

12-1-1990

# Nitrate Concentrations of Ground Water Benton County, Arkansas


Charles R. Smith

*University of Arkansas, Fayetteville*

Kenneth F. Steele

*University of Arkansas, Fayetteville*

Follow this and additional works at: <http://scholarworks.uark.edu/awrctr>

 Part of the [Fresh Water Studies Commons](#), and the [Water Resource Management Commons](#)

---

## Recommended Citation

Smith, Charles R. and Steele, Kenneth F. 1990. Nitrate Concentrations of Ground Water Benton County, Arkansas. Arkansas Water Resources Center, Fayetteville, AR. MSC073. 48

This Technical Report is brought to you for free and open access by the Arkansas Water Resources Center at ScholarWorks@UARK. It has been accepted for inclusion in Technical Reports by an authorized administrator of ScholarWorks@UARK. For more information, please contact [scholar@uark.edu](mailto:scholar@uark.edu), [ccmiddle@uark.edu](mailto:ccmiddle@uark.edu).



# Arkansas Water Resources Center

## NITRATE CONCENTRATIONS OF GROUND WATER BENTON COUNTY, ARKANSAS

Prepared by

Charles R. Smith, Research Assistant  
Department of Geology  
118 Ozark Hall  
University of Arkansas  
Fayetteville, Arkansas 72701

And

Kenneth F. Steele, Principal Investigator  
Arkansas Water Resources Research Center  
113 Ozark Hall  
University of Arkansas  
Fayetteville, Arkansas 72701

Final Report for Contract 0001357  
Submitted to:  
Arkansas Department of Pollution Control and Ecology

December 1990

**Publication No. MSC-073**

Arkansas Water Resources Center  
Ozark Hall 113  
University of Arkansas  
Fayetteville, Arkansas 72701

## ABSTRACT

Because ground water in fractured carbonate aquifers is particularly susceptible to contamination from surface sources, there is concern about nitrate contamination of ground water supplies in northwest Arkansas. Surface application of animal wastes, commercial fertilizers, animal impoundments, septic systems, and municipal sewage collection and treatment systems represent potential sources of contaminants, especially nitrate. A survey of ground water nitrate concentrations was conducted in Benton County, Arkansas during 1990. Sixty-eight randomly selected ground water samples were collected from springs and wells during successive wet (5-19 to 6-5-90) and dry (7-19 to 8-3-90) seasons. Fifty-two samples were collected from the shallow, unconfined Boone-St. Joe limestone formations of the Springfield Plateau aquifer. Sixteen wells were completed in the more productive Ozark aquifer. Owner reported well depths and Mg/Ca ratios were used to determine the source aquifer for each sample.

Nitrate concentrations for wells and springs of the Springfield Plateau aquifer were higher than those of the Ozark aquifer during both seasons. Mean concentrations for the shallow aquifer are 2.63 mg/L  $\text{NO}_3\text{-N}$  in the wet season, and 1.80 mg/L in the dry. The nitrate concentrations are higher during the wet season: a period of maximum recharge. Wells producing from the Ozark aquifer had significantly lower mean values as a population. Mean values for this confined aquifer were 0.11 and 0.15 mg/L for the wet and dry seasons, respectively.

TABLE OF CONTENTS

	page
Abstract	
Table of Contents .....	ii
List of Figures	
List of Tables .....	
Introduction .....	1
Nature of Concerns .....	1
Potential Sources of Nitrate Contamination .....	2
Study Area Location and General Information .....	4
Location and Land Use .....	4
Livestock Production Statistics .....	4
Population Distribution and Growth Estimates .....	5
General Geology .....	5
General Hydrogeology .....	10
Basement Confining Unit .....	10
St. Francois Aquifer .....	10
St. Francois Confining Unit .....	12
Ozark Aquifer .....	13
Gasconade and Roubidoux Formations .....	14
Everton Formation .....	16
Clifty Formation and Sylvania Sandstone .....	16
Ozark Confining Unit .....	18
Springfield Plateau Aquifer .....	18
Methods of Investigation .....	19
Selection of Sampling Sites .....	19
Field Analyses and Sample Collection .....	22
Sample Preservation .....	25
Laboratory Analyses .....	25
Precision and Accuracy .....	27
Discussion .....	32
Conclusions .....	39
References Sited .....	40
Appendix A .....	44
Appendix B .....	45
Appendix C .....	48

### LIST OF FIGURES

- Figure 1: Geographic location and physiography of the Ozark Plateaus Geologic Province ..... page 6
- Figure 2: Generalized geologic map of Benton County, Arkansas ..... page 8
- Figure 3: Generalized stratigraphic section for northwest Arkansas ..... page 9
- Figure 4: Generalized stratigraphic section for northwest Arkansas showing aquifers and confining units of the Ozark Plateaus Aquifer System ..... page 11
- Figure 5: Location map showing sample sites ..... page 21
- Figure 6: Total monthly rainfall data for the period of January 1989 through August 1990. Average precipitation values for the period 1941 through 1970 are also presented .....page 23
- Figure 7: Bar chart of wet and dry season nitrate concentrations for the Springfield Plateau aquifer. page 35
- Figure 8: Bar chart of wet and dry season nitrate concentrations for the Ozark aquifer ..... page 35

### LIST OF TABLES

- Table 1: Summary of duplicate analyses for wet and dry season samples ..... page 28
- Table 2: Summary of spiked sample analyses ..... page 30
- Table 3: Summary of results from analyses of EPA blind quality control samples ..... page 31
- Table 4: Results of field duplicate and trip blank analyses ..... page 32
- Table 5: Comparison of mean nitrate concentrations and mean Mg:Ca ratios as reported for wet and dry seasons in various studies in northwest Arkansas ..... page 38

## INTRODUCTION

### **Nature of Concerns**

Measurements of nitrate concentrations are usually reported in one of two forms: nitrate ( $\text{NO}_3$ ) or nitrate-nitrogen ( $\text{NO}_3\text{-N}$ ). In 1962, the United States Public Health Service established a limit of 10 mg/L  $\text{NO}_3\text{-N}$  for domestic water supplies. This limit is equivalent to 45 mg/L  $\text{NO}_3$  and has been carried forward as the current national primary drinking water standard (EPA, 1985).

Nitrate is the dominant form of nitrogen in oxidizing waters, but it is not a direct toxicant. In the human gastrointestinal tract, nitrate may be reduced to form nitrite and, subsequently, introduce health risks. In the blood stream, nitrite can impair the transport of oxygen to bodily tissues by the oxidization of hemoglobin to methemoglobin. Anoxemia (or subnormal oxygenation of arterial blood) can yield permanent damage to tissue, or death if dosages are extreme. Adults are less susceptible to ingestion of large quantities of nitrate than are infants under the age of six months. Most reported cases of methemoglobinemia involve infants, and very few cases have been reported where  $\text{NO}_3\text{-N}$  concentrations did not exceed 10 mg/L (Rajagopal and Tobin, 1989).

A carcinogenic relationship between nitrate ingestion and human health has also been suggested. Upon reduction to nitrite in the gastrointestinal tract, reaction may occur with

amines and amides (from foods and water) to form cancer inducing N-nitroso compounds. Epidemiological studies have shown correlations between nitrate ingestion and the incidence of stomach cancers (NRC, 1977)

Additionally, a study in Australia has demonstrated that fetal malformations may be directly linked to ground water nitrate consumption. This regional study showed that higher incidences of death due to congenital malformations had occurred in an area of nitrate ground water concentration in excess of 10 mg/L, than had occurred in surrounding areas showing negligible concentrations (Scragg et al., 1982).

#### **Potential Sources of Nitrate Contamination**

Poultry, beef, and hog production in Benton County account for a large portion of the local economy. The vast quantities of waste products associated with these industries represent potential sources for nitrate contamination of ground water from both point source and non-point source perspectives.

Land application of animal wastes as fertilizer has been a common practice for many years in northwest Arkansas, and affects of such application on ground water chemistry has been the focus of several studies. Ogden (1979) analyzed waters from 253 wells completed in the Boone-St. Joe aquifer Benton County. He concluded that poultry houses (point sources of nitrate) and fertilizer spreading (non-point

sources) could easily contaminate this shallow, unconfined aquifer

Leidy (1989), in a comparison of ground water chemistry of the Boone-St. Joe and Cotter aquifers, showed that the shallower and unconfined aquifer had significantly different chemical character than did the deeper confined aquifer. Nitrate, fecal coliform, fecal streptococcus, orthophosphate, and chloride all exhibited statistically higher levels in the nearer surface environment.

Studies have shown that the shallow aquifer in northwest Arkansas is directly affected by local land usage (Steele et al., 1990; Steele and McCalister, 1990; Steele and McCalister, 1991). Ground water nitrate concentrations in areas devoid of cattle and poultry production (control area) were compared with concentrations in areas of active production (experimental area). Mean concentrations for the experimental area were higher than those of the control. presence of grazing cattle, septic systems, and poultry litter application in the area made the precise source of contaminants difficult to determine. However, because of the greater volume of poultry liter generated annually in the experimental area, the authors attributed the greatest input of nitrate to the system to be from the land application of poultry litter. Furthermore, deeper wells in the confined Everton Formation repeatedly showed lower concentrations of nitrate than those seen in the shallower Boone-St. Joe



aquifer

Septic systems are numerous in the rural areas of the county and each represents a potential point source for nitrate contamination. Large municipal sewage collection networks, through leakage, are possible non-point sources of the contaminant. Additionally, municipal sewage treatment facilities should be considered as potential point sources.

#### STUDY AREA LOCATION AND GENERAL INFORMATION

##### **Study Area Location and General Land Use**

Benton County, Arkansas is located in the northwesternmost corner of the state. To the north, it is bordered by McDonald and Barry Counties in Missouri, and to the west by Delaware County, Oklahoma. In Arkansas, the study area is bordered (from southwest to northeast) by Washington, Madison, and Carroll Counties (Figure 1).

Total land area of Benton County is 843.5 square miles, or 539,820 acres. Of the total acreage, 302,659 acres are reported to be in farmland (56% of total area). Of the total farmland acreage, 23% (or 69,434 acres) is harvested cropland. A large portion of the remaining farmland is used as pasture (Arkansas Agricultural Statistics, 1989)

##### **Livestock Production Statistics**

Benton County ranked second of all counties in the state in broiler production in 1989 with a total output of

80,549,000 birds. This represents an increase in production of approximately 33% since 1980. The county ranked first in turkey production in 1989 with 4,005,000 birds (44 % increase since 1980). Beef production in the county ranked second in the state with 118,000 head, and dairy cattle ranked first with 8000 head. Hogs produced in 1989 totaled 128,000 and represents the highest county production in the state (USDA, 1980 and USDA, 1990).

#### **Population Distribution and Growth Estimates**

Preliminary results of the 1990 census indicate that 43,302 persons reside outside of the municipalities of Benton County. This represents 45% of the total county population of 96,972 individuals. Total population has increased by 29.6% between the 1980 census and the 1990 census (Santi, 1990). As population increases, both the number of wells serving rural residents and the number of potential septic tank sources increase. The projected population for the year 2000 is 125,917. This projection yields an expected growth of 29.8% over the next 10 years (Santi and McGehee, 1990)

#### **GENERAL GEOLOGY**

Benton County is on the southern flank of the isostatically uplifted Ozark Plateaus Geologic Province (Figure 1). This province has been characterized by Imes and Emmett (1990) as a broad anticlinal fold whose axis extends

