A QUANTITATIVE ANALYSIS OF SELECTED PARAMETERS OF GROUND-WATER QUALITY IN OKLAHOMA

By

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A QUANTITATIVE ANALYSIS OF SELECTED PARAMETERS OF GROUND-WATER QUALITY IN OKLAHOMA

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CHAPTER I

INTRODUCTION

General Overview

The function of ground water in meeting our nation's water demand is an important issue. As of 1985, 53 percent of the nation's population used ground water as a source of drinking water (United States Geological Survey, 1985, p.3).

One of the primary limiting factors of ground-water use is quality. Ground water was once thought to be not-subject to contamination by man's activities. In recent years this assumption has been reversed by the recognition of many instances in which ground water has been polluted directly by man's actions. In addition to this influence, physical, chemical and biological processes that occur naturally can affect ground-water quality.

The perception of ground water as a valuable resource is increasing among scientists, legislators and the public. This perception is made evident by more numerous local, federal and state laws, as well as by court cases and attention from the media and support groups. As growing populations and economic development elevate the demand for water, maintenance of ground-water quality will be increasingly more important.

Purpose

The purpose of this study is to summarize ground-water quality in the State of Oklahoma and to determine where quality is significantly different among aquifers. Quality of ground water is evaluated herein by reference to these variables: total dissolved solids, conductivity, hardness, calcium, magnesium, sodium, potassium, chloride, sulfate, bicarbonate, fluoride, silica and nitrate. Descriptive statistics of each constituent in each aquifer are recorded. These statistics are neither site- nor time-specific; they give general information on quality of water within aquifers. In addition to descriptive statistics, aquifers are compared to other aquifers by the selected constituents or attributes.

Previous Investigations

An atlas of ground-water quality in the United States shows general maps of chemical quality of drinking water from aquifers used by municipalities of less than 10,000 people (Pettyjohn and others, 1979). Data came largely from records of domestic wells and municipal water wells. Chemical constituents included sodium, potassium, calcium, magnesium, chloride, sulfate, hardness, and dissolved solids. By patterns, the maps show ranges in hardness of water; by contour lines, maps show variation in dissolved solids (Figure 1). Maxima, minima and means of constituents are recorded for selected counties.

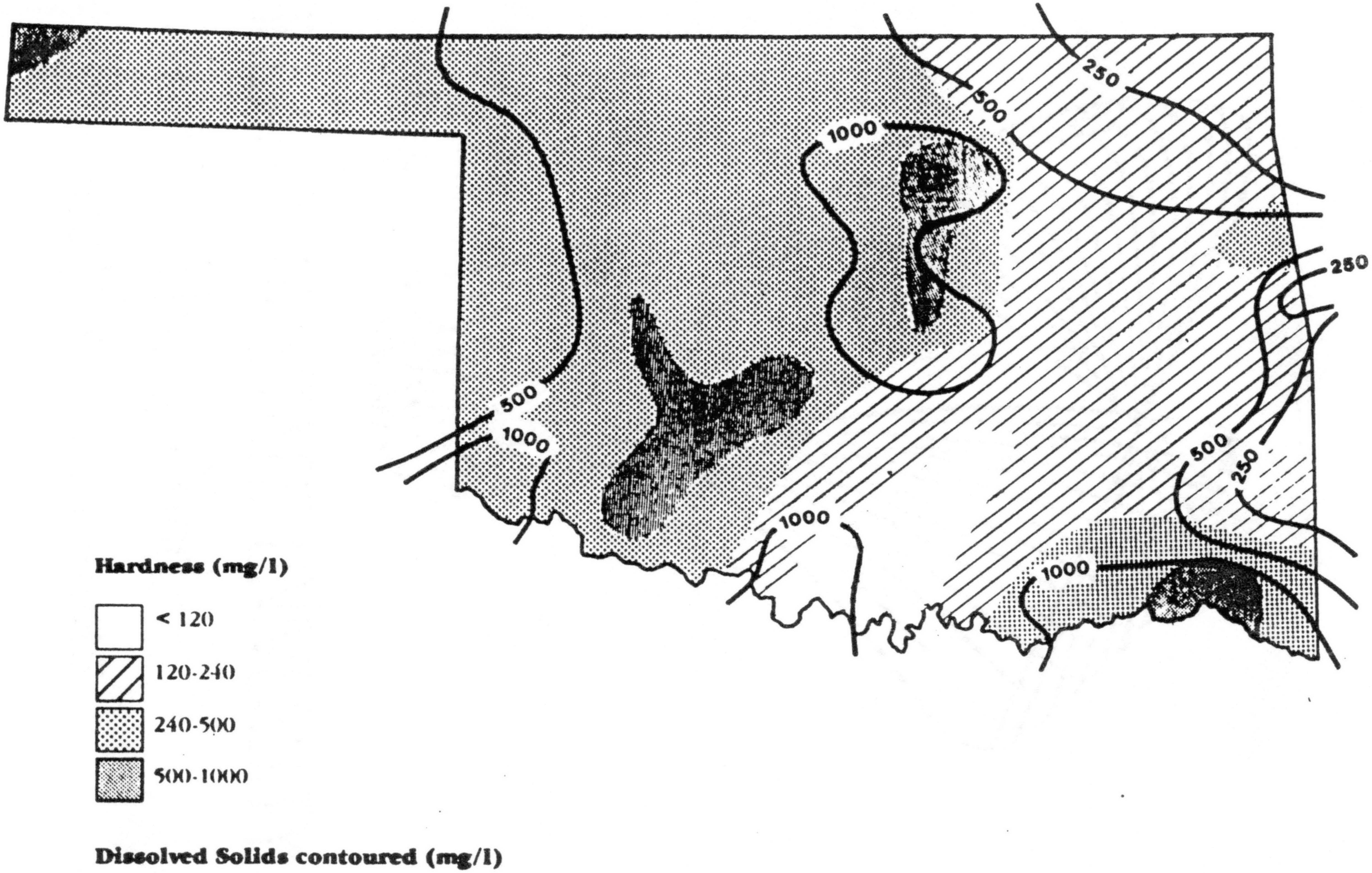


Figure 1. Ranges of Hardness of Water (Patterns) and Variation in Total Dissolved Solids (Contoured). Contour Interval 500 mg/l (After Pettyjohn and Others, 1979, p. 193).

A national summary of ground-water quality and hydrologic events describes evaluation of several chemical constituents in the principal aquifers of each state (U.S.G.S., 1988). In Oklahoma, constituents documented are dissolved solids, hardness, fluoride, chloride and sulfate. The data were summarized as stem-and-leaf plots (Figure 2). Types of water, based on the average concentrations of constituents, were given for the major aquifers (Figure 3). In addition to representing chemical characteristics of ground water, effects of land use and ground-water quality management are discussed.

A water atlas of Oklahoma was intended to provide a single source of information to aid in better understanding, management and investigation of water (Pettyjohn and others, 1983). Included are maps and short discussions of physical features, climatic conditions, surface water, ground water, water quality, water use, oil and gas resources, and mineral resources. Maxima, minima and medians of hardness, dissolved solids, sulfate and chloride are shown for the major aquifers.

A statistical summary of ground-water quality in Oklahoma for the period 1986-1988 shows descriptive statistics for major aquifers, for various inorganic substances (Fabian and Myers, 1990). The statistics are mean, median, standard deviation, and 96-percent confidence intervals. Data from the 1986-1988 period are compared to data collected from 1983-1985, to test the proposition that

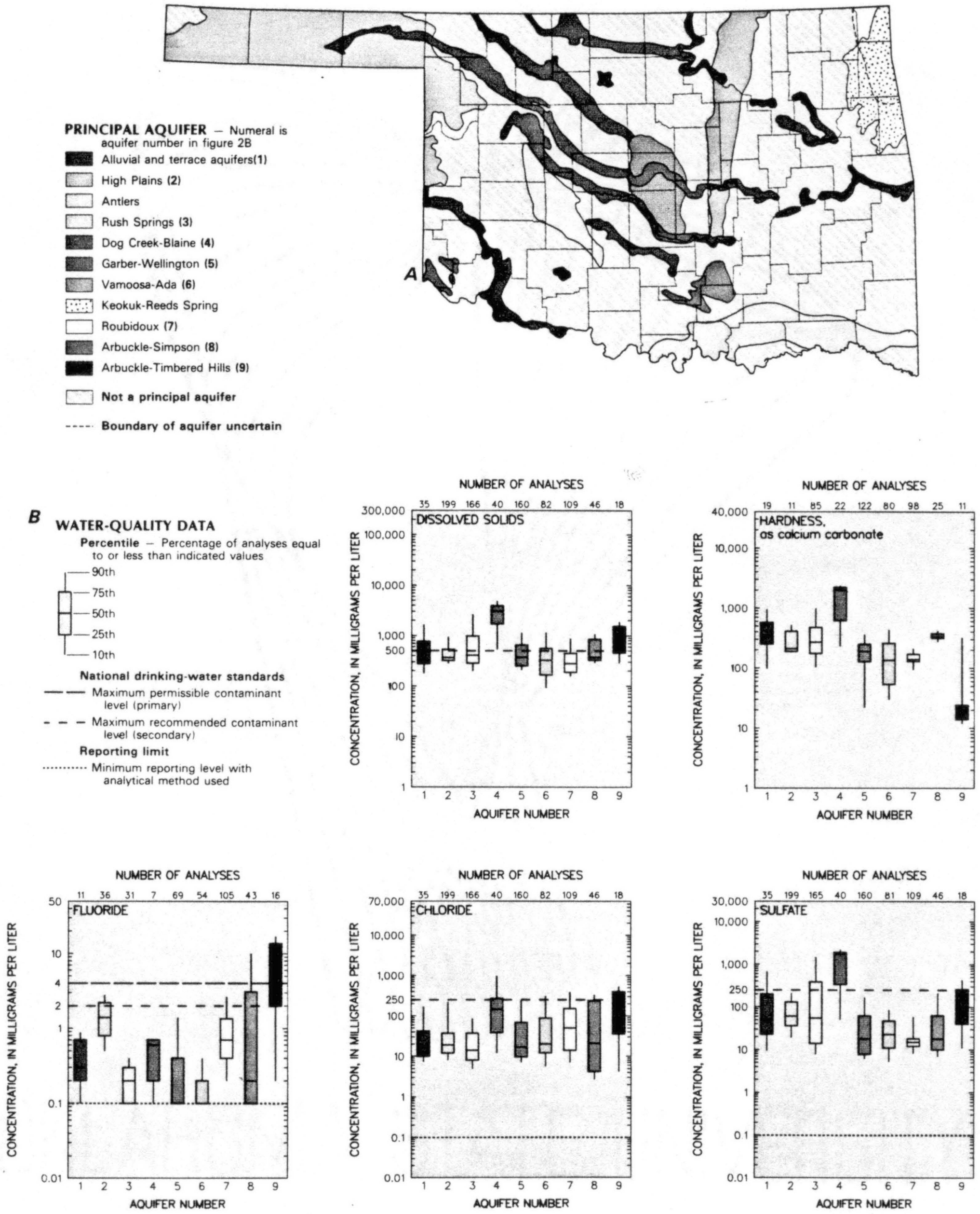


Figure 2. Aquifers and Selected Percentile Statistics of Constituents in Oklahoma (After U.S.G.S., 1988, p. 416).

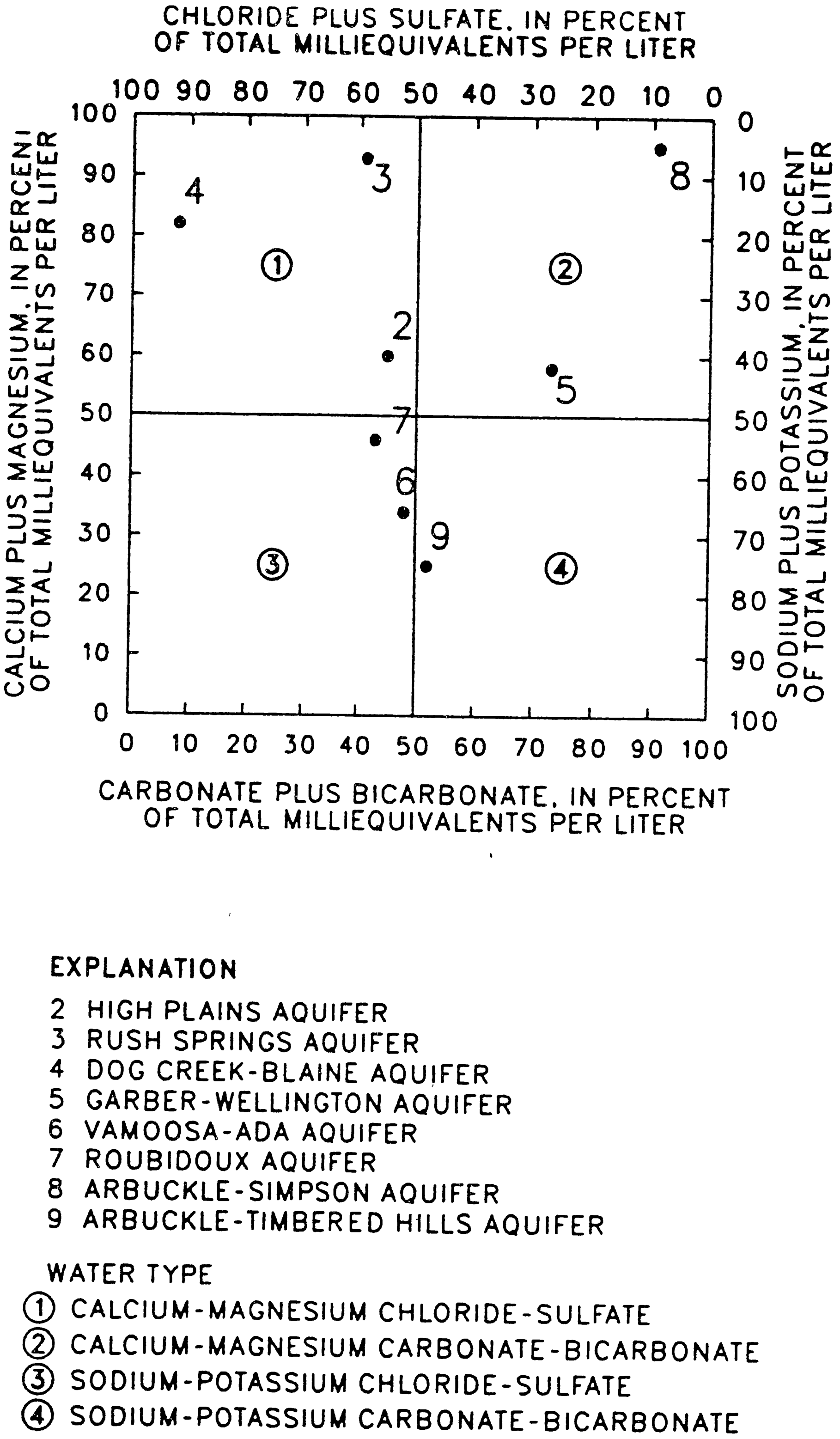


Figure 3. Classification of Water in Principal Aquifers of Oklahoma, According to Major Dissolved Solids (After U.S.G.S., 1988, p. 419).

water quality was not significantly different from one period to the next.

A comprehensive water plan was designed to accomplish the water-related goals of Oklahoma; it includes strategies for the control, protection, conservation, development and utilization of water resources (Oklahoma Water Resources Board (O.W.R.B.), 1980). No statistical analyses of ground-water quality were made, but potential problems and general relationships were addressed.

Quality of ground water in Oregon was analyzed statistically by Miller and Gonthier (1984). Ground-water quality conditions and hydrogeologic conditions are described by aquifer units, drainage basins and flow systems. Descriptive statistics for 19 variables are set out by aquifers and drainage basins. The aquifers and drainage basins are compared for differences by each variable. Samples from one basin are compared according to type of flow system and position within the flow system.

CHAPTER II

DESCRIPTION OF THE STUDY AREA

Location and Geology

Oklahoma's climate ranges from semiarid in the west to humid in the east; rainfall ranges from less than 16 inches in the northwest to more than 54 inches in the southeast (O.W.R.B., 1984, p. 49) (Figure 4).

Most rocks that crop out or underlie the soil are sedimentary. Generally they dip westward at low angles. The oldest rocks exposed are igneous and metamorphic; they are in the central parts of the Wichita and Arbuckle Mountains.

Ground-Water Regions

In Oklahoma, ground water is available almost everywhere and accounts for about 61 percent of the total water used (O.W.R.B., 1984, p. 62). The major water-bearing strata are sand, gravel, limestone, dolomite, sandstone and gypsum. Aquifers range in age from Cambrian to Quaternary (O.W.R.B., 1984, p. 62). Figure 5 shows major aquifers in Oklahoma; numerous minor basins, not shown, also yield significant amounts of ground water.

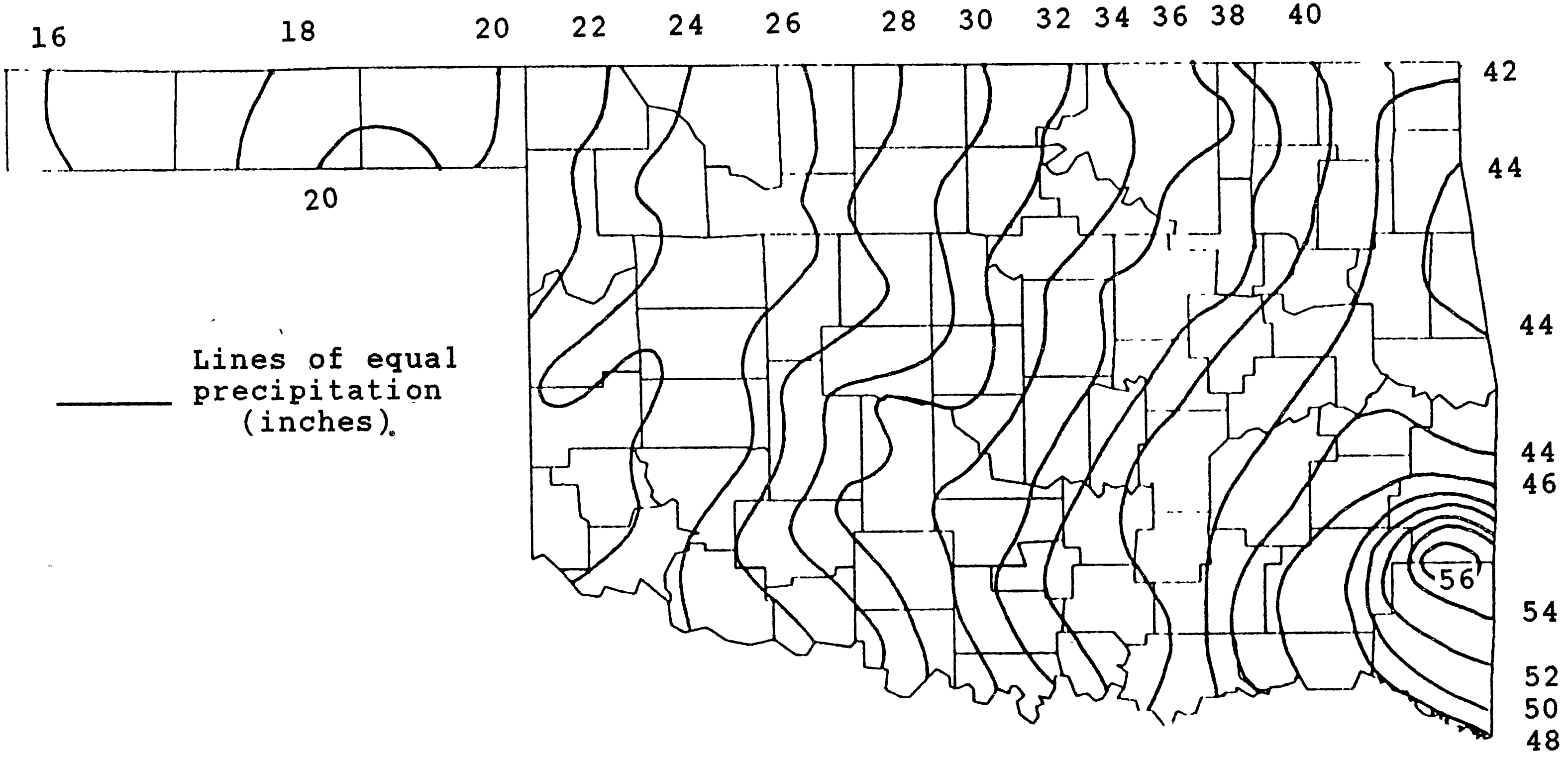


Figure 4. Ranges of Precipitation in Oklahoma (Modified from O.W.R.B., 1980, p. 48).

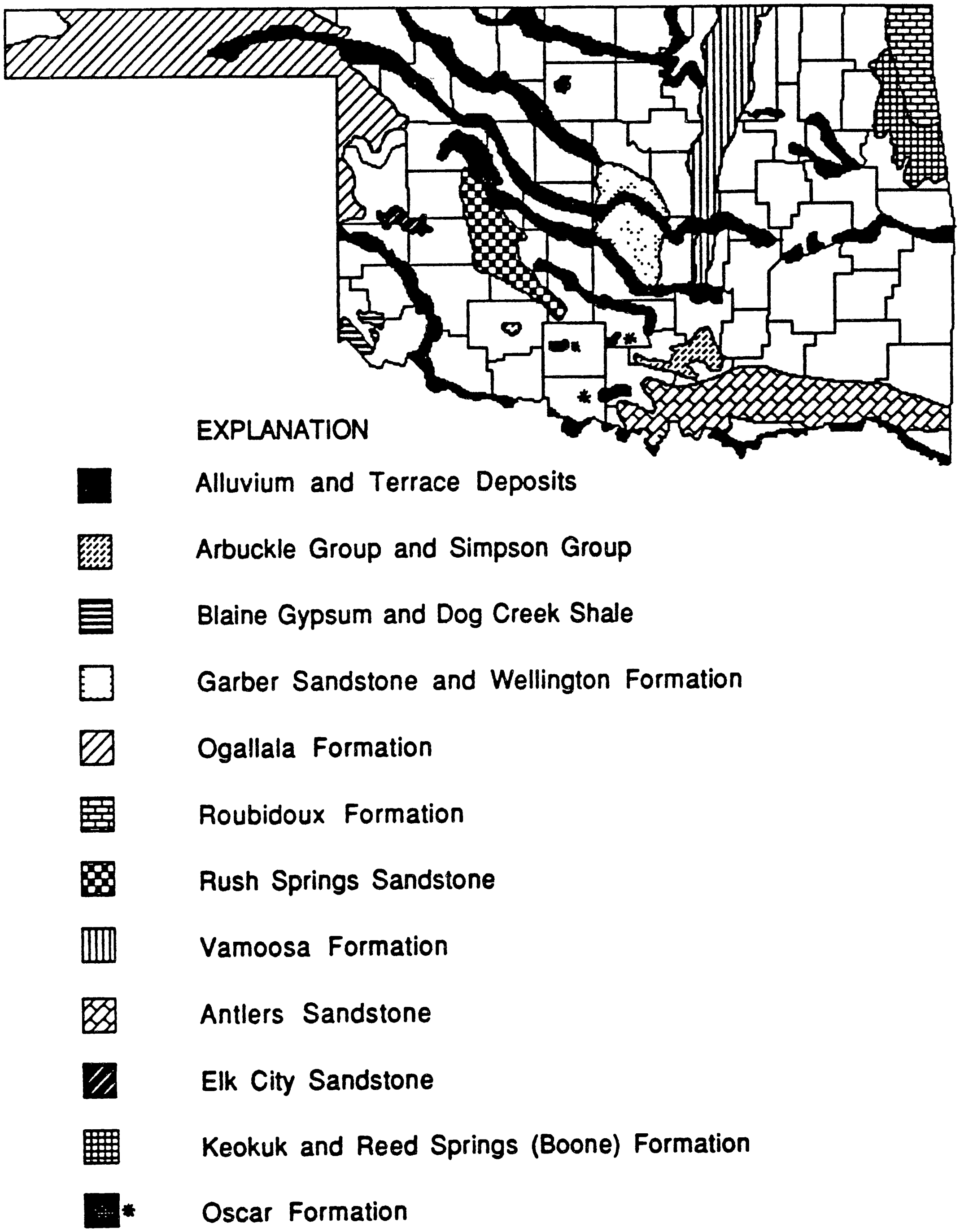


Figure 5. Major Aquifers in Oklahoma (Modified from O.W.R.B., 1980, p. 62a).

CHAPTER III

GROUND-WATER QUALITY

Natural Factors

Quality of water generally is defined by concentrations of its chemical constituents. Quality is altered as water moves through the hydrologic cycle and interacts with the atmosphere, soil and rocks.

Ground-water quality is influenced by many natural factors: the quality and quantity of precipitation, soils, rocks, length of flowpath and time of water in the flowpath, quantities and types of gasses, pH, and climate. These and other factors were described in detail by Freeze and Cherry (1979) and Hem (1989).

Artificial Factors

Man's activities can influence the quality of ground water significantly. These activities include, but are not limited to, waste disposal, mining, oil and gas production, agricultural practices, storage, transportation and handling of commercial materials, and underground injection of liquid waste.

Drinking-water Standards

In an attempt to protect humans from health-risk associated with consumption of contaminated waters, the Environmental Protection Agency (E.P.A.) established drinking-water standards through the Safe Drinking Water Act. Primary maximum contaminant levels (MCL's) were defined for substances which are known to be a health-risk. Components that affect the aesthetic quality of water were given secondary maximum contaminant levels (SMCL's). Table 1 shows limits for elements, compounds and properties considered in this investigation.

Chemical Constituents

Calcium

Calcium is distributed widely in the minerals of rocks and soils. Among the many sources of calcium are: feldspars (anorthite, $CaAl_2Si_2O_8$), fluoropatite ($Ca_5(PO_4)_3F$), dolomite ($CaMg(CO_3)_2$), gypsum ($CaSO_4 \cdot 2H_2O$), anhydrite ($CaSO_4$), and calcite ($CaCO_3$), a common cementing agent between particles of sandstone and other detrital rocks (Aly and Faust, 1981, p. 3).

Artificial sources of calcium are road salts, precipitates from evaporation of irrigation water, leachates from municipal solid waste and industrial wastewater (Chester and Novotny, 1981, p. 22). One of the main adverse effects of calcium is the buildup of scale in pipes

TABLE 1

E.P.A. DRINKING WATER STANDARDS FOR SELECTED ELEMENTS, COMPOUNDS AND PROPERTIES

	Standard	
Constituent	Primary Maximum Contaminant Level (MCL)	Secondary Maximum Contaminant Level (SMCL)
Calcium	-	-
Magnesium	-	-
Sodium	-	-
Potassium	-	-
Sulfate	-	250 mg/l
Chloride	-	250 mg/l
Bicarbonate	-	-
Fluoride	4 mg/l	2 mg/l
Nitrate (as nitrogen)	10 mg/l	-
Nitrate (as nitrate)	45 mg/l	-
Silica	-	-
Dissolved solids	-	500 mg/l
Conductivity	-	-
Hardness	-	-

(Modified from Code of Federal Regulations, 1991, Title 40, Part 141, Section 62, p. 673, and Part 143 Section 3, p. 759.)

and boilers (Aly and Faust, 1981, p. 3). No limits have been set for calcium in drinking water.

Magnesium

Magnesium is in many rocks. A few principal sources are: dolomite (CaMg(CO3)2), serpentine (Mg6(OH)8Si4O10), magnesite (MgCO3), huntite (Mg3Ca(CO3)4), brucite (Mg(OH)2)), forsterite (MgSiO4), magnesioferrite (MgFe2O4), and cordierite (Mg2Al3(AlSi5O18)) (Aly and Faust, 1981, p. 4). A major artificial source of magnesium is leachates from municipal solid waste (Chester and Novotny, 1981, p. 22). Magnesium, like calcium, also forms scales in pipes and boilers (Aly and Faust, 1981, p. 4). No drinking-water limits have been set for magnesium.

Sodium

Mineralogic sources of sodium are in evaporites such as halite (NaCl) and thenardite (Na2SO4) (Aly and Faust, 1981, p. 7). Sources from weathered igneous rocks include orthoclase and microcline (KAlSi3O8), albite (NaAlSi3O8) and anorthite (CaAl2Si2O8) (Hem, 1989, p. 100). Other natural sources of sodium are sea sprays and hot springs (Hounslow, 1991, p. 3.3). Some sources of sodium from man's activities are road salts, irrigation water, solid waste, industrial wastewaters, and oil-field brines (Chester and Novotny, 1981, p. 22).

Although no E.P.A. limits have been placed on sodium in drinking water, high concentrations can produce water with a "salty" taste (Aly and Faust, 1981, p. 8). In relation to cardiovascular diseases and to women with toxemia associated with pregnancy, the medical profession occasionally expresses concern about the sodium content of drinking water (National Academy of Sciences, 1977, p. 35768).

Potassium

Some principal sources of potassium are orthoclase (KAlSi3O8), mica (KAl2(AlSi3)O10(OH)2), leucite (KAlSi2O6), and sylvite (KCl) (Hounslow, 1991, p. 3.3). Artificial sources of potassium include potash fertilizer and leachates from solid waste (Chester and Novotny, 1981, p. 22). There is no limit for potassium in drinking water.

Chloride

Occurrence of chloride in rocks may be the lowest of major constituents in ground water because of the very high solubility of chloride salts in water. One of the few sources among igneous rocks is sodalite (Na8Cl2(AlSiO4)6); other geologic sources include these evaporites: halite (NaCl), sylvite (KCl), bischofite (MgCl2 · 6H2O) and carnallite (KMgCl3 · 6H2O) (Aly and Faust, 1981, p. 15). Sea spray and hot springs are also natural sources of chloride (Hounslow, 1991, p. 3.3).

Concentration of chloride in most water in natural onshore settings is low. High chloride concentrations can generally be attributed to man's activities. Sources from these activities include road salts, irrigation water, septic tanks, solid-waste leachates, industrial wastewater and oil-field brines.

The E.P.A. has set a secondary maximum contaminant level of 250 mg/l for chloride in drinking water. Where chloride concentrations exceed 400 mg/l, water may taste "salty" (U.S.E.P.A., 1972, p. 61). High chloride concentrations (>1000 mg/l) may cause detrimental health effects (Pettyjohn and White, 1986, p. 8).

Sulfate

Sulfate and other compounds of sulfur are generally in almost all ground water. Sources of sulfate are evaporites, such as: gypsum ($CaSO4 \cdot 2H2O$), anhydrite ($CaSO4$), epsomite ($MgSO4 \cdot 7H2O$), and mirabilite ($NaSO4 \cdot 10H2O$) (Aly and Faust, 1981, p. 13). Chemical weathering of pyrite ($FeS2$) also contributes to sulfate concentrations (Hem, 1989, p. 112).

Sulfate can be entrained in ground water from oxidation of industrially produced sulfides, landfill leachates and industrial wastewaters (Chester and Novotny, 1981, p. 22). Sulfate has a secondary maximum contaminant level of 250 mg/l in drinking water. High sulfate concentrations can produce gypsum scales in hot-water systems, and can induce a laxative effect in humans (Aly and Faust, 1981, pp. 13-14).

