EVALUATION OF THE GEOCHEMISTRY IN THE

ARBUCKLE-SIMPSON AQUIFER: FINDING FLOW

PATHS

By

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CHAPTER I

INTRODUCTION

The Arbuckle-Simpson aquifer, located in south-central Oklahoma, is an important water source for many cities in this area of Oklahoma (Figure 1). The aquifer underlies approximately 500 square miles in the Arbuckle Mountains (Fairchild, 1990), which includes all or part of Garvin, Pontotoc, Murray, Johnston, Coal, Carter, Marshall and Atoka counties. Recently, there has been a proposal to pump the aquifer to provide drinking water to central Oklahoma. This thesis will evaluate the existing water chemistry to assist in the evaluation of the aquifer flow paths.

The Problem

It is important to understand characteristics of aquifers for agricultural, industrial, and municipal water supply. For many cities, water stored in aquifers is the sole source of drinking water. Understanding the recharge and discharge rates of an aquifer can help maintain a sustainable water supply. In 2002, the Central Oklahoma Water Association (COWA) proposed pumping the Arbuckle-Simpson aquifer to provide water to Canadian County and other possible areas in Oklahoma. The proposal estimated that 80,000

acre-feet per year of water could be pumped from the aquifer and transferred in an 88-mile pipeline. At this point, it is unclear how pumping water of this magnitude could affect the Arbuckle-Simpson aquifer and the environment. Currently, there is a five-year project to evaluate the study area and estimate how pumping would affect the streams, springs and the surrounding environment (OWRB, 2006). The study reported in this thesis is part of this larger project.

Goals and Objectives

The goal of this study is to provide pertinent information on the Arbuckle-Simpson aquifer to aid state and local decision makers. This information will help in determining how the water resources can be used without affecting the streams, springs and the Arbuckle-Simpson aquifer.

The objectives of this thesis are to:

1. Assemble historical chemistry data from several agencies and publications.
2. Develop a database containing all data to facilitate a means for researchers to obtain information on the study area.
3. Analyze the magnesium/calcium ratios to determine the flow paths of the surface waters and groundwater.
4. Determine if brine from surrounding formations has influence on the water chemistry.

5. Analyze for possible cation exchange reactions that may influence the water chemistry.

6. Gain some insight on recharge zones, discharge zones and flow paths in the aquifer.

Methods

The primary analysis method of this study consists of examining water chemistry, particularly the concentration of magnesium and calcium ions, using past and present data from area streams, springs, and wells. The chemical analysis of the samples will be used to determine if a correlation exists and determine the potential locations of recharge and discharge. Historical data will be collected and organized in a database (see Database Plan Chapter IV). In addition, calcium and magnesium ratios will be analyzed to evaluate rock-water interactions. Once the ratios have been studied and compared with the rock types in the area, the direction(s) of water flow will be estimated.

The historical chemistry data will be obtained from different agencies as well as from published sources, and then all data will be stored into a database management program, Enviro Data®. This program will allow for an easy output of the parameters that were studied. These parameters are commonly reported in parts per million. Once the calcium, magnesium, sodium and chloride values are extracted from Enviro Data®, each value will be converted to millimoles per liter (mmols/l). This will be completed by the following conversion steps:

$$\text{ppm} \cong \frac{1\,\text{mg}}{l}\,; \qquad \left(\frac{\text{mg}}{l}\right)\left(\frac{\text{mmol}}{\text{mg}}\right) = \frac{\text{mmol}}{l} \qquad \text{(Equation 1)}$$

Once all conversions have been made the data will be plotted in Excel. ArcMap will be used to spatially display the data.

CHAPTER II

LITERATURE REVIEW AND PREVIOUS INVESTIGATIONS

The Arbuckle-Simpson is a carbonate aquifer, but it is important to compare this aquifer to other types to better understand how it differs. Since carbonate aquifers contain limestone and dolomite, the components of these rocks need to be investigated. Limestone is composed of limestone or calcium carbonate, whereas dolomite is composed of calcium magnesium carbonate. Carbonate equilibrium will be examined to determine if the samples are under-, at-, or super- saturated with respect to dolomite and calcite. To differentiate between the two rock types, the calcium/magnesium ratio will be examined. Other investigations of geochemical models will be considered to determine which analyses can be completed with the historical chemistry data.

Background

The Arbuckle-Simpson aquifer, located in south-central Oklahoma, is an important water source for municipal water supply for local cities (Figure 1). It underlies approximately 500 square miles in the Arbuckle Mountains (Fairchild, 1990), which includes all or part of Garvin, Pontotoc, Murray, Johnston, Coal, Carter, Marshall and Atoka counties.
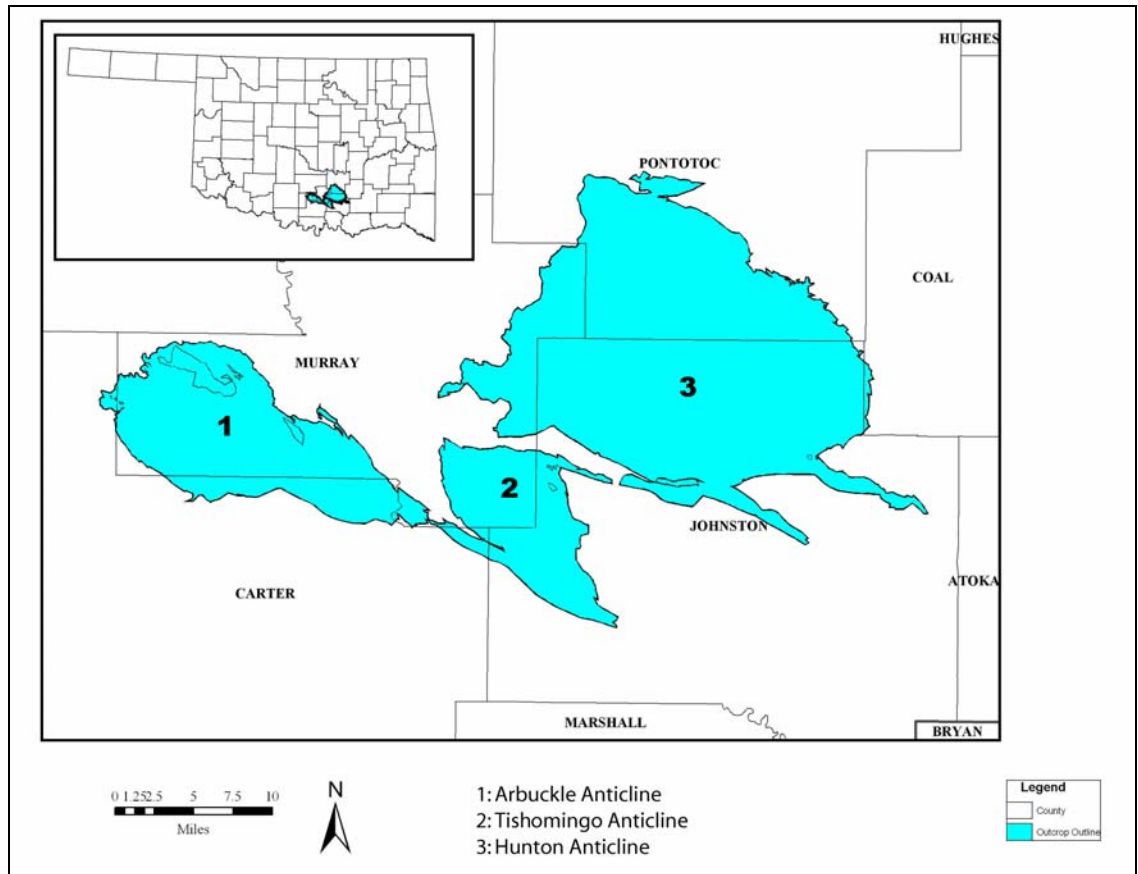
Figure 1: Map of Study Area (Adapted from GIS layers provided by USGS, 2006)

The Arbuckle-Simpson aquifer, which is composed of carbonate and sandstone formations, outcrops in three anticlines: Hunton, Tishomingo, and Arbuckle. The Hunton anticline is located on the east side of the study area, the Tishomingo Anticline is located centrally, and Arbuckle Anticline is located in the west (Figure 1).

In the study area the Arbuckle and Simpson Groups are composed of several formations (Fairchild, 1990). The Arbuckle Group (Cambrian and Ordovician age) lithology is mainly dolomite and limestone, whereas the Simpson Group (Ordovician age) is composed of shale, sandstone and limestone (Fairchild, 1990). The Arbuckle Group dominates the study area, with a

maximum thickness of 6,700 feet, which is more than twice thickness of any other group in the study area (Ham, 1955). The western portion of the study area is defined by a series of folds and faults, while the eastern part is rolling topography (Fairchild, 1990).

Aquifers Types

There are five types of aquifers that yield water in North America. One type, sand and gravel aquifers, has intergranular porosity and contain water which is under unconfined conditions (USGS, 2006). The second type, sandstone aquifers, often has low porosity because of cementation, but do contain fractures and joints that transmit the waters. In addition, they extend over great areas and therefore produce large quantities of water (USGS, 2006). The third type, sandstone and carbonate rock aquifers, contains carbonate rocks that are embedded with sandstone. Both rock types are water yielding, but the carbonate rocks will undergo dissolution. The dissolution is caused by slightly acidic water which forms openings which can range in size from meters to hundreds of meters wide (USGS, 2006). Type four, igneous and metamorphic rock aquifers, has insignificant porosity and is therefore only permeable where fractures exists (USGS, 2006). The last type is carbonate rock aquifers, which is dominantly composed of limestone, but also include dolomite and marble formations. Some carbonate aquifers yield almost no water while others are known as the most productive aquifers in the world. The aquifers that yield insignificant water are often found to be in confined areas.

Dolomite/Calcite Properties

The Arbuckle-Simpson aquifer is composed of dolomite and calcite. To better understand the aquifer, carbonate mineral properties need to be studied in order to determine how they interact with water. These properties will also predict what types of typical water analysis should be seen in these types of aquifers.

The carbonate minerals can be found in about the 20% of the earth's surface (Langmuir, 1997). There are several carbonate minerals: calcite ($CaCO_3$), dolomite ($CaMg(CO_3)$), magnesian calcites ($Ca_{1-x}Mg_xCO_3$ where x is usually <0.2), aragonite ($CaCO_3$) and magnesite ($MgCO_3$) (Langmuir, 1997).

Calcite and aragonite have the same chemical composition. The major difference between these two minerals is the crystal structure. Calcite has a tendency to form a structure that is triagonal (in one plane) (Figure 3) whereas aragonite is composed of triangular carbonate ion groups (CO_3) stretching into two planes (Figure 2) (Nomura, 2006). These carbonate ion groups tend to lie in two planes rather than a single plane as they do in calcite. The alignment can be seen in Figures 2 & 3, where calcium and oxygen ions are labeled and the carbon atom is depicted in yellow. Since calcite will form into a more stable structure than aragonite, aragonite's crystal structure will alter to that of calcite over time.

Dolomite has a hexagonal crystal structure where calcium and magnesium ions are present in equivalent amounts (Figure 4) (Hem, 1997).
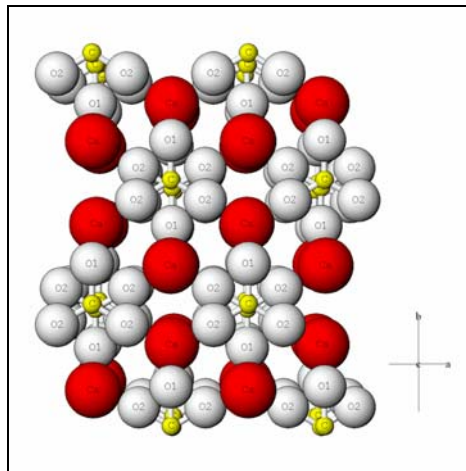
**Figure 2: Structural Formation of Aragonite
(Nomura, 2006)**
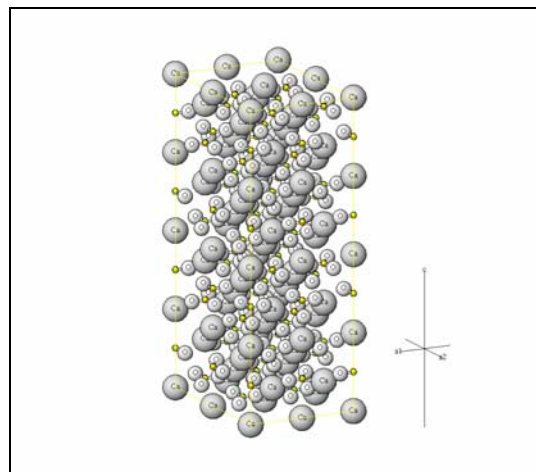
**Figure 3: Structural Formation of Calcite
(Nomura, 2006)**
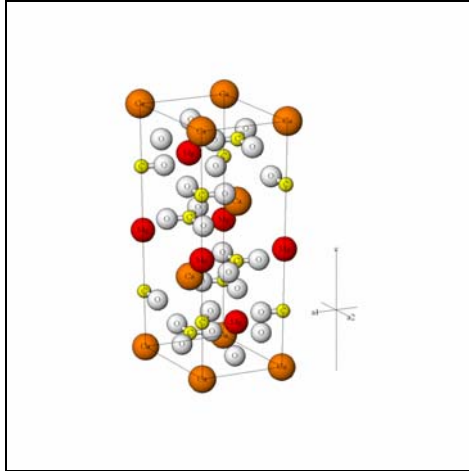
Figure 4: Structural Formation of Dolomite
(Nomura, 2006)

The solubility of carbonates has an inverse relationship with temperature, such that the solubility decreases with increasing temperature (Langmuir, 1997). In the case of calcium carbonates, the temperature effect on solubility is a 6-fold decrease between 0 to 90 degrees, whereas a 14-fold decrease on solubility is evident in calcium magnesium carbonates (Langmuir, 1997). There is also an inverse relationship with the solubility of CO_2 with regards to temperature. As the temperature increases, the solubility of CO_2 decreases (Langmuir, 1997).

pH is another parameter that is a strong control variable for carbonate systems. Through the dissociation of a calcium carbonate (Equation 2), the end product result is carbonic acid. As a result, with the increase of carbonic acid (HCO_3^-) the pH drops from 8.3 to 7.0, which is found to be typical for some ground waters (Langmuir, 1997).

$$2CaCO_3 + H_2O \rightarrow 2Ca^{2+} + 2HCO_3^- \qquad \text{(Equation 2)}$$
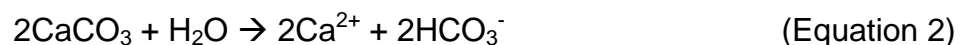
Carbonate Equilibrium

It is important to study the carbonate equilibrium to determine if the flow paths are making contact with the rock types in the study area. Dolomite and calcite equilibrium can be determined by calculating the ion activity product (IAP) and comparing the values to their respected equilibrium constant (K). The dissociation of calcite and dolomite can been seen in equation 3 and 4.

Limestone

$$CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^- \qquad \text{(Equation 3)}$$

Dolomite

$$MgCa(CO_3)_2 + H^+ \rightarrow Mg^{2+} + Ca^{2+} + HCO_3^- \qquad \text{(Equation 4)}$$
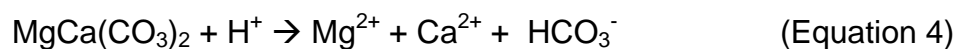
The equilibrium constants can be expressed as:

Limestone $\quad K = [Ca^{2+}][HCO_3^-] / [H^+] \qquad$ (Equation 5)

Dolomite $\quad K = [Mg^{2+}][Ca^{2+}][HCO_3^-] / [H^+] \qquad$ (Equation 6)
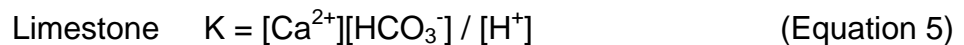
Once the IAP is calculated and compared with the K value, the following is true (Masterton, 1989):

1. If IAP > K, the solution is supersaturated

2. If IAP < K, the solution is undersaturated

3. If IAP = K, the solution is saturated or at equilibrium

Calcium Ion Properties

The calcium ion is a major constituent in most natural waters, with one oxidation state, Ca^{2+} (Hem, 1992). Sources of calcium in waters originate from

contact with igneous, metamorphic and sedimentary rocks. Carbonates are a common calcium source from sedimentary rocks. Calcium has been found to be the dominate cation in river water (Hem, 1992). It has been determined that when waters are in contact with air, the calcium concentrations are found to be close to equilibrium (Hem, 1992). With concentrations nearing equilibrium, it was predicted that the pH of such waters would increase or become more alkaline (Hem, 1992).

Magnesium Ion Properties

The magnesium ion found in water has one significant oxidation state (Mg^{2+}). Major sources of magnesium are igneous rocks (Hem, 1992). Since calcium and magnesium properties are similar, the stability properties are similar. Magnesium plays an important role in areas where limestone is present. It is readily dissolved into solution, but the process is relatively irreversible. As a result, the magnesium - calcium ratio will increase with respect to length of the flow path (Hem, 1992).

Calcium/Magnesium Ratio

Hanshaw and Back (1979) studied calcium and magnesium ratios and discovered that if the molar ratio is less than 1.0, then a process called dolomitization takes place. This process will happen spontaneously over time with the availability of magnesium. Kramer (1969) analyzed brine waters and found that calcium and magnesium ratios ranged from 1.5 to 3.5 for dolomitic

rocks, whereas the mean value was very close to the 1:1 ratio of calcium and magnesium. Langmuir (1997) stated that the equilibrium constant between dolomite and calcite is 0.38 – 1.35 for a calcium/magnesium ratio.

