NITRATE CONCENTRATIONS OF GROUND WATER

NORTHERN MADISON COUNTY, ARKANSAS

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Final Report for Contract 0001357

Submitted to

Arkansas Department of Pollution Control and Ecology

December, 1990

AWRRC

Arkansas Water Resources Research Center

AWRRC Misc. Publication No. 74

TABLE OF CONTENTS

ABSTRACT

The presence of an extensive network of solution channels in the fractured carbonate bedrock and a thin permeable regolith in northwest Arkansas makes aquifers in this region susceptible to contamination. Because of these conditions, there is concern about nitrate contamination of the ground water from land applied animal wastes, commercial fertilizers, rural septic systems and municipal sewage systems.

In response to these concerns a survey was conducted of the nitrate concentration in rural water wells in the carbonate aquifers of a 420 mi^2 area of northern Madison County during "wet" and "dry" seasons in 1990. Information from well owners, drilling records, Mg/Ca (meq/L) ratios as well as other chemical parameters were utilized to determine the primary aquifer source. Thirty-one samples were collected from the mostly unconfined, shallow, more commonly used Springfield Plateau aquifer (Boone-St. Joe aquifer). Seventeen wells were completed in the deeper, confined Ozark aquifer. Another sixteen wells were determined to be from undifferentiated shallow non-carbonate aquifers.

The deeper Ozark aquifer is much less susceptible to nitrate contamination than the overlying Springfield Plateau aquifer. Comparison of seasonal mean nitrate plus nitrite (mg/L as N) values suggests that more nitrate is introduced to the Springfield Plateau aquifer during the wet (2.89 mg/L) season than in the dry (1.79 mg/L) season. The deeper Ozark aquifer seasonal mean nitrate values were slightly higher in the dry (0.16 mg/L) season compared to the wet (0.13 mg/L) season. Overall, nitrate levels in ground water in northern Madison County are generally below the 10 mg/L as N standards for drinking water.

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

INTRODUCTION

Potential for Concern

In carbonate terrains, the quality of ground water for domestic use can vary widely. Across Northern Arkansas the presence of a highly fractured limestone/dolostone bedrock covered with a thin regolith makes the aquifer units highly susceptible to surface derived contamination. An extensive network of solution channels and conduits in the rocks causes rapid recharge (Rosenshein, 1988). Agricultural activities can cause contamination of such aquifers (Imes and Emmett, 1990).

Point source contamination of nitrate plus nitrite is a possibility from domestic septic systems, municipal sewage treatment lagoons, and from fertilizer spread on lawns, fields and orchards. Runoff from confined dairy and hog operations along with use of poultry litter as fertilizer also must be considered as potential non-point sources of contamination of nitrate plus nitrite. According to Gilmour (1987) if a rainfall event occurs soon after application, more than 50% of the available N could be utilized in plant uptake or as contamination of ground and surface waters. In this report nitrate plus nitrite (as N) will be referred to simply as nitrate due to low expected nitrite values.

Previous Investigations

The overall economy throughout Northwest Arkansas is directly related to agricultural activities. These activities have been suggested as a source for contamination of the springs in the Boone-St. Joe Formation of the shallow Springfield Plateau aquifer in Northwest Arkansas (Wagner et al., 1976; Steele, 1985; Steele and Adamski, 1987).

Ogden (1979) analyzed 253 wells for nitrate and other chemical parameters in Benton County. In these wells, pollution indicators, nitrate, phosphate, sulfate and chloride, were found to be statistically related. Many of the wells had higher levels of pollutants than background, but few exceeded nitrate values greater than the safe drinking water limit of 10 ppm (U.S. Environmental Protection Agency, 1985).

Leidy (1989) compared water from 17 springs in the Boone-St. Joe Formation in Boone County to water from 17 wells completed in the Cotter Formation of the deeper Ozark aquifer. Results from Wilcoxon tests indicated significantly higher concentrations of nitrate, chloride, orthophosphate, fecal coliform, and fecal streptococcus bacteria in the shallower ground water flow systems.

Comparison of the well water from the Boone-St. Joe Formation to both those from the deeper Everton Formation and a control area were conducted by McCalister (1990) and Steele and McCalister (1990 and 1991). Mean nitrate values were almost twice as high in shallower wells compared to the deeper Ozark aquifer. A Wilcoxon comparison of the wells in the Boone-St. Joe aquifer to nitrate concentrations in springs within the control area as well as to other control (mostly forested with low population) areas also demonstrated significantly higher mean concentrations of nitrate.

STUDY AREA

In ten years, Madison County has had a population growth of 2.0% (Santi, 1990) from 11,373 to 11,597. During the same period poultry (broilers and turkeys) production has risen 25.7% from 36.1 million to over 43.6 million birds. Livestock (cattle and hogs) production has risen 71.25% from 56,000 to over 95,900 animals (U.S. Department of Agriculture, 1980 and 1990).