Bicarbonate

Bicarbonate in ground water originates from dissolution of carbonate rocks, oxidation of organic materials and precipitation (Chester and Novotny, 1981, p. 22). Some of the more common sources in rocks are calcite and aragonite ($CaCO3$), dolomite ($CaMg(CO3)2$), magnesite ($MgCO3$) and nahcolite (($NaHCO3$) (Hounslow, 1991, p. 3.4). No limits for bicarbonate have been set in drinking water.

Fluoride

Fluoride is generally a minor constituent in ground water because mineralogic sources are quite insoluble in water. One of the most common fluoride-yielding minerals is fluorite ($CaF2$); other sources are fluorapatite ($Ca5(PO4)3F$), and cryolite ($Na3AlF6$) (Aly and Faust, 1981, p. 20).

The E.P.A. has set a primary maximum contaminant level of 4 mg/l and a secondary maximum contaminant level of 2 mg/l for fluoride in drinking water. Although, fluoride is essential in the formation of teeth and bones and aids in the prevention of dental caries, concentrations in excess of 4 mg/l may cause stained or mottled teeth (Tate and Trussell, 1977, p. 486). In high concentrations, fluoride is toxic and may cause chronic fluorosis (Pettyjohn and White, 1986, p. 9).

Silica

Silicon is the second most abundant element in the earth's crust and commonly is reported in water samples as dissolved in the form of $SiO2$ (silica). Some sources of silicon are quartz, feldspars, clay minerals,and the hydrous aluminum silicates (Aly and Faust, 1981, p. 25). Other sources are ferromagnesian silicates such as amphiboles, micas, olivine and pyroxenes (Hounslow, 1991, p. 3.2). Crystalline quartz ($SiO2$), a major constituent in many rocks, is comparatively resistant to chemical weathering, but elevated temperature and pH tend to increase the solubility in water (Aly and Faust, 1981, p. 25). No drinking-water limits have been set for silica.

Nitrate

Nitrate is commonly reported in water samples as dissolved as nitrogen (N^{3-} to N^{5+}) or dissolved as nitrate ($NO3^-$); 1 mg/l dissolved as nitrogen equals 4.5 mg/l dissolved as nitrate. For reader convenience, both representations were used in this study, but the representations should not be viewed as two different constituents of ground-water quality. Known mineral sources of nitrate are few. Soda niter ($NaNO3$) is a component of the famous nitrate deposits in Chile. Nitrate commonly originates from a sequence of biologically mediated reactions in which organic nitrogen compounds are oxidized (Tate and Trussell, 1977, p. 486).

Man induced sources of nitrate are widespread: fertilizers, barnyards or feedlots, septic tanks, municipal waste and industrial wastewater (Chester and Novotny, 1981, p. 22). Primary maximum contaminant levels of 10 mg/l, dissolved as N, and 45 mg/l, dissolved as NO3, have been set for nitrate in drinking water. Nitrate concentrations in excess of the E.P.A. standards can cause methemoglobinemia ("blue-babies") in small children (Pettyjohn and White, 1986, p. 8).

Total Dissolved Solids

Total dissolved solids (TDS) is the sum of concentrations of all minerals dissolved in a sample of water. TDS is generally reported as residue on evaporation. True TDS can be estimated by multiplying the amount of bicarbonate by 0.5083 and then adding the product to residue on evaporation. This equation is based on the premise that at 180 degrees Celcius bicarbonate ions are unstable and half will be converted to carbonate ions, CO2 and H2O (Hem, 1989, p. 156). Table 2 shows a typical classification of ground water by TDS.

The E.P.A. has set a secondary maximum contaminant level of 500 mg/l for TDS in drinking water. High TDS concentrations in water can have a wide variety of adverse effects for users: the water may taste bad, it may be laxative, it may corrode and encrust metals, and it may be toxic to aquatic life (Aly and Faust, 1981, p. 3).

TABLE 2

CLASSIFICATION OF GROUND WATER, BASED ON TOTAL DISSOLVED SOLIDS

Descriptive Terms	Range of Total Dissolved Solids (mg/l)
Slightly saline	1,000 - 3,000
Moderately saline	3,000 - 10,000
Very saline	10,000 - 35,000
Briny	More than 35,000

(Modified from Hem, 1989, p. 157.)

Conductivity

The American Society for Testing and Materials (1964, p. 383) defined conductivity of water as "...the reciprocal of the resistance in ohms measured between opposite faces of a centimeter cube of an aqueous solution at a specified temperature." The standard temperature is generally 25 degrees Celcius and the micromho is the unit of measurement of conductivity. Conductivity is correlated positively with TDS and can be used as a good estimator of TDS. Values of TDS are generally between 55 and 76 percent of conductivity values (Hounslow, 1991, p. 2.8). No limits have been set for conductivity in drinking water, although the limits for TDS would encompass conductivity.

Hardness

In most current literature, hardness is a measurement of calcium and magnesium concentrations. Hardness generally is reported as a concentration of an equivalent of calcium carbonate ($CaCO_3$) but may be referred to by descriptive terms (Table 3). Total hardness can be described as carbonate (temporary) hardness and noncarbonate (permanent) hardness. Carbonate hardness is equivalent to the sum of bicarbonate and carbonate (alkalinity); if carbonate hardness is not equivelant to total hardness then the remainder is termed "noncarbonate hardness" (Hem, 1989, p. 158-159).

TABLE 3

CLASSIFICATION OF HARDNESS, BASED ON $CaCO_3$ CONCENTRATIONS (mg/l)

Descriptive Terms	Range of Concentration
Soft	0 - 60
Moderately hard	61 - 120
Hard	121 - 180
Very hard	More than 180

(Modified from Hem, 1989, p. 159.)

Elevated levels of hardness are correlated with buildup of scales in pipes and boilers, and hard water can produce an insoluble residue when combined with soap (Pettyjohn and White, 1986, p. 7). Because no health problems have been attributed to hardness of water, no drinking water limits have been set for concentrations of hardness.

CHAPTER IV

METHODOLOGY

Data Base

The U.S. Geological Survey's National Water Data Storage and Retrieval System (WATSTORE) was the data base used in this study. Ground water and surface water samples from approximately 200,000 stations, with about 15,000,000 observations of some 2600 constituents, are stored in the data file. Data were collected and tested for a variety of purposes, by numerous individuals, from several decades and over a large area. The file is stored on read-only optical disks (CD-ROM) and was accessed through the Oklahoma State University School of Geology by a data-delivery system (Hydrodata QW).

Standardized Data

Measurements in the WATSTORE data base for chemical constituents primarily are recorded as concentrations. Wet and dry periods, recharge and discharge areas, and lengths and times of flowpaths are some of the factors that influence concentrations directly. These factors commonly introduce special forms of variation into the distributions of concentrations. When chemical constituents are converted to a percentage of TDS, the effects of concentrated and diluted variations can be minimized. Values as a percentage of TDS were analyzed for the following constituents: bicarbonate, calcium, chloride, fluoride, potassium, magnesium, nitrate, silica, sodium and sulfate.

Statistical Procedures

Data were not collected necessarily to test a working hypothesis, but statistical analyses were applied for descriptive purposes. No control could be exerted over the design for collecting or testing the data, but conditions for collecting and testing cited earlier were the basis for assuming that samples were effectively collected at random.

Test of Distribution

The distribution of the data was tested using Lilliefors' test for normality. The null hypothesis was Ho: The sample was drawn randomly from a population distributed normally. Alternate hypotheses are these: (Ha1) the sample was drawn randomly from a non-normal distribution; (Ha2) the sample was not drawn randomnly, but was drawn from a normal distribution; and (Ha3) the sample was not drawn randomly, and was drawn from a non-normal distribution. The first step of the test is to "standardize" the sample by converting the data to a mean of zero and a standard deviation of one. Distribution of this standardized sample is then compared to a normal distribution. The critical test statistic, DMAX, is derived from the maximal difference between class frequencies of the sample, and frequencies predicted by the normal distribution. The final statistic describes the probability that Ho is true. An example of Lilliefors' test for normality is in Appendix A and step by step detailed procedures are in Conover (1980, pp. 357-361).

Descriptive Statistics

Descriptive statistics are given as minima and maxima, and the 10th, 25th, 50th, 75th, and 90th percentiles. The 50th percentile is the median; half the measurements are smaller and half are larger.

Test for Different Populations

The Kruskal-Wallis test was used to test hypothesis Ho: two or more samples were drawn from one population or from populations with identical means. The alternative hypothesis (Ha) is that samples were drawn from populations not equal with respect to the mean (Siegel, 1956, p. 184-193).

The test is based on ranks of data. Ranking is accomplished by placement of data from each population in ascending order, in one sample. A rank is assigned to each data value according to its postion in the sample. The sum of the ranks for each population is used in an equation to give the final test statistic, a chi-square approximation. The probability of Ho being true is derived from the chi-squared statistic. An example of the Kruskal-Wallis test is in Appendix B and step by step procedures are in Conover (1980, pp. 229-237).

Piper Diagrams

Major anions in most water samples are bicarbonate, carbonate, sulfate, and chloride. Major cations are calcium, magnesium, sodium and potassium. Samples that were analyzed for these constituents were plotted on Piper diagrams (Figure 6). The lower portion of a Piper diagram consists of two equilateral triangles, one for cations and one for anions. Points, representing major ions as percentages of milliequivalents per liter, are plotted on the two triangles. Each point represents percentages of major ions and each vertex of the triangles represents 100 percent of a particular ion or group of ions. Points in the triangles are extended up to their point of intersection in a diamond plot, which occupies the upper portion of the diagram. A circle is plotted around points in the diamond plot. The size of a circle is representative of the dissolved-solids concentration.

Piper diagrams can show general relationships of dominant anions and cations and also water types in relation to the combination of anions and cations. Detailed discussions of Piper Plots are in Hem (1989, pp. 178-180).

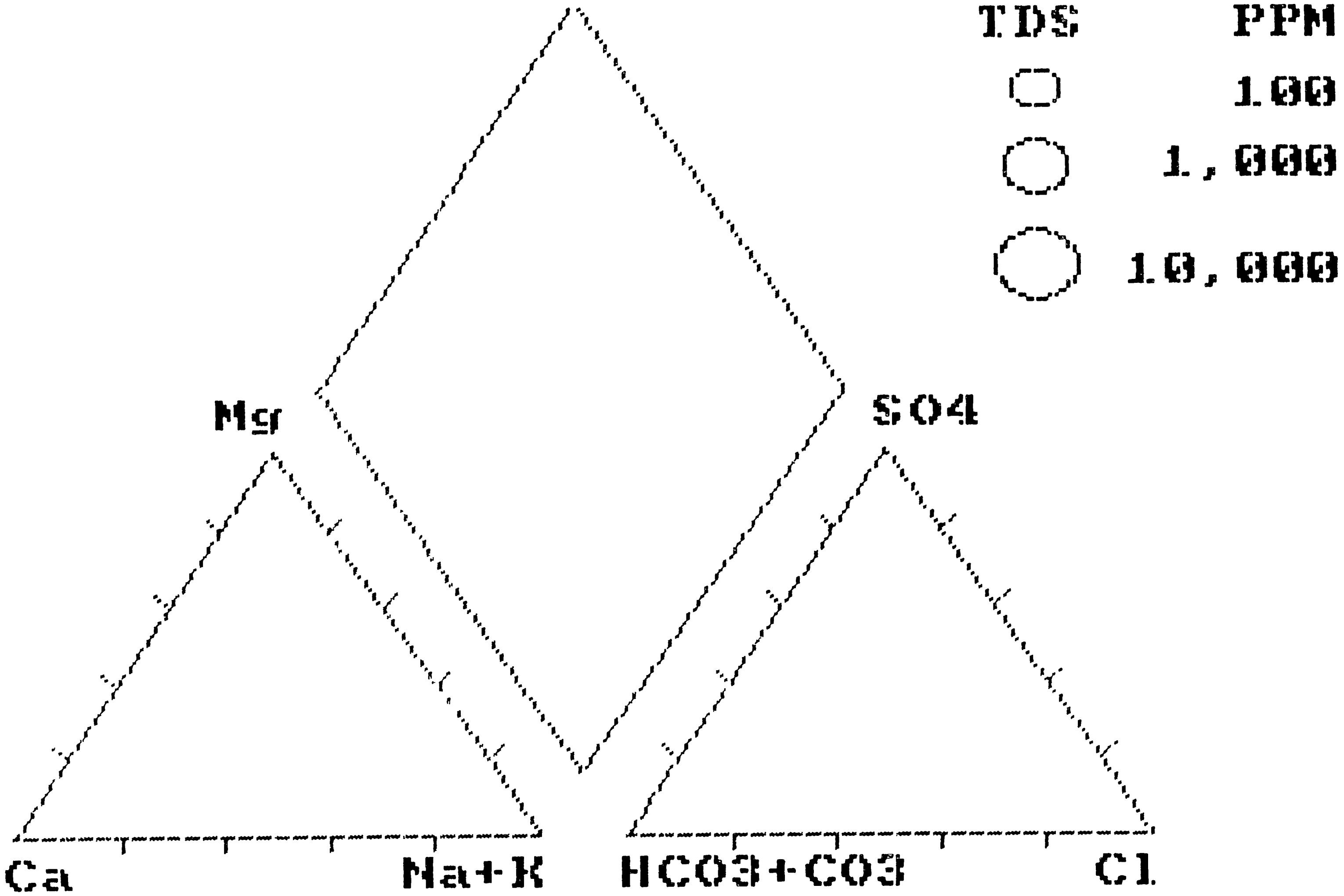


Figure 6. Piper Diagram.

Computer Hardware

The primary system used is an IBM-compatible 386 (International Business Machines) personal computer. Other hardware included: an Apple Macintosh personal computer, a Hitachi CD-ROM drive, a Hewlett Packard Laser Jet printer, a Macintosh Laser Write printer , and a Panasonic dot-matrix printer.

Computer Software

Several computer programs were utilized in this study. Software included: SYSTAT by Systat, Microsoft Excel (EXCEL) and Microsoft Word (WORD) by Microsoft Corporation, Hydrodat QW by EarthInfo, WATEVAL by A. Hounslow and K. Goff (1990), SEP100 by K. Goff (1991), MapMaker by Strategic Mapping, SuperPaint by B. Snider, and Apple File Exchange by Apple.

CHAPTER V

PROCEDURES

Data

The program "Hydrodat QW" was used for access to records of ground-water samples in WATSTORE. The program enables the user to select criteria for specific data sets. Samples used in this investigation were limited to those coded by the following criteria: state (Oklahoma), site code (GW, ground-water site), and geologic unit code (aquifer). For the twelve major aquifers in Oklahoma (Figure 5), one query was run. For each query, state and site codes were marked and the "keywords" function of the program was used to identify and mark geologic unit codes pertaining to the aquifer. All samples for each aquifer were found by the program and stored as a data file.

The program "SEP100" was used to manipulate the data files into usable forms. The program served two major functions: (1) creation of a latitude-and-longitude file for mapping, and (2) creation of a data file in a format transferable to a spreadsheet.

Files with fewer than 20 samples were not used. This eliminated evaluation of four major aquifers: the Antlers

Sandstone, the Elk City Sandstone, the Keokuk and Reed Springs (Boone) Formation, and the Oscar Formation.

Mapping

One feature of the program "MapMaker" is combination of several boundary files as one map. Latitude-and-longitude files created by SEP100 were combined with the boundary file of Oklahoma to produce a map of sampling sites for each aquifer. EXCEL was used to combine the latitude-and-longitude files of the aquifers as one file. This file was used to produce a map of all sampling sites.

Statistical Procedures

Testing for Distributions of Variables

Aquifer data files were imported independently into EXCEL. Spreadsheet columns contained measurements of individual water-quality constituents. Data was sorted into ascending order by columns. Columns were inserted between the above mentioned columns showing measurements of constituents. These new columns were used to compute square roots, squares and logarithms. Files were stored and imported into SYSTAT. SYSTAT was used to compute Lilliefors' DMAX statistic and probabilities of normal distribution. Probabilities of samples having been drawn randomly from a normal distribution are in Appendix C.

At an alpha-level of 0.05, the null hypotheses (that samples were drawn randomly from normal populations), were rejected in the majority cases. Transformations of the data to squares, square roots and logarithms had little effect on the test statistics.

This working hypothesis was tested: Conversion of measurements to percentages of total dissolved solids would so transform the data that data-sets would "conform" to parameters of the normal distribution. To convert concentrations to percentages of TDS, original SEP100 data files were imported into EXCEL. Dissolved solids in these files were recorded as residue on evaporation. Measurements of bicarbonate records were multiplied by 0.5083; the product was added to the residue on evaporation to give the sum of constituents (Hem, 1989, p. 157). Analyses converted to a percentage of TDS values were limited to samples with recorded measurements of residue on evaporation, and bicarbonate. Empty columns were inserted between columns showing measurements of constituents; the new columns were used to convert values to a percentage of TDS. Values were converted by dividing concentrations of each constituent by the concentration of the sum of constituents. Steps used for testing the original data for normality were performed to give Lilliefors' DMAX statistic and probabilities of samples having been drawn randomly from normal distributions. Probabilities of these transformed data-sets having been drawn randomly from a normal distribution are in Appendix D.

Results of the Lilliefor's test on the percentage-of-TDS values were similar to results of anlyses of the untransformed samples. At an alpha-level of 0.05 most hypotheses specifying random samples from normal distributions were rejected.

Percentile Statistics

Overall, this proposition was rejected: "Samples were random samples from populations distributed normally." Therefore, percentile statistics were chosen to summarize the constituents of ground-water quality and nonparametric statistics were chosen to evaluate hypotheses about samples.. These statistics were computed in EXCEL, from the sorted files. The number of analyses of each constituent was entered into an algorithm that computed percentiles.

Nonparametric Test

The Kruskal-Wallis, a one-way analysis of variance by ranks, nonparametric or distribution-free statistical test was used to compare aquifers by constituents. Nonparametric tests are appropriate for analysis of data drawn -- presumedly at random, from non-normal distributions.

The Kruskal-Wallis test statistic and probability were computed in the program "SYSTAT". SYSTAT performs the test based on a "grouping variable" and a "dependent variable". The grouping variable for this study was the aquifer and the dependent variable was the constituent. Files for these procedures were created in EXCEL. Sorted files for aquifers were copied into one file. The created file consisted of aquifer names filling the first column and water-quality constituents filling remaining columns. Procedures were done for concentration values and for percentage-of-TDS values.

Pairs of aquifers were compared by selecting two aquifers as the grouping variable and one constituent as the dependent variable. For each constituent, twenty-eight comparisons were made; this was based on all the possible combinations of the eight aquifers, taken two at a time.

Piper Diagrams

The program "WATEVAL" was used to produce Piper diagrams. Original SEP100 data files were imported into EXCEL. Data used in the plots was limited to samples analyzed for major cations and anions. EXCEL and WORD were used to manipulate files into the format that WATEVAL uses to produce the Piper diagrams.

CHAPTER VI

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY

All Selected WATSTORE Data

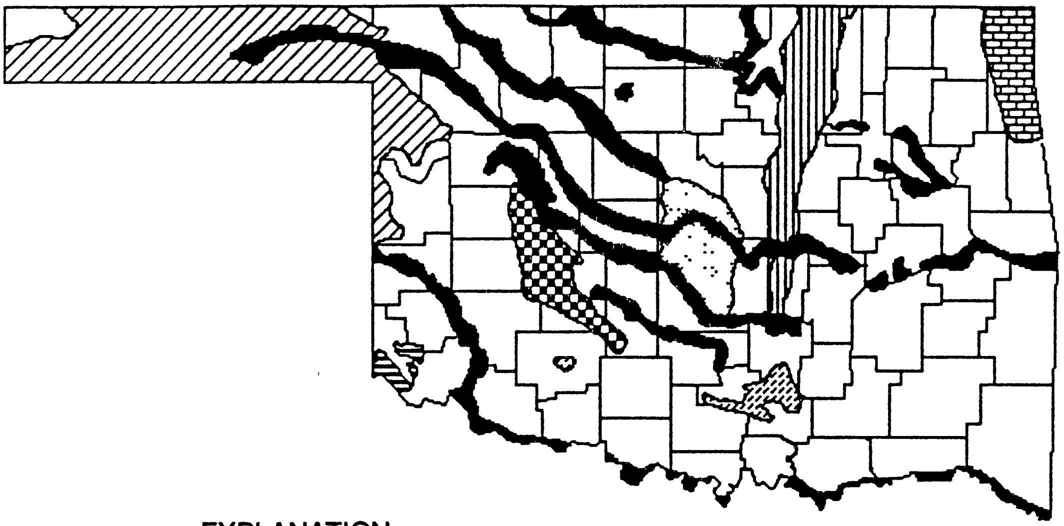
Aquifers selected for statistical analyses were those for which WATSTORE contained at least 20 samples. Aquifers and sampling sites selected are shown in Figures 7 and 8.

Percentile statistics for the total data set are shown in Tables 4 and 5. Each constituent analyzed showed a wide range between minimal and maximal concentrations. Maximal concentrations are uncommonly high; they are most likely results of contamination, not related to natural causes.

Medial concentrations of the total data set for selected constituents are below E.P.A. limits for drinking water. Table 6 shows numbers and percentages of samples exceeding E.P.A. limits. The constituent that yielded the largest percentage of samples exceeding E.P.A. limits was dissolved solids; almost half (49.6 percent) of the samples were above the E.P.A. limit.

Alluvium and Alluvial Terrace Deposits

Alluvium and alluvial terrace deposits are of Quaternary age (O.W.R.B., 1980, p. 63) and are along major



EXPLANATION

■	Alluvium and Terrace Deposits
▒	Arbuckle Group and Simpson Group
▤	Blaine Gypsum and Dog Creek Shale
□	Garber Sandstone and Wellington Formation
▨	Ogallala Formation
▦	Roubidoux Formation
▩	Rush Springs Sandstone
▥	Vamoosa Formation

Figure 7. Principal Aquifers of Oklahoma from Which at Least Twenty WATSTORE Samples Were Recorded. Vertical Order Not Related to Geologic Age (Modified from O.W.R.B., 1980, p. 62a).

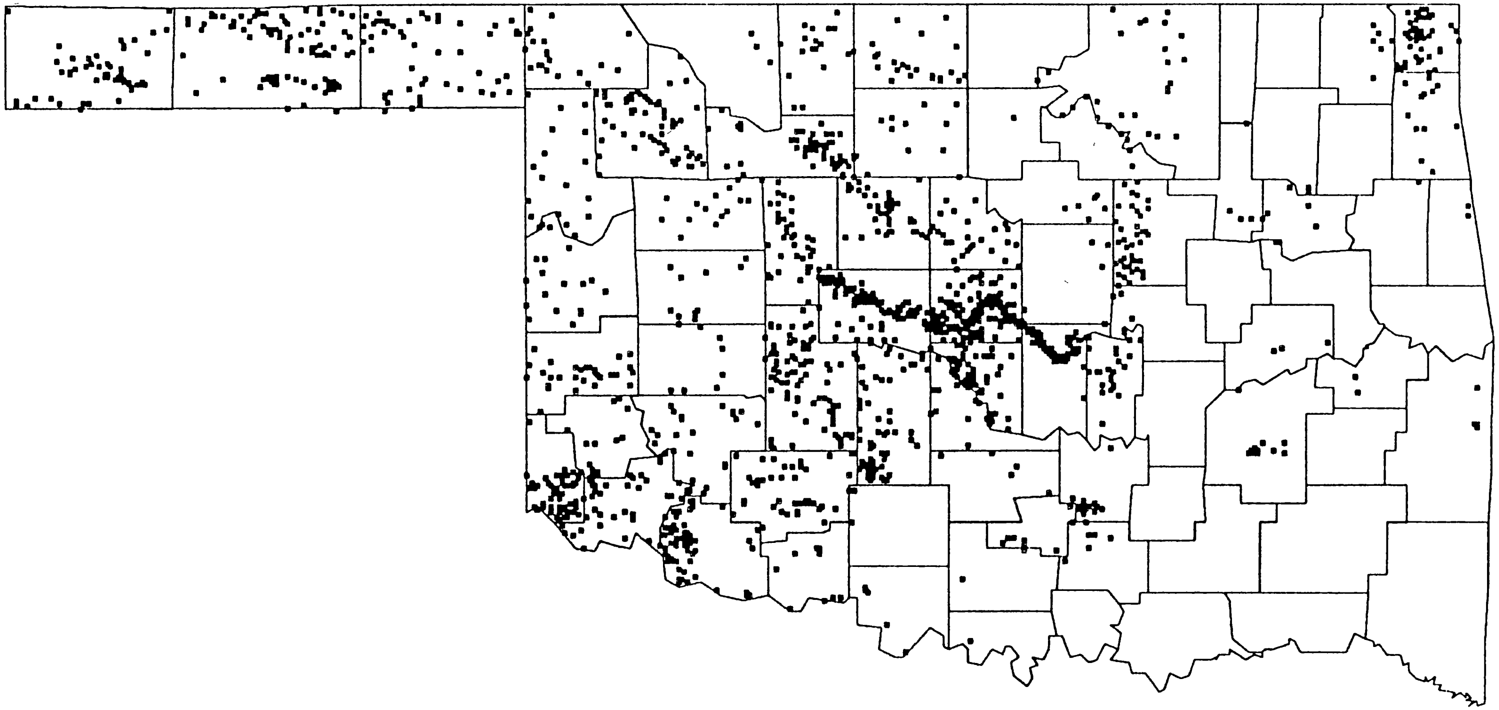


Figure 8. Locations of Sampling Sites, All WATSTORE Samples Selected. (Samples Outside Boundaries of Major Aquifers were from Minor Deposits of Alluvium and Alluvial Terrace.)

TABLE 4

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, ALL WATSTORE SAMPLES SELECTED

Constituent or Property	No. of * Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Dissolved solids (residue on evaporation)	1626	57	222	313	496	1090	3270	113000
Specific conductance (micromhos/cm)	1964	50	375	511	763	1529	3580	125000
Hardness, total (dissolved as CaCO3)	1793	2	88	160	254	460	1770	8430
Sodium, dissolved	769	1.4	7.8	16	40	120	290	3220
Calcium, dissolved	1072	1.7	16	32	54	96	250	1200
Magnesium, dissolved	1025	0	7.1	13	21	37	96	922
Potassium, dissolved	701	0	1	1.7	3	4.6	6.5	70
Sulfate, dissolved	1884	0.2	10	18	54	200	1450	12700
Chloride, dissolved	1935	1	8	14	40	160	170	65000
Bicarbonate (dissolved as HCO3)	1705	0	148	190	248	339	437	1250
Fluoride, dissolved	727	0	0.1	0.2	0.5	1	2.4	70
Nitrate, dissolved as nitrogen	1261	0	0	0.18	1.7	5	11	190
Nitrate, dissolved as nitrate	1262	0	0.2	1.2	7.2	21	50	830
Silica, dissolved as SiO2	539	0	9	10	14	24	31	640

*Number of samples which contained records for Constituent or Property
Units are mg/l except as noted
2142 total samples

TABLE 5

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, ALL WATSTORE SAMPLES SELECTED

Constituent	No. of* Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Sodium	712	.00313	.02068	.04216	.08046	.15441	.25746	.58382
Calcium	986	.00116	.03376	.06467	.10996	.14014	.16760	.38956
Magnesium	940	0	.01622	.02644	.03686	.05252	.06706	.42463
Potassium	647	0	.00154	.00265	.00527	.00842	.01138	.09471
Sulfate	1618	.00014	.02127	.04274	.09174	.20687	.42087	.67985
Chloride	1622	.00069	.01754	.02910	.06475	.16499	.31507	.67916
Bicarbonate (as HCO3)	1494	0	.06129	.21293	.42872	.54529	.63932	.78892
Fluoride	628	0	.00010	.00034	.00092	.00176	.00427	.22853
Nitrate (as nitrogen)	1108	0	.00006	.00028	.00170	.00734	.01757	.08686
Nitrate (as nitrate)	1109	0	.00024	.00124	.00753	.03257	.07802	.38740
Silica (as SiO2)	480	0	.00979	.01682	.02805	.04390	.07518	.34624

*Represents number of samples with records necessary to convert values to a percentage of TDS
Values are percentages of TDS
2142 total samples

TABLE 6

SAMPLES EXCEEDING E.P.A. DRINKING-WATER LIMITS, ALL WATSTORE DATA SELECTED

Constituent	Number of Samples	EPA Limit (mg/l)	Number Exceeding Limit	Percentage Exceeding Limit
Nitrate (as nitrogen)	1261	10*	142	11.3
Nitrate (as nitrate)	1262	45*	142	11.3
Fluoride	727	4*	41	5.6
Fluoride	727	2**	104	14.3
Chloride	1935	250**	352	18.2
Sulfate	1884	250**	422	22.4
Dissolved solids	1626	500**	806	49.6

* MCL (based on health risks)
** SMCL (based on aesthetic criteria)

rivers (Figure 7) and many smaller streams, not shown. Alluvium and alluvial terrace deposits generally are unconsolidated and consist of clay, silt, sand and gravel. Deposits range in thickness from a few feet to around 300 feet; well yields commonly range from 100 to 300 gallons per minute (gpm), but some exceed 1000 gpm (U.S.G.S., 1985, p.348). Water from the alluvium and alluvial terrace deposits mostly is used for domestic, irrigation, industrial and municipal supplies (O.W.R.B., 1988, p. 63).

Sampling sites for the alluvium and alluvial terrace deposits are shown in Figure 9 and percentile statistics are in Tables 7 and 8. Except for dissolved solids, medial concentrations of selected constituents are less than E.P.A. drinking-water standards. Numbers and percentages of samples that exceeded E.P.A. limits are in Table 9.

Medial concentrations from alluvium and alluvial terrace deposits were larger than medial concentrations from the total data set for all constituents selected, except potassium and fluoride. Maximal concentrations in the entire data set for magnesium, fluoride, and nitrate were from samples taken from alluvium and alluvial terrace deposits. In Table 10 are ranks of medial values of 14 variables, from among all aquifers selected, for alluvium and alluvial terrace deposits.

