HYDROGEOCHEMISTRY OF THE WASHITA RIVER

ALLUVIUM IN CADDO AND GRADY

COUNTIES, OKLAHOMA

By

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Bachelor of Arts

University of Northern Iowa

Cedar Falls, Iowa

1972

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
Master of Science
May, 1975

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PREFACE

This study defines the hydrogeochemistry of the
alluvium ground water of the Washita River in Caddo and
Grady Counties, Oklahoma. Factor maps, analysis of
variance, factor analysis and phase diagrams are utilized
in the determination of significant chemical processes.

The author wishes to express his appreciation to his
major adviser, Dr. Douglas Kent, for guidance and assistance
throughout this study, and to Dr. Zuhair Al-Shaieb, co-
adviser, for his helpful commentary and assistance.
Appreciation is also expressed to Dr. John E. Stone for
his editorial assistance in the preparation of the final
manuscript.

Considerable thanks is given to Mr. Jim Naney and
other staff personnel of the Agricultural Research Service,
Chickasha, Oklahoma, for permission to use their wells and
their invaluble assistance with the collection of portions
of the data. Appreciation is also extended to the Arts and
Science Research Foundation, Oklahoma State University, for
their financial assistance to the research project; and to
Dr. Anthony Gaudy, Chairman of the Bioenvironmental Group of
the School of Civil Engineering, and to the Environmental
Protection Agency for granting an EPA Traineeship to the

author. Finally, special thanks is extended to my wife,
Linda, for her assistance in the completion of this
manuscript.

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INTRODUCTION

The geochemistry of ground water has become an important consideration in the study of the water environment. Increasing environmental concern at both the state and national levels emphasizes the need for study in the area of ground-water chemistry. Because over one-fourth of the water consumed in the United States is derived from ground water (MacKichan and Kammerer, 1961), it is hoped that the present research will contribute to the understanding of the processes acting to affect the ground-water chemistry.

From an extensive survey of the literature on ground-water geochemistry, there appears to be a lack of studies detailing the factors affecting the geochemistry of ground water. This study is an attempt to fill this void by definitively looking at the relationships between ground-water chemistry, aquifer mineralogy, permeability, bedrock lithology associated with the aquifer and land use.

The study area selected for this research includes a complex alluvial aquifer in a 325 square mile area centering on Chickasha, Oklahoma (see Figure 1). This region is ideal for investigation, because the area has been studied in detail for eleven years as a part of the Great Plains Small

Watershed Research Project of the Agricultural Research

Service, United States Department of Agriculture. A

substantial amount of data has been collected on the weather

and climate, surface and ground-water hydrology, and aquifer

permeability and sediment characteristics.
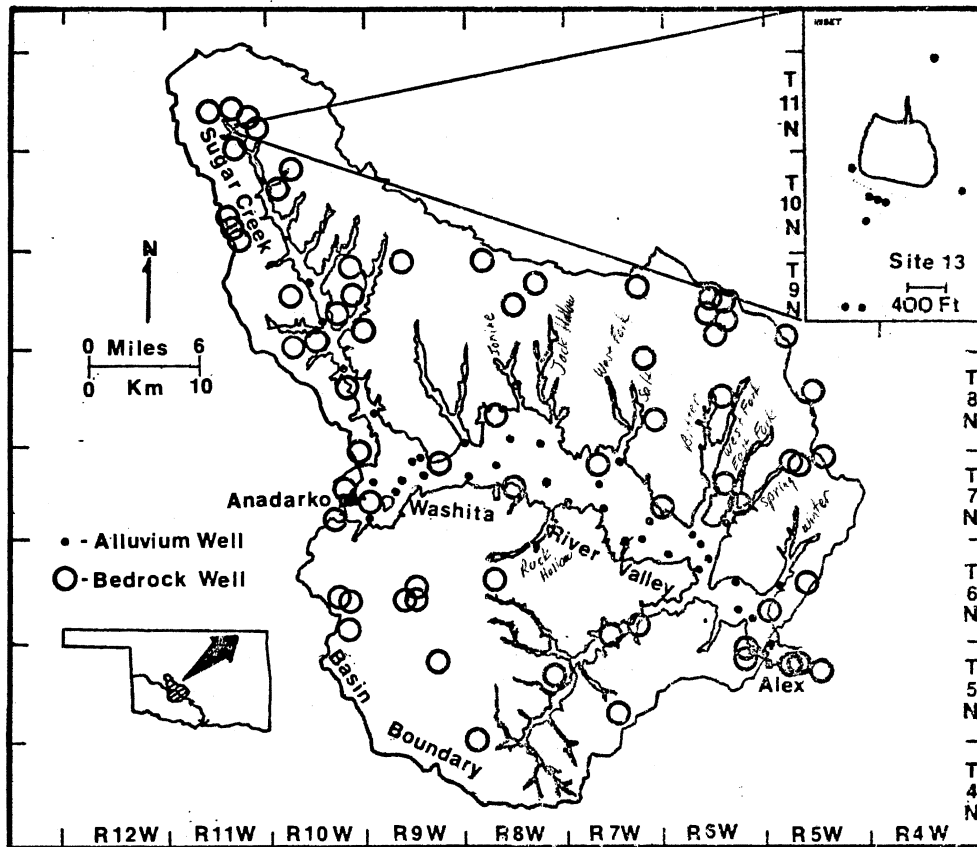
Figure 1. Index Map to the Washita River Alluvium
Study Area Between Anadarko and Alex,
Oklahoma, and Map of Wells in Alluvium
and Bedrock Used in This Study (Bedrock
wells were not used in the final analysis).

LITERATURE REVIEW

Past research primarily has involved studies of the relationship between ground-water quality and mineralogy, sources of agricultural and industrial pollution, and regional reconnaisance of ground- and surface-water quality. Several studies also have dealt with the theoretical principles governing the geochemical milieu of ground-water systems.

The many possible pollutants of waters attributable to agricultural practices include fertilizers, herbicides, and pesticides. Feth (1966) reviewed the nitrate geochemistry in natural waters and listed fertilizers, animal and human waste, and industrial processes as possible sources of nitrate pollution. Scalf, Dunlap, McMillion, and Keeley (1969) studied the behavior of nitrate as well as DDT during recharge and pumping of the Ogallala aquifer. They found that nitrate is not inhibited in movement through an aquifer, but concluded that DDT is completely absorbed near the recharging point. Studies reported by Peele and Gillingham (1972), Walker (1973), and Stewart, Viets, and Hutchinson (1968) also indicate pollution of ground water by fertilizer.

The fate of DDT and other pesticides applied to cotton plots was studied by Sheets, Bradley, and Jackson (1972). They found that less than 1% of the DDT applied was present in runoff, while no DDT was detected in well Water. Lewallen (1971) documented the pollution of a private well from DDT contamination of backfill around the well. Over a four year period this concentration of DDT was found to gradually decline as a result of metabolic activity. Lewallen found very little downward movement of DDT through the soil. Weber, Monaco, and Worsham (1973) have published an excellent overview of the fate of herbicides in the environment. Degradation of herbicides is accomplished by biological decomposition, chemical decomposition, and photo-decomposition. Transfer processes listed by Weber et al. include absorption and exudation by plants and animals, retention in vegetation and transfer in the harvested product, adsorption by soil particles, volatilization into the atmosphere, surface runoff, and movement through the soil as either liquid or gas. Weber et al. concluded that there is no evidence of a potential buildup or persistence of herbicides in the soil to a level which could be considered a hazard.

McMillion and Maxwell (1970) investigated the potential pollution of the Ogallala aquifer in Texas, Oklahoma, and Kansas by the injection of oil-field brines into deep salt-water zones. Schmidt (1973) and Motts and Saines (1969) evaluate potential ground-water pollution caused by

municipal waste. Schmidt (1973) also studied the potential problems associated with the use of sewage effluent in crop irrigation.

Trace metals recently have been linked with both industrial and natural pollution. A general survey of trace metals in the waters of the United States was completed by Kopp and Kroner (1970). The chemistry of trace metals has been reviewed by various investigators including Jenne (1968), Kraynov (1971), Kraynov, Volkov, and Korol'kova (1966), Ellis, Barnhisel, and Phillips (1970) and Hem (1972). Huang (1973) has studied the geochemistry of trace elements in surface and ground waters of the Hillsborough and Alfia River Basins, Florida. The relationships between the geochemistry of the water and the source rock types, seasonal variations, and organic activity were also evaluated in his study. A study of the trace elements of ground waters in the Baton Rouge, Louisiana area and their potential health hazards were reported by Ferrel (1973).

The hypothesis that ground-water quality is dependent upon the mineralogy of the aquifer is not of recent origin. Chebotarev (1955), in an excellent review of the origin, occurrence, and distribution of the soluble salts in the crust of weathering, cites Plinius' philisophical concept (23-79 AD) that "...water take their nature from the strata through which they flow...." In 1960, Baas Becking, Kaplan,

and Moore published their document on the Eh-pH limits of
the natural environment. This work laid a foundation for
relating the quality of water to the natural ecological
system. Feth, Roberson, and Polzer (1964) published one of
the first definitive studies of the sources of the major
dissolved ions in natural water. Cohen (1962) discussed
the possible sources of sulfate in ground water in the
Truckee Meadows area, Nevada. Back and Hanshaw (1965)
reviewed the geochemistry of ground water including the
effects of clay minerals on water composition. Lloyd (1965),
Seaber (1965), Back (1966), Wallace and Cooper (1970), Jacks
(1973), Price and Raglund (1968), and Barnes and Bentall
(1968) discussed the hydrogeochemistry of aquifers as
related to mineralogy of the aquifers.

Mineral-water equilibria has been discussed in detail
by Morgan (1967), Bricker, Godfrey, and Cleaves (1968), and
Kramer (1967). These studies have taken into account Eh-pH
and mineral-phase equilibria. In addition to these articles
the research by Helgeson, Brown, and Leeper (1969) supplies
t he mineral stability diagrams needed in investigating
water-mineral equilibria. Other theoretical discussions of
water-mineral equilibria may be found in the texts by
Broecker and Oversby (1971), Krauskopf (1967), and Garrels
and Christ (1965), and articles by Morgan (1967), Hem (1963)
and Bostrom (1967).

The relationships of clays to the dissolved metals in
water have been studied by several researchers. Ashry

(1973) studied the occurrence of trace metals in Egyptian Nile sediments as related to clay mineralogy. Geochemical changes due to weathering of soils under varying climatic conditions were studied by McLaughlin (1955). Keller (1964) discussed the origin and weathering of clays. The adsorption of elements by clays has been studied by Siever and Woodford (1973), Lehman and Wilson (1971), Kittrick (1970) and Weaver (1970). Drever (1969) studied the relation of clay mineral formation to river-water chemistry.

Regional ground-water reconnaisance studies have been reported frequently in the U. S. Geological Survey Water-Supply Papers in which the hydrology or hydrogeology of a specific region is described. These reports most often contain a section describing the water quality. The chemistry of natural waters and the techniques used in water-quality studies are described in the Water Supply Paper 1473 (Hem, 1970). The Oklahoma State Geological Survey, in conjunction with the U. S. Geological Survey, has published a number of hydrologic atlases. In addition, descriptions of the geology and ground-water quality have been published by the Oklahoma State Geological Survey for specific areas of Oklahoma. Those studies which have furnished information for the present research are those by Tanaka and Davis (1963) and Davis (1955). The Oklahoma Water Resources Board (1969-1970) has published data on the ground-water quality of Oklahoma in its series on the appraisal of the water and related land resources of

Oklahoma. Levings (1971) investigated the ground and surface-water quality of the Sugar Creek tributary of the Washita River in Caddo County, Oklahoma.

None of the cited studies have investigated more than a few variables, and most of the references have not included statistical analyses of the data. Dawdy and Feth (1967) utilized factor analysis to evaluate only the major element chemistry. None of these studies describe the relationships between the hydrogeochemistry and clay mineralogy, permeability, and bedrock lithology.

The present research is proposed to delineate the relationships and factors which are controlling the ground-water chemistry of an alluvium aquifer in southwest Oklahoma. The parameters being studied are (1) permeability, (2) aquifer mineralogy, (3) bedrock lithology, (4) land use, and (5) major and trace element ground-water chemistry. The processes affecting the hydrogeochemistry are evaluated by using distribution maps of the variables and making comparisons between maps, by using factor analysis on the data, and by using analysis of variance on the land-use data.

DATA COLLECTION AND ANALYSIS

To attain the objective of describing the hydro-geochemistry of the Washita River alluvium, observation wells maintained by the Agricultural Research Service were used to obtain ground-water and sediment samples. Data obtained during the drilling of these wells over the past ten years by the Agricultural Research Service supplied information on the permeability characteristics of the alluvium. The wells are $1\frac{1}{4}$ in. diameter with polyethylene, stainless steel, or galvanized iron casing.

Well sampling followed a two mile grid pattern as closely as possible. Since some areas of the alluvium are void of observation wells, the well sampling was done to maintain a fairly even distribution. Forty-nine wells were sampled for ground-water chemistry data, and 19 wells were sampled for sediment. An additional 24 sediment samples were obtained from core samples and stream cuts.

Ground-water samples were collected with a suction pump and hose. Each well-water sample was collected in both one-liter and 100 ml polyethylene bottles. The bottles were completely filled and capped immediately so as to minimize entrapped air. The temperature was obtained from a separate water sample collected in a large beaker. The two sample bottles were kept cool in an ice chest from the time of

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collection until they were processed. Sediment samples were obtained from the bottom of cased wells using a suction pump. The sediment was collected in polyethylene bottles and refrigerated until analyzed.

The water samples were processed in the laboratory on the same day they were collected. Sediment in the water samples were filtered using a 4-micron Millipore brand filter. The filtrate of the liter bottle was acidified with HNO_3 (1 ml) and used for the cation determinations. The anion concentrations and the pH were measured using the non-acidified filtrate.

The concentrations of Ca^{++}, Mg^{++}, Na^+, K^+, total Fe, Mn^{++}, Si, Cu^{++}, Pb^{++}, Zn^{++}, and Cd^{++} were determined using a Perkin-Elmer Model 403 atomic absorption spectrophotometer and the standard methods of Brown, Skougstad, and Fishman (1970). The Sargent-Welch Model PBL pH meter was used to measure the pH. The anions were determined colorimetrically using the Hach Model DR-EL/2 spectrometer for NO_2^-, NO_3^-, NH_4^+, PO_4^{-3}, and $SO_4^=$. The Cl^-, CO_2, $CO_3^=$, and HCO_3^- concentrations were determined by titration techniques described in the Hach Chemical Company's DR-EL/2 Methods Manual (1973) which follow those set forth in Standard Methods for the Examination of Water, Sewage, and Industrial Wastes (American Public Health Association, 1955).

Sediment samples were acid leeched and analyzed for Cu^{++}, Pb^{++}, Zn^{++}, Mn^{++}, and Cd^{++} that might be adsorbed to the sediment. A portion of dried sediment was sieved

through a U. S. Bureau of Standard no. 80 mesh screen
(0.177 mm opening). The material passing through the
screen was split and sized to 5 grams and digested in 20
ml of aqua regia acid for 30 min. The solution then was
filtered through a Whatman no. 42 filter paper and brought
to 100 ml with distilled water. The solution then was
analyzed directly in the Perkin-Elmer 403 using the methods
for direct determination of Cu^{++}, Pb^{++}, Zn^{++}, Cd^{++} and Mn^{++}.
The actual concentration of the metals in the sediment
sample was obtained by multiplying the observed value by a
dilution factor of 20.

The clay mineral content of the sediment was deter-
mined for each sample on a Norelco x-ray unit equipped
with a strip chart recorder. Each sample was prepared by
(1) settlement of the sediment in a test tube, (2) extrac-
tion of a portion of the sediment equal to and less than
silt sized, (3) placement of the sample on a porcelain slide
to dry, and (4) determination of the clays on the slide
using the x-ray unit. The sample also was glycolated in
order to assess the presence of chlorite. First-order
peak areas were measured from the chart paper for each clay
present. Relative percentages of the three clay minerals
illite, montmorillonite, and kaolinite were determined by
dividing the cumulative area of the first-order peaks of
each clay-mineral type into the first-order peak area of
each separate clay type.

DATA DESCRIPTION

Parameters

Parameters investigated in the study are (1) ground-water chemistry, (2) bedrock lithology, (3) aquifer mineralogy, (4) depth to sampling point of ground-water sample, (5) ground-water movement, (6) permeability, and (7) land use. The relationships of these parameters can be evaluated by comparing the concentration of the chemical constituents in the ground water with the patterns of occurrence of the other parameters. The patterns of occurrence are illustrated by factor maps. These factor maps include (1) major elements in ground water, (2) trace elements in ground water, (3) bedrock lithology, (4) ground-water table elevation, (5) well-bottom permeability, (6) weighted average permeability for the saturated alluvial thickness, (7) clay mineralogy, and (8) land use. These maps are used as an aid in developing the statistical design for a more quantitative analysis of the relationships between the parameters listed above.

Ground-Water Chemistry

The results of well-water sampling for ground-water chemistry are shown in Figures 2 and 3 as stiff diagram maps. Appendix D lists the results of chemical analyses for all measured wells. Both major and trace constituent maps show patterns of occurrence which can be generalized for large regions of the study area.

Clusters of similar dissolved mineral content can be delineated on both major and trace element maps. Four general areas of contrasting chemical character are labeled on Figures 2 and 3 as areas I, II, III, and IV and are seperated by heavy lines. Area I is low in dissolved mineral content, as is area IV. Areas II and III are characterized by higher dissolved mineral content, with area II having the highest degree of mineralized waters.

Surface waters generally seem to follow the trends delineated by the ground water. Surface water in areas II and III have considerably higher dissolved mineral contents than do areas I and IV.
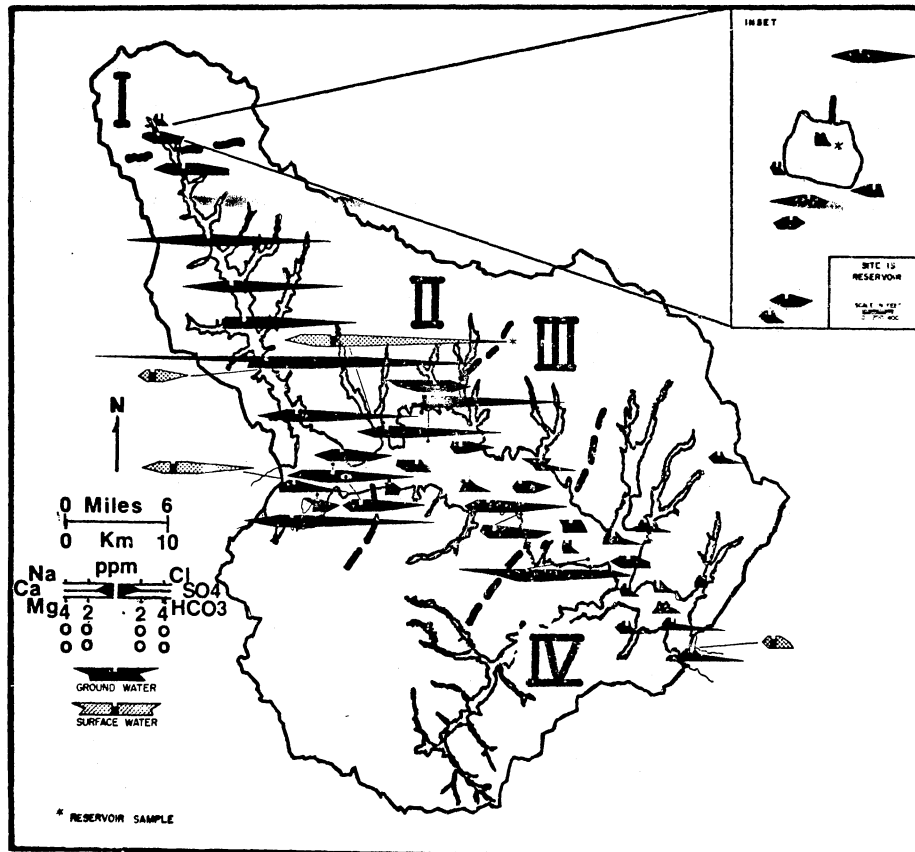
Figure 2. Major Element Stiff Diagram Map for Na, Ca, Mg, Cl, SO_4, and HCO_3, in the Washita River Alluvium near Chickasha, Oklahoma, Fall, 1973.
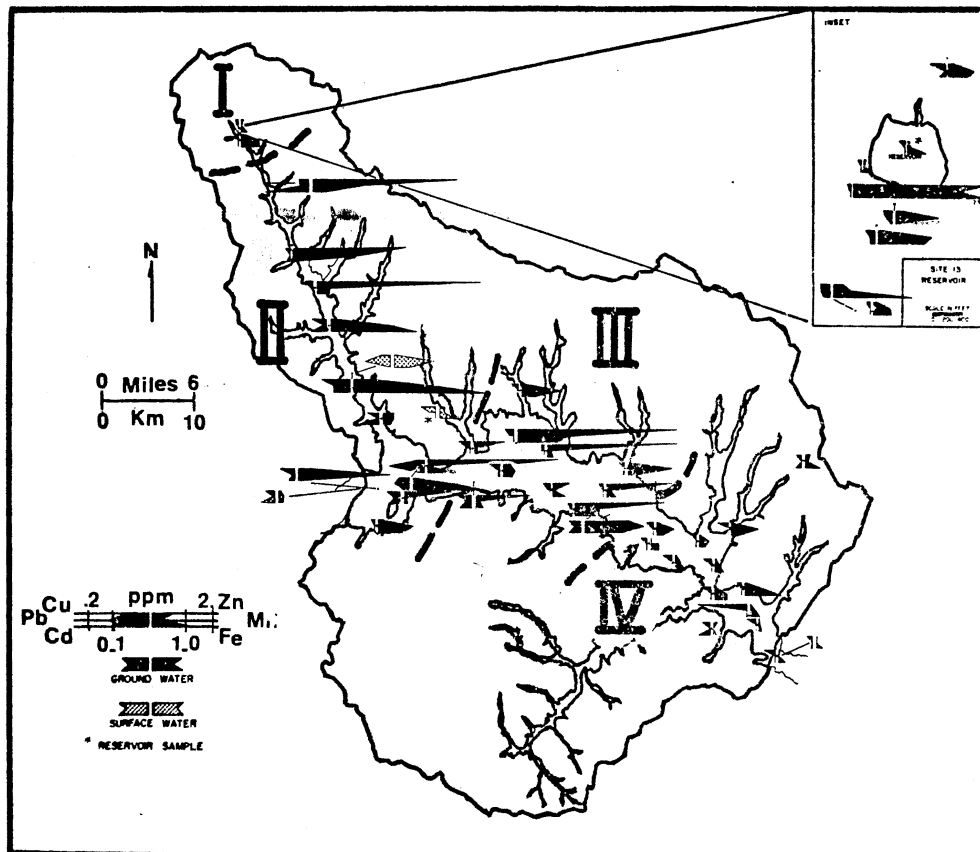
Figure 3.   Minor Element Stiff Diagram Map for Cu,
             Pb, Cd, Zn, Mn, Fe, in the Washita
             River Alluvium near Chickasha,
             Oklahoma, Fall, 1973.

