93		40	9.4	180	140	0.3	315	8.4	11	28700
May	6.7	42	5.5	7.7	3.1	110	117.73		34	8.7	158	130	0.3	302	8.2	17	16080

TABLE IV (continued)

STATION 1935 mg/l	SiO2	Ca++	Mg++	Na+	K+	HCO3-	HCO3- (calc)	CO3--	SO4--	Cl-	Dissolved Solids	Hardness (CaCO3)	Reported SAR	Cond. (mmhos-25C)	pH (Units)	Temp. (C)	Discharge (cfs)
June	3.8	35	4.9	7.5	2.6		91.46		32	11	158	110	0.3	270	7.8	24.5	9408
July	3.5	34	4.8	9.7	3.3		95.77		25	15	150	100	0.4	260	8.1	30	4095
August	3.6	35	4.8	7.7	1.9		103.24		26	8.6	142	110	0.3	270	7.9	29	2521
September	3.8	40	4.9	8.4	3.1		108.62		31	12	170	120	0.3	320	7.4	26.5	2760
October	0.5	40	5.5	9.9	3.3		117.33		31	11	163	120	0.4	301	7.9		894
November	0.8	39	5.6	9.8	2.9		108.09		32	14	172	120	0.4	293	8.5	13	1295
December	0.7	39	5.4	9.6	3.3		104.02		34	14	176	120	0.4	303	8.4	5.5	1163
January 1979	1.2	40	5.5	11	3.5		111.65		31	16	177	120	0.4	306	7.8	1	1558
February	0.9	39	5.5	12	2.9		109.17		34	15	181	120	0.5	319	8.2	3	4272
March	1.7	52	5.6	11	3.3		146.22		37	13	165	130	0.4	310	7.9	10.5	13690
April	4.5	38	5.3	8.9	3		91.07		44	11	158	120	0.4	280	7.3	23.5	13200
May	3.1	40	5	8.6	2.9		125.22		35		166	120	0.3	270	7.6	20	8476
June	2	38	5.3	11	3.5		96.56		40	14	178	120	0.4	302	7.6	24.5	12250
July	3.2	38	5.5	9.3	2.9		108.01		35	9	171	120	0.4	289	7.8	25	13600
August	3.1		5.4		3				40	8.8	163	110		277	8	29	7523
September	4.1	36	5.2	8.5	3.5		100.19		35	7.9	153	110	0.4	264	6.8	28	400
October	1.7	33	4.9	7.9	3.5		90.46		31	9.4	156	100	0.3		7.4	19.5	4915
November	1.2	37	5.3	11	3.6		110.94		29	12	170	110	0.4		8.6	12.5	8243
December	2.8	38	5.2	10	3.9		109.55		30	12	168	120	0.4	290	7.9	6.5	2131