Figure 10 is a Piper plot of samples from alluvium and alluvial terrace deposits. Points plotted for cations and anions show much scatter. Alkalinity (HCO3+CO3) was the

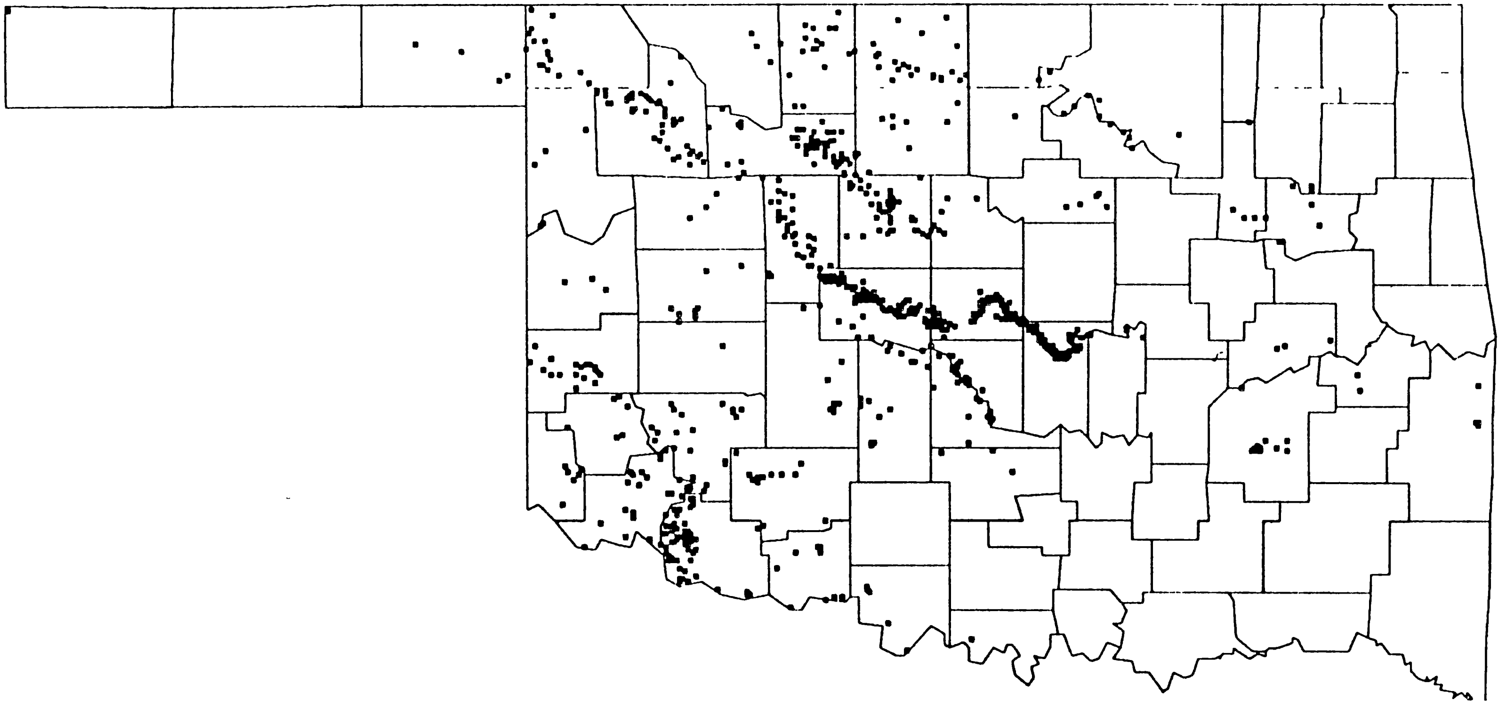


Figure 9. Locations of Sampling Sites, Alluvium and Alluvial Terrace Deposits. (Samples Outside Boundaries Shown in Figure 7 are from Minor Deposits of Alluvium and Alluvial Terrace.)

TABLE 7

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, ALLUVIUM AND TERRACE DEPOSITS

Constituent or Property	No. of * Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Dissolved solids (residue on evaporation)	611	68	276	407	618	1280	2980	11520
Specific conductance (micromhos/cm)	828	82	405	574	862	1630	3270	16300
Hardness, total (dissolved as CaCO3)	660	12	160	234	339	570	1240	4940
Sodium, dissolved	216	5.5	14	29	59	144	283	1500
Calcium, dissolved	364	3	31	52	80	119	200	664
Magnesium, dissolved	347	0.3	9.2	16	27	44	83	922
Potassium, dissolved	189	0	1.2	1.6	2.6	4	6.4	70
Sulfate, dissolved	714	2	17	31	83	270	901	6730
Chloride, dissolved	748	3	10	21	56	188	555	8320
Bicarbonate (dissolved as HCO3)	644	0	154	224	300	402	516	872
Fluoride, dissolved	183	0	0.1	0.3	0.5	0.7	1.1	70
Nitrate, dissolved as nitrogen	536	0	0.05	0.41	2.7	7.2	13	190
Nitrate, dissolved as nitrate	537	0	0.2	1.8	12	32	59	830
Silica, dissolved as SiO2	149	0	14	20	24	28	32	48

*Number of samples which contained records for Constituent or Property
Units are mg/l except as noted
902 total samples

TABLE 8

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, ALLUVIUM AND TERRACE DEPOSITS

Constituent	No. of* Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Sodium	216	0.01260	.03296	.05167	.08642	.12858	.17064	.40812
Calcium	352	0.00407	.05301	.08596	.11735	.14271	.16270	.38956
Magnesium	335	0.00041	.02231	.02819	.03532	.04483	.05967	.11378
Potassium	189	0.00000	.00140	.00215	.00325	.00498	.00799	.09471
Sulfate	607	0.01094	.04207	.06056	.10781	.21755	.34862	.63307
Chloride	609	0.00541	.02130	.03775	.08123	.14966	.26627	.67916
Bicarbonate (as HCO3)	568	0	.08334	.24214	.41076	.52317	.58746	.75738
Fluoride	179	0	.00012	.00032	.00054	.00100	.00138	.22853
Nitrate (as nitrogen)	469	0	.00005	.00034	.00319	.01062	.02113	.06216
Nitrate (as nitrate)	470	0	.00020	.00151	.01369	.04680	.09343	.27629
Silica (as SiO2)	149	0	.01008	.01924	.03551	.05265	.08861	.34624

*Represents number of samples with records necessary to convert values to a percentage of TDS

Values are percentages of TDS

902 total samples

TABLE 9

SAMPLES EXCEEDING E.P.A. DRINKING-WATER LIMITS, ALLUVIUM AND TERRACE DEPOSITS

Constituent	Number of Samples	EPA Limit (mg/l)	Number Exceeding Limit	Percentage Exceeding Limit
Nitrate (as nitrogen)	536	10*	90	16.8
Nitrate (as nitrate)	537	45*	90	16.8
Fluoride	183	4*	4	2.2
Fluoride	183	2**	5	2.7
Chloride	748	250**	150	20.1
Sulfate	714	250**	186	26.1
Dissolved solids	611	500**	377	61.7

* MCL (based on health risks)
** SMCL (based on aesthetic criteria)

TABLE 10

RANKS OF MEDIAN VALUES, ALLUVIUM AND TERRACE DEPOSITS, AMONG MEDIANS OF THE COMBINED DATA SET

Values Compared as	Constituent or Property						
	Calcium	Magnesium	Sodium	Potassium	Chloride	Bicarbonate	Sulfate
Concentrations	7	6	6	5	7	5	7
Percentages of TDS	5	3	5	4	5	3	7

Values Compared as	Constituent or Property						
	Fluoride	Silica	Nitrate (as nitrate)	Nitrate (as nitrogen)	Dissolved Solids	Hardness	Conductivity
Concentrations	4	6	7	7	7	7	7
Percentages of TDS	4	6	6	6	-	-	-

Possible ranks are 1 to 8, with 1 representing smallest values.

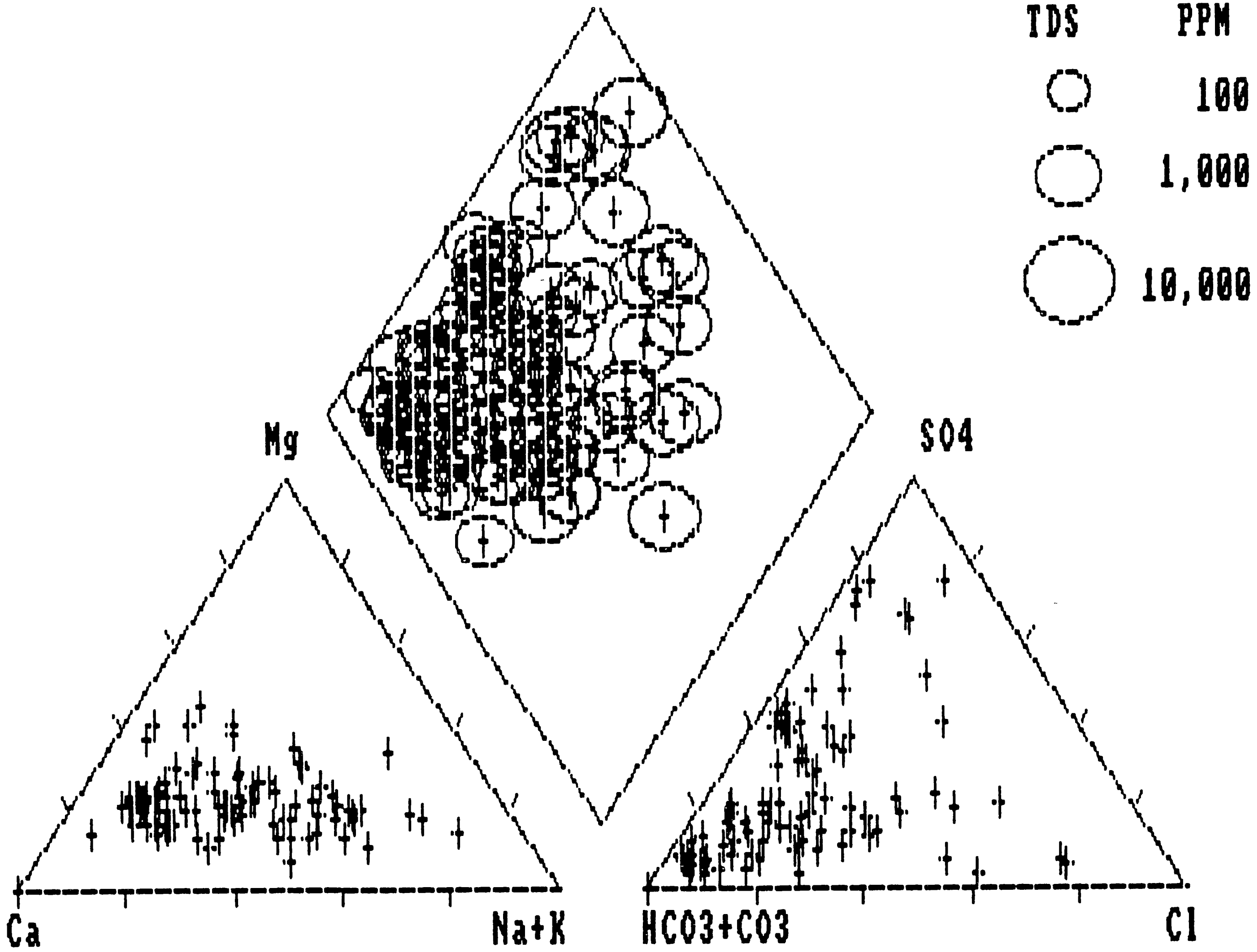


Figure 10. Piper Plot, Alluvium and Alluvial Terrace Deposits.

predominant anion for many analyses. Predominant cations are mostly calcium and sodium + potassium. The diamond plot shows the majority of samples as calcium-magnesium bicarbonate-carbonate water types.

Arbuckle-Simpson Aquifer

The Arbuckle-Simpson aquifer is composed of the Arbuckle Group and the Simpson Group. The aquifer is of Ordovician and Cambrian age (O.W.R.B., 1980, p. 65); it is mostly in southern Oklahoma (Figure 7). The aquifer is unconfined to confined and consists of limestone, dolomite, and sandstone (U.S.G.S., 1985, p. 350). Locally the aquifer is as thick as 9000 ft.; well yields commonly are 100 to 500 gpm, but some exceed 2000 gpm (U.S.G.S., 1985, p. 350). The Arbuckle-Simpson aquifer primarily is used for drinking water (U.S.G.S., 1988, p. 419).

Sampling sites for the Arbuckle-Simpson aquifer are shown in Figure 11 and percentile statistics are in Tables 11 and 12. Medial concentrations of selected constituents are below E.P.A. drinking-water standards. Numbers and percentages of samples exceeding E.P.A. standards are in Table 13.

Medial concentrations from the Arbuckle-Simpson aquifer were larger than medial concentrations from the total data set for specific conductance, hardness, calcium, magnesium, bicarbonate and fluoride. Dissolution of limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) should contribute to larger medial

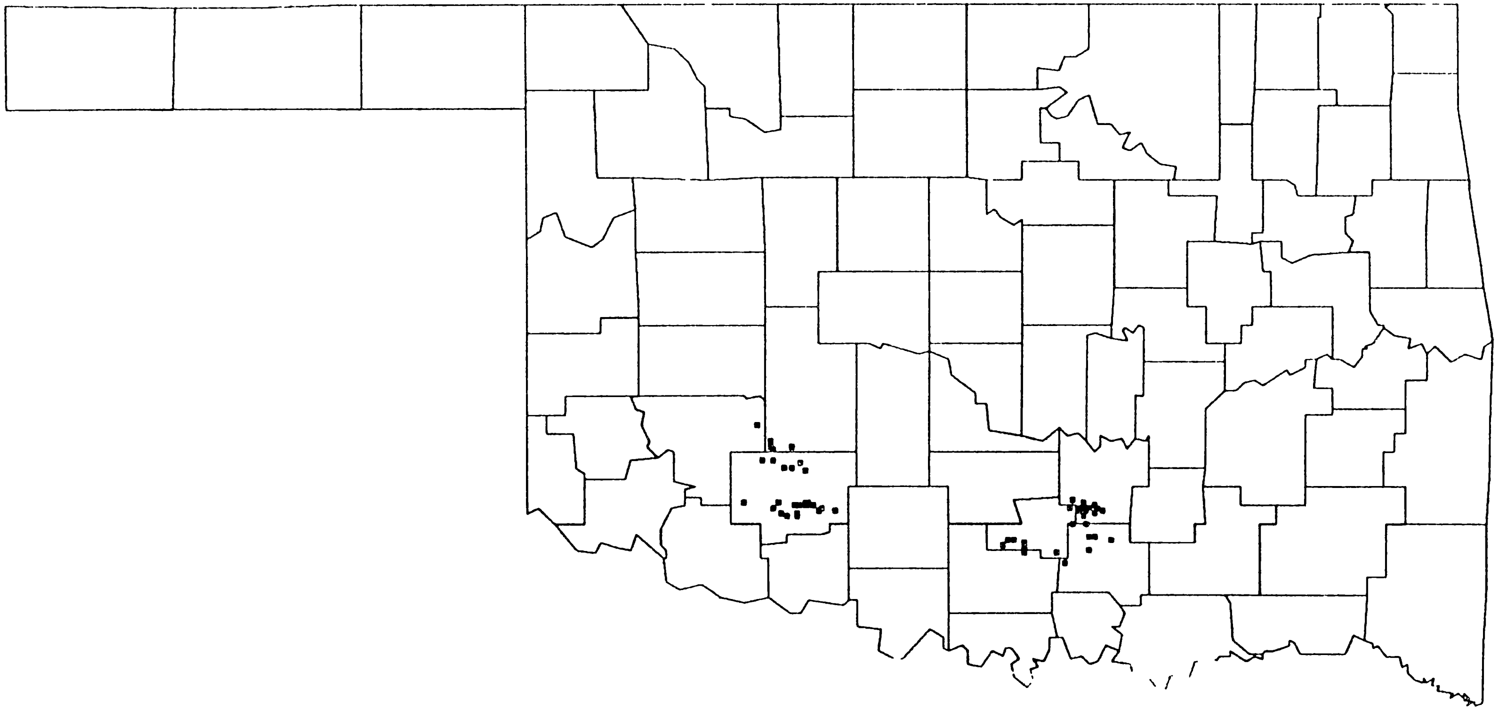


Figure 11. Locations of Sampling Sites, Arbuckle-Simpson Aquifer.

TABLE 11

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, ARBUCKLE-SIMPSON AQUIFER

Constituent or Property	No. of * Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Dissolved solids (residue on evaporation)	66	246	292	332	480	886	1450	6380
Specific conductance (micromhos/cm)	64	140	511	580	800	1560	2870	10700
Hardness, total (dissolved as CaCO3)	66	6	12	21	258	330	380	800
Sodium, dissolved	30	1.4	2.5	4	5	8	69	390
Calcium, dissolved	37	2	4	8	72	86	97	130
Magnesium, dissolved	37	0.5	0.5	4	30	40	46	54
Potassium, dissolved	30	0.3	0.4	1	1	2	2	5.3
Sulfate, dissolved	66	3.9	7.4	12	38	72	220	840
Chloride, dissolved	66	1.7	3	6	30	280	360	3000
Bicarbonate (dissolved as HCO3)	66	24	167	290	324	380	404	482
Fluoride, dissolved	61	0	0	0	1	9	11	35
Nitrate, dissolved as nitrogen	35	0	0.02	0	0	0	3	19
Nitrate, dissolved as nitrate	35	0	0.1	0	1	2	15	85
Silica, dissolved as SiO2	21	7.4	7.5	8	10	11	11	18

*Number of samples which contained records for Constituent or Property
Units are mg/l except as noted
66 total samples

TABLE 12

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, ARBUCKLE-SIMPSON AQUIFER

Constituent	No. of* Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Sodium	30	0.00313	.00503	.00655	.00998	.01542	.11589	.33291
Calcium	37	0.00239	.00320	.00478	.13569	.14436	.19228	.22476
Magnesium	37	0.00024	.00060	.00549	.06034	.07583	.07860	.10356
Potassium	30	0.00052	.00089	.00150	.00189	.00276	.00320	.00890
Sulfate	66	0.00807	.01472	.02293	.05288	.07930	.14324	.48793
Chloride	66	0.00375	.00543	.01089	.05629	.25428	.28943	.47422
Bicarbonate (as HCO3)	66	0.00812	.17799	.27671	.46066	.71144	.75556	.78892
Fluoride	61	0	0	.00019	.00085	.00879	.00998	.03380
Nitrate (as nitrogen)	35	0	.00002	.00005	.00010	.00086	.00406	.01484
Nitrate (as nitrate)	35	0	.00010	.00019	.00043	.00378	.01791	.06639
Silica (as SiO2)	21	0.00939	.01248	.01330	.01666	.01931	.02138	.02189

*Represents number of samples with records necessary to convert values to a percentage of TDS
Values are percentages of TDS
66 total samples

TABLE 13

SAMPLES EXCEEDING E.P.A. DRINKING-WATER LIMITS, ARBUCKLE-SIMPSON AQUIFER

Constituent	Number of Samples	EPA Limit (mg/l)	Number Exceeding Limit	Percentage Exceeding Limit
Nitrate (as nitrogen)	35	10*	1	2.9
Nitrate (as nitrate)	35	45*	1	2.9
Fluoride	61	4*	23	37.7
Fluoride	61	2**	25	41.0
Chloride	66	250**	18	27.3
Sulfate	66	250**	7	10.6
Dissolved solids	66	500**	32	48.5

* MCL (based on health risks)
** SMCL (based on aesthetic criteria)

values for calcium, magnesium and bicarbonate. Medial concentrations of sodium, potassium, and silica from the Arbuckle-Simpson aquifer were the lowest of aquifers evaluated. Ranks of medial values, from aquifers selected, for the Arbuckle-Simpson aquifer are in Table 14.

Figure 12 is a Piper plot for the Arbuckle-Simpson aquifer. Points are clustered around the bicarbonate + carbonate corner of the anion triangle . Predominant cations are calcium and magnesium. The diamond plot shows that water types are generally calcium-magnesium bicarbonate-carbonate.

Blaine-Dog Creek Aquifer

The Blaine-Dog Creek aquifer is composed of the Blaine Gypsum and Dog Creek Shale. The aquifer is of Permian age (O.W.R.B., 1980, p. 64), is in extreme south-western Oklahoma (Figure 7), and is generally gypsum, anhydrite, dolomite and limestone interbedded with shale; water commonly comes from secondary porosity associated with solution openings (O.W.R.B., 1980, p. 64). Thicknesses range from about 200 to about 300 ft.; well yields commonly range from 100 to 500 gpm, but some exceed 2500 gpm (U.S.G.S., 1985, p. 350). Water from the Blaine-Dog Creek aquifer primarily is used for irrigation (U.S.G.S., 1988, p. 418).

Sampling sites for the Blaine-Dog Creek aquifer are shown in Figure 13 and percentile statistics are in Tables

TABLE 14

RANKS OF MEDIAN VALUES, ARBUCKLE-SIMPSON AQUIFER, AMONG MEDIANS OF THE COMBINED DATA SET

Values Compared as	Constituent or Property						
	Calcium	Magnesium	Sodium	Potassium	Chloride	Bicarbonate	Sulfate
Concentrations	6	7	1	1	5	7	4
Percentages of TDS	7	8	1	2	4	6	3

Values Compared as	Constituent or Property						
	Fluoride	Silica	Nitrate (as nitrate)	Nitrate (as nitrogen)	Dissolved Solids	Hardness	Conductivity
Concentrations	7	1	2	2	6	6	6
Percentages of TDS	6	2	1	1	-	-	-

Possible ranks are 1 to 8, with 1 representing smallest values.

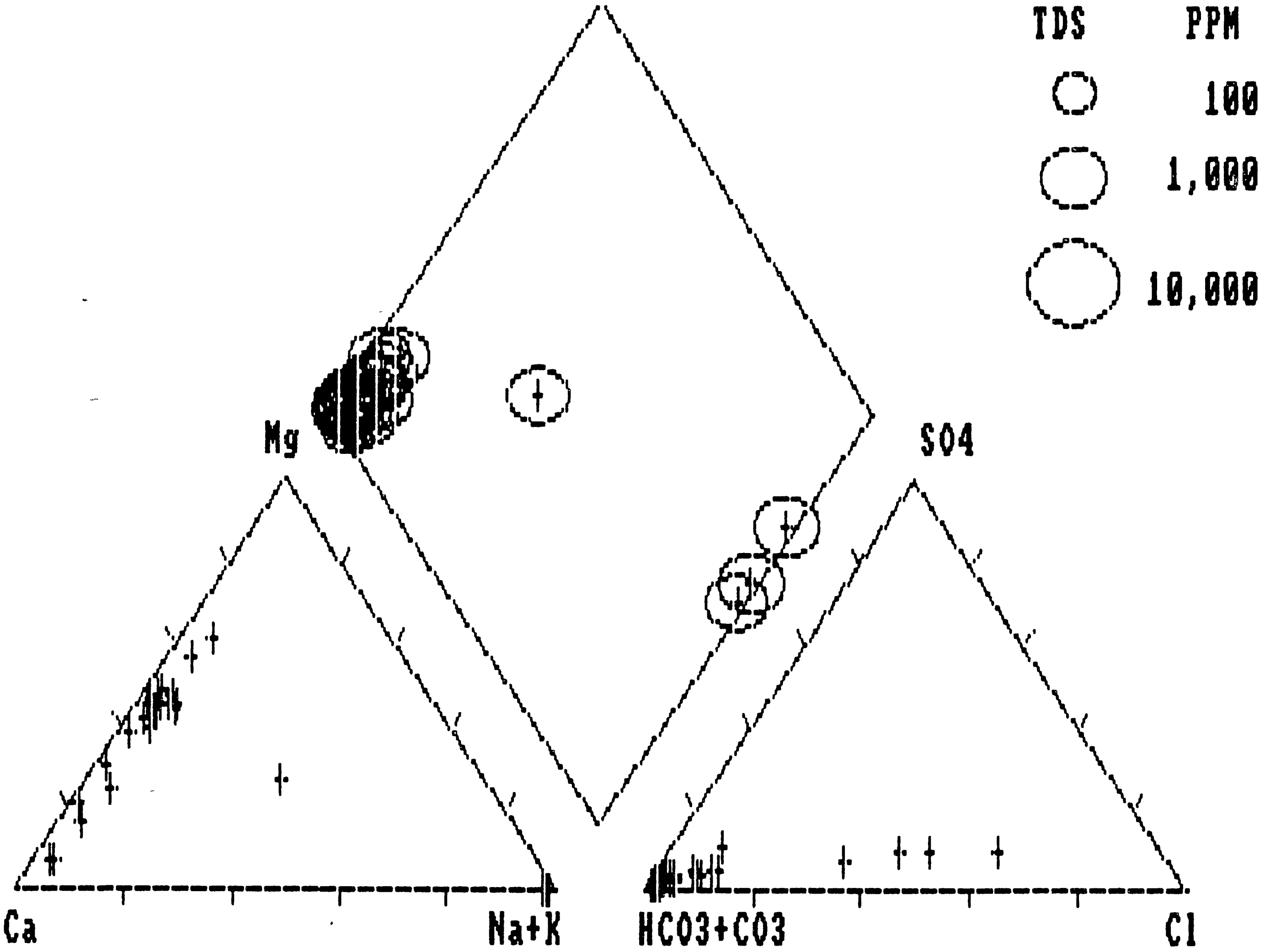


Figure 12. Piper Plot, Arbuckle-Simpson Aquifer.

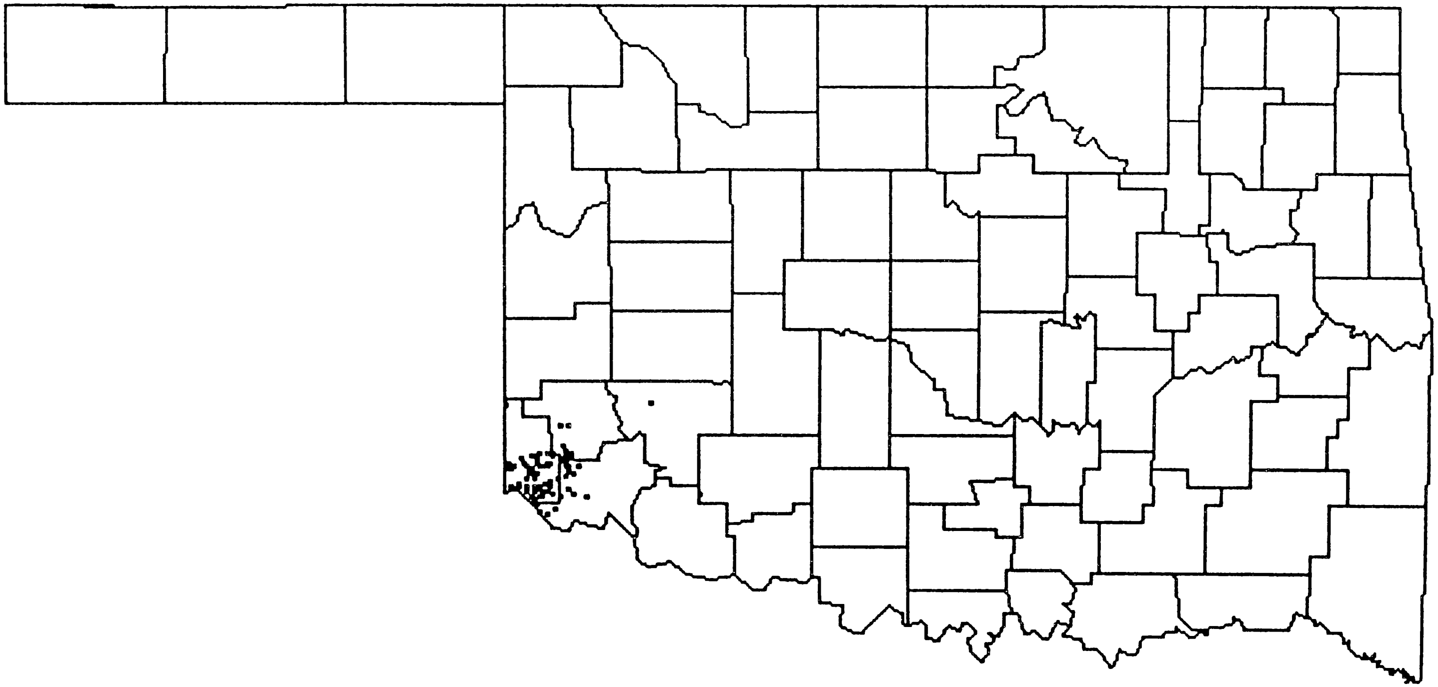


Figure 13. Locations of Sampling Sites, Blaine-Dog Creek Aquifer.

15 and 16. Medial concentrations of dissolved solids, chloride and sulfate from the Blaine-Dog Creek aquifer exceed E.P.A. drinking water standards. Numbers and percentages of samples exceeding E.P.A. standards are in Table 17. Percentages of samples exceeding E.P.A. standards from the Blaine-Dog Creek aquifer are uncommonly high; this phenomenon makes the aquifer unsuitable as a source of drinking water.

Medial concentrations from the Blaine-Dog Creek aquifer were higher than medial concentrations from the total data set for all constituents selected except fluoride. Of the entire data set, maximal concentrations for sodium, calcium and potassium are from the Blaine-Dog Creek aquifer. Medial concentrations from the Blaine-Dog Creek aquifer for dissolved solids, conductivity, hardness, sodium, calcium, magnesium, potassium, sulfate, chloride, and nitrate were the largest among aquifers selected. Ranks of medial values, from aquifers selected, for the Blaine-Dog Creek aquifer are in Table 18.

Figure 14 is a Piper plot for the Blaine-Dog Creek aquifer. Sulfate was the predominant anion in most samples; sodium and calcium are predominant cations. The diamond plot shows the majority of water as being of the calcium-magnesium-sodium sulfate-chloride type.