Bedrock Lithology

Introduction. The bedrock lithology map (Figure 4) was prepared from the lithologic descriptions of the formations reported in the studies of Tanaka and Davis (1963) and Davis (1955). Because of the general contrasts in lithologic nature of the formations, the study area was mapped as to lithologic character directly from the formations. The following is a description of the geologic strata present in the study area.

The Permian System. The bedrock formations in the study area represent only the Permian System. The oldest formations are in the eastern part of the study area with the formations dipping 5 to 10° to the west. The Chickasha Formation, which crops out in the eastern part of the study area (largest stiple pattern in Figure 4), is the oldest strata and is made up of a heterogeneous mixture of medium-dark red sandstone, shale, siltstone, and siltstone conglomerate with iron and calcite cement. The outcrops seen by this investigator are predominantly channeled siltstones with cherty, pebble conglomerate occurring in the bottom of the channels. Overlying and outcropping to the west of the Chickasha Formation is the Dog Creek-Blaine Formation (horizontal line pattern in Figure 4). This formation is mostly dark red, even bedded, dolomitic shale interbedded with thin gypsiferous sandstone. To the west and overlying the Dog Creek-Blaine Formation is the Marlow Formation
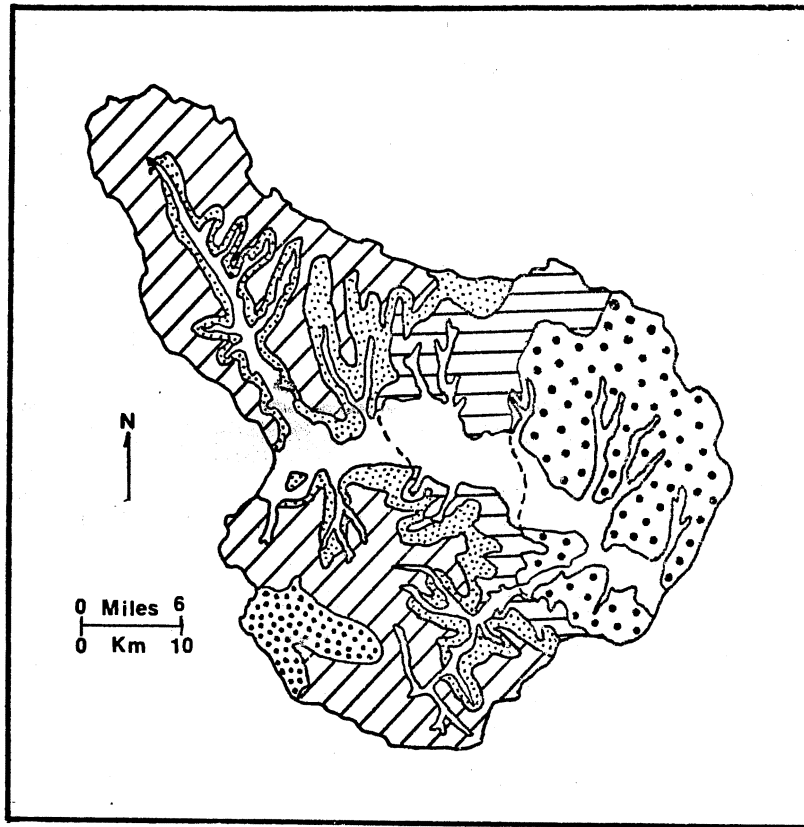
KEY

QUAT.
Alluvial and terrace deposits--
clays, silts, sands, and gravels,
0-150 ft thick.

PERMIAN

Cloud Chief Formation--irregular,
impure gypsum interbedded with
gypsiferous shale, 0-15 ft thick.

Rush Springs Sandstone--red, cross-
bedded, fine-grained sandstone with
silty lenses, 0-280 ft thick.

Marlow Formation--mostly even-bedded
brick red, sandy, gypsiferous
shale, 0-120 ft thick.

Dog Creek-Blaine Formation--mostly
dark red even-bedded shale inter-
bedded with gypsiferous sand 0-230
ft thick.

Chickasha Formation--heterogeneous
mixture of sandstone, shale, silt-
stone, and siltstone conglomerate
135-260 ft thick.

Figure 4. Bedrock Lithology Map of the Washita
River Basin Area, Chickasha, Okla.

(smallest stiple pattern in Figure 4). The Marlow
Formation consists of mainly even bedded, red, sandy,
dolomitic, gypsiferous shale. The Marlow Formation crops
out over most of the west half of the study area, with out-
crops along the entire western half of the Washita River
valley and along most of the length of the Sugar Creek
tributary to the north (except a portion at the north end
of the Sugar Creek which is in the Rush Springs Sandstone).
Overlying the Marlow Formation is the Rush Springs Sand-
stone (diagonal line pattern in Figure 4) which consists
of red, cross-bedded, fine-grained sandstone with silty
lenses and iron cement. This formation outcrops throughout
the Sugar Creek drainage basin in the northwest part of the
study area as well as in the southwest part of the study area.
The youngest formation in the study area of Permian age is
the Cloud Chief Formation, which consists of irregular,
impure gypsum interbedded with gypsiferous shale. The
Cloud Chief Formation (medium stiple pattern in Figure 4)
crops out mainly in the southwest part of the study area.

The Quaternary System. Valleys incised into the bed-
rock contain Quaternary alluvial deposits of a heterogeneous
mixture of grain sizes from clay to gravel. Personnel from
the Agricultural Research Service at Chickasha, Oklahoma,
and from Oklahoma State University have studied the alluvial
deposits using over 250 cased observation wells and 500
uncased borings with records showing the type and distri-
bution of sediments.

Mineralogic composition is heterogeneous in distribution. Using a random sample of 20 alluvial wells, bottom sediment samples were studied under the petrographic microscope using the oil emersion method. The mineral content of the alluvium is primarily quartz sand grains which are very fine to coarse and rounded. Trace minerals found include orthoclase, microcline perthite, plagioclase, magnetite, and limonite. Sericitization of orthoclase and microcline does not seem to be complete. Mineral grains of fibrous habit are in trace abundance and may be zeolites. Effervescence of the sediment samples in HCl acid indicated that calcite was present in most samples.

X-ray diffraction determination of the clay minerology was made on 43 alluvium sediment samples and 12 bedrock outcrop samples. The clays identified were kaolinite, illite, and montmorillonite. The frequency of occurrence of the clay minerals identified in the samples are presented in Table I.

TABLE I

CLAY MINERALOGY OF THE ALLUVIUM AND
BEDROCK, WASHITA RIVER STUDY AREA
CHICKASHA, OKLAHOMA

Clay Mineral	Alluvium			Bedrock		
	Mean	High	Low	Mean	High	Low
Illite	40%	74%	26%	51%	79%	13%
Montmorillonite	41%	66%	0%	24%	77%	0%
Kaolinite	19%	33%	0%	25%	47%	0%

Clay mineral distribution within the study area is shown in Figure 5. Although the sampling is not evenly distributed over the study area, one cluster of similar clay percentages is located in the east-central portion of the study area (outlined by bold, dashed line).
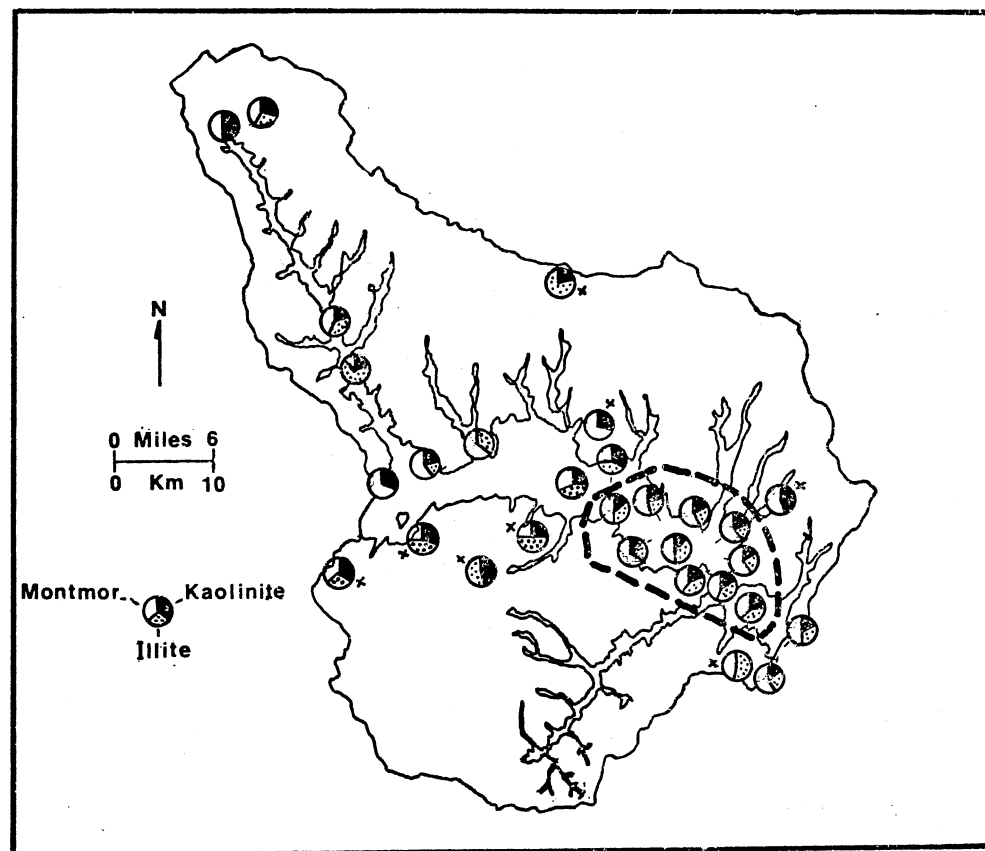
Figure 5. Clay Mineral Distribution: Kaolinite, Illite, and Montmorillonite, in Washita River Alluvium and Surrounding Bedrock (Bedrock = ×) near Chickasha, Oklahoma, Fall, 1973.

Inferred Soluble Nature of the Bedrock

Using the lithologic descriptions of the bedrock
formations, a conceptual model of the soluble nature of
the formations was developed. The ranking of these
formations as to solubilities is shown in Table II.

TABLE II

ORDINAL RANKING OF THE INFERRED SOLUBLE NATURE
OF BEDROCK FOR USE IN FACTOR ANALYSIS

Rank	Bedrock Formation
1 (Least Soluble)	Rush Springs Sandstone (quartz, iron cement)
2	Chickasha Formation (quartz, iron and $CaCO_3$ cement)
3	Dog Creek-Blaine Formation (quartz, clays, gypsum, and dolomite)
4 (Most Soluble)	Marlow Formation (gypsum, dolomite, clay, quartz, and iron cement)

This purely inferential ranking of the soluble
nature of the bedrock formations provides an indication
as to the relative degree of contribution each bedrock
formation might give to the dissolved mineral content of
the ground waters. The Rush Springs Sandstone would be
expected to contain ground waters of a relatively low
concentration of dissolved solids. The Chickasha Form-

ation would also contain a lower dissolved mineral content in its ground water, but may contribute higher amounts of Ca^{++} and CO_3^{--} to the ground water due to the presence of $CaCO_3$ cement. Both the Dog Creek-Blaine and Marlow Formations would be expected to have a higher dissolved mineral content because of the higher content of gypsum ($CaSO_4$), dolomite (($Ca,Mg)CO_3$) and leechate derived from the clays. Trace constituents have not been included in this ranking because the sources of trace elements have not been described in detail for the bedrock formations of the study area. Copper is the only trace element reported to occur in deposits in southwestern Oklahoma. The occurrence of copper in these deposits have been described by Stroud, McMahan, Stroup, and Hibpshman (1972, p. 3) to occur in the Blaine and San Angelo Formations, which are equivilent to the Dog Creek-Blaine Formation of the study area.

Ground-Water Movement

Ground-water movement in the study area is important for the evaluation of the distribution of chemical constituents in the ground water. Origins of the ground water which flow through the alluvium are important in relating different chemical sources to the distribution of the chemical content in the ground water. A ground-water table elevation map has been constructed using ground-water elevations for the 1970 water year supplied by

Agricultural Research Service at Chickasha, Oklahoma.
Control points were spaced about 2 miles aport. Because
the data was restricted to the alluvium of the main valley
and tributary valleys, bedrock ground-water elevations had
to be inferred. The ground-water elevation contours are
shown in Figure 6.
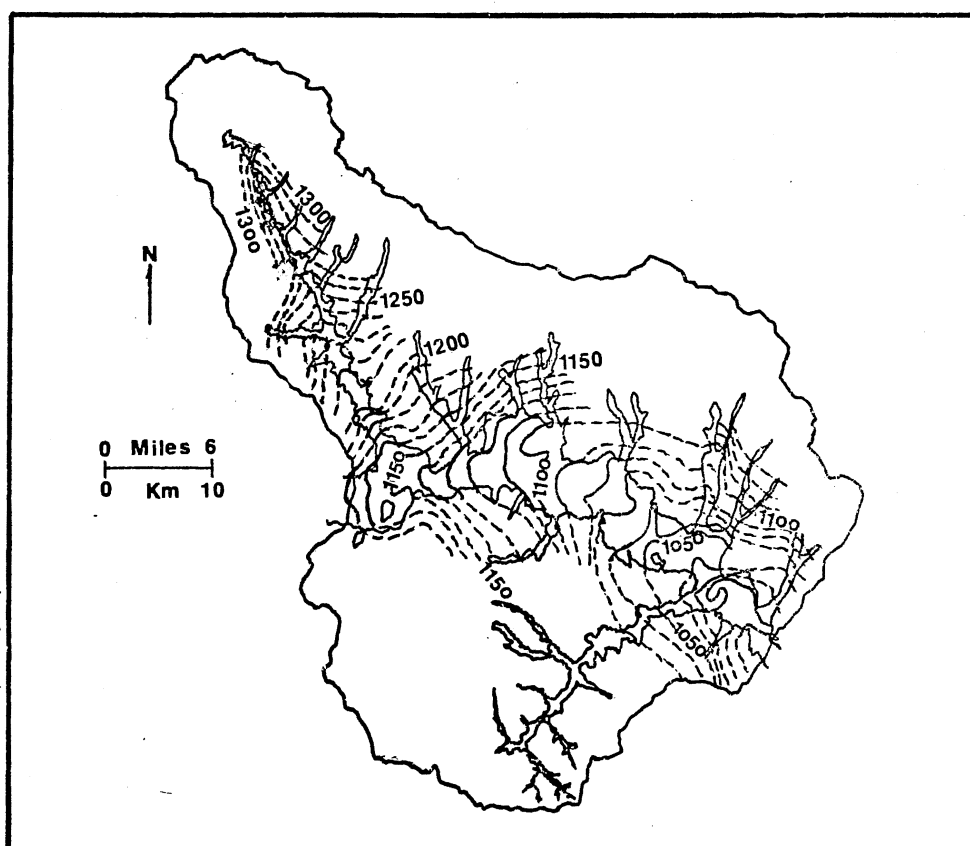
Figure 6. Ground-Water Elevation Contour Map for
           Washita River Alluvium and Surrounding
           Bedrock near Chickasha, Oklahoma
           Fall, 1973 (Contour Interval = 10 ft,
           Elevation Above Mean Sea Level).

The flow direction of the ground water is down gradient and perpendicular to the contour lines shown on the ground-water elevation contour map. The predominant flow direction is to the southeast. The flow direction within the alluvium is downstream whereas the flow within the bedrock is generally towards the alluvium.

Permeability

The distribution of permeability in the alluvium was obtained from data compiled by the Agricultural Research Service, Chickasha, Oklahoma. Work done by Kent, et al (1973) established a relationship between median grain size and coefficient of permeability. This relationship was based on laboratory and pump test data from cored wells and is shown in Figure 7 as a plot of median grain size versus the coefficient of permeability. Four permeability ranges were selected from this plot for purposes of assigning permeabilities to wash samples of borings knowing only the predominant grain size. Range 1, silt to very fine sand, is shown to have a permeability range of 1 to 10 gpd/ft^2. Range 2, very fine to fine sand, represents a permeability range of 10 to 100 gpd/ft^2. Range 3, fine to medium sand, includes the permeability range between 100 to 500 gpd/ft^2. Range 4, medium to coarse sand, is shown to have a permeability range of greater than 500 gpd/ft^2.
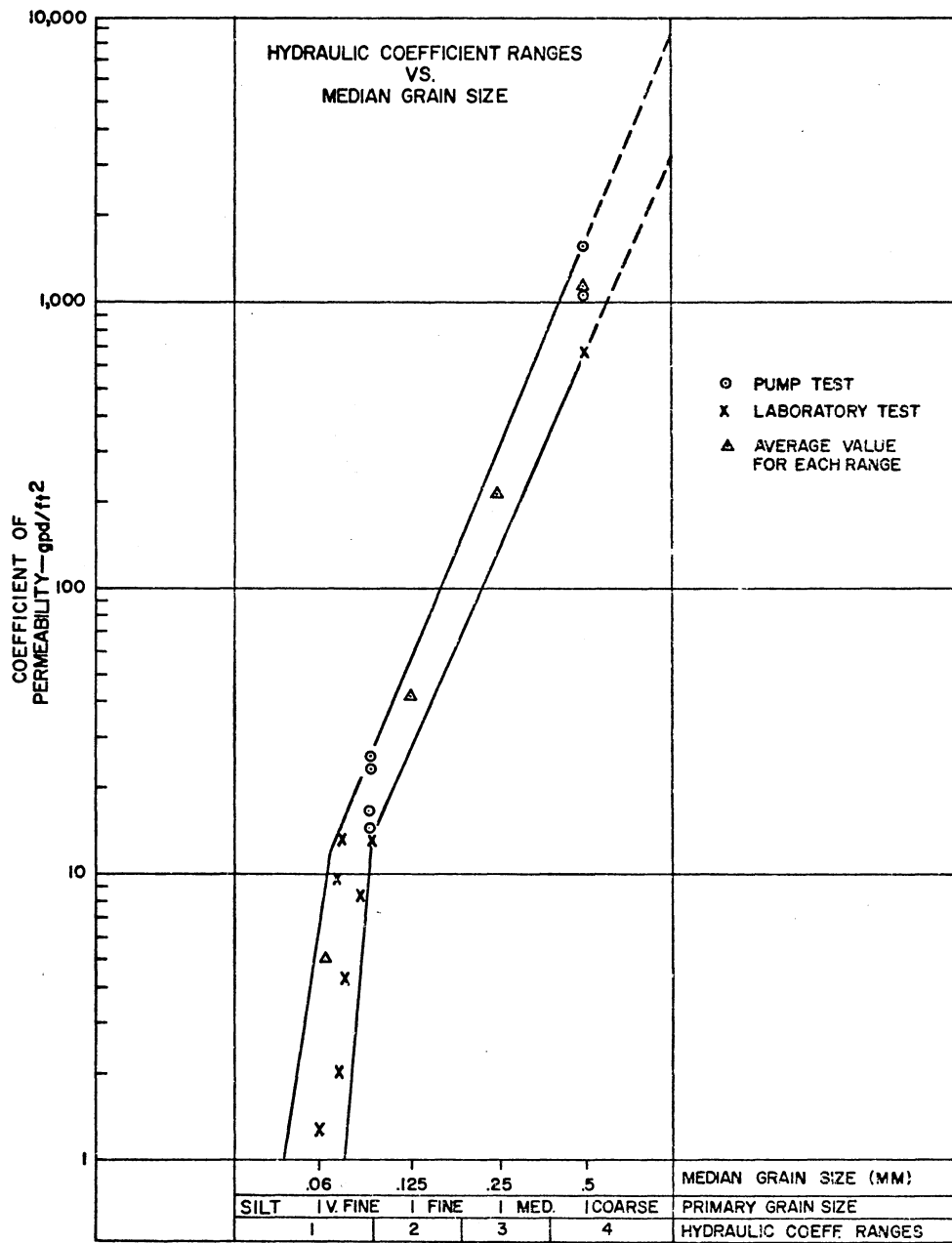
Figure 7. Relationship Between the Coefficient
of Permeability and Median Grain
Size for the Washita River Alluvium
(Kent, et al, 1973, p. 2).

Using this method of inferring permeability by predominant or median grain size, the distribution of permeability within the Washita River alluvium and associated bedrock has been described. Using the predominant grain size at the bottom of each well sampled, an assignment of a permeability range was made to each well sample taken. These ranges constitute the well-bottom permeability ranges which are shown as scaled circles in Figure 8. The average well-bottom permeability is Range 2.2, with 7 wells containing Range 1, 32 wells with Range 2, 3 wells containing Range 3, and 7 wells with Range 4.
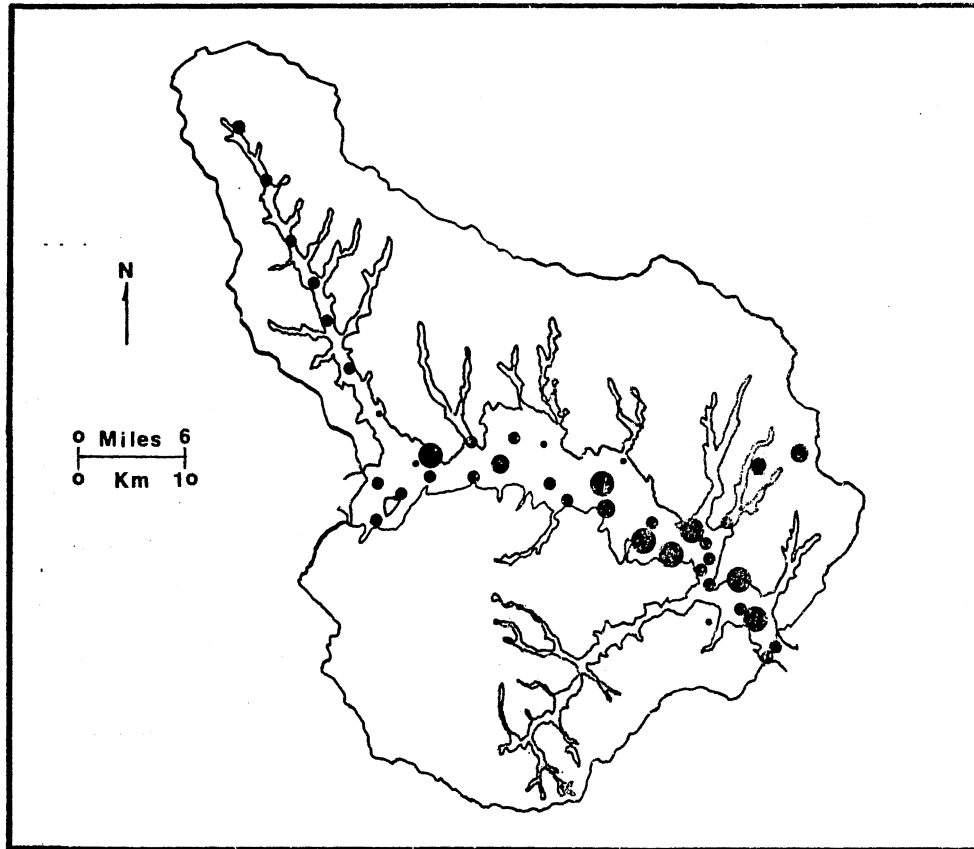
KEY

. Permeability Range = 0 - 1 gpd/ft^2

• Permeability Range = 1 - 10 gpd/ft^2

● Permeability Range = 10 - 70 gpd/ft^2

⬤ Permeability Range = 70 - 500 gpd/ft^2

Figure 8. Well Bottom Permeability of Sampled Wells
in Washita River Alluvium near
Chickasha, Oklahoma, Fall, 1973.