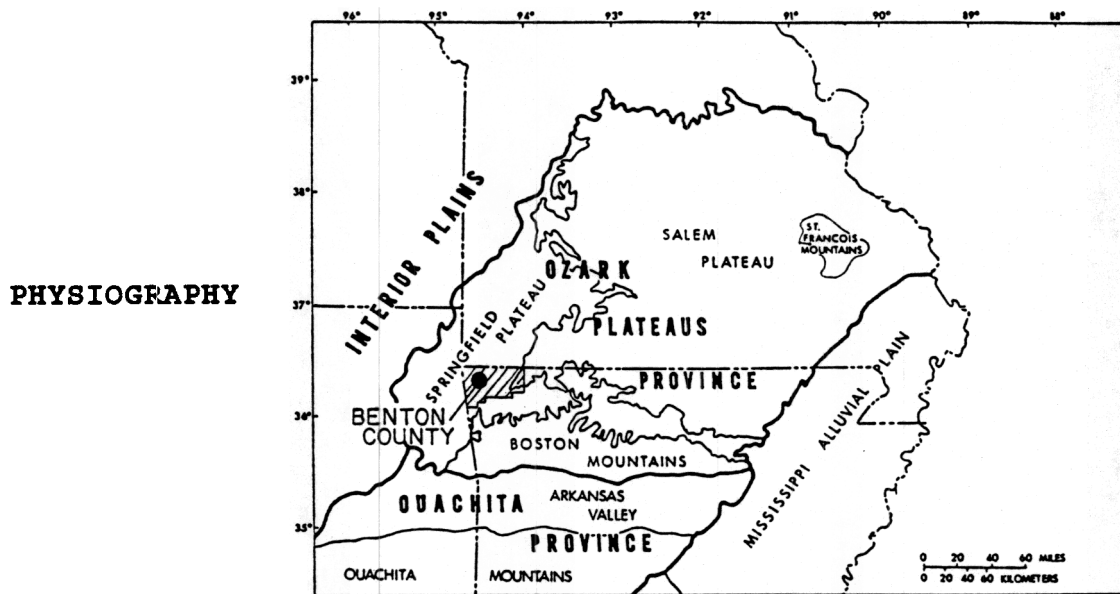
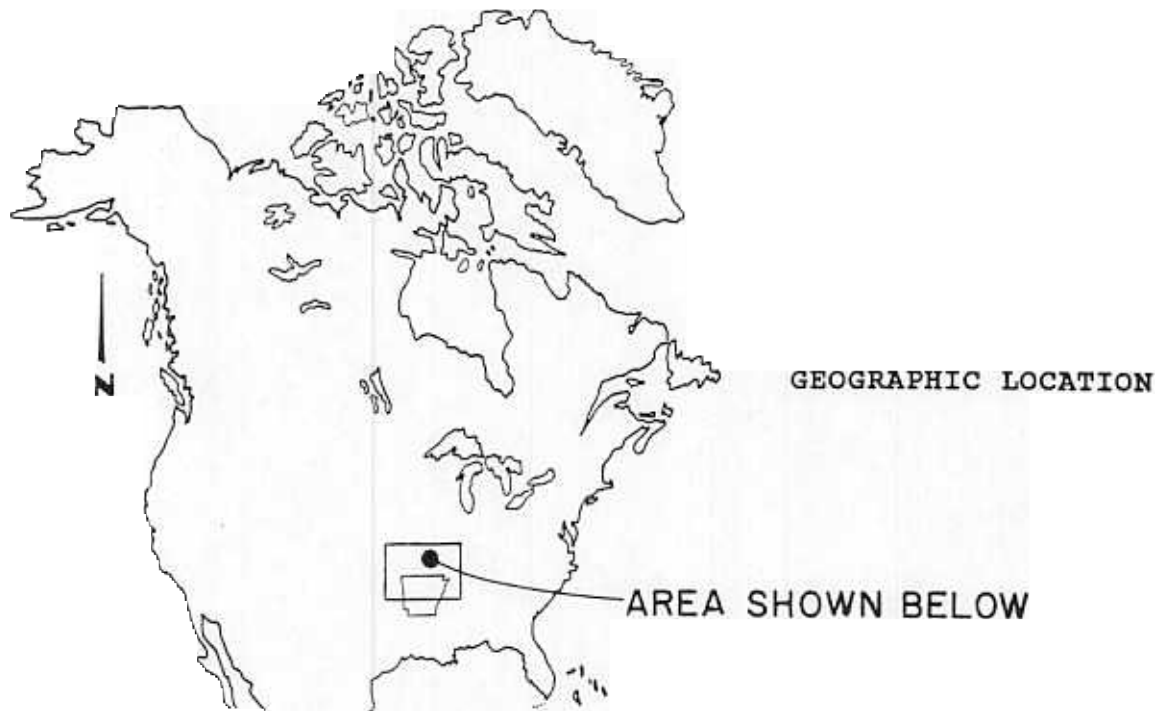
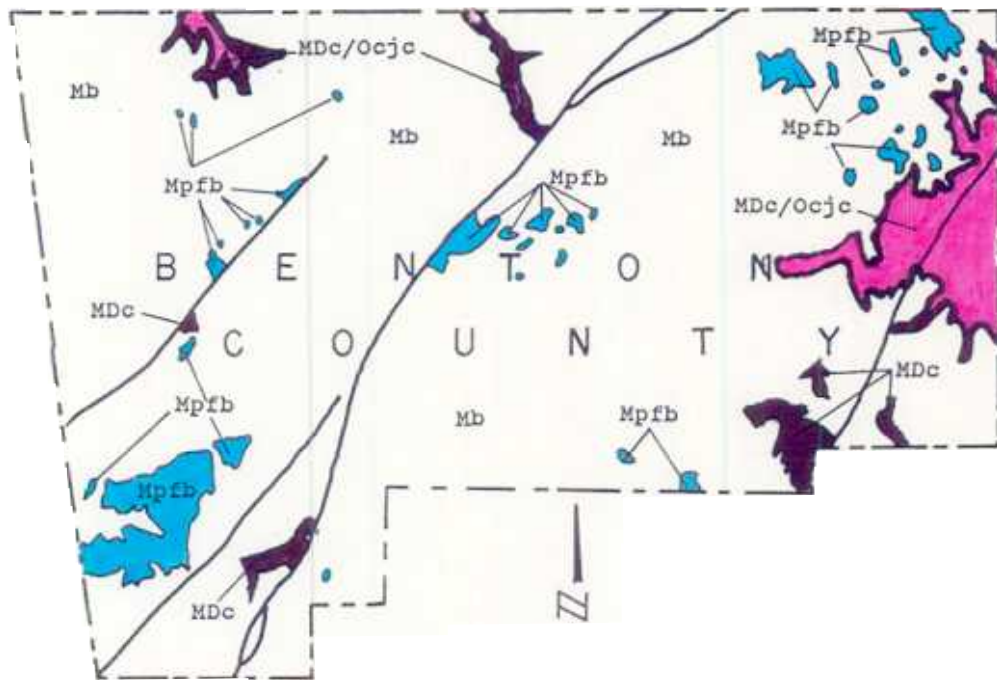


Figure 1: Geographic location and physiography of the Ozark Plateaus Geologic Province. (After Imes and Emmett, 1990)

from the extreme northwestern corner of Arkansas to the St. Francois Mountains of southeast Missouri. The area of uplift is comprised of four physiographic subdivisions: 1) the St. Francois Mountains; 2) the Boston Mountains; 3) the Salem Plateau; and 4) the Springfield Plateau

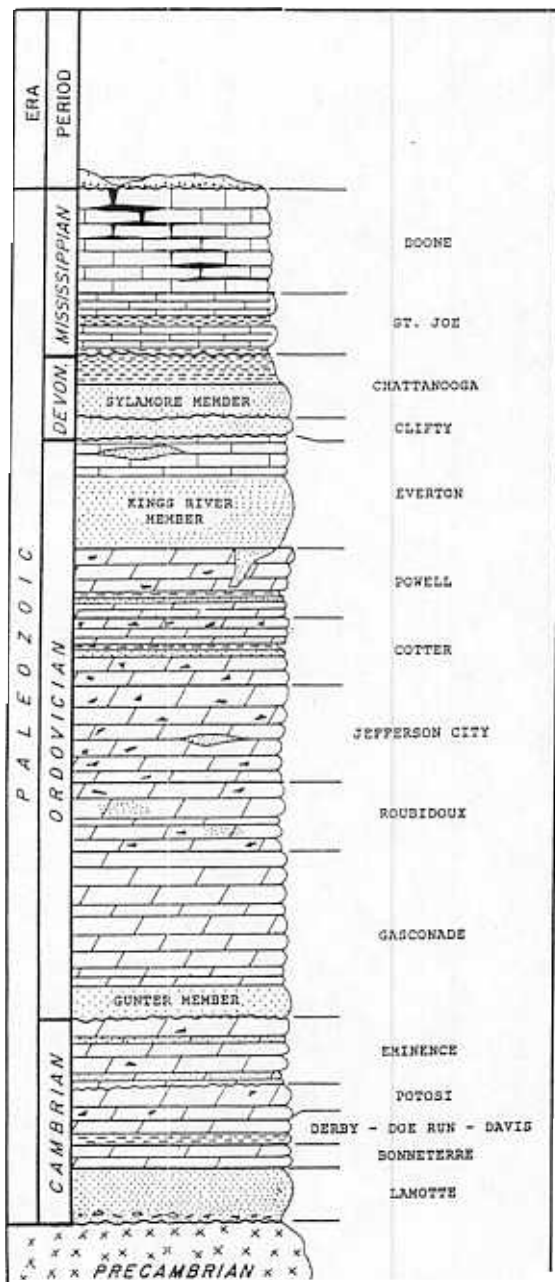
Mississippian age rocks (primarily Boone Limestone) are exposed at the surface over approximately 90% of the study area (Figure 2). These surface exposures generally demark the portion of the county that lies within the Springfield Plateau subdivision. Minor exposures of Ordovician age Cotter Dolomite also crop out within this subdivision near the towns of Sulphur Springs and Bella Vista, Arkansas. In the eastern portion of the county, where Ordovician dolomite is more extensively exposed, the Salem Plateau subdivision is present. Precambrian igneous basement rocks underlie a complex sedimentary sequence deep in the subsurface. Figure 3 presents a generalized graphical representation of, and descriptions of, the lithologies encountered at depth within the study area.

The sedimentary rocks were deposited in an essentially horizontal position and have undergone only mild post-depositional deformation (Croneis, 1930). Several high angle normal faults, which trend southwest to northeast, crosscut the sedimentary sequence within the county and interrupt an otherwise regional dip of less than one degree to the south-southwest. In addition to the faults, joints are observed in



- Mpfb *MISSISSIPPIAN - PITKIN, FAYETTEVILLE, BATESVILLE UNDIFFERENTIATED*
  
- Mb *MISSISSIPPIAN - BOONE*
  
- MDc *MISSISSIPPIAN / DEVONIAN CHATTANOOGA*
  
- Ocjc *ORDOVICIAN - POWELL, COTTER, JEFFERSON CITY UNDIFFERENTIATED*

Figure 2 Generalized geologic map of Benton County, Arkansas. (After A.G.C., 1976)



**REGOLITH** Typically red to red-brown silty clay; increasing fragmented chert content with depth

**BOONE LIMESTONE FORMATION**  
**LOWER** Fine to very-fine grained, grain-supported calcarenites; penecontemporaneous chert nodules, bands, and anastomosing bodies  
**UPPER** Grainstones and packstones with some mud-dominated intervals; white to buff diagenetic chert along bedding planes (Shelby, 1986)

**ST. JOE FORMATION**  
**PIERSON MEMBER** Unsorted, grain-supported, calcarenites; minor calcilutites  
**NORTHVIEW MEMBER** Greenish-gray to red silty shale; occasional interbedded argillaceous lime wackestone  
**COMPTON MEMBER** Greenish-gray to dark gray, grain supported calcarenites; some secondary dolomite; chert lenses and nodules in upper unit  
**BACHELOR MEMBER** Greenish-gray shale; some gray to brown phosphatic quartz sandstone (Shelby, 1986)

**CHATTANOOGA FORMATION**  
**CHATTANOOGA SHALE MEMBER** Carbonaceous, fissile, black shale  
**SYLAMORE SAND MEMBER** Well-rounded, medium to coarse-grained, quartz sandstone; some chert and phosphate (Pudue and Miser, 1916)

**CLIFTY FORMATION**  
 Crossbedded limestone; substantial amounts of quartz sand (Purdue and Miser, 1916)

**EVERTON FORMATION**  
**UPPER** Fine-grained limestone; interbedded lenses of sandstone  
**LOWER** Fine to medium-grained, rounded to sub-angular, saccharoidal quartzarenite - Kings River Member (Clardy, 1964)

**POWELL AND COTTER DOLOMITES**  
 Light gray to brown cherty dolomites; thin beds of green shale and sandstone

**JEFFERSON CITY DOLOMITE**  
 Cherty, silty dolomite; few sand lenses; oolitic locally

**ROUBIDOUX FORMATION**  
 Light gray to brown, finely crystalline dolomite; some dolomitic sandstone bodies; some chert (Melton, 1976)

**GASCONADE FORMATION**  
 Light gray to brown dolomite with basal member of sandy dolomite or sandstone - Gunter Member (Melton, 1976)

**EMINENCE FORMATION**  
 Light gray, medium to coarse grained dolomite; minor nodular chert; thin beds of sandy dolomite (Melton, 1976)

**POTOSI FORMATION**  
 Medium to fine-grained dolomite with abundant chert (Melton, 1976)

**DERBY - DOE RUN AND DAVIS FORMATIONS**  
 Fine-grained dolomite and shales with some sandstones. Absent in portions of northwest Arkansas (Ines and Emmett, 1990).