Geochemical modeling

Previous investigations using chemistry to establish ground water flow patterns have been conducted, but there were few studies that analyzed magnesium/calcium ratios. Most studies that were conducted analyzed different ion ratios to examine flow.

In one study, hydrochemical evolution was analyzed along a flow path. This was examined by analyzing Ca-Mg-HCO$_3$ hydrochemical facies to determine recharge areas. Total dissolved solids (TDS), electrical conductivity (EC) and ionic concentrations were also used to determine ground water residence time and ground water types (Cetindag, et al. 2004). They found that these parameters plus water quality are related to ground water residence time.

Uliana and Sharp (2001) conducted a study using geochemical data in the Trans-Pecos Texas area to trace flow paths. They gathered data from 2800 sampling sites, but only used the data from 1400 wells that spanned over 50 years to delineate 11 hydrochemical facies. (Uliana and Sharp, 2001). The PHREEQC program was used to simulate the chemical reactions along the flow path (Parkhurst, 1995). PHREEQC is a computer program that models chemical reactions and transport processes in water. Chloride/bicarbonate ratios and sodium/chloride ratios were used to determine the pathway of groundwater in an

unconfined aquifer dominated by carbonates. They found that the streams were being recharged by a regional baseflow from the Salt Basin that would flow through the Apache Mountains. They determined that recharge was from stormflow.

Another study used transport modeling to study the flow in dolomites. This was analyzed by conducting calculations under different conditions. Textures were observed and then correlated with the water flow and dissolution/precipitation reactions (Ayora et al., 1998).

Historical chemistry data were used to analyze calcium, magnesium and other parameters to determine possible flow paths through the Arbuckle-Simpson aquifer. The GIS software, ArcMap (Version 8.1) was used to spatially plot different ranges of calcium-magnesium ratios. This carbonate geochemistry model was applied to the Arbuckle-Simpson aquifer to aid in decisions regarding the increase use of the aquifer.

This thesis tests five hypotheses of the origins of the balance of cations (Ca^{2+} and Mg^{2+}) in water from the Arbuckle-Simpson aquifer. The five reactions evaluated were:

1. Equilibrium with aragonite
2. Equilibrium with limestone
3. Equilibrium with dolomite and limestone
4. Brine mixing, and
5. Cation exchange

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Other possible reactions exist, but this thesis utilized existing geochemical data in order to evaluate the geochemistry of the aquifer. Further studies will be required to test other potential geochemical mechanisms for the origins of the waters in the aquifer.

CHAPTER III

THE ARBUCKLE-SIMPSON AQUIFER

The Arbuckle-Simpson aquifer has been studied for more than a hundred years. The studies examined for this thesis were the geological and hydrogeological investigations.   By examining the studies conducted and examining the current usage, the affects of pumping of the aquifer can be reached.

Usage

Discharge from the Arbuckle-Simpson aquifer has been dated back to 1911, when the City of Ada used water from Byrds Mill Spring for public water supply (Savoca, 1994). Currently wells located in this area are pumping 5,000 acre-feet per year (OWRB, 2006).

Geology

There are two aquifers in the study area: the Simpson and the Arbuckle. Since these two units are not easily differentiated in many borings, they are combined and referred as the Arbuckle-Simpson aquifer. The aquifer is confined under the Chickasaw National Recreation Area, but is unconfined south and east

of this area (Hanson and Cates, 1994). The Arbuckle-Simpson is a carbonate system aquifer which consists of limestone, dolomite, and sandstone (Hanson and Cates, 1994). The carbonate rocks are of Cambrian and Ordovician age (Ham, 1955; Hanson and Cates, 1994). About two thirds of the Arbuckle-Simpson aquifer contains limestone and dolomite; the dolomite dominates in the eastern part and the limestone in the western part (Fairchild et al., 1990).   The aquifer is approximately 9,000 feet thick (USGS, 2006).

Hydrogeology

The Arbuckle-Simpson aquifer has a high permeability that results from fractures where there has been dissolution of the rocks.

> The average transmissivity of the aquifer is estimated to be 15,000 feet squared per day and the average storage coefficient where the aquifer is confined is estimated to be $8*10^{-3}$; in unconfined areas, the aquifer has an estimated specific yield of 20 percent. Freshwater may extend to depths of greater than 3,000 feet. Wells completed in the Arbuckle-Simpson aquifer commonly yield from 100 to 500 gallons per minute and locally yield as much as 2,500 gallons per minute. Springs that issue from the aquifer discharge from 50 to 18,000 gallons per minute. The water is a calcium bicarbonate type and commonly is hard but has a dissolved-solids concentration of generally less than 500 milligrams per liter (OWRB, 2006).

The aquifer is recharged by rainfall that has flowed through fractures containing limestone (Fairchild, 1978). Fairchild states that the flow through the aquifer is toward the south, and is discharged through the springs. Fairchild inventoried 80 springs and stated that most are connected to faults or fractures in the study area.

Fairchild (1990) graphed the flow of surface and ground water. This can be seen in Figure 5, where the surface water flows can be documented flowing from the northwest to the southeast on the Hunton anticline. In addition, there is some flow to the northeast on the perimeter of the northeastern side of the Hunton, if we assume the flow lines are moving perpendicular to the hydraulic gradient. On the Tishomingo anticline, the eastern part shows flow towards the east, whereas the western part shows flow to the southwest. The Arbuckle anticline, flow is radial from the center out to the sides. Fairchild (1990) also conducted a study on the ground water flow. The ground water flow is displayed on a contour map (Figure 6) and shows the flow for the Hunton anticline to be dominant from the northwest to the southeast.

**Figure 5: Principal streams, streamflow gaging sites and springs
in the study area (Fairchild, 1990, p 3)**

**Figure 6: Rise of the water table in the eastern part of the
Arbuckle Mountains in response to rainfall from
25 March to 25 April 1977 (Fairchild, 1990, p. 23)**

Over the last 86 years, there has been a decrease in flow from the
artesian wells producing from the Arbuckle-Simpson aquifer (Hanson and Cates,
1994). There is not an immediate effect on springs and wells due to current
pumping of the aquifer, but some researchers have stated artesian wells could
be restored if pumping from the aquifer were reduced (Hanson and Cates, 1994).
This depletion is being linked to the continual decrease of the hydraulic head in
the aquifer (Hanson and Cates, 1994). The ground and surface waters are
believed to be a mix of waters that have come in contact with the rocks of the
Arbuckle and Simpson groups.

Even though there are about 400 wells in the study area that have been monitored since 1938, the chemistry data for many of these wells are nonexistent or incomplete.

CHAPTER IV

DATABASE PLAN

The purpose of constructing a database for the Arbuckle-Simpson project is to properly organize and allow easy access to the data. There were many criteria to consider in the construction of this database. Some of these criteria encountered in the Arbuckle-Simpson project are sharing data among multiple agencies, combining individual databases, and organizing published and unpublished information. Once the database has been constructed, it will allow researchers, decision makers, and the public to provide additional information as well as provide access to the data to help analyze and understand the aquifer.

All historical water chemistry data were stored in a program called Enviro Data® (GeoTech, 1991).   Data were collected from the following agencies: Oklahoma Environmental Health (OEH), United States Environmental Protection Agency (USEPA), United States Geological Services (USGS), Oklahoma Department of Environmental Quality (ODEQ), and from published articles.

The information was stored in two different Excel spreadsheets labeled as Stations and Data, then imported into Enviro Data®. The Stations spreadsheet has all pertinent information for the sampling site, which contains 11 headings (red and bolded) (Table 1 & 2) that are required (if the information is unknown a

"z" should used). A list of approved terms for each heading is in Appendix A, page 32.

StationName	SiteName	ShortName
StationGroup	Location_CX	Location_CY
GroundElevation	DatumElevation	Depth
ScreenTop	ScreenBase	StationTypeCode
StationDate_D	StationText	LocationCode
SamplingFreqCode	StationUnitsCode	Location_LL_LX
Location_LL_LY	StaGeoUnitCode	QCStationCode
PropertyDescrip	RegulatoryID	DrillerName
InstallerName	CurrentStatusCode	LocationSource
LocationPrecision	StationSymbol	DrivingDirections

Table 1: Headings for Stations Excel Spreadsheet

SiteName	StationName	SampleDate_D	TaskNumber
ParameterName	ReportingUnits	FlagCode	
ShortName			

Table 2: Headings for the Data Excel Spreadsheet

Limitations

Out of the 2,927 water samples, there were a total of 74 that contained complete analysis, with 360 containing concentration data for calcium and

magnesium along with location. A complete analysis is termed as waters tested for major ions, nitrate, temperature, and pH. Major ions include calcium, magnesium, potassium, sodium, chloride, sulfate, carbonate and/or bicarbonate, In addition, only samples that included locations were used in the evaluation of magnesium/calcium ratios. This was completed to show the spatial relationship between the samples location of origin, distribution of the aquifer, springs, and streams in the study area.

CHAPTER V

RESULTS

The hypotheses explaining the origins of the balance of cations (Ca^{2+} and

Mg^{2+}) in the waters of the Arbuckle-Simpson aquifer were analyzed. Carbonate

equilibrium, brine mixing, cation exchange were the three areas investigated to

help determine potential flow paths and infer the processes influencing the

chemistry.

Carbonate Equilibrium

Magnesium and calcium concentrations were plotted in an excel graph

with three slope lines. Langmuir (1976) stated that magnesium/calcium

equilibrium values for dolomite and calcite were between 0.38 and 1.35. The

slope of 0.38 and 1.35 were graphed onto the graph, in addition a theoretical

slope of 1:1 was also graphed. Figure 7 shows the equilibrium plot for all the

surface waters and Figure 8 for the ground water samples in the study area.

Theses two figures show the relationship between calcium and magnesium with

respect to the equilibrium of dolomite and calcite. Using the numbers described

by Langmuir (1976), slopes of 0.38 and 1.35 were plotted, along with a

theoretical 1:1 slope and water chemistry of surface water (Figure 7) and ground

water (Figure 8). Data that falls on the left side of the 0.38 slope would indicate a

sample that was higher in magnesium and low in calcium, whereas the data on the right side of the 1.35 slope indicates data lower in magnesium and high in calcium. The data that fall around the 1.00 slope indicate equilibrium between magnesium and calcium.
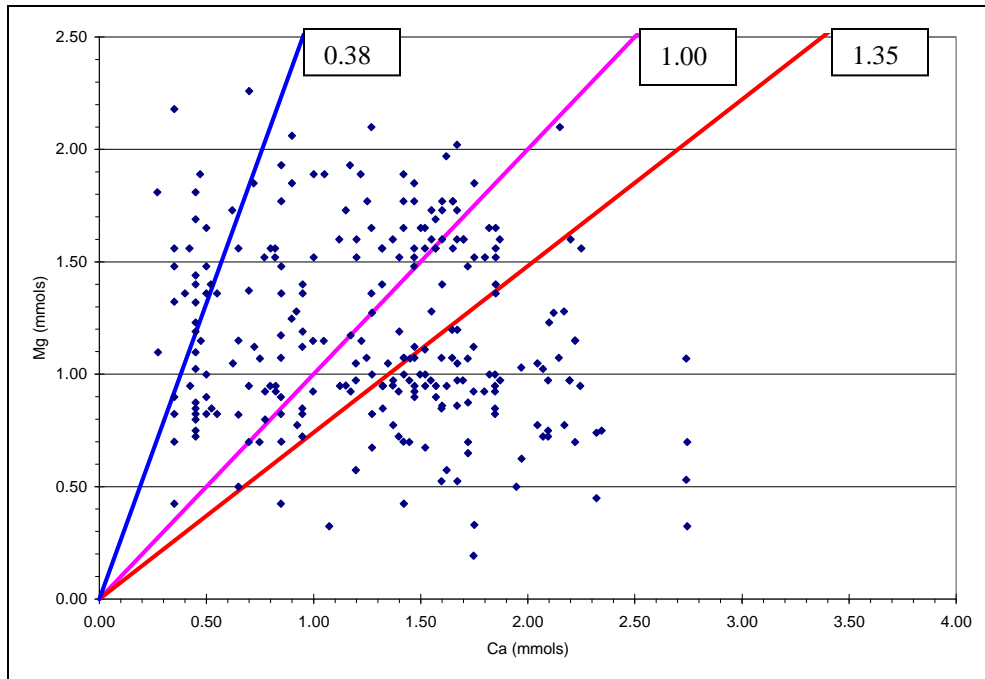
Figure 7: Magnesium Concentrations versus Calcium Concentrations of Surface Water Data
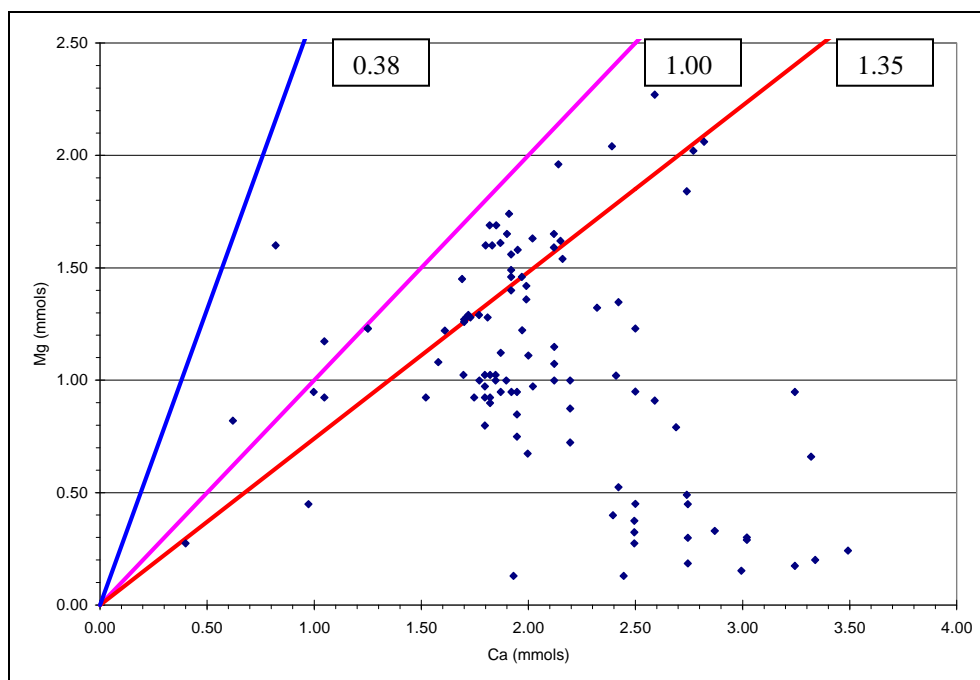
**Figure 8: Magnesium Concentrations versus Calcium
Concentrations of Ground Water Data**

Equilibrium constants (K) for calcite and dolomite were compared to the

ion activity product (IAP) of the samples. These were both graphed on a log

scale versus temperature. The K for both calcite and dolomite were graphed as

a straight line and the IAP were plotted as scattered points. Since all IAP values

for surface waters are greater than K for dolomite, all are supersaturated with

respect to dolomite (Figure 9). For calcite, 97% of all surface water samples are