The weighted average permeability also was determined for the saturated thickness of each well sampled in the alluvium. This measurement of permeability was used as a control in order to determine whether or not there were any significant effects of vertical ground-water movement on the hydrogeochemistry of the alluvium. The distribution of weighted permeabilities for the wells sampled is shown using scaled circles in Figure 9. The weighted average permeability range for the saturated alluvial thickness was Range 1 in 5 wells, Range 2 in 31 wells, Range 3 in 6 wells, and Range 4 in 5 wells.

The distribution of both permeability parameters, well-bottom and weighted average, are approximately the same for the wells sampled in the alluvium. Range 2 is predominant in the western half of the study area, while Ranges 3 and 4 are predominant in the eastern half of the study area.
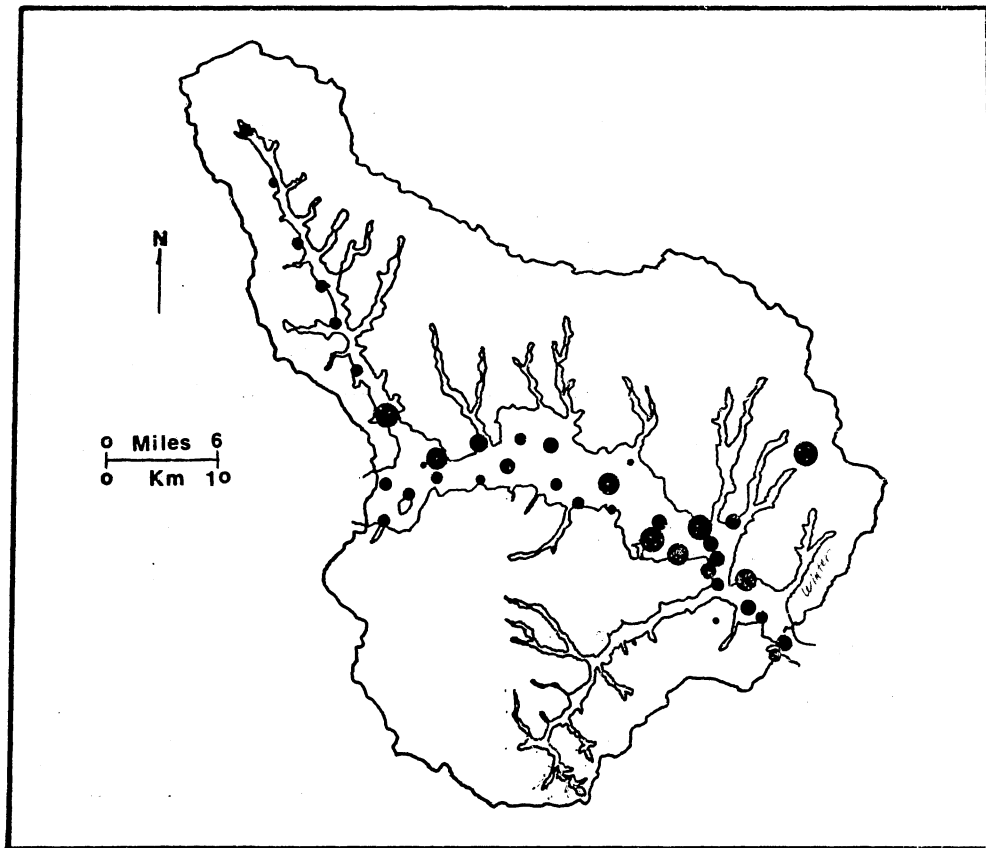
KEY

. Permeability Range = 0 - 1 gpd/ft^2
. Permeability Range = 1 - 10 gpd/ft^2
● Permeability Range = 10 - 70 gpd/ft^2
● Permeability Range = 70 - 500 gpd/ft^2

Figure 9. Weighted Permeability of Saturated Thickness
of Alluvium of Sampled Wells in Washita
River Alluvium near Chickasha, Oklahoma
Fall, 1973.

Land Use

A chemical land-use map (Plate 1 in sleeve) was developed in order to show potential sources of chemical constituents in ground water which are associated with land-use activities. The map was prepared using high altitude aerial photography. The aerial photographs were taken on May 4, 1973 at an altitude of 60,000 feet and included 9 in. by 9 in. color ektachrome and false-color infrared prints and transparencies. By overlaying the photographs with matte acetate, urban development, industries, cropland, woodland, prairie and pasture lands, oil fields, and large surface-water impoundments were distinguished and mapped. These features were field checked in order to establish the ground truth for the identification of these land-use signatures on the photographs.

The agricultural land use was subdivided further into spring fallow (those lands not planted) and crop lands (those lands supporting actively growing crops). The separation of these land-use patterns in the aerial photographs was accomplished by identifying the infrared signatures. The planting and growing seasons of the crops grown in the area were determined.[1] The crops, in order of decreasing acreage, include wheat, alfalfa, sorghum, cotton, and peanuts.

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[1] Dr. John F. Stone, Agronomy Department, Oklahoma State University, and Grady County Extension Agent of Oklahoma State University were consulted.

Wheat and alfalfa are planted in the fall and are actively growing during the time the aerial photographs were taken (May,4, 1973). Sorghum, cotton, and peanuts are planted in the latter part of May. Therefore, these crops were not growing when the photographs were taken. The wheat and alfalfa are distinguished in the infrared photos by the bright red color which represents healthy vegetation. Barren ground (not red) represents the fallowed fields where cotton, sorghum, and peanuts are grown at other times of the year.

Other infrared signatures identifiable are those of woodlands, grasslands, bodies of water, oil field operations, and urban areas. Woodlands show as a dark, dull red, bumpy-textured surface. Grasslands are a mottled, very pale brownish-red color. Bodies of water are black if clear, or are blue if they contain suspended sediment. Oil field operations are distinguished as spiderweb-like networks of white lines (pipe lines and service roads), rectangular white patches (gravelled areas around individual oil wells), and groups of white circular structures (tank batteries).

The predominant land-use patterns shown on Plate 1 (in sleeve) indicate that (1) agricultural practices dominate in the valleys, (2) pasture and grassland dominate in the upland plains, and (3) woodlands dominate on the slopes and bluffs of the Rush Springs Sandstone. Wheat and alfalfa are concentrated in the central and western portions of the Washita River valley, whereas sorghum and cotton

are in the eastern portion of the valley. Peanut cultivation is insignificant within the study area, but does occur in the eastern part of the area. The major peanut growing region is adjacent to the northwestern boundary of the study area and is grown on the upland plains of the Rush ● Springs Sandstone.

Fertilization rates[2] for wheat, sorghum, alfalfa, and cotton vary considerably. Nitrogen fertilizer application is 100 lbs per acre for wheat and sorghum, 30-80 lbs per acre for cotton, and 10-20 lbs per acre for alfalfa and peanuts. Phosphate (P_2O_5) application is approximately 50 lbs per acre for wheat, sorghum, cotton and peanuts, and 80-120 lbs per acre for alfalfa. Potash application rates are approximately 50 lbs per acre for wheat, sorghum, and peanuts, and 100 lbs per acre for cotton and alfalfa.

Oil field operations include the large Cement Field in the southwest corner of the study area (outlined in bold line on Plate 1) and smaller fields in the central and north-central portion of the study area (Norge, Verden, and Chickasha Fields). Oil from the Cement Field is piped out of the area to Cyril, Oklahoma where the Apco Oil Refinery is located. The Norge, Chickasha, and Verden Fields are served by the Koch Oil Company pipelines which extend to the northeast. The Cement Field is unified for

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[2] OSU Extension Facts, No.s 2205, 2210, 2216, 2217, 2219, Oklahoma State University were consulted.

secondary recovery operation. Secondary recovery is not being used in the newer Norge, Chickasha, and Verden fields.

The use of brine evaporation pits in the Washita River valley is limited to one pit located in the SW ¼, Sec. 10, T7N, R8W. The pit was not being used at the time of observation for this study. An oil slick was observed in one ground-water sample north of the Washita River valley (well no. 264, NE ¼, NW ¼, NE ¼, Sec. 17, T8N, R8W). Within the valley of the Washita River, the oil wells are relatively new and in excellent maintenance No older wells which might allow contamination of the environment by leakage through rusty pipes and casings are located in the Washita River valley.

STATISTICAL TREATMENT OF DATA

Analysis of Variance on Land Use

One of the stated objectives of this research is to investigate the effects of land use upon ground-water chemistry. At the same time the well-water samples were collected, the dominant land use at each sampling site was recorded. Thus, a comparison of the dominant land use with other parameters can be made using statistical analysis. Of the 49 wells sampled, 27 are on cropland, 15 are on pasture land, 3 are in urban areas, 3 are in oil field areas and 1 is on woodlands (see Plate 1). The small sample sizes for urban, oil field, and woodland areas restrict the statistical analysis to cropland and pasture land. Analysis of variance (AOV) was used to determine if differences exist between ground-water chemistry in cropland and pasture land.

The major differences to be expected in the ground-water chemistry of pasture land and cropland would be related to the relative amount of fertilizer applied to each area. This would be reflected in the concentration of the fertilizer components, nitrogen, phosphate, and potassium. Cropland applications of fertilizer are much greater than for pasture lands, where they are generally not applied.

Therefore, it is expected that the ground-water content of nitrogen, phosphate, and potassium within the saturated zone would be higher under cropland areas. However, the concentrations of these constituents will be variable under cropland areas because the fertilization rates are not constant from crop to crop, nor from farmer to farmer.

Factors which affect the rate of fertilizer movement into the saturated ground-water zone are soil and aquifer permeability, rainfall amounts and distribution, type of fertilizer applied, and methods of application. The rainfall factor can be considered minor since the annual rainfall amount is equally distributed over the study area. Aquifer permeability is considered constant by comparing the ground-water chemistry for only those wells completed in sediments of equal permeability. The soil permeability was assumed to be constant over the alluvium within the study area because most of the soils are silty to sandy loam. The variation in the type of fertilizer used and the manner of application cannot be accounted for, because this data is not known.

A statistical sample of 16 cropland wells and 11 pasture-land wells with permeability of Range 2 were selected. One-way analysis of variance was performed on each fertilizer component, total N, K^+, and PO_4^{-3}, for the cropland wells versus the pasture-land wells. The null hypothesis is that there is no difference between the means of the fertilizer components in the ground-water areas under-

lying the cropland and pasture land. Results of the AOV
on total nitrogen, phosphate, and potassium are shown in
Tables III, IV, V, respectively.

TABLE III

ANALYSIS OF VARIANCE TABLE FOR CROPLAND
VERSUS PASTURE LAND ON TOTAL NITROGEN
IN GROUND WATER

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio	Level of Significance
Between	0.0381	1	0.0381		
Within	0.3087	25	0.0523	0.727	0.594
Total	1.3468	26			

$\bar{N}$ (Cropland) = 15.5 ppm

$\bar{N}$ (Pasture) = 10.7 ppm

TABLE IV

ANALYSIS OF VARIANCE TABLE FOR CROPLAND
VERSUS PASTURE LAND ON PHOSPHATE IN
GROUND WATER

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio	Level of Significance
Between	4.832	1	4.832		
Within	68.101	25	2.724	1.774	0.192
Total	72.933	26			

$\overline{PO_4}$ (Cropland) = 1.14 ppm

$\overline{PO_4}$ (Pasture) = 0.28 ppm

TABLE V

ANALYSIS OF VARIANCE TABLE FOR CROPLAND
VERSUS PASTURE ON POTASSIUM IN
GROUND WATER

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio	Level of Significance
Between	26.642	1	26.642		
Within	183.376	25	7.335	3.632	0.065
Total	210.018	26			

$\bar{K}$ (Cropland) = 4.3 ppm

$\bar{K}$ (Pasture) = 2.3 ppm

Although the sample sizes used in the analysis of
variance tests are too small to assure accurate represent-
ation of the population, the results can be used to suggest
trends in the data. A 0.1 level of significance was used
as the determining level of rejection of the null hypo-
thesis. Total nitrogen content in the ground water is not
significantly different under pasture land and cropland
(0.594 level on Table III). Phosphate approaches a signi-
ficant difference (0.192 level on Table IV). However, the
potassium concentrations in the ground water is significantly
different in the two areas (0.065 level on Table V). Even
though significant differences do not exist in all three
cases, concentrations are higher in the cropland as compared
to the pasture land. The latter conclusion is based on the
relative mean concentrations listed in Tables III, IV, and V.

A more accurate appraisal of the effects of fertilization upon the ground-water content of nitrogen, phosphate, and potassium will require further investigation of other factors. These factors include (1) alternate sources of these constituents and (2) the distribution of pasture land and cropland in the study area.

Alternate sources of nitrogen to the ground water are decomposition of organic material buried in the alluvium and nitrogen content of rocks. Feth (1966, pp. 41-58) mentions the occurrence of nitrogen in rocks, and cites as average values for NH_3 in clays and sandstones 580 g/ton and 135 g/ton, respectively (about 640 and 149 ppm, respectively). The organic sources of nitrogen can be very important sources to the ground water. Organic material is buried in the alluvium and, upon decomposition, releases nitrogen compounds to the ground water. These two sources have not been studied in this research. To the knowledge of this investigator, no other definitive studies of these two factors have been made. The actual relationship of fertilization to nitrogen content of the ground water may have been masked by these alternate sources.

Sources of phosphorus in ground water other than fertilizers are mainly organic decomposition and minerals. The organic source would probably be more important than the mineral source because of the high amounts of organic material expected to occur and the general insolubility of phosphorus bearing minerals. Potassium occurrence in the ground

water is greatly confounded by the weathering of feldspars and micas resulting in the release of potassium (K^+) into solution.

Because the concentration of potassium in the ground water may result from mineral weathering, the distribution of cropland and pasture land in the study area may add to the confoundment of the AOV. Most of the wells that were sampled in the pasture lands occur on the upland areas formed by the Rush Springs Sandstone. However, the wells that are in cropland areas occur in the Marlow, Dog Creek-Blaine, and Chickasha Formation outcrop areas. This bias in sampling is shown in Table VI. This sampling bias may explain why there is a significantly higher concentration of potassium in the cropland areas. As shown in Table VI, the mean concentration of potassium in the ground water of the Rush Springs Sandstone is much lower than the potassium concentrations of the ground waters in the Chickasha, Marlow, and Dog Creek-Blaine Formations. Therefore, there is no way to use these data to test the significance of the potassium content of the ground waters due to fertilization.

TABLE VI

FREQUENCY DISTRIBUTION OF 42 WELLS
IN THE BEDROCK VERSUS LAND USE
AREAS AND MEAN K^+ CONTENT OF
GROUND WATER IN EACH
BEDROCK, CHICKASHA,
OKLAHOMA

Bedrock	Cropland	Pasture	Mean K^+
Rush Springs Ss.	0	9	2.1 ppm
Chickasha Fm.	10	4	4.2 ppm
Marlow Fm.	7	2	5.7 ppm
Dog Creek-Blaine Fm.	10	0	6.3 ppm

Factor Analysis of the Alluvium

Hydrogeochemistry

A purpose of this study is to identify the factors which control the hydrogeochemistry of the Washita River alluvium. The factors include concentrations of trace and common chemical constituents in the ground water, aquifer clay mineralogy, bedrock lithology, depth of collected ground-water sample, and aquifer permeability (at well bottom and weighted average permeability for saturated alluvial thickness). Land-use distribution was not considered because of insufficient data for each land-use category. The relationships between factors are evaluated using factor analysis. Factor analysis utilizes a correlation matrix of all paired correlations between variables to find general factors, or processes, which control portions of the variance in the matrix of variables (see Appendix A for a brief description of factor analysis interpretation). Computations for the factor analysis were processed on the Oklahoma State University IBM 360/65 using the Statistical Analysis System (SAS) library package. The SAS package is based on a principal axis technique using orthogonal rotation by the varimax solution.

The factor analysis program required data to be at least ordinally scaled (unless there is a dichotomous relationship, i.e., yes-no type). Thus, the data on the

bedrock lithology outcrop area in which the well was located
(Rush Springs Sandstone, Marlow, Dog Creek-Blaine, or
Chickasha Formation) had to be converted to an ordinal
scale based on the soluble nature of the formations. The
ordinal ranking of the bedrock lithologies suggested in
Table II (p. 21) was utilized. Thus, wells which occur
within the outcrop areas of the Rush Springs Sanstone,
Chickasha, Dog Creek-Blaine, and Marlow Formations were
labelled "1", "2", "3", and "4", respectively, with "4"
representing the highest solubility. Permeability ranges
were used for the permeability at well bottom and weighted
average permeability for saturated alluvial thickness.
Percentages of the three clay mineral species were used to
describe the clay mineralogy. Depth of sampling was used
as an additional variable in factor analysis. The data on
the metal leechate (as described on pp. 10-11) was included
in the factor analysis.

The ground-water chemical data were transformed from
raw data (parts per million) to activities (in moles per
liter) for use in the factor analysis. The ionic strength
of the solution was calculated for each well sample using
the concentrations of bicarbonate, chloride, sulfate,
sodium, calcium, and magnesium. These ionic species
accounted for approximately 99% of those ions tested. The
equation for ionic strength, I, is given in Equation (1).
The ionic strength was used to claculate

the activity coefficients, γ, for individual ions using Equation (2). Equation (2) is after Davies as cited in Krauskopf (1967, p. 74). The molar activity, a, of each ion was calculated by multiplying the molar concentration of the ion by the activity coefficient and is shown in Equation (3).

$$I = \tfrac{1}{2}\sum_i c_i z_i^2 \qquad (1)$$

$$\gamma_i = 10^{\left[-0.5z_i^2\left(\frac{I^{\frac{1}{2}}}{1+I^{\frac{1}{2}}} - 0.2I\right)\right]} \qquad (2)$$

$$a_i = c_i \gamma_i \qquad (3)$$

Where:

c_i = concentration of ion i (moles/liter)

z_i = valence of ion i

I = ionic strength

γ_i = activity coefficient of ion i

a_i = molar activity of ion i

For interpretation of the factor analysis, variables with factor loadings greater than ± 0.400 are considered to be significantly related to that factor. The sign of a specific factor loading (whether positive or negative) indicates the direction of relationship between the factor and that variable. Those variables loaded negatively vary inversely with the factor, and those variables loaded positively vary directly with the factor. Additional information for factor analysis is provided in Appendix A.

The interpretation of the factor analysis results for the alluvium hydrogeochemistry is shown in Figure 10. The correlation matrix, eigenvalue, and unrotated factor matrices used to develop the matrix of Figure 10 are shown in Appendix H-K. Because the matrix in Figure 10 is large, the insignificant loadings (less then $\pm$ 0.400) have been blocked out.

Factor 1 (Figure 10) shows that 19% of the total explained variance of the matrix is accounted for by the covariances of HCO_3^-, CO_2, Mg^{++}, Ca^{++}, K^+, NH_4^+, Mn^{++}, Si, and illite. The specific loadings for these variables are -.834, -.794, -.697, -.405, -.656, -.747, -.453, -.644, and -.621, respectively. Factor 1 may be described as a carbonate-illite mineral assemblage. The significance of the association between Mg^{++}, Ca^{++}, and Mn^{++} can be explained by the carbonate mineral equilibria of the type expressed by Equations (4), (5), and (6).

$$MgCO_3 + H_2CO_3 \rightleftharpoons Mg^{++} + 2HCO_3^- \qquad (4)$$

$$CaCO_3 + H_2CO_3 \rightleftharpoons Ca^{++} + 2HCO_3^- \qquad (5)$$

$$MnCO_3 + H_2CO_3 \rightleftharpoons Mn^{++} + 2HCO_3^- \qquad (6)$$

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \qquad (7)$$
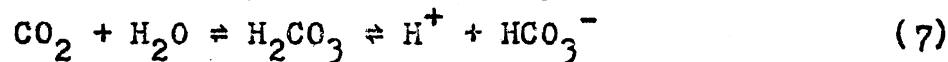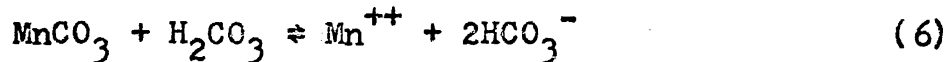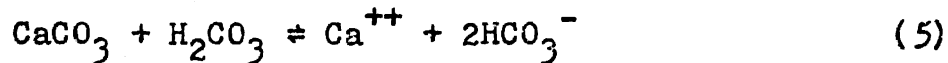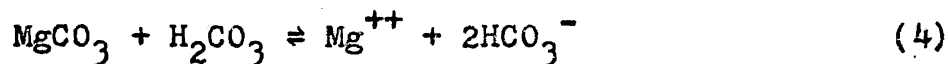
The loadings on CO_2 and HCO_3^- in Factor 1 are represented by Equation (6). Because all of the equations (4-6) include a carbonate reaction, it is implicit that as CO_2 increases in the ground water Equation (7) would shift to the right, thereby increasing the HCO_3^- in the ground water.

FACTOR	1	2	3	4	5	6	7	8	9	COMMUNALITY
PH						0.550		-0.448		0.774
BEDROCK				-0.415	0.753					0.937
BPERM									0.823	0.802
WDPERM									0.616	0.550
KAOLIN			0.900							0.849
ILLITE	-0.621		0.502	-0.432						0.921
MONT			-0.815							0.911
DEPTH			-0.476							0.407
CU CLAY		0.708								0.657
MN CLAY		0.851								0.788
ZN CLAY		0.833								0.866
PB CLAY		0.936								0.891
CD CLAY		0.795								0.679
NH4	-0.747									0.674
NO2							0.885			0.845
NO3							0.807			0.731
PO4						0.822				0.741
CO3				-0.432		0.508			0.446	0.670
CO2	-0.794									0.804
HCO3	-0.834									0.858
CL				-0.942						0.940
NA				-0.909						0.858
SO4				-0.712						0.826
CA	-0.405									0.511
MG	-0.679									0.615
MN	-0.453							0.654		0.789
FE								0.860		0.760
K	-0.656								0.432	0.725
SI	-0.644									0.838
CU					0.424	0.631				0.822
PB					0.697					0.700
CD							0.680			0.747
ZN					0.665				0.453	0.778
TOTAL VARIANCE	4.864	3.957	2.570	3.094	2.263	1.967	2.383	2.003	2.162	
PERCENT TOTAL VARIANCE	19.25	15.66	10.17	12.25	8.96	7.79	9.43	7.93	8.56	

Figure 10. Rotated Factor Matrix of the Alluvium Hydrogeochemistry Factor Analysis (Only significant factor loadings are shown).