**BONNETERRE FORMATION**  
 Light gray dolomite; locally shaley and glauconitic zones (Melton, 1976)

**LAMOTTE FORMATION**  
 Quartz sandstone grading laterally to conglomerate and arkose (Melton, 1976)

**PRECAMBRIAN COMPLEX**  
 Granite, gneiss, and intermediate plutonic rocks; some volcanics and metavolcanics (Melton, 1976)

Figure 3  
 Generalized stratigraphic section for northwest Arkansas

surface exposures throughout the study area

### GENERAL HYDROGEOLOGY

Imes and Emmett (1990) have developed a comprehensive description of the Ozark Plateaus Aquifer System. Three regional aquifers are present within the sedimentary sequence and are either bounded by, or are separated by, major ground water confining lithologies (Figure 4). The following hydrogeologic description of Benton County draws heavily from this work

#### **Basement Confining Unit**

The Precambrian igneous basement rocks serve as the lowermost confining unit of the system. These rocks are primarily rhyolitic and granitic with some metamorphic and metasedimentary rocks. Primary porosities are low and the rocks are very nearly impermeable. Secondary permeability is confined to areas that have been faulted or fractured, but wells in such zones in the exposures of the St. Francois Mountains rarely show flows greater than 10 gallons per minute (gpm). The structural top of the confining unit in the subsurface of Benton County is typically at an elevation of 1000 feet below mean sea level (Imes and Emmett, 1990).

#### **St. Francois Aquifer**

The lowermost water producing unit in the Ozark Plateaus

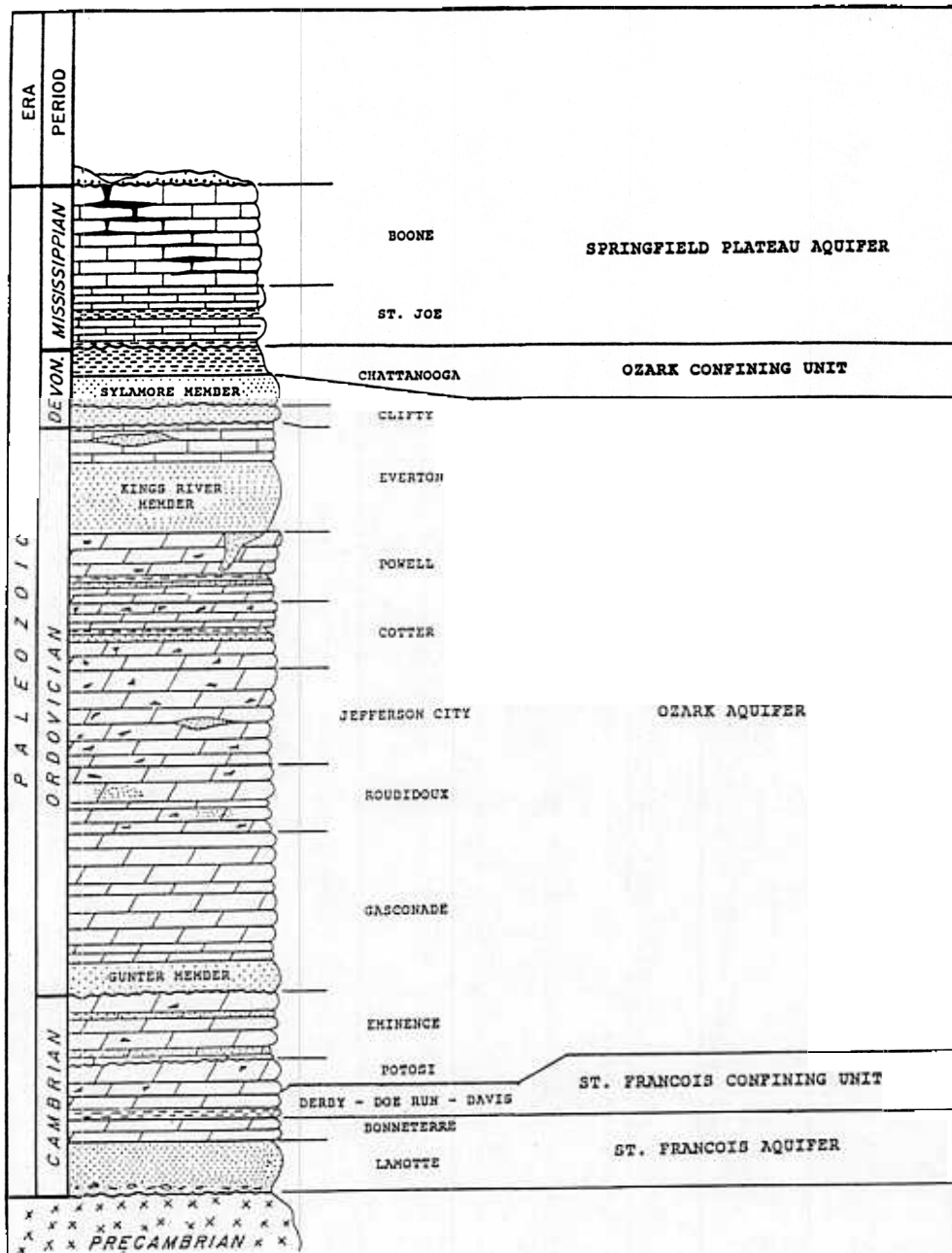


Figure 4: Generalized stratigraphic section for northwest Arkansas showing aquifers and confining units of the Ozark Plateaus Aquifer System (after Imes and Emmett, 1990)



Aquifer System is the St. Francois Aquifer. It consists primarily of permeable sandstone and dolostone. The Lamotte Sandstone Formation and the Bonnetarre Dolostone Formation, both of Lower Cambrian age, comprise this confined aquifer. Flows range from 100 to 500 gpm, but the source is rarely used because wells in the overlying Ozark and Springfield Plateau aquifers yield sufficient quantities of water at much shallower depths. Thickness of the aquifer in the Benton County subsurface ranges from 100 to 200 feet. Elevations on the top of the Bonnetarre Formation vary between 750 and 500 feet below mean sea level (Imes and Emmett, 1990).

#### **St. Francois Confining Unit**

The St. Francois aquifer and the Ozark aquifer are hydrogeologically isolated from one another by the St. Francois confining unit. This aquitard consists of the Davis Formation, and the Derby and Doe Run Dolomites of middle Cambrian age. These lithologies are missing in the subsurface in several isolated areas of the Ozark Plateaus Province, including north-central Benton County

Clastic rocks are predominant near the base of the confining unit and carbonates are more predominant near the top (Melton, 1976). Considerable shale content within the formations contribute to their effectiveness as a confining unit, but the distribution of the shale is not uniform. Some areas have sandstone as the dominant clastic rock and, as

suggested by Imes and Emmett (1990), the confining capability of the Davis Formation may be inhibited in these zones. The Derby and Doe Run Dolostones typically have less shale content than the underlying Davis Formation, however, like

Davis, the shale content is variable. Combined sand-to-shale ratios for the three formations in the Benton County subsurface indicate total shale thicknesses ranging from 0

(where the confining layers are absent) up to 20 feet. The relatively fine-grained nature of the dolostone within these formations, and their lack of significant secondary permeability development, enhance their ground water confining potential.

The combined thickness of these confining lithologies varies across the county from 0 to 100 feet. Where present in the study area subsurface, the top of the confining unit expresses elevations between 800 and 400 feet below mean sea level (Imes and Emmett, 1990).

#### **Ozark Aquifer**

The Ozark aquifer is a confined system that is composed of a variety of sedimentary rock types. Although each different lithology expresses varying degrees of water producing capacity, they can collectively be viewed as a single regional aquifer. The rocks range in age from Late Cambrian to Middle Devonian, and include primarily dolostones, limestones, and sandstones

In the study area, the aquifer is confined below by the St. Francois Confining Unit (where present), and above by the Upper Devonian Chattanooga Shale Formation. The latter is referred to by Imes and Emmett as the Ozark confining unit.

The aquifer is exposed in very few areas of Benton County, and is generally less than 300 feet below land surface where not exposed. Typically, the structural top of the aquifer across the county is at an elevation of approximately 1000 feet above mean sea level. Thickness of the sedimentary units that comprise the aquifer vary from approximately 1500 to 2000 feet, and show a general thickening trend from north to south.

Imes and Emmett (1990) describe five zones in this confined aquifer. They base the distinctions between zones on their regional hydrogeologic properties and on the relative hydraulic conductivities of adjacent rocks in the sequence. In the study area, the absence of several key lithologies makes their zonation impractical to employ. Instead, the more prolific water producing horizons of the Ozark aquifer in the Benton County subsurface will be discussed in ascending order.

#### **Gasconade and Roubidoux Formations**

The Gasconade Dolomite and the Roubidoux Formation are important high capacity ground water sources in the study area. Melton (1976) reported flow rates from twelve

municipal and privately owned wells penetrating these horizons. The average flow rate for the wells was 244 gpm, and the flows ranged from 30 to 500 gpm

The Gunter Sandstone Member is the basal unit of the Gasconade Formation. Regionally, it shows lateral variation between a sandstone and sandy dolomite. In the Benton County subsurface, the sand content varies from approximately 40% to less than 10% in a traverse from east to west (Knight, 1954). Overlying the Gunter is a cherty dolomite section. Caplan (1954) describes the lower portions of the section as containing the greatest chert content which, according to Melton (1976), may be as great as 50%.

The Roubidoux Formation contains cherty dolomite and dolomitic sandstone. Melton (1976) reports that the well developed sandstone bodies observed in Missouri are not defined by subsurface studies in northern Arkansas. In 1954, Caplan made the generalization that the sand intervals predominantly occurred at the top, near the middle, and at the base of the formation

Neither of these Lower Ordovician formations crop out in Arkansas. Subsurface thicknesses for the Gasconade and Roubidoux in Benton County typically range from 300 to 450 feet, and from 160 to 220 feet, respectively. Elevations of the contact between the two formations varies from 200 feet below mean sea level to 200 feet above (Melton, 1976). The variation in contact elevation is strongly controlled by both

a deepening trend from northeast to southwest, and by the presence of high angle normal faults across the study area.

### **Everton Formation**

The Middle Ordovician Everton Formation contains massive Kings River Sandstone Member and an upper unit of fine-grained limestone with interbedded sandstone. As reported by McCalister (1990), the upper limestone unit makes up only a small portion of the formation, and the Kings River Member is the more widely used source of ground water in northwest Arkansas. This is particularly true when the overlying formations do not yield adequate supplies of water (Widmann, 1982). The Kings River Sandstone, according to Clardy (1964), is a fine- to medium-grained, rounded to subangular, quartzarenite cemented with calcite and silica.

Arrington 1962), in describing the geology of the Rogers quadrangle, records that the Kings River Member is absent in the northeastern part of the quadrangle and thickens to 65 feet in the southeastern part. Staley (1962) states that the sandstone reaches a maximum thickness of 40 feet in the War Eagle Quadrangle and is absent north of the White River. Generally, the Everton Formation is not present in the northern two thirds of Benton County.

### **Clifty Formation and Sylamore Sandstone**

The Middle Devonian Clifty Formation disconformably

overlies the Everton (where it is present), and the Powell Formation where the Everton is absent. In turn, the Clifty is disconformably overlain by the Devonian Sylamore Sandstone Member of the Chattanooga Shale Formation. Both the Clifty and the Sylamore are orthoquartzites cemented with silica or carbonate. Neither the Clifty nor the Sylamore are present as continuous lithologies across the study area. Staley (1962), working in the War Eagle Quadrangle, reports a variation in the Sylamore thickness from 2 inches to seven feet, and also the member's absence in other areas. In sections measured near Sulphur Springs by Mapes (1968) a thickness of 3.5 feet of Sylamore resting unconformably on the Cotter Formation was observed. Additionally, he notes the presence of cylindrical sandstone bodies with exposed thicknesses of 20 feet penetrating the Cotter Formation. These are similar to the cave or solution channel filling sands described by Purdue and Miser (1916) and are potential pathways for ground water movement. Arrington (1962) noted the presence of both Sylamore and Clifty sandstones overlying the Everton in the Rogers Quadrangle.

Hydrogeologically, the three sandstone lithologies of the Kings River Member, the Clifty Formation, and the Sylamore Member, could behave conjunctively as a single aquifer if all three are present. Erosional truncation has removed the sands in part, and their availability as a ground water reservoir is correspondingly diminished.

### **The Ozark Confining Unit**

The Chattanooga Shale Member of the Chattanooga Formation serves as the upper confining unit of the Ozark aquifer, and as the lower confining lithology of the overlying Salem Plateau Aquifer. It is a black, fissile, carbonaceous shale with very low permeability and primary porosity. Secondary porosity, in the form of joints and faults, can allow the recharge of the deeper confined aquifer. This shale formation ranges in thickness from 0 to 60 feet in the Benton County subsurface, with an average thickness of approximately 45 feet (Terry, 1980).

### **Springfield Plateau Aquifer**

The most widely used source of ground water by rural residents in Benton County is the Springfield Plateau aquifer. It is comprised of the St. Joe and Boone Formations of lower Mississippian age, and is often referred to as the Boone - St. Joe aquifer by other authors.

The St. Joe consists of four members: Bachelor, Compton, Northview and Pierson (ascending order) The Bachelor Member is a calcareous shale which overlies the shale of the Chattanooga Formation. The Compton and Pierson Members are limestones and are separated by the terrigenous Northview member (Manger et al., 1988).