Garber-Wellington Aquifer

The Garber-Wellington aquifer is of Permian age (O.W.R.B., 1980, p. 64) and is in central Oklahoma (Figure

TABLE 15

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, BLAINE-DOG CREEK AQUIFER

Constituent or Property	No. of * Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Dissolved solids (residue on evaporation)	126	287	2560	3090	3630	5710	7910	21500
Specific conductance (micromhos/cm)	135	457	1860	3190	3940	6600	9940	30200
Hardness, total (dissolved as CaCO3)	135	140	840	2000	2130	2400	2950	4840
Sodium, dissolved	22	38	43	152	311	913	1070	3220
Calcium, dissolved	70	34	98	588	600	620	680	1200
Magnesium, dissolved	67	14	79	121	152	188	266	762
Potassium, dissolved	22	2.6	3	5.8	6.6	9.6	11	70
Sulfate, dissolved	141	15	680	1720	1910	2100	2430	5350
Chloride, dissolved	141	6.5	64	150	265	1250	2400	9850
Bicarbonate (dissolved as HCO3)	139	55	134	178	208	248	265	607
Fluoride, dissolved	19	0	0.03	0.3	0.5	0.7	0.7	0.9
Nitrate, dissolved as nitrogen	98	0	0.81	1.7	2.7	5	6.3	100
Nitrate, dissolved as nitrate	98	0	3.6	7.6	12	22	28	450
Silica, dissolved as SiO2	18	3	10	15	16	17	24	26

*Number of samples which contained records for Constituent or Property
Units are mg/l except as noted
141 total samples

TABLE 16

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, BLAINE-DOG CREEK AQUIFER

Constituent	No. of* Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Sodium	22	.01333	.01565	.04441	.10101	.15516	.17713	.27975
Calcium	70	.00889	.05558	.11004	.15457	.17412	.18984	.22052
Magnesium	67	.01622	.02771	.03509	.03972	.04517	.05030	.14029
Potassium	22	.00051	.00085	.00151	.00173	.00207	.00292	.00524
Sulfate	126	.03751	.17440	.32296	.46717	.54470	.55856	.60280
Chloride	125	.00434	.02658	.04744	.08568	.21339	.31284	.46537
Bicarbonate (as HCO3)	126	.00838	.01987	.03456	.05207	.07113	.08388	.58730
Fluoride	19	0	.00001	.00008	.00013	.00019	.00026	.00054
Nitrate (as nitrogen)	88	0	.00020	.00046	.00080	.00148	.00206	.03115
Nitrate (as nitrate)	88	0	.00091	.00209	.00357	.00650	.00917	.13629
Silica (as SiO2)	18	.00042	.00120	.00272	.00397	.00473	.00526	.01711

*Represents number of samples with records necessary to convert values to a percentage of TDS
Values are percentages of TDS
141 total samples

TABLE 17

SAMPLES EXCEEDING E.P.A. DRINKING-WATER LIMITS, BLAINE-DOG CREEK AQUIFER

Constituent	Number of Samples	EPA Limit (mg/l)	Number Exceeding Limit	Percentage Exceeding Limit
Nitrate (as nitrogen)	98	10*	6	6.1
Nitrate (as nitrate)	98	45*	6	6.1
Fluoride	19	4*	0	0.0
Fluoride	19	2**	0	0.0
Chloride	141	250**	77	54.6
Sulfate	141	250**	131	92.9
Dissolved solids	126	500**	123	97.6

* MCL (based on health risks)
** SMCL (based on aesthetic criteria)

TABLE 18

RANKS OF MEDIAN VALUES, BLAINE-DOG CREEK AQUIFER, AMONG MEDIANS OF THE COMBINED DATA SET

Values Compared as	Constituent or Property													
	Calcium	Magnesium	Sodium	Potassium	Chloride	Bicarbonate	Sulfate	Fluoride	Silica	Nitrate (as nitrate)	Nitrate (as nitrogen)	Dissolved Solids	Hardness	Conductivity
Concentrations	8	8	8	8	8	3	8	5	4	8	8	8	8	8
Percentages of TDS	8	4	6	1	7	1	8	1	1	5	5	-	-	-

Possible ranks are 1 to 8, with 1 representing smallest values.

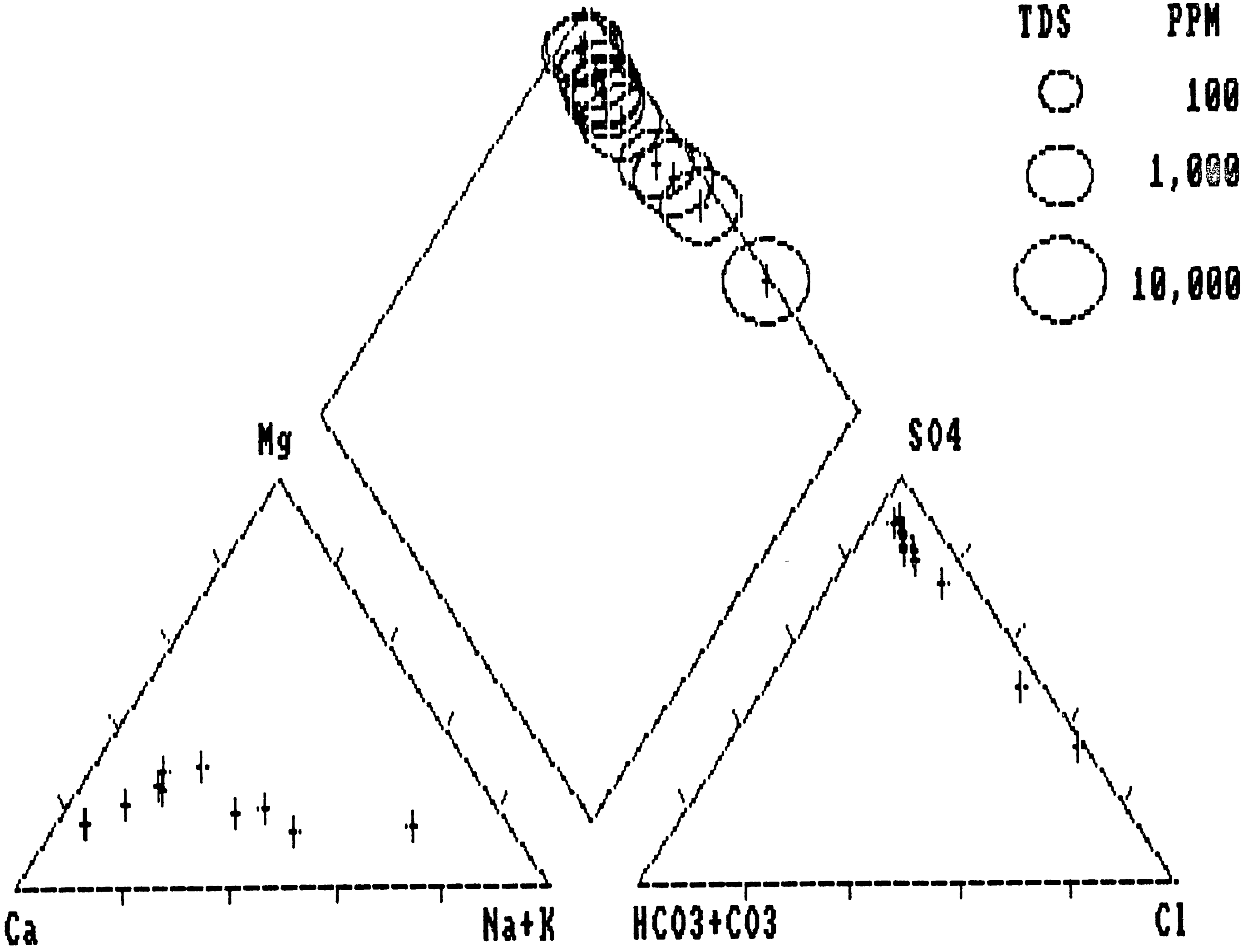


Figure 14. Piper Plot, Blaine-Dog Creek Aquifer.

7). The aquifer comprises the Garber Sandstone and The Wellington Formation; they were deposited under similar conditions and are composed of fine-grained sandstone, shale and siltstone (O.W.R.B., 1980, p. 64). The aquifer commonly is 800 to 1000 ft. thick; well yields generally range from 100 to 300 gpm, but some exceed 500 gpm (U.S.G.S., 1985, p. 350). Water from the Garber-Wellington aquifer is used primarily for public supply and self-supplied domestic purposes (U.S.G.S., 1988, p. 418).

Sampling sites for the Garber-Wellington aquifer are shown in Figure 15 and percentile statistics are in Tables 19 and 20. Medial concentrations of selected constituents from the Garber-Wellington aquifer are under E.P.A. drinking-water limits. Numbers and percentages of samples exceeding E.P.A. limits are in Table 21.

Medial concentrations from the Garber-Wellington aquifer were smaller than medial concentrations from the total data set for all selected constituents except magnesium and bicarbonate. The medial concentration for fluoride from the Garber-Wellington aquifer was the lowest from all aquifers selected. Ranks of medial values, from aquifers selected, for the Garber-Wellington aquifer are in Table 22.

Figure 16 is a Piper plot for the Garber-Wellington aquifer. Bicarbonate + carbonate are principal anions. Points in the cation section are scattered, but calcium and magnesium are predominant in the majority of samples. The

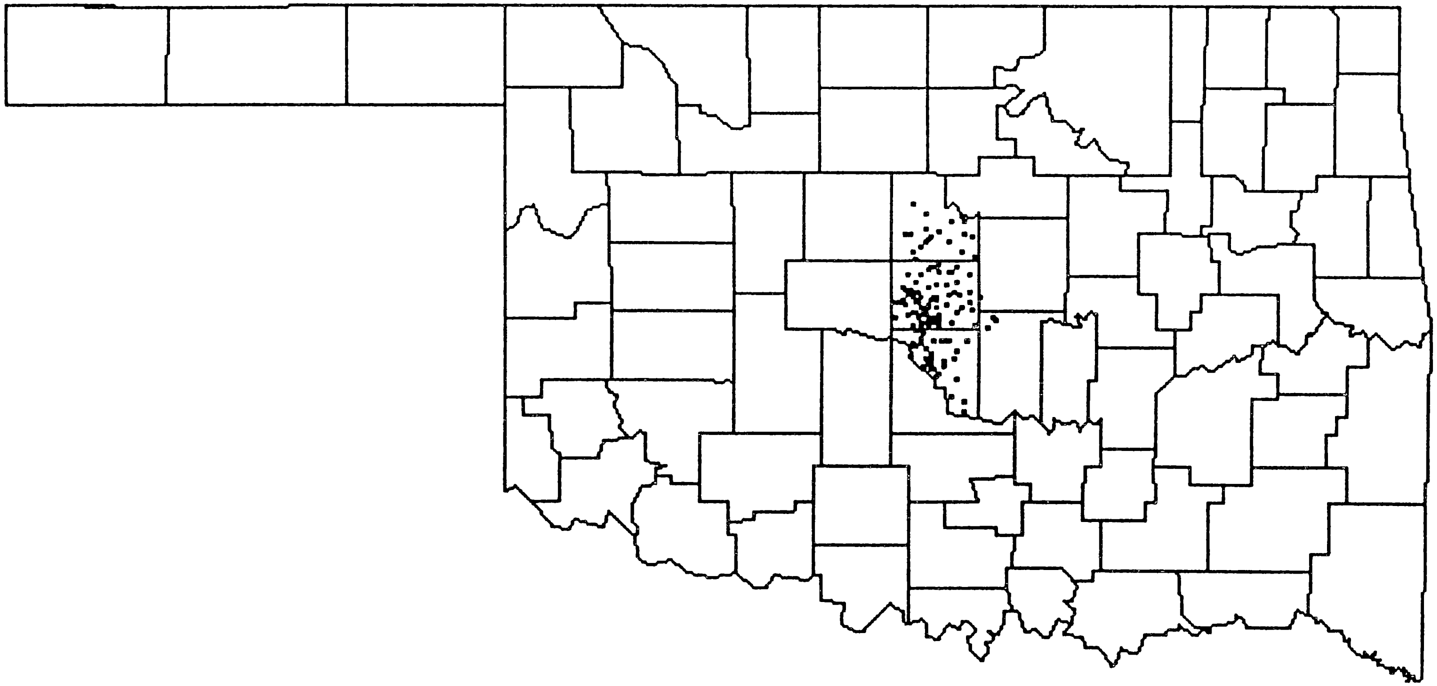


Figure 15. Locations of Sampling Sites, Garber-Wellington Aquifer.

TABLE 19

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, GARBER-WELLINGTON AQUIFER

Constituent or Property	No. of * Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Dissolved solids (residue on evaporation)	159	101	210	268	396	679	1490	5590
Specific conductance (micromhos/cm)	198	138	404	469	658	1100	1810	8330
Hardness, total (dissolved as CaCO3)	191	2	14	58	180	250	390	3000
Sodium, dissolved	78	4.5	7.6	9.7	22	139	272	790
Calcium, dissolved	144	1.9	7.6	25	40	58	86	680
Magnesium, dissolved	138	0	3.7	15	22	30	42	320
Potassium, dissolved	66	0.4	0.8	1.1	1.5	2.2	3	16
Sulfate, dissolved	196	1	6.3	9.4	22	65	215	1830
Chloride, dissolved	207	4	8	11	22	67	230	3000
Bicarbonate (dissolved as HCO3)	187	0	206	250	317	364	430	854
Fluoride, dissolved	86	0	0	0.1	0.2	0.7	2	14
Nitrate, dissolved as nitrogen	148	0	0.05	0.11	0.25	0.77	6.3	52
Nitrate, dissolved as nitrate	148	0	0.2	0.5	1.1	3.4	28	231
Silica, dissolved as SiO2	70	1.5	8.4	10	12	15	21	532

*Number of samples which contained records for Constituent or Property
Units are mg/l except as noted
225 total samples

TABLE 20

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, GARBER-WELLINGTON AQUIFER

Constituent	No. of* Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Sodium	69	.01364	.02046	.02458	.05653	.13437	.27538	.34518
Calcium	128	.00181	.01078	.04549	.08724	.12483	.13480	.16667
Magnesium	123	0	.00466	.02729	.04916	.06241	.07053	.10798
Potassium	57	.00009	.00104	.00228	.00386	.00461	.00563	.03718
Sulfate	158	.00036	.01621	.02095	.03791	.09692	.18151	.60856
Chloride	158	.00870	.01889	.02459	.04116	.09566	.24848	.55740
Bicarbonate (as HCO3)	151	0	.17283	.36746	.56032	.66707	.70618	.75266
Fluoride	64	0	0	.00018	.00031	.00069	.00133	.01051
Nitrate (as nitrogen)	125	0	.00005	.00014	.00050	.00194	.00927	.06131
Nitrate (as nitrate)	125	0	.00021	.00060	.00219	.00860	.04072	.26655
Silica (as SiO2)	55	.00143	.01156	.02099	.03089	.03528	.06667	.09388

*Represents number of samples with records necessary to convert values to a percentage of TDS

Values are percentages of TDS

225 total samples

TABLE 21

SAMPLES EXCEEDING E.P.A. DRINKING-WATER LIMITS, GARBER-WELLINGTON AQUIFER

Constituent	Number of Samples	EPA Limit (mg/l)	Number Exceeding Limit	Percentage Exceeding Limit
Nitrate (as nitrogen)	148	10*	14	9.5
Nitrate (as nitrate)	148	45*	14	9.5
Fluoride	86	4*	1	1.2
Fluoride	86	2**	10	11.6
Chloride	207	250**	20	9.7
Sulfate	196	250**	20	10.2
Dissolved solids	159	500**	60	37.7

* MCL (based on health risks)
** SMCL (based on aesthetic criteria)

TABLE 22

RANKS OF MEDIAN VALUES, GARBER-WELLINGTON AQUIFER, AMONG MEDIANS OF THE COMBINED DATA SET

Values Compared as	Constituent or Property						
	Calcium	Magnesium	Sodium	Potassium	Chloride	Bicarbonate	Sulfate
Concentrations	3	4	3	2	3	6	2
Percentages of TDS	3	6	3	5	3	8	2

Values Compared as	Constituent or Property						
	Fluoride	Silica	Nitrate (as nitrate)	Nitrate (as nitrogen)	Dissolved Solids	Hardness	Conductivity
Concentrations	1	3	4	4	4	3	4
Percentages of TDS	3	5	4	4	-	-	-

Possible ranks are 1 to 8, with 1 representing smallest values.

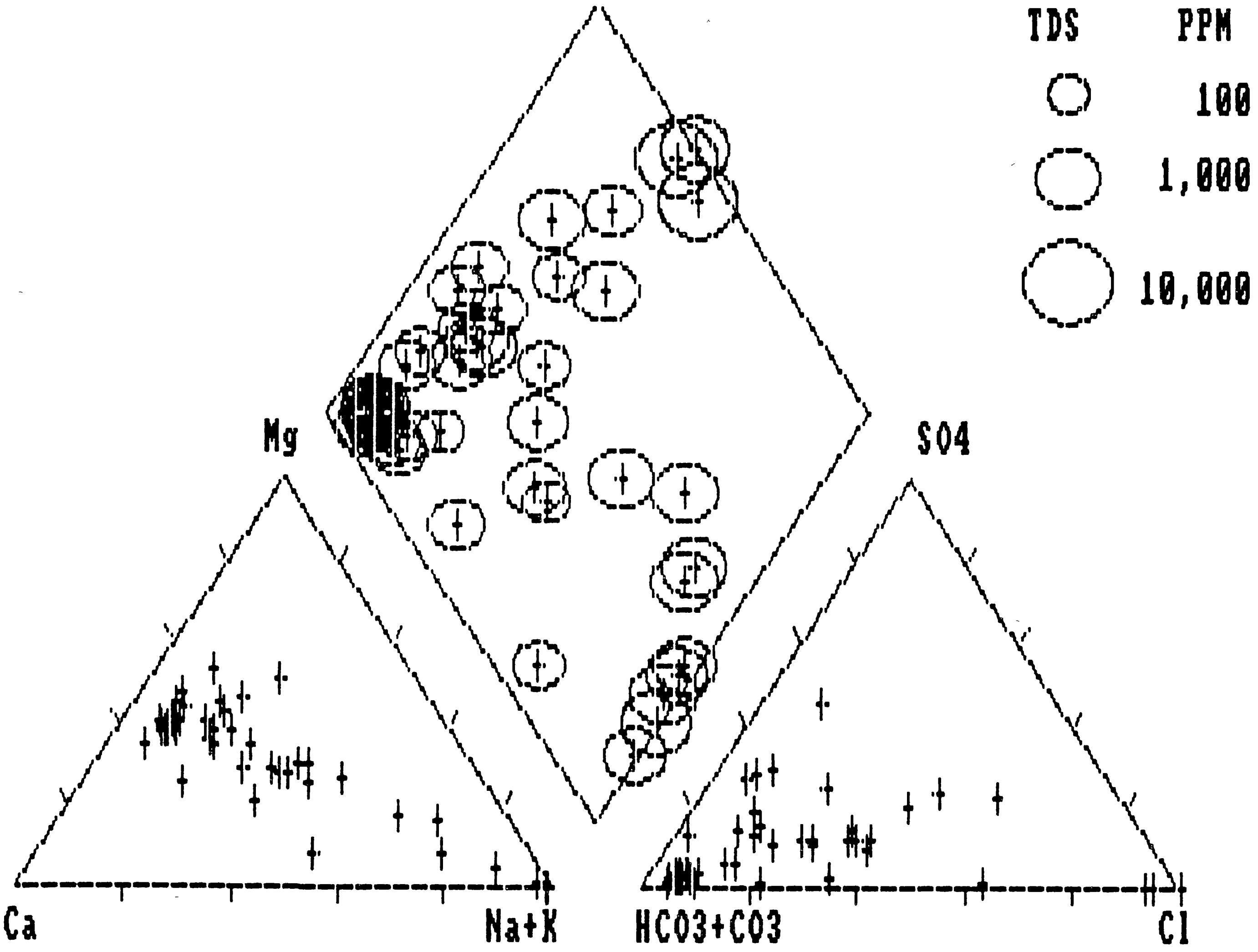


Figure 16. Piper Plot, Garber-Wellington Aquifer.

diamond plot shows much scatter, but a large portion of samples are calcium-magnesium, bicarbonate-carbonate water.

Ogallala Aquifer

The Ogallala aquifer is of Tertiary age (O.W.R.B., 1980, p. 63) and is in northwestern Oklahoma (Figure 7). The aquifer generally is unconfined and commonly is sand, siltstone, clay, gravel, thin limestones and caliche (O.W.R.B., 1980, p. 63). The aquifer is about 300 ft. thick; well yields vary, mostly from 500 to 1000 gpm, but some exceed 2000 gpm (U.S.G.S., 1985, p. 348). Water from the Ogallala aquifer is used primarily for irrigation, but is also a principal source of potable water (U.S.G.S., 1988, p. 418).

Sampling sites for the Ogallala aquifer are in Figure 17 and percentile statistics are in Tables 23 and 24. Medial concentrations for selected constituents are below E.P.A. drinking-water standards. Numbers and percentages of samples in the Ogallala aquifer exceeding E.P.A. standards are in Table 25.

Medial concentrations from the Ogallala aquifer for calcium, magnesium, potassium, sulfate, fluoride, nitrate and silica were larger than medial concentrations from the total data set. Of the total data set, maximal concentrations for hardness, sulfate, bicarbonate and silica were from the Ogallala aquifer. Medial concentrations from the Ogallala aquifer for fluoride and silica were the

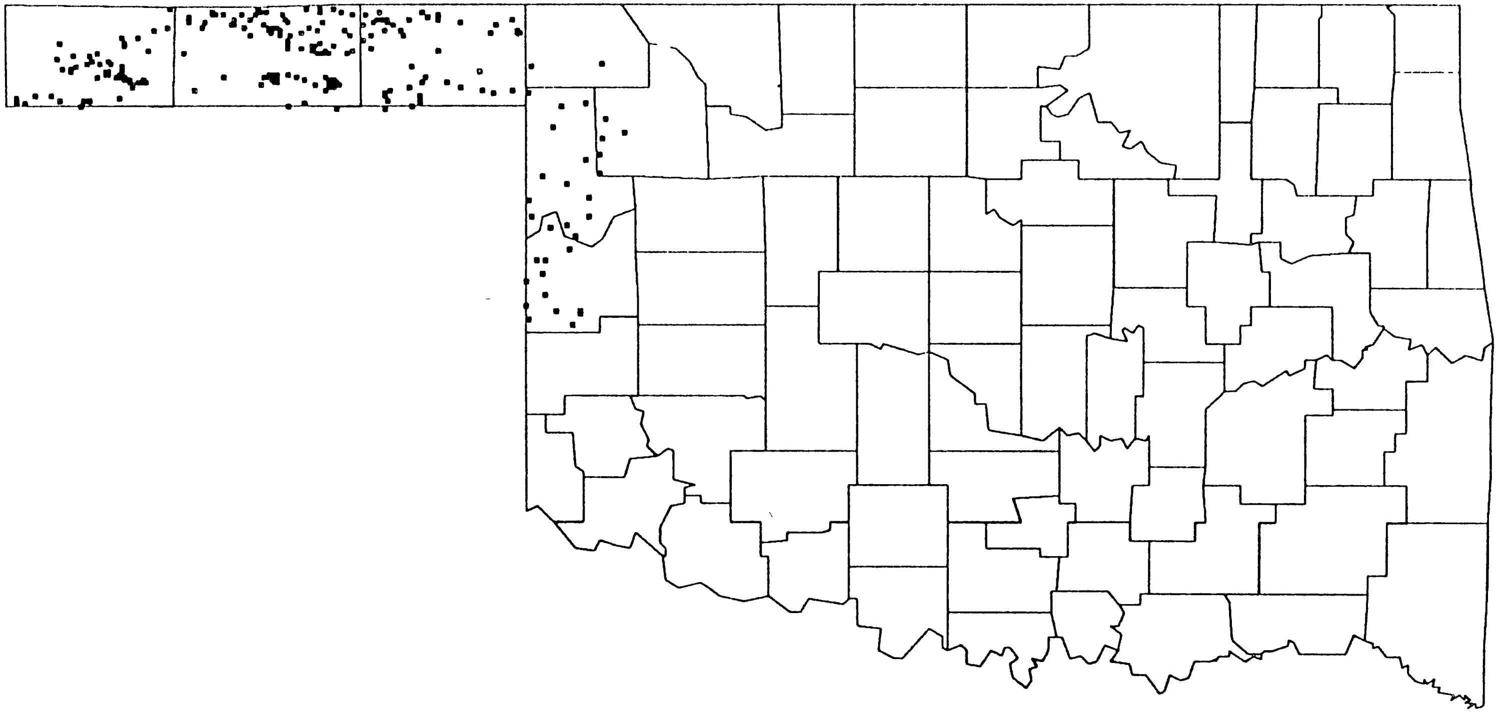


Figure 17. Locations of Sampling Sites, Ogalalla Aquifer.

TABLE 23

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, OGALLALA AQUIFER

Constituent or Property	No. of * Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Dissolved solids (residue on evaporation)	202	140	280	319	368	549	1040	24300
Specific conductance (micromhos/cm)	245	153	459	506	588	828	1380	21700
Hardness, total (dissolved as CaCO3)	245	16	184	206	242	310	390	8430
Sodium, dissolved	119	4.2	20	23	29	40	86	654
Calcium, dissolved	61	8	25	33	55	79	110	132
Magnesium, dissolved	53	11	14	21	26	29	45	79
Potassium, dissolved	119	0	3.3	4	4.7	6	6.3	10
Sulfate, dissolved	243	4	20	37	63	125	200	12700
Chloride, dissolved	245	2	8	12	20	48	230	4500
Bicarbonate (dissolved as HCO3)	242	6	196	216	232	256	316	1250
Fluoride, dissolved	79	0	0.5	0.6	1.2	2	2.4	3.3
Nitrate, dissolved as nitrogen	186	0	0.23	0.99	1.7	2.5	4.3	27
Nitrate, dissolved as nitrate	186	0	1.0	4.4	7.7	11	19	120
Silica, dissolved as SiO2	55	0.01	24	28	32	34	38	640

*Number of samples which contained records for Constituent or Property
Units are mg/l except as noted
247 total samples

TABLE 24

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, OGALLALA AQUIFER

Constituent	No. of* Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Sodium	79	.01671	.04216	.05254	.05945	.07960	.12526	.27875
Calcium	21	.01707	.02101	.02370	.06851	.10590	.12247	.16017
Magnesium	13	.01437	.01437	.03062	.04876	.06106	.06634	.07215
Potassium	79	0	.00422	.00771	.00994	.00994	.01369	.03036
Sulfate	79	.00555	.02478	.04166	.06948	.08472	.09409	.10001
Chloride	202	.00469	.01787	.02383	.03838	.07316	.28702	.50643
Bicarbonate (as HCO3)	201	.00164	.20962	.37450	.48442	.53270	.59756	.67668
Fluoride	38	0	.00061	.00105	.00156	.00381	.00485	.00716
Nitrate (as nitrogen)	170	0	.00028	.00121	.00346	.00537	.00928	.03994
Nitrate (as nitrate)	170	0	.00124	.00534	.01575	.02369	.04125	.17753
Silica (as SiO2)	14	.00063	.00063	.03787	.06403	.07524	.07901	.08147

*Represents number of samples with records necessary to convert values to a percentage of TDS
Values are percentages of TDS
247 total samples

TABLE 25

SAMPLES EXCEEDING E.P.A. DRINKING-WATER LIMITS, OGALLALA AQUIFER

Constituent	Number of Samples	EPA Limit (mg/l)	Number Exceeding Limit	Percentage Exceeding Limit
Nitrate (as nitrogen)	186	10*	2	1.1
Nitrate (as nitrate)	186	45*	2	1.1
Fluoride	79	4*	0	0.0
Fluoride	79	2**	22	27.8
Chloride	245	250**	24	9.8
Sulfate	243	250**	14	5.8
Dissolved solids	202	500**	59	29.2

* MCL (based on health risks)
** SMCL (based on aesthetic criteria)

largest of aquifers analyzed. Ranks of medial values, from aquifers selected, for the Ogallala aquifer are in Table 26.

Figure 18 is a Piper diagram for the Ogallala aquifer. Bicarbonate + carbonate are predominant anions; calcium and magnesium are predominant cations. The diamond portion shows the majority of samples as calcium-magnesium, bicarbonate-carbonate water.

Roubidoux Aquifer

The Roubidoux aquifer is Ordovician age (O.W.R.B., 1980, p. 65) and is in northeastern Oklahoma (Figure 7). The aquifer is confined and consists of dolomite and interbedded sandstones (O.W.R.B., 1980, p. 65). The aquifer's average thickness is about 160 ft.; well yields commonly are about 200 gpm, but some are more than 2000 gpm (U.S.G.S., 1985, p. 350). Water from the Roubidoux aquifer is the principal public and industrial supply for Ottawa County (U.S.G.S., 1988, p. 419).

Sampling sites for the Roubidoux aquifer are shown in Figure 19 and percentile statistics are in Tables 27 and 28. All medial concentrations are below E.P.A. drinking-water standards. Numbers and percentages of samples exceeding E.P.A. standards are in Table 29.

Medial concentrations for sodium, potassium, chloride and fluoride from the Roubidoux aquifer were larger than medial concentrations from the total data set. Maximal concentrations of the total data set for dissolved solids,

TABLE 26

RANKS OF MEDIAN VALUES, OGALLALA AQUIFER, AMONG MEDIANS OF THE COMBINED DATA SET

Values Compared as	Constituent or Property Calcium	Magnesium	Sodium	Potassium	Chloride	Bicarbonate	Sulfate
Concentrations	4	5	4	7	2	4	6
Percentages of TDS	1	5	4	8	2	7	4

Values Compared as	Constituent or Property Fluoride	Silica	Nitrate (as nitrate)	Nitrate (as nitrogen)	Dissolved Solids	Hardness	Conductivity
Concentrations	8	8	5	5	2	5	2
Percentages of TDS	7	7	7	7	-	-	-

Possible ranks are 1 to 8, with 1 representing smallest values.

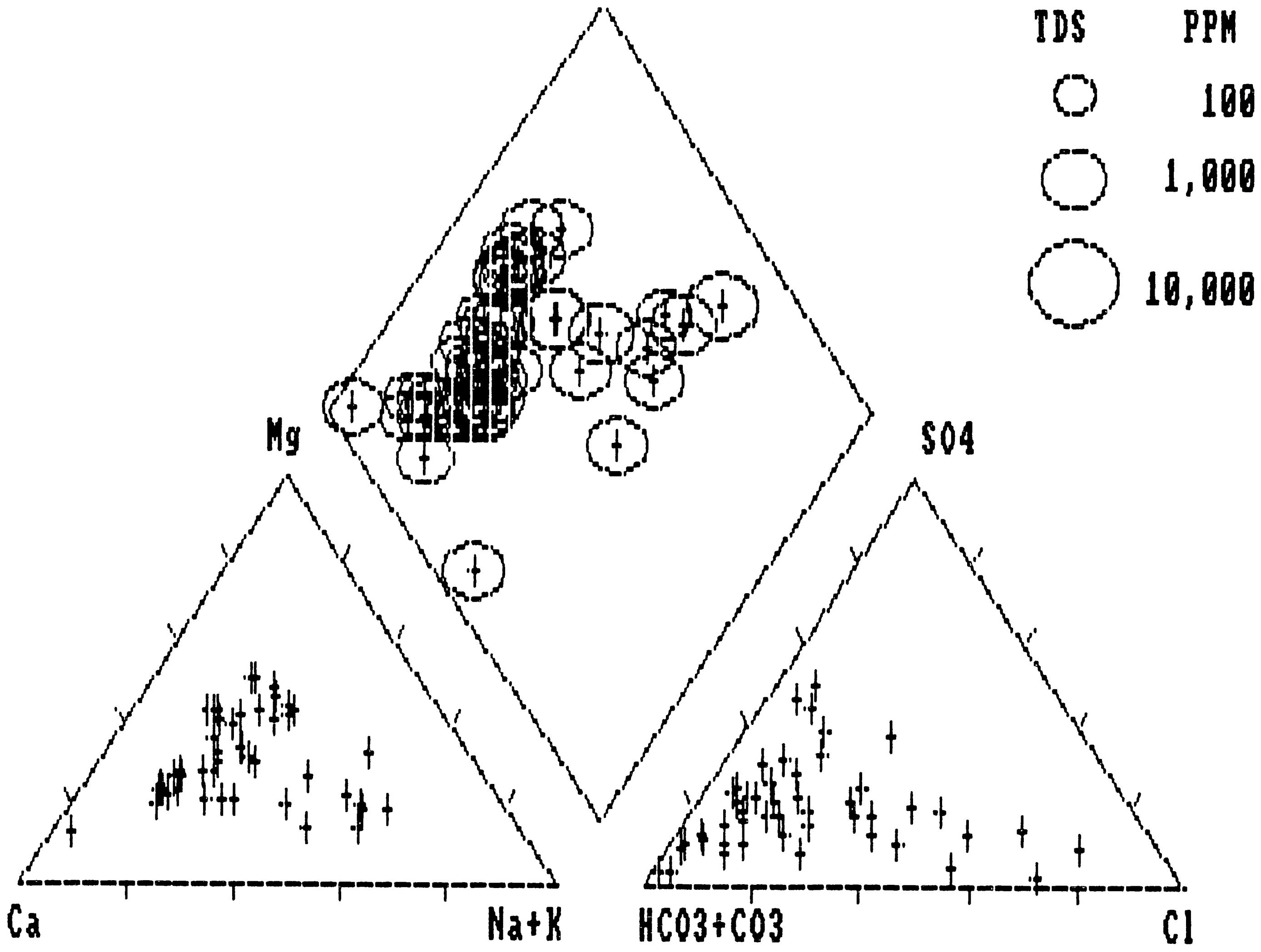


Figure 18. Piper Plot, Ogalalla Aquifer.