The study area (figure 1) covers 420 mi^2 (670 km^2) and encompasses the northern portion of Madison County where carbonate aquifers are utilized for domestic and agricultural usage. Most of the area is on the Springfield Plateau with the southern boundary approximated by the escarpment of the Boston Mountain Plateau and the extreme northern part on the Salem Plateau (figure 2).

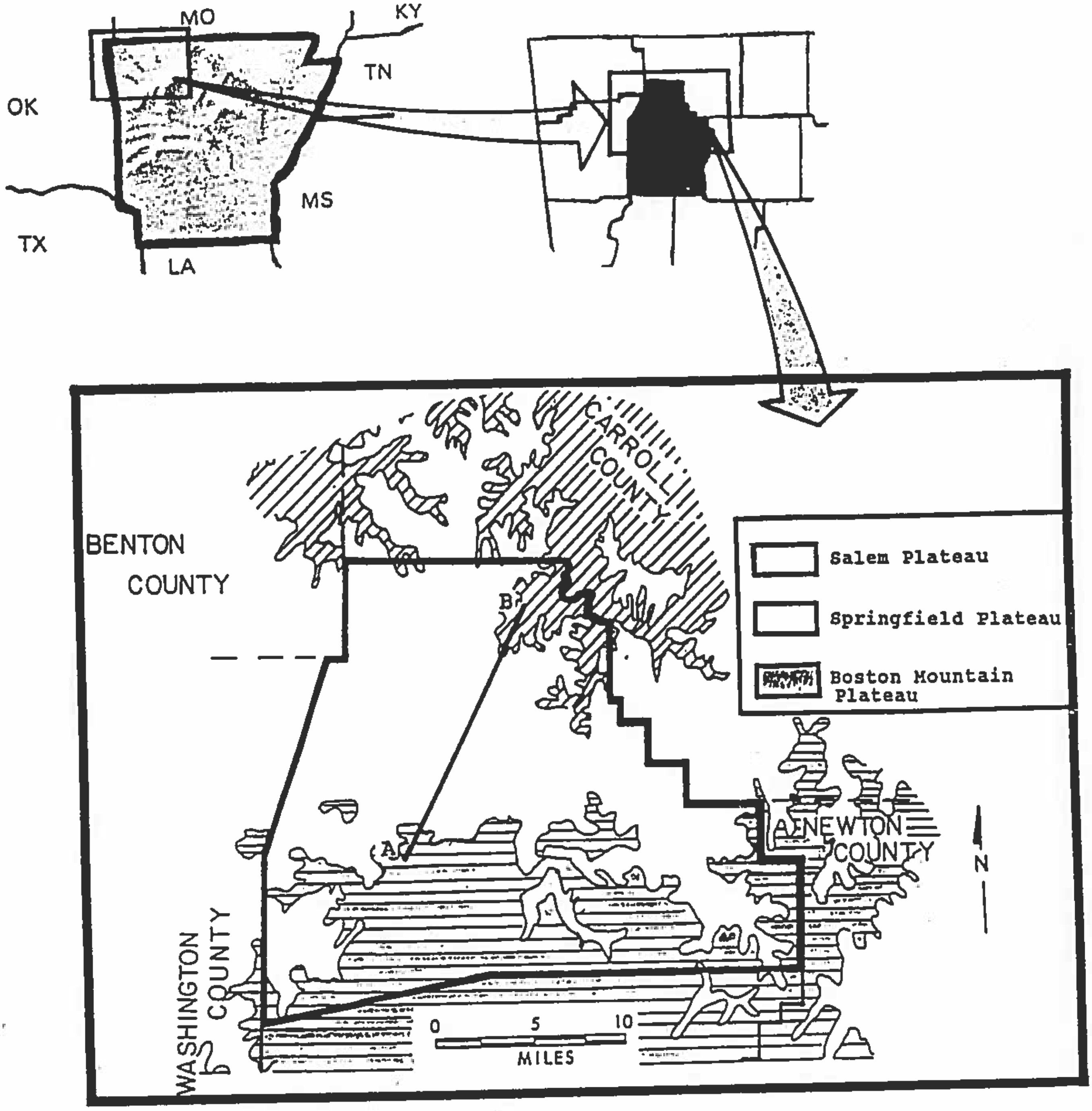

Figure 1: Location of study area showing the major physiographic provinces and cross-section line A-B.