The Boone Formation, as reported by Ogden (1979), is 60 to 70 percent chert, and the remainder of the formation is

limestone. The formation is informally subdivided into Upper and Lower Boone on the basis of chert origins (Manger et al., 1988). The chert in both upper and lower divisions occurs parallel with bedding and could conceivably perch water on a local scale.

Karst features are moderately developed within the aquifer, and dissolution of the carbonates is typically controlled by chert intervals, fractures, and bedding orientation. Thin soil horizons can allow rapid infiltration of meteoric water and dissolved contaminants. Ogden (1979) defined two major recharge areas for the aquifer in Benton County. Based on 413 ground water level measurements in the county, ground water highs were determined to indicate recharge areas near the towns of Decatur and Lowell. Additionally, Ogden conducted 39 aquifer tests and reported ranges in the coefficient of transmissibility and specific capacity for the aquifer to be 24.8 to 24,640 gpd/ft and 0.03 to 30 gpm/ft, respectively. The wide variations are attributed to secondary permeability development. Thickness of the aquifer ranges from 0 feet (were absent due to erosion) up to 300 feet.

#### METHODS OF INVESTIGATION

##### **Selection of Sample Locations**

Random sampling was conducted using a grid system. Because the study area is generally rectangular in shape, and



because a well developed network of roads leaves very few remote areas, it was convenient to establish a rectangular sampling grid of 0° 5' latitude and 0° 5' longitude. Each intersection of the grid lines was targeted for sample collection. However, during the initial sampling round it was determined that a tighter grid would be necessary to increase the density of the sample distribution. Additional sample locations were established as nearly as possible to grid lines intersecting at 0° 2.5' latitude and 0° 5' longitude. Of the sixty-eight sample locations chosen in this fashion (Figure 5), forty-eight wells are within the Springfield Plateau aquifer and twenty are completed in the Ozark aquifer.

Residential wells in Benton County were the focus of sample collection, however, four spring samples have been included. The springs are a drinking water source for the residents living at those locations. Five well samples were collected outside Benton County. These locations do not exceed the county borders by more than one-half mile in two cases, and are less than one-quarter mile in the remaining three. Municipal water distribution networks near the target locations or uncooperative local residents forced the inclusion of these outlying samples. Although these samples are outside of the study area, their locations are very close to intersecting lines of the sampling grid. Finally, several grid corners within the county have not been represented by

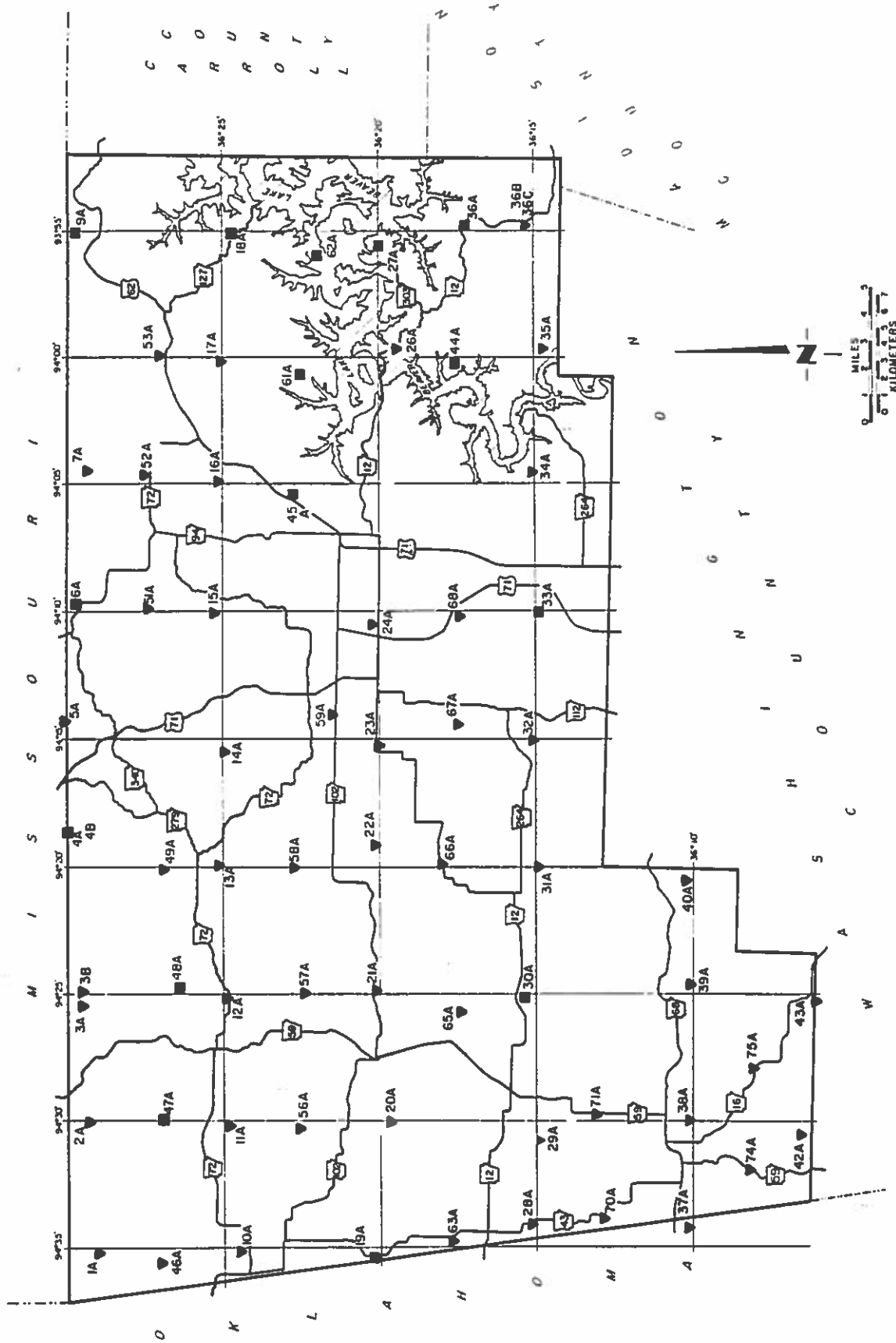


Figure 5: Location map of Springfield Plateau (▼) and Ozark (■) aquifer sample sites.

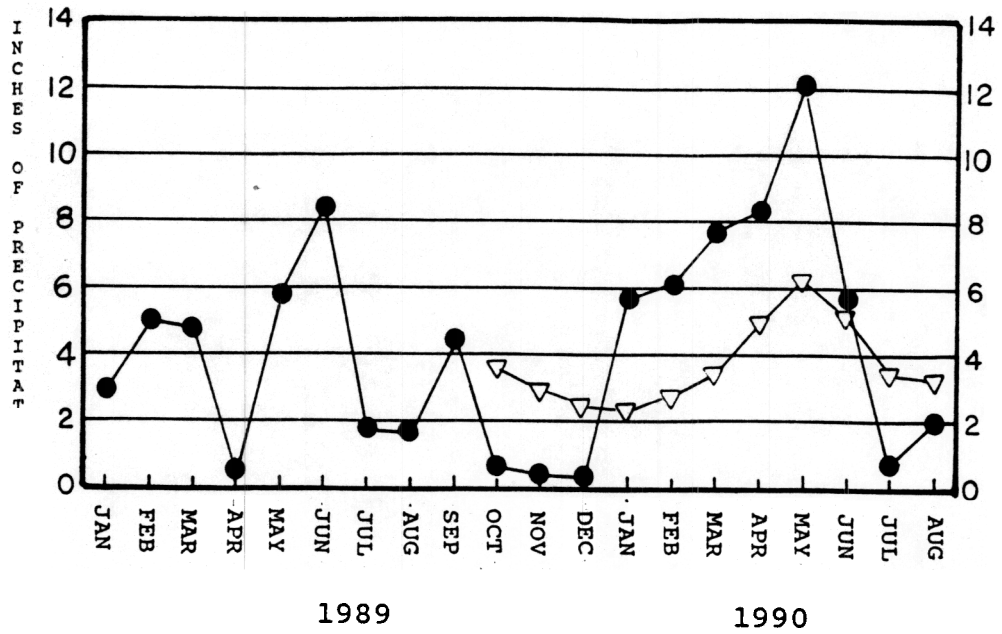
sample collection because there were no suitable sampling sites near the targeted locations. These areas are served by rural water distribution, and residents no longer have operative water wells.

Two rounds of samples were collected during successive wet and dry seasons. Wet season samples were obtained between May 19 and June 6, 1990. Dry season collection took place from July 19 to August 3, 1990. Figure 6 illustrates monthly rainfall totals for the period of January, 1989 through August, 1990. All of the sites sampled in the wet season were re-sampled in the dry season.

#### **Field Analyses and Sample Collection**

Surface geology, local land use, and topographic information was observed and recorded for each sample location. Conversations with residents also supplied valuable information. Well depths reported in the study were supplied by the individual owners. All pertinent information was recorded on field questionnaires. Appendix A lists the type of data acquired in the field.

Water temperature, pH, specific conductance, and total alkalinity as calcium carbonate ( $\text{CaCO}_3$ ) were determined in the field at the time of sample collection. Temperature was determined with a mercury bulb thermometer. Hydrogen ion activity (pH) was measured with a Markson Corporation model 88 pH meter and a Cole-Palmer corporation pH probe (model



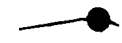

 Monthly totals recorded at Arkansas Agricultural Experiment Station, Fayetteville, Arkansas (1989 and 1990).  
 Average monthly precipitation data summarized from reporting stations at Gravette, Rogers, and Siloam Springs, Arkansas (1941 through 1970).

Figure 6: Total monthly rainfall data for the period of January 1989 through August 1990. Average precipitation values for the period 1941 through 1970 are also presented.

5685-45). Field conductance of the samples was measured with a YSI Corporation model 33 conductivity meter and adjusted to specific conductance at 25° C. Titration for total alkalinity as CaCO<sub>3</sub> was performed on a 10 mL sample using phenolphthalein and bromocresol green / methyl red indicators. Sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) titrant of 0.02N was added until the endpoint was reached.

When possible, wells included in the study were purged by allowing the pump to run for a minimum of five minutes for the shallower wells, and a minimum of ten minutes in deeper. Daily use of the domestic wells often served as partial purging. By purging the wells prior to field analyses and sample collection, water stored in bore holes and in holding tanks was removed and a more representative aquifer sample was obtained

Samples were collected in 1000 mL polypropylene bottles and immediately stored on ice. All samples were transported to the University of Arkansas, Department of Geology Geochemistry laboratory and filtered through 0.45 micron membranes using standard vacuum filtration techniques. Each sample was filtered within 18 hours of the time of collection and each remained on ice until filtering was begun. membranes were washed by soaking in deionized water for a minimum of 12 hours, and by flushing with 250 mL deionized water immediately prior to use. The water used to flush the filter membranes was collected as daily filter blanks. The

1000 mL plastic collection bottles were thoroughly cleaned with deionized water until the conductance value for the rinse water was less than  $\mu\text{S}/\text{cm}$

### Sample Preservation

Three aliquots were derived from each 1000 mL sample. A 500 mL of sample, to be used for chloride (Cl) and sulfate ( $\text{SO}_4$ ) analyses, was refrigerated at  $4^\circ\text{C}$  for not more than 28 days. A 250 mL sample, for nitrate ( $\text{NO}_3$ ) and ammonium ( $\text{NH}_3$ ) analyses, was acidified to a pH of less than 2.0 with 1:1 sulfuric acid and refrigerated at  $4^\circ\text{C}$  in new plastic bottles for not more than 28 days. The remainder of the sample was acidified to a pH of less than 2.0 with 1:1 nitric acid and stored at room temperature for analysis of calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) cation concentration. All analyses were performed within the time limits established by the U. S. Environmental Protection Agency (EPA, 1982).

Only nitrate (nitrate nitrite nitrogen) and Mg:Ca ratio (expressed in milliequivalents per liter) are discussed in this report. Other data are given in Appendix B. Discussion of these other parameters will be included in Smith (1991).

### Laboratory Analyses

Methodology for nitrate analyses followed the Hach Company

adaptations of Standard Methods (Hach, 1984). Anion concentrations, in the forms of nitrate + nitrite, were determined using EPA approved Standard Method 418 C -Cadmium Reduction Method (APHA, 1985). A Bausch & Lomb Spectronic 20 Colorimeter was used for nitrate + nitrite concentration determinations. Hach Company reagents were used in the analyses.

Standard solutions were prepared in accordance with Standard Methods, and calibration curves were developed based on their analyses. Wet and dry season analyses were performed using differing reagent lots and separate calibration curves were prepared for each lot used. Blanks were acidified and refrigerated in the same manner as the samples. All blanks were analyzed and the resulting values were averaged. The average has been subtracted from the analyses results in order to remove any interferences from the reagents, or any contamination introduced by either filtering or other sample manipulations

Nitrate + nitrite analyses that yielded initial transmission values less than twelve percent were diluted and reanalyzed. The degree of dilution was dependent on magnitude of the initial readings, and was chosen such that the value obtained in the reanalysis would fall near central portion of the transmission scale. Dilutions of 50:1, 25:1, 10:1, and 5:1 were necessary for many of the wet and dry season samples.