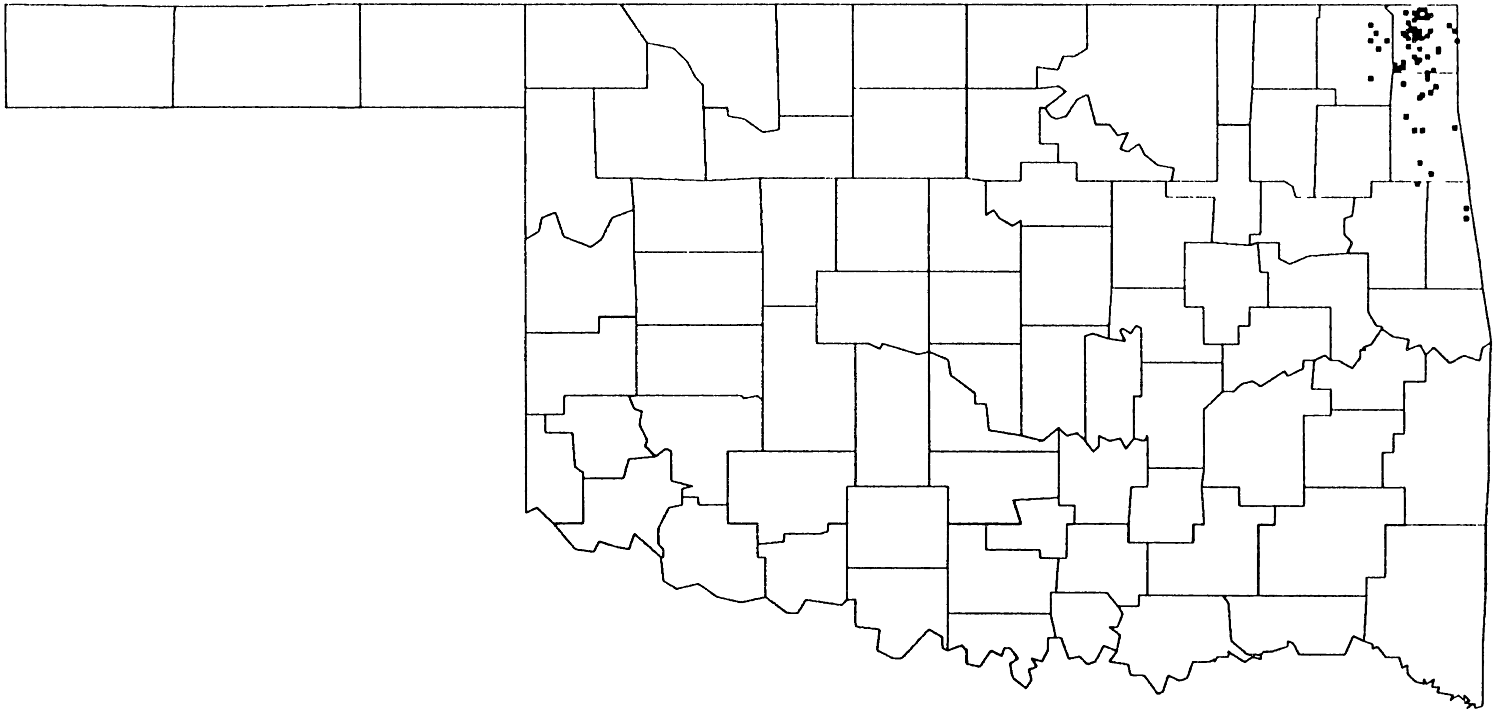


Figure 19. Locations of Sampling Sites, Roubidoux Aquifer.

TABLE 27

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, ROUBIDOUX AQUIFER

Constituent or Property	No. of * Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Dissolved solids (residue on evaporation)	199	88	158	200	290	480	954	113000
Specific conductance (micromhos/cm)	238	92	303	416	588	967	1703	125000
Hardness, total (dissolved as CaCO3)	210	58	86	123	140	164	210	740
Sodium, dissolved	181	1.4	7	13	44	120	270	3200
Calcium, dissolved	199	14	19	29	32	38.4	49	440
Magnesium, dissolved	200	1.1	8	11	14	16	21	110
Potassium, dissolved	184	0.4	1.9	2.1	3.1	4.3	7.9	27
Sulfate, dissolved	238	0.3	8.5	11.2	15	18	38	2596
Chloride, dissolved	236	1	7	15	55	170	389	65000
Bicarbonate (dissolved as HCO3)	186	124	148	161	174	190	212	724
Fluoride, dissolved	222	0.1	0.2	0.38	0.7	1.3	3	13
Nitrate, dissolved as nitrogen	61	0	0	0	0.05	0.2	0.5	1
Nitrate, dissolved as nitrate	61	0	0	0	0.2	0.9	2.2	4.5
Silica, dissolved as SiO2	168	7.4	9	9.6	10	11	12	36

*Number of samples which contained records for Constituent or Property
Units are mg/l except as noted
269 total samples

TABLE 28

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, ROUBIDOUX AQUIFER

Constituent	No. of* Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Sodium	176	.01056	.01778	.03806	.13199	.22910	.27497	.32051
Calcium	184	.01207	.03846	.04790	.07855	.11989	.13784	.27778
Magnesium	185	.00227	.01622	.02127	.03231	.04811	.06131	.11111
Potassium	179	.00146	.00522	.00690	.00804	.00898	.01138	.02121
Sulfate	199	.00014	.01514	.01979	.03758	.05011	.10664	.43344
Chloride	199	.00069	.03142	.06100	.19077	.34532	.43522	.58491
Bicarbonate (as HCO3)	169	.09741	.20249	.33447	.45686	.60693	.68131	.75158
Fluoride	192	0	.00081	.00130	.00177	.00317	.00444	.01121
Nitrate (as nitrogen)	47	0	0	0	.00012	.00019	.00079	.00276
Nitrate (as nitrate)	47	0	0	0	.00049	.00082	.00353	.01242
Silica (as SiO2)	165	.00661	.01110	.01662	.02693	.03308	.04379	.15663

*Represents number of samples with records necessary to convert values to a percentage of TDS
Values are percentages of TDS
269 total samples

TABLE 29

SAMPLES EXCEEDING E.P.A. DRINKING-WATER LIMITS, ROUBIDOUX AQUIFER

Constituent	Number of Samples	EPA Limit (mg/l)	Number Exceeding Limit	Percentage Exceeding Limit
Nitrate (as nitrogen)	61	10*	0	0.0
Nitrate (as nitrate)	61	45*	0	0.0
Fluoride	222	4*	12	5.4
Fluoride	222	2**	41	18.5
Chloride	236	250**	42	17.8
Sulfate	238	250**	5	2.1
Dissolved solids	199	500**	47	23.6

* MCL (based on health risks)
** SMCL (based on aesthetic criteria)

conductivity and chloride were from the Roubidoux aquifer. Of all aquifers analyzed, the lowest medial concentrations for dissolved solids, sulfate, bicarbonate, and nitrate were from the Roubidoux aquifer. Ranks of medial values, from aquifers selected, for the Roubidoux aquifer are in Table 30.

Figure 20 is the Piper diagram for samples from the Roubidoux aquifer. Principal anions are bicarbonate + carbonate and chloride; principal cations are calcium and sodium. The diamond plot shows calcium-magnesium bicarbonate-carbonate to sodium chloride as principal types of water.

A distinct trend on the Piper plot is the series of plotted analyses lying on "straight lines" which, when extrapolated, pass through the Na + K corner of the cation triangle and the Cl corner of the anion triangle. This trend indicates the possibility of NaCl being either added or removed from solution.

Rush Springs Aquifer

The Rush Springs aquifer is of Permian age (O.W.R.B., 1980, p. 64) and is in central Oklahoma (Figure 7). The aquifer generally is unconfined to partly confined and consist of fine-grained sandstone with some shale, dolomite and gypsum; the sandstone is cemented with calcium carbonate or calcium sulfate and solution removal of these agents has increased porosity in many areas (O.W.R.B., 1980, p. 64).

TABLE 30

RANKS OF MEDIAN VALUES, ROUBIDOUX AQUIFER, AMONG MEDIANS OF THE COMBINED DATA SET

Values Compared as	Constituent or Property Calcium	Magnesium	Sodium	Potassium	Chloride	Bicarbonate	Sulfate
Concentrations	2	2	5	6	6	1	1
Percentages of TDS	2	1	8	7	8	5	1

Values Compared as	Constituent or Property Fluoride	Silica	Nitrate (as nitrate)	Nitrate (as nitrogen)	Dissolved Solids	Hardness	Conductivity
Concentrations	6	2	1	1	1	2	3
Percentages of TDS	8	4	2	2	-	-	-

Possible ranks are 1 to 8, with 1 representing smallest values.

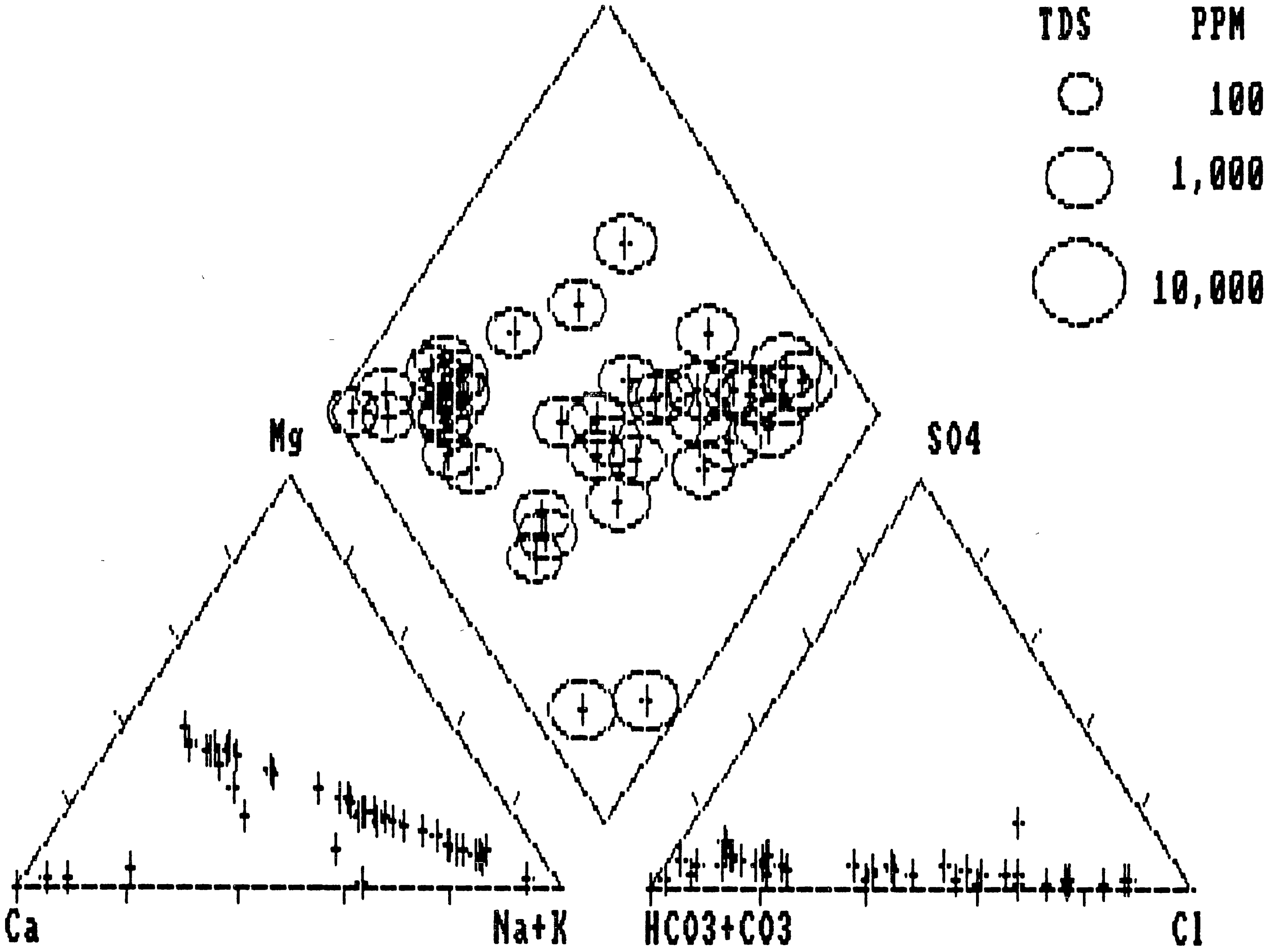


Figure 20. Piper Plot, Roubidoux Aquifer.

The aquifer generally is 200 to 300 ft. thick; well yields commonly range from 200 to 600 gpm, but some are greater than 1000 gpm (U.S.G.S., 1985, p. 350). Water from the Rush Springs aquifer is used extensively for irrigation (U.S.G.S., 1988, p. 418).

Sampling sites for the Rush Springs aquifer are shown in Figure 21 and percentile statistics are in Tables 31 and 32. All medial concentrations are below E.P.A. drinking-water limits. Numbers and percentages of samples exceeding E.P.A. limits are in Table 33.

Medial concentrations from the Rush Springs aquifer for calcium, sulfate, nitrate and silica were larger than medial concentrations from the total data set. Medial concentrations for conductivity and chloride from the Rush Springs aquifer were the smallest of all aquifers analyzed. Ranks of medial values, from aquifers selected, for the Rush Springs aquifer are in Table 34.

Figure 22 is a Piper plot for the Rush Springs aquifer. Bicarbonate + carbonate and sulfate are predominant anions; predominant cations are calcium and magnesium. The diamond portion shows calcium-magnesium bicarbonate-carbonate to calcium-magnesium sulfate-chloride as principal types of water.

Vamoosa Aquifer

The Vamoosa aquifer is of Upper Pennsylvanian age (O.W.R.B., 1980, p. 64); it extends from north-central to

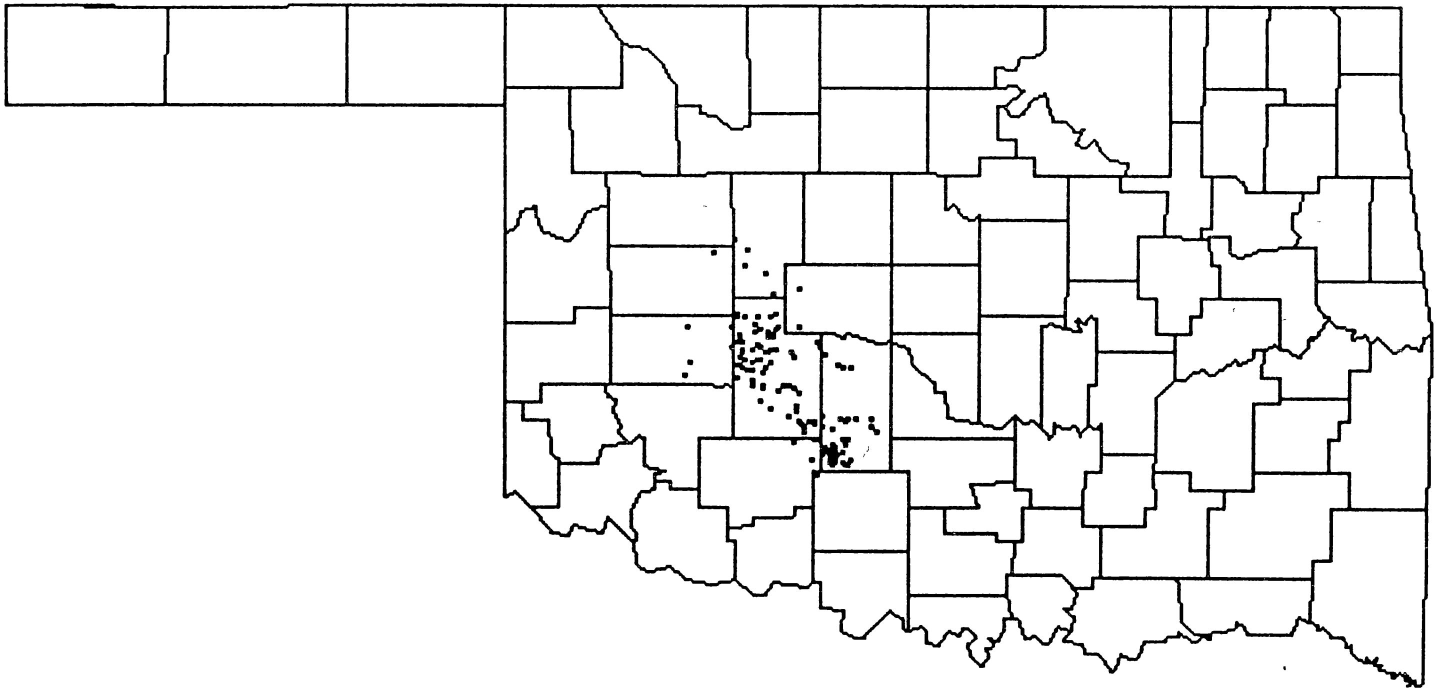


Figure 21. Locations of Sampling Sites, Rush Springs Aquifer.

TABLE 31

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, RUSH SPRINGS AQUIFER

Constituent or Property	No. of * Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Dissolved solids (residue on evaporation)	165	79	202	280	407	976	2600	6820
Specific conductance (micromhos/cm)	155	50	264	389	527	1140	2470	9060
Hardness, total (dissolved as CaCO3)	189	48	120	168	240	615	1600	2300
Sodium, dissolved	26	4	8 5	12	20	42	151	484
Calcium, dissolved	100	6.6	12	35	62	98	274	605
Magnesium, dissolved	86	0.3	7.3	10	18	34	68	330
Potassium, dissolved	20	0	0.4	1	2	3.4	5	11
Sulfate, dissolved	187	3	8.7	14	60	285	1300	3800
Chloride, dissolved	191	2.8	5	8	15	37	72	2000
Bicarbonate (dissolved as HCO3)	186	0.4	75	145	200	264	326	626
Fluoride, dissolved	31	0	0	0	0.2	0.3	0.4	40
Nitrate, dissolved as nitrogen	184	0	0.2	0.68	1.9	6.3	16	80
Nitrate, dissolved as nitrate	184	0	0.9	3	8.3	28	72	352
Silica, dissolved as SiO2	14	0.1	0.1	22	24	28	29	30

*Number of samples which contained records for Constituent or Property
Units are mg/l except as noted
191 total samples

TABLE 32

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, RUSH SPRINGS AQUIFER

Constituent	No. of* Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Sodium	26	.01007	.01342	.02760	.03770	.07179	.11960	.58382
Calcium	98	.00602	.03042	.08209	.12926	.17349	.20085	.25172
Magnesium	84	.00814	.01770	.02229	.03443	.04667	.06233	.42463
Potassium	20	0	.00061	.00115	.00193	.00386	.01678	.04099
Sulfate	164	.00579	.01966	.03728	.09711	.38381	.56773	.67985
Chloride	165	.00170	.00955	.01470	.02473	.05073	.08238	.35213
Bicarbonate (as HCO3)	161	.00144	.05969	.20982	.42968	.57248	.64036	.70678
Fluoride	31	0	0	.00000	.00024	.00049	.00096	.03591
Nitrate (as nitrogen)	161	0	.00018	.00078	.00443	.01510	.03308	.08686
Nitrate (as nitrate)	161	0	.00080	.00343	.01973	.06711	.14703	.38740
Silica (as SiO2)	14	.00034	.00034	.01636	.02548	.04459	.05796	.10066

*Represents number of samples with records necessary to convert values to a percentage of TDS
Values are percentages of TDS
191 total samples

TABLE 33

SAMPLES EXCEEDING E.P.A. DRINKING-WATER LIMITS, RUSH SPRINGS AQUIFER

Constituent	Number of Samples	EPA Limit (mg/l)	Number Exceeding Limit	Percentage Exceeding Limit
Nitrate (as nitrogen)	184	10*	28	15.2
Nitrate (as nitrate)	184	45*	28	15.2
Fluoride	31	4*	1	3.2
Fluoride	31	2**	1	3.2
Chloride	191	250**	5	2.6
Sulfate	187	250**	52	27.8
Dissolved solids	165	500**	70	42.4

* MCL (based on health risks)
** SMCL (based on aesthetic criteria)

TABLE 34

RANKS OF MEDIAN VALUES, RUSH SPRINGS AQUIFER, AMONG MEDIANS OF THE COMBINED DATA SET

Values Compared as	Constituent or Property						
	Calcium	Magnesium	Sodium	Potassium	Chloride	Bicarbonate	Sulfate
Concentrations	5	3	2	3	1	2	5
Percentages of TDS	6	2	2	3	1	4	6

Values Compared as	Constituent or Property						
	Fluoride	Silica	Nitrate (as nitrate)	Nitrate (as nitrogen)	Dissolved Solids	Hardness	Conductivity
Concentrations	2	7	6	6	5	4	1
Percentages of TDS	2	3	8	8	-	-	-

Possible ranks are 1 to 8, with 1 representing smallest values.

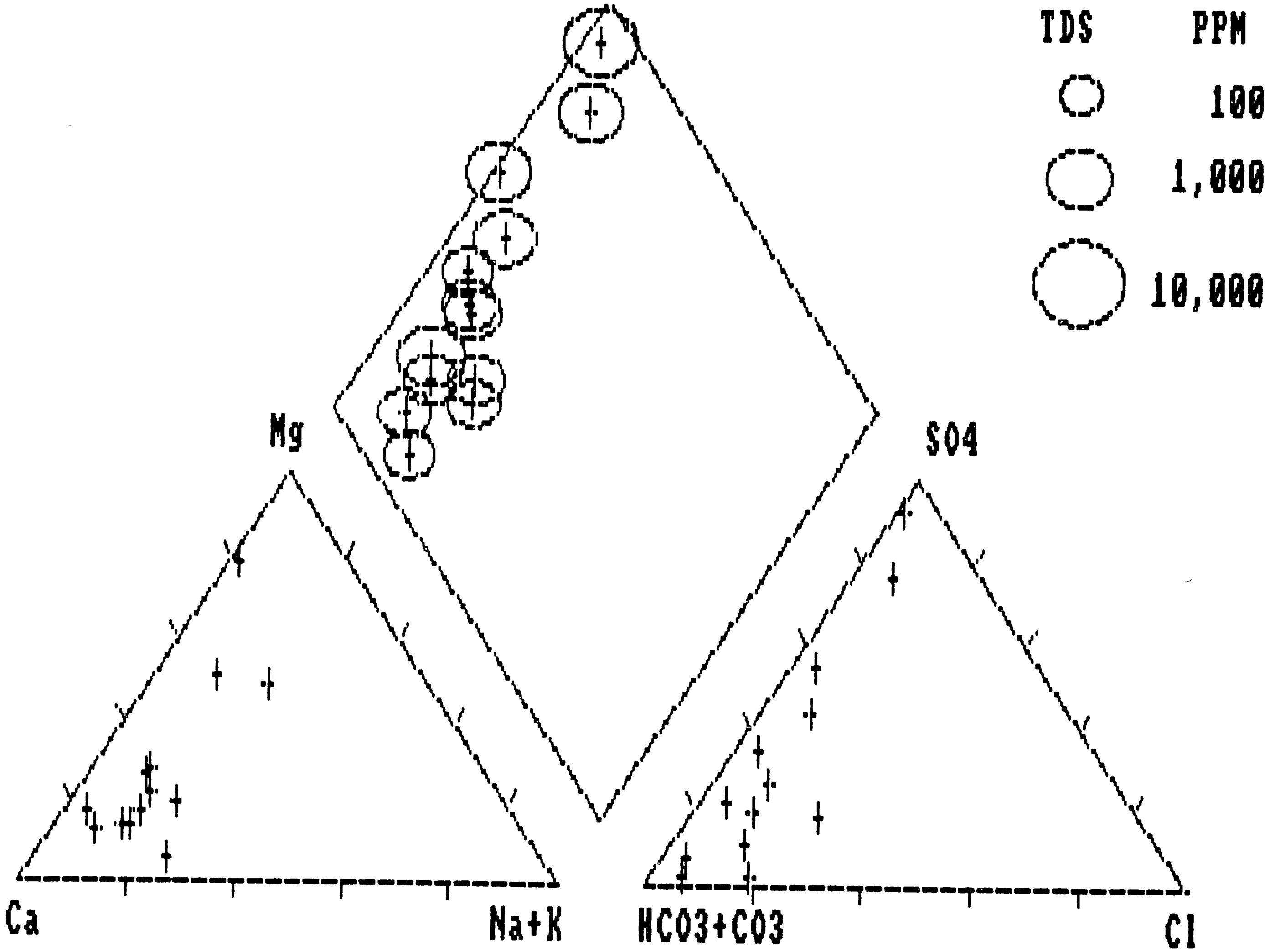


Figure 22. Piper Plot, Rush Springs Aquifer.

central Oklahoma (Figure 7). The aquifer is unconfined to confined and consists of interbedded sandstone, siltstone, shale and conglomerate (O.W.R.B., 1980, p. 64). Thickness ranges from 100 to 300 ft.; well yields commonly range from 100 to 100 gpm but some exceed 500 gpm (U.S.G.S., 1985, p. 350). Water from the Vamoosa aquifer is used primarily for public supply (U.S.G.S., 1988, p. 419).

Sampling sites for the Vamoosa aquifer are in Figure 23 and percentile statistics are in Tables 35 and 36. Medial concentrations of selected constituents are below E.P.A. drinking-water limits. Numbers and percentages of samples exceeding E.P.A. limits are in Table 37.

Medial concentrations from the Vamoosa aquifer for sodium, bicarbonate and silica were larger than medial concentrations from the total data set . Medial concentrations of hardness, calcium and magnesium from the Vamoosa aquifer, were the lowest of aquifers evaluated; the medial concentration of bicarbonate from the Vamoosa aquifer was the highest of aquifers evaluated. Ranks of medial values, from aquifers selected, for the Vamoosa aquifer are in Table 38.

Figure 24 is a Piper plot for the Vamoosa aquifer. Points are scattered and not conclusive for predominant cations or anions. The diamond plot is also scattered and depicts a wide variety of water types in the Vamoosa formation.

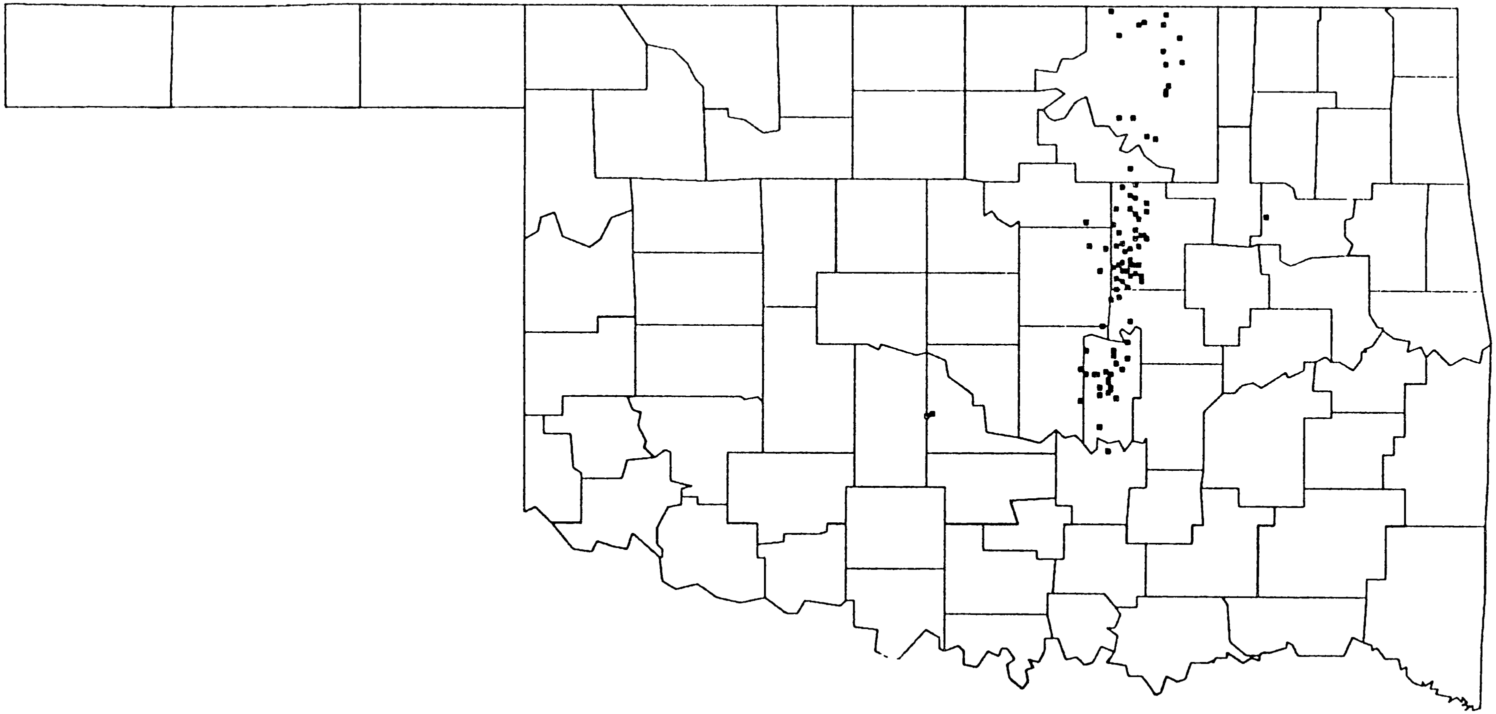


Figure 23. Locations of Sampling Sites, Vamoosa Aquifer.