also supersaturated with respect to dolomite. In addition, all IAP values for

ground waters are also greater than K for dolomite; therefore all are

supersaturated with respect to dolomite (Figure 10). For calcite, 89% of all

ground water samples are also supersaturated with respect to dolomite.
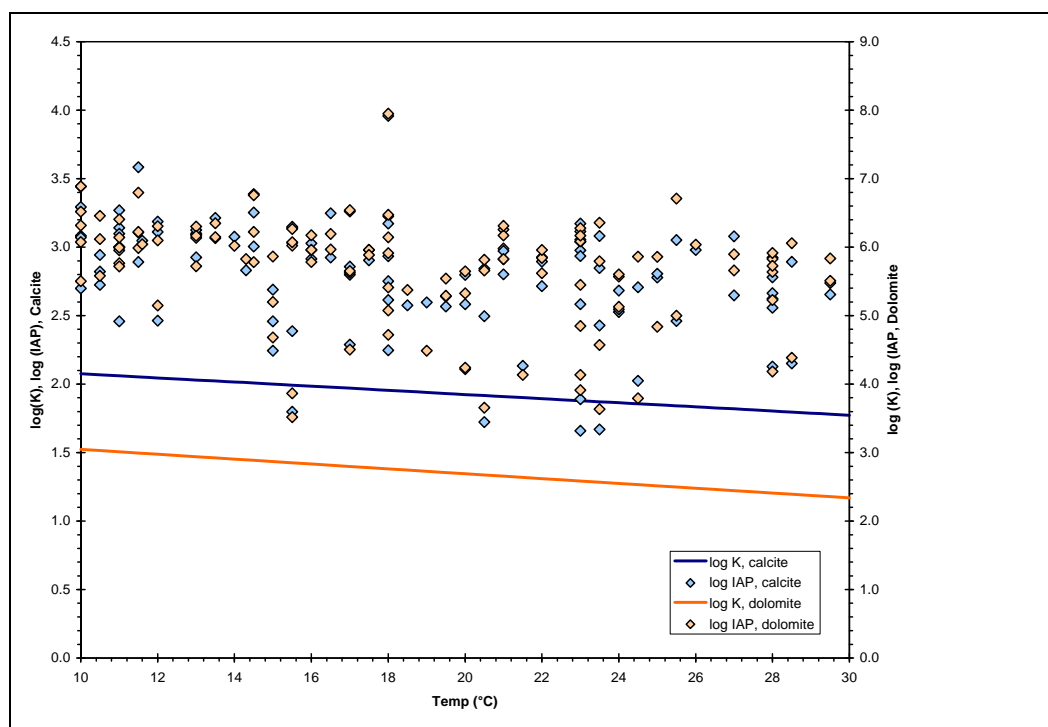
Figure 9: Equilibrium Constant compared to Ion Activity Product of Surface Water.
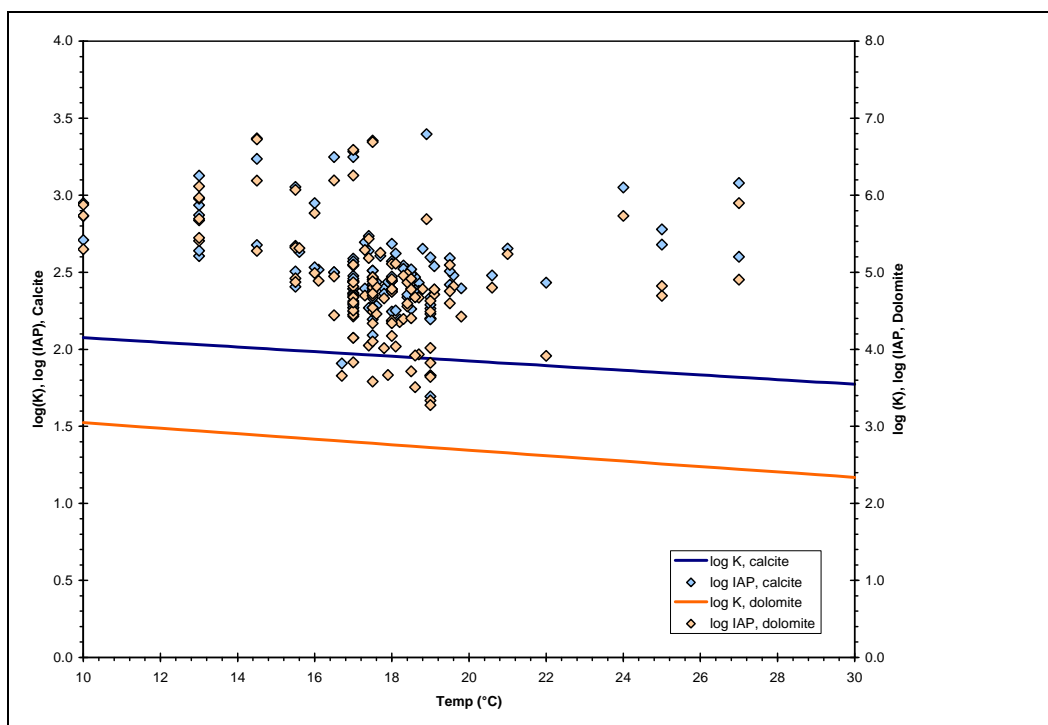
Figure 10: Equilibrium Constant compared to Ion Activity Product of Ground Water.

Spatial maps were constructed from the data displayed in Figures 7 and 8.

A range was taken between the three slope lines from these figures and spatially

plotted using ArcMap. Ranges for each of the slope lines were determined to

ensure data points would be selected. For the 0.38 equilibrium slope, ranges

from 0.2 and 0.56 were selected; for 1, ranges from 0.9 and 1.1 were selected;

and for the 1.32 slope, a range of 1.3 and 1.4 was selected. This was done

separately for surface and ground waters. Figures 11, 12, and 13, present the

concentrations for each range for surface water and Figures 14, 15, and 16 for

ground water. Spatially there is no difference in each of the figures for surface

water; this can be attributed to lack of spatially variable data in the study area.

For the ground water (Figures 14-16), a trend is observed and could indicate a

flow path from the northwestern part to the southeastern part of the Hunton.

There are two areas in Figure 21 that indicate discharge by examining the high

ratio of calcium and magnesium. The area in the northwestern part of the

Hunton contradicts the flow paths displayed by Fairchild (1990).
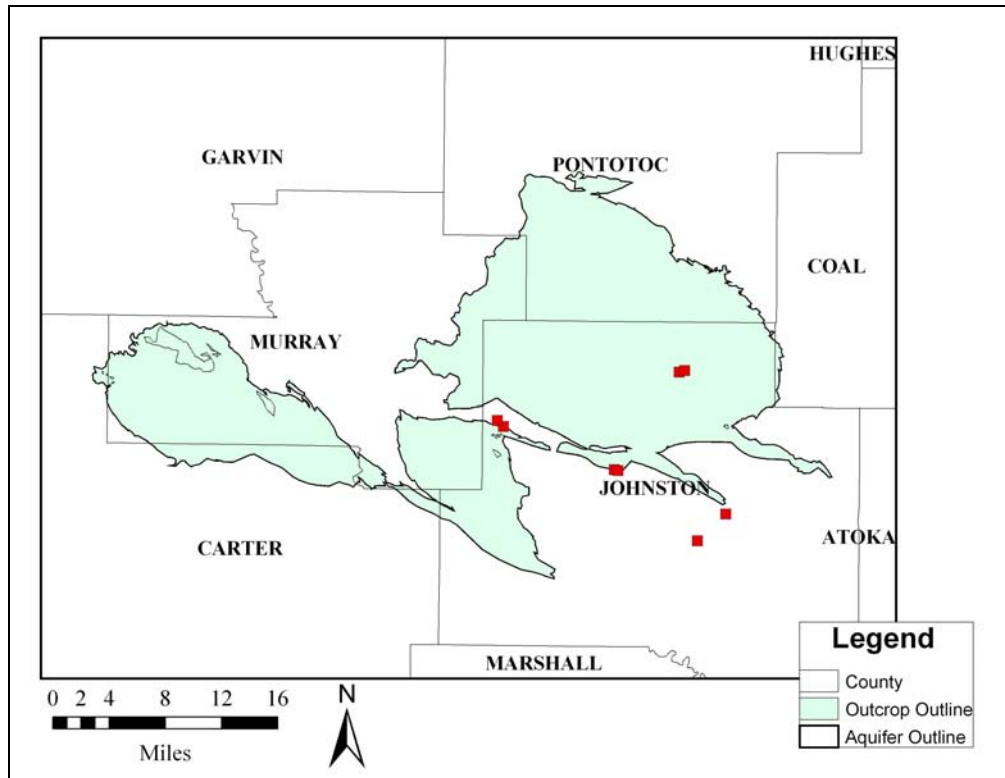
Figure 11: Surface Water Data with Ca/Mg Ratio within 0.2-0.56 Range (Adapted from GIS layers provided by USGS, 2006)
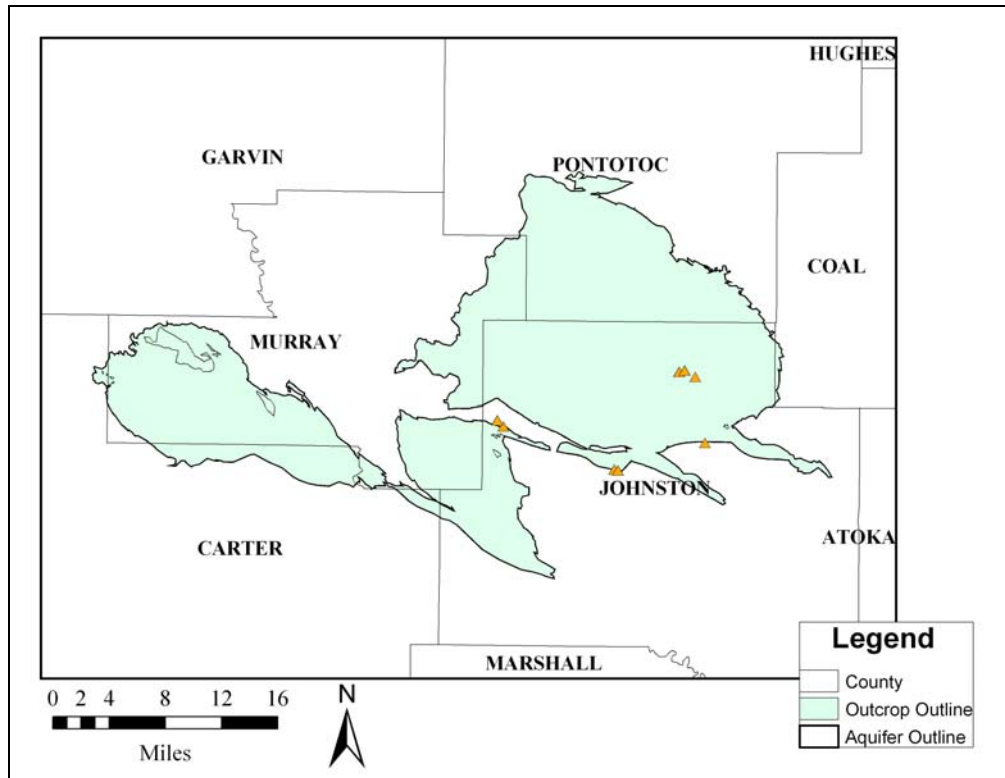
Figure 12: Surface Water with Ca/Mg Ratio within 0.9-1.1 Range (Adapted from GIS layers provided by USGS, 2006)
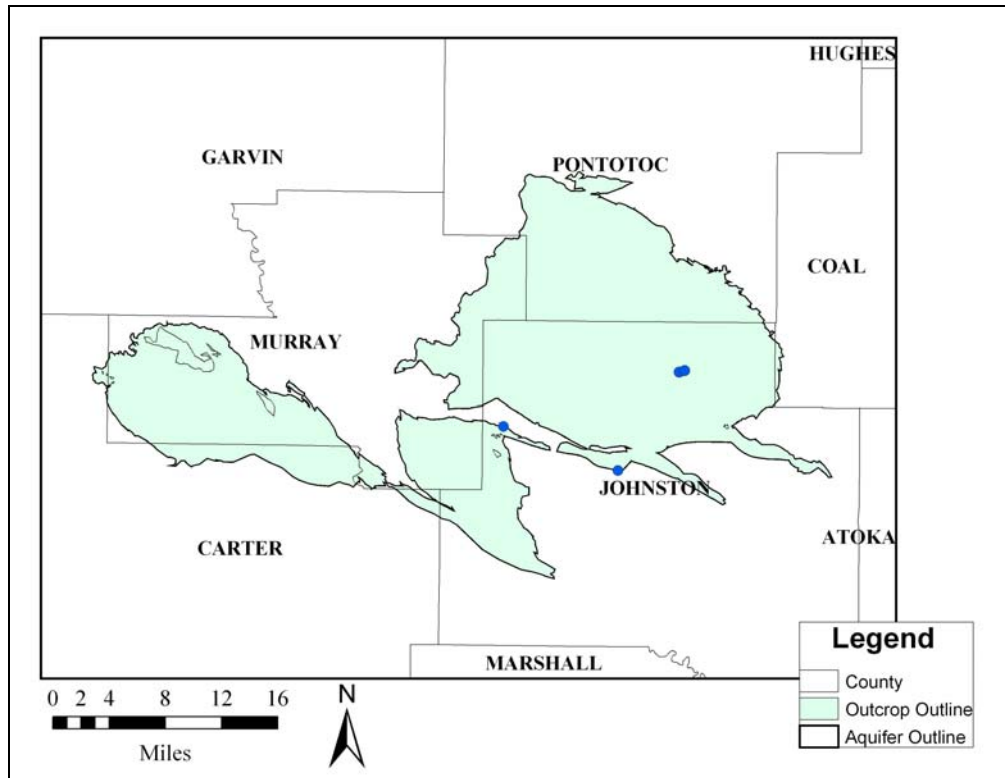
Figure 13: Surface Water with Ca/Mg Ratio within 1.3-1.4 Range (Adapted from GIS layers provided by USGS, 2006)
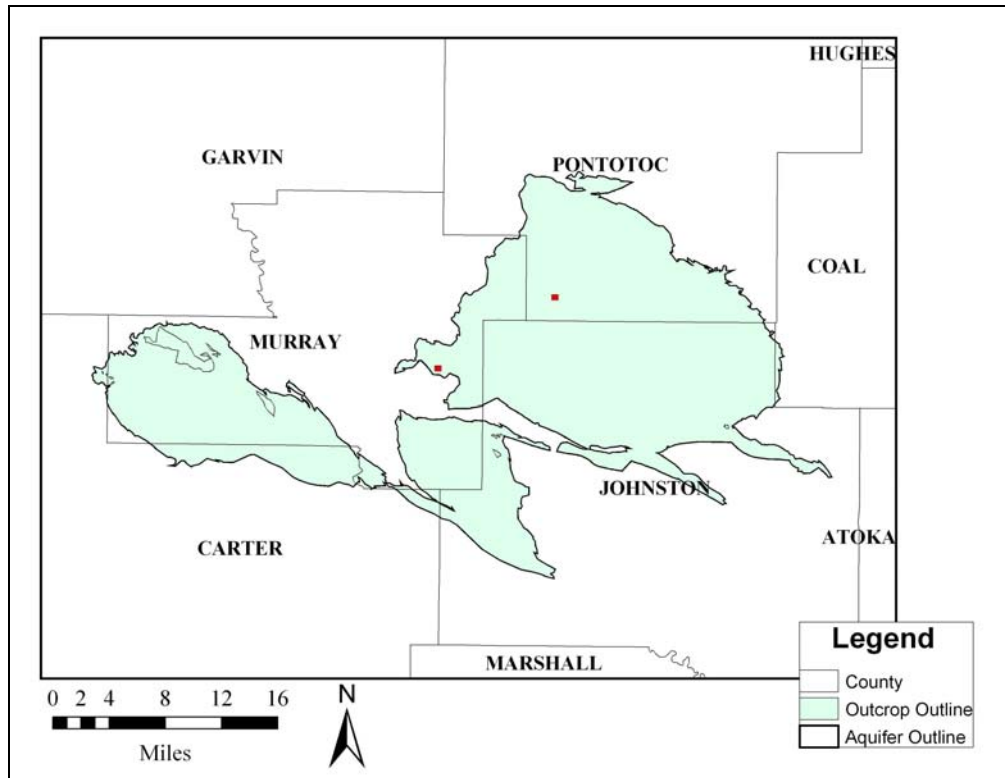
Figure 14: Ground Water with Ca/Mg Ratio within 0.2-0.56 Range (Adapted from GIS layers provided by USGS, 2006)
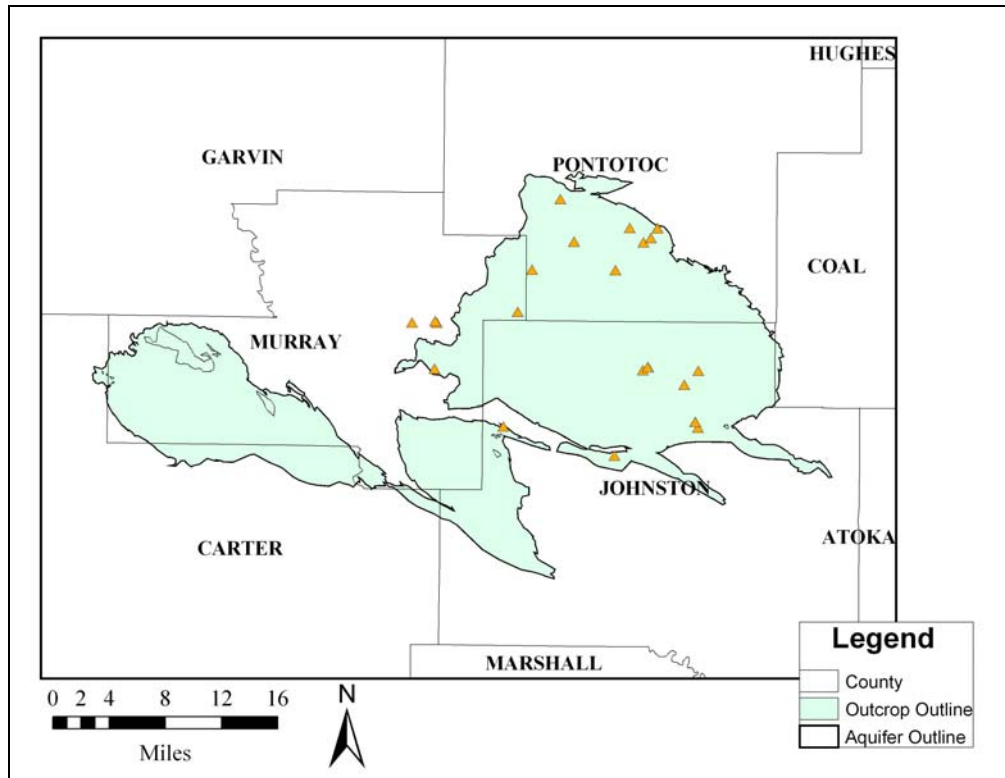
Figure 15: Ground Water with Ca/Mg within 0.9-1.1 Range
(Adapted from GIS layers provided by USGS, 2006)
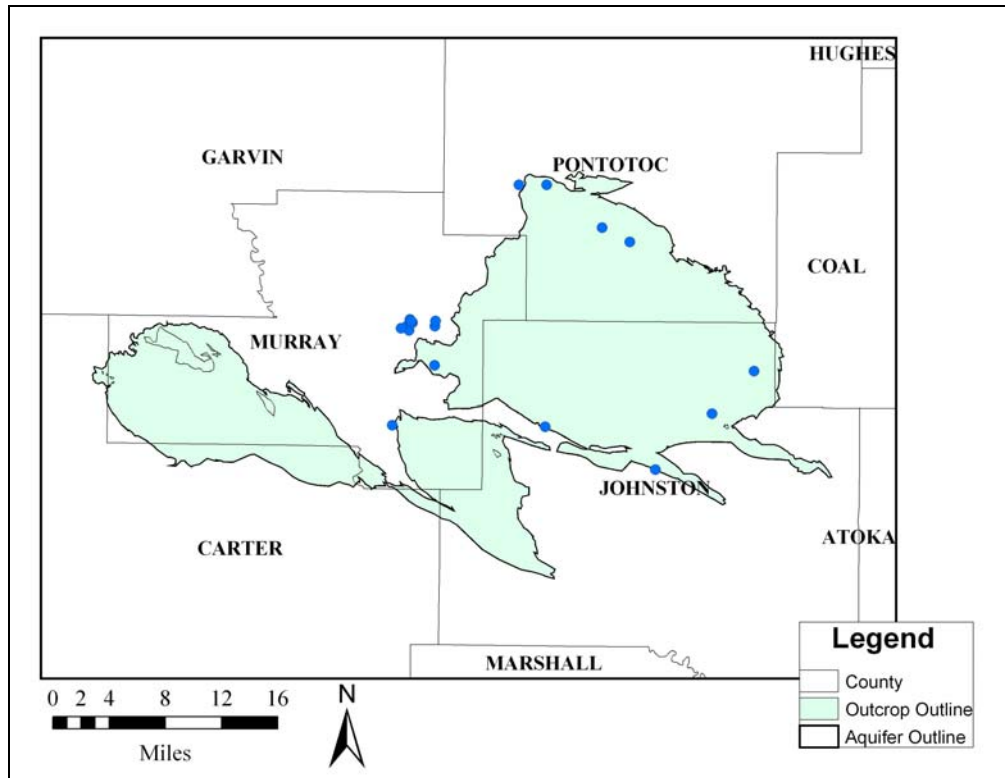
**Figure 16: Ground Water with Ca/Mg within 1.3-1.4 Range
(Adapted from GIS layers provided by USGS, 2006)**