Although the specific loading for pH is only +.390 in Factor 1, the value is close to the significant level of .400 which suggests some control of pH by the carbonate equilibria. Control of the pH in the reaction expressed in Equation (6) supports this suggestion.

The solubility relationships for calcite in the ground water can be obtained from the plot of ground-water data on the solubility diagram of Figure 11. The plot of individual wells show that the majority of well water is supersaturated with respect to calcite. From Figure 11, the alluvium ground water is precipitating calcite. This is supported by the fact that most of the sediment samples from the alluvium do effervesce in HCl. Thus, the interpretation of Factor 1 (Figure 10) as a carbonate equilibria control is supported.

The significance of illite, K^+, and Si in Factor 1 (Figure 10) may be explained by the model represented by Equation (8).

$$3KAlSi_3O_8 + 2H^+ \rightleftarrows KAl_3Si_3O_{10}(OH)_2 + 6SiO_2 + 2K^+ \quad (8)$$
$$\text{K-Feldspar} \qquad \text{Illite (K-Mica)}$$
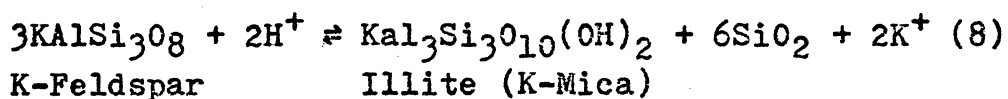
This equation illustrates an association between an increase in H^+ due to the reaction of CO_2 with water (Equation (7)) and an increase in illite, Si, and K^+.

Factor 2 (Figure 10) accounts for 15.66% of the total matrix variance and contains significant factor loadings for the metal leechates from the sediment which include Cu^{++},
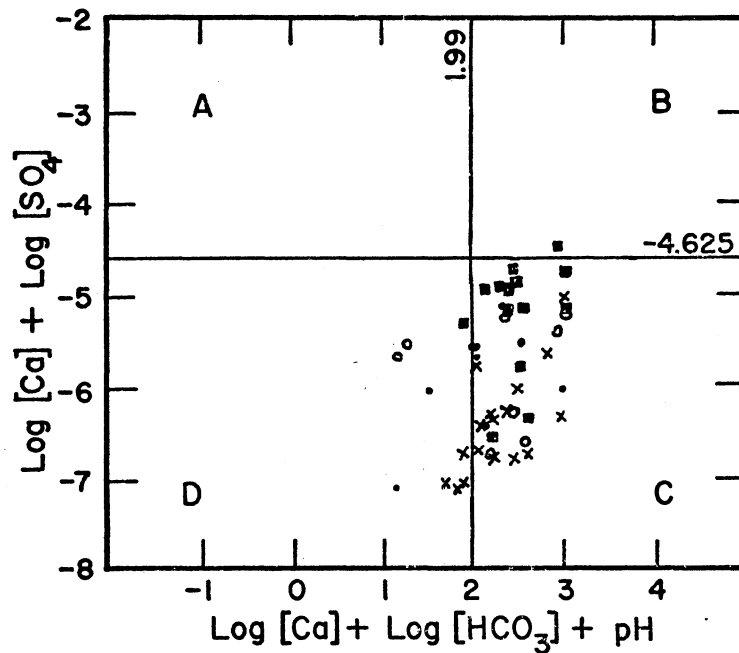
A- GYPSUM SUPERSATURATION

B- GYPSUM AND CALCITE SUPERSATURATION

C- CALCITE SUPERSATURATION

D- UNSATURATED

- • RUSH SPRINGS BEDROCK AREA
- × CHICKASHA BEDROCK AREA
- ◦ BLAINE BEDROCK AREA
- ▪ MARLOW BEDROCK AREA

Figure 11.   Calcite and Gypsum Equilibrium
             Solubility Limits, 25°C and
             1 Atm Pressure (After Hem,
             1970, Figure 27, p. 254)

Mn^{++}, Zn^{++}, Pb^{++}, and Cd^{++}. The specific factor loadings for these metals are .708, .851, .833, .936, and .795, respectively. The fact that the loadings for these metals occur in a factor by themselves indicates that these metals vary independently with those metals which occur in solution (see Factors 1, 5, 6, 7, and 8).

Factor 3 (Figure 10) contains 10.17% of the total matrix variance and includes significant loadings for kaolinite, illite, montmorillonite, and depth (.900, .502, -.815, and -.476, respectively). The positive and negative loadings indicate that an inverse relationship may exist between montmorillonite and the two variables kaolinite and illite. This relationship involves a replacement process between these variables. The association of sampling depth with the clay minerals indicates that some variance of the clays is controlled by their depth. The relationship indicated is one of increasing montmorillonite with depth below surface.

To further assess the relationships between montmorillonite, illite and kaolinite as indicated in Factor 3 (Figure 10), clay stability diagrams are used to indicate their stability in the ground water. The clay stability relationships are based on ground-water cation and silica content. Figure 12 represents the system $Na_2O-Al_2O_3-SiO_2-H_2O$ and indicates that kaolinite is the stable phase in relation to Na^+ in the ground water of most sampled wells. Na-montmorillonite is stable in only a few wells. Figure 13 represents the system $K_2O-Al_2O_3-SiO_2-H_2O$ and indicates that, with
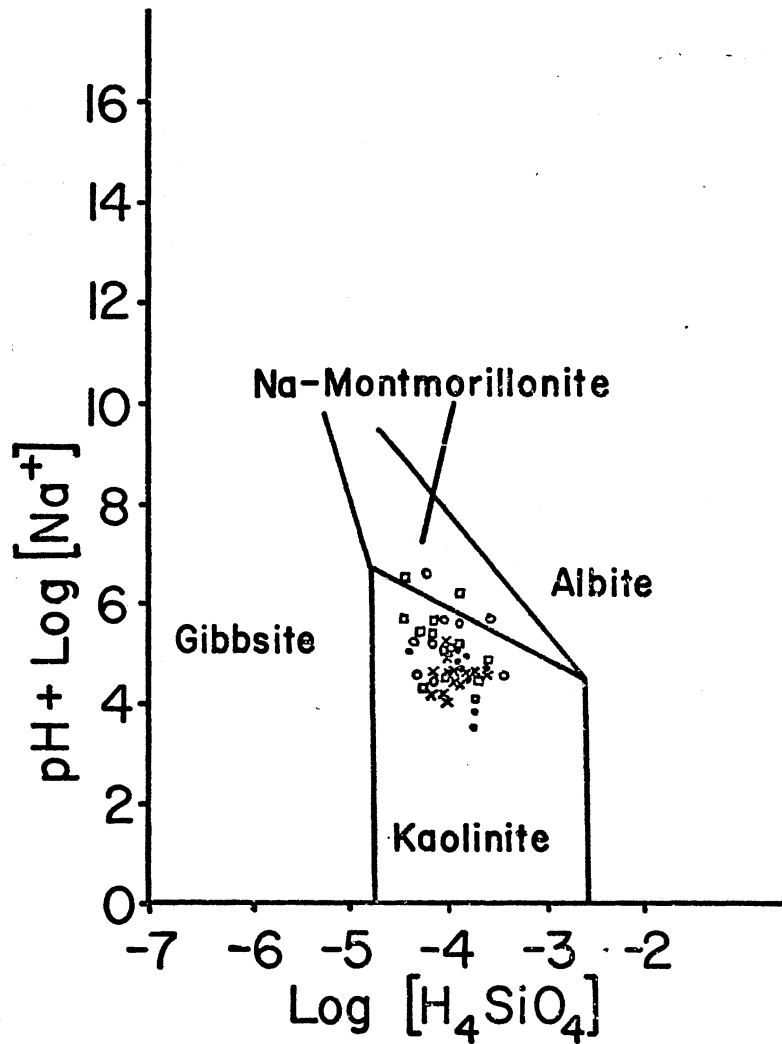
Figure 12. Stability Relations of Phases
in the System $Na_2O-Al_2O_3-SiO_2-$
H_2O at 25°C and 1 Atm Pressure
(After Feth et al, 1964,
Figure 13, p. 62)
• = Rush Springs Bedrock Area
× = Chickasha Bedrock Area
• = Dog Creek-Blaine Bedrock Area
□ = Marlow Bedrock Area
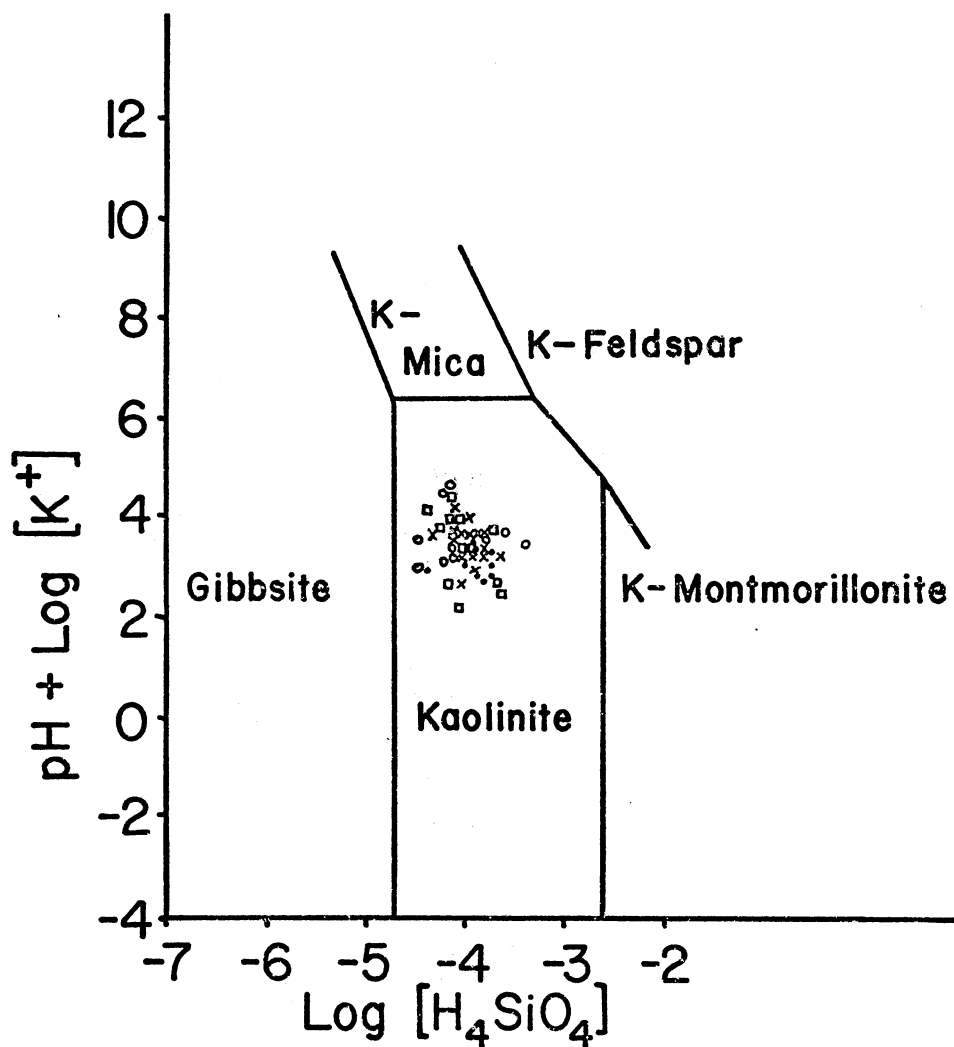
Figure 13. Stability Relations of Phases in the System $K_2O\text{-}Al_2O_3\text{-}SiO_2\text{-}H_2O$ at $25^\circ C$ and 1 Atm Pressure (After Feth et al, 1964, Figure 14, p. 65)
    • = Rush Springs Bedrock Area
    × = Chickasha Bedrock Area
    ∘ = Dog Creek-Blaine Bedrock Area
    □ = Marlow Bedrock Area

respect to K^+, kaolinite is the stable phase. Figure 14 represents the system $MgO-Al_2O_3-SiO_2-H_2O$ and indicates that the ground water is in delicate equilibrium with respect to Mg-clays. The plotted points occur predominantly in a narrow kaolinite field which is controlled by dissolved silica in the ground water. Some points are located in the gibbsite $(Al(OH)_3)$ field, a few points are located in the Mg-chlorite field, and a few are located in the Mg-montmorillonite field. Figure 15 represents the system $CaO-Al_2O_3-SiO_2-H_2O$ and indicates the ground water is not in equilibrium with any clay mineral with respect to the Ca^{++} content of ground water. Leonhardite (a zeolite) is shown to be stable with respect to Ca^{++} in Figure 15, but leonhardite would not form because the ground water is supersaturated with respect to calcite. Calcite would form in preference to leonhardite. Based on the stability diagrams, the stable clay mineral within the alluvium is kaolinite.

Combining the factor analysis and stability diagrams, the processes controlling the clay mineralogy in the alluvium may be hypothesized. The major process controlling clay mineral occurrence is a weathering sequence of montmorillonite to illite and kaolinite. This sequence is inferred by the factor loadings and stability relationships. Equations (9) and (10) (p. 54) describe the weathering reactions involved. K-mica is used in Equation (9) instead of illite for simplification.
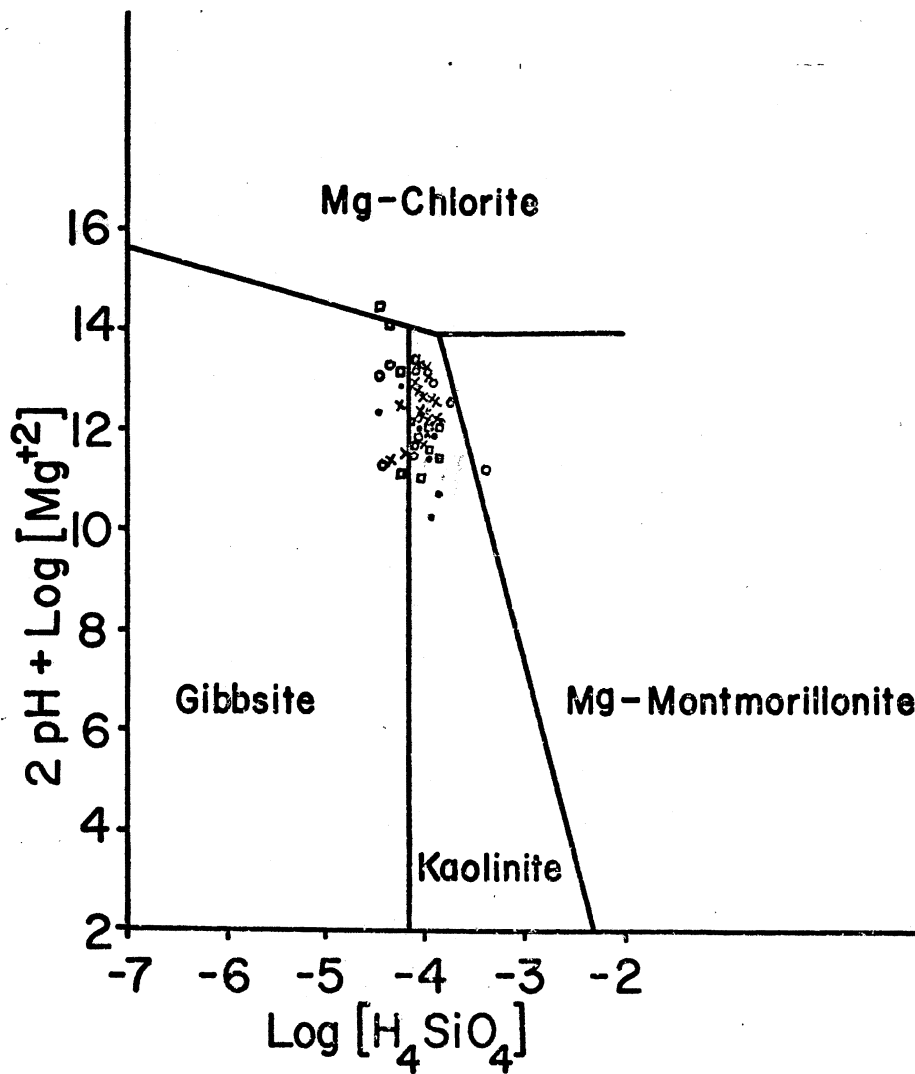
Figure 14. Stability Relations of Phases in the
System $MgO-Al_2O_3-SiO2-H_2O$ at 25^oC
and 1 Atm Pressure (After Helgeson
et al, 1969, p. 23)
• = Rush Springs Bedrock Area
x = Chickasha Bedrock Area
o = Dog Creek-Blaine Bedrock Area
□ = Marlow Bedrock Area
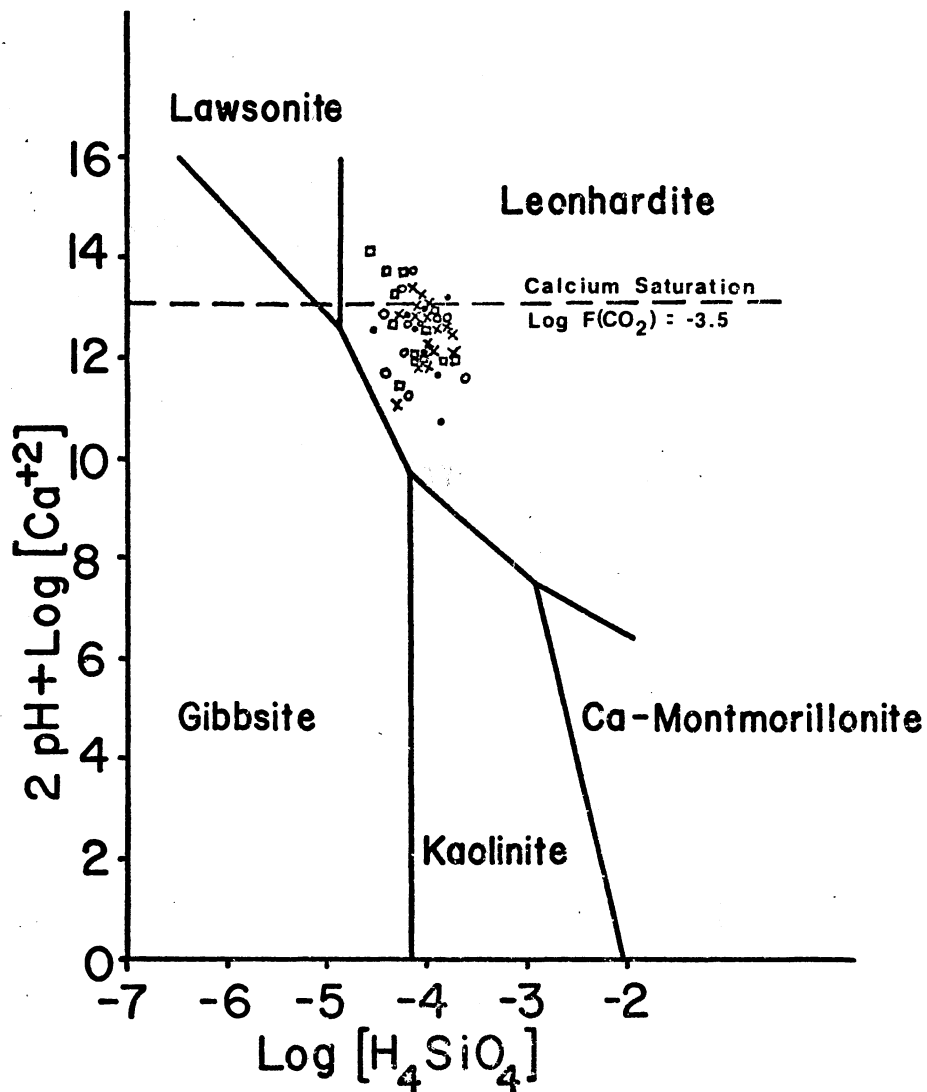
Figure 15. Stability Relations of Phases in the
System $CaO-Al_2O_3-SiO_2-H_2O$ at 25°C
and 1 Atm Pressure (After Helgeson
et al, 1969, p. 26)
• = Rush Springs Bedrock Area
x = Chickasha Bedrock Area
o = Dog Creek-Blaine Bedrock Area
◘ = Marlow Bedrock Area

$$3Al_2Si_4O_{10}(OH)_2 + 2K^+ \rightleftharpoons 2KAl_3Si_3O_{10}(OH)_2 +$$

Montmorillonite   K-Mica

$$+ 6SiO_2 + 2H^+ \qquad (9)$$

$$Al_2Si_4O_{10}(OH)_2 + H_2O \rightleftharpoons Al_2Si_2O_5(OH)_4 + 2SiO_2 \qquad (10)$$

Montmorillonite   Kaolinite
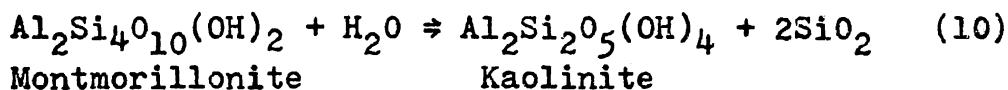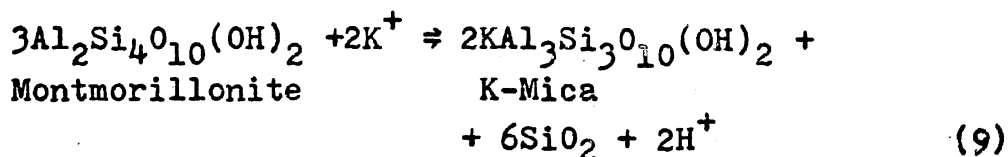
The probable reason that the above reactions (Equations (9) and (10)) do not significantly relate to the cations in the factor analysis (Figure 10) is that the amount of clay is small in comparison to the amounts of total dissolved cations in the ground water. The other processes such as carbonate equilibria apparently are much more important than the clay-water system. Other factors which complicate the clay relationships are the unknown contribution of detrital clay and the weathering of the minor amounts of feldspar in the alluvium. A model which represents the inferred relationships for the clay-water system is shown in Figure 16. The model shows the input of detrital clay, feldspars, and reactive ionic species, as well as the characteristic clays and ions produced from the sequential weathering process.
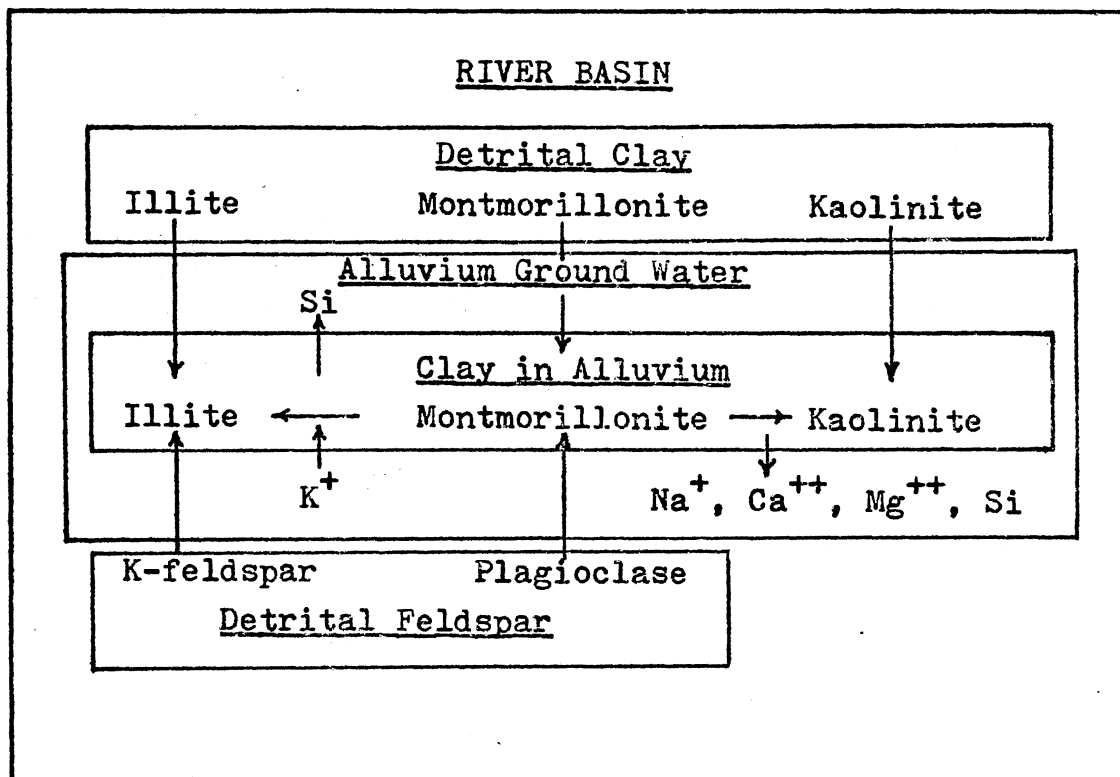
Figure. 16. Model of the Clay Mineral Weathering
Sequence with Input and Output of Minerals
and Clays and Ions in the Alluvium of the
Washita River.