TABLE 35

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, VAMOOSA AQUIFER

Constituent or Property	No. of * Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Dissolved solids (residue on evaporation)	98	57	121	204	385	960	1540	9530
Specific conductance (micromhos/cm)	101	51	154	350	664	1340	2750	26200
Hardness, total (dissolved as CaCO3)	97	5	26	42	120	290	760	3400
Sodium, dissolved	97	2.9	8.3	13	67	180	380	1900
Calcium, dissolved	97	1.7	5.1	11	27	62	160	840
Magnesium, dissolved	97	0.1	2	3.6	12	31	67	320
Potassium, dissolved	71	0.4	0.8	1.1	2	3.2	5.6	25
Sulfate, dissolved	99	0.2	7.6	13	26	59	190	2100
Chloride, dissolved	101	2.4	6.5	12	25	110	570	4800
Bicarbonate (dissolved as HCO3)	55	12	122	208	332	416	486	895
Fluoride, dissolved	46	0	0.1	0.1	0.2	0.2	0.3	1
Nitrate, dissolved as nitrogen	13	0	0	0.02	0.23	1.7	6.1	13
Nitrate, dissolved as nitrate	13	0	0	0.1	1	7.5	27	58
Silica, dissolved as SiO2	44	8.3	10	13	16	18	21	26

*Number of samples which contained records for Constituent or Property
Units are mg/l except as noted
101 total samples

TABLE 36

DESCRIPTIVE STATISTICS OF SELECTED GROUND-WATER QUALITY, VAMOOSA AQUIFER

Constituent	No. of* Samples	Minimum	10th Percentile	25th Percentile	Median 50th Percentile	75th Percentile	90th Percentile	Maximum
Sodium	94	.01330	.03643	.05663	.10768	.20366	.28447	.35044
Calcium	96	.00116	.00607	.05571	.09625	.14545	.18442	.22302
Magnesium	96	.00014	.00194	.01999	.03944	.06769	.08333	.16962
Potassium	71	.00076	.00153	.00313	.00579	.00905	.01291	.09174
Sulfate	96	.00154	.00990	.03385	.08712	.14528	.18959	.56854
Chloride	98	.01101	.02217	.03715	.08511	.18066	.37270	.55118
Bicarbonate (as HCO3)	52	.03818	.11738	.21751	.40264	.52289	.61406	.71401
Fluoride	44	0	.00008	.00040	.00071	.00120	.00165	.00526
Nitrate (as nitrogen)	13	0	0	.00009	.00022	.00326	.01643	.03575
Nitrate (as nitrate)	13	0	0	.00041	.00106	.01447	.07331	.15824
Silica (as SiO2)	44	.00147	.01552	.04523	.06969	.12857	.19118	.25926

*Represents number of samples with records necessary to convert values to a percentage of TDS
Values are percentages of TDS
101 total samples

TABLE 37

SAMPLES EXCEEDING E.P.A. DRINKING-WATER LIMITS, VAMOOSA AQUIFER

Constituent	Number of Samples	EPA Limit (mg/l)	Number Exceeding Limit	Percentage Exceeding Limit
Nitrate (as nitrogen)	13	10*	1	7.7
Nitrate (as nitrate)	13	45*	1	7.7
Fluoride	46	4*	0	0.0
Fluoride	46	2**	0	0.0
Chloride	101	250**	16	15.8
Sulfate	99	250**	7	7.1
Dissolved solids	98	500**	38	38.8

* MCL (based on health risks)
** SMCL (based on aesthetic criteria)

TABLE 38

RANKS OF MEDIAN VALUES, VAMOOSA AQUIFER, AMONG MEDIANS OF THE COMBINED DATA SET

Values Compared as	Constituent or Property						
	Calcium	Magnesium	Sodium	Potassium	Chloride	Bicarbonate	Sulfate
Concentrations	1	1	7	4	4	8	3
Percentages of TDS	4	3	7	6	6	2	5

Values Compared as	Constituent or Property						
	Fluoride	Silica	Nitrate (as nitrate)	Nitrate (as nitrogen)	Dissolved Solids	Hardness	Conductivity
Concentrations	3	5	3	3	3	1	5
Percentages of TDS	5	8	3	3	-	-	-

Possible ranks are 1 to 8, with 1 representing smallest values.

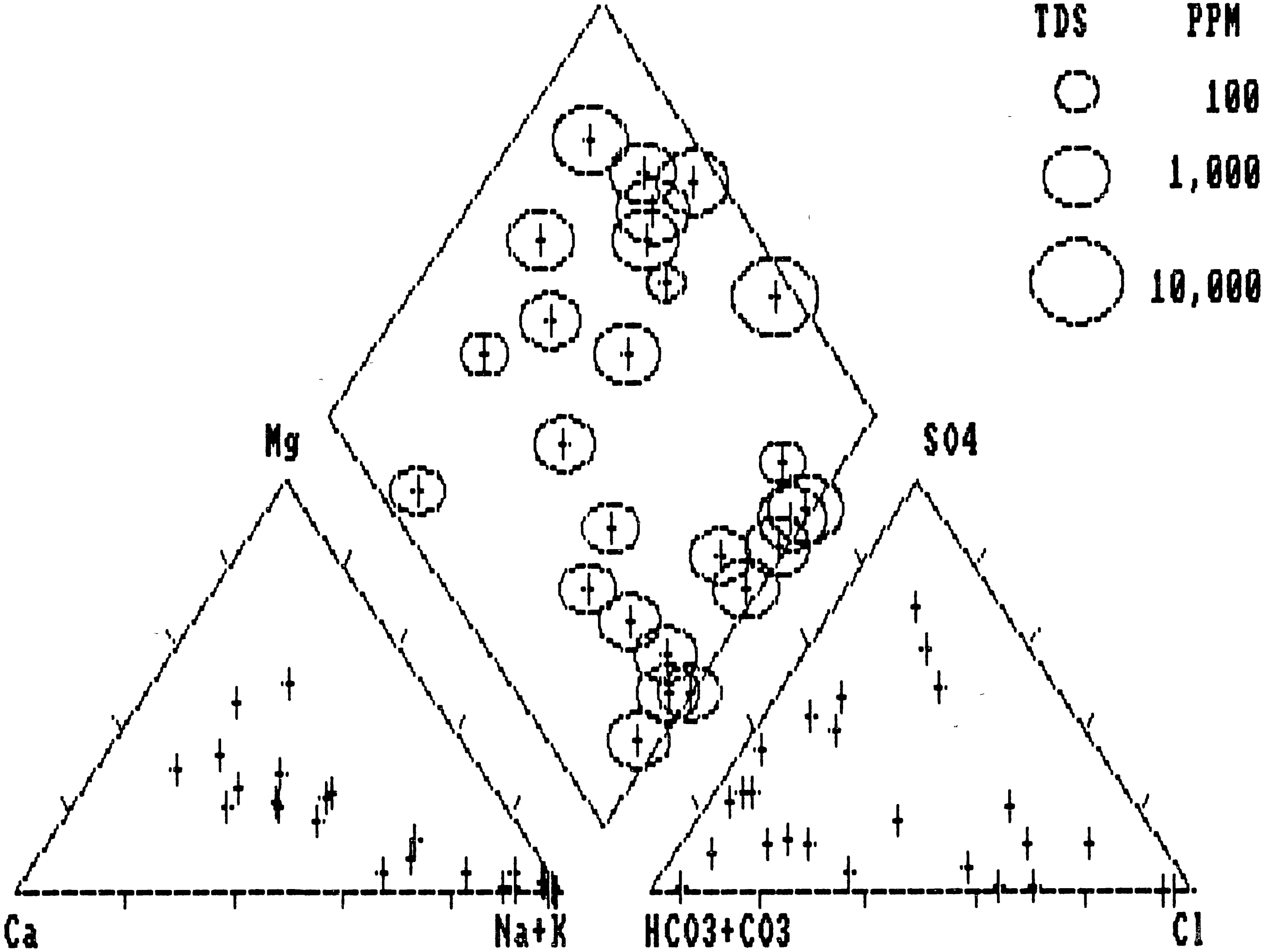


Figure 24. Piper Plot, Vamoosa Aquifer.

CHAPTER VII

COMPARISONS OF CONSTITUENTS BY AQUIFERS

Differences among constituents amoung aquifers, measured as concentrations and as percentages of TDS, are evident from the descriptive statistics. Of course, in any sampling, differences arise due simply to chance. Kruskal-Wallis tests were used to evaluate the null hypothesis that differences between aquifers for each constituent were matters of chance alone and therefore not significant. In all cases, the level critical for judgement of significance (the alpha-level) was 0.05.

Comparisons by All Aquifers

Probabilities from Kruskal-Wallis chi-squared test statistic for each constituent by all aquifers are in Table 39. The working hypothesis tested: Samples of all constituents were drawn from one population for each instance, if the working hypothesis were true, the probability of drawing such samples at random was less than one chance in a thousand. Accordingly, the working hypothesis was rejected.

TABLE 39

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED TEST STATISTIC, ALL AQUIFERS SELECTED

	Constituents Compared as	
Constituent or Property	Concentrations	Percentages of TDS
Calcium	<.001	<.001
Potassium	<.001	<.001
Magnesium	<.001	<.001
Sodium	<.001	<.001
Bicarbonate (as HCO_3)	<.001	<.001
Sulfate	<.001	<.001
Chloride	<.001	<.001
Fluoride	<.001	<.001
Nitrate (as nitrogen)	<.001	<.001
Nitrate (as nitrate)	<.001	<.001
Silica (as SiO_2)	<.001	<.001
Dissolved Solids	<.001	<.001
Hardness (as $CaCO_3$)	<.001	<.001
Conductivity	<.001	<.001

Hypothesis tested: Samples of all constituents were drawn from one population.

Comparisons by Pairs of Aquifers

The Kruskal-Wallis test also was used to test the working hypothesis that no significant difference exists among aquifers, with respect to constituents measured. Aquifers were evaluated by constituent, in pairs of aquifers. Probabilities from the Kruskal-Wallis test statistics for pairs of aquifers are in Appendix E, with constituents compared as concentrations, and in Appendix F, with constituents compared as percentages of TDS.

Tables 40 and 41 are summaries of probabilities. Aquifers judged to be not significantly different are indicated by the same letter. For example, in Table 40, an aquifer designated by CDE, was judged to be not significantly different from any other aquifer designated by C, D, or E, with respect to the constituent under evaluation (letters also represent the relative values of constituents; A represents the smallest values). The column entitled "percentage of like units" represents the percentage of tests that did not indicate significant differences.

No attempt was made to explain all differences that arose as results of the tests. Many differences may be the result of a combination of factors. Besides aquifer units, other natural as well as artificial factors may be responsible for differences.

Results of Table 40 of particular interest are the significantly large concentrations of calcium, chloride, magnesium, potassium, sodium, sulfate, conductivity,

TABLE 40

SUMMARY OF KRUSKAL-WALLIS TESTS, PAIRS OF AQUIFERS

		Aquifer Unit							
Constituent	Percentage of Like Units	Alluvium & Terrace Deposits	Arbuckle-Simpson Aquifer	Blaine-Dog Creek Aquifer	Garber-Wellington Aquifer	Ogallala Aquifer	Roubidoux Aquifer	Rush Springs Aquifer	Vamoosa Aquifer
Bicarbonate	25	D	D	B	D	C	A	B	D
Calcium	21.4	E	CD	F	B	D	A	D	ABC
Chloride	32.1	D	BCD	E	B	B	C	A	BC
Fluoride	32.1	C	CDE	BC	AB	E	D	A	A
Magnesium	28.6	D	BCD	E	C	D	A	C	AB
Nitrate as N	25	DF	B	F	C	E	A	EF	BCD
Nitrate as NO3	21.4	D	B	D	C	E	A	DE	BC
Potassium	10.7	D	A	G	B	F	E	BCD	C
Silicate	7.1	E	A	D	C	F	B	E	D
Sodium	35.7	D	A	E	BC	C	BC	B	BCD
Sulfate	14.3	D	B	E	B	C	A	C	B
Conductivity	32.1	D	D	E	BC	BC	AB	A	AC
Hardness	25	F	ABD	G	B	DE	A	E	AB
Dissolved solids	28.6	D	C	E	B	B	A	BC	AB

Working hypothesis: A pair of aquifers is not significantly different, with respect to concentrations of constituent "x".
Aquifers designated by the same letter were judged to be not significantly different (alpha = 0.05).

TABLE 41

SUMMARY OF KRUSKAL-WALLIS TESTS, PAIRS OF AQUIFERS

		Aquifer Unit							
Constituent	Percentage of Like Units	Alluvium & Terrace Deposits	Arbuckle-Simpson Aquifer	Blaine-Dog Creek Aquifer	Garber-Wellington Aquifer	Ogallala Aquifer	Roubidoux Aquifer	Rush Springs Aquifer	Vamoosa Aquifer
Bicarbonate	32.1	B	DE	A	E	CD	D	BC	BC
Calcium	35.7	D	CDE	E	A	AB	A	DE	BC
Chloride	32.1	C	BC	C	B	B	D	A	C
Fluoride	28.6	C	CD	A	B	D	D	AB	C
Magnesium	71.4	C	BCDE	D	E	CDE	AB	ACD	BCDE
Nitrate as N	25	DE	AB	C	C	E	A	F	BCD
Nitrate as NO3	25	DE	AB	C	C	E	A	F	BCD
Potassium	21.4	B	A	A	B	E	D	AB	C
Silicate	25	DE	B	A	D	EF	C	CDE	F
Sodium	28.6	D	A	CDE	BC	C	E	B	E
Sulfate	14.3	D	B	E	B	D	A	D	C

Working hypothesis: A pair of aquifers is not significantly different, with respect to constituent "X", expressed as a percentage of TDS.
Aquifers designated by the same letter were judged to be not significantly different (alpha = 0.05).

hardness and total dissolved solids in the Blaine-Dog Creek aquifer. High calcium, magnesium and sulfate concentrations were most likely from dolomite ($CaMg(CO_3)_2$), limestone ($CaCO_3$) and gypsum ($CaSO_4 \cdot 2 H_2O$) in the aquifer. High concentrations of these constituents would explain higher values for hardness, conductivity and dissolved solids. Higher concentrations of sodium and chloride are not readily explained by natural phenomena. Possible sources of these constituents are local discharges of oil-field brines or septic tanks.

Concentrations of total dissolved solids in the Garber-Wellington, Ogallala, Rush Springs and Vamoosa aquifers were not significantly different. This relationship could be explained by similarities in composition of the aquifers; they are primarily sand or sandstone with siltstone and shale.

Bicarbonate, calcium, magnesium and hardness concentrations from the Roubidoux Formation are as low as or lower than concentrations from other aquifers. This relationship is not expected because dolomite ($CaMg(CO_3)_2$), a primary source for those constituents, is a principal component of the Roubidoux aquifer and is uncommon in several other aquifers.

Of chemical constituents analyzed, there are generally few natural sources of sodium, chloride and fluoride. This circumstance could explain the highest percentage of like units from those constituents.

Results of Table 41 for constituents compared as a percentage of TDS show some interesting relationships. One is the high percentage of like units, where magnesium is concerned. Less than 30 percent of comparisons for magnesium were significantly different.

Statistically high values of nitrate are found in data concerning the Ogallala and Rush Springs aquifers. The combination of extensive irrigation, agricultural practices and generally unconfined systems may contribute to higher nitrate values.

The Blaine Formation had significantly high concentrations of sulfate. These higher values are most likely from the abundance of gypsum ($CaSO4$) in the aquifer.

Tables 42 to 45 show numbers and percentages of constituents that were not significantly different between pairs of aquifers. About 24 percent (95 of 392) of comparisons made for constituents as concentrations were not significantly different. Almost 30 percent (95 of 302) of comparisons made for constituents as a percentage of TDS were not significantly different. Conversion of data to percentages of TDS, mentioned in the methodology section, tends to reduce variance in the data.

TABLE 42

NUMBERS OF CONSTITUENTS, NOT SIGNIFICANTLY DIFFERENT, PAIRS OF AQUIFERS

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	5						
Blaine-Dog Creek	3	1					
Garber-Wellington	2	5	1				
Ogallala	0	5	0	4			
Roubidoux	0	3	0	2	2		
Rush Springs	4	3	3	5	6	2	
Vamoosa	3	8	1	11	4	7	5

Alpha = 0.05
Constituents analyzed as concentrations
14 Constituents analyzed

TABLE 43

PERCENTAGES OF CONSTITUENTS, NOT SIGNIFICANTLY DIFFERENT, PAIRS OF AQUIFERS

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	35.7						
Blaine-Dog Creek	21.4	7.1					
Garber-Wellington	14.3	35.7	7.1				
Ogallala	0	35.7	0	28.6			
Roubidoux	0	21.4	0	14.3	14.3		
Rush Springs	28.6	21.4	21.4	35.7	42.9	14.3	
Vamoosa	21.4	57.1	7.1	78.6	28.6	50.0	35.7

Alpha = 0.05
Constituents analyzed as concentrations
14 Constituents analyzed

TABLE 44

NUMBERS OF CONSTITUENTS, NOT SIGNIFICANTLY DIFFERENT, PAIRS OF AQUIFERS

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	4						
Blaine-Dog Creek	2	4					
Garber-Wellington	2	4	3				
Ogallala	5	4	2	4			
Roubidoux	0	5	1	1	3		
Rush Springs	6	3	4	4	4	2	
Vamoosa	6	6	5	3	4	2	2

Alpha = 0.05
Constituents analyzed as percentages of TDS
11 Constituents analyzed

TABLE 45

PERCENTAGES OF CONSTITUENTS, NOT SIGNIFICANTLY DIFFERENT, PAIRS OF AQUIFERS

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	36.4						
Blaine-Dog Creek	18.2	36.4					
Garber-Wellington	18.2	36.4	27.3				
Ogallala	45.5	36.4	18.2	36.4			
Roubidoux	0	45.5	9.1	9.1	27.3		
Rush Springs	54.5	27.3	36.4	36.4	36.4	18.2	
Vamoosa	54.5	54.5	45.5	27.3	36.4	18.2	18.2

Alpha = 0.05
Constituents analyzed as percentages of TDS
11 Constituents analyzed

CHAPTER VIII

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was to summarize ground-water quality in Oklahoma and to determine the general cases in which significant differences exist among aquifers. Ground-water quality was evaluated by the following variables: total dissolved solids, conductivity, hardness, calcium, magnesium, sodium, potassium, chloride, sulfate, bicarbonate, fluoride, silica, and nitrate. Data used for the study came from U.S. Geological Survey records (WATSTORE) and was accessed by the computer program "Hydrodata QW". Statistical testing was done by the computer program "SYSTAT".

Distribution functions of data were evaluated with Lilliefors' test for normality. The test indicated that the majority of samples were not drawn randomly from a normal population. On the whole, no reason was preceived for conclusion that the samples were nonrandom; therefore, percentile statistics were chosen to summarize variables. Statistical parameters recorded were minima and maxima, and 10th, 25th, 50th, 75th, and 90th percentiles. Numbers and percentages of samples exceeding E.P.A. drinking-water limits were determined for each aquifer.

The Kruskal-Wallis test, a nonparametric or distribution-free test, was used to compare aquifers for selected variables. Samples from all aquifers for each variable were tested for the hypothesis: All samples were drawn from populations that were not significantly different, with respect to contents of variables measured. The hypothesis was rejected for each variable; therefore, pairs of aquifers were tested under the same hypothesis. Probabilities were recorded and summarized for each variable, and numbers and percentages of variables not significantly different for pairs of aquifers also were recorded.

Conclusions

The U.S. Geological Survey's National Water Data Storage and Retrieval System (WATSTORE) provided an adequate supply of records for statistical analyses. Conditions for collection of samples supported the assumption that samples were effectively random, and standards of the U.S.G.S. provided confidence of accurate records.

Results of distribution tests indicated that ground-water quality, within aquifers and sampled over a large area, generally does not follow a normal distribution. Conversion of measurements to percentages of TDS, which tends to reduce effects of recharge and discharge areas, wet and dry periods, and lengths and times of flowpaths, commonly does not produce distributions that conform to the normal distribution. A possible explanation for the non-normal distributions is the occurance of multiple populations within aquifers. Although identifying multiple populations was not the intended purpose of this study, Appendix G contains examples on inferring and identifying multiple populations from samples. In many instances, nonparametric or distribution-free statistical tests are necessary for analysis of ground-water quality.

Of variables analyzed, the largest percentage of samples exceeding E.P.A. drinking-water limits did so on the basis of total dissolved solids. The majority of these samples (500 of 806) were from alluvium and alluvial terrace deposits, and from the Blaine-Dog Creek aquifer. The Blaine-Dog Creek aquifer had uncommonly large percentages of samples exceeding E.P.A. drinking-water limits for chloride, sulfate, and dissolved solids. Except for the Blaine-Dog Creek aquifer, ground-water is generally suitable for most uses.

Results of Kruskal-Wallis tests indicated that ground-water quality varied significantly between aquifers. Compared as percentages of TDS, variables showed fewer differences. Aquifers with similar lithologies differed significantly for many variables; this relationship indicates ground water is altered by many factors other than the rock that contains it.

Further Investigations

Statistical procedures used in this investigation can be applied to a variety of measurements of water. In addition to ground-water quality, such statistics could be used to test differences in stream-water quality, well yields, stream flow, water-quality changes with time and distance, and other similar variables. Data from this investigation could be evaluated further to determine whether ground-water quality within aquifers has changed with time.

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APPENDIXES

APPENDIX A

EXAMPLE OF LILLIEFORS' TEST FOR NORMALITY

ASSUMPTION: The sample is random.

HYPOTHESES: (Ho) The random sample has a normal distribution, with unspecified mean and variance.
(Ha) The sample is not from a normal distribution.

STEPS

(1) Arrange the sample from smallest to largest (Xi).
(2) Compute the mean of the sample.
(3) Compute the standard deviation of the sample (s).
(4) Convert to "standardized" sample (Si) by subtracting the mean from each observation and dividing the difference by s.
(5) Compute the frequencies of Si (F(Si)) by subtracting 1 from the position of each observation within the sample and dividing the difference by the total number of observations (n).
(6) Use Table for Normal Distributions (Conover, 1980, p. 428-429) to determine the expected frequencies (Fe(Si)) of the observations in Si.
(7) Compute the absolute value of the differences (D) between Fe(Si) and f(Si).
(8) DMAX is the maximum D.
(9) Use the Table for Lilliefors' Test Statistic for Normality (Conover, 1980, p. 463) to determine probability of Ho being true.

EXAMPLE OF LILLIEFORS' TEST FOR NORMALITY

DATA: NINETEEN OBSERVATIONS OF FLUORIDE CONCENTRATIONS (mg/l) WERE DRAWN FROM THE BLAINE GYPSUM AND DOG CREEK SHALE.

	STEP 1 Xi	(Xi-MEAN)^2	STEP 4 Si	STEP 5 F(Si)	STEP 6 Fe(Si)	STEP 7 D
1	0	0.240	-1.98	0.000	0.024	0.024
2	0	0.240	-1.98	0.053	0.024	0.029
3	0.2	0.084	-1.17	0.105	0.121	0.016
4	0.3	0.036	-0.77	0.158	0.220	0.062
5	0.3	0.036	-0.77	0.211	0.220	0.009
6	0.4	0.008	-0.36	0.263	0.360	0.097
7	0.4	0.008	-0.36	0.316	0.360	0.044
8	0.5	0.000	0.04	0.368	0.516	0.148
9	0.5	0.000	0.04	0.421	0.516	0.095
10	0.5	0.000	0.04	0.474	0.516	0.042
11	0.5	0.000	0.04	0.526	0.516	0.010
12	0.6	0.012	0.45	0.579	0.674	0.095
13	0.7	0.044	0.85	0.632	0.802	$\boxed{0.170}$
14	0.7	0.044	0.85	0.684	0.802	0.118
15	0.7	0.044	0.85	0.737	0.802	0.065
16	0.7	0.044	0.85	0.789	0.802	0.013
17	0.7	0.044	0.85	0.842	0.802	0.040
18	0.7	0.044	0.85	0.895	0.802	0.093
19	0.9	0.169	1.66	0.947	0.952	0.005

STEP 2: SUM OF Xi = 9.3
NO. OF OBSERVATIONS = 19
MEAN = 9.3 / 19
MEAN = 0.48947

STEP 3: SUM OF (Xi-MEAN)^2= 1.0978
STANDARD DEVIATION = (1.0978/19-1) ^.5
STANDARD DEVIATION = 0.24697

STEP 8: DMAX IS .170

STEP 9: FROM TABLE, FOR SAMPLE SIZE 19
P = .85 THEN DMAX = .169
P = .90 THEN DMAX = .179

*PROBABILITY OF RANDOM SAMPLE HAVING BEEN DRAWN FROM A NORMAL DISTRIBUTION IS SLIGHTLY LESS THAN .15

TABLE 46

AREAS OF THE NORMAL DISTRIBUTION

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.0000	.0040	.0080	.0120	.0160	.0199	.0239	.0279	.0319	.0359
0.1	.0398	.0438	.0478	.0517	.0557	.0596	.0636	.0675	.0714	.0753
0.2	.0793	.0832	.0871	.0910	.0948	.0987	.1026	.1064	.1103	.1141
0.3	.1179	.1217	.1255	.1293	.1331	.1368	.1406	.1443	.1480	.1517
0.4	.1554	.1591	.1628	.1664	.1700	.1736	.1772	.1808	.1844	.1879
0.5	.1915	.1950	.1985	.2019	.2054	.2088	.2123	.2157	.2190	.2224
0.6	.2257	.2291	.2324	.2357	.2389	.2422	.2454	.2486	.2517	.2549
0.7	.2580	.2611	.2642	.2673	.2704	.2734	.2764	.2794	.2823	.2852
0.8	.2881	.2910	.2939	.2967	.2995	.3023	.3051	.3078	.3106	.3133
0.9	.3159	.3186	.3212	.3238	.3264	.3289	.3315	.3340	.3365	.3389
1.0	.3413	.3438	.3461	.3485	.3508	.3531	.3554	.3577	.3599	.3621
1.1	.3643	.3665	.3686	.3708	.3729	.3749	.3770	.3790	.3810	.3830
1.2	.3849	.3869	.3888	.3907	.3925	.3944	.3962	.3980	.3997	.4015
1.3	.4032	.4049	.4066	.4082	.4099	.4115	.4131	.4147	.4162	.4177
1.4	.4192	.4207	.4222	.4236	.4251	.4265	.4279	.4292	.4306	.4319
1.5	.4332	.4345	.4357	.4370	.4382	.4394	.4406	.4418	.4429	.4441
1.6	.4452	.4463	.4474	.4484	.4495	.4505	.4515	.4525	.4535	.4545
1.7	.4554	.4564	.4573	.4582	.4591	.4599	.4608	.4616	.4625	.4633
1.8	.4641	.4649	.4656	.4664	.4671	.4678	.4686	.4693	.4699	.4706
1.9	.4713	.4719	.4726	.4732	.4738	.4744	.4750	.4756	.4761	.4767
2.0	.4772	.4778	.4783	.4788	.4793	.4798	.4803	.4808	.4812	.4817
2.1	.4821	.4826	.4830	.4834	.4838	.4842	.4846	.4850	.4854	.4857
2.2	.4861	.4864	.4868	.4871	.4875	.4878	.4881	.4884	.4887	.4890
2.3	.4893	.4896	.4898	.4901	.4904	.4906	.4909	.4911	.4913	.4916
2.4	.4918	.4920	.4922	.4925	.4927	.4929	.4931	.4932	.4934	.4936
2.5	.4938	.4940	.4941	.4943	.4945	.4946	.4948	.4949	.4951	.4952
2.6	.4953	.4955	.4956	.4957	.4959	.4960	.4961	.4962	.4963	.4964
2.7	.4965	.4966	.4967	.4968	.4969	.4970	.4971	.4972	.4973	.4974
2.8	.4974	.4975	.4976	.4977	.4977	.4978	.4979	.4979	.4980	.4981
2.9	.4981	.4982	.4982	.4983	.4984	.4984	.4985	.4985	.4986	.4986
3.0	.4987	.4987	.4987	.4988	.4988	.4989	.4989	.4989	.4990	.4990

modified from Conover, 1980, p. 428-431

TABLE 47

QUANTILES OF THE LILlIEFORS TEST STATISTIC FOR NORMALITY

Sample Size (n)			p=		
	.80	.85	.90	.95	.99
4	.300	.319	.352	.381	.417
5	.285	.299	.315	.337	.405
6	.265	.277	.294	.319	.364
7	.247	.258	.276	.300	.348
8	.233	.244	.261	.285	.331
9	.223	.233	.249	.271	.311
10	.215	.224	.239	.258	.294
11	.206	.217	.230	.249	.284
12	.199	.212	.223	.242	.275
13	.190	.202	.214	.234	.268
14	.183	.194	.207	.227	.261
15	.177	.187	.201	.220	.257
16	.173	.182	.195	.213	.250
17	.169	.177	.189	.206	.245
18	.166	.173	.184	.200	.239
19	.163	.169	.179	.195	.235
20	.160	.166	.174	.190	.231
25	.142	.147	.158	.173	.200
30	.161	.136	.144	.161	.187
>30	$\frac{.736}{n^{.5}}$	$\frac{.768}{n^{.5}}$	$\frac{.805}{n^{.5}}$	$\frac{.886}{n^{.5}}$	$\frac{1.031}{n^{.5}}$

modified from Conover, 1980, p.463

APPENDIX B

EXAMPLE OF KRUSKAL-WALLIS TEST

KRUSKAL-WALLIS TEST

Ho: All of the population-distribution functions are identical

Ha: At least one of the populations tends to yo uield larger obsrvations than at least one of the other populations.

Data consist of k random samples of possible different sizes (n).

STEPS:(1) Arrange data in ascending order in one sample (size N).

(2) Assign ranks to the data in accordance to their position. Ties are averaged.

(3) Sum the ranks for each of k samples.

(4) Compute the sum of the squares of all ranks $((Rk)^2)$.

(5) Compute the test statistic from the equations:
$T=1/S^2$ (sum each k $\{(\text{sum of ranks}/n)-N)N+1)^2/4\})$
where $S^2 = 1/(N-1)\ ((Rk)^2 - N(N+1)^2/4)$

(6) Use T in the Chi-Square Distribution Table, with k-1 degrees of freedom, for probability that Ho is true.

EXAMPLE OF KRUSKAL-WALLIS TEST

Data: Potassium concentrations (mg/l) from twenty observations in the Rush Springs aquifer and thirty observations from the Arbuckle-Simpson aquifer.