Figure 17 shows the calcium magnesium ratio that is less than 0.38 and Figure 18 shows the ratio greater than 1.35 for surface waters. Again, there is no really difference between the two areas. This results from a lack of data in the northern part of the Hunton. The ground water samples contained no data for the calcium magnesium ratios less than 0.38. Figure 19 displays the calcium magnesium ratio greater than 1.35. These areas indicate usual geochemistry that should be studied in more detail.
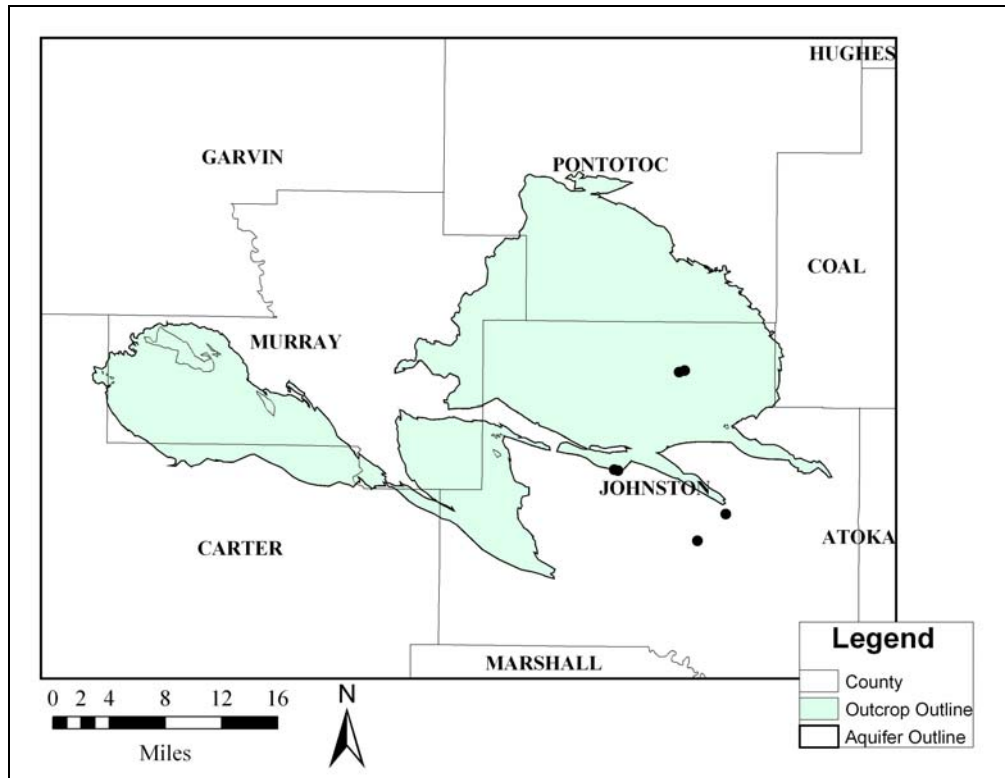
Figure 17: Surface Water with Ca/Mg Less than 0.38 (Adapted from GIS layers provided by USGS, 2006)
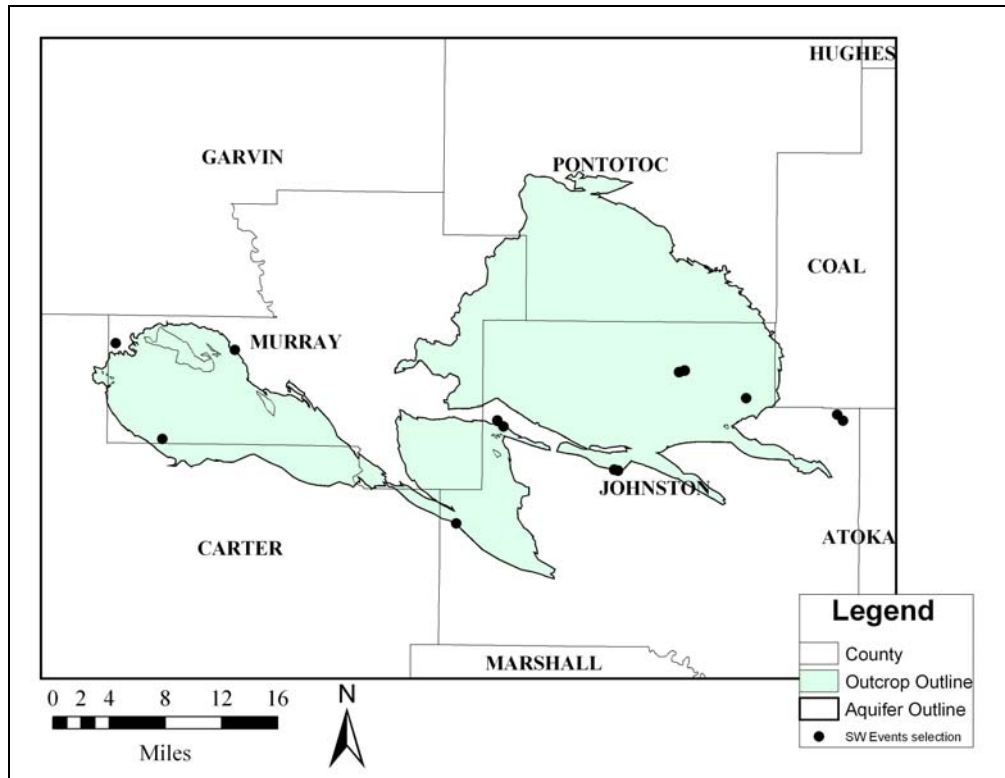
Figure 18: Surface Water with Ca/Mg Greater than 1.35 (Adapted from GIS layers provided by USGS, 2006)
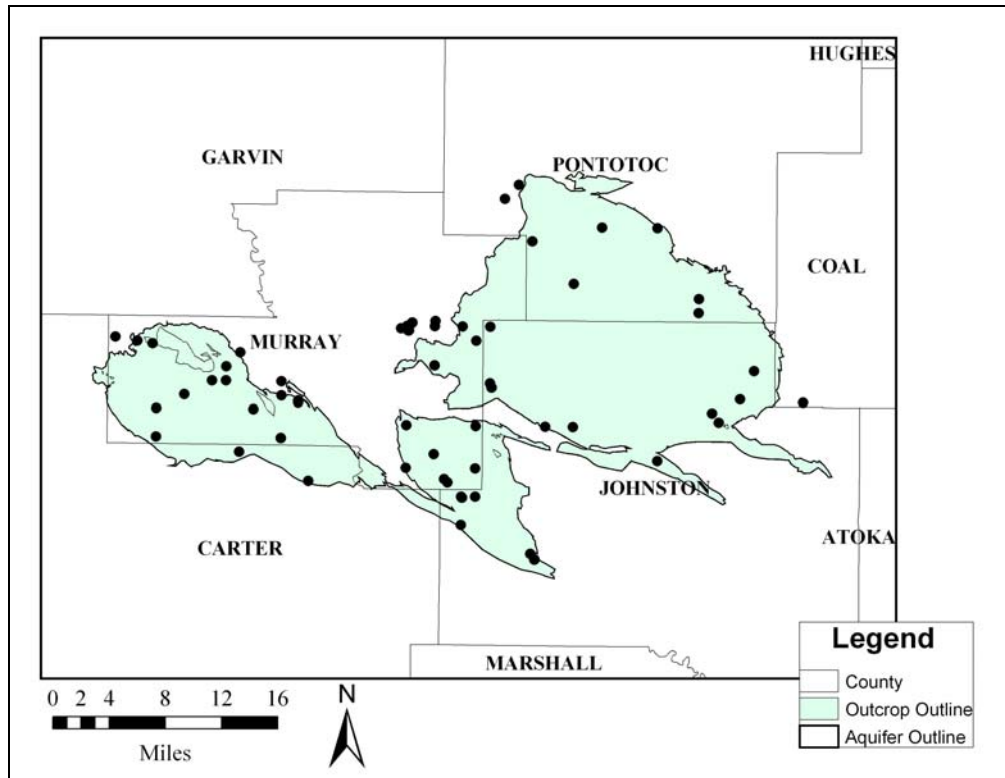
Figure 19: Ground Water with Ca/Mg Greater than 1.35 (Adapted from GIS layers provided by USGS, 2006)

Brine Mixing

A brine mixing model was used to determine the percent of brine that would be required to influence water chemistry. A rain (fresh) and a brine sample's chloride concentration was mixed at different percentages and compared to the surface and ground water chloride concentrations. The rain sample had a measured chloride of 0.236 mg/l (Parkhurst, 1996). The chloride sample was from a well located in the study area that had a chloride concentration of 112,000 mg/l (Personal Communication, R. Ross, 2006).

Table 10 shows the values of chloride concentrations when the brine and rain chloride concentrations are mixed. These concentrations are spatially shown in Figures 17 and 18. If we assume that chloride is conservative, and the

only source of chloride is from rainwater or brine in formations adjacent to the

Arbuckle-Simpson aquifer, significant amount of brine are not present in the

water samples. In the surface water (Figure 20), there is less than 0.05 % of

brine in all of the samples. In the ground water map (Figure 21), there are two

areas where greater than 0.5 percent of brine is influencing the chemistry, one

located around Vendome Well located in Sulphur and the second location on the

east of the Hunton anticline. For ground water, 97% of the samples would

require less than 0.1 percent of brine, but there are two areas that would require

0.5 – 2.0 percent. One area located at or near Sulphur and is adjacent to oil

fields. The second area, located on the east side of Hunton anticline, is

influenced by 0.1-0.5 percent of brine.
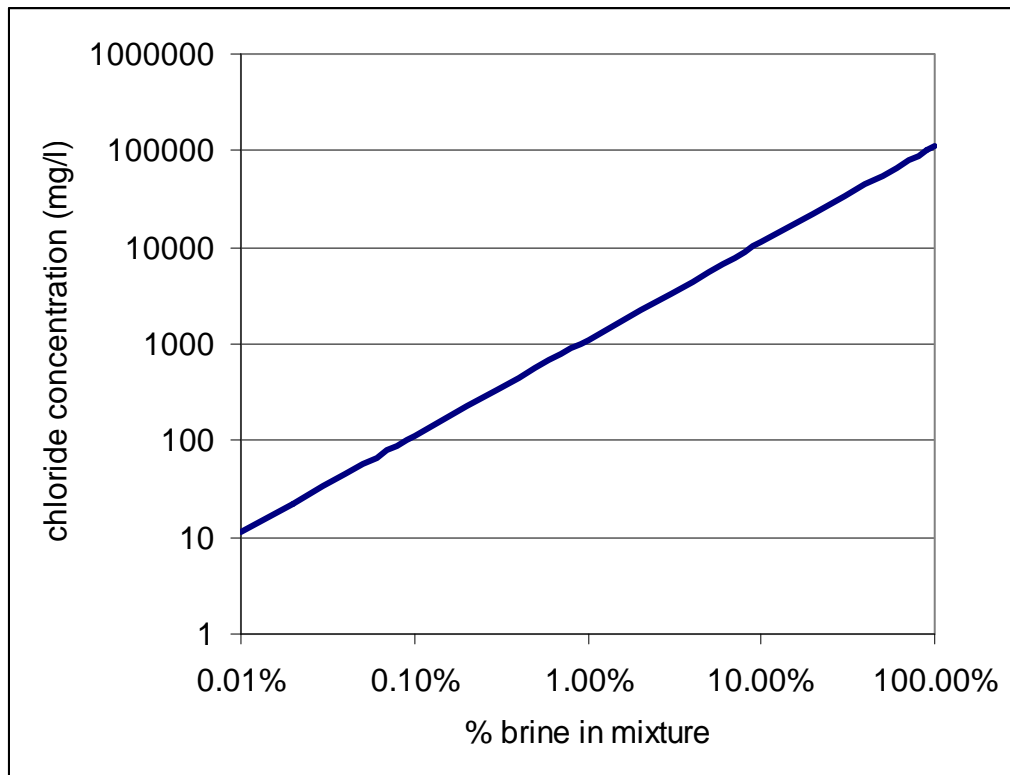
Table 3: Percentage of Brine needed to Influence Fresh Water
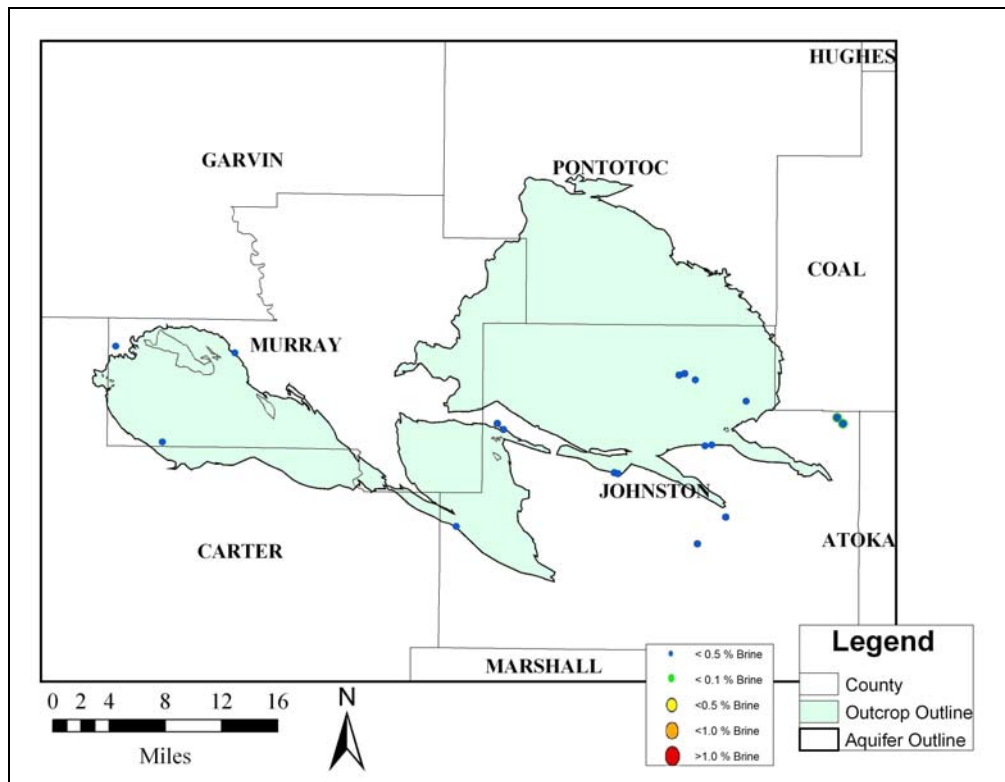
**Figure 20: Percentage of Brine Influencing Surface Water
(Adapted from GIS layers provided by USGS, 2006)**
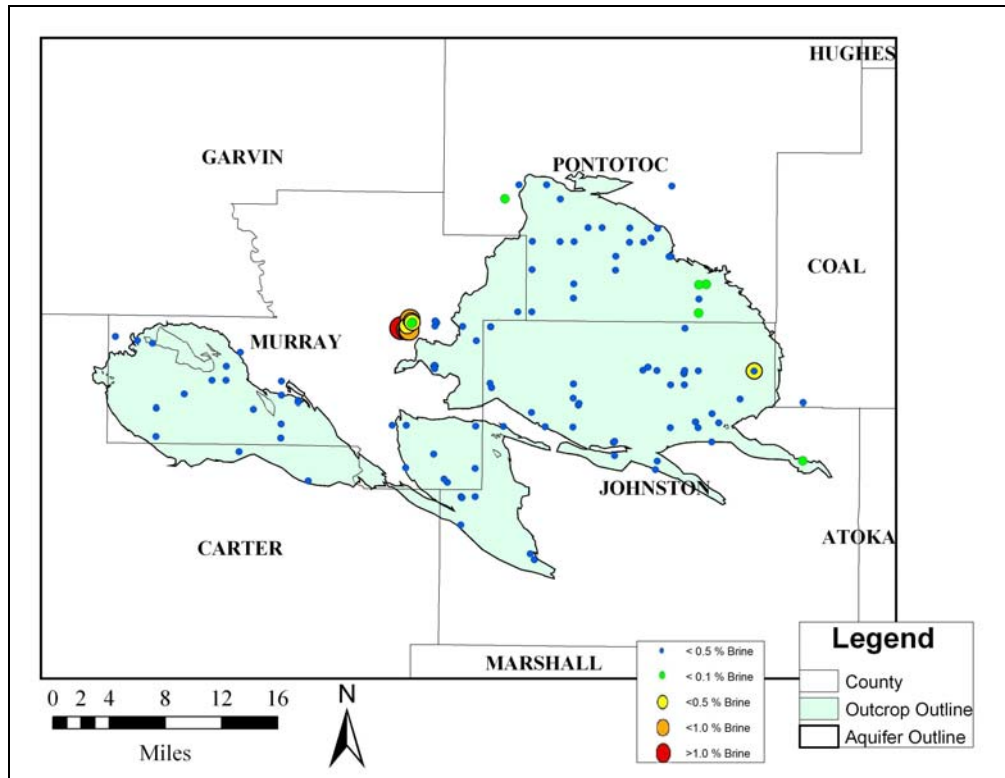
**Figure 21: Percentage of Brine Influencing Ground Water
Cation Exchange (Adapted from GIS layers provided by USGS, 2006)**

Cation Exchange

Cation exchange is another possibility of influence on the chemistry; therefore, sodium concentrations versus calcium concentrations and sodium concentrations versus magnesium concentrations were plotted to analyze the correlation between each of the two cations (Figure 19 & 20). Both graphs show a theoretical 2:1 line to represent the ratio of exchange. Since sodium has a 1^+ charge and both calcium and magnesium have a 2^+ charge, there would need to be two sodium ions exchanged for every one calcium or magnesium ion. From the graphs, it is possible that there is a cation exchange taking place.