Wet season analyses of nitrate + nitrite concentrations were performed on acidified samples. However, because of a reformulation of Hach Company reagent NitraVer VI, the dry season samples were neutralized to pH  $7.0 \pm 0.1$  prior to analysis. Calibration curves prepared for this sampling period were developed by analyzing standards that were first acidified and then neutralized in the same manner as sample neutralization. Sodium hydroxide (NaOH) was added to each sample and standard until neutrality was achieved. The volume of base added to each sample was recorded, and the concentrations reported have been adjusted to compensate for the diluting affects of the additions.

#### **Precision and Accuracy**

Duplicate analyses were conducted for thirteen of sixty-eight wet season samples (19%), and for nine of sixty-eight dry season samples (13%). Both diluted and non-diluted samples were chosen for duplicate checks on precision. Table 1 lists the initial and duplicate analyses results for the two seasons



SAMPLE NUMBER	SEASON CONDITIONS	INITIAL ANALYSIS	DUPLICATE ANALYSIS	REPORTED MEAN
5A	WET	0.091	0.098	0.09
11A	WET	0.202	0.238	0.22
15A	WET	0.149	0.156	0.15
16A	WET	1.709	1.736	1.72
29A	WET	1.680	1.700	1.69
30A	WET	0.091	0.098	0.10
31A	WET	0.765	0.699	0.73
33A	WET	0.075	0.075	0.08
36C	WET	0.280	0.405	0.34
45A	WET	0.481	0.449	0.47
59A	WET	1.680	1.680	1.68
65A	WET	1.578	1.616	1.60
75A	WET	1.279	1.269	1.27
6A	DRY	0.097	0.124	0.11
7A	DRY	0.044	0.035	0.04
21A	DRY	0.126	0.161	0.14
28A	DRY	0.272	0.242	0.26
32A	DRY	1.973	1.621	1.80
36B	DRY	6.418	6.243	6.33
37A	DRY	0.591	0.674	0.63
45A	DRY	0.144	0.055	0.10
48A	DRY	0.758	0.821	0.79

$\sigma_p$  (wet season) = 0.04       $\sigma_p$  (dry season) = 0.10  
degrees of freedom = 13      degrees of freedom = 9

$\sigma_p$  (both seasons) = 0.07  
degrees of freedom = 22

Table 1: Summary of duplicate analyses for wet and dry season samples. Values shown represent mg/L nitrate + nitrite.

The equation given by Skoog and West (1974) for pooling duplicate/triplicate analyses has been used in order to establish a single overall measure of precision. Precision is defined as  $\sigma_p$  where:

$$\sigma_p = [(\sum |\text{Deviation from mean}|^2) \div (\text{Degrees of freedom})]^{0.5}$$

For the wet season analyses,  $\sigma_p = 0.04$  and for the dry season,  $\sigma_p = 0.10$ . The decrease in precision between

successive wet and dry season analyses is suspected to be the result of increased sample manipulation during neutralization of the dry season samples.

Skoog and West (1974) state that in order for this method to yield a good approximation of the standard deviation, the degrees of freedom (DF) should be greater than twenty. Degrees of freedom is the capability of variation in a chemical system. This is the number of intensive, independent variables necessary to completely define the system. In this case, the degrees of freedom would equal the number of analyses minus the number of samples. For the wet season, the number of degrees of freedom is expressed as 26 analyses minus 13 samples, or  $DF = 13$ . During the dry season, 18 analyses were performed on 9 samples yielding a DF of 9. Because a single overall measure of precision is desired for the study as a whole, and because individual determinations of the standard deviation for the two sampling seasons are generated with DF values of less than twenty, all duplicate data for both seasons have been combined for precision determination. The combined results yield a  $\sigma_p$  value of 0.07 and degrees of freedom totaling 22.

Nine samples and one blank from the dry sampling season which represented both diluted and non-diluted samples, were chosen to be analyzed as spiked samples. One mL of 10 ppm  $NO_3-N$  spike was added to each of the samples. The spiked samples were neutralized using NaOH and then analyzed. The

reported values for these analyses have been adjusted for the volume changes associated with neutralization. Table 2 shows the results of spiked sample analyses

SAMPLE NUMBER	EXPECTED [NO <sub>3</sub> ] AFTER SPIKE	ACTUAL [NO <sub>3</sub> ] AFTER SPIKE	PERCENT RECOVERED
1A	1.367	1.321	96.6
2A	0.484	0.457	94.4
15A	0.549	0.425	77.4
21A	0.322	0.344	103.7
24A	0.309	0.342	110.7
31A	0.358	0.358	100.0
39A	0.269	0.181	67.3
70A	1.092	1.015	92.9
75A	0.238	0.202	84.9
BLANK	0.200	0.201	100.5

Table 2: Summary of spiked sample analyses. Values shown indicate mg/L nitrate + nitrite.

The Environmental Monitoring and Support Laboratory of the United States Environmental Protection Agency in Cincinnati, Ohio supplied blind quality control samples. The results of analyses on these samples are given in Table 3. Also included are the true values of parameter concentrations, and the range in the 95% confidence interval for the various parameters.

PARAMETER	TRUE VALUE	95% CONFIDENCE INTERVAL	EXPERIMENTAL VALUE
Calcium .....	20.0	17.5-22.2	19.5
Magnesium .....	5.0	4.18-5.62	5.25
Sodium .....	20.0	17.8-22.3	20.0
Potassium .....	5.0	4.17-5.71	4.20
Total Alk. as CaCO <sub>3</sub> .....	27.3	24.1-30.5	30.6
Nitrate-N .....	1.57	1.43-1.71	1.45
Sulfate .....	20.0	16.3-23.1	20.6
Chloride .....	52.1	48.2-55.4	49.9

Table 3: Summary of results from analyses on EPA blind quality control samples. All values given in mg/L.

Trip blanks and field duplicates were collected and analyzed as part of the QA/QC regimen. All field duplicates and trip blanks were collected, filtered, acidified, neutralized, and analyzed in the same manner described for the dry season samples. Trip blanks were carried to the field at the time of field duplicate collection. Previously used collection bottles were utilized to determine any collection bottle contamination. The results of these analyses are listed in Table 4.

FIELD DUPLICATE	INITIAL VALUE	DUPLICATE VALUE	PERCENT ERROR	TRIP BLANKS
1	0.02	0.02	00.00	<0.01
2	2.39	2.53	02.85	<0.01
3	2.84	2.74	01.79	<0.01
SET 4	6.55	6.83	02.09	<0.01
SET 5	2.21	1.94	06.51	<0.01

Table 4: Results of field duplicate and trip blank analyses. Values shown are mg/L NO<sub>3</sub>-N.

### DISCUSSION

Sample locations have been categorized based on completion in the Springfield Plateau aquifer versus the deeper Ozark aquifer. Well depths, topographic elevation at well heads, surface geology, and local stratigraphic information were used to predict the aquifer in which the individual wells were completed. Mg:Ca ratios (in milliequivalents per liter) allowed further refinement of determinations of the producing aquifer. The shallower Springfield Plateau aquifer is predominantly limestone, and has low Mg:Ca ratios. Magnesium to calcium ratios for this aquifer range from 0.02 to 0.25. The Ozark aquifer (typically dolomitic rocks) has ratios from 0.31 to 1.06.

Fifty-two samples were collected from the Springfield Plateau aquifer, and sixteen samples were taken from the Ozark aquifer during each of the sampling seasons.

The use of magnesium to calcium ratios as an aquifer discriminator does not provide as clear a line of demarcation as desired. Eight wells, which have been included in the shallow and unconfined Springfield Plateau aquifer, were deeper than would be expected for this near surface producer. Upon examination of structure contour and isopachous maps of the confining Chattanooga Shale in the area (Smith, 1991), these eight wells (15a, 20a, 26a, 35a, 36b, 46a, 49a, and 65a) were verified to be wells penetrating the lithologies of the Ozark aquifer. The results of analyses of the other chemical parameters included in this study (and field notes on well construction) were reviewed in an attempt to resolve these conflicting indicators. Based on the observations made, it can be concluded that the primary function of bore volume below the confining layer in these wells is one of storage. Volumes of water flowing to the wells from the deeper rocks varies in each case, but the greatest input to these wells is from the shallow aquifer and, therefore, they have been included in the Springfield Plateau data set. Increased mixing is indicated as ratio values diverge from the lower extremes seen for known Springfield Plateau aquifer wells (typically 0.02 to 0.17).

The wet and dry season Mg:Ca ratios for well number 75a

(0.35 and 0.30) indicate water from the Ozark aquifer. This well, however, is 110 feet deep and terminates approximately 130 feet above the Chattanooga Shale. The very low alkalinity and pH values seen in both seasons (as well as other chemical analyses results) seem to indicate that most of the water produced from this well is derived from the regolith in the vicinity of the well. Both magnesium and calcium concentrations are considerably lower than those seen in known Ozark aquifer wells. This well has been included in the Springfield Plateau data set despite the slightly higher ratios.

The Springfield Plateau aquifer was the most frequently sampled (76%) ground water source in the study area. Because the well sites were randomly chosen, it can be concluded that the Boone-St. Joe Formations of the Springfield Plateau aquifer are the more heavily relied upon ground water sources in the county by rural residents. Random sampling generated a grouping of Ozark aquifer wells in the eastern, and across the northern portions of the county. These observations are consistent with the thicknesses of these aquifers in Benton County.

Figures 7 and 8 illustrate nitrate concentrations in the two aquifers. All anion, cation, and field analyses results have been tabulated in Appendix B. The deeper Ozark aquifer has significantly lower nitrate concentrations than the Springfield Plateau aquifer during the wet season (2.63

WET vs. DRY NITRATE VALUES  
for Springfield Plateau Aquifer

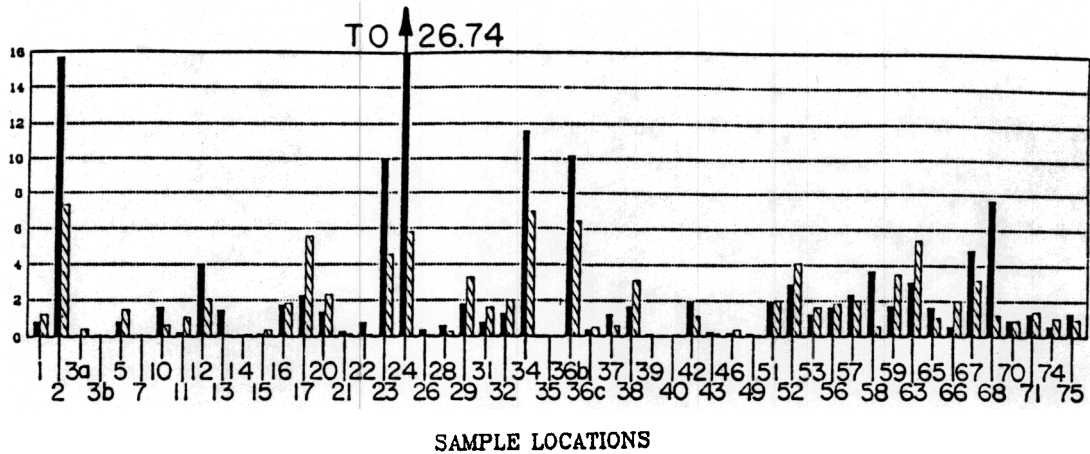


Figure 7: Bar chart of nitrate + nitrite concentrations for wet and dry seasons in the Springfield Plateau aquifer. Solid bars indicate wet season concentrations. Hatched bars are dry season concentrations. Values shown are mg/L.

WET vs. DRY NITRATE VALUES  
for Ozark Aquifer

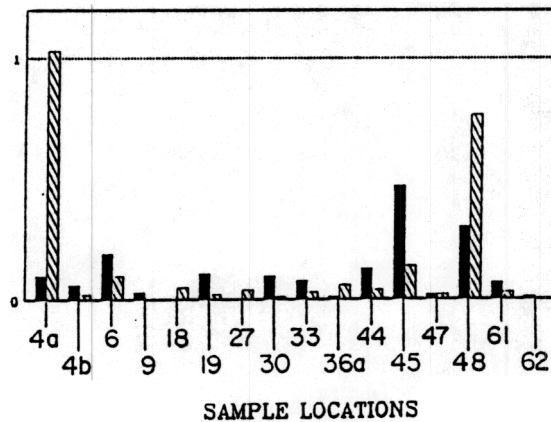


Figure 8: Bar chart of nitrate + nitrite concentrations for wet and dry seasons in the Ozark aquifer. Solid bars indicate wet season concentrations. Hatched bars are dry season concentrations. Values shown are mg/L.



versus 0.11 mg/L) and during the dry season (1.80 versus 0.15 mg/L). The shallow aquifer data also indicate higher concentrations of nitrate (2.63 mg/L) during the wet season than during the dry season (1.80 mg/L). The higher wet season values are probably a result of more nitrogen availability (e.g. land application of poultry litter occurs during the spring) and greater recharge during this season. The combination of these factors could introduce surface contaminants into the aquifer.