Arbuckle Simpson	Rush Springs
0.3	0
0.4	0.4
0.4	0.8
0.4	0.8
0.5	1
0.7	1.1
0.8	1.2
0.8	1.3
0.8	1.4
0.9	2
1	2.4
1	2.4
1	3
1	3.2
1	3.4
1	4
1.2	5
1.2	5
1.2	10
1.4	11
1.4	
1.5	
1.5	
1.6	
1.7	
1.8	
2.1	
2.2	
3.1	
5.3	

rank	rank^2	k	data
1	1	rs	0
2	4	ab	0.3
4.5	20.25	ab	0.4
4.5	20.25	ab	0.4
4.5	20.25	ab	0.4
4.5	20.25	rs	0.4
7	49	ab	0.5
8	64	ab	0.7
11	121	ab	0.8
11	121	ab	0.8
11	121	ab	0.8
11	121	rs	0.8
11	121	rs	0.8
14	196	ab	0.9
18	324	ab	1
18	324	ab	1
18	324	ab	1
18	324	ab	1
18	324	ab	1
18	324	ab	1
18	324	rs	1
22	484	rs	1.1
24.5	600.25	ab	1.2
24.5	600.25	ab	1.2
24.5	600.25	ab	1.2
24.5	600.25	rs	1.2
27	729	rs	1.3
29	841	ab	1.4
29	841	ab	1.4
29	841	rs	1.4
31.5	992.25	ab	1.5
31.5	992.25	ab	1.5
33	1089	ab	1.6
34	1156	ab	1.7
35	1225	ab	1.8
36	1296	rs	2
37	1369	ab	2.1
38	1444	ab	2.2
39.5	1560.25	rs	2.4
39.5	1560.25	rs	2.4
41	1681	rs	3
42	1764	ab	3.1
43	1849	rs	3.2
44	1936	rs	3.4
45	2025	rs	4
46.5	2162.25	rs	5
46.5	2162.25	rs	5
48	2304	ab	5.3
49	2401	rs	10
50	2500	rs	11

sum of the ranks for Arbuckle-Simpson =647 n=30
sum of the ranks for Rush Springs = 628 n=20
sum of squares of all ranks = 42873.5

S^2=1/(50-1)(42873.5-50((50+1)^2)/4)
S^2 = 211.449

T=1/211.449((647/30-50((50+1)^2)/4)+(628/20-50((50+1)^2)/4))
T=5.488

*From chi-square distribution table (Conover, 1980, p. 432), 5.488 is between p=.975 (5.024) and p=.990 (6.635). The probability of the samples being from the same population is between .010 and.025.

TABLE 48

CHI-SQUARED DISTRIBUTION

				p=			
k=	0.750	0.900	0.950	0.975	0.990	0.995	0.999
1	1.323	2.706	3.841	5.024	6.635	7.879	10.83
2	2.773	4.605	5.991	7.378	9.21	10.60	13.82
3	4.108	6.251	7.815	9.438	11.34	12.84	16.27
4	5.385	7.779	9.488	11.14	13.28	14.86	18.47
5	6.626	9.236	11.07	12.83	15.09	16.75	20.51
6	7.841	10.64	12.59	14.45	16.81	18.55	22.46
7	90.37	12.02	14.07	16.01	18.48	20.28	24.32
8	10.22	13.36	15.51	17.53	20.09	21.96	23.13
9	11.39	14.68	16.92	19.02	21.67	23.59	27.88
10	12.55	15.99	18.31	20.48	23.21	25.19	29.59

Modified from Conover, 1980, p. 432.
Probability of Ho being true is 1-p.

APPENDIX C

PROBABILITIES, FROM LILLIEFORS' DMAX TEST STATISTIC, OF SAMPLES HAVING BEEN DRAWN RANDOMLY FROM NORMAL DISTRIBUTIONS

TABLE 49

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS, LILLIEFORS' DMAX TEST STATISTIC, ALLUVIUM AND TERRACE DEPOSITS

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	644	<.001	<.001	0.015	<.001
Calcium	364	<.001	<.001	<.001	<.001
Chloride	748	<.001	<.001	<.001	<.001
Conductivity	828	<.001	<.001	<.001	<.001
Fluoride	183	<.001	<.001	<.001	<.001
Hardness	660	<.001	<.001	<.001	<.001
Potassium	189	<.001	<.001	<.001	<.001
Magnesium	347	<.001	<.001	<.001	0.001
Nitrate (as nitrogen)	536	<.001	<.001	<.001	<.001
Nitrate (as nitrate)	537	<.001	<.001	<.001	<.001
Silica	149	0.002	<.001	<.001	<.001
Sodium	216	<.001	<.001	<.001	0.023
Sulfate	714	<.001	<.001	<.001	<.001
Dissolved Solids	611	<.001	<.001	<.001	<.001

constituents tested as concentrations

TABLE 50

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS, LILLIEFORS' DMAX TEST STATISTIC, ARBUCKLE-SIMPSON AQUIFER

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	66	<.001	0.091	<.001	<.001
Calcium	37	<.001	0.026	<.001	<.001
Chloride	66	<.001	<.001	<.001	0.001
Conductivity	64	<.001	<.001	<.001	0.004
Fluoride	61	<.001	<.001	<.001	<.001
Hardness	66	<.001	<.001	<.001	<.001
Potassium	30	0.009	<.001	0.213	0.212
Magnesium	37	0.003	0.001	<.001	<.001
Nitrate (as nitrogen)	35	<.001	<.001	<.001	<.001
Nitrate (as nitrate)	35	<.001	<.001	<.001	<.001
Silica	21	0.017	<.001	0.068	0.165
Sodium	30	<.001	<.001	<.001	<.001
Sulfate	66	<.001	<.001	<.001	0.019
Dissolved Solids	66	<.001	<.001	<.001	<.001

constituents tested as concentrations

TABLE 51

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS, LILLIEFORS' DMAX TEST STATISTIC, BLAINE-DOG CREEK AQUIFER

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	139	<.001	<.001	<.001	<.001
Calcium	70	<.001	<.001	<.001	<.001
Chloride	141	<.001	<.001	<.001	0.002
Conductivity	135	<.001	<.001	<.001	<.001
Fluoride	19	0.149	0.112	0.02	0.11
Hardness	135	<.001	<.001	<.001	<.001
Potassium	22	<.001	<.001	<.001	0.021
Magnesium	67	<.001	<.001	0.001	<.001
Nitrate (as nitrogen)	98	<.001	<.001	<.001	0.001
Nitrate (as nitrate)	98	<.001	<.001	<.001	0.001
Silica	18	0.008	<.001	0.012	0.001
Sodium	22	0.001	<.001	0.214	0.423
Sulfate	141	<.001	<.001	<.001	<.001
Dissolved Solids	126	<.001	<.001	<.001	<.001

constituents tested as concentrations

TABLE 52

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS, LILLIEFORS' DMAX TEST STATISTIC, GARBER-WELLINGTON AQUIFER

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	187	0.007	<.001	<.001	<.001
Calcium	144	<.001	<.001	<.001	<.001
Chloride	207	<.001	<.001	<.001	<.001
Conductivity	198	<.001	<.001	<.001	<.001
Fluoride	86	<.001	<.001	<.001	<.001
Hardness	191	<.001	<.001	<.001	<.001
Potassium	66	<.001	<.001	<.001	0.007
Magnesium	138	<.001	<.001	<.001	<.001
Nitrate (as nitrogen)	148	<.001	<.001	<.001	<.001
Nitrate (as nitrate)	148	<.001	<.001	<.001	<.001
Silica	70	<.001	<.001	<.001	<.001
Sodium	78	<.001	<.001	<.001	<.001
Sulfate	196	<.001	<.001	<.001	<.001
Dissolved Solids	159	<.001	<.001	<.001	<.001

constituents tested as concentrations

TABLE 53

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS, LILLIEFORS' DMAX TEST STATISTIC, OGALLALA AQUIFER

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	242	<.001	<.001	<.001	<.001
Calcium	61	0.251	<.001	0.586	0.206
Chloride	245	<.001	<.001	<.001	<.001
Conductivity	245	<.001	<.001	<.001	<.001
Fluoride	79	0.003	<.001	0.077	0.027
Hardness	245	<.001	<.001	<.001	<.001
Potassium	119	0.002	<.001	<.001	<.001
Magnesium	53	<.001	<.001	<.001	0.004
Nitrate (as nitrogen)	186	<.001	<.001	<.001	0.001
Nitrate (as nitrate)	186	<.001	<.001	<.001	<.001
Silica	55	<.001	<.001	<.001	<.001
Sodium	119	<.001	<.001	<.001	<.001
Sulfate	243	<.001	<.001	<.001	0.011
Dissolved Solids	202	<.001	<.001	<.001	<.001

constituents tested as concentrations

TABLE 54

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS, LILLIEFORS' DMAX TEST STATISTIC, ROUBIDOUX AQUIFER

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	186	<.001	<.001	<.001	<.001
Calcium	199	<.001	<.001	<.001	<.001
Chloride	236	<.001	<.001	<.001	0.003
Conductivity	238	<.001	<.001	<.001	<.001
Fluoride	222	<.001	<.001	<.001	<.001
Hardness	210	<.001	<.001	<.001	<.001
Potassium	184	<.001	<.001	<.001	<.001
Magnesium	200	<.001	<.001	<.001	<.001
Nitrate (as nitrogen)	61	<.001	<.001	<.001	<.001
Nitrate (as nitrate)	61	<.001	<.001	<.001	<.001
Silica	168	<.001	<.001	<.001	<.001
Sodium	181	<.001	<.001	<.001	<.001
Sulfate	238	<.001	<.001	<.001	<.001
Dissolved Solids	199	<.001	<.001	<.001	<.001

constituents tested as concentrations

TABLE 55

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS, LILLIEFORS' DMAX TEST STATISTIC, RUSH SPRINGS AQUIFER

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	186	0.016	<.001	0.047	<.001
Calcium	100	<.001	<.001	<.001	0.021
Chloride	191	<.001	<.001	<.001	<.001
Conductivity	155	<.001	<.001	<.001	<.001
Fluoride	31	<.001	<.001	<.001	<.001
Hardness	189	<.001	<.001	<.001	<.001
Potassium	20	0.051	<.001	0.668	0.59
Magnesium	86	<.001	<.001	<.001	0.022
Nitrate (as nitrogen)	184	<.001	<.001	<.001	<.001
Nitrate (as nitrate)	184	<.001	<.001	<.001	0.022
Silica	14	0.017	0.473	<.001	<.001
Sodium	26	<.001	<.001	<.001	0.058
Sulfate	187	<.001	<.001	<.001	<.001
Dissolved Solids	165	<.001	<.001	<.001	<.001

constituents tested as concentrations

TABLE 56

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS, LILLIEFORS' DMAX TEST STATISTIC, VAMOOSA AQUIFER

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	55	0.706	0.002	0.183	<.001
Calcium	97	<.001	<.001	<.001	0.577
Chloride	101	<.001	<.001	<.001	<.001
Conductivity	101	<.001	<.001	<.001	0.308
Fluoride	46	<.001	<.001	<.001	<.001
Hardness	97	<.001	<.001	<.001	0.661
Potassium	71	<.001	<.001	<.001	0.06
Magnesium	97	<.001	<.001	<.001	0.225
Nitrate (as nitrogen)	13	<.001	<.001	0.009	0.002
Nitrate (as nitrate)	13	<.001	<.001	0.008	0.009
Silica	44	0.448	0.074	0.449	0.274
Sodium	97	<.001	<.001	<.001	<.001
Sulfate	99	<.001	<.001	<.001	0.038
Dissolved Solids	98	<.001	<.001	<.001	0.198

constituents tested as concentrations

APPENDIX D

PROBABILITIES, FROM LILLIEFORS' DMAX TEST STATISTIC, OF SAMPLES HAVING BEEN DRAWN RANDOMLY FROM NORMAL DISTRIBUTIONS

TABLE 57

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS, LILLIEFORS' DMAX TEST STATISTIC, ALLUVIUM AND TERRACE DEPOSITS

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	568	<.001	<.001	<.001	<.001
Calcium	352	0.004	<.001	<.001	0.001
Chloride	609	<.001	<.001	<.001	<.001
Fluoride	179	<.001	<.001	<.001	<.001
Potassium	189	<.001	<.001	<.001	<.001
Magnesium	335	<.001	<.001	<.001	<.001
Nitrate (as nitrogen)	469	<.001	<.001	<.001	<.001
Nitrate (as nitrate)	470	<.001	<.001	<.001	<.001
Silica	149	<.001	<.001	<.001	<.001
Sodium	216	<.001	<.001	0.385	<.001
Sulfate	607	<.001	<.001	<.001	<.001

constituents tested as percentages of TDS

TABLE 58

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS, LILLIEFORS' DMAX TEST STATISTIC, ARBUCKLE-SIMPSON AQUIFER

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	66	<.001	<.001	<.001	<.001
Calcium	37	<.001	0.006	<.001	<.001
Chloride	66	<.001	<.001	<.001	<.001
Fluoride	61	<.001	<.001	<.001	<.001
Potassium	30	0.001	<.001	0.042	0.001
Magnesium	37	0.001	0.001	<.001	0.001
Nitrate (as nitrogen)	35	<.001	<.001	<.001	<.001
Nitrate (as nitrate)	35	<.001	<.001	<.001	<.001
Silica	21	0.685	0.698	0.586	0.483
Sodium	30	<.001	<.001	<.001	<.001
Sulfate	66	<.001	<.001	0.001	<.001

constituents tested as percentages of TDS

TABLE 59

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS LILLIEFORS' DMAX TEST STATISTIC, BLAINE DOG-CREEK AQUIFER

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	126	<.001	<.001	<.001	<.001
Calcium	70	<.001	0.01	<.001	<.001
Chloride	125	<.001	<.001	<.001	<.001
Fluoride	19	0.054	<.001	0.191	0.054
Potassium	22	0.011	<.001	0.1	0.012
Magnesium	67	<.001	<.001	0.01	<.001
Nitrate (as nitrogen)	88	<.001	<.001	<.001	<.001
Nitrate (as nitrate)	88	<.001	<.001	<.001	<.001
Silica	18	<.001	<.001	0.008	<.001
Sodium	22	0.225	0.017	0.525	0.267
Sulfate	126	<.001	<.001	<.001	<.001

constituents tested as percentages of TDS

TABLE 60

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS LILLIEFORS' DMAX TEST STATISTIC, GARBER-WELLINGTON AQUIFER

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	151	<.001	0.001	<.001	<.001
Calcium	128	<.001	<.001	<.001	<.001
Chloride	158	<.001	<.001	<.001	<.001
Fluoride	64	<.001	<.001	<.001	<.001
Potassium	57	<.001	<.001	<.001	<.001
Magnesium	123	0.001	<.001	<.001	<.001
Nitrate (as nitrogen)	125	<.001	<.001	<.001	<.001
Nitrate (as nitrate)	125	<.001	<.001	<.001	<.001
Silica	55	<.001	<.001	0.002	<.001
Sodium	69	<.001	<.001	0.002	<.001
Sulfate	158	<.001	<.001	<.001	<.001

constituents tested as percentages of TDS

TABLE 61

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS, LILLIEFORS' DMAX TEST STATISTIC, OGALLALA AQUIFER

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	201	<.001	<.001	<.001	<.001
Calcium	21	0.344	0.056	0.266	0.318
Chloride	202	<.001	<.001	<.001	<.001
Fluoride	38	<.001	<.001	0.031	<.001
Potassium	79	0.03	<.001	0.001	0.033
Magnesium	13	0.487	0.579	0.529	0.485
Nitrate (as nitrogen)	170	<.001	<.001	0.015	<.001
Nitrate (as nitrate)	170	<.001	<.001	0.021	<.001
Silica	14	0.033	0.096	0.013	0.029
Sodium	79	<.001	<.001	<.001	<.001
Sulfate	202	<.001	<.001	0.001	<.001

constituents tested as percentages of TDS

TABLE 62

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS, LILLIEFORS' DMAX TEST STATISTIC, ROUBIDOUX AQUIFER

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	169	0.002	<.001	0.002	0.003
Calcium	184	<.001	<.001	<.001	<.001
Chloride	199	<.001	<.001	<.001	<.001
Fluoride	192	<.001	<.001	<.001	<.001
Potassium	179	<.001	<.001	<.001	<.001
Magnesium	185	<.001	<.001	0.007	<.001
Nitrate (as nitrogen)	47	<.001	<.001	<.001	<.001
Nitrate (as nitrate)	47	<.001	<.001	<.001	<.001
Silica	165	<.001	<.001	0.011	<.001
Sodium	176	<.001	<.001	<.001	<.001
Sulfate	199	<.001	<.001	<.001	<.001

constituents tested as percentages of TDS

TABLE 63

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS, LILLIEFORS' DMAX TEST STATISTIC, RUSH SPRINGS AQUIFER

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	161	0.002	<.001	<.001	<.001
Calcium	98	0.547	0.001	0.004	0.286
Chloride	165	<.001	<.001	<.001	<.001
Fluoride	31	<.001	<.001	<.001	<.001
Potassium	20	<.001	<.001	0.002	<.001
Magnesium	84	<.001	<.001	<.001	<.001
Nitrate (as nitrogen)	161	<.001	<.001	<.001	<.001
Nitrate (as nitrate)	161	<.001	<.001	<.001	<.001
Silica	14	0.042	0.004	0.496	0.047
Sodium	26	<.001	<.001	0.037	<.001
Sulfate	164	<.001	<.001	<.001	<.001

constituents tested as percentages of TDS

TABLE 64

PROBABILITIES OF RANDOM SAMPLES FROM NORMAL DISTRIBUTIONS, LILLIEFORS' DMAX TEST STATISTIC, VAMOOSA AQUIFER

Constituent	Number of Samples	Raw Values	Values Squared	Square Roots of Values	Logarithms of Values
Bicarbonate	52	0.187	0.042	0.019	0.065
Calcium	96	0.024	<.001	<.001	0.016
Chloride	98	<.001	<.001	<.001	<.001
Fluoride	44	0.002	<.001	0.338	0.002
Potassium	71	<.001	<.001	0.001	<.001
Magnesium	96	0.062	<.001	0.014	0.09
Nitrate (as nitrogen)	13	<.001	<.001	0.003	<.001
Nitrate (as nitrate)	13	<.001	<.001	0.003	<.001
Silica	44	0.022	<.001	0.8	0.05
Sodium	94	<.001	<.001	0.028	<.001
Sulfate	96	<.001	<.001	0.353	<.001

constituents tested as percentages of TDS

APPENDIX E

PROBABILITIES, FROM KRUSKAL-WALLIS CHI-SQUARED APPROXIMATION. WORKING HYPOTHESIS: CONSTITUENTS WERE DRAWN FROM ONE POPULATION

TABLE 65

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, CALCIUM

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	0.01						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	<.001	0.006	<.001				
Ogallala	<.001	0.464	<.001	0.003			
Roubidoux	<.001	<.001	<.001	0.003	<.001		
Rush Springs	0.003	0.616	<.001	<.001	0.233	<.001	
Vamoosa	<.001	0.082	<.001	0.089	0.001	0.204	<.001

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as concentrations

TABLE 66

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, CHLORIDE

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	0.119						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	<.001	0.319	<.001				
Ogallala	<.001	0.245	<.001	0.922			
Roubidoux	<.001	0.584	<.001	<.001	<.001		
Rush Springs	<.001	0.009	<.001	<.001	<.001	<.001	
Vamoosa	0.002	0.891	<.001	0.217	0.261	0.108	<.001

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as concentrations

TABLE 67

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, CONDUCTIVITY

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	0.912						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	<.001	0.004	<.001				
Ogallala	<.001	<.001	<.001	0.319			
Roubidoux	<.001	<.001	<.001	0.055	0.237		
Rush Springs	<.001	<.001	<.001	0.007	0.009	0.366	
Vamoosa	<.001	0.013	<.001	0.374	0.759	0.924	0.571

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as concentrations

TABLE 68

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, FLUORIDE

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	0.164						
Blaine-Dog Creek	0.687	0.379					
Garber-Wellington	0.002	0.002	0.102				
Ogallala	<.001	0.506	<.001	<.001			
Roubidoux	<.001	0.902	0.031	<.001	<.001		
Rush Springs	<.001	0.002	0.001	0.08	<.001	<.001	
Vamoosa	<.001	0.001	<.001	0.089	<.001	<.001	0.91

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as concentrations

TABLE 69

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, HARDNESS

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	<.001						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	<.001	0.406	<.001				
Ogallala	<.001	0.061	<.001	<.001			
Roubidoux	<.001	0.112	<.001	0.003	<.001		
Rush Springs	<.001	<.001	<.001	<.001	0.759	<.001	
Vamoosa	<.001	0.684	<.001	0.715	<.001	0.533	<.001

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as concentrations

TABLE 70

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, BICARBONATE

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	0.18						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	0.899	0.061	<.001				
Ogallala	<.001	<.001	<.001	<.001			
Roubidoux	<.001	<.001	<.001	<.001	<.001		
Rush Springs	<.001	<.001	0.457	<.001	<.001	<.001	
Vamoosa	0.96	0.797	<.001	0.68	<.001	<.001	<.001

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as concentrations

TABLE 71

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, MAGNESIUM

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	0.122						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	0.001	0.493	<.001				
Ogallala	0.747	0.818	<.001	0.022			
Roubidoux	<.001	0.026	<.001	<.001	<.001		
Rush Springs	0.001	0.949	<.001	0.251	0.002	0.002	
Vamoosa	<.001	0.242	<.001	0.005	<.001	0.405	0.008

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as concentrations

TABLE 72

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, NITRATE AS NITROGEN

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	0.001						
Blaine-Dog Creek	0.582	<.001					
Garber-Wellington	<.001	0.027	<.001				
Ogallala	0.002	<.001	<.001	<.001			
Roubidoux	<.001	0.001	<.001	<.001	<.001		
Rush Springs	0.969	<.001	0.086	<.001	0.086	<.001	
Vamoosa	0.069	0.537	0.001	0.68	0.013	0.017	0.005

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as concentrations

TABLE 73

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, NITRATE AS NITRATE

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	<.001						
Blaine-Dog Creek	0.626	<.001					
Garber-Wellington	<.001	0.027	<.001				
Ogallala	<.001	<.001	<.001	<.001			
Roubidoux	<.001	0.001	<.001	<.001	<.001		
Rush Springs	0.774	<.001	0.085	<.001	0.081	<.001	
Vamoosa	0.007	0.537	0.001	0.675	0.014	0.017	0.005

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as concentrations

TABLE 74

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, POTASSIUM

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	<.001						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	<.001	0.005	<.001				
Ogallala	<.001	<.001	<.001	<.001			
Roubidoux	0.001	<.001	<.001	<.001	<.001		
Rush Springs	0.176	0.019	<.001	0.276	<.001	0.018	
Vamoosa	0.009	<.001	<.001	0.043	<.001	<.001	0.962

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as concentrations

TABLE 75

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, SILICA

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	<.001						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	<.001	<.001	0.003				
Ogallala	<.001	<.001	<.001	<.001			
Roubidoux	<.001	0.016	<.001	<.001	<.001		
Rush Springs	0.854	<.001	0.002	<.001	<.001	<.001	
Vamoosa	<.001	<.001	0.87	0.001	<.001	<.001	<.001

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as concentrations

TABLE 76

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, SODIUM

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	<.001						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	0.001	<.001	<.001				
Ogallala	<.001	<.001	<.001	0.289			
Roubidoux	0.002	<.001	<.001	0.541	0.376		
Rush Springs	<.001	<.001	<.001	0.636	0.042	0.194	
Vamoosa	0.22	<.001	<.001	0.128	0.26	0.15	0.096

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as concentrations

TABLE 77

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, SULFATE

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	<.001						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	<.001	0.201	<.001				
Ogallala	0.002	<.001	<.001	<.001			
Roubidoux	<.001	<.001	<.001	<.001	<.001		
Rush Springs	0.007	0.016	<.001	<.001	0.578	<.001	
Vamoosa	<.001	0.631	<.001	0.41	<.001	<.001	0.001

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as concentrations

TABLE 78

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS,DISSOLVED SOLIDS

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	0.034						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	<.001	0.009	<.001				
Ogallala	<.001	0.006	<.001	0.539			
Roubidoux	<.001	<.001	<.001	<.001	<.001		
Rush Springs	<.001	0.102	<.001	0.346	0.688	<.001	
Vamoosa	<.001	0.015	<.001	0.243	0.24	0.148	0.066

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as concentrations

APPENDIX F

PROBABILITIES, FROM KRUSKAL-WALLIS CHI-SQUARED APPROXIMATION. WORKING HYPOTHESIS: CONSTITUENTS WERE DRAWN FROM ONE POPULATION

TABLE 79

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, CALCIUM

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	0.426						
Blaine-Dog Creek	<.001	0.068					
Garber-Wellington	<.001	0.002	<.001				
Ogallala	<.001	0.035	<.001	0.357			
Roubidoux	<.001	0.004	<.001	0.989	0.296		
Rush Springs	0.109	0.402	0.089	<.001	0.001	<.001	
Vamoosa	0.034	0.256	<.001	0.047	0.081	0.034	0.008

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as percentages of TDS

TABLE 80

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, CHLORIDE

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	0.441						
Blaine-Dog Creek	0.062	0.091					
Garber-Wellington	<.001	0.661	<.001				
Ogallala	<.001	0.610	<.001	0.352			
Roubidoux	<.001	<.001	<.001	<.001	<.001		
Rush Springs	<.001	0.004	<.001	<.001	<.001	<.001	
Vamoosa	0.312	0.178	0.688	<.001	<.001	<.001	<.001

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as percentages of TDS

TABLE 81

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, FLUORIDE

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	0.059						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	<.001	0.001	0.003				
Ogallala	<.001	0.254	<.001	<.001			
Roubidoux	<.001	0.057	<.001	<.001	0.595		
Rush Springs	<.001	0.001	0.387	0.214	<.001	<.001	
Vamoosa	0.116	0.393	<.001	<.001	<.001	<.001	<.001

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as percentages of TDS

TABLE 82

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, BICARBONATE

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	0.001						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	<.001	0.934	<.001				
Ogallala	<.001	0.275	<.001	<.001			
Roubidoux	<.001	0.309	<.001	0.002	0.843		
Rush Springs	0.294	0.006	<.001	<.001	0.074	0.009	
Vamoosa	0.682	0.031	<.001	<.001	0.078	0.046	0.944

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as percentages of TDS

TABLE 83

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, MAGNESIUM

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	0.153						
Blaine-Dog Creek	0.009	0.273					
Garber-Wellington	<.001	0.330	0.029				
Ogallala	0.052	0.699	0.157	0.747			
Roubidoux	0.029	0.119	0.003	0.001	0.038		
Rush Springs	0.597	0.306	0.066	0.007	0.072	0.417	
Vamoosa	0.200	0.655	0.989	0.494	0.519	0.065	0.347

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as percentages of TDS

TABLE 84

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, NITRATE AS NITORGEN

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	<.001						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	<.001	0.002	0.199				
Ogallala	0.635	<.001	<.001	<.001			
Roubidoux	<.001	0.526	<.001	<.001	<.001		
Rush Springs	0.013	<.001	<.001	<.001	0.011	<.001	
Vamoosa	0.053	0.141	0.162	0.505	0.014	0.034	0.007

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as percentages of TDS

TABLE 85

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, NITRATE AS NITRATE

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	<.001						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	<.001	0.002	0.188				
Ogallala	0.664	<.001	<.001	<.001			
Roubidoux	<.001	0.551	<.001	<.001	<.001		
Rush Springs	0.012	<.001	<.001	<.001	0.010	<.001	
Vamoosa	0.055	0.141	0.165	0.505	0.014	0.023	0.007

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as percentages of TDS

TABLE 86

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, POTASSIUM

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	<.001						
Blaine-Dog Creek	<.001	0.470					
Garber-Wellington	0.935	<.001	<.001				
Ogallala	<.001	<.001	<.001	<.001			
Roubidoux	<.001	<.001	<.001	<.001	<.001		
Rush Springs	0.068	0.649	0.497	0.106	<.001	<.001	
Vamoosa	<.001	<.001	<.001	<.001	<.001	<.001	0.004

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as percentages of TDS

TABLE 87

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, SILICA

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	<.001						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	0.173	<.001	<.001				
Ogallala	0.102	0.004	<.001	0.013			
Roubidoux	<.001	<.001	<.001	0.012	0.002		
Rush Springs	0.368	0.010	<.001	0.456	0.060	0.739	
Vamoosa	<.001	<.001	<.001	<.001	0.078	<.001	0.001

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as percentages of TDS

TABLE 88

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, SODIUM

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	<.001						
Blaine-Dog Creek	0.628	<.001					
Garber-Wellington	0.048	<.001	0.321				
Ogallala	0.001	<.001	0.199	0.520			
Roubidoux	0.003	<.001	0.223	0.019	0.002		
Rush Springs	<.001	<.001	0.013	0.214	0.007	0.001	
Vamoosa	0.002	<.001	0.170	0.001	<.001	0.566	<.001

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as percentages of TDS

TABLE 89

PROBABILITIES FROM KRUSKAL-WALLIS CHI-SQUARED STATISTIC FOR PAIRS OF AQUIFERS, SULFATE

Aquifer	Alluvium & Terrace	Arbuckle-Simpson	Blaine-Dog Creek	Garber-Wellington	Ogallala	Roubidoux	Rush Springs
Arbuckle-Simpson	<.001						
Blaine-Dog Creek	<.001	<.001					
Garber-Wellington	<.001	0.933	<.001				
Ogallala	0.555	<.001	<.001	<.001			
Roubidoux	<.001	0.036	<.001	0.038	<.001		
Rush Springs	0.926	<.001	<.001	<.001	0.842	<.001	
Vamoosa	<.001	0.005	<.001	0.002	<.001	<.001	0.008

Ho: The pair of aquifers is not significantly different, with respect to constituent "x".
Constituent tested as percentages of TDS

APPENDIX G

MULTIPLE POPULATIONS

MULTIPLE POPULATIONS

As described earlier, the majority of data sets were considered not to have been drawn from normal distributions. This circumstance was true for concentrations and percentages of TDS, and for data transformed to logarithms, square roots, and squares. Generally, major elements are normally distributed and minor elements are lognormally distributed (Hounslow, 1990, p. 4.14). Chemical constituents evaluated in this study are major constituents, present in concentrations exceeding 1.0 mg/l (Hem, 1980, p. 54), and might be expected to follow normal distributions.

Percentile-statistics tables show inconsistencies between percentiles and uncommonly large maximal values for many constituents. Many of these maximal values probably are results of non-normal contamination and represent a population different from "background" or natural conditions. Inconsistencies in percentiles could be from multiple natural populations, which occur in aquifers.

Figures 25, 26, and 27 are histograms of hypothetical samples of calcium concentrations from populations A, B, and C. Curvatures of the graphs are bell-shaped, which is indicative of a normally distributed population. Figure 28 is a histogram of populations A and B combined in one sample. The two populations and their respective end

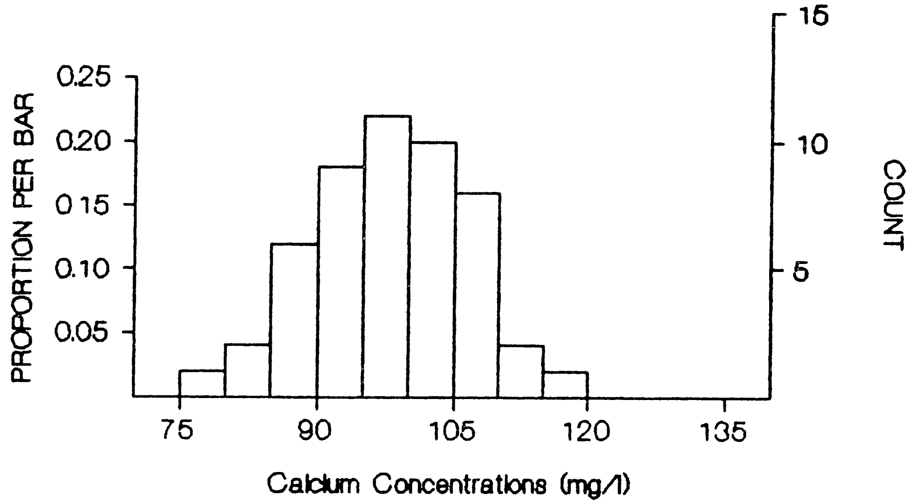

Figure 25. Histogram, Calcium Concentrations, Population A.