There were no points that fell along the 2:1 line in the Figure 11, indicating possible no cation exchange between sodium and calcium. For Figure 20, there are nine points that fall on the line; these points could represent cation exchange.

Since the sodium concentrations seemed to be low compared to the other cations, a graph of sodium concentrations versus chloride concentrations was constructed. A theoretical line representing the mixture of chloride concentrations, brine, and a fresh water sample is displayed on the graph (Figure 21). The graph was constructed to show if the sodium ions were being bonded to chloride ions. Overall, the sodium and chloride concentrations follow the 1:1 trend line showing possible bonding between these ions.
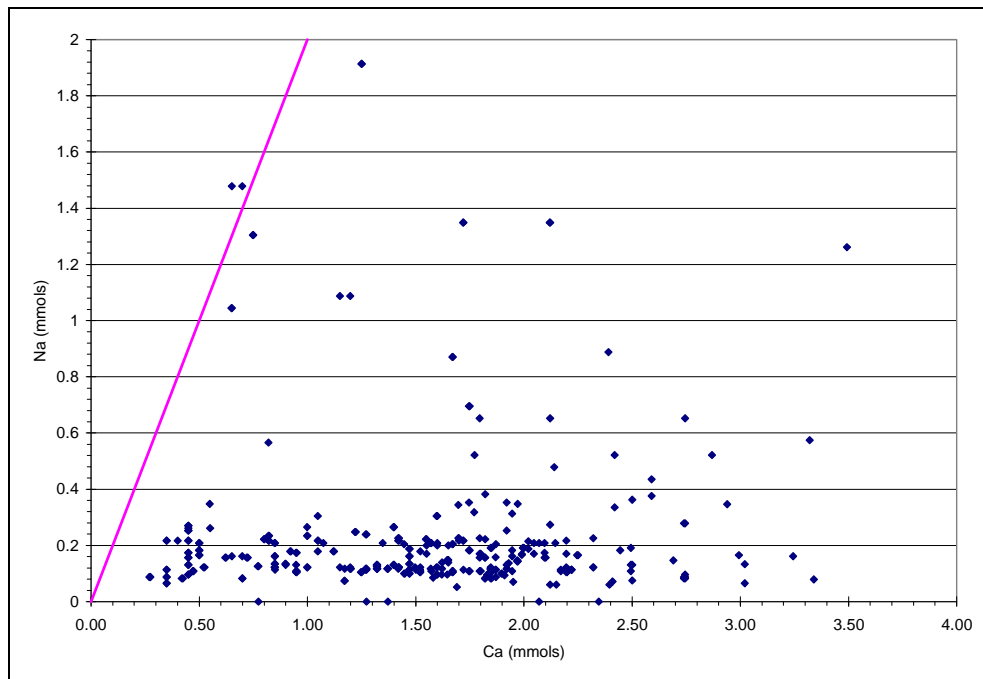
Figure 22: Sodium Concentrations versus Calcium Concentrations
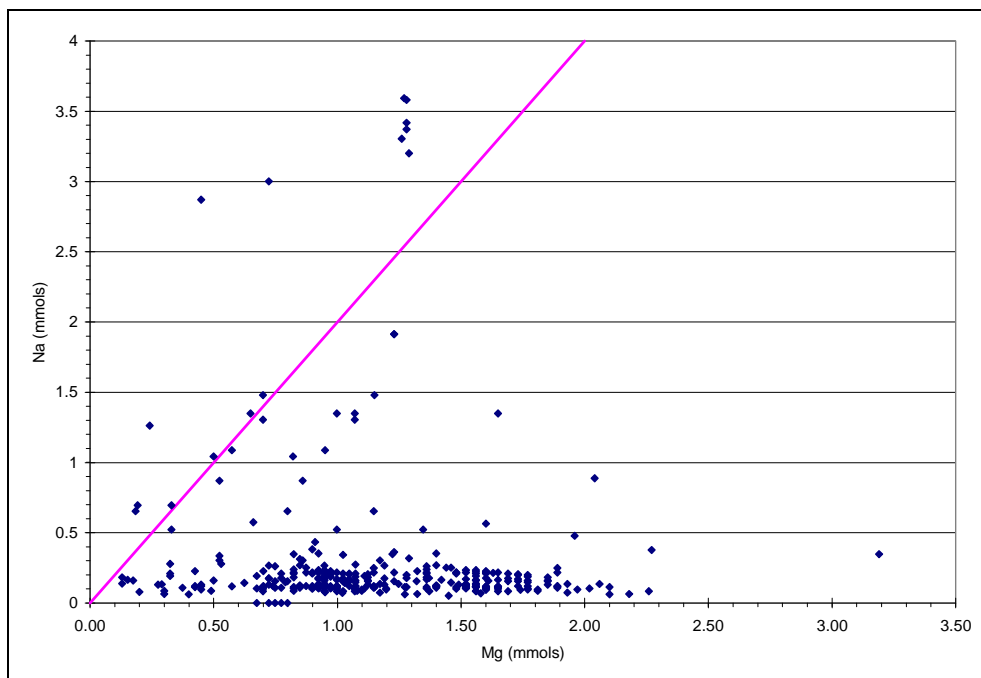
Figure 23: Sodium Concentrations versus Magnesium Concentrations
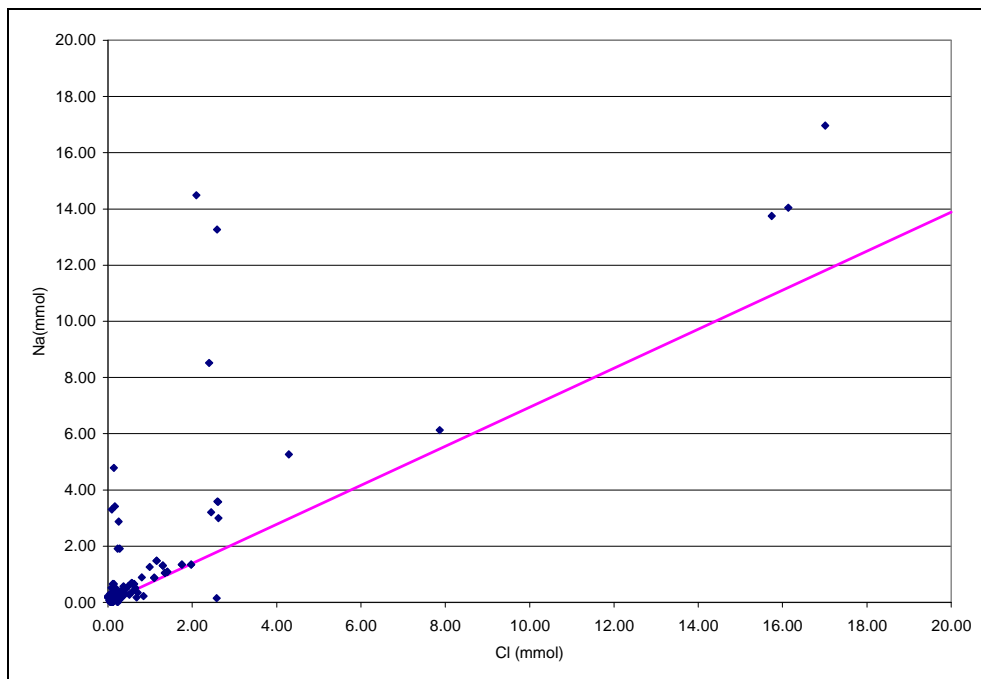
Figure 24: Sodium Concentrations versus Chloride Concentrations

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CHAPTER VI

DISCUSSIONS

The five hypotheses testing of the origins of the balance of cations (Ca^{2+} and Mg^{2+}) in the waters of the Arbuckle-Simpson aquifer resulted in an outcome with many clear signatures from the water chemistry. However, some questions remain.

Carbonate Equilibrium

Since aragonite and high magnesium calcite disappears within a million years unless protected from normal geochemical reactions, it will not be found in the Cambrian and Ordovician formations that were deposited 488+ million years ago (Schlager, 2005). Therefore, equilibrium with aragonite and high magnesium calcite can be excluded when determining a source of calcium in the ground water.

Using the chemistry data, Log IAP was calculated. Both the Log K and Log IAP were plotted against temperature (Figure 8 & 9). The graph shows that all samples are oversaturated with respect to dolomite, and a majority of the samples were oversaturated with respect to calcite. This shows that all waters in the area are indicative of waters that have been exposed to dolomite and/or calcite.

Brine mixing

Since the aquifer borders are oil-bearing reservoirs with significant brine content, brine mixing may alter the chemistry of the aquifer by adding ions. Parkhurst et. al. (1996) studied ground water quality and analyzed rain water. They reported that the chloride content of rain water in central Oklahoma was 0.236 mg/l. The rain water value was compared to a brine water value. The reported chloride value for the brine water was 112,000 mg/l (Personal Communication, R. Ross, 2006). Using these two values, percentages of the brine water was calculated to determine what effect it would have on the chloride content of the "fresh" rain water (Figure 10). Once values were determined, ArcMap was used to plot the values spatially over the study area. For surface water, less than 0.1 percent brine was represented in the chloride content of the waters (Figure 22 & 23, Appendix C).

Cation Exchange

To determine if cation exchange was being exhibited in the study area, three graphs were constructed. In one graph, sodium was plotted against magnesium, and in the second graph, sodium was plotted against calcium (Figure 11 & 12). Each showed a low amount of sodium compared to the two dominant cations (calcium and magnesium).

Future Work

The major hurdle in this study was finding historical samples that contained a complete analysis. Water chemistry samples should be taken along the edges of the aquifer to see if the oil field reservoirs are influencing the chemistry. In addition, surface water samples are very limited in the northern part of the Hunton anticline, as wells as surface and ground water samples in the central part of the Hunton anticline. In order to understand if cation exchange is influencing the calcium-magnesium ratios, cation exchange capacity should be analyzed on the clay material located within the faults. Samples taken at depth would allow a view at the flow at the bottom of the aquifer.

CHAPTER VII

CONCLUSIONS

The five hypotheses were examined and many inferences have been made concerning the flow paths of the Arbuckle-Simpson aquifer. In addition to understanding possible discharge areas, there is an understanding of what areas need to be examined to better understand the ground water flow. Also, possible areas of brine mixing were found in two regions of the study area.

As part of this study, 2927 samples of ground water and surface water from the Arbuckle-Simpson aquifer were compiled in a water chemistry database. The majority of samples prior to 2005 did not contain a complete analysis of major ions. Of the 2927 samples, 359 had analysis of both calcium and magnesium concentration. All but two of these samples have accompanying chloride concentration data. The age of the Arbuckle-Simpson formations excludes equilibrium with aragonite as a source of calcium in the ground water.

Using chloride as a conservative tracer, brine mixing from petroleum reservoirs would account for less than 0.1% of the water composition for 97 percent of the 359 analyses. The remaining analyses could be generated with less than 2.0 percent brine mixing.

Equilibrium between ground water and calcite can explain the calcium magnesium ratio for large areas of the Arbuckle and Tishimingo anticlines. This reflects the presence of significant amounts of calcite in the formation of these areas.

Equilibrium between ground water and a dolomite/calcite mixture can explain the calcium magnesium ratio for two significant areas of the aquifer. The area in or around Sulphur, Oklahoma appears to be in equilibrium with a dolomite/calcite mixture. This is supported by the age of the waters from the Vendome well which is found at ten thousand years old (OWRB, 2005). The other area is the eastern boundary of the Hunton anticline extending from the far north through the far south portion of the boundary. This may indicate the location of discharge from deeper portions of the aquifer.

Cation exchange cannot be excluded as a potential mechanism for altering the water chemistry of the waters of the Arbuckle-Simpson aquifer. However, it does not appear to be a dominant mechanism for the majority of the waters.

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APPENDIX A

Database Definitions and Contents

Database Definitions

For the Stations spreadsheet each is defined as the following:

StationName: Agency's Name (OEH, USGS, etc.) followed by the number

assigned by Agency (for example, USGS 00500056). The USEPA labeled

their sites by site name; this was used instead of Agency Number (for

example, Unnamed Spring Next to Oil Creek).

SiteName: Arbuckle-Simpson

ShortName: Common Name

StationGroup: z (for unknown)

Location_CX: X coordinates

Location_CY: Y coordinates

StationTypeCode: SP for spring; WW for water well; OW for oil well; SW

for surface water; and SH for sinkhole.

LocationCode: z (for unknown)

SamplingFreqCode: z (for unknown)

StationsUnitCode: z (for unknown)

Location_LL_LX: Longitude in decimal degrees

Location_LL_LY: Latitude in decimal degrees

StaGeoUnitCode: z (for unknown)

QCStationCode: z (for unknown)

CurrentStatusCode: z (for unkown)

For the Data spreadsheet each is defined as the following:

SampleDate_D: Month/Day/Year (for example, 4/19/1967)

ParameterName: See Appendix A

ReportingUnits: listed units by Agency (See Appendix A)

FlagCode: z (for unknown)

ShortName: Common name

Database Contents

Currently, the Arbuckle-Simpson database contains 515 Stations with 2,927 Samples which results in 70,248 analyses or parameters. The sample dates range from March 1905 – June 2005.

The sources were divided into five categories based on source of information. These five categories are USEPA, ODEQ, OEH and USGS and publications containing geochemistry data. The USEPA data was compiled from five different agencies, whereas the remaining three categories (ODEQ, OEH and USGS) reported in-house information. Data collection should be an ongoing process throughout the remaining investigation and there will be a continuing search to find other historic data.

1. USEPA (United States Environmental Protection Agency)

This data set contained 4435 samples and was obtained online using the USEPA's database called Storet (http://www.epa.gov/storet/). Most of these samples were excluded from the database, because either they were outside of the study area or did not contain water chemistry data. Two agencies were excluded completely, MDSD and HQ, because each contained data for heavy

metal contents in fish tissue. The samples are composed of data from the following agencies (as named by the USEPA): Corps of Engineers, USEPA Region 6, Oklahoma Conservation Commission, OWRB, USEPA MDSD, USEPA HQ and the National Park Service.

Corps of Engineers

Information consisted of surface water data ranging from 1972 – 1985. Eight samples were analyzed for fecal coliform only, whereas the majority of samples were analyzed for the following parameters: temperature, turbidity, color, specific conductance, dissolved oxygen, COD (chemical oxygen demand), pH, alkalinity, total nitrogen, nitrate, total phosphorus, total calcium, total magnesium, total sodium, total potassium, total chloride, total sulfate, total fluoride, total cadmium, total copper, total iron, total lead, total manganese, total nickel, total zinc, hardness, phosphorus and total mercury.

USEPA (United States Environmental Protection Agency)

The samples were broken down into four categories, USEPA, USEPA Region 6, USEPA MDSD and USEPA HQ. All were samples from surface water. The year range for each is listed as follows; USEPA from 1973-1974, Region 6 from 1969-1970, MDSD from 1984 and HQ from 1970-1986.

USEPA samples were analyzed for the following parameters: temperature, turbidity, specific conductance, dissolved oxygen, pH, alkalinity, two nitrogen

methods (ammonia and kjeldahl), ammonia, nitrate, nitrite, total and dissolved phosphorus for three different sample sites.

Region 6 samples were analyzed for the following: temperature, specific conductance, BOD, COD, pH, hardness, dissolved sodium, total chloride, total sulfate and total phenol. A few samples were tested for bicarbonate, hardness, hexavalent chromium, dissolved copper, total iron, dissolved lead, total manganese, dissolved nickel, dissolved zinc and total dissolved solids.

MDSD and HQ data contains only information regarding organics and heavy metals in fish tissue.