Factor 4 (Figure 10) contains 12.25% of the total variance in the factor matrix. The significant loadings in this factor are for Na^+, Cl^-, $SO_4^=$, illite, bedrock, and $CO_3^=$ (-.909, -.942, -.712, -.432, -.415, and -.432, respectively). This unique group of variables indicates that the amounts of Na^+, Cl^-, $SO_4^=$, illite, and $CO_3^=$ in the ground water of the alluvium are controlled primarily by the solubility of the surrounding bedrock lithology. Therefore, the presence of bedrock which possesses a higher solubility will result in higher concentrations of Na^+, Cl^-, $SO_4^=$, and $CO_3^=$ in the ground water. The presence of these constituents indicates that the solubility of the bedrock is primarily due to the presence of NaCl and gypsum.

To understand why Ca^{++} is not involved in Factor 4, the relationship between the solubility of gypsum and calcite must be evaluated. The plot of well samples in Figure 11 indicates that all but one well contain ground water undersaturated with respect to gypsum, whereas most wells are supersaturated with respect to calcite. The following equations can be used to derive the solubility relationships between gypsum and calcite (Krauskopf, 1967, p. 18).

$$CaSO_4 + CO_3^= \rightleftarrows SO_4^= + CaCO_3 \qquad (11)$$
$$\text{Gypsum} \qquad\qquad\qquad \text{Calcite}$$
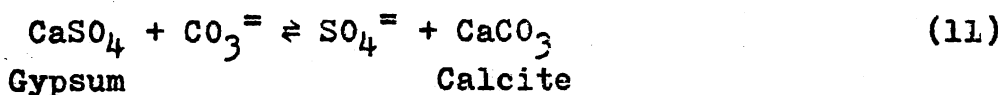
$$K_{sp} = (Ca^{++})(SO_4^=) = 3.4 \times 10^{-5} \qquad (12)$$

$$K'_{sp} = (Ca^{++})(CO_3^=) = 4.5 \times 10^{-9} \qquad (13)$$

$$K = \frac{(SO_4^=)}{(CO_3^=)} = \frac{K_{sp}}{K'_{sp}} = 7.6 \times 10^3 \qquad (14)$$

Equation (14) shows that $CaSO_4$ is about 7600 times more soluble than $CaCO_3$. This will cause the gypsum in the bedrock to rapidly dissolve and release Ca^{++} and $SO_4^=$ to solution. The subsequent precipitation of $CaCO_3$ from the alluvium ground water will extract Ca^{++} from solution, leaving the $SO_4^=$ as shown in Equation (11). The occurrence of calcite in the alluvium supports this interpretation. Therefore, the carbonate equilibria will control the Ca^{++} concentration in the ground water of the alluvium.

The inclusion of illite in Factor 4 (Figure 10) indicates that a proportion of the illite is being controlled by contributions from the bedrock lithologies. The variance of illite may be due to detrital origins of illite. The origin of illite could be the detritus transported from the surrounding bedrock into the alluvium.

Factor 5 (Figure 10) accounts for 8.96% of the total variance and contains significant loadings for bedrock, as well as dissolved Cu^{++}, Pb^{++}, and Zn^{++}. The loadings are .753, .424, .697, and .665, respectively. As in Factor 4, the association of variables in this factor indicates that bedrock controls portions of copper, lead, and zinc in solution. Copper deposits have been identified in the Dog Creek-Blaine Formation (see Stroud, et al, 1972). However, minerals of lead and zinc have not been reported from this area.

Factor 6 (Figure 10) contains 7.79% of the total variance. This factor includes significant loadings for PO_3^{-3}, Cu^{++}, pH, and $CO_3^{=}$ and are .822, .631, .550, and .508, respectively. A complexing of copper by phosphate and carbonate in the ground water might explain this group of variables. The pH would exert some control on the degree of complexing of the copper with the ligands.

Factor 7 (Figure 10) accounts for 9.43% of the total variance and contains high loadings for nitrite, nitrate, and cadmium in the ground water. The loadings are .885, .807, and .680, respectively. This group could be explained by the occurrence of nitrite-nitrate complexing of cadmium.

Factor 8 (Figure 10) accounts for 7.93% of the total variance. This factor includes significant loadings for total iron, Mn^{++}, Zn^{++}, and pH. Values of the loadings are .860, .654, .453, and -.448, respectively. The negative loading for pH and the positive loadings for iron, Mn^{++}, and Zn^{++} indicate an inverse relationship. A redox equilibria could control the concentrations of a major portion of the iron and of smaller percentages of manganese and zinc in the ground water.

In order to evaluate the redox equilibria, the Eh of the ground water must be known. Although the Eh of the alluvium ground-water samples was not determined, the Eh can be calculated by assuming that only the Fe^{++} species is present and that the colloidal iron hydroxide species is

absent. Equation (15) describes the redox equilibria for iron (Krauskopf, 1967, p. 249). Equations (16) and (17) express the Eh-pH function of the solubility of iron.

$$Fe^{++} + 3H_2O \rightleftharpoons Fe(OH)_3 + 3H^+ + 3e^-, \quad E^O = +1.06v \quad (15)$$
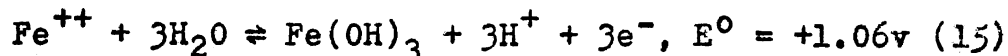
$$E = E^O + .0591\log \frac{(H^+)^3}{(Fe^{++})} \quad (16)$$

$$E = 1.06v - .177pH - .0591\log(Fe^{++}) \quad (17)$$

Using Equation (17), the activity of iron and the measured pH, the Eh of the well-water samples was calculated and plotted in Figures 17 and 18 (see Appendix L for the Fe^{++}, pH, and calculated Eh data for the well samples). The stability of the iron as a function of Eh-pH is shown in Figure 17 using a sulfur activity of 96 mg/l, a HCO_3^- activity of 1000 mg/l, and dissolved iron activity of .0056 mg/l. Figure 18 shows the solubility of iron in mg/l as a function of Eh-pH. The positions of the plotted points in both diagrams describe the general conditions in the alluvium. Because the Eh-pH function is linear, the data should plot linearly on the Eh-pH diagrams. If the assumption that the iron measured in the ground water is Fe^{++}, then the Eh-pH plot shoud have a high correlation, and the data will plot very close to a line. The plots of data in Figures 17 and 18 do show strong linear trends, and a calculation of the correlation coefficient shows that the Eh-pH relationship has a significant correlation of -.882. Therefore, the assumption that only Fe^{++} ions are present in the ground water is probably correct.
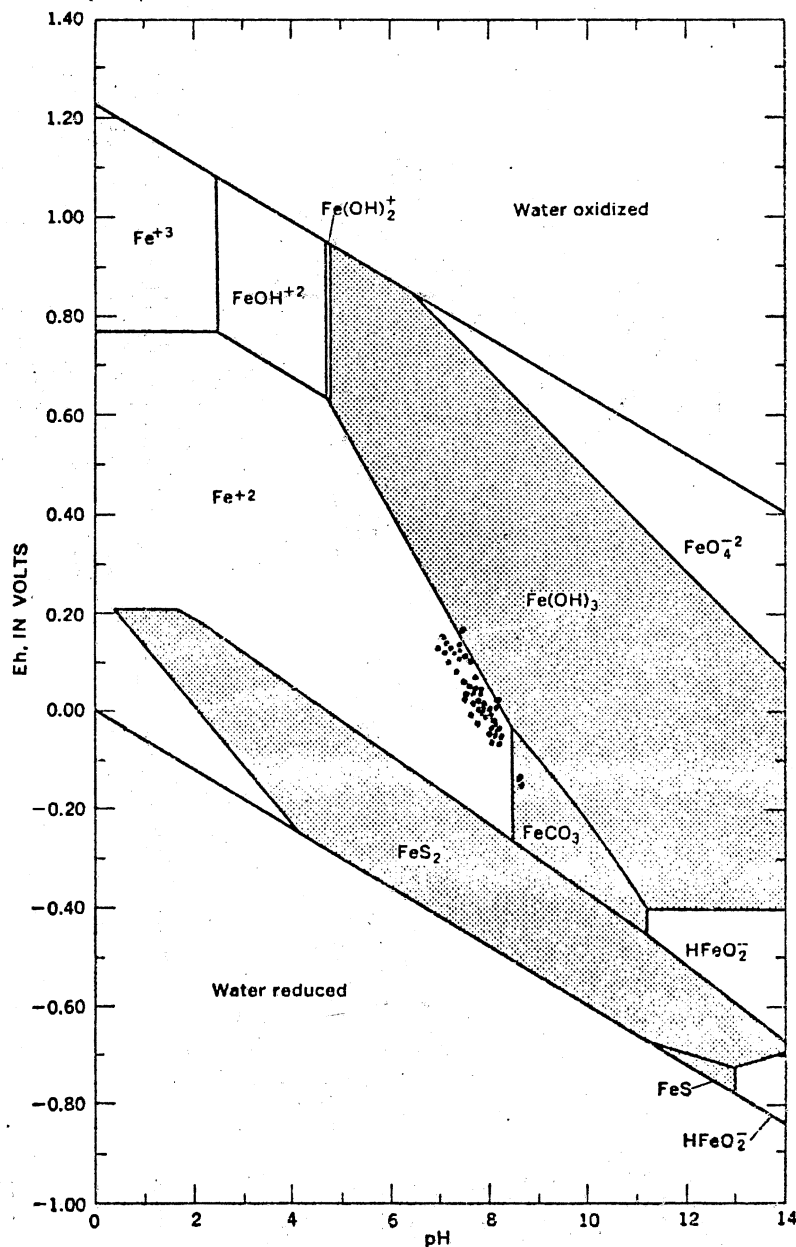
Figure 17. Fields of Stability for Solid and
Dissolved Species of Iron as a
Function of Eh and pH at 25°C and
1 Atm, Activity of Sulfur Species
is 96 mg/l as $SO_4^=$ and $HCO_3^=$ is
1000 mg/l, and iron 0.0056 mg/l.
(After Hem, 1970, Figure 14,p.118)
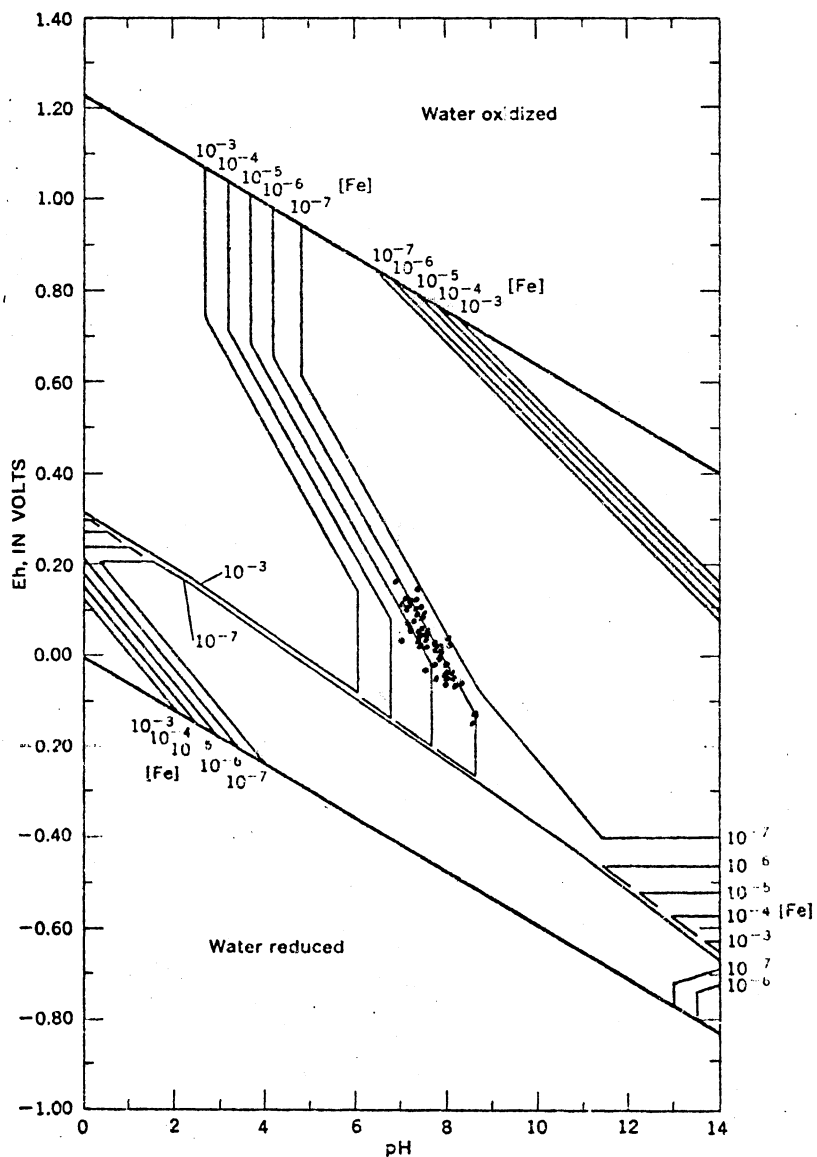
Figure 18. Solubility of Iron in Moles/1 as a
Function of Eh and pH at 25°C and
1 Atm, Activity of Sulfur Species
is 96 mg/1 as $SO_4^=$, HCO_3^- is 61 mg/1.
(After Hem, 1970, Figure 15, p. 119)

The stability of manganese can be investigated by using Figure 19, which shows the fields of stability and solubility of manganese as a function of Eh-pH. The same Eh-pH values used in Figures 17 and 18 are used here. Figure 19 shows that the manganese carbonate and MnO_2-Mn_2O_3 mineral equilibria are controlling the amount of Mn^{++} in solution. This conclusion supports the inferences made from Factors 1 and 8; the carbonate and redox equilibria may control a large portion of Mn^{++} variance in the ground water. The carbonate equilibrium equation (Equation (6)) and the redox reaction (Equation (18)) are given below and show the two controlling relationships of Mn^{++} in the ground water of the alluvium.

$$MnCO_3 + H^+ \rightleftharpoons Mn^{++} + HCO_3^- \tag{6}$$
Rhodochrosite

$$Mn^{++} + 2H_2O \rightleftharpoons MnO_2(c) + 4H^+ + 2e^-$$
$$E^o = +1.23 \text{ v} \tag{18}$$
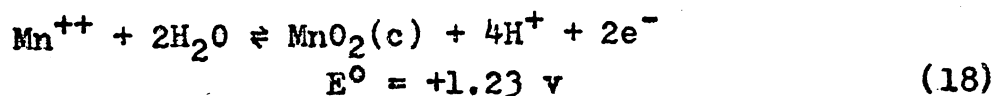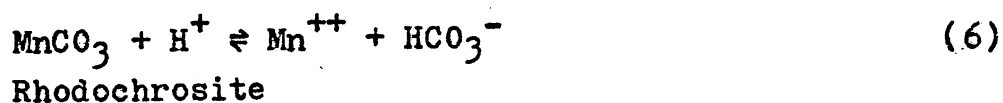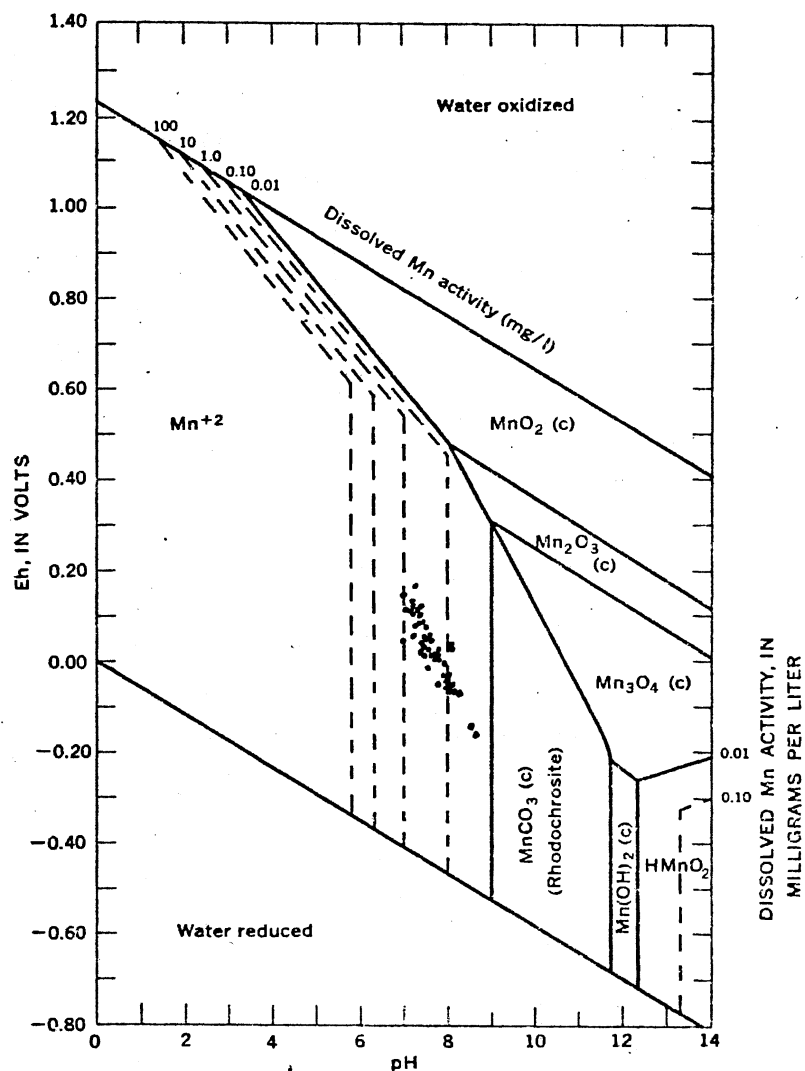
Figure 19. Fields of Stability of Solids and
Solubility of Manganese as a Function
of Eh and pH at 25°C and 1 Atm.
Acitivity of HCO₃ is 100 mg/l,
Sulfur Species Absent. (After Hem,
1970, Figure 16, p. 128)

Factor 9 (Figure 10), representing 8.56% of the total matrix variance, contains high loadings on well-bottom permeability, weighted average permeability for the alluvial saturated thickness, $CO_3^=$, and K^+. The loadings are .823, .616, .446, and .432, respectively. This factor grouping indicates that a small portion of the variances of $CO_3^=$ and K^+ might be controlled by permeability.

In order to evaluate whether or not permeability effects were being masked by the effects of bedrock, a single bed-rock area (Chickasha Formation) was evaluated by using correlation coefficients between the permeability and the chemical constituents. The correlation coefficients between permeability and the chemical constituents which were greater then $\pm.500$ are shown in Table VII. It can be concluded from the table of correlations that the permeability of the alluvium is related to the occurrence of NO_3^-, Si, Cd^{++}, Mg^{++}, and Cl^- in the associated ground water.

TABLE VII

WELL-BOTTOM PERMEABILITY CORRELATIONS
WITHIN THE CHICKASHA FORMATION
AREA OF ALLUVIUM
N = 11

Ion:	NO_3^-	Si	Cd^{++}	Mg^{++}	Cl^-
Well-Bottom Permeability	+.822	+.630	+.578	+.551	-.507

SUMMARY

Conclusions

The purpose of this research was to describe the
general processes which control the hydrogeochemistry
of the Washita River alluvium between Anadarko and Alex,
Oklahoma. Parameters considered in this study are
(1) bedrock lithology, (2) permeability, (3) mineralogy
of the aquifer, (4) agricultural land use, and (5) ground-
water chemistry. The processes described which apparently
control the ground-water chemistry are (1) bedrock sources
of ions, (2) permeability, (3) agricultural land use, and
(4) chemical equilibria (carbonate equilibria, redox equi-
libria, clay-water equilibria, and metal-ligand complexing).
A conceptual model of the inferred processes described in
this study is shown in Figure 20. The model represents the
the probable sources of ions and related controlling factors
which have been significantly related to the ground water
in the alluvium. The correlated controlling factors include
the carbonate, redox, clay-water, and metal-ligand complex
equilibria, and permeability. Significant sources of ions
in the ground water include the bedrock and the agricultural
practices.