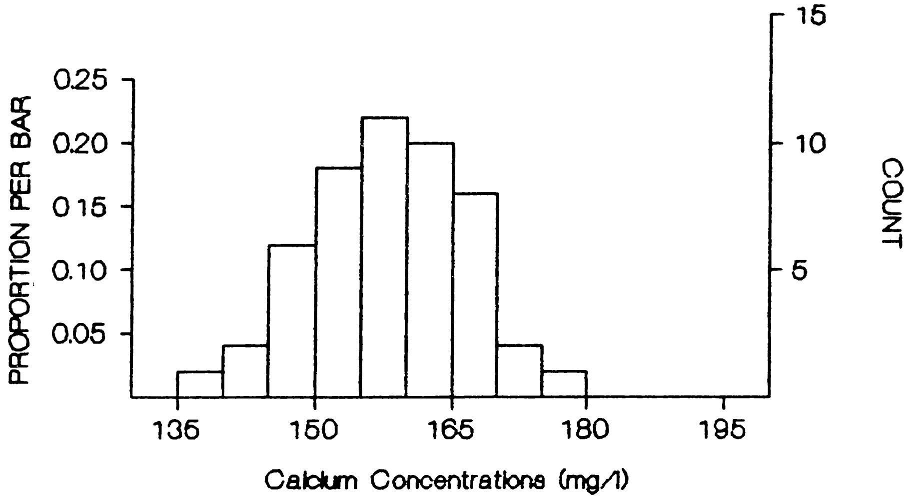

Figure 26. Histogram, Calcium Concentrations, Population B.

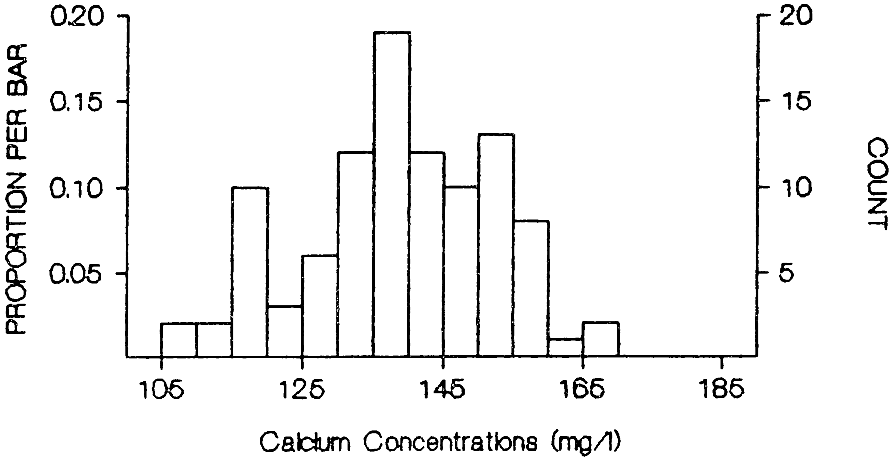

Figure 27. Histogram, Calcium Concentrations, Population C.

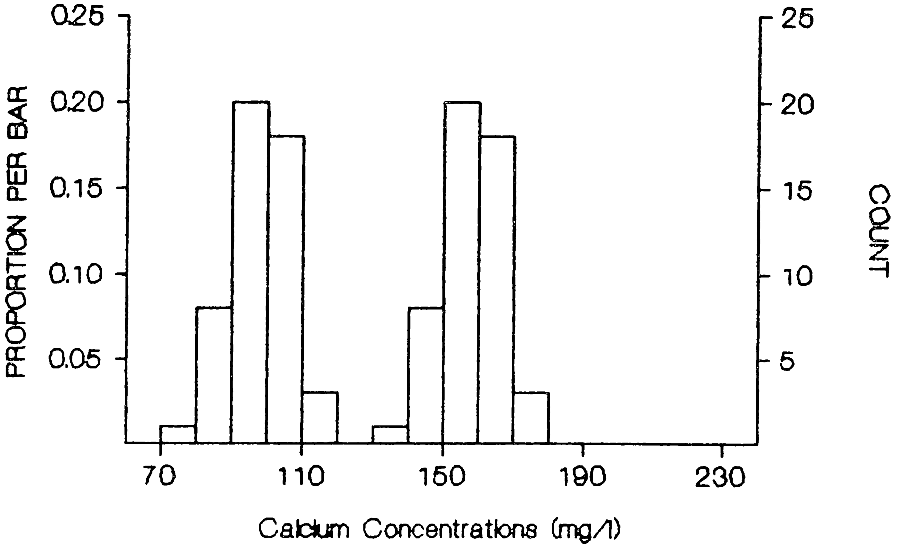

Figure 28. Histogram, Calcium Concentrations, Populations A and B.

members can be distinguished easily in the histogram. Figure 29 is a combination of populations A and C. Populations overlap in this graph and end members are not apparent.

Cumulative frequency plots can be constructed by adding the frequency of any class, or any data-point to the total frequencies of all preceding data. Cumulative normal probability plots represent these frequencies by standard deviations. Standard deviation (z) can be converted to a probability from the table of normal-curve areas. The z values of -2, -1, 0, 1, and 2 correspond to probabilities of 2.3, 15.9, 50, 84.1 and 97.7 percent.

Figure 30 is a probability plot of the sample with population A. Data on the plot are on a relatively straight line, which therefore can be taken to indicate a normally distributed population. The mean of the sample is the value at z = 0 (98.5 mg/l), and the standard deviation is the difference between values of z = 1, or -1, and 0 (107 - 98.5 = 8.5). Figure 31 is a cumulative probability plot of the bimodal, combined samples A and B. The plot shows evidence of two populations by the two relatively straight lines, one above z=0 and one below. The vertical line (at z=0) is the result of two populations that do not overlap.

Figure 32 is a cumulative probability plot of samples A and C. Two "straight" lines, one between z values of -2 and -1 and one between 0 and 2, are evidence of the two populations: the curvature between z values of -1 and 0 is

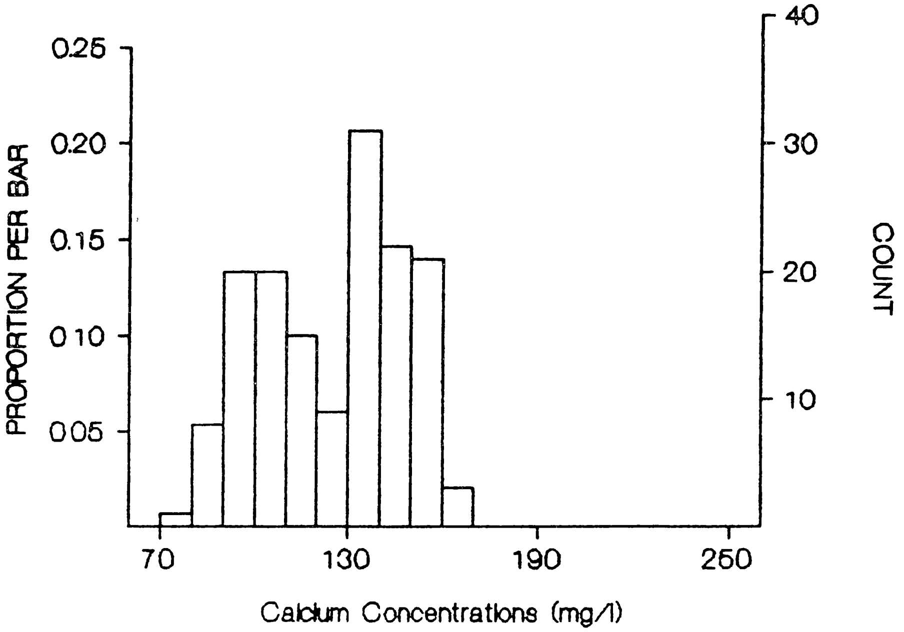

Figure 29. Histogram, Calcium Concentrations, Populations A and C.

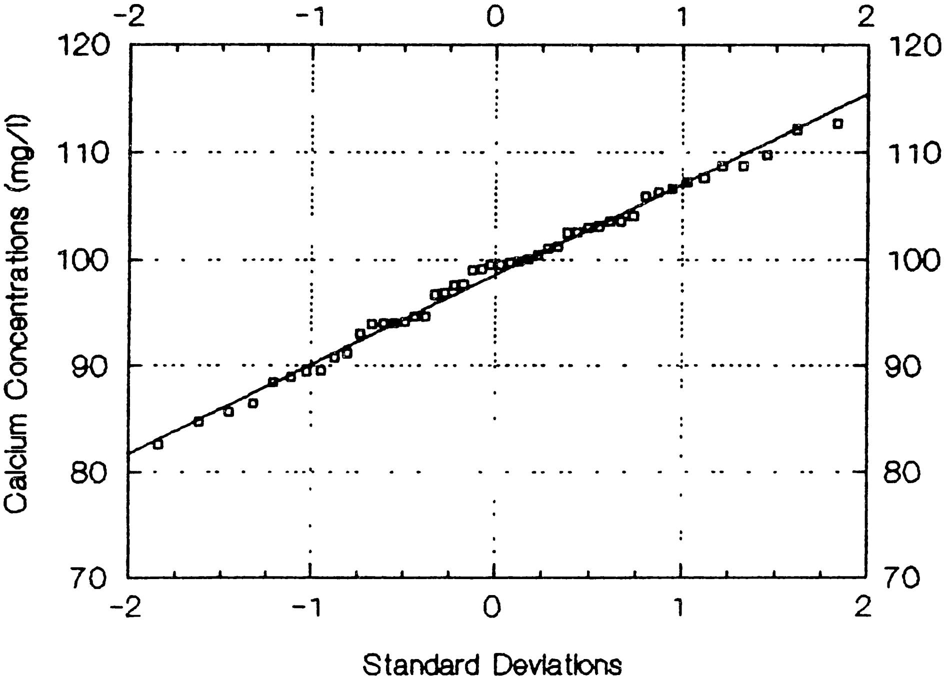

Figure 30. Probability Plot, Calcium Concentrations, Population A.

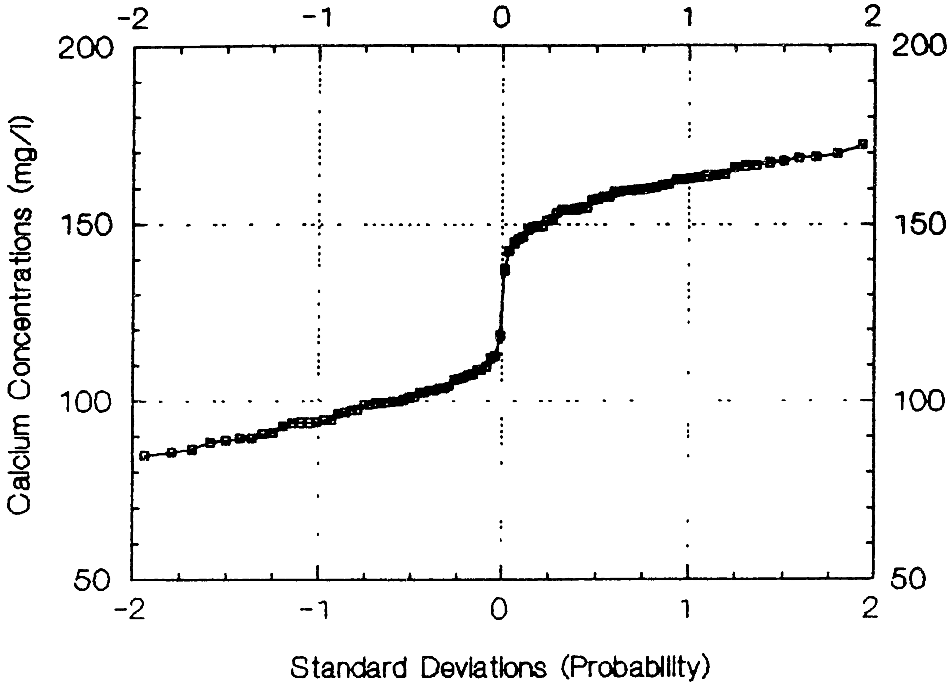

Figure 31. Probability Plot, Calcium Concentrations, Populations A and B.

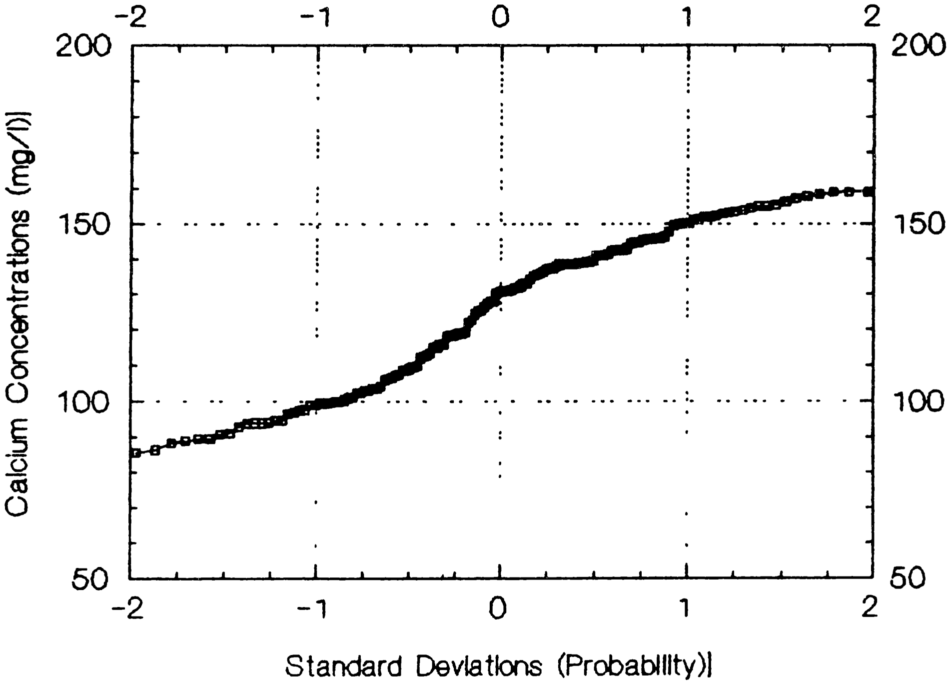

Figure 32. Probability Plot, Calcium Concentrations, Populations A and C.

where the populations overlap. An inflection point, at about z= -0.44, is where the curvature changes directions; the point represents the proportion of different populations (Sinclair, 1976 p. 32).

Procedures used to discriminate different populations within a single sample are known as "partitioning" (Sinclair, 1976, p. 32). In Figure 32, the inflection point is at approximately -0.44 z (0.17 probability (from a standard table of probability (areas under the normal curve (Table 46, p.112)))), which suggests that the lower population (the one with the smaller mean) makes up 33 percent of the sample and the upper population makes up 67 percent of the sample. The relationship of the populations is generalized in the following equation:

$$P(A+B) = f(A)P(A) + f(b)P(B)$$

where $P(A+B)$ is the cumulative probability of the combined populations, $f(A)$ and $f(B)$ are the proportions of the total sample represented by populations A and B, and $P(A)$ and $P(B)$ are the cumulative probabilities of populations A and B (Sinclair, 1976, p. 35)

Figure 33 is a histogram of the sample of magnesium concentrations from the Arbuckle-Simpson aquifer. The frequency distribution suggests strongly that two populations are present, but it does not permit clear distinction between the populations. Figure 34 is a cumulative probability plot of the same sample. The plot shows two "straight" lines, one between z values of -2 and

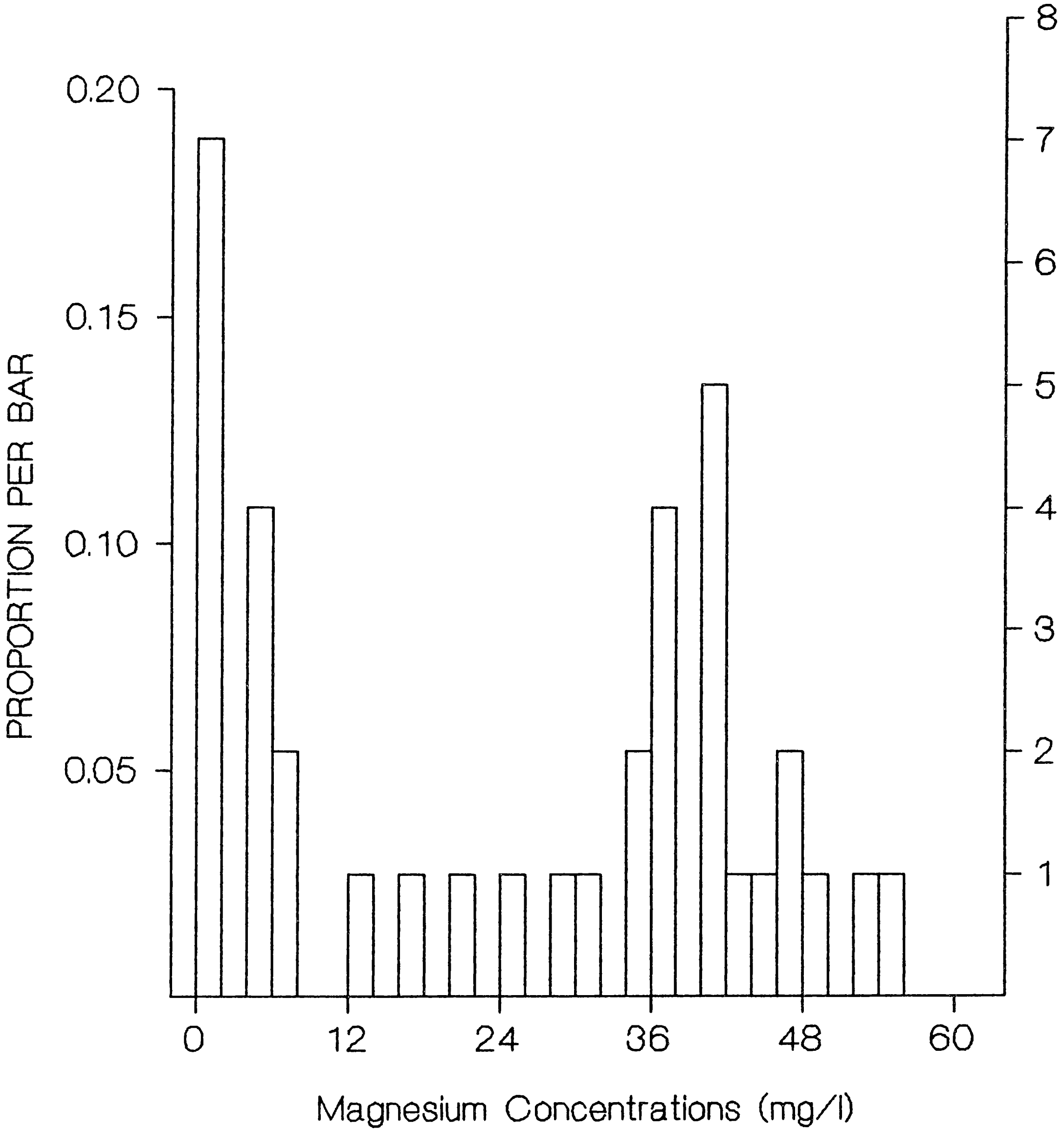

Figure 33. Histogram, Magnesium Concentrations, Arbuckle-Simpson Aquifer.

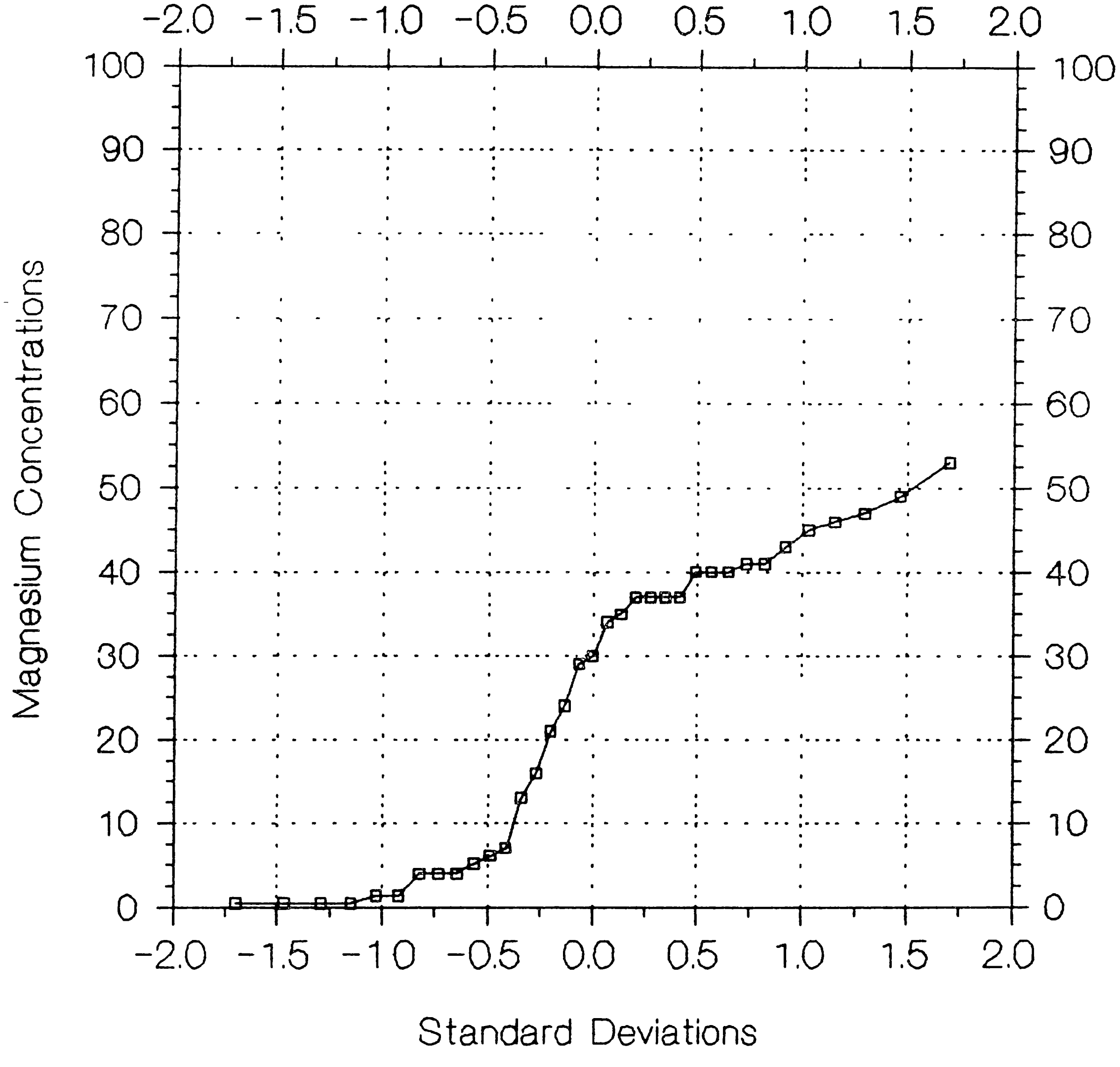

Figure 34. Probability Plot, Magnesium Concentrations, Arbuckle-Simpson Aquifer.

-0.5 and one between z values of 0 and 2. Overlap of the two populations occurs between z values of -0.5 and 0.

The inflection point is at z = -0.25 (.099 probability), which translates to 40 percent of the samples being from one population and 60 percent of the samples being from a second population. To separate the populations, frequencies of points on the two "straight-line" segments must be converted to frequencies of individual populations. Conversions are made by dividing frequencies by proportions; this value can be converted to a z value and plotted. The two "straight-lines" resulting from the conversions represent the two populations. Tables 90 and 91 give the conversions and Figure 35 shows the relationship.

Partitioning of magnesium concentrations in the Arbuckle-Simpson aquifer indicated two populations, 40 percent from the lower population and 60 percent from the upper population. The mean of the lower population was 4 mg/l; the standard deviation was 1.5 mg/l. The mean of the upper population was 39 mg/l; the standard deviation was 7 mg/l. Figure 35 covers from -2 to 2 standard deviations, which encompasses approximately 95 percent of each population. Values between 7 mg/l and 23 mg/l probably are a mixture of the two populations.

The preceding example is believed to show a convincing case of two normally distributed populations in one sample. While this situation is common, samples, with more than two

TABLE 90

CONVERSIONS TO DETERMINE MULTIPLE POPULATIONS OF MAGNESIUM CONCENTRATIONS, ARBUCKLE-SIMPSON AQUIFER, "LOWER" POPULATION

Sample Number n	Data Magnesium (mg/l)	Cumulative Frequency (f) (= n/37)	f\P (= f/.4)	Standard Deviations z
1	0.5	0.03	0.07	-1.48
2	0.5	0.05	0.14	-1.08
3	0.5	0.08	0.20	-0.84
4	0.5	0.11	0.27	-0.61
5	0.5	0.14	0.34	-0.41
6	1.4	0.16	0.41	-0.23
7	1.4	0.19	0.47	-0.07
8	4	0.22	0.54	0.1
9	4	0.24	0.61	0.28
10	4	0.27	0.68	0.47
11	5.2	0.30	0.74	0.64
12	6.1	0.32	0.81	0.88
13	7	0.35	0.88	1.17

Note: Column 4 shows cumulative frequency of the 40% of the total sample judged to belong to the "lower" population. Of course, the cumulative frequency would sum to 1, which is the total area under the normal curve. In the case of Sample 1, 0.07 of the total area would be in the left-hand tail of the normal curve, approximately 1.48 standard deviations left of the mean.

Sample size = 37

TABLE 91

CONVERSIONS TO DETERMINE MULTIPLE POPULATIONS OF MAGNESIUM CONCENTRATIONS, ARBUCKLE-SIMPSON AQUIFER, "UPPER" POPULATION

Sample Number n	Data Magnesium (mg/l)	Cumulative Frequency (f) (= n/37)	f\P (= f/.6)	Standard Deviations z
22	37	0.59	0.68	-0.47
23	37	0.62	0.63	-0.34
24	37	0.65	0.59	-0.23
25	37	0.68	0.54	-0.1
26	40	0.70	0.50	0
27	40	0.73	0.45	0.13
28	40	0.76	0.41	0.23
29	41	0.78	0.36	0.35
30	41	0.81	0.32	0.47
31	43	0.84	0.27	0.61
32	45	0.86	0.23	0.74
33	46	0.89	0.18	0.92
34	47	0.92	0.14	1.08
35	49	0.95	0.09	1.34
36	53	0.97	0.05	1.65

Note: Column 4 shows cumulative frequency of the 60% of the total sample judged to belong to the "upper" population. Of course, the cumulative frequency would sum to 1, which is the total area under the normal curve. In the case of Sample 36, 0.05 of the total area would be in the right-hand tail of the normal curve, approximately 1.65 standard deviations right of the mean.

Sample size = 37

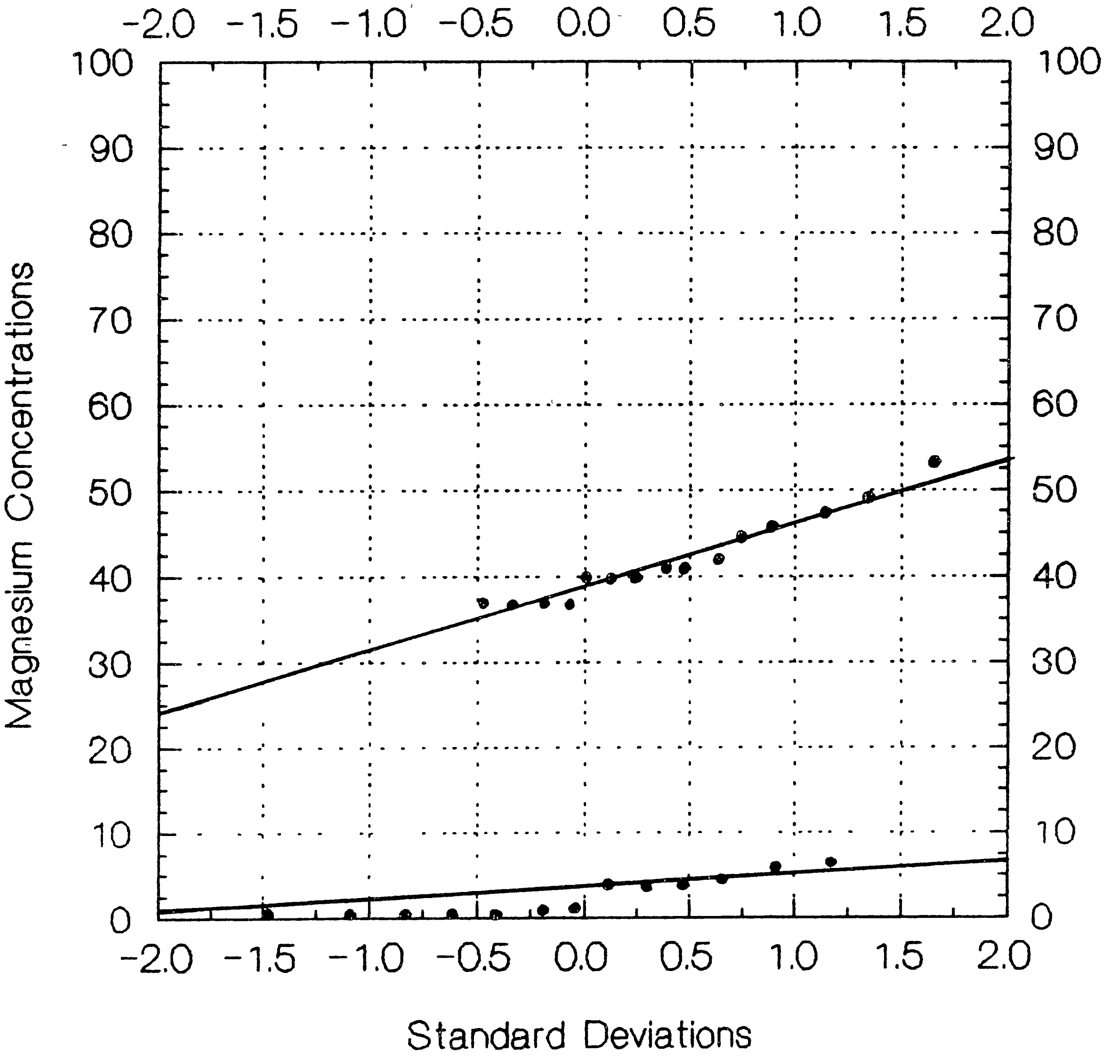

Figure 35. Probability Plot, Two
Populations of Magnesium,
Arbuckle-Simpson Aquifer.

populations, and with log-normal distributions can also occur.

Because identification and evaluation of multiple populations within aquifers were not among the primary purposes of this study, the topic was not treated in detail. For a full explanation of procedures, the reader is referred to the work of Sinclair (1976).

VITA

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