TABLE V

USGS GROUND WATER QUALITY

WELL NUMBER	LOCATION ()=Reed & Schoff #	MONTH	YEAR	SP Cond.	pH (Units)	Temp. (C)	Ca++	Mg++	Na+	K+	HCO3-	CO3--	SO4--	Cl-	Dissolved Solids	Hardness (CaCO3)	Calculated SAR
1	14N-19E-24D	1	36		7.2				58		450		56	30	607	380	
2	14N-20E-30BC	1	36		6		65	17	72		342		51	40	459	253	2.05
3	15N-19E-11	9	44		8.6	18	37	7.2	21		125		27	10	205		0.82
4	15N-19E-12C	9	44		8.7	18	28	3.8	45		163		9	3	231	86	2.11
5	15N-19E-15A	9	44		8.4	17	100	32	17		394		31	13	415	381	0.38
6	15N-19E-21BD	9	44		8.3	17	63	24	8.5		266		34	1	272	256	0.23
7	15N-19E-02CAA	6	46	244	7.3	14.5	52	3.9	7.6		80		35	11	212		0.27
8	15N-19E-04CAA	6	46	687	6.9		92	20	23		306		21	73	536		0.56
9	15N-19E-10CD	6	46	345	6.8	16.5	53	8.9	9.4		180		23	16	266		0.31
10	15N-19E-15BCC	6	46	504	7	16.5	84	14	4.1		313		12	7.1	382		0.11
11	15N-19E-15DCC	6	46	591	7.2		83	24	8.7		332		17	14	372		0.22
12	15N-19E-22CBC	6	46	617	7.1		102	18	5.5		410		13	5.1	382		0.13
13	15N-19E-23AAB	6	46	455	6.9	16.5	62	18	11		264		23	9.6	308		0.32
14	15N-19E-23BBB	6	46	357	7	16.5	53	16	7.8		253		8.6	5.3	332		0.24
15	15N-19E-23CCC	6	46	555	7	16	76	24	9.4		296		33	4.6	374		0.24
16	15N-19E-25ACC	6	46	697	7.4	16.5	106	30	8.3		447		18	18	422		0.18
17	15N-19E-10CAA(5)	7	48	529			82	15	14		312		24	7	318	266	0.37
18	15N-19E-15AAA(6)	7	48	604			44	11	80		317		55	7	373	155	2.79
19	15N-19E-22AAA(7)	7	48	355		18.5	44	18	6.8		202		7.9	5	204	184	0.22
20	15N-19E-27AAA(8)	7	48	467		19.5	86	20	6.9		342		2.5	4	317	296	0.17
21	15N-19E-28A	8	48	715		18	116	26	21		449		59	9	416	396	0.46
22	15N-19E-28AAA	7	48	584			76	24	6		311		31	8.5	421	382	0.15
23	15N-19E-10(2A)	7	48	448			65	11	15		240		20	15	255	207	0.45
24	15N-19E-11(3)	7	48	282			18	3.9	39		131		32	15	181	61	2.17
25	15N-19E-12(4)	7	48	724			33	13	102		188		110	40	442	136	3.79
26	15N-19E-25(13)	7	48	445			64	27	19		369		2.1	4.2	298	270	0.50
27	15N-19E-24(19)	7	48	596			72	22	23		307		39	18	402	270	0.61
28	15N-19E-22(21)	7	48	680			100	27	16		442		21	5.8	391	360	0.37
29	15N-19E-16(26)	7	48	633			89	18	26		377		11	12	371	296	0.66

TABLE V (continued)