BEDROCK SOURCE CONTROL

$(Ca^{++}, Mg^{++}, SO_4^{=},$

$Na^+, Cl^-, Cu^{++},$

$Pb^{++}, Zn^{++})$--Factors 1, 4 and 5

AGRICULTURAL PRACTICES

(N, PO_4^{-3}, K^+)--AOV

ALLUVIUM
GROUND-WATER

CHEMICAL EQUILIBRIA

CARBONATE EQUILIBRIA $(CO_2, HCO_3^-, Ca^{++}, Mg^{++}, Mn^{++}, H^+)$--Factor 1

REDOX EQUILIBRIA (Fe^{++}, Mn^{++})--Factor 8

CLAY-WATER EQUILIBRIA (Various Cations, Si, H^+)--Factor 3, Fig. 16

METAL-LIGAND COMPLEXING $(Cu^{++}-PO_4^{-3}, Cd^{++}-NO_2^- -NO_3^-)$--Factors 6+7

PERMEABILITY

$(K^+, Cd^{++}, Mg^{++}, Si, NO_3^-, Cl^-)$--Factor 9, Table VII

Figure 20. Conceptual Model of the Factors Affecting the Hydrogeochemistry
of the Washita River Alluvium and the Ions in Solution
Associated with the Factors.

Suggestions for Future Study

Results of this study have revealed areas where improvements of data collection and analysis need to be made. Additional sampling sites and an improved scheme of ranking the solubilities of the bedrock are needed to improve the analytical results.

Additional sampling sites should be located in areas charactersitic of each land-use category shown on the chemical land-use map (Plate 1). Areas having the same permeability range would be used for the land-use categories being compared. This would provide more reliable statistical correlations (AOV).

An improved quantitative ranking of the solubilities within the bedrock is needed in order to improve the results from the factor analysis. One improved method would be to rank the type of bedrock lithology by averaging the total dissolved solids (TDS) of the ground water occurring within each bedrock type. Although the ranking utilized in this study was based on unit differences between solubility ranks (ie. 1, 2, 3, and 4), the actual solubility of gypsum is 7600 times more soluble than calcite (see p. 57). The total dissolved solids would be used to indicate the relative degree of solubility of all mineral constituents occurring within each bedrock type. Therefore, the use of average TDS would provide a more accurate ranking (ie. 1, 10, 100, and 1000). This method would maximize the variance between factors.

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APPENDIX A

INTERPRETATION OF FACTOR ANALYSIS SCORES

The basic principle in factor analysis is the identification of patterns representing significant variation in the data. The matrix of intercorrelated variables will possess common factors and can be described more clearly in terms of these factors.

The total variance of a variable can be divided into common, specific, and error variances. Common variance is that variance which correlates with other dependent variables. Specific variance is that portion of the total variance which does not correlate with any other measured variable. Error variance is that portion of the total variance which is due to chance variance from sampling error, measurement error, etc. These subdivisions of the total variance can be symbolized by the following equation.

$$v_j^2 = v_{j1}^2 + v_{j2}^2 + \ldots + v_{jr}^2 + v_{js}^2 + v_{je}^2 \tag{1}$$

Where v_j^2 is the total variance of variable j, $v_{j1}^2 + v_{j2}^2 + \ldots + v_{jr}^2$ are the common variances for each of the r number of factors, v_{js}^2 is the specific variance, and v_{je}^2 is the error variance. Division of Equation (1) by v_j^2 gives the following equation (Equation (2)).

$$1.0 = \frac{v_{j1}^2}{v_j^2} + \frac{v_{j2}^2}{v_j^2} + \ldots + \frac{v_{jr}^2}{v_j^2} + \frac{v_{js}^2}{v_j^2} + \frac{v_{je}^2}{v_j^2} \tag{2}$$

This standardized form of Equation (1) equates the total variance to unity and represents each sub-type of variance as a proportion of the total variance. Equation (2) can be redefined by the following equation:

$$1.0 = a_{j1}^2 + a_{j2}^2 + \ldots + a_{jr}^2 + s_j^2 + e_j^2 \tag{3}$$

where a_{jr} is the factor loading on variable j by factor r, s_j^2 is the proportion of the total variance due to specific variance, and e_j^2 is the proportion of the total variance due to error variance.

The sum of the squares of the r-factor loadings represents the communality, or that portion of the total variance of variable j which is accounted for by the common variance of variable j with all the other variables. The equation for communality is thus:

$$h_j^2 = a_{j1}^2 + a_{j2}^2 + \ldots + a_{jr}^2 \tag{4}$$

where h_j^2 is the communality of variable j for r factors. Therefore, Equation (3) can be rewritten as:

$$1.0 = h_j^2 + s_j^2 + e_j^2 \tag{5}$$

In factor analysis, the unrotated factor matrix contains the factors which are found by maximizing the variance explained by each consecutive factor. The rth

factor is the factor which would be followed by factors representing only an insignificant portion of the variance left to be explained (generally considered as 5% of the total matrix variance). In this process of obtaining r number of factors, the independence or orthogonality between factors must be maintained.

When the first matrix is rotated, the orthogonal factors are rotated with their orthogonal nature maintained. The factors are rotated until the loadings of variables for any single factor are maximized. Thus, the rotated factor matrix simplifies the factor structure by causing the loadings a_{j1}, a_{j2}, ..., a_{jr} of a variable to approach +1.0, 0.0, or -1.0 for any one factor. Thus, the communality (h_j^2) of a variable will result from the fewest number of factors. This creates a simple structure in the rotated factor matrix which facilitates interpretation of the loadings for any one factor.

APPENDIX B

ANALYSIS OF VARIANCE[3]

Analysis of variance is a statistical procedure for
the testing of differences among the means of two or more
sample populations. If it is assumed that the sample pop-
ulations are normally distributed, then the samples drawn
randomly from the same population will have the same mean
($\bar{P}$) and variance (s_P^2) as the population. This is illustra-
ted in Figure 21.
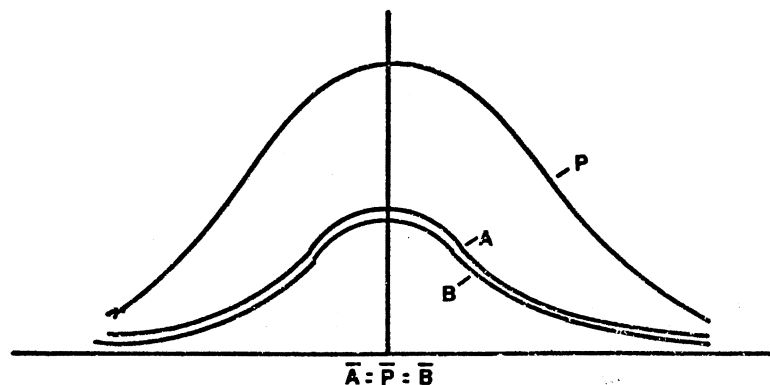
Figure 21. Two Samples A and B Drawn Randomly
from the Same Population; $\bar{A} = \bar{B} = \bar{P}$
and $s_A^2 = s_B^2 = s_P^2$.

_____

[3]Edwards, Allen L., 1967, Statistical Methods, 2nd ed.,
Holt, Rinehart, and Winston, Inc., pp. 257-290.

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If, on the other hand, the two sample populations are not of the same population, the means will be unequal and the variances of the separate samples will be less than the variance of the combined samples (referred to as the pooled population). This is illustrated in Figure 22.
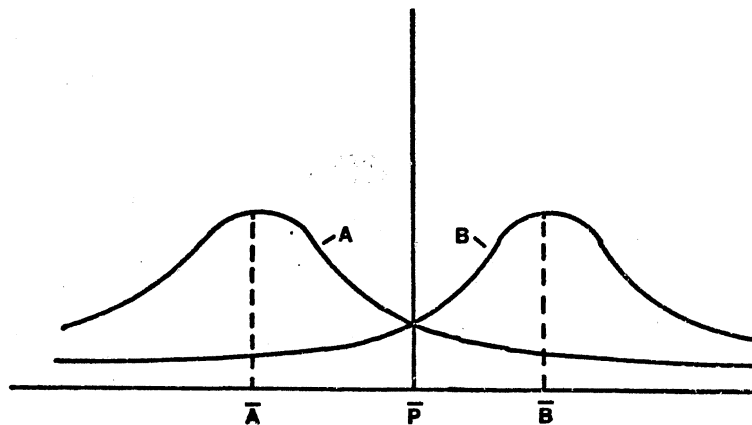
Figure 22. Two Samples A and B Drawn from Different Populations; $\bar{A} \neq \bar{B} \neq \bar{P}$ (P is the Pooled Population) and $s_A^2 < s_P^2$ and $s_B^2 < s_P^2$.

Analysis of variance tests the null hypothesis that $\bar{A}$ equals $\bar{B}$ by looking at the difference between the sample variances and the pooled population variance. If the difference is significantly greater than that suggested by chance, the null hypotesis is rejected in favor of an alternative hypothesis: $\bar{A}$ does not equal $\bar{B}$. Therefore, sample A and B have not been drawn from the same population.

The computations for one-way analysis of variance for two samples can be summarized by the following equations.

$$s_p^2 = \frac{\sum_{j=1}^{n_A}(X_{Aj}-\bar{X}_A)^2 + \sum_{j=1}^{n_B}(X_{Bj}-\bar{X}_B)^2}{n_A + n_B - 2} \qquad (1)$$

$$s_M^2 = \sum_{i=1}^{k} n_i(\bar{X}_i-\bar{X}_p)^2 \qquad (2)$$

where:

s_p^2 = pooled variance

s_M^2 = variance of sample means

X_{Aj} = j^{th} observation in sample A

$\bar{X}_A$ = mean of sample A

X_{Bj} = j^{th} observation in sample B

$\bar{X}_B$ = mean of sample B

n_A = number of observations in sample A

n_B = number of observations in sample B

$\bar{X}_p$ = pooled population mean

$\bar{X}_i$ = mean of ith sample (in this case, i = A, B)

n_i = number of observations in i^{th} sample

k = number of samples (in this case, k = 2)

$$F\text{-ratio} = \frac{s_M^2}{s_p^2} \qquad (3)$$

The significance of the difference between s_p^2 and s_M^2 (from Equations (1) and (2)) is found by the F-ratio test shown in Equation (3). Standard tables of the F-distribution for specified significance levels are used to evaluate the

F-ratio computed. In order to find the correct F-test value from the tables, the level of significance is decided upon, and the corresponding F-test value is found using (number of groups minus one), (number of observations minus number of groups) degrees of freedom. If the computed F-ratio is less than the F-test value from the table, the null hypothesis is accepted. If the F-ratio is greater than the F-test value from the table, the null hypothesis is rejected in favor of an alternative hypothesis. The level of significance is the probability that the difference found between the two sample means is due to chance. For example, a .05 level of significance is interpreted to mean that the computed F-ratio is expected to be greater than the F-test value as a result of chance 5% of the time.

APPENDIX C

LOCATIONS OF THE ALLUVIUM WELLS

Well	a=NE¼, b=NW¼ c=SW¼, d=SE¼	Section	Township	Range
18	acc	20	T11N	R11W
20	bdc	20	11	11
31	acc	20	11	11
32	acc	20	11	11
33	acc	20	11	11
47	dcc	20	11	11
774	bac	20	11	11
784	dcc	20	11	11
786	dcc	20	11	11
87	ccc	4	10	11
95	bdc	26	10	11
106	acc	12	9	11
108	bba	30	9	10
115	abb	9	8	10
133	aaa	27	8	10
150	bbb	8	7	9
175	dad	27	7	10
185	dda	15	7	10
190	aab	24	7	10
203	bba	17	7	9
247	dcc	35	8	9
250	aab	14	7	9
259	bbb	7	7	8
262	aad	31	8	8
264	bab	17	8	8
271	ddd	33	8	8
282	bca	15	7	8
290	dad	23	7	8
297	bbb	29	7	7
299	dda	18	7	7
303	bab	9	7	7
309	ccd	34	7	7
312	dcc	26	7	7
318	aab	12	6	7

LOCATIONS OF THE ALLUVIUM WELLS (Continued)

Well	a=NE¼, b=NW¼ c=SW¼, d=SE¼	Section	Township	Range
339	bbb	21	T 6 N	R 6 W
341	dda	32	6	6
392	dbb	7	5	5
393	aab	7	5	5
399	aad	18	6	5
401	aad	5	7	5
427	dcc	27	7	6
433	ccd	8	6	6
434	bbb	9	6	6
435	bca	5	6	6
437	cbc	32	7	6
442	bab	16	7	6
506	bbc	26	6	6
512	dad	16	6	6
514	daa	35	6	6

CHEMICAL ANALYSES OF THE ALLUVIUM GROUND WATER IN PPM

Well	K+	Fe**	Mn++	Mg++	Ca++	SO4=	Na+	Cl-	HCO3=	CO3=	CO2	PO4≡	NO3-	NO2-	NH4+	pH
18	3.40	0.20	0.000	7	40	12	9	15	60	0	44	0.00	6.4	.00	5.30	6.95
20	3.10	29.00	3.500	24	179	52	17	35	67	0	16	0.00	6.5	.03	0.00	7.00
31	0.60	0.00	0.800	20	370	28	17	13	154	0	44	0.00	0.5	.00	0.00	7.75
32	1.00	2.50	0.680	60	102	280	53	25	83	0	16	0.20	0.0	.00	0.00	7.60
33	1.60	0.30	1.430	35	303	140	32	25	100	0	20	0.00	0.5	.00	0.00	7.60
47	3.60	0.40	1.750	21	110	160	44	27	80	0	12	0.00	1.2	.00	0.32	7.65
774	1.70	0.70	0.850	53	221	440	27	15	117	0	22	0.52	1.3	.00	0.53	7.60
784	1.40	0.60	0.550	16	128	200	22	15	100	0	20	0.58	9.0	.22	1.16	7.45
786	2.60	2.60	0.580	12	79	37	20	15	107	0	20	0.34	0.1	.00	2.75	7.75
87	1.00	0.40	1.640	70	234	365	128	110	360	0	99	2.00	50.0	.53	1.80	7.17
95	13.20	0.10	2.100	30	605	1000	10	35	167	0	60	2.20	14.0	.06	1.70	7.50
106	0.72	0.44	0.420	31	390	900	50	33	156	0	80	0.50	0.4	.00	1.60	7.13
108	8.03	0.28	2.000	160	160	910	140	200	229	0	99	1.30	5.6	.10	9.70	7.28
115	6.50	4.40	2.700	132	164	3150	1480	800	350	0	60	0.00	1.3	.00	1.30	7.40
132	3.99	0.25	0.340	50	313	990	69	25	107	0	16	0.50	6.4	.00	2.60	7.59
150	15.60	0.90	0.020	87	212	392	43	30	207	0	36	0.36	7.2	.10	4.60	8.00
175	4.10	0.80	1.150	103	385	1150	79	100	87	0	36	0.00	0.0	.00	5.70	8.10
185	1.54	0.15	2.980	98	110	164	35	5	421	0	99	1.30	0.0	.00	3.10	7.28
190	1.04	0.09	0.070	35	24	166	96	10	61	36	8	0.30	0.2	.00	4.10	8.75
203	2.34	0.99	0.380	68	138	510	46	33	131	0	80	1.10	2.2	.00	0.60	8.95
251	0.88	0.24	0.110	30	24	78	31	15	55	12	0	8.50	5.8	.03	0.00	8.62
750	14.60	2.50	1.390	84	368	650	230	58	96	0	28	0.00	0.6	.00	3.20	7.50
247	4.00	0.16	0.080	80	225	930	132	75	149	0	28	0.50	7.0	.00	3.70	7.34
255	10.00	0.30	0.350	63	154	58	140	20	107	0	20	0.62	1.5	.02	0.00	7.45
262	5.00	1.28	1.650	143	37	1100	46	20	122	0	60	0.30	5.0	.03	8.80	7.17
264	3.80	0.40	1.320	114	300	280	370	105	123	0	48	1.20	0.0	.00	4.70	7.52
271	2.00	0.20	0.150	36	74	260	53	60	27	0	28	0.41	0.0	.00	0.00	7.20
282	1.40	0.40	0.060	55	26	73	32	10	180	0	24	0.00	0.0	.00	0.00	8.05
290	17.80	0.70	0.580	128	177	625	60	20	205	0	40	0.00	32.0	.04	5.60	8.05
297	8.90	1.21	1.950	34	102	450	77	5	339	0	99	6.50	2.2	.00	18.60	7.16
303	2.80	0.30	1.470	26	67	31	150	65	274	0	26	1.20	1.5	.00	0.00	7.95
312	2.20	0.20	0.550	50	51	99	78	70	120	67	32	2.53	1.2	.00	0.50	8.00
318	11.60	0.30	0.180	67	236	860	540	670	100	160	17	3.80	0.0	.07	2.60	8.20
295	3.30	0.30	0.130	15	54	240	5	70	107	0	16	0.95	0.0	.00	2.90	7.85
309	2.80	0.26	0.260	20	25	22	10	25	79	0	0	0.00	3.5	.00	0.00	7.96
339	6.10	0.40	0.400	37	59	12	13	12	80	0	28	0.63	6.0	.03	1.40	7.55
341	1.40	0.10	0.000	44	90	21	12	8	130	0	50	0.72	15.0	.00	0.65	7.35
390	5.30	0.27	0.810	65	65	56	14	15	174	0	0	7.50	4.0	.00	0.00	7.87
392	2.00	0.20	0.000	88	89	57	24	8	412	0	80	0.85	13.0	.07	1.80	7.75
395	1.20	0.20	0.050	57	52	16	22	16	20	0	28	0.75	0.0	.00	0.40	7.80
401	1.00	0.05	0.010	33	77	37	12	12	194	0	44	0.49	0.0	.00	0.00	7.40
427	1.80	0.02	0.900	72	50	27	20	15	200	0	36	0.91	1.7	.00	0.80	8.10
433	2.60	0.23	0.180	82	87	62	11	12	229	0	0	0.00	55.0	.00	0.00	7.78
434	7.60	0.30	0.120	45	134	160	40	40	167	0	24	0.00	2.2	.00	0.90	8.00
435	4.60	0.30	0.920	95	68	184	20	10	323	0	0	0.00	11.0	.00	1.50	7.75
437	1.90	0.20	0.320	72	63	60	34	12	208	0	46	3.20	0.0	.00	0.90	7.60
506	2.00	0.33	0.150	74	31	50	26	10	168	0	0	0.00	3.0	.00	0.00	8.15
512	20.00	3.00	0.900	59	45	45	18	20	488	0	88	0.00	0.0	.00	23.90	7.12
514	3.30	0.10	0.003	76	74	20	27	10	427	40	52	5.20	12.0	.07	2.60	7.50

Values in parts per million (ppm).
**Measured as total iron.

Well	Zn++	Cd++	Pb++	Cu++	Si
18	0.06	.0000	.006	.009	13.4
20	4.27	.0000	.006	.010	15.4
31	0.04	.0000	.000	.005	17.8
32	0.05	.0540	.003	.026	2.2
33	0.20	.0040	.020	.028	11.2
47	0.33	.0000	.000	.035	11.7
774	0.15	.0180	.000	.050	13.8
784	0.10	.0000	.002	.014	13.8
786	0.26	.0210	.015	.032	11.4
87	4.71	.1440	.030	.350	18.8
95	3.70	.0120	.000	.015	16.5
106	5.31	.0000	.010	.284	10.3
108	0.18	.0520	.011	.480	9.7
115	0.42	.0000	.001	.044	12.6
133	0.35	.0750	.007	.410	11.4
150	4.26	.0160	.116	.018	5.6
175	0.11	.0006	.002	.011	7.2
185	0.42	.0200	.008	.479	15.2
190	1.52	.0330	.021	.431	2.4
203	5.32	.0000	.022	.264	6.0
251	1.76	.0400	.022	.505	3.6
750	0.09	.0200	.051	.033	6.6
247	1.00	.0000	.008	.381	8.5
255	0.24	.0060	.005	.036	5.2
262	5.17	.0000	.015	.269	6.7
264	0.10	.0000	.000	.026	7.9
271	4.26	.0000	.010	.010	2.8
282	0.54	.0000	.010	.023	2.9
290	3.00	.0000	.007	.017	5.5
297	1.43	.0380	.024	.394	30.2
303	0.06	.0060	.006	.020	18.4
312	0.07	.0000	.002	.025	11.7
318	0.04	.0000	.000	.032	6.4
295	2.20	.0000	.003	.016	8.6
309	0.00	.0000	.000	.200	5.5
339	0.03	.0020	.000	.032	11.0
341	0.04	.0040	.000	.027	8.4
390	0.00	.0050	.005	.250	9.5
392	0.06	.0020	.000	.039	16.0
395	0.03	.0000	.000	.027	12.4
401	0.14	.0020	.000	.019	5.7
427	0.06	.0000	.000	.038	7.2
433	0.00	.0250	.000	.142	11.0
434	0.04	.0000	.000	.028	7.2
435	0.00	.0050	.000	.190	14.1
437	0.02	.0040	.000	.014	9.9
506	0.00	.0010	.005	.162	9.0
512	0.00	.0000	.000	.018	4.0
514	0.04	.0000	.000	.034	14.8