Oklahoma Conservation Commission

The data consisted of samples from surface waters obtained from 1959-1992. Some analyses contain pH and flow, whereas the majority of samples were analyzed for the following: temperature, pH, two alkalinity methods (total and phenolphthalein), total nitrate, total phosphorus, total hardness, calcium, total chloride, total sulfate and total iron.

OWRB(Oklahoma Water Resource Board)

The samples collected included surface waters ranging from 1981-1982. The samples were analyzed for the following: temperature, flow, specific conductance, dissolved oxygen, pH, alkalinity, total nitrogen, ammonia, nitrite, nitrate, total phosphorus, dissolved phosphorus, hardness, total dissolved solids, settleable solids and turbidity. Some samples were analyzed for temperature,

flow, specific conductance, dissolved oxygen and pH only. Other samples were analyzed only for alkalinity, hardness, and turbidity. There were ten to fifteen samples that reported flow only.

<u>National Park Service</u>

The samples consisted of surface waters ranging from 1951-1994. The majority of the samples were analyzed for the following: temperature, specific conductance, pH, carbon dioxide, alkalinity, bicarbonate/carbonate ion, hardness, dissolved calcium, dissolved magnesium, dissolved sodium and dissolved chloride. A few samples analyzed for dissolved arsenic, dissolved cadmium, dissolved chromium, dissolved copper, dissolved iron, dissolved lead, dissolved manganese, dissolved zinc, dissolved aluminum and dissolved mercury. Some samples recorded the flow and drainage area.

2. ODEQ (Oklahoma Department of Environmental Quality)

This data set consisted of samples from quarries around Mill Creek ranging from the years 2000 to the present and was obtained by electronic delivery from ODEQ. Over 74 samples reported discharge levels only, with a few reporting total suspended solids and pH measurements.

3. OEH (Oklahoma Environmental Heath)

This data set included 32 wells ranging from 1999 to present (these files were located in house; there is an outside storage area with data older than

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1999, because of the condition of the storage area these were not collected). The data were obtained from OEH in paper format. The wells were sampled for the following: pH, alkalinity, turbidity, hardness, total dissolved solids, total chloride, total fluoride, total nitrate, total nitrite, total sulfate, total calcium, total iron, and total manganese.

4. USGS (United States Geological Survey)

This data set consisted of 66 springs and wells that supplied over 500 samples ranging from 1952 to present. The data were obtained from the USGS website. Most samples were analyzed for the following: pH, specific conductance, temperature, hardness, dissolved calcium, dissolved magnesium, dissolved potassium, dissolved sodium, alkalinity, acid neutralizing capacity, bicarbonate/carbonate ion, dissolved chloride, dissolved silicon, sulfate and total dissolved solids. A few samples were also analyzed for bicarbonate/carbonate ion, dissolved arsenic, dissolved chloride, dissolved iron and dissolved manganese.

In addition, USGS provided data from 29 samples that were analyzed for the following: specific conductance, dissolved oxygen, pH, bicarbonate/carbonate ion, ammonia, nitrite, nitrate, orthophosphate, dissolved calcium, dissolved magnesium, dissolved sodium, dissolved potassium, dissolved chloride, dissolved sulfate, dissolved fluoride, dissolved silica, dissolved arsenic, dissolved barium, dissolved beryllium, dissolved boron, dissolved cadmium, dissolved chromium, dissolved cobalt, dissolved copper, dissolved iron, dissolved lead,

dissolved manganese, dissolved thallium, dissolved molybdenum, dissolved nickel, dissolved silver, dissolved strontium, dissolved vanadium, dissolved zinc, dissolved antimony, dissolved aluminum, dissolved lithium, dissolved selenium, dissolved uranium, alkalinity, carbon-14, total dissolved solids, dissolved iodide, bromide, carbon-13/carbon-12 ration, deuterium/protium ration, oxygen-18/oxygen-16 ratio and acid neutralizing capacity. (Personal Communication, S. Christenson, 2005)

In 2005, the OWRB and USGS drilled a deep well (>1000 ft) in the south central part of the Hunton anticline. In 2006, the USGS provided the samples from that well. The samples were analyzed by at the OSU Soils, Water and Forage Analytical Laboratory. These samples were analyzed for the following: major cations/anions, temperature, boron, total soluble solids and hardness

5. Publications that contain geochemistry information

A search of chemistry data on the Arbuckle-Simpson was conducted using a database that was completed by OSU. The following publications contained chemistry data on the area:

Gould, C. N. and S. L. Schoff (1939). Geological report on water conditions at Platt National Park, Oklahoma. Report no. 249, Open-File Report (OFR) 39-14. Oklahoma Geological Survey (OGS) and National Park Service (NPS)**:** 1-38.

- Listed values for chlorine, sodium, calcium, magnesium and potassium

- Flow for the years 1906, 1911 and 1939

United States Department of the Interior: Bureau of Reclamation - Region 5: Office of Engineering (1963). Appendices to Definite Plan Report Arbuckle Project Oklahoma: Appendix A: Plans and Estimates. Appendix B: Hydrology. Amarillo, TX, U.S. Department of the Interior**:** 49.

- Listed values for total dissolved solids, total hardness, non-CO_3 hardness, chloride, sulphate, magnesium and sodium/potassium.

Oklahoma Water Resources Board (1966). Ground water in the northern part of the Arbuckle Mountains, Pontotoc County, Oklahoma. <u>Publication 23</u>. Oklahoma City**:** 11.

- Listed values for temperature, silica, calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate, chloride, fluoride, nitrate, phosphate, boron, total dissolved solids, hardness, percent sodium, sodium adsorption ratio, specific conductance, pH and percent alkalinity.
- Years 1956 – 1959.

Fairchild, R. W. (1984). Springs in the Arbuckle Mountain area, south-central Oklahoma. <u>Oklahoma Geology Notes</u>. Oklahoma Geological Survey (OGS). Oklahoma City**:** 4-11.

- Listed values for calcium, magnesium, hardness, total dissolved solids, carbon dioxide, bicarbonate, sodium, chloride, fluoride, specific conductance, temperature and pH.

Fairchild, R. W., R. L. Hanson, et al. (1990). Hydrology of the Arbuckle Mountains area, south-central Oklahoma. <u>Circular 91</u>. Oklahoma Geological Survey (OGS). Norman, OK**:** 112.

- Listed values for calcium, magnesium, hardness, total dissolved solids, carbon dioxide, bicarbonate, sodium, chloride, fluoride, specific conductance, temperature and pH. Analyses were broken down into three categories; wells, springs and streams.
- An additional table listed values for aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury and zinc.

Hanson, R. L. and S. W. Cates (1994). Hydrogeology of the Chickasaw National Recreation Area, Murray County, Oklahoma. <u>Water-Resources Investigations Report 94-4102</u>. U.S. Geological Survey (USGS). Oklahoma City, OK**:** 1-86.

- Listed values for specific capacity, transmissivity and total dissolved solids.

Gao, G., S. I. Dworkin, et al. (1996). "Geochemistry of Late Ordovician Viola Limestone, Oklahoma: Implications for marine carbonate mineralogy and isotopic compositions." <u>Journal of Geology</u> **104**(3): 359-367.

- Listed values for calcium carbonate, magnesium, iron, manganese and strontium.

Nord, J. D. (1996). Geologic and hydrologic controls on flow at Vendome Well, Sulphur, OK. <u>Geology</u>. Stillwater, OK, Oklahoma State University**:** 147.

- Listed values for pH, conductivity, bicarbonate, calcium, chloride, magnesium and sodium.

Andrews, W. and S. Burrough (2000). Hydrology and water quality near Bromide Pavilion in Chickasaw National Recreation Area, Murray County, Oklahoma, 2000. <u>Water-Resources Investigations Report 01-4250</u>. Oklahoma Geological Survey (OGS). Oklahoma City**:** 31.

- Graphed values for water level, temperature, specific conductance, pH, dissolved oxygen and turbidity for Rock Creek, Medicine Spring and Bromide Springs.

- Listed values for discharge, pH, hardness, alkalinity, total dissolved solids, calcium, magnesium, sodium, potassium, sulfate, chloride, fluoride, bromide, silica, nitrate, ammonia, ferric oxide and iron for Bromide and Medicine Springs for the years of 1906, 1963 and 1987.

- Summary of historic data of water-quality analyses of Rock Creek and Vendome Well.
    - o Broken down into three categories
        - Rock Creek north of Sulphur (1958-1961)
        - Rock Creek at Sulphur (1990-1995)
        - Vendome Well (1955-1990)

APPENDIX B

Chemical Data

LAT	LONG	STATIONNAM	SW/GW	DATE	Ca	Mg	Na	Cl
34.4543	-96.9410	Antelope Spring	gw	10/21/1993	68.30	30.60	76	3.13
34.5047	-96.9713	Black Sulphur Spring	gw	10/21/1993	64.50	29.60	121	152.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	11/23/1954	86.00	51.00	1.4	3.50
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	7/14/1954	28.00	55.00	1.9	3.20
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	11/14/1977	73.00	40.00	1.9	8.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	5/28/1954	11.00	44.00	2	3.20
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	9/16/1954	64.00	43.00	2.2	3.50
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	8/19/1953	59.00	36.00	2.3	2.80
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	1/12/1954	74.00	37.00	2.4	3.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	2/25/1954	61.00	27.00	2.4	3.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	4/20/1954	38.00	33.00	2.4	3.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	12/21/1954	88.00	39.00	2.4	3.50
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	7/18/1956	67.00	49.00	2.4	5.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	8/28/1956	50.00	43.00	2.4	5.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	11/18/1952	67.00	39.00	2.5	2.50
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	3/10/1953	70.00	37.00	2.5	2.50
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	12/7/1961	38.00	34.00	2.5	6.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	1/16/1952	87.00	31.00	2.6	2.20
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	3/6/1952	89.00	28.00	2.6	2.20
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	2/4/1953	75.00	39.00	2.6	2.50
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	6/23/1953	59.00	38.00	2.6	2.80
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	9/30/1953	89.00	28.00	2.6	3.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	2/1/1955	74.00	33.00	2.6	3.50
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	8/21/1956	51.00	51.00	2.6	5.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	6/11/1952	57.00	46.00	2.7	2.40
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	12/23/1952	48.00	39.00	2.7	2.50
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	6/2/1953	74.00	34.00	2.7	2.80
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	1/4/1956	74.00	40.00	2.7	4.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	4/23/1952	34.00	17.00	2.8	2.40
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	9/3/1952	57.00	43.00	2.8	2.50
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	9/24/1956	40.00	46.00	2.8	5.50
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	3/2/1955	53.00	34.00	2.9	3.50
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	5/21/1956	66.00	43.00	3.4	4.50
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	11/17/1953	84.00	30.00	3.6	3.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	9/21/1956	29.00	45.00	3.6	5.50
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	8/24/1954	34.00	43.00	3.7	3.30
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	2/14/1956	18.00	41.00	4	4.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	10/19/1961	37.00	31.00	4.1	5.80
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	10/31/1956	70.00	45.00	4.2	5.70
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	11/2/1961	20.00	36.00	4.8	6.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	6/13/1955	68.00	39.00	5	3.60
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	7/27/1955	69.00	36.00	5	4.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	3/2/1962	32.00	38.00	5.1	6.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	7/22/1952	68.00	39.00	5.2	2.50
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	1/12/1962	18.00	35.00	5.8	6.00
34.4543	-96.6340	BLUE RIVER 0.5 MILES NORTH OF CONNERVILLE	sw	3/29/1956	56.00	29.00	6.1	4.40
34.3095	-96.5741	BLUE RIVER 2.5 MILES NORTH OF CHEADLE CEMETERY	sw	10/2/1957	21.00	34.00	2.8	4.90
34.3095	-96.5741	BLUE RIVER 2.5 MILES NORTH OF CHEADLE CEMETERY	sw	1/8/1959	18.00	29.00	3	6.50
34.4543	-96.5741	BLUE RIVER 2.5 MILES NORTH OF CHEADLE CEMETERY	sw	8/28/1956	34.00	47.00	3.1	4.50
34.3095	-96.5741	BLUE RIVER 2.5 MILES NORTH OF CHEADLE CEMETERY	sw	3/19/1958	18.00	32.00	3.6	5.60
34.3095	-96.5741	BLUE RIVER 2.5 MILES NORTH OF CHEADLE CEMETERY	sw	6/11/1958	20.00	40.00	3.8	6.20
34.3095	-96.5741	BLUE RIVER 2.5 MILES NORTH OF CHEADLE CEMETERY	sw	11/12/1957	38.00	29.00	4	5.20
34.3095	-96.5741	BLUE RIVER 2.5 MILES NORTH OF CHEADLE CEMETERY	sw	1/17/1958	20.00	33.00	4.2	5.50
34.3095	-96.5741	BLUE RIVER 2.5 MILES NORTH OF CHEADLE CEMETERY	sw	11/5/1958	16.00	33.00	5	6.40
34.3095	-96.5741	BLUE RIVER 2.5 MILES NORTH OF CHEADLE CEMETERY	sw	1/27/1960	18.00	30.00	5	6.60
34.3095	-96.5741	BLUE RIVER 2.5 MILES NORTH OF CHEADLE CEMETERY	sw	3/23/1960	22.00	33.00	6	9.00
34.3095	-96.5741	BLUE RIVER 2.5 MILES NORTH OF CHEADLE CEMETERY	sw	9/5/1958	18.00	34.00	6.2	6.30
34.3095	-96.6007	BLUE RIVER 5.5 MILES SOUTH OF SEELY CHAPEL	sw	10/21/1977	63.00	38.00	2.7	3.00
34.3823	-96.6006	CANYON SPRING NEXT TO CANYON CREEK	gw	11/15/1977	85.00	40.00	31	62.00
34.5446	-96.9059	CHAPMAN SPRING LOCATED 1/4 MI. EAST OF OIL CREEK	gw	10/18/1977	110.00	12.00	2	2.70

LAT	LONG	STATIONNAM	SW/GW	DATE	Ca	Mg	Na	Cl
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 1	sw	9/10/1951	55	31		2.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 10	sw	12/23/1952	48	39	2.7	3.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 11	sw	2/4/1953	75	39	2.6	3.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 12	sw	3/10/1953	70	37	2.5	3.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 13	sw	6/2/1953	74	34	2.7	3.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 14	sw	6/23/1953	59	38	2.6	3.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 15	sw	8/19/1953	59	36	2.3	3.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 16	sw	9/30/1953	69	28	2.6	3.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 17	sw	11/17/1953	84	30	3.6	4.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 18	sw	1/12/1954	74	37	2.4	4.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 19	sw	2/25/1954	61	27	2.4	4.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 2	sw	11/27/1951	94	30		3.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 20	sw	4/20/1954	38	33	2.4	3.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 21	sw	5/28/1954	11	44	2	4.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 22	sw	7/14/1954	28	55	1.9	4.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 23	sw	8/24/1954	34	43	3.7	4.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 24	sw	9/18/1954	64	43	2.2	5.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 25	sw	11/28/1954	85	51	1.4	5.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 26	sw	12/21/1954	88	39	2.4	5.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 27	sw	2/1/1955	74	33	2.6	6.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 28	sw	3/2/1955	53	34	2.9	6.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 29	sw	6/13/1955	88	39	5	8.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 3	sw	1/16/1952	87	31	2.5	2.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 30	sw	7/27/1955	69	35	5	3.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 31	sw	9/21/1955	29	45	3.6	3.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 32	sw	10/31/1955	70	45	4.2	4.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 33	sw	1/4/1956	74	40	2.7	5.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 34	sw	2/14/1956	18	41	4	5.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 35	sw	3/29/1956	56	29	6.1	6.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 36	sw	5/21/1956	66	43	3.4	6.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 37	sw	7/18/1956	67	48	2.4	6.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 38	sw	8/21/1956	51	51	2.6	8.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 39	sw	8/28/1956	50	43	2.4	10.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 4	sw	3/5/1952	89	28	2.6	2.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 40	sw	9/24/1958	40	46	2.8	3.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 41	sw	10/19/1961	37	31	4.1	3.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 42	sw	11/2/1961	20	36	4.8	4.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 43	sw	12/2/1961	38	34	2.5	4.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 44	sw	1/12/1962	18	35	5.8	4.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 45	sw	3/2/1962	32	38	5.1	6.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 5	sw	4/23/1952	34	17	2.8	2.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 6	sw	6/11/1952	57	43	2.8	3.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 7	sw	7/22/1952	68	39	5.2	0.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 8	sw		57	43	2.8	2.00
34.4557	-96.6271	Circ 91 Blue River at Connerville, OK 9	sw	11/18/1952	67	39	2.5	3.00
34.2816	-96.6096	Circ 91 Blue River at Wilburn, OK 1	sw	8/28/1956	34	47	3.1	5.00
34.2816	-96.6096	Circ 91 Blue River at Wilburn, OK 10	sw	1/27/1960	18	30	6	6.00
34.2816	-96.6096	Circ 91 Blue River at Wilburn, OK 11	sw	3/28/1960	22	33	8	7.00
34.2816	-96.6096	Circ 91 Blue River at Wilburn, OK 2	sw	10/2/1957	21	34	2.8	5.00
34.2816	-96.6096	Circ 91 Blue River at Wilburn, OK 3	sw	11/12/1957	38	29	4	6.00
34.2816	-96.6096	Circ 91 Blue River at Wilburn, OK 4	sw	1/17/1958	20	33	4.2	6.00
34.2816	-96.6096	Circ 91 Blue River at Wilburn, OK 5	sw	3/19/1958	18	32	3.6	6.00
34.2816	-96.6096	Circ 91 Blue River at Wilburn, OK 6	sw	8/11/1958	20	40	3.8	5.00
34.2816	-96.6096	Circ 91 Blue River at Wilburn, OK 7	sw	9/5/1958	18	34	6.2	9.00
34.2816	-96.6096	Circ 91 Blue River at Wilburn, OK 8	sw	11/5/1958	18	33	5	9.00
34.2816	-96.6096	Circ 91 Blue River at Wilburn, OK 9	sw	1/8/1959	18	29	3	6.00
34.3832	-96.5922	Circ 91 Blue River nr Connerville, OK 1	sw	10/21/1977	53	38	2.7	4.00
34.6018	-96.6623	Circ 91 Byrds Mill Spring nr Fittstown, OK 1	sw	12/22/1954	84	29	4	5.00
34.6018	-96.6623	Circ 91 Byrds Mill Spring nr Fittstown, OK 2	sw	11/29/1955	58	39	4.7	7.00