WELL NUMBER	LOCATION ( )=Reed & Schoff #	MONTH	YEAR	SP Cond.	pH (Units)	Temp. (C)	Ca++	Mg++	Na+	K+	HCO3-	CO3--	SO4--	Cl-	Dissolved Solids	Hardness (CaCO3)	Calculated SAR
30	15N-19E-22(31)	8	48	691			94	30	12		370		40	10	417	358	0.27
31	15N-19E-21(P3)	8	48	715			116	26	21		449		59	9	453	396	0.46
32	16N-16E-20	7	51	899	7.2		131	38	33		569		19	48	518	483	0.65
33	16N-17E-20	8	51	210	6.5		8.4	3.1	26	1.1	42		8.8	5.8	159	34	1.94
34	16N-16E-29DDA	12	54	762	7.9	17	102	26	29	1.2	42		47	16	510	360	0.66
35	14N-19E-24ABB	7	58	879	7.8	18.5			9		500			11		500	
36	14N-19E-35BAA	7	58	1040	7.4	17.5			9.4		544			6.1	702	640	
37	15N-19E-08DCB	10	58	876	7.6		139	34	13	1.6	520		48	20	555	485	0.26
38	15N-19E-09DAA	10	58	395	8.1	19.5	56	9.8	14	0.9	164		39	22	274	180	0.45
39	15N-19E-11CAB	10	58	292	7.3	18	22	9	24	5	168		11	3.6	217	92	1.08
40	15N-19E-15DDD	10	58	526	8	17.5	62	28	12	1.3	308		37	4	335	270	0.32
41	15N-19E-16DCC	10	58	548	8.3		94	11	6.2	1.8	304		27	4.5	354	280	0.16
42	15N-19E-21DCC	10	58	590	8.3	17.5	96	17	12	0.4	356		14	9.2	369	310	0.30
43	15N-19E-23DDD	10	58	485	8.4	17.5	67	23	12	1.3	304		15	3.3	302	260	0.32
44	15N-19E-24BAA	10	58	595	8.4	18	45	27	57	3.7	310		42	17	378	224	1.65
45	15N-19E-24BBB2	10	58	514	8.4	17.5	64	24	19	0.8	286		29	9.3	335	360	0.51
46	15N-19E-24DDD	10	58	707	8.2	16.5	98	13	14	1.5	380		1.2	6.7	442	300	0.35
47	15N-19E-26BBB	10	58	523	8.2	17.5	66	31	12	3	290		32	16	323	290	0.30
48	15N-19E-27BCC	10	58	383	8.2	18	43	26	9.3	2.9	244		9.1	2.6	255	216	0.28
49	15N-19E-27DAD	10	58	365	8.2	18.5	35	22	12	0.8	160		26	0.8	214	176	0.39
50	15N-19E-28AAA2	10	58	573	8.2	18	91	25	6.2	0.9	374		18	2.6	341	330	0.15
51	15N-19E-16ADD	10	58	362	8.1	19	42	13	16	1	160		38	14	238	160	0.55
52	14N-19E-35DCC	9	59	545	8.1		34	29	39		236		62	22	320	204	1.18
53	14N-20E-31CCC	8	59	145	7.7		13	2.8	18		84		4.5	6.1		44	1.18
54	15N-19E-22BBB2	3	60	893	8		120	20	66		592		35	1.8	532	380	1.47
55	16N-16E-19AAA	12	66	1020	8.1				43		444		20	95	658	438	
56	16N-17E-11BBC	11	66	460	8.1				39		280		11	6	297	164	
57	16N-16E-23AAA	7	86	250	7.3		10	3	21		68		20	10	137	30	1.49
58	16N-17E-28DAA	7	86	350	7.3		23	7	43		191		20	10	224	77	2.01

TABLE V (continued)

WELL NUMBER	LOCATION ( )=Reed & Schoff #	MONTH	YEAR	SP Cond.	pH (Units)	Temp. (C)	Ca++	Mg++	Na+	K+	HCO3-	CO3--	SO4--	Cl-	Dissolved Solids	Hardness (CaCO3)	Calculated SAR
59	14N-20E-DAA(OT)	7	87	130	6.1		6	1	28		55		20	10	127	20	2.78
60	16N-16E-23AAA(2)	7	87	350	6.6		9	3	21		61		20	10	139	40	1.54
61	16N-17E-28DAA	7	87	525	7		25	7	47		216		20	10	248	100	2.13
62	14N-20E-DAA2	7	88	210	6.1		6	1	10		21		20	10	91	10	0.99
63	16N-16E-23AAA(3)	7	88	350	6.6		14	4	27		71		20	10	139	18	1.63
64	16N-17E-28DAA(3)	7	88	525	7.5		26	8	54		209		20	10	235	68	2.37