Nitrate (nitrate + nitrite as nitrogen) concentrations for the two sampling seasons showed a wide range of variance. Many of the samples had concentrations below detection limits, and five samples during the wet season contained nitrate equal to, or in excess of, the EPA maximum contaminant level (10 mg/L as N) for drinking water (EPA, 1985). The highest concentration determined (26.7 mg/L) was during the wet season period. The highest dry season concentration was 7.3 mg/L. Extreme highs in nitrate concentrations for several of the shallow aquifer wells in this study are possibly anomalous because of point sources such as poorly functioning and poorly located septic systems. These high values would seem to yield unrealistically high determinations of mean ground water nitrate content. However, all sample locations were chosen without regard to site characteristics. Therefore, septic system contamination of ground water could be a significant contributor of nitrate

to the system over a county-wide scale, and the high values should be included in this consideration of general ground water quality. County residents participating in the study were informed of the results of nitrate and other analyses (Appendix C).

Table 5 compares mean nitrate concentrations and mean Mg:Ca ratios (in both wet and dry seasons) for wells from the two aquifers in Benton County with results of a similar study conducted over the same time frame in Madison County Arkansas (Austin and Steele, 1990). Data from studies by Leidy (1989) and McCalister (1990) are also included.

Similarities in hydrogeology, methods of investigation employed, and time frame of sample collection between this study in Benton County and the concurrently conducted study in Madison County, allow direct comparison of the results. The nitrate concentrations for both aquifers in both counties are similar (Table 5). The results from Leidy (1989) and McCalister (1990) are also generally similar to those for the current studies. The most significant differences are the higher dry season nitrate values for these two studies compared to those for Benton and Madison Counties. Because these studies were not conducted during the same year variations in the hydrologic conditions and the availability of nitrate during the different time periods may explain these differences in nitrate concentrations

AQUIFER	COUNTY/ INVESTIGATOR	[NO3]		Mg:Ca	
		mg/L		me/L	
		Wet	Dry	Wet	Dry
Springfield Plateau aquifer	BENTON/ SMITH, 1990	(52) 2.63 [4.64]	(52) 1.80 [1.95]	0.07	0.06
	MADISON/ AUSTIN, 1990	(28) 2.89 [4.46]	(31) 1.79 [2.09]	0.09	0.10
	BOONE/ LEIDY, 1989	(14) 2.10 [2.78]	(14) 2.78 3.53]	0.06	0.08
	NE WASHINGTON/ MCCALISTER, 1990	(26) 2.90 3.06]	(20) 2.44 [2.04]	0.04	0.04
Ozark aquifer	BENTON/ SMITH, 1990	(16) 0.11 [0.12]	(16) 0.15 [0.29]	0.64	0.62
	MADISON/ AUSTIN, 1990	(15) 0.13 [0.28]	(17) 0.16 [0.18]	0.53	0.56
	BOONE/ LEIDY, 1989	(16) 0.27 [0.49]	(16) 0.44 [0.81]	0.72	0.79
	NE WASHINGTON/ MCCALISTER, 1990	(18) 1.59 [4.33]	(18) 1.51 [5.10]	0.28	0.24

Table 5: Comparison of mean nitrate concentrations and mean Mg:Ca ratios as reported for wet and dry seasons in various studies in northwest Arkansas. Nitrate values are in mg/L. Values in parentheses are number of samples. Values in brackets are standard deviation.

The degree of input by the various potential sources of ground water nitrate are not fully understood. Further complexities within the flow of the system have yet to be defined on a large scale basis. Statistical, geochemical, hydrogeologic follow up work on this preliminary report could further enhance our understanding of both source potential and ground water flow in Benton County. These aspects of "big picture" will be encompassed in a Master of Science thesis (Smith, 1991)

#### CONCLUSIONS

This investigation has confirmed previous investigators' findings: land use in this carbonate terrain is a potential source of contamination. The shallower Springfield Plateau aquifer is more contaminated than deeper, confined Ozark aquifer. Further growth and development of the region will increase potential sources of nitrate to the system. Improper land management could continue to degrade the general ground water quality. The Springfield Plateau and Ozark Aquifers are not uniquely isolated from one another. Therefore, if increases in mean nitrate concentration occur regionally in the shallow producer, mean values in the more productive Ozark aquifer should too be expected to increase over time via recharge from the shallower zone.

## REFERENCES CITED

- APHA, 1985. Standard methods for the examination of water and wastewater (16th addition). American Public Health Association, Washington, D. C. 1268 p.
- Arrington, J. L., 1962. The geology of Rogers quadrangle, Benton County, Arkansas. Unpublished Master of Science Thesis, University Of Arkansas, Fayetteville, Arkansas. 61 p.
- Austin, A. Y., and Steele, K. F., 1990. Nitrate concentrations of ground water, northern Madison County, Arkansas. Completion report for Arkansas Department of Pollution Control and Ecology, Arkansas Water Resources Research Center Miscellaneous Publication # 74. 51 p.
- Caplan, W. M., 1954. Subsurface geology and related oil and gas possibilities of northeastern Arkansas. Arkansas Division of Geology Bulletin No. 20. 124 p.
- Clardy, B. F., 1964. Subsidence structures of the Price Mountain syncline. Unpublished Master of Science Thesis, University of Arkansas, Fayetteville, Arkansas. pp 9-41.
- Croneis, C., 1930. Geology of the Arkansas Paleozoic area with especial reference to oil and gas possibilities. Arkansas Geological Survey Bulletin No 3. 457 p.
- EPA, 1983. Methods for chemical analysis of water and wastewater. U. S. Environmental Protection Agency, EPA-600/4-79-020. 430 p.
- EPA, 1985. National primary drinking water regulations; synthetic organic chemicals, inorganic chemicals, and microorganisms; proposed rule. Federal Register, v. 50 No. 219, pp 46934- 47022.
- Hach, 1984. Procedures for water and wastewater analysis. Hach Company, Loveland, Colorado. 125 p.
- Imes, J. L., and Emmett, J. F., 1990. Geohydrology of the Ozark Plateaus aquifer system in parts of Missouri, Arkansas, Oklahoma, and Kansas. U. S. Geological Survey Professional Paper 1414-F. 298 p.
- Knight, R. D., 1954. The Gunter member of the Gasconade formation (lower Ordovician) in southern Missouri. Missouri Geological Survey and Water Resources, Report of Investigations No. 17. pp 57-79.

- Leidy, V. A., 1989. Groundwater quality and potential for contamination in karst terrain of northwest Arkansas. Unpublished Master of Science Thesis, University of Arkansas, Fayetteville, Arkansas. 152 p.
- Manger, W. L., Shelby, P. R., and Farris, S. G., 1988. Devonian - lower Mississippian lithostratigraphy, northwestern Arkansas. The Compass, Earth Science Journal of Sigma Gamma Epsilon. v 65, no. 4. pp 223-231
- Mapes, R. H., 1968. Geology of the Sulphur Springs area, Benton County, Arkansas. Unpublished Master of Science Thesis. University of Arkansas, Fayetteville, Arkansas. 66 p.
- McCalister, W. K., 1990. The effects of land applied animal wastes on ground-water chemistry in northwest Arkansas Unpublished Master of Science Thesis, University of Arkansas, Fayetteville, Arkansas. 123 p.
- Melton, R. W., 1976. Regional hydrogeology of the Roubidoux and Gasconade formations, Arkansas and Missouri. Unpublished Master of Science Thesis, University of Arkansas, Fayetteville, Arkansas. 160 p.
- NRC, 1977. Drinking water and public health, v. 1. National Research Council, Safe Drinking Water Committee, National Academy Press.
- Ogden, A. E., 1980. Hydrogeologic and geochemical investigation of the Boone-St. limestone aquifer in Benton County, Arkansas. Arkansas Water Resources Research Center Publication No. 68. 133 p.
- Purdue, A. H. and Miser H. D., 1916. Description of Eureka Springs and Harrison quadrangles (Arkansas - Missouri). U. S. Geological Survey, Geologic Atlas, Folio 202, 21p.
- Rajagopal, R. and Tobin, G., 1989. Expert opinion and ground-water quality protection: the case of nitrate in drinking water. Groundwater, v. 27, no. 6. pp 835-847.
- Santi, L. L., 1990. An analysis of preliminary 1990 census counts for the State of Arkansas. University of Arkansas at Little Rock, Division of Demographic Research, DDR Working Paper 90-05. 45 p.
- Santi, L. L. and McGehee, M. A., 1990. Population Estimates for the State of Arkansas, 1980 to 1989. University of Arkansas at Little Rock, Division of Demographic Research, DDR Working Paper 90-01. 21 p.

- Scragg, R. K., Dorsch, M. M., McMichael, A. J., and Baghurst P. A., 1982. Birth defects and household water supply. *Medical Journal of Australia*, v. 2. pp 577-579.
- Shelby, P. R., 1986. Depositional history of the St. Joe Boone formations in northern Arkansas. Unpublished Master of Science Thesis, University of Arkansas, Fayetteville, Arkansas. 92 p.
- Skoog, D. A., and West D. M., 1969. Analytical chemistry, an introduction, second edition. pp 45-46.
- Smith, C. R., 1991. A hydrogeologic and geochemical investigation of groundwater resources in Benton County, Arkansas. Proposed Master of Science Thesis, University of Arkansas, Fayetteville, Arkansas.
- Staley, G. G., 1962. The geology of the War Eagle quadrangle, Benton County, Arkansas. Unpublished Master of Science Thesis, University of Arkansas, Fayetteville, Arkansas. 53 p.
- Steele, K. F., McCalister, W. K., and Adamski J. C., 1990. Nitrate and bacteria contamination of limestone aquifers in poultry/cattle producing areas of northwestern Arkansas, U.S.A. Environmental Contamination, 4th International Conference, October, 1990, Barcelona, Spain. pp 528-530.
- Steele, K. F., and McCalister, W. K., 1990. The effects of land applied agricultural waste on ground-water quality in Washington County, Arkansas. Completion Report to the Arkansas Department of Pollution Control and Ecology. Arkansas Water Resources Research Center, Misc. Pub. No. 68. 23 p.
- Steele, K. F., and McCalister, W. K., 1991. Potential nitrate pollution of ground water in limestone terrain by poultry litter, Ozark Region, U.S.A. North Atlantic Treaty Organization Publication. (in press).
- Terry, S. H., 1980. Devonian - lowermost Mississippian lithostratigraphy and conodont biostratigraphy of the Battsleville district, northeastern Arkansas. Unpublished Master of Science Thesis, University of Arkansas, Fayetteville Arkansas. 100 p.
- USDA, 1980. 1979 agricultural statistics for Arkansas. U. S Department of Agriculture, Division of Economics, Statistics, and Cooperatives Service, Little Rock, Arkansas. 44 p.

USDA, 1990. Arkansas agricultural statistics, 1989. U. S. Department of Agriculture, National Agricultural Statistics Service, Little Rock, Arkansas. 56 p.

Widmann, R. K., 1982. Episodic and seasonal effects of rainfall on springwater chemistry in a limestone terrain. Unpublished Master of Science Thesis, University of Arkansas, Fayetteville, Arkansas. 131 p.





## APPENDIX B

### FORMAT:

Sample number - 1a, 2a, 3a, 3b ... etc. Sample locations as shown on figure 5.

Date sampled - Wet season collection period was 5-19-90 to 6-5-90. Dry season collection was from 7-19-90 to 8-3-90.

Longitude and latitude - Locations are given in degrees longitude and latitude to four decimal places.

Temperature - Sample temperature is given in degrees Celcius.

pH - Negative logarithm of the hydrogen ion activity.