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LAT	LONG	STATIONNAM	SW/GW	DATE	Ca	Mg	Na	Cl
34.4122	-96.4350	Circ 91 Delaware Creek nr Wapanucka, OK 1	sw	2/24/1958	28	28	34	41.00
34.4122	-96.4350	Circ 91 Delaware Creek nr Wapanucka, OK 2	sw	4/7/1958	30	28	30	46.00
34.4122	-96.4350	Circ 91 Delaware Creek nr Wapanucka, OK 3	sw	1/26/1960	26	20	24	48.00
34.4122	-96.4350	Circ 91 Delaware Creek nr Wapanucka, OK 4	sw	3/23/1960	48	23	25	50.00
34.4122	-96.4350	Circ 91 Delaware Creek nr Wapanucka, OK 5	sw	6/3/1960	69	26	31	70.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 1	sw	9/3/1952	42	46	5	7.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 10	sw	8/19/1953	40	37	5.4	7.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 11	sw	9/30/1953	33	38	5.4	7.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 12	sw	11/23/1954	90	38	3.8	9.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 13	sw	12/21/1954	74	38	4.4	7.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 14	sw	2/1/1955	86	43	4.8	8.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 15	sw	3/1/1955	82	31	4.8	10.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 16	sw	6/13/1955	34	33	4.8	9.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 17	sw	7/27/1955	59	43	4.3	9.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 18	sw	9/21/1955	49	46	5.7	7.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 19	sw	1/27/1960	51	33	5.5	10.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 2	sw	10/9/1952	54	42	4.8	7.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 20	sw	5/3/1960	51	27		8.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 3	sw	11/18/1952	67	42	4.7	7.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 4	sw	12/23/1952	84	39	4.8	6.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 5	sw	2/4/1953	83	41	4.8	6.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 6	sw	3/10/1953	45	38	4.1	6.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 7	sw	4/14/1953	63	38	4.8	7.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 8	sw	6/2/1953	57	40	5	7.00
34.3977	-96.8541	Circ 91 Mill Creek nr Mill Creek, OK 9	sw	8/23/1952	33	37	5	7.00
34.4702	-97.1859	Circ 91 Murray County Unname 1	sw	9/7/1978	64	21	7	10.00
34.3977	-97.1336	Circ 91 Murray County Unname 10	gw	9/7/1978	73	37	5.1	9.00
34.3832	-97.1336	Circ 91 Murray County Unname 11	gw	9/1/1978	100	13	4.4	4.00
34.3396	-97.0986	Circ 91 Murray County Unname 12	sw	8/31/1978	78	20	3.7	6.00
34.3977	-96.9938	Circ 91 Murray County Unname 13	gw	10/19/1977	39	18	66	9.00
34.3686	-96.9414	Circ 91 Murray County Unname 14	gw	10/18/1977	78	30	2.5	2.00
34.3541	-96.9764	Circ 91 Murray County Unname 15	gw	10/19/1977	140	9.7	29	35.00
34.3396	-96.9240	Circ 91 Murray County Unname 16	gw	10/18/1977	100	15	2.5	3.00
34.4412	-97.2034	Circ 91 Murray County Unname 2	gw	8/31/1978	130	7	3.7	3.00
34.4412	-97.2209	Circ 91 Murray County Unname 3	gw	9/7/1978	97	21	7.7	14.00
34.4847	-97.3431	Circ 91 Murray County Unname 4	sw	9/8/1978	70	7.7	16	20.00
34.4267	-97.2558	Circ 91 Murray County Unname 5	gw	9/7/1978	98	5.2	4.2	3.00
34.4412	-97.1336	Circ 91 Murray County Unname 6	sw	9/1/1978	43	13	4.8	9.00
34.4267	-97.1336	Circ 91 Murray County Unname 7	gw	9/1/1978	120	6.1	3.8	2.00
34.4557	-96.9414	Circ 91 Murray County Unname 8	gw	10/10/1977	73	36	8.8	12.00
34.3832	-97.2907	Circ 91 Murray County Unname 9	sw	9/8/1978	110	13	6.4	6.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 1	sw	9/10/1951	31	32		3.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 10	sw	2/4/1953	61	40	2.5	3.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 11	sw	3/10/1953	55	39	2.7	3.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 12	sw	4/14/1953	51	40	2.7	3.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 13	sw	6/2/1953	53	38	2.7	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 14	sw	6/23/1953	53	38	3	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 15	sw	8/19/1953	34	36	2.8	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 16	sw	9/30/1953	31	37	2.9	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 17	sw	11/17/1953	61	38	2.8	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 18	sw	1/12/1954	56	37	3	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 19	sw	2/25/1954	47	37	2.7	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 2	sw	11/27/1951	83	29		4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 20	sw	4/20/1954	60	40	2.8	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 21	sw	5/28/1954	14	33	2	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 22	sw	7/14/1954	18	44	2.2	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 23	sw	8/24/1954	19	46	2.5	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 24	sw	9/18/1954	47	47	1.7	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 25	sw	11/23/1954	110	28	1.9	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 26	sw	12/21/1954	64	34	2.8	4.00

LAT	LONG	STATIONNAM	SW/GW	DATE	Ca	Mg	Na	Cl
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 27	sw	2/1/1955	66	48	2.2	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 28	sw	3/2/1955	58	28	2.3	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 29	sw	8/13/1955	28	38	3.7	4.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 3	sw	1/16/1952	79	25	3.3	5.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 30	sw	7/27/1955	59	37	3.1	5.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 31	sw	9/21/1955	36	50	3.1	5.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 32	sw	11/12/1957	72	37	3.9	5.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 33	sw	1/17/1958	17	38	1.9	5.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 34	sw	3/19/1958	14	53	1.5	5.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 35	sw	6/11/1958	25	42	3.6	5.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 36	sw	11/5/1958	14	36	5	5.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 37	sw	1/8/1959	14	17	2.6	5.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 4	sw	3/5/1952	93	18	2.8	5.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 5	sw	4/23/1952	65	23	2.7	6.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 6	sw	6/11/1952	59	45	3.7	8.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 7	sw	9/3/1952	38	45	3	8.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 8	sw	10/9/1952	48	42	2.8	9.00
34.3541	-96.7144	Circ 91 Pennington Creek nr Reagan, OK 9	sw		82	42	3.9	24.00
34.5149	-96.8374	Circ 91 Pontotoc County Unname 1	gw	9/23/1956	72	41	3.6	11.00
34.5728	-96.6447	Circ 91 Pontotoc County Unname 10	gw	11/18/1977	75	38	2	3.00
34.5583	-96.7148	Circ 91 Pontotoc County Unname 11	gw	11/17/1977	71	40	12	6.00
34.5438	-96.6097	Circ 91 Pontotoc County Unname 12	gw	11/15/1977	85	40	31	62.00
34.5149	-96.6097	Circ 91 Pontotoc County Unname 13	gw	11/17/1977	130	38	196	85.00
34.6453	-96.8374	Circ 91 Pontotoc County Unname 14	gw	9/23/1956	72	32	15	4.00
34.6308	-96.8549	Circ 91 Pontotoc County Unname 15	gw	11/16/1977	88	29	69	93.00
34.6308	-96.7849	Circ 91 Pontotoc County Unname 16	gw	11/16/1977	97	54	12	23.00
34.6018	-96.7498	Circ 91 Pontotoc County Unname 17	gw	10/3/1956	42	37	4.1	4.00
34.6018	-96.7323	Circ 91 Pontotoc County Unname 18	gw	9/23/1956	78	34	7.2	4.00
34.6453	-96.6447	Circ 91 Pontotoc County Unname 19	gw	9/23/1956	16	11	110	5.00
34.5873	-96.7673	Circ 91 Pontotoc County Unname 2	gw	10/3/1956	93	53	5.2	30.00
34.6018	-96.6623	Circ 91 Pontotoc County Unname 20	gw	5/3/1951	81	39	4.3	6.00
34.6018	-96.6623	Circ 91 Pontotoc County Unname 21	gw	9/23/1958	61	37	4.1	6.00
34.5873	-96.7849	Circ 91 Pontotoc County Unname 3	gw	10/3/1956	72	37	5.2	4.00
34.5873	-96.8199	Circ 91 Pontotoc County Unname 4	gw	10/3/1956	88	35	2.8	5.00
34.5583	-96.8199	Circ 91 Pontotoc County Unname 5	gw	9/23/1956	79	49	8	25.00
34.5294	-96.7673	Circ 91 Pontotoc County Unname 6	gw	2/6/1959	42	47	7	2.00
34.5149	-96.8199	Circ 91 Pontotoc County Unname 7	gw	11/10/1977	70	37	8.1	20.00
34.5873	-96.6798	Circ 91 Pontotoc County Unname 8	gw	1/18/1959	75	45	4.7	3.00
34.5873	-96.6973	Circ 91 Pontotoc County Unname 9	gw	10/3/1956	88	40	3.9	6.00
34.4557	-96.6271	Circ 91 Unnamed Site 1	sw	11/14/1977	73	40	1.9	3.00
34.4992	-96.8716	Circ91 Carter County Unname 1	gw	8/31/1978	110	7.4	15	5.00
34.4992	-96.8716	Circ91 Johnston County 1	gw	11/16/1977	85	43	6.3	18.00
34.4557	-96.6096	Circ91 Johnston County 10	sw	11/15/1977	65	38	3.2	4.00
34.4557	-96.5398	Circ91 Johnston County 11	gw	11/17/1977	110	18	2.2	6.00
34.4267	-96.5572	Circ91 Johnston County 12	sw	11/15/1977	67	21	20	39.00
34.3977	-96.8541	Circ91 Johnston County 13	sw	10/20/1977	62	39	5.1	6.00
34.4122	-96.8192	Circ91 Johnston County 14	gw	10/4/1956	40	38	6.1	11.00
34.3977	-96.8017	Circ91 Johnston County 15	gw	12/5/1977	78	38	4.2	4.00
34.3977	-96.7668	Circ91 Johnston County 16	gw	11/18/1977	96	16	1.4	2.00
34.3832	-96.7144	Circ91 Johnston County 17	gw	10/2/1977	76	40	2.3	3.00
34.3686	-96.7144	Circ91 Johnston County 18	sw	10/21/1977	63	36	2.5	3.00
34.3977	-96.6096	Circ91 Johnston County 19	gw	11/4/1977	73	41	3.6	0.00
34.4412	-96.8716	Circ91 Johnston County 2	gw	10/20/1977	80	27	4.4	5.00
34.3251	-96.9065	Circ91 Johnston County 21	gw	10/18/1977	110	12	2	3.00
34.2961	-96.9065	Circ91 Johnston County 22	sw	10/17/1977	57	17	5.2	6.00
34.2671	-96.8192	Circ91 Johnston County 23	gw	10/20/1977	100	11	3	3.00
34.4412	-96.7668	Circ91 Johnston County 3	gw	11/18/1977	74	40	2.8	7.00
34.4267	-96.7668	Circ91 Johnston County 4	gw	11/3/1977	72	39	2.5	4.00
34.4992	-96.6271	Circ91 Johnston County 5	gw	11/17/1977	85	46	15	22.00
34.4557	-96.6795	Circ91 Johnston County 6	gw	11/4/1977	74	41	1.9	2.00

LAT	LONG	STATIONNAM	SW/GW	DATE	Ca	Mg	Na	Cl
34.4557	-96.6271	Circ91 Johnston County 7	gw	11/15/1977	77	38	2.7	4.00
34.4412	-96.6271	Circ91 Johnston County 8	gw	11/17/1977	68	41	7.9	7.00
34.3241	-96.6271	COLBERT CREEK 2.5 MI. NORTHWEST OF CAMP CLASSEN	sw	9/7/1978	64.00	21.00	7	9.50
34.4727	-96.8695	COLVERT SPRING 500 FEET NORTH OF MILL CREEK	gw	10/20/1977	80.00	27.00	4.4	5.40
34.4367	-96.6278	CUMMINGS SPRING NEXT THE BLUE RIVER	gw	11/15/1977	77.00	38.00	2.7	3.70
34.4525	-96.8137	DAUBE SPRING NEXT TO MILL CREEK	gw	10/20/1977	100.00	11.00	3	3.10
34.2611	-96.5495	DELAWARE CREEK 1.9 MI EAST OF PILGRIM CEMETERY	sw	11/15/1977	67.00	21.00	20	39.00
34.4059	-96.4277	DELAWARE CREEK 2 MILES NORTH OF WAPANUCKA	sw	1/26/1960	26.00	20.00	24	48.00
34.4059	-96.4277	DELAWARE CREEK 2 MILES NORTH OF WAPANUCKA	sw	3/23/1960	46.00	23.00	25	50.00
34.4059	-96.4277	DELAWARE CREEK 2 MILES NORTH OF WAPANUCKA	sw	4/7/1958	30.00	26.00	30	46.00
34.4059	-96.4277	DELAWARE CREEK 2 MILES NORTH OF WAPANUCKA	sw	5/3/1960	69.00	26.00	31	70.00
34.4279	-96.4277	DELAWARE CREEK 2 MILES NORTH OF WAPANUCKA	sw	2/24/1958	26.00	28.00	34	41.00
34.4059	-96.6130	DIAMOND SPRING NEXT TO DIAMOND SPRING CREEK	gw	11/4/1977	73.00	41.00	3.6	6.30
34.4039	-97.3428	EIGHTMILE CREEK 1 MI SOUTH OF HENNEPIN CEMETERY	sw	9/8/1978	70.00	8.00	16	20.00
34.4779	-97.2825	HICKORY CREEK 0.5 MILES NORTH OF MOUNTAIN LAKE	sw	9/8/1978	110.00	13.00	6.4	5.60
34.3807	-96.9711	Hillside Spring	gw	10/21/1993	111.00	49.20	333	74.20
34.5020	-96.6134	LITTLE BLUE CREEK .5 MI. SOUTH OF SEELY CEMETERY	sw	11/15/1977	66.00	38.00	3.2	3.60
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	11/23/1954	90.00	38.00	3.8	7.00
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	3/10/1953	45.00	39.00	4.1	6.50
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	7/27/1955	59.00	43.00	4.3	8.80
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	12/21/1954	74.00	38.00	4.4	7.00
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	10/9/1952	64.00	42.00	4.6	5.80
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	2/1/1955	66.00	43.00	4.6	7.20
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	3/1/1955	62.00	31.00	4.6	7.20
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	11/18/1952	67.00	42.00	4.7	6.00
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	12/23/1952	64.00	39.00	4.8	6.00
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	2/4/1953	63.00	41.00	4.8	6.20
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	4/14/1953	63.00	38.00	4.8	6.50
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	6/13/1955	34.00	33.00	4.8	8.00
34.4494	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	9/3/1952	42.00	46.00	5	5.50
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	6/2/1953	57.00	40.00	5	6.50
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	6/23/1953	33.00	37.00	5	6.80
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	10/20/1977	62.00	39.00	5.1	9.50
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	8/19/1953	40.00	37.00	5.4	7.00
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	9/30/1953	33.00	38.00	5.4	7.00
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	1/27/1960	51.00	33.00	5.5	9.00
34.4038	-96.8621	MILL CREEK 2 MI. DUE WEST OF TOWN OF MILL CREEK	sw	9/21/1955	49.00	46.00	5.7	9.00
34.4038	-96.9123	OIL CREEK 1/4 MI UPSTREAM OF 1000 ACRE RESERVOIR	sw	10/17/1977	57.00	17.00	5.2	10.00
34.2974	-96.9701	Pavilion Spring - Outlet A	gw	10/21/1993	68.40	31.00	78.6	5.90
34.5027	-96.9701	Pavilion Spring - Outlet B	gw	10/21/1993	72.60	31.00	82.3	92.60
34.5027	-96.9701	Pavilion Spring - Outlet C	gw	10/21/1993	68.30	30.90	82.6	92.00
34.5027	-96.9701	Pavilion Spring - Outlet D	gw	10/21/1993	69.00	31.40	73.6	86.80
34.5027	-96.9701	Pavilion Spring - Outlet E	gw	10/21/1993	110.00	44.70	305	91.70
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	3/19/1958	14.00	53.00	1.5	5.00
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	9/16/1954	47.00	47.00	1.7	4.50
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	11/23/1954	110.00	26.00	1.9	4.50
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	1/17/1958	17.00	38.00	1.9	5.00
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	5/28/1954	14.00	38.00	2	4.00
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	7/14/1954	18.00	44.00	2.2	4.20
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	2/1/1955	65.00	48.00	2.2	4.50
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	3/2/1955	58.00	26.00	2.3	4.50
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	8/24/1954	19.00	46.00	2.5	4.20
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	2/4/1953	61.00	40.00	2.6	3.50
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	8/19/1953	34.00	36.00	2.6	3.90
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	11/17/1953	61.00	38.00	2.6	4.00
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	4/20/1954	60.00	40.00	2.6	4.00
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	1/8/1959	14.00	17.00	2.6	6.00
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	4/23/1952	55.00	23.00	2.7	2.80
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	3/10/1953	55.00	39.00	2.7	3.80
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	4/14/1953	51.00	40.00	2.7	3.80