TABLE VI

OG&E GROUND WATER QUALITY

DATE	pH	SPECIFIC COND.	TDS	M-ALK			CHLORIDE		SULFATE		CALCIUM		MAGNESIUM		SODIUM (by diff.)	HARDNESS as CaCO3
				as CaCO3 mg/l	as HCO3 mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	
7/3/80				207	252	4.14	12.0	0.3	35.00	0.73	16.00	0.79	10.00	0.82	82.15	81
8/4/80				333	406	6.65	10.0	0.3	38	0.79	91	4.50	10	0.82	55.08	268
10/2/80				175	213	3.50	10.0	0.3	46	0.95	80	3.95	11	0.91		245
11/3/80				371	452	7.41	10.0	0.3			142	7.02	10	0.82		395
12/5/80				229	279	4.58	15.0	0.4							114.48	
3/3/81	7.08	680		360	439	7.19	29.0	0.8	38	0.79	140	6.92	20	1.65	5.42	432
4/1/81	7.00	640		400	488	7.99	19.0	0.5	38	0.79	134	6.62	4	0.33	54.21	351
5/14/81	6.90	600		280	341	5.59	10.0	0.3	63	1.31	179	8.84	11	0.86		490
6/3/81	7.20	560		255	311	5.10	21.0	0.6	34	0.71	203	10.03	10	0.82		548
7/10/81	7.13	640		360	439	7.19			62	1.29	207	10.23	18	1.48		591
9/4/81									64	1.33	143	7.07	12	0.99		406
10/2/81	6.87	600		410	500	8.19	5.0	0.1	45	0.93	86	4.25	12	0.96	92.86	263
11/5/81	7.00	440		300	366	5.99	10.0	0.3	22	0.46	78	3.85	3	0.27	59.72	208
12/3/81	6.94	580					15.0	0.4	46	0.95	142	7.02	14	1.17		413

TABLE VI (continued)

DATE	pH	SPECIFIC COND.	TDS	M-ALK as CaCO3 mg/l	as HCO3 mg/l	meq/l	CHLORIDE mg/l	meq/l	SULFATE mg/l	meq/l	CALCIUM mg/l	meq/l	MAGNESIUM mg/l	meq/l	SODIUM (by diff.) mg/l	HARDNESS as CaCO3
5/4/82	6.77	790		440	536	8.79	15.0	0.4	56	1.16	154	7.61	1	0.08	61.51	388
1/6/83	6.93	560	349	330	402	6.59	13.5	0.4	25	0.52	190	9.39	16	1.32		540
4/15/83	6.88	700	360	410	500	8.19	22.0	0.6	18	0.37	230	11.36	23	1.89		669
7/12/83	6.93	520	434	365	445	7.29	9.7	0.3	45	0.92	217	10.72	14	1.15		599
10/7/83	6.92	650	608	300	366	5.99	10.7	0.3	235	4.88	179	8.84	10	0.82	34.46	488
1/6/84	7.06	600	359	310	378	6.19	12.0	0.3	37	0.77	119	5.85	7	0.53	20.95	322
4/19/84	6.98	650	414	340	415	6.79	12.0	0.3	41	0.85	128	6.30	7	0.58	25.36	347
6/1/84	7.10	550	341				3.0	0.1	32	0.66	111	5.48	6	0.49		302
7/25/84	7.08	615	479	256	312	5.12	9.0	0.3	108	2.24	114	5.63	7	0.58	32.09	313
8/21/84	6.96	710	512	241	294	4.82	8.0	0.2	375	7.78	164	8.10	11	0.91	87.32	454

TABLE VI (continued)