APPENDIX E

CHEMICAL ANALYSES OF ALLUVIUM

GROUND WATER IN ACTIVITIES

AS MOLES PER LITER

Well	$NH_4^+ \times 10^{-4}$	$NO_2^- \times 10^{-6}$	$NO_3^- \times 10^{-4}$	$PO_4^{-3} \times 10^{-5}$	$CO_2 \times 10^{-3}$	$CO_3^= \times 10^{-4}$	$HCO_3^- \times 10^{-3}$	$Cl^- \times 10^{-3}$	$Na^+ \times 10^{-3}$
18	4.844	0.0	0.968	0.0	1.000	0.0	0.922	0.397	0.367
20	0.0	0.5823	0.936	0.0	0.364	0.0	0.981	0.882	0.660
31	0.0	0.0	0.070	0.0	1.000	0.0	2.195	0.319	0.643
32	0.0	0.0	0.0	0.212	0.364	0.0	1.197	0.621	2.028
33	0.0	0.0	0.070	0.0	0.453	0.0	1.424	0.613	1.209
47	0.159	0.0	0.173	0.0	0.273	0.0	1.174	0.682	1.714
774	0.255	0.0	0.181	0.346	0.500	0.0	1.659	0.366	1.016
784	0.576	4.271	1.296	0.429	0.454	0.0	1.463	0.378	0.854
786	1.401	0.0	0.015	0.274	0.454	0.0	1.607	0.388	0.797
87	0.852	9.813	6.868	1.262	2.249	0.0	5.025	2.643	4.740
95	0.778	1.074	1.859	1.229	1.363	0.0	2.254	0.813	0.358
106	0.743	0.0	0.054	0.296	1.818	0.0	2.138	0.779	1.818
108	4.481	1.808	0.751	0.753	2.249	0.0	3.121	4.691	5.061
115	0.565	0.0	0.164	0.0	1.363	0.0	4.487	17.652	50.334
133	1.209	0.0	0.864	0.296	0.363	0.0	1.467	0.590	2.511
150	2.191	1.863	0.995	0.232	0.818	0.0	2.908	0.725	1.603
175	2.608	0.0	0.0	0.0	0.818	0.0	1.174	2.324	2.829
185	1.502	0.0	0.0	0.891	2.249	0.0	6.019	0.123	1.327
190	2.059	0.0	0.029	0.231	0.182	3.496	0.904	0.255	3.772
203	0.288	0.0	0.306	0.727	1.818	0.0	1.853	0.804	1.726
251	0.0	0.560	0.860	6.290	0.0	1.418	0.829	0.389	1.240
750	1.483	0.0	0.081	0.0	0.636	0.0	1.313	1.365	8.342
247	1.722	0.0	0.946	0.298	0.636	0.0	2.046	1.773	4.808
259	0.0	0.382	0.213	0.436	0.454	0.0	1.542	0.496	5.352
262	4.118	0.549	0.679	0.182	1.363	0.0	1.684	0.475	1.685
264	2.193	0.0	0.0	0.721	1.091	0.0	1.693	2.488	13.510
271	0.0	0.0	0.0	0.300	0.636	0.0	0.394	1.507	2.051
282	0.0	0.0	0.0	0.0	0.545	0.0	2.673	0.256	1.261
290	2.634	0.736	4.370	0.0	0.909	0.0	2.845	0.478	2.209
297	9.001	0.0	0.309	0.443	2.249	0.0	4.840	0.123	2.916
303	0.0	0.0	0.217	0.089	0.591	0.0	4.022	1.642	5.481
312	0.249	0.0	0.173	0.189	0.727	7.080	1.763	1.770	3.039
318	1.188	1.251	0.0	0.211	0.386	11.254	1.347	15.538	19.302
299	1.452	0.0	0.0	0.072	0.364	0.0	1.581	1.780	0.196
309	0.0	0.0	0.525	0.0	0.0	0.0	1.206	0.657	0.405
339	0.713	0.598	0.887	0.507	0.636	0.0	1.201	0.310	0.518
341	0.327	0.0	2.189	0.556	1.136	0.0	1.928	0.204	0.472
390	0.0	0.0	0.580	5.666	0.0	0.0	2.563	0.380	0.547
392	0.883	1.343	2.563	0.606	1.818	0.0	5.963	0.199	0.921
399	0.202	0.0	0.0	0.592	0.636	0.0	0.299	0.411	0.871
401	0.0	0.0	0.0	0.382	0.999	0.0	2.885	0.307	0.473
427	0.400	0.0	0.247	0.691	0.818	0.0	2.951	0.381	0.793
433	0.0	0.0	7.887	0.0	0.0	0.0	3.337	0.301	0.425
434	0.442	0.0	0.314	0.0	0.545	0.0	2.419	0.997	1.537
435	0.732	0.0	1.560	0.0	0.0	0.0	4.655	0.248	0.765
437	0.447	0.0	0.0	2.382	1.045	0.0	3.049	0.303	1.322
506	0.0	0.0	0.436	0.0	0.0	0.0	2.484	0.254	1.020
512	11.885	0.0	0.0	0.0	2.000	0.0	7.160	0.505	0.701
514	1.284	1.353	1.721	3.798	1.182	4.085	6.224	0.251	1.044

APPENDIX E (Continued)

Well	$SO_4^= \times 10^{-3}$	$Ca^{++} \times 10^{-3}$	$Mg^{++} \times 10^{-3}$	$Mn^{++} \times 10^{-5}$	$Fe^* \times 10^{-5}$	$K^+ \times 10^{-4}$	$Si \times 10^{-3}$	$Cu^{++} \times 10^{-6}$	$Pb^{++} \times 10^{-7}$
18	0.096	0.767	0.221	0.0	0.241	0.815	1.396	0.109	0.223
20	0.338	2.787	0.616	3.975	25.515	0.705	1.604	0.098	0.181
31	0.162	5.115	0.456	0.807	0.0	0.133	1.854	0.044	0.0
32	1.704	1.488	1.443	0.723	1.992	0.225	0.229	0.239	0.085
33	0.805	4.176	0.795	1.438	0.219	0.336	1.167	0.243	0.533
47	1.054	1.736	0.546	2.015	0.359	0.825	1.219	0.348	0.0
774	2.480	2.985	0.735	0.838	0.496	0.376	1.438	0.426	0.0
784	1.299	1.994	0.411	0.625	0.528	0.320	1.438	0.138	0.060
786	0.269	1.378	0.345	0.738	2.719	0.610	1.187	0.352	0.506
87	1.912	2.938	1.448	1.502	0.254	0.218	1.958	2.771	0.728
95	4.437	6.433	0.526	1.629	0.049	2.781	1.719	0.101	0.0
106	4.315	4.482	0.587	0.352	0.244	0.154	1.073	2.058	0.222
108	4.238	1.786	2.944	1.628	0.148	1.708	1.010	3.379	0.237
115	10.245	1.278	1.696	1.535	1.335	1.300	1.312	0.216	0.015
133	4.764	3.610	0.951	0.286	0.139	0.854	1.187	2.982	0.156
150	2.117	2.744	1.857	0.019	0.598	3.420	0.583	0.147	2.904
175	5.105	4.096	1.807	0.893	0.394	0.864	0.750	0.074	0.041
185	0.960	1.543	2.266	3.049	0.113	0.344	1.583	4.237	0.217
190	1.137	0.394	0.947	0.084	0.086	0.240	0.250	4.451	0.667
203	2.845	1.845	1.499	0.371	0.691	0.516	0.625	2.226	0.569
251	0.576	0.425	0.875	0.142	0.256	0.207	0.375	5.635	0.753
750	3.077	4.175	1.571	1.150	1.358	3.115	0.688	0.236	1.119
247	4.499	2.609	1.529	0.068	0.089	0.857	0.885	2.786	0.179
259	0.352	2.239	1.510	0.414	0.238	2.249	0.542	0.330	0.141
262	5.464	0.440	2.807	1.433	0.749	1.077	0.698	2.019	0.345
264	1.371	3.520	2.205	1.130	0.229	0.816	0.823	0.192	0.0
271	1.666	1.137	0.912	0.168	0.172	0.455	0.292	0.097	0.297
282	0.506	0.432	1.505	0.073	0.388	0.324	0.302	0.241	0.321
290	3.183	2.161	2.576	0.517	0.425	3.854	0.573	0.131	0.165
297	2.617	1.422	0.781	1.983	0.900	1.983	3.146	3.464	0.647
303	0.204	1.057	0.676	1.692	0.269	0.641	1.917	0.199	0.183
312	0.654	0.807	1.304	0.635	0.180	0.504	1.219	0.249	0.061
318	3.779	2.485	1.163	0.138	0.145	2.339	0.667	0.212	0.0
299	1.625	0.876	0.401	0.153	0.281	0.761	0.896	0.164	0.094
309	0.171	0.467	0.616	0.354	0.301	0.667	0.573	2.356	0.0
339	0.087	1.027	1.062	0.508	0.417	1.429	1.146	0.351	0.0
341	0.144	1.485	1.197	0.0	0.096	0.323	0.875	0.281	0.0
390	0.374	1.040	1.715	0.946	0.248	1.218	1.031	2.523	0.155
392	0.352	1.318	2.148	0.0	0.163	0.452	1.750	0.364	0.0
399	0.113	0.883	1.596	1.066	0.201	0.280	1.292	0.289	0.0
401	0.258	1.286	0.908	0.012	0.049	0.232	0.594	0.200	0.0
427	0.182	0.806	1.914	1.059	0.019	0.414	0.750	0.386	0.0
433	0.395	1.329	2.065	0.201	0.197	0.591	1.146	1.368	0.0
434	0.993	1.994	1.104	0.130	0.246	1.718	0.750	0.263	0.0
435	1.116	0.989	2.278	0.976	0.238	1.034	1.469	1.743	0.0
437	0.393	0.988	1.862	0.366	0.178	0.435	1.031	0.138	0.0
506	0.339	0.504	1.984	0.178	0.310	0.461	0.938	1.662	0.157
512	0.296	0.708	1.531	1.033	2.683	4.579	0.417	0.179	0.0
514	0.128	1.132	1.916	0.003	0.086	0.751	1.544	0.279	0.0

*Measured as total iron.

APPENDIX E (Continued)

Well	$Cd^{++} \times 10^{-8}$	$Zn^{++} \times 10^{-5}$
18	0.0	0.071
20	0.0	4.076
31	0.0	0.034
32	28.081	0.045
33	1.966	0.169
47	0.0	0.319
774	8.669	0.124
784	0.0	0.095
786	13.069	0.278
87	64.461	3.625
95	4.550	2.412
106	0.0	3.741
108	20.695	0.123
115	0.0	0.201
133	30.84	0.247
150	7.384	3.381
175	0.276	0.072
185	10.001	0.361
190	19.312	1.529
203	0.0	4.361
251	25.239	1.909
750	8.091	0.056
247	0.0	0.711
259	3.111	0.214
262	0.0	3.774
264	0.0	0.072
271	0.0	4.012
282	0.0	0.549
290	0.0	2.245
297	18.888	1.222
303	3.376	0.058
312	0.0	0.063
318	0.0	0.026
299	0.0	2.189
309	0.0	0.0
339	1.241	0.032
341	2.353	0.040
390	2.853	0.0
392	1.056	0.054
399	0.0	0.031
401	1.191	0.143
427	0.0	0.059
433	13.617	0.0
434	0.0	0.036
435	2.593	0.0
437	2.237	0.019
506	0.058	0.0
512	0.0	0.0
514	0.0	0.038

APPENDIX F

SULIN CLASSIFICATION OF THE GROUND WATER

SAMPLED IN THE ALLUVIUM

Well	$\dfrac{Na^+}{Cl^-}$ *	$\dfrac{Na^+-Cl^-}{SO_4^=}$ *	$\dfrac{Cl^--Na^+}{Mg^{++}}$ *	Classification Name
18	0.92	-0.13	0.05	Chloride-Magnesium
20	0.75	-0.23	0.13	"
31	2.02	0.64	-0.23	Sulfate-Sodium
32	3.27	0.27	-0.32	"
33	1.97	0.24	-0.24	"
47	2.51	0.35	-0.67	"
87	1.80	0.32	-0.43	"
95	0.44	-0.03	0.22	Chloride-Magnesium
106	2.34	0.07	-0.49	Sulfate-Sodium
108	1.08	0.02	-0.03	"
115	2.85	0.64	-3.85	"
133	4.26	0.11	-0.56	"
150	2.21	0.13	-0.14	"
175	1.22	0.03	-0.07	"
185	10.80	0.40	-0.17	"
190	14.91	1.13	-1.35	"
203	2.15	0.10	-0.19	"
247	2.71	0.19	-0.55	"
251	3.19	0.57	-0.38	"
259	10.80	4.58	-1.06	Bicarbonate-Sodium
262	3.55	0.07	-0.12	Sulfate-Sodium
264	5.44	2.25	-1.40	Bicarbonate-Sodium
271	1.36	0.11	-0.20	Sulfate-Sodium
282	4.94	0.73	-0.24	"
290	4.63	0.16	-0.19	"
297	23.76	0.34	-1.15	"
299	0.11	-0.35	1.42	Chloride-Calcium
303	3.56	7.27	-2.19	Bicarbonate-Sodium
309	0.62	-0.59	0.16	Chloride-Magnesium

*Expressed as milliequivalent percent.

APPENDIX F (Continued)

Well	$\dfrac{Na^+}{Cl^-}$[*]	$\dfrac{Na^+-Cl^-}{SO_4^=}$[*]	$\dfrac{Cl^--Na^+}{Mg^{++}}$[*]	Classification Name
401	1.54	0.24	-0.07	Sulfate-Sodium
427	2.06	0.79	-0.08	"
433	1.41	0.11	-0.02	"
434	1.54	0.18	-0.16	"
435	3.09	0.15	-0.10	"
312	1.72	0.69	-0.35	Sulfate-Sodium
318	1.24	0.26	-0.83	"
339	1.67	0.91	-0.07	"
341	2.31	0.68	-0.08	"
390	1.44	0.16	-0.03	"
392	4.63	0.69	-0.11	"
399	2.12	1.52	-0.11	Bicarbonate-Sodium
437	4.37	0.91	-0.19	Sulfate-Sodium
506	4.01	0.82	-0.14	"
512	1.03	0.01	-0.01	Bicarbonate-Sodium
514	4.16	2.14	-0.14	"
750	6.12	0.64	-1.21	Sulfate-Sodium
774	2.78	0.08	-0.28	"
784	2.26	0.13	-0.41	"
786	2.06	0.58	-0.45	"

*Expressed as milliequivalent percent.

Sulin's classification is as follows:

Types of Water:

1. Sulfate-Sodium (fresh water)
2. Bicarbonate-Sodium (fresh water)
3. Chloride-Magnesium (associated with evaporites)
4. Chloride-Calcium (associated with oil-field brine)

Classification Scheme:

Types of Water		$\dfrac{Na^+}{Cl^-}$	$\dfrac{Na^+-Cl^-}{SO_4^=}$	$\dfrac{Cl^--Na^+}{Mg^{++}}$
$SO_4^=-Na^+$	=	> 1.0	< 1.0	< 0
$HCO_3^--Na^+$	=	> 1.0	> 1.0	< 0
Cl^--Mg^{++}	=	< 1.0	< 0	> 1.0
Cl^--Ca^{++}	=	< 1.0	< 0	< 1.0

From Sulin, 1946, as cited in Dickey, P. A. and Hunt, J. M., 1972, p. 145.

APPENDIX G

CLAY AND METAL LEECHATE DATA

FOR THE ALLUVIUM

Well Number	Kaolinite %	Illite %	Montmorillonite %	Cu^{++} Leechate ppm	Pb^{++} Leechate ppm	Zn^{++} Leechate ppm	Cd^{++} Leechate ppm	Mn^{++} Leechate ppm	Depth Feet
13-N	12	19	69	2.4	6.0	31.0	0	60.0	6.0
13-N	8	31	61	4.2	18.0	32.0	2.0	433.0	49.0
13-S	25	25	50	12.0	4.0	66.0	0.4	85.0	2.0
13-S	12	25	63	1.2	4.0	26.0	0	61.0	3.0
13-S	8	29	63	24.0	10.0	88.0	0.04	285.0	37.0
13-S	50	50	0	2.6	4.0	34.0	0	164.0	60.0
20	28	28	44	-	-	-	-	-	18.0
31	27	46	27	1.2	4.8	23.0	0.42	108.0	1.0
108	22	49	29	2.0	2.0	28.0	0.6	80.0	30.0
185	30	70	0	24.0	24.0	172.0	1.6	377.0	25.0
247	0	36	64	4.0	10.0	63.0	0	267.0	25.0
297	13	37	50	0.4	6.0	72.0	0	80.0	35.0
299	33	40	27	0.4	4.0	35.0	0	108.0	41.0
309	4	30	66	1.2	2.0	24.0	0	131.0	35.0
318	11	41	48	1.0	10.0	37.0	0.6	127.0	40.0
339	15	42	43	4.0	4.0	50.0	0.8	174.0	50.0
390	12	29	59	2.4	6.0	40.0	0.8	149.0	30.0
392	16	34	50	6.0	8.0	56.0	0.2	274.0	30.0
312	21	26	53	-	-	-	-	-	36.0
115	16	74	10	-	-	-	-	-	30.0
433	20	40	40	3.8	2.0	30.0	0	119.0	35.0
434	14	27	59	5.2	6.0	44.0	0	145.0	40.0
435	15	26	59	8.0	6.0	67.0	0	245.0	35.0
437	16	28	56	5.2	4.0	60.0	0	258.0	35.0
506	23	40	37	5.2	6.0	62.0	0	188.0	40.0
512	6	59	35	18.0	12.0	206.0	0.6	160.0	43.0
786	27	40	33	1.4	6.6	15.4	0.5	180.0	1.0
774	50	50	0	0.4	4.5	8.0	0.4	108.0	1.0
784	12	35	53	-	-	-	-	-	45.0

APPENDIX G (Continued)

Well Number	Kaolinite %	Illite %	Montmorillonite %	Cu^{++} Leechate ppm	Pb^{++} Leechate ppm	Zn^{++} Leechate ppm	Cd^{++} Leechate ppm	Mn^{++} Leechate ppm	Depth Feet
750	10	10	80	27.4	8.0	67.0	0.4	246.0	19.0
750	20	20	60	8.6	4.0	30.0	0	115.0	38.0
750	22	25	53	0	0	14.0	0	38.0	40.0
750	12	13	75	-	-	-	-	-	44.0
750	14	24	61	15.2	6.0	49.0	0.2	276.0	46.0
750	9	20	71	-	-	-	-	-	52.0
750	14	18	68	37.6	30.0	95.0	1.4	310.0	53.0
750	5	26	69	-	-	-	-	-	54.0
750	13	17	70	67.4	16.0	98.0	0.4	220.0	56.0
751	27	18	64	1.0	10.0	18.0	1.2	114.0	4.0
751	18	18	64	33.6	6.0	51.0	1.4	167.0	12.0
751	15	15	70	14.0	4.0	14.0	0	38.0	22.0

CORRELATION MATRIX FOR THE ALLUVIAL

GROUND-WATER FACTOR ANALYSIS

VARIABLE	BEDROCK	BPERM	WDPERM	KAOLIN	ILLITE	MONT	DEPTH	CU CLAY	MN CLAY	ZN CLAY	PB CLAY	CD CLAY
PH	0.063	0.067	0.066	0.093	-0.338	0.182	0.070	-0.118	0.033	-0.139	-0.031	-0.054
BEDROCK		-0.105	-0.042	-0.251	0.457	-0.174	0.307	0.003	-0.177	-0.046	-0.048	-0.012
BPERM			0.538	-0.265	-0.042	0.181	0.346	0.176	0.239	0.331	0.234	0.080
WDPERM				-0.338	-0.186	0.322	0.330	0.159	0.255	0.233	0.181	-0.008
KAOLIN					0.344	-0.774	-0.275	-0.088	-0.126	-0.163	-0.100	0.027
ILLITE						-0.826	-0.132	-0.322	0.080	0.218	0.103	0.240
MONT							0.230	0.200	0.042	-0.057	-0.012	-0.159
DEPTH								0.164	0.161	0.152	0.125	-0.070
CU CLAY									0.511	0.611	0.648	0.396
MN CLAY										0.738	0.836	0.647
ZN CLAY											0.773	0.490
PB CLAY												0.755

VARIABLE	NH4	NO2	NO3	PO4	CO3	CO2	HCO3	CL	NA	SO4	CA	MG
PH	-0.316	-0.164	-0.066	0.198	0.360	-0.587	-0.199	0.027	-0.032	-0.188	-0.195	0.027
BEDROCK	0.118	0.166	0.056	0.159	0.126	0.377	0.121	0.278	0.322	0.562	0.197	0.331
BPERM	0.289	0.062	-0.075	0.197	0.298	0.063	0.305	0.129	-0.032	-0.101	-0.196	-0.023
WDPERM	0.078	-0.152	-0.171	-0.099	0.163	-0.127	0.026	0.105	0.024	-0.021	-0.047	0.030
KAOLIN	-0.161	-0.080	-0.026	-0.085	-0.066	0.035	-0.029	-0.079	-0.077	-0.029	0.206	-0.018
ILLITE	0.359	0.105	0.089	0.065	0.029	0.580	0.577	0.418	0.463	0.525	0.417	0.482
MONT	-0.161	-0.023	-0.027	0.011	0.019	-0.405	-0.365	-0.245	-0.279	-0.340	-0.367	-0.302
DEPTH	0.093	0.132	0.055	0.049	0.094	-0.040	0.015	0.044	0.012	-0.032	-0.289	0.050
CU CLAY	-0.045	-0.122	-0.144	-0.162	-0.104	-0.199	-0.164	-0.148	-0.151	-0.257	-0.339	-0.286
MN CLAY	-0.022	-0.148	-0.077	-0.059	-0.075	-0.113	0.062	-0.106	-0.156	-0.239	-0.276	-0.084
ZN CLAY	0.402	-0.138	-0.109	-0.012	-0.069	0.135	0.306	-0.094	-0.130	-0.199	-0.257	0.014
PB CLAY	0.071	-0.135	-0.161	-0.052	0.010	-0.059	0.032	-0.045	-0.107	-0.200	-0.257	-0.162
CD CLAY	0.018	-0.071	-0.156	0.002	0.022	-0.014	-0.023	-0.011	-0.078	-0.167	-0.168	-0.123
NH4		0.044	0.028	0.138	0.009	0.580	0.495	0.058	0.056	0.256	0.107	0.320
NO2			0.580	0.129	0.064	0.362	0.293	0.128	0.052	0.117	0.220	0.168
NO3				0.074	-0.046	0.235	0.393	-0.084	-0.029	0.084	0.204	0.369
PO4					0.311	0.187	0.290	0.068	0.027	0.016	0.033	0.214
CO3						-0.022	0.044	0.488	0.249	0.086	0.017	0.088
CO2							0.731	0.206	0.228	0.453	0.457	0.570
HCO3								0.190	0.238	0.266	0.291	0.679
CL									0.904	0.654	0.181	0.230
NA										0.683	0.174	0.264
SO4											0.508	0.435
CA												0.330

APPENDIX H (Continued)

VARIABLE	MN	FE	K	SI	CU	PB	CD	ZN
PH	-0.343	-0.264	-0.063	-0.315	0.126	0.093	-0.004	-0.291
BEDROCK	0.002	-0.234	0.250	-0.136	0.479	0.381	0.306	0.381
BPERM	-0.203	-0.016	0.321	-0.086	-0.070	0.134	-0.128	-0.007
WDPERM	-0.308	-0.073	0.117	-0.304	-0.109	-0.082	-0.168	-0.126
KAOLIN	0.216	0.145	-0.212	0.159	-0.068	0.074	0.217	0.203
ILLITE	0.438	0.013	0.433	0.436	0.346	0.218	0.326	0.063
MONT	-0.395	-0.072	-0.179	-0.354	-0.191	-0.175	-0.321	-0.133
DEPTH	-0.162	-0.138	0.155	-0.134	-0.016	-0.158	-0.161	-0.091
CU CLAY	-0.161	-0.078	-0.179	-0.336	-0.122	-0.177	-0.148	-0.226
MN CLAY	-0.118	-0.107	-0.133	-0.098	0.036	-0.222	-0.147	-0.317
ZN CLAY	0.060	-0.052	0.158	-0.045	0.111	-0.173	-0.106	-0.257
PB CLAY	-0.047	-0.086	-0.081	-0.150	0.029	-0.179	-0.129	-0.263
CD CLAY	0.039	-0.061	-0.062	-0.131	0.026	-0.132	-0.060	-0.217
NH4	0.260	0.033	0.622	0.314	0.237	0.193	0.134	0.112
NO2	0.164	0.017	0.079	0.306	0.176	0.263	0.643	0.328
NO3	0.079	0.020	0.174	0.346	0.194	0.101	0.486	0.239
PO4	0.117	-0.057	0.105	0.344	0.506	0.147	0.278	0.103
CO3	-0.101	-0.042	0.130	0.039	0.065	-0.014	-0.006	-0.053
CO2	0.472	0.013	0.401	0.624	0.327	0.207	0.308	0.386
HCO3	0.412	0.010	0.467	0.672	0.316	0.153	0.266	0.109
CL	0.168	0.023	0.261	0.152	-0.004	-0.019	0.030	0.005
NA	0.215	0.010	0.235	0.179	0.012	0.023	0.032	-0.020
SO4	0.302	-0.011	0.392	0.307	0.261	0.177	0.182	0.355
CA	0.431	0.144	0.418	0.557	0.094	0.247	0.219	0.318
MG	0.363	-0.005	0.485	0.434	0.374	0.232	0.205	0.199
MN		0.573	0.263	0.627	0.250	0.083	0.219	0.283
FE			0.080	0.186	-0.061	0.044	-0.016	0.352
K				0.268	0.029	0.384	0.028	0.196
SI					0.309	0.124	0.309	0.190
CU						0.265	0.564	0.296
PB							0.332	0.479
CD								0.244