Specific conductance -  $\mu\text{S}/\text{cm}$  at 25° C

Total alkalinity - mg/L  $\text{CaCO}_3$

Anion and cation concentrations:

$\text{NO}_3$ ,  $\text{NH}_3$ ,  $\text{SO}_4$ , CL, Na, K, Ca, Mg in mg/L

**WET SEASON DATA FOR SPRINGFIELD PLATEAU AQUIFER**

SAMP.#	DATE SAMPLE	LONGITUDE	LATITUDE	TEMP	pH	SP COND uS/cm	ALKALINITY mg/L as CaCO3	[NO3] mg/L	[NH3] mg/L	[SO4] mg/L	[Cl] mg/L	[Na] mg/L	[K] mg/L	[Ca] mg/L	[Mg] mg/L	Mg:Ca epm
1a	5-23-90	94.5862	36.4830	18.5	6.3	204	89	0.77	<0.01	<3.00	14.13	4.80	1.80	32.50	1.50	0.08
2a	5-23-90	94.5011	36.4878	17.0	6.8	635	211	15.62	0.02	<3.00	40.00	20.00	2.55	110.00	2.40	0.04
3a	5-21-90	94.4245	36.4909	13.5	6.6	251	145	0.03	0.02	7.50	2.63	1.43	0.95	51.00	1.20	0.04
3b	5-21-90	94.4238	36.4909	16.5	6.9	243	145	0.03	0.02	8.19	2.76	2.18	1.10	47.00	1.80	0.06
5a	5-21-90	94.2394	36.5017	13.5	6.8	223	117	0.81	<0.01	8.38	4.00	4.40	2.85	38.00	2.10	0.09
7a	5-25-90	94.0745	36.4878	17.0	6.7	434	289	0.04	<0.01	<3.00	2.69	1.90	0.57	90.00	1.80	0.03
10a	5-23-90	94.5851	36.4090	16.5	7.1	369	183	1.57	<0.01	16.88	10.50	10.50	2.90	61.00	2.10	0.06
11a	5-21-90	94.5032	36.4132	13.5	6.0	223	117	0.22	<0.01	8.38	6.13	4.40	1.03	39.00	1.05	0.04
12a	5-27-90	94.4199	36.4144	17.0	6.8	333	145	4.01	<0.01	<3.00	1.25	6.30	0.95	56.00	1.20	0.04
13a	5-27-90	94.3323	36.4189	16.5	6.9	373	183	1.42	0.02	<3.00	12.63	5.30	1.30	70.00	0.90	0.02
14a	5-27-90	94.2582	36.4155	16.0	6.9	352	206	0.04	<0.01	<3.00	2.75	1.90	3.00	72.00	0.90	0.02
15a	5-27-90	94.1674	36.4211	17.0	6.9	376	206	0.15	<0.01	<3.00	7.50	1.45	1.10	77.00	0.90	0.02
16a	5-27-90	94.0809	36.4186	15.0	6.4	187	95	1.72	<0.01	<3.00	3.63	1.90	1.43	34.00	0.90	0.04
17a	5-25-90	94.0021	36.4172	17.0	6.6	456	250	2.26	0.10	<3.00	9.50	3.50	2.50	89.00	1.65	0.03
20a	5-23-90	94.5003	36.3288	17.5	6.9	417	217	1.30	0.12	<3.00	11.50	5.30	0.70	80.00	1.05	0.02
21a	5-19-90	94.4142	36.3356	16.0	6.9	200	106	0.28	0.12	<3.00	3.88	2.15	1.30	36.50	0.90	0.04
22a	5-19-90	94.3181	36.3356	16.5	7.8	247	144	0.74	0.14	10.63	6.13	7.00	0.83	42.00	2.70	0.11
23a	5-27-90	94.2539	36.3344	16.0	5.9	271	95	9.99	<0.01	<3.00	11.51	7.00	2.30	36.50	2.55	0.12
24a	5-28-90	94.1755	36.3373	15.5	6.7	406	133	26.74	<0.01	6.50	18.50	12.50	1.65	65.00	2.40	0.06
26a	5-28-90	93.9947	36.3234	17.5	6.7	581	389	0.33	0.01	<3.00	8.38	36.00	1.85	83.00	7.05	0.14
28a	5-23-90	94.5677	36.2562	17.5	6.5	422	234	0.56	<0.01	8.88	3.50	6.80	0.57	82.00	2.10	0.04
29a	5-23-90	94.5131	36.2491	17.5	6.6	297	139	1.74	<0.01	5.75	10.88	5.95	0.78	51.00	1.80	0.06
31a	5-20-90	94.3337	36.2494	15.0	6.2	234	122	0.73	0.11	<3.00	5.63	3.20	0.57	42.00	0.75	0.03
32a	5-20-90	94.2500	36.2528	13.5	6.8	297	156	1.23	0.11	<3.00	5.50	2.15	1.35	55.00	1.35	0.04
34a	5-28-90	94.0748	36.2528	17.5	7.0	413	195	11.59	<0.01	<3.00	9.50	11.30	0.70	76.00	1.05	0.02
35a	5-28-90	93.9929	36.2443	16.5	7.2	380	217	<0.01	<0.01	14.88	2.75	6.30	2.13	64.00	8.25	0.21
36b	5-28-90	93.9117	36.2554	16.5	6.7	340	133	10.19	<0.01	16.50	6.63	9.55	9.75	43.00	6.00	0.23
37a	5-28-90	93.9114	36.2551	13.5	6.7	219	117	0.34	0.02	<3.00	3.25	1.20	1.03	40.00	1.20	0.05
36c	5-23-90	94.5869	36.1706	17.0	6.8	381	211	1.18	0.02	8.13	6.63	4.70	0.63	74.00	1.20	0.03
37a	5-22-90	94.5000	36.1703	----	6.6	341	172	1.64	<0.01	<3.00	7.21	3.80	0.83	62.00	1.05	0.03
38a	5-22-90	94.4106	36.1695	14.0	6.5	164	72	0.09	0.02	5.50	2.38	0.98	0.83	23.50	1.05	0.07
39a	5-22-90	94.3422	36.1717	16.5	6.7	697	428	<0.01	0.01	<3.00	10.13	94.00	2.45	68.00	2.55	0.06
40a	5-23-90	94.5089	36.1099	17.5	6.6	326	156	1.90	0.01	<3.00	14.50	4.40	0.57	58.00	0.90	0.03
42a	5-23-90	94.4220	36.1012	17.0	7.0	357	172	0.23	0.01	19.13	6.25	2.15	0.50	68.00	0.75	0.02
43a	6-01-90	94.5918	36.4498	17.0	6.9	377	206	0.17	<0.01	<3.00	5.82	11.50	0.50	62.00	3.30	0.09
49a	6-05-90	94.3344	36.4478	17.5	7.1	350	200	0.12	<0.01	<3.00	4.00	11.20	0.83	61.00	2.25	0.06
51a	6-05-90	94.1635	36.4563	18.5	7.3	358	195	1.87	<0.01	<3.00	----	60.00	0.41	2.00	0.15	0.12
52a	6-05-90	94.0773	36.4575	17.0	6.5	299	122	2.90	<0.01	<3.00	13.00	10.50	1.15	47.00	1.50	0.05
53a	6-05-90	93.9989	36.4498	16.0	6.9	509	306	1.20	<0.01	<3.00	12.38	5.60	1.08	81.00	4.65	0.09
56a	6-01-90	94.5043	36.3767	15.0	7.0	262	111	1.57	0.01	6.75	6.00	3.80	2.10	43.00	1.35	0.05
57a	6-01-90	94.4160	36.3741	14.0	6.7	257	122	2.33	<0.01	<3.00	4.63	1.65	1.08	48.00	1.20	0.04
58a	6-01-90	94.3333	36.3781	17.5	6.7	289	117	1.64	<0.01	<3.00	9.75	7.70	0.88	48.00	1.65	0.06
59a	6-05-90	94.2358	36.3580	15.0	6.1	347	145	1.68	0.01	9.88	14.38	14.50	0.63	55.00	2.40	0.07
63a	6-01-90	94.5784	36.2965	15.5	6.4	424	150	3.05	0.12	20.88	24.88	15.50	9.55	61.00	3.90	0.11
65a	6-01-90	94.4284	36.2911	15.5	5.9	204	100	1.60	<0.01	<3.00	3.75	2.15	0.42	37.00	1.20	0.05
66a	5-31-90	94.3309	36.3013	15.5	6.4	145	56	0.53	0.02	<3.00	5.50	2.15	2.65	19.50	1.80	0.15
67a	5-31-90	94.2401	36.2928	17.0	6.7	233	78	4.86	<0.01	<3.00	11.50	8.30	0.50	27.50	0.75	0.05
67a	5-31-90	94.1695	36.2916	15.5	6.9	515	222	7.68	0.01	<3.00	6.88	2.97	0.50	89.00	1.35	0.03
68a	5-31-90	94.5454	36.2157	17.0	6.8	516	228	0.89	<0.01	10.63	14.88	3.80	0.42	86.00	2.85	0.05
70a	5-31-90	94.4965	36.2199	15.5	5.5	159	33	1.21	0.02	<3.00	2.63	4.40	0.70	10.00	1.05	0.17
71a	5-31-90	94.5319	36.1377	16.5	6.2	329	122	0.59	<0.01	<3.00	17.88	7.30	0.70	48.00	0.90	0.03
74a	5-31-90	94.4649	36.1363	16.5	5.2	183	17	1.27	0.01	<3.00	24.50	10.50	0.63	7.00	1.50	0.35

**WET SEASON DATA FOR OZARK AQUIFER**

SAMP.#	DATE SAMPLE	LONGITUDE	LATITUDE	TEMP	pH	SP COND uS/cm	ALKALINITY mg/L as CaCO3	[NO3] mg/L	[NH3] mg/L	[SO4] mg/L	[Cl] mg/L	[Na] mg/L	[K] mg/L	[Ca] mg/L	[Mg] mg/L	Mg:Ca epm
4a	5-21-90	94.3103	36.4971	16.0	6.9	563	317	0.10	0.02	12.13	3.50	58.00	4.70	37.50	18.60	0.81
4b	5-21-90	94.3067	36.4960	17.0	6.9	535	322	0.06	<0.01	9.25	6.25	45.00	5.50	42.00	20.70	0.81
6a	5-25-90	94.1624	36.4937	17.5	6.9	274	145	0.19	<0.01	19.13	4.00	32.00	3.20	17.00	7.20	0.70
9a	5-25-90	93.9174	36.4946	16.5	6.6	403	234	0.03	<0.01	13.94	4.00	3.50	1.65	67.00	13.20	0.32
18a	5-25-90	93.9177	36.4107	17.5	6.8	456	256	<0.01	<0.01	21.38	2.25	1.90	3.10	68.00	15.75	0.38
19a	5-23-90	94.5883	36.3381	17.5	6.9	403	211	0.11	<0.01	7.25	16.50	41.00	5.10	28.50	10.95	0.63
27a	5-28-90	93.9255	36.3333	19.0	7.8	477	222	<0.01	0.01	11.00	32.50	19.50	3.00	45.50	22.20	0.80
30a	5-19-90	94.4188	36.2568	16.5	7.8	274	161	0.10	0.10	8.50	3.63	27.50	2.85	16.00	8.25	0.85
33a	5-20-90	94.1677	36.2494	16.0	6.5	546	289	0.08	0.11	<3.00	20.00	60.00	1.23	34.50	10.95	0.52
36a	5-28-90	93.9114	36.2874	16.0	8.0	393	178	0.01	<0.01	<3.00	----	38.00	4.10	33.50	11.25	0.55
44a	5-28-90	94.0028	36.2931	17.5	7.6	477	284	0.13	<0.01	<3.00	9.19	84.00	3.50	23.00	7.65	0.55
45a	5-28-90	94.0901	36.3792	16.0	7.1	438	245	0.47	0.01	<3.00	5.75	3.80	1.03	71.00	13.43	0.31
47a	6-01-90	94.4982	36.4490	17.0	6.6	356	206	0.02	0.01	<3.00	3.75	6.30	8.75	41.00	15.45	0.62
48a	6-01-90	94.3979	36.4399	16.0	6.2	457	245	0.30	0.01	19.00	5.13	4.70	0.88	69.00	18.30	0.44
61a	6-05-90	94.0106	36.3753	17.0	7.6	506	284	0.07	0.01	<3.00	7.50	104.00	3.70	7.50	4.80	1.06
62a	6-05-90	93.9323	36.3257	17.0	6.8	525	272	0.01	<0.01	19.25	2.00	1.45	0.57	60.00	29.70	0.82