DATE	pH	SPECIFIC COND.	TDS	M-ALK			CHLORIDE		SULFATE		CALCIUM		MAGNESIUM		SODIUM (by diff.)	HARDNESS as CaCO3
				as CaCO3	as HCO3											
				mg/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	
9/17/84	6.87	880	698	280	341	5.59	11.6	0.3	460	9.54	193	9.54	13	1.07	111.30	535
10/17/84	7.08	400	295	215	262	4.30	10.0	0.3	29	0.60	100	4.94	6	0.49		274
11/26/84	7.19	490	303	240	293	4.80	4.0	0.1	24	0.50	110	5.43	5	0.41		295
12/18/84	6.94	460	292	256	312	5.12	5.0	0.1	39	0.81	106	5.24	6	0.49	7.66	289
1/24/85	6.89	650	378	323	394	6.45	8.0	0.2	34	0.71	134	6.62	6	0.49	6.20	359
2/28/85	6.95	640	393	310	378	6.19	10.0	0.3	40	0.83		0.00	6	0.49	156.01	
3/18/85	6.91	610	380	340	415	6.79	19.0	0.5	48	1.00	124	6.13	6	0.49	39.05	334
4/17/85	6.85	735	476	360	439	7.19	21.0	0.6	71	1.47	128	6.32	8	0.66	52.13	352
5/20/85	7.09	300	194	170	207	3.40	4.0	0.1	14	0.29	67	3.31	4	0.33	3.68	184
6/17/85	7.14	290	192	232	283	4.64	7.0	0.2	12	0.25	64	3.16	4	0.33	36.43	176
7/16/85	7.03	490	273	238	290	4.76	6.0	0.2	18	0.37	85	4.20	5	0.41	15.74	233
8/19/85	6.93	520	339	260	317	5.20	5.0	0.1	36	0.75	102	5.04	6	0.49	12.59	279
9/19/85	7.33	315	212	155	189	3.10	6.0	0.2	22	0.46	74	3.66	5	0.41		205
10/23/85	7.17	230	150	140	171	2.80	5.0	0.1	11	0.23	49	2.42	4	0.33	9.54	139
11/18/85	7.18	310	190	172	210	3.44	4.0	0.1	12	0.25	59	2.92	4	0.33	12.70	164
12/17/85	7.13	520	293	140	171	2.80	6.0	0.2	14	0.29	107	5.29	6	0.49		292
6/16/86	7.12	490	320	330	402	6.59	1.0		15	0.31	98	4.84	5	0.41	37.82	265
7/21/86	7.20	480	284	265	323	5.30	1.0		16	0.33	101	4.99	6	0.49	3.28	277
8/19/86	7.06	450	353	124	151	2.48	0.0		23	0.48	111	5.48	7	0.58		306
9/19/86	7.02	550	367	322	393	6.43	0.0		42	0.87	104	5.14	9	0.74	32.66	297
10/23/86		210	139	132	161	2.64	0.0		10	0.21	67	3.31	5	0.41		188
11/17/86	7.23	390	260	290	354	5.79	0.0		14	0.29	71	3.51	4	0.33	51.48	194
12/15/86	7.14	590	359	396	483	7.91	1.0		31	0.64	146	7.21	12	0.99	8.12	414

TABLE VI (continued)