| LAT	LONG	STATIONNAM	SW/GW	DATE	Ca	Mg	Na	Cl
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	6/2/1953	53.00	38.00	2.7	3.80
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	2/25/1954	48.00	37.00	2.7	4.00
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	3/5/1952	93.00	18.00	2.8	2.50
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	10/9/1952	46.00	42.00	2.8	3.00
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	12/21/1954	64.00	34.00	2.8	4.50
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	9/30/1953	31.00	37.00	2.9	4.00
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	9/3/1952	36.00	45.00	3	3.00
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	6/23/1953	53.00	38.00	3	3.80
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	1/12/1954	56.00	37.00	3	4.00
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	7/27/1955	59.00	37.00	3.1	4.80
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	9/21/1955	36.00	50.00	3.1	4.80
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	1/16/1952	79.00	25.00	3.3	91.40
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	6/11/1958	25.00	42.00	3.6	5.00
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	6/11/1952	59.00	45.00	3.7	3.00
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	6/13/1955	26.00	38.00	3.7	4.80
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	11/18/1952	62.00	42.00	3.9	3.50
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	11/12/1957	72.00	37.00	3.9	4.80
34.3534	-96.7101	PENNINGTON CREEK ON EAST EDGE OF REAGAN	sw	11/6/1958	14.00	36.00	5	5.00
34.4952	-96.9774	Red Flag Spring	gw	10/21/1993	77.10	36.30	3	734.00
34.4945	-96.9740	Sulphur Bromide Spring	gw	10/21/1993	113.00	50.10	390	603.00
34.4949	-96.9753	Taff's Spring	gw	10/21/1993	24.80	20.00	1228	654.00
34.4590	-96.6732	TISDELL SPRING NEXT THE BLUE RIVER	gw	11/4/1977	74.00	41.00	1.9	2.30
34.4202	-96.7601	UNNAMED SPRING 4 MILES EAST OF MILL CREEK TOWN	gw	11/3/1977	72.00	39.00	2.5	3.50
34.4969	-96.9840	Unnamed Spring in Bed of Rock Cr	gw	10/21/1993	69.20	31.10	77.5	1800.00
34.3822	-96.7155	UNNAMED SPRING NEXT TO SPRING CREEK	gw	10/20/1977	76.00	40.00	2.3	3.20
34.5728	-96.7148	USGS 00500053	gw	10/19/2004	67.60	35.20	1.18	1.86
34.5294	-96.6097	USGS 00500054	gw	10/19/2004	108.00	19.30	3.38	2.71
34.4557	-97.2034	USGS 00500055	gw	10/20/2004	96.50	24.80	1.63	1.72
34.4992	-96.9414	USGS 00500056	gw	10/20/2004	79.10	35.40	3.37	3.35
34.4992	-96.9764	USGS 00500057	gw	10/20/2004	86.60	37.40	316	558.00
34.4557	-96.9414	USGS 00500058	gw	10/20/2004	85.80	47.60	11	15.00
34.4993	-96.8716	USGS 00500059	gw	10/18/2004	95.80	49.60	20.4	28.30
34.4992	-96.9065	USGS 00500060	gw	10/18/2004	100.00	30.00	8.33	4.10
34.4847	-96.8891	USGS 00500061	gw	10/20/2004	133.00	16.10	13.2	17.20
34.4412	-96.7668	USGS 00500062	gw	10/22/2004	80.80	39.60	4.93	8.37
34.4412	-96.6446	USGS 00500063	gw	10/21/2004	104.00	55.10	8.66	9.82
34.4557	-96.5398	USGS 00500064	gw	10/21/2004	84.80	38.70	141	279.00
34.6453	-96.8024	USGS 00500065	gw	10/18/2004	76.90	35.40	5.81	13.40
34.4122	-97.1685	USGS 00500066	gw	10/21/2004	134.00	5.00	1.81	1.61
34.3686	-97.1859	USGS 00500067	gw	10/21/2004	115.00	8.10	12	2.79
34.3832	-97.1336	USGS 00500068	gw	10/21/2004	121.00	7.00	3.06	3.32
34.3977	-96.9764	USGS 00500069	gw	10/19/2004	77.50	3.10	3.15	2.94
34.3977	-96.8891	USGS 00500070	gw	10/19/2004	79.70	33.10	3.88	5.65
34.3541	-96.8891	USGS 00500071	gw	10/19/2004	704.00	33.20	4.09	6.26
34.3977	-96.8017	USGS 00500072	gw	10/20/2004	79.90	34.50	3.82	3.27
34.3977	-96.6446	USGS 00500073	gw	10/19/2004	74.80	39.10	3.62	6.69
34.3251	-96.8891	USGS 00500074	gw	10/22/2004	100.00	23.00	1.73	1.42
34.3832	-96.5922	USGS 00500075	gw	10/21/2004	78.10	38.40	1.61	1.82
34.4122	-96.5922	USGS 00500166	gw	11/4/2004	71.10	31.40	7.32	5.18
34.6018	-96.6973	USGS 00500167	gw	11/5/2004	118.00	77.50	7.97	10.80
34.3832	-96.7144	USGS 00500169	gw	11/4/2004	76.70	42.30	2.15	2.43
34.4557	-96.6620	USGS 00500171	gw	11/3/2004	73.20	38.90	2.17	2.27
34.4122	-97.2907	USGS 00500172	gw	11/5/2004	121.00	7.30	1.5	1.22
34.5438	-96.7673	USGS 00500173	gw	11/3/2004	63.20	26.30	1.97	2.28
34.5027	-96.9393	USGS 07329847	gw	7/2/1987	50.00	30.00	44	8.00
34.5046	-96.9411	USGS 07329849	gw	7/2/1987	50.00	30.00	44	10.00
34.4589	-96.9414	USGS 07329880	gw	12/20/1954	77.00	34.00	8.1	13.00
34.4589	-96.9414	USGS 07329880	gw	3/5/1952	104.00	22.00	10	12.00
34.4589	-96.9414	USGS 07329880	gw	12/28/1955	33.00	39.00	13	13.00
34.5058	-96.9730	Vendome Well	gw	10/21/1993	86.10	39.30	323	572.00

APPENDIX C

Maps
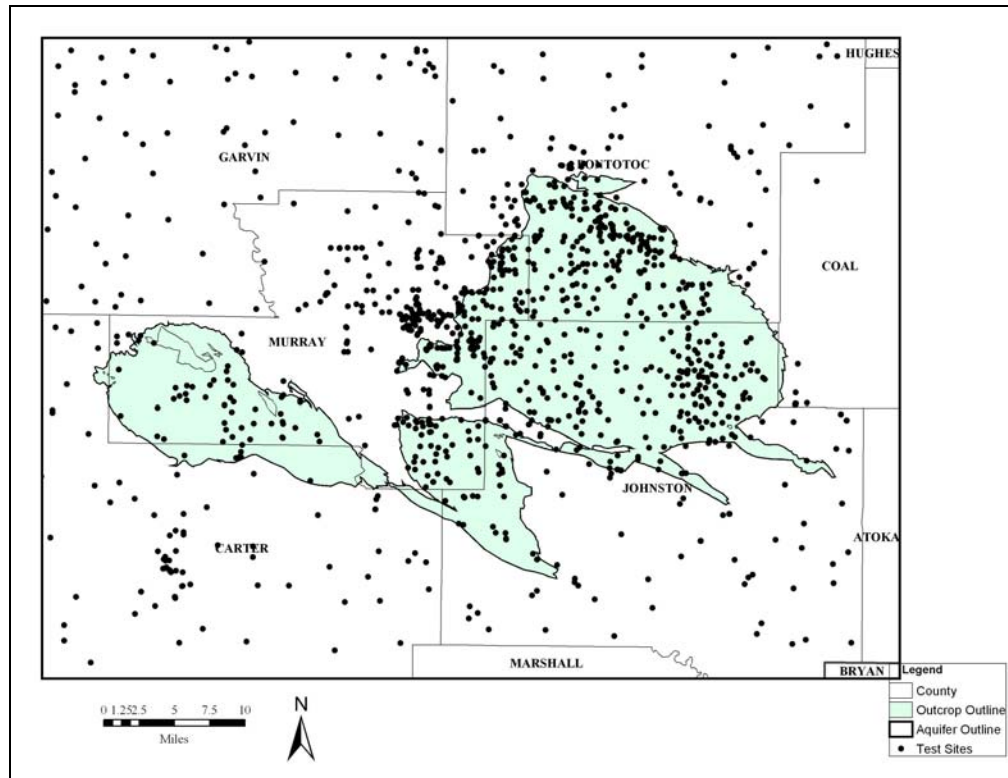
**Figure 25: Locations for All Historical Data**
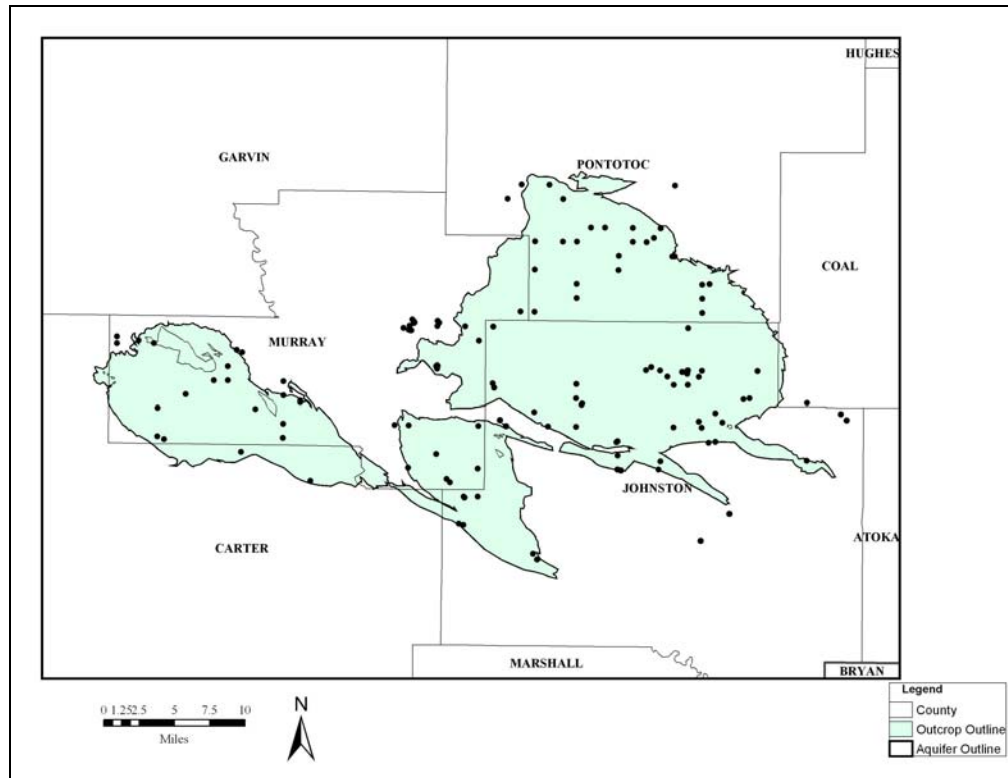
Figure 26: Locations of Samples that Contained Calcium and Magnesium Values along with Coordinates

APPENDIX D

Glossary

Aquifer – a consolidated or unconsolidated geologic unit (material, stratum, or

    formation) or set of connected units that yields a significant (economic)

    quantity of water of suitable quality to wells or springs in economically

    usable amounts.

Aquifer system – intercalated permeable and poorly permeable materials that

    comprise two or more permeable units separated by aquitards that impede

    vertical ground water movement but do not affect the regional hydraulic

    continuity of the system.

Aquitard – a geologic material, stratum, or formation that neither contains nor

    transmits water (i.e., has zero or negligible permeability and porosity).

Brine – water with a salinity $>10^4$ mg/L. Hem's (1985) classification, a brine has

    a salinity of >35,000 mg/L.

Carbonate – karst developed in limestone or dolomitic rock

Discharge – (1) the volumetric flow rate of a stream, spring, or groundwater

    system; or (2) the water leaving a groundwater system by flow to surface

    water, the land surface, or the atmosphere.

Fault – a fracture which has experienced translation or movement of the fracture walls parallel to the plane of the fracture.

Fracture – a subplanar discontinuity in a rock or soil formed by mechanical stresses. A fracture is visible to the naked eye and is open (i.e., not filled with minerals.

Fresh water – water with a salinity of <1,000 mg/l; drinkable or potable water is implied.

Groundwater – (1) generally all water beneath the land surface; (2) sometimes, it is more narrowly defined as phreatic water or water beneath the water table.

Hydrochemical facies – how the groundwater chemistry changes over space. Typically, the facies reflect the major ionic constituents.

Karst – a geologic terrain or surface landscape with distinctive characteristics o relief and drainage arising primarily from dissolution or rock (or soils) by natural waters. Karstic terrains are underlain by rocks that have undergone significant dissolution by groundwater flow and are characterized by: (1) closed depressions of various size and arrangement,

(2) disrupted surface drainage, and (3) caves and underground drainage systems.

Outcrop – where a formation is present at the Earth's surface.

Parameter – (1) a defined physical quantity with a numerical value or a value within a certain range; (2) a characteristic of a population (e.g. the mean); (3) an algebraic symbol representative of a well-defined physical quantity with a numerical value.

Permeability – the ease with which a porous medium can transmit water or other fluids.

pH – a measure of the acidity of a solution, based upon the negative logarithm of the hydrogen ion concentration.

Recharge – the process by which water enters the groundwater system or, more precisely, enters the phreatic zone.

Reservoir – (1) an impoundment of surface water behind a dam or manmade depression; (2) a porous and permeable subsurface formation or part of a formation containing a natural, individual, and separate accumulation of hydrocarbons (oil or gas).

Water table – a surface at or near the top of the phreatic zone (zone of

saturation) where the fluid pressure is equal to atmospheric pressure. In

the field, the water table is defined by the level of water in wells that barely

penetrate the phreatic (saturated) zone.

Glossary adapted from Sharp, J. M., Jr., (2003). A Glossary of Hydrogeological

Terms: Department of Geological Sciences, The University of Texas, Austin,

Texas, 52 p.

VITA

Shayne Renee Cole

Candidate for the Degree of

Master of Science

Thesis: EVALUATION OF THE GEOCHEMISTRY IN THE ARBUCKLE-SIMPSON AQUIFER: FINDING FLOW PATHS

Major Field: Environmental Science

Biographical:

Personal Data: Born in Little Rock, Arkansas on December 15, 1971, the daughter of Donald R. and Diane L. Cole

Education: Graduated from Wilbur D. Mills High School, Little Rock, Arkansas in June 1990; received Bachelor of Art degree in Chemistry with a minor in Biology from the University of Arkansas at Little Rock in December 1998. Completed the requirements for the Master of Science degree with a major in Environmental Science at Oklahoma State University in December 2006.

Experience: Employed by Oklahoma State University, Stillwater, OK from November 2004 to September 2006 as a graduate research assistant in the Department of Geology and from August 2002 to May 2003 as a graduate teaching assistant in the Department of Chemistry. Employed by Accurate Labs and Training, Stillwater, OK from April 2002 to November 2004 as a laboratory technician. Employed by Little Rock Wastewater Utility, Little Rock, AR from January 2001 to October 2001 as a laboratory technician II. Employed by American Red Cross, Little Rock, AR from January 2000 to August 2000 as a technical assistant. Employed by University of Arkansas at Little Rock from January 1996 to December 1998 as a research assistant and a quantitative analysis lab assistant.

Name: Shayne Renee Cole

Date of Degree: December, 2006

Institution: Oklahoma State University

Location: Stillwater, Oklahoma

Title of Study: EVALUATION OF THE GEOCHEMISTRY IN THE ARBUCKLE-SIMPSON AQUIFER: FINDING FLOW PATHS

Pages in Study: 76

Candidate for the Degree of Master of Science

Major Field: Environmental Science

Scope and Method of Study:

The purpose of this study was to evaluate the historical water chemistry data in the Arbuckle-Simpson aquifer to better understand the flows paths. Historical water chemistry data was gathered from several agencies and publications ranging from 1905 to 2006. Calcium/magnesium ratios were analyzed to determine possible areas of discharge. Other ions were investigated to find out if there were other influences on the calcium and magnesium concentrations. Chloride concentrations were used as a tracer to study the affects of brine mixing with the water chemistry. Cation exchange was also examined to determine if there is any influence on the water chemistry.

Findings and Conclusions:

Historical water chemistry analyses were found not to contain complete information. Out of the 2,927 samples only 74 contained complete analyses. 359 samples were used to evaluate the water chemistry. Using chloride as a conservative tracer, brine mixing from petroleum reservoirs would account for less than 0.1% of the water composition for 97 percent of the 359 analyses. Equilibrium between ground water and calcite can explain the calcium magnesium ratio for large areas of the Arbuckle and Tishimingo anticlines. This indicates unusual geochemistry in the area that should be studied in greater depth. Cation exchange cannot be excluded as a potential mechanism for altering the water chemistry of the waters of the Arbuckle-Simpson aquifer. However, it does not appear to be a dominant mechanism for the majority of the waters.

ADVISER'S APPROVAL: Dr. Deeann Sanders