**DRY SEASON DATA FOR SPRINGFIELD PLATEAU AQUIFER**

SAMP.#	DATE SAMPLE	LONGITUDE	LATITUDE	TEMP	pH	SP COND uS/cm	ALKALINITY mg/L as CaCO3	[NO3] mg/L	[NH3] mg/L	[SO4] mg/L	[Cl] mg/L	[Na] mg/L	[K] mg/L	[Ca] mg/L	[Mg] mg/L	Mg:Ca epm
1a	8-03-90	94.5862	36.4830	20.0	6.8	328	161	1.17	<0.01	3.25	25.38	7.80	0.88	57.00	1.35	0.04
2a	7-27-90	94.5011	36.4878	18.0	7.0	573	256	7.30	<0.01	3.76	40.25	17.80	2.45	104.00	1.80	0.03
3a	7-27-90	94.4245	36.4909	16.5	7.1	303	183	0.38	<0.01	6.00	4.13	2.43	1.15	62.00	1.35	0.04
3b	7-27-90	94.4238	36.4909	17.0	7.2	451	272	0.02	<0.01	<3.00	4.63	13.50	2.65	70.00	10.65	0.25
5a	7-25-90	94.2394	36.5017	16.0	6.6	292	145	1.47	<0.01	7.50	4.25	6.30	2.65	49.00	3.00	0.10
7a	7-23-90	94.0745	36.4878	17.0	6.9	429	245	0.04	<0.01	3.25	2.63	2.15	0.50	87.00	1.80	0.03
10a	7-19-90	94.5851	36.4090	16.5	7.3	327	172	0.63	<0.01	8.75	4.13	3.80	0.57	64.00	1.20	0.03
11a	7-27-90	94.5032	36.4132	----	6.7	174	189	1.04	<0.01	9.00	19.38	8.80	0.83	63.00	1.35	0.04
12a	7-27-90	94.4199	36.4144	16.5	7.1	312	139	2.01	<0.01	<3.00	11.13	6.30	0.83	54.00	1.20	0.04
13a	7-25-90	94.3323	36.4189	18.0	7.1	346	172	0.03	<0.01	<3.00	13.25	7.00	0.42	65.00	0.90	0.03
14a	7-27-90	94.2582	36.4155	16.5	7.2	348	194	0.10	<0.01	<3.00	2.63	1.90	0.65	74.00	0.90	0.02
15a	7-23-90	94.1674	36.4211	17.0	7.0	380	200	0.35	<0.01	<3.00	7.13	1.45	1.10	80.00	0.90	0.02
16a	7-23-90	94.0809	36.4186	17.0	7.1	328	156	1.82	<0.01	<3.00	9.38	4.70	1.50	61.00	1.35	0.04
17a	7-23-90	94.0021	36.4172	16.0	6.8	509	245	5.53	<0.01	<3.00	11.13	3.80	2.45	100.00	1.95	0.03
20a	7-29-90	94.5003	36.3288	17.5	6.6	405	200	2.31	<0.01	3.60	9.88	4.40	0.68	79.00	1.05	0.02
21a	7-29-90	94.4142	36.3356	19.0	6.8	239	128	0.13	<0.01	<3.00	5.25	3.25	2.65	42.00	1.35	0.05
22a	7-29-90	94.3181	36.3356	18.0	7.9	493	267	0.08	<0.01	9.13	12.75	59.00	0.90	30.00	3.00	0.16
23a	7-25-90	94.2539	36.3344	16.0	6.7	341	139	4.52	<0.01	<3.00	10.88	8.25	0.95	58.00	2.25	0.06
24a	7-25-90	94.1755	36.3373	16.0	7.0	471	172	5.78	<0.01	4.88	24.13	14.25	1.45	79.00	2.25	0.05
26a	7-25-90	93.9947	36.3234	17.5	7.5	576	339	0.04	<0.01	3.60	16.00	73.00	2.60	67.00	5.80	0.20
28a	8-03-90	94.5677	36.2562	19.5	7.3	415	228	0.27	<0.01	8.00	3.50	6.30	0.63	47.00	1.50	0.05
29a	7-29-90	94.5131	36.2491	19.0	6.8	276	122	3.24	<0.01	4.00	10.50	6.30	0.42	82.00	2.10	0.04
31a	7-28-90	94.3337	36.2494	16.0	7.1	238	111	1.59	<0.01	4.50	5.25	2.95	0.57	44.00	0.75	0.03
32a	7-28-90	94.2500	36.2528	18.5	7.3	322	161	1.97	<0.01	8.00	5.00	2.70	0.75	63.00	1.20	0.03
34a	8-03-90	94.0748	36.2528	17.5	7.2	433	200	6.93	<0.01	3.60	9.63	10.30	0.50	78.00	0.90	0.02
35a	7-25-90	93.9929	36.2443	17.0	6.7	393	222	<0.01	<0.01	9.94	2.69	6.30	2.60	67.00	8.25	0.20
36b	7-25-90	93.9117	36.2544	16.0	6.9	305	117	6.42	<0.01	8.25	7.50	8.80	5.50	40.50	5.80	0.24
36c	7-25-90	93.9114	36.2551	15.0	7.0	316	178	0.47	<0.01	<3.00	5.25	1.93	0.83	60.00	1.65	0.05
37a	7-26-90	94.5869	36.1706	19.0	----	361	195	0.59	<0.01	6.00	6.50	4.10	0.63	71.00	1.20	0.03
38a	7-20-90	94.5000	36.1703	19.5	7.2	409	183	3.11	<0.01	3.25	8.88	4.10	1.35	71.00	1.20	0.03
39a	7-21-90	94.4106	36.1695	22.5	7.1	200	111	0.01	<0.01	<3.00	3.13	1.65	1.03	36.50	1.20	0.05
40a	7-19-90	94.3422	36.1717	16.0	6.8	747	495	0.04	<0.01	<3.00	15.25	92.00	1.95	56.00	1.30	0.10
42a	7-24-90	94.5089	36.1099	16.5	6.9	315	133	1.11	<0.01	3.25	14.13	4.10	0.57	56.00	0.90	0.03
43a	7-20-90	94.4220	36.1012	20.5	7.2	362	189	0.14	<0.01	14.88	6.75	1.90	0.42	72.00	0.75	0.02
46a	7-19-90	94.5918	36.4498	17.0	7.3	345	195	0.36	<0.01	<3.00	4.88	7.00	0.42	65.00	1.65	0.04
49a	7-25-90	94.3344	36.4478	18.0	7.2	362	211	0.05	<0.01	<3.00	3.75	19.50	0.83	59.00	1.80	0.05
51a	7-23-90	94.1635	36.4563	18.5	7.4	301	139	1.97	<0.01	3.60	7.50	2.45	0.63	55.00	0.90	0.02
52a	7-23-90	94.0773	36.4575	16.5	6.5	293	128	4.09	<0.01	<3.00	10.75	9.00	0.63	47.00	1.05	0.04
53a	7-23-90	93.9989	36.4498	17.0	7.1	445	239	1.59	<0.01	3.60	11.00	5.00	0.88	80.00	4.65	0.10
56a	7-29-90	94.5043	36.3767	17.5	7.3	257	122	1.79	<0.01	<3.00	7.75	4.50	1.95	45.00	1.35	0.05
57a	7-29-90	94.4160	36.3741	15.5	7.0	336	172	1.99	<0.01	4.75	6.38	2.15	0.95	65.00	1.13	0.03
58a	7-25-90	94.3333	36.3781	18.0	7.3	384	217	0.54	<0.01	6.75	4.63	2.98	0.42	78.00	1.05	0.02
59a	7-27-90	94.2358	36.3580	16.0	6.8	356	161	3.50	<0.01	8.25	15.25	15.00	0.57	56.00	2.10	0.06
63a	8-03-90	94.5784	36.2965	16.0	7.1	600	272	5.37	<0.01	12.25	25.25	36.00	6.30	103.00	3.30	0.05
65a	7-29-90	94.4284	36.2911	16.5	5.9	204	106	1.03	<0.01	3.60	3.25	2.15	0.42	36.50	1.05	0.05
66a	7-29-90	94.3309	36.3013	16.0	6.8	255	128	1.97	<0.01	3.25	5.00	2.42	1.43	46.00	1.80	0.06
67a	7-28-90	94.2401	36.2928	17.5	6.2	194	72	3.16	<0.01	3.25	10.63	7.70	0.50	32.50	0.90	0.05
68a	7-28-90	94.1695	36.2916	17.5	7.0	396	217	1.19	<0.01	5.50	4.63	2.70	0.42	82.00	1.20	0.03
70a	8-03-90	94.5454	36.2157	17.0	7.3	445	234	0.89	<0.01	8.75	13.63	4.10	0.57	87.00	3.00	0.06
71a	7-29-90	94.4965	36.2199	16.0	7.2	223	117	1.36	<0.01	3.25	3.13	4.40	0.50	40.00	0.90	0.04
74a	7-24-90	94.5319	36.1377	17.5	6.4	286	122	1.03	<0.01	3.60	19.25	7.75	0.63	48.00	0.90	0.03
75a	7-20-90	94.4649	36.1363	18.5	5.4	88	17	0.94	<0.01	3.25	15.25	7.70	0.57	5.75	1.05	0.30

**DRY SEASON DATA FOR OZARK AQUIFER**

SAMP.#	DATE SAMPLE	LONGITUDE	LATITUDE	TEMP	pH	SP COND uS/cm	ALKALINITY mg/L as CaCO3	[NO3] mg/L	[NH3] mg/L	[SO4] mg/L	[Cl] mg/L	[Na] mg/L	[K] mg/L	[Ca] mg/L	[Mg] mg/L	Mg:Ca epm
4a	7-25-90	94.3103	36.4971	19.0	7.5	557	317	1.03	<0.01	3.25	11.38	59.00	5.40	34.00	18.60	0.90
4b	7-25-90	94.3067	36.4960	17.5	7.2	522	306	0.02	<0.01	3.25	8.38	47.00	5.90	42.00	21.30	0.84
6a	8-03-90	94.1624	36.4937	17.5	7.9	262	122	0.10	<0.01	13.94	3.75	27.50	2.65	17.00	7.50	0.73
9a	7-23-90	93.9174	36.4946	17.5	7.0	456	256	<0.01	0.01	12.32	3.25	3.23	0.83	74.00	14.85	0.33
18a	7-23-90	93.9177	36.4107	----	7.2	454	250	0.05	<0.01	16.12	2.63	2.15	1.45	64.00	17.70	0.46
19a	8-03-90	94.5883	36.3381	16.5	7.8	394	195	0.02	0.01	3.60	14.75	41.00	4.40	26.00	10.80	0.69
27a	7-25-90	93.9255	36.3333	21.5	7.8	477	206	0.04	<0.01	11.38	33.38	21.00	3.00	46.00	22.50	0.81
30a	7-28-90	94.4188	36.2568	19.0	7.8	250	139	0.01	<0.01	7.13	3.25	24.00	2.90	16.00	8.10	0.83
33a	8-03-90	94.1677	36.2494	16.5	7.4	486	272	0.03	0.01	<3.00	19.63	59.00	1.15	34.00	10.65	0.52
36a	7-25-90	93.9114	36.2874	16.5	8.0	400	183	0.06	<0.01	5.50	37.50	42.00	3.90	30.00	10.65	0.59
44a	7-25-90	94.0028	36.2931	17.0	7.8	518	295	0.04	<0.01	<3.00	7.38	64.00	3.40	18.00	6.30	0.58
45a	7-23-90	94.0901	36.3792	16.0	7.4	440	250	0.14	<0.01	3.60	4.32	3.40	0.60	69.00	14.33	0.34
47a	7-27-90	94.4982	36.4490	17.5	6.7	353	200	0.02	<0.01	3.25	4.75	6.80	8.50	41.00	14.55	0.58
48a	7-27-90	94.3979	36.4399	16.5	7.1	295	145	0.76	<0.01	14.99	2.50	1.92	0.68	54.00	4.35	0.13
61a	8-03-90	94.0106	36.3753	18.5	8.5	805	284	0.03	<0.01	3.60	120.70	120.00	3.30	10.00	4.80	0.79
62a	7-23-90	93.9323	36.3257	16.0	6.8	717	389	<0.01	<0.01	49.82	2.88	1.67	1.85	85.00	37.35	0.72

APPENDIX C

December 20, 1990

Dear Participant,

My sincere thanks is extended to you for allowing me access to your springs and wells during the ground-water quality study performed in the spring and summer of this year. The results of the chemical analyses are enclosed. Your samples are highlighted in yellow.

The current U. S. drinking water standards recommend the following maximum contaminant levels: 1) Nitrate - 10 ppm; 2) Chloride - 250 ppm; 3) Magnesium - 150 ppm.

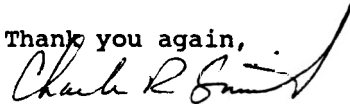
Maximum contaminant levels are established as a means to protect public health. In the case of nitrate, infants and expectant mothers are the most susceptible to ingestion of the compound.

The following is a description of the parameters that were tested for in your water samples:

- pH - This is a measure of the acidic or basic character of the water. Neutral water has a pH of 7.0
- COND - Specific conductance, this is a measure of the current carrying capacity of the water. Values shown are in microseimens per centimeter.
- ALK - Alkalinity as calcium carbonate given in parts per million (ppm). This is a measure of the acid neutralizing capacity of the water.
- NO<sub>3</sub> - Nitrate plus nitrite in ppm.
- NH<sub>3</sub> - Ammonium in ppm.
- SO<sub>4</sub> - Sulfate in ppm.
- Cl - Chloride in ppm.
- Na - Sodium in ppm.
- K - Potassium in ppm.
- Ca - Calcium in ppm.
- Mg - Magnesium in ppm.

I urge you to examine the results from your samples. Please realize that these results are not intended to indicate that your water is either "good" or "bad". Health problems can arise from many different constituents of ground water. Furthermore, the chemical content of ground water is altered with time through the effects of rainfall events and through changes in land use practices in areas of recharge. The analyses performed did not include heavy metals or bacterial content. Therefore an appraisal of the "good" or "bad" character of your water cannot be made based on these results.

Thank you again,

  
Charles R. Smith