DATE	pH	SPECIFIC COND.	TDS	M-ALK as CaCO3	as HCO3		CHLORIDE		SULFATE		CALCIUM		MAGNESIUM		SODIUM (by diff.)	HARDNESS as CaCO3
				mg/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	
1/19/87	7.14	420	259	262	319	5.24	0.0		19	0.39	64	3.16	3	0.25	50.85	172
2/19/87	7.06	550	348	305	372	6.09	0.0		25	0.52	83	4.10	6	0.49	46.22	232
3/18/87	7.08	580	360	310	378	6.19	1.0		35	0.73	119	5.88	7	0.58	10.65	326
4/20/87	7.05	570	328	305	372	6.09	1.0		25	0.52	105	5.19	6	0.49	21.33	287
6/16/87	7.09	810	546	180	219	3.60	7.0	0.2	244	5.06	121	5.98	9	0.74	48.95	339
7/20/87	7.12	390	216	200	244	4.00	1.0		20	0.41	170	8.40	12	0.99		474
8/20/87	7.16	1000	694	134	163	2.68	9.0	0.3	412	8.55	155	7.66	20	1.65	49.81	469
9/28/87	7.01	520	276	310	378	6.19	1.0		41	0.85	115	5.68	11	0.91	10.48	332
10/19/87	7.00	540	390	310	378	6.19	2.0	0.1	59	1.22	133	6.57	11	0.91		377
11/16/87	7.12	420	208	240	293	4.80	6.0	0.2	26	0.54	94	4.64	6	0.49	8.39	259
12/21/87	7.20	510	302	320	390	6.39	5.0	0.1	20	0.41	103	5.09	5	0.41	33.20	278
1/18/88	7.27	530		295	360	5.89	3.0	0.1	22	0.46	159	7.86	13	1.07		450
2/15/88	7.22	540	348	320	390	6.39	1.0		38	0.79	119	5.88	11	0.91	9.11	342
3/21/88	7.13	600	402	370	451	7.39	5.0	0.1	49	1.02	127	6.27	9	0.74	35.16	354
4/18/88	7.15	510	412	370	451	7.39	18.0	0.5	232	4.81	130	6.42	9	0.74	127.11	361
5/16/88	7.14	680	528	240	293	4.80	7.0	0.2	210	4.36	155	7.66	15	1.23	10.47	448
6/20/88	7.32	950	706	160	195	3.20	12.0	0.3	400	8.30	167	8.25	16	1.32	51.90	483
7/18/88	7.11	960	736	170	207	3.40	16.0	0.5	400	8.30	182	8.99	18	1.48	38.32	528
8/16/88	7.17	890	693	160	195	3.20	12.0	0.3	345	7.16	153	7.56	17	1.40	39.73	452
9/19/88	7.07	970	720	142	173	2.84	14.0	0.4	438	9.09	165	8.15	20	1.65	57.74	494
10/17/88	7.26	1000	766	140	171	2.80	30.0	0.8	400	8.30	135	6.67	22	1.81	79.27	427
11/22/88	7.30	690	427	250	305	5.00	25.0	0.7	160	3.32	125	6.18	13	1.07	40.63	365
12/19/88	7.32	820	508	150	183	3.00	15.0	0.4	220	4.56	153	7.56	16	1.32		448
1/16/89	7.26	600	380	320	390	6.39	15.0	0.4	80	1.66	116	5.73	11	0.91	42.15	335
2/20/89	7.30	430	274	280	341	5.59	5.0	0.1	12	0.25	92	4.55	8	0.66	17.88	262
3/20/89	7.29	510	289	300	366	5.99	5.0	0.1	22	0.46	95	4.69	8	0.66	28.39	270
4/17/89	7.23	470	336	305	372	6.09	4.0	0.1	34	0.71	98	4.84	6	0.49	36.11	269

TABLE VI (continued)

DATE	pH	SPECIFIC COND.	TDS	M-ALK as CaCO3	as HCO3		CHLORIDE		SULFATE		CALCIUM		MAGNESIUM		SODIUM (by diff.)	HARDNESS as CaCO3
				mg/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	
5/15/89	7.26	600	352	250	305	5.00	3.0	0.1	100	2.07	108	5.34	9	0.74	24.69	306
6/23/89	7.12	500	360	370	451	7.39	6.0	0.2	50	1.04	84	4.15	3	0.25	96.24	222
7/17/89	7.07	740	597	220	268	4.40	11.0	0.3	300	6.22	161	7.95	16	1.32	37.99	468
8/21/89	7.13	820	776	190	232	3.80	9.0	0.3	360	7.47	177	8.75	12	0.99	40.91	491
9/19/89	7.16	900	695	170	207	3.40	10.0	0.3	360	7.47	130	6.42	19	1.56	72.39	403
11/20/89	7.28	850	661	180	219	3.60	14.0	0.4	395	8.20	116	5.73	17	1.40	115.79	359
12/18/89	7.33	800	682	142	173	2.84	15.0	0.4	400	8.30	140	6.92	18	1.48	72.38	423

VITA 2

Gary Jennings Rowell

Candidate for the Degree of

Master of Science

Thesis: THE EFFECTS OF STREAM FLOW REGULATION ON THE ALLUVIAL AQUIFER NEAR MUSKOGEE OKLAHOMA AND THE SUITABILITY OF THE GROUND WATER FOR IRRIGATION

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Biographical:

Personal Data: Born in Muskogee, Oklahoma, November 17, 1952, the son of Leldon and Anna Rowell.

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Professional Experience: Exploration geologist for various petroleum companies, 1979 - present.

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