APPENDIX I

EIGENVECTOR MATRIX OF THE ALLUVIAL

GROUND-WATER FACTOR ANALYSIS

FACTOR	1	2	3	4	5	6	7	8	9
PH	0.10794	-0.07825	-0.21926	-0.00049	0.35192	0.30660	-0.21390	-0.00622	0.06905
BEDROCK	-0.16321	0.05015	-0.23727	-0.01412	0.28732	-0.44181	-0.08264	-0.03955	-0.13651
BPERM	0.02898	0.24197	-0.24778	0.11866	-0.16954	0.16732	-0.16564	0.23899	0.26656
WDPERM	0.08955	0.17086	-0.27667	-0.00201	-0.17368	-0.00308	-0.07183	0.07291	0.20157
KAOLIN	-0.06565	-0.12905	0.33960	-0.15469	0.17571	0.13882	-0.20945	0.08058	0.34190
ILLITE	-0.27623	0.16651	0.11781	-0.22059	0.13015	-0.02769	-0.08139	-0.12500	0.10866
MONT	0.21607	-0.04150	-0.26034	0.23943	-0.18356	-0.04179	0.16320	0.05024	-0.25350
DEPTH	0.04856	0.14357	-0.26926	0.10422	-0.04837	-0.09668	0.12525	-0.04327	0.05411
CU CLAY	0.17143	0.25891	0.08254	0.03216	0.04347	-0.22667	0.10723	0.15157	0.00374
MN CLAY	0.12613	0.37279	0.12846	0.00857	0.11443	0.03377	0.08470	0.03324	0.03842
ZN CLAY	0.05338	0.43700	0.11527	0.04722	-0.02268	-0.01724	-0.04529	-0.02509	-0.02810
PB CLAY	0.11386	0.39808	0.13913	-0.03235	0.13494	-0.05551	0.04807	0.14082	-0.00045
CD CLAY	0.06901	0.30401	0.19490	-0.08956	0.20338	-0.03205	0.01603	0.14443	-0.00370
NH4	-0.16608	0.22181	-0.03989	0.10157	-0.23638	-0.02367	-0.22993	-0.13291	-0.07492
NO2	-0.15639	-0.03407	-0.04012	0.29645	0.08673	-0.06505	0.40204	0.19543	0.27907
NO3	-0.14285	-0.04267	0.00286	0.30511	0.04799	0.04684	0.37380	0.06860	0.28000
PO4	-0.10383	0.04365	-0.12185	0.20471	0.20159	0.33504	-0.10670	0.12281	-0.36904
CO3	-0.03168	0.04013	-0.28013	-0.11456	0.14482	0.34353	-0.00695	0.29974	0.02645
CO2	-0.29441	0.13477	0.05335	0.07572	-0.12757	-0.09541	0.04755	-0.12065	-0.05195
HCO3	-0.25515	0.21029	-0.00004	0.12104	-0.10344	0.22921	0.04923	-0.17013	0.07436
CL	-0.15284	0.05983	-0.25147	-0.38851	0.05552	0.06935	0.24529	0.24529	0.02798
NA	-0.16556	0.03173	-0.20519	-0.40252	0.04366	-0.00970	0.24137	0.07077	-0.04847
SO4	-0.25307	-0.00239	-0.16193	-0.25687	0.01551	-0.22917	0.07512	-0.00542	-0.08867
CA	-0.23874	-0.08882	0.06128	-0.07429	-0.10110	-0.01337	-0.03544	0.01256	0.11000
MG	-0.25139	0.08193	-0.09589	0.04786	-0.00242	0.10483	-0.03819	-0.23057	-0.01521
MN	-0.22620	0.02752	0.23564	-0.04974	-0.15502	0.07844	0.05152	0.22765	-0.27489
FE	-0.05998	-0.06464	0.17452	-0.01786	-0.28408	0.04358	-0.01824	0.54240	-0.13955
K	-0.20089	0.14082	-0.17887	0.00013	-0.23479	-0.00484	-0.25247	-0.04075	0.14964
SI	-0.26368	0.01893	-0.14883	0.08354	-0.12098	0.30145	0.15055	-0.03459	-0.12491
CU	-0.17139	0.07653	-0.02314	0.22311	0.33924	-0.01408	-0.10672	0.01005	-0.37578
PB	-0.15342	-0.05719	-0.07443	0.16480	0.09872	-0.18201	-0.39923	0.19037	0.19579
CD	-0.19063	-0.04136	0.06351	0.23433	0.32171	-0.02944	0.13472	0.09412	0.14526
ZN	-0.18001	-0.12570	0.11733	0.16774	-0.05400	-0.30672	-0.15254	0.37515	-0.00081

APPENDIX J

UNROTATED FACTOR MATRIX OF THE ALLUVIAL

GROUND-WATER FACTOR ANALYSIS

FACTOR	1	2	3	4	5	6	7	8	9
PH	0.29002	-0.15930	-0.38426	-0.00078	0.52360	0.40481	-0.26731	-0.00738	0.07839
BEDROCK	-0.43853	0.10209	-0.41690	-0.02275	0.42748	-0.58333	-0.10328	-0.04695	-0.15497
BPERM	0.07786	0.49261	-0.43538	0.19118	-0.25225	0.22092	-0.20700	0.28367	0.30261
WDPERM	0.24060	0.34784	-0.48614	-0.00324	-0.25840	-0.00407	-0.08977	0.08655	0.22883
KAOLIN	-0.17641	-0.26271	0.59671	-0.24924	0.26142	0.18329	-0.26175	0.09564	0.38814
ILLITE	-0.74220	0.33897	0.20700	-0.35541	0.19364	-0.03656	-0.10171	-0.14837	0.12335
MONT	0.58057	-0.08448	-0.45744	0.39576	-0.27310	-0.05518	0.23395	0.05965	-0.29346
DEPTH	0.13048	0.29228	-0.47311	0.16793	-0.07196	-0.12765	0.15653	-0.05136	0.06143
CU CLAY	0.46061	0.52708	0.14503	0.05182	0.06467	-0.29941	0.13400	0.17872	0.00425
MN CLAY	0.33889	0.75893	0.22571	0.01381	0.17025	0.04459	0.10485	0.03945	0.04362
ZN CLAY	0.14344	0.88964	0.20253	0.07608	-0.03374	-0.02277	-0.05660	-0.02978	-0.03191
PB CLAY	0.30593	0.81041	0.24446	-0.05213	0.20225	-0.07329	0.06008	0.16715	-0.00051
CD CLAY	0.18543	0.61890	0.34246	-0.14431	0.30260	-0.04232	0.02004	0.17143	-0.00420
NH4	-0.44624	0.45156	-0.07009	0.16364	-0.35170	-0.03126	-0.28734	-0.15775	-0.08505
NO2	-0.42020	-0.06935	-0.07050	0.47765	0.12904	-0.08558	0.50242	0.32197	0.31682
PO4	-0.27987	0.08887	-0.21410	0.32934	0.29993	0.44235	-0.13335	0.14577	-0.41895
CO3	-0.08511	0.08170	-0.49222	-0.18457	0.21547	0.45357	-0.00896	0.35577	0.03002
CO2	-0.79107	0.27436	0.09374	0.12201	-0.18994	-0.12597	0.05943	-0.14321	-0.05898
HCO3	-0.68557	0.42811	-0.00007	0.19502	-0.15391	0.30263	0.06152	-0.20194	0.08442
CL	-0.41068	0.12181	-0.44186	-0.62597	0.08260	0.09165	0.30654	0.24393	0.03177
NA	-0.44486	0.06460	-0.36054	-0.64855	0.06496	-0.01281	0.30163	0.08400	-0.05503
SO4	-0.67997	-0.00486	-0.28452	-0.41387	0.02307	-0.30257	0.09387	-0.00644	-0.10066
CA	-0.64148	-0.18082	0.10767	-0.11969	-0.15042	-0.01765	-0.04428	0.01491	0.12488
MG	-0.67547	0.16680	0.07712	0.00360	-0.00360	0.13840	-0.04772	-0.27368	-0.01726
MN	-0.60778	0.05603	0.41405	-0.08014	-0.23064	0.10356	0.06438	0.27021	-0.31207
FE	-0.16115	-0.13159	0.30665	-0.02878	-0.42266	0.05754	-0.02279	0.64370	-0.15843
K	-0.53978	0.28668	-0.31429	0.00020	-0.34933	-0.00639	-0.31551	-0.04836	0.16994
SI	-0.70849	0.03855	0.26152	0.13460	-0.18000	0.39801	0.18814	-0.04106	-0.14180
CU	-0.46051	0.15580	-0.04066	0.35947	0.50474	-0.01859	-0.13337	0.01192	-0.42661
PB	-0.41222	-0.11643	-0.13078	0.26552	0.14688	-0.24032	-0.49891	0.22585	0.22227
CD	-0.51220	-0.08420	0.11159	0.40833	0.47866	-0.03887	0.16836	0.11172	0.16540
ZN	-0.48367	-0.25589	0.02061	0.27026	-0.08034	-0.40497	-0.19063	0.44528	-0.00092

APPENDIX K

ROTATED FACTOR MATRIX OF THE ALLUVIUM

GROUND-WATER FACTOR ANALYSIS

FACTOR	1	2	3	4	5	6	7	8	9	COMMUNALITY
PH	0.390	-0.134	0.139	0.008	-0.030	0.550	-0.101	-0.448	0.264	0.774
BEDROCK	-0.167	0.020	-0.181	-0.415	0.753	0.109	0.064	-0.298	-0.179	0.937
BPERM	-0.158	0.220	-0.189	0.040	0.018	0.113	0.011	0.032	0.823	0.802
WDPERM	-0.005	0.138	-0.319	-0.069	-0.004	-0.112	-0.123	-0.129	0.616	0.550
KAOLIN	0.094	-0.052	0.900	0.082	-0.000	-0.053	0.038	0.085	-0.098	0.849
ILLITE	-0.621	0.188	0.502	-0.432	0.188	-0.010	0.041	-0.067	-0.142	0.921
MONT	0.356	-0.102	-0.815	0.253	-0.129	0.053	-0.040	0.013	0.157	0.911
DEPTH	-0.037	0.133	-0.476	-0.089	0.049	-0.036	0.109	-0.227	0.293	0.407
CU CLAY	0.235	0.708	-0.222	0.104	0.044	-0.191	-0.023	0.015	0.049	0.657
MN CLAY	-0.002	0.851	-0.028	0.086	-0.184	0.020	-0.012	-0.103	0.101	0.788
ZN CLAY	-0.320	0.833	-0.098	0.138	-0.068	-0.018	-0.118	-0.031	0.147	0.866
PB CLAY	0.026	0.936	-0.012	0.009	-0.047	0.008	-0.061	-0.014	0.087	0.891
CD CLAY	0.056	0.795	0.184	-0.045	-0.014	0.050	-0.058	0.013	-0.041	0.679
NH4	-0.747	0.101	-0.120	0.075	0.175	0.002	-0.125	0.079	0.182	0.674
NO2	-0.080	-0.069	-0.073	-0.079	0.154	0.007	0.885	0.114	0.044	0.845
NO3	-0.218	-0.144	-0.050	0.065	-0.051	-0.012	0.807	-0.061	-0.030	0.731
PO4	-0.198	-0.035	-0.099	0.022	0.055	0.822	0.082	0.070	0.003	0.741
CO3	0.122	-0.049	0.027	-0.432	-0.088	0.508	0.019	0.004	0.446	0.670
CO2	-0.794	0.009	0.185	-0.162	0.201	-0.054	0.240	0.159	-0.143	0.804
HCO3	-0.834	0.072	0.078	-0.086	-0.111	0.165	0.296	0.015	0.129	0.858
CL	-0.080	-0.040	0.028	-0.942	-0.047	0.076	0.035	0.056	0.176	0.940
NA	-0.147	-0.087	0.015	-0.909	-0.026	-0.006	-0.026	0.007	-0.009	0.858
SO4	-0.369	-0.195	0.003	-0.712	0.341	-0.084	0.004	0.026	-0.144	0.826
CA	-0.405	-0.319	0.309	-0.216	0.148	-0.107	0.144	0.213	-0.060	0.511
MG	-0.679	-0.156	0.052	-0.195	0.089	0.194	0.157	-0.134	-0.000	0.615
MN	-0.453	0.011	0.203	-0.160	-0.004	0.100	0.052	0.654	-0.276	0.789
FE	0.024	-0.061	0.095	0.012	0.017	-0.033	-0.032	0.860	0.065	0.760
K	-0.656	-0.126	-0.009	-0.155	0.243	-0.052	-0.073	0.028	0.432	0.725
SI	-0.644	-0.153	0.185	-0.075	-0.237	0.232	0.307	0.348	-0.183	0.838
CU	-0.301	0.122	-0.045	0.003	0.424	0.631	0.177	-0.054	-0.321	0.822
PB	-0.155	-0.199	0.232	0.110	0.697	0.117	0.120	0.033	0.235	0.700
CD	-0.129	-0.016	0.235	-0.003	0.324	0.273	0.680	-0.034	-0.181	0.747
ZN	-0.100	-0.249	0.044	0.023	0.665	-0.034	0.233	0.453	-0.005	0.778
TOTAL VARIANCE	4.864	3.957	2.570	3.094	2.263	1.967	2.383	2.003	2.162	
PERCENT TOTAL VARIANCE	19.25	15.66	10.17	12.25	8.96	7.79	9.43	7.93	8.56	

APPENDIX L

IRON, pH, AND CALCULATED Eh FOR

ALLUVIUM WELLS

Well	pH	log(Fe)[*]	Eh[**]
18	6.95	-5.64	.612
20	7.00	-3.60	.032
32	7.60	-4.70	-.013
33	7.60	-5.70	.046
47	7.65	-5.45	.030
774	7.80	-5.30	-.010
784	7.45	-5.30	.053
786	7.75	-4.57	-.040
87	7.17	-5.60	.120
95	7.50	-6.30	.100
106	7.13	-5.62	.130
108	7.28	-5.83	.110
115	7.40	-4.90	.040
133	7.59	-5.85	.070
150	8.00	-5.22	-.050
175	8.10	-5.40	-.050
190	8.75	-6.07	-.131
203	6.99	-5.15	.120
251	8.62	-5.60	-.140
259	7.45	-5.60	.070
262	7.17	-5.12	.090
264	7.52	-5.64	.060
271	7.20	-5.77	.130
282	8.05	-5.40	-.040
247	7.34	-7.00	.170
297	7.16	-5.37	.110
299	7.85	-5.82	.010
303	7.95	-5.05	-.050
309	7.96	-5.55	-.020
312	8.00	-5.57	-.030
318	8.20	-5.47	-.050
339	7.55	-5.38	.040
341	7.35	-5.38	.110

[*]Fe in activity (moles/l)

[**]Eh in volts $= 1.06v - .177pH - .059 \log(Fe^{++})$

APPENDIX L (Continued)

Well	pH	log(Fe)[*]	Eh[**]
392	7.75	-5.60	.030
390	7.87	-6.00	.000
399	7.80	-5.80	.020
401	7.40	-6.30	.120
427	8.10	-6.70	.030
433	7.78	-5.70	.020
434	8.00	-5.60	-.030
435	7.75	-5.60	.020
437	7.60	-5.75	.060
185	7.38	-6.00	.100
506	8.15	-5.52	-.050
512	7.12	-4.57	.070
514	7.50	-6.07	.090

[*]Fe in activity (moles/l)

[**]Eh in volts = $1.06v - .177pH - .059\log(Fe^{++})$

2

VITA

Lyle Ramsay Silka

Candidate for the Degree of

Master of Science

Thesis: HYDROGEOCHEMISTRY OF THE WASHITA RIVER ALLUVIUM IN CADDO AND GRADY COUNTIES, OKLAHOMA

Major Field: Geology

Biographical:

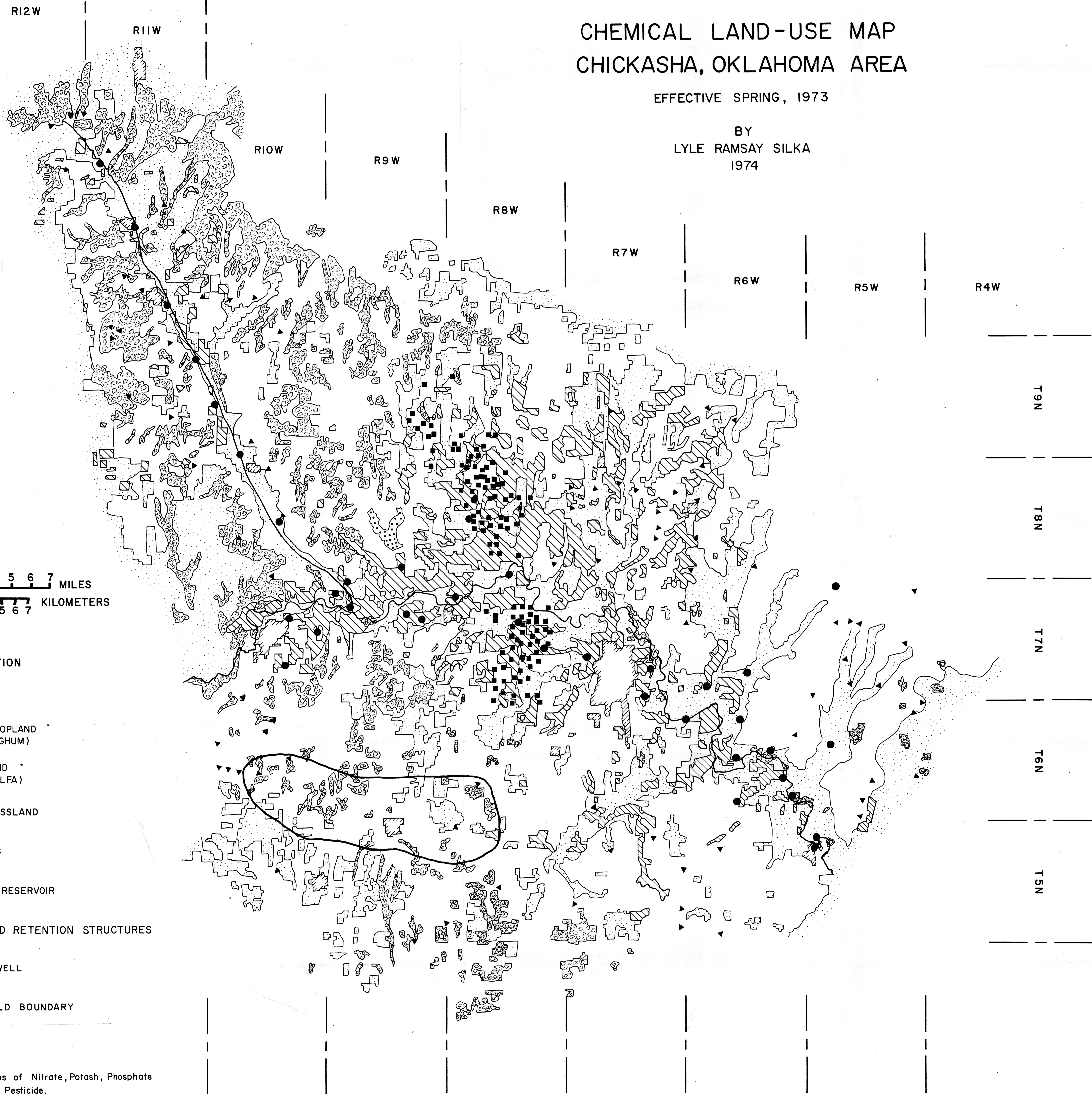Personal Data: Born in Independence, Iowa, November 25, 1949, the son of Mr. and Mrs. Earl Silka.

Education: Graduated from Anamosa Community High School, Anamosa, Iowa, in May, 1968; received Bachelor of Arts degree in Geology from the University of Northern Iowa in 1972; enrolled in Master of Arts program at Oklahoma State University, 1972-74; completed requirements for the Master of Science degree in Geology at Oklahoma State University, May, 1975.

Professional Experience: Laboratory technician, Twin City Testing and Engineering Laboratories, 1969-70; paid student assistant, Earth Science Department, University of Northern Iowa, 1970-72; graduate teaching assistant, Department of Geology, Oklahoma State University, 1972-74; Environmental Protection Agency Traineeship recipient, 1973-74; graduate teaching assistant, Department of Geology, Kansas University, 1974; graduate research assistant, Department of Geology, Kansas University, 1975.
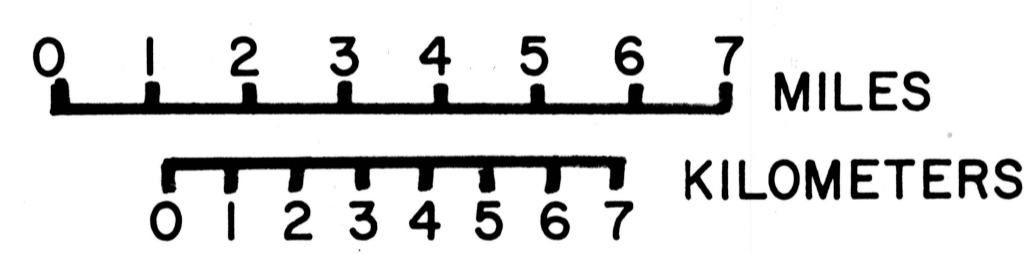
CHEMICAL LAND-USE MAP
CHICKASHA, OKLAHOMA AREA

EFFECTIVE SPRING, 1973

BY
LYLE RAMSAY SILKA
1974

R12W
R11W
R10W
R9W
R8W
R7W
R6W
R5W
R4W

T9N
T8N
T7N
T6N
T5N

N

SCALE

0 1 2 3 4 5 6 7 MILES
0 1 2 3 4 5 6 7 KILOMETERS

EXPLANATION

WOODLAND

SPRING FALLOW CROPLAND *
(COTTON and SORGHUM)

PLANTED CROPLAND *
(WHEAT and ALFALFA)

PASTURE and GRASSLAND

URBANIZED AREAS

LAKE CHICKASHA RESERVOIR

▼ UPSTREAM FLOOD RETENTION STRUCTURES

■ INDIVIDUAL OIL WELL

CEMENT OIL FIELD BOUNDARY

STREAMS

* Chemical applications of Nitrate, Potash, Phosphate
  Herbicide and Pesticide.

● WATER WELLS