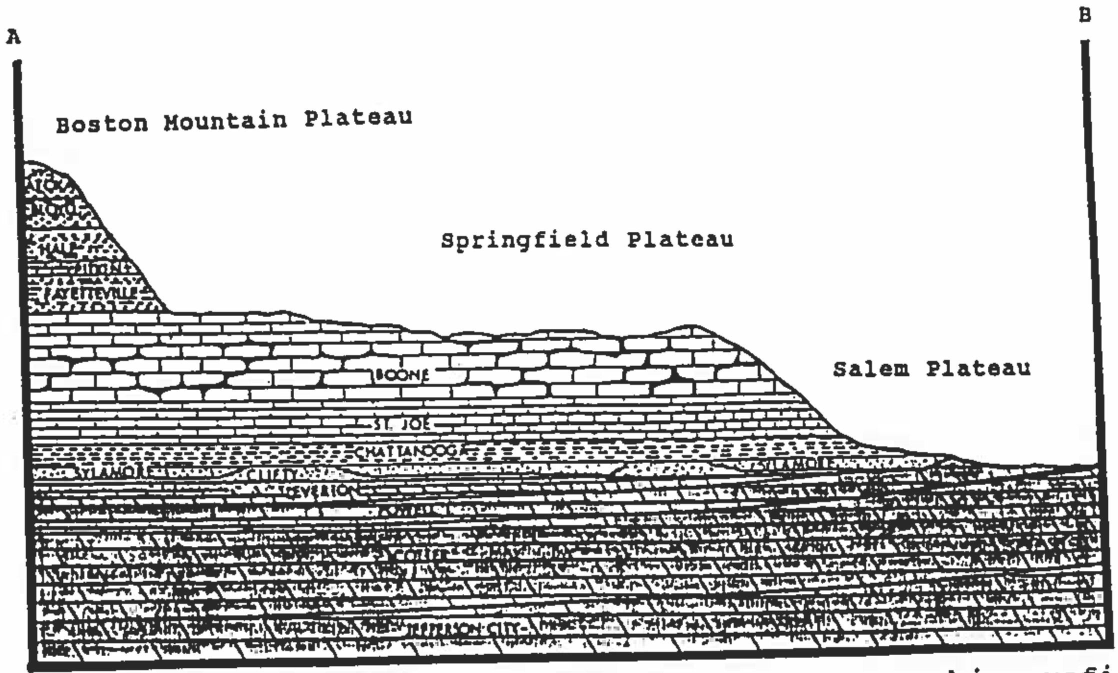

Figure 2: Cross-section A-B. Generalized topographic profile of Salem Plateau, Springfield Plateau, and Boston Mountain Plateau (from Ogden, 1979)

A thin, permeable regolith overlies a karstified carbonate plateau throughout northern Madison County. Solution channels form along joints and bedding planes creating a conduit network (figure 3).

The northern half of Madison County (figure 1) was used for this study because: (1) it has a high concentration of livestock and poultry production in a relatively rural area and (2) there is the possibility of several carbonate aquifers presently utilized

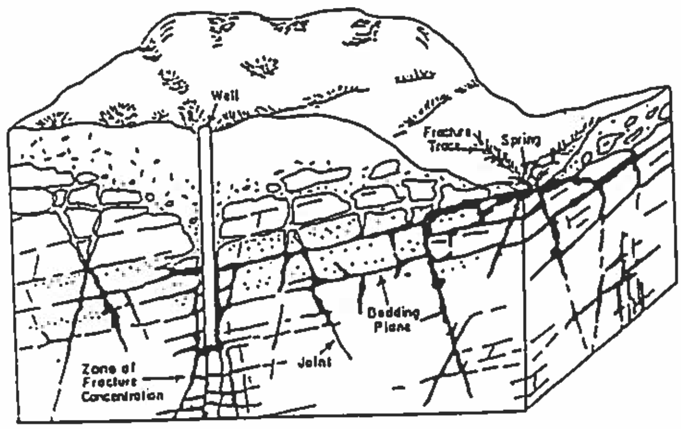

Figure 3: Karstified carbonate terrain showing bedding planes and jointing (from Steele and McCallister, 1990).

for domestic use being affected by land applied animal wastes.

Within the study area 27.8 million broilers and 1.1 million turkeys were produced in 1989 generating 228.3 million pounds of waste plus litter. In addition there are 57 dairy and 35 swine operations generating 159.1 million pounds of waste (Madison County S.C.S., personal communication, 1990 and U.S. Department of Agriculture, 1975)

This large growth in livestock and poultry production and the use of the associated waste and litter as a source of fertilizer has caused a shift in land usage. The litter is a valuable source of nitrate fertilizer and is spread on pasturelands. Application generally does not follow any consistent management practice and results in an uneven spreading on the cropland and pastureland which account for approximately 50% of the study area (figure 4). This lack of management in the uneven spreading is raising concerns about the amount of nitrate and other potential contaminants available to be leached into the local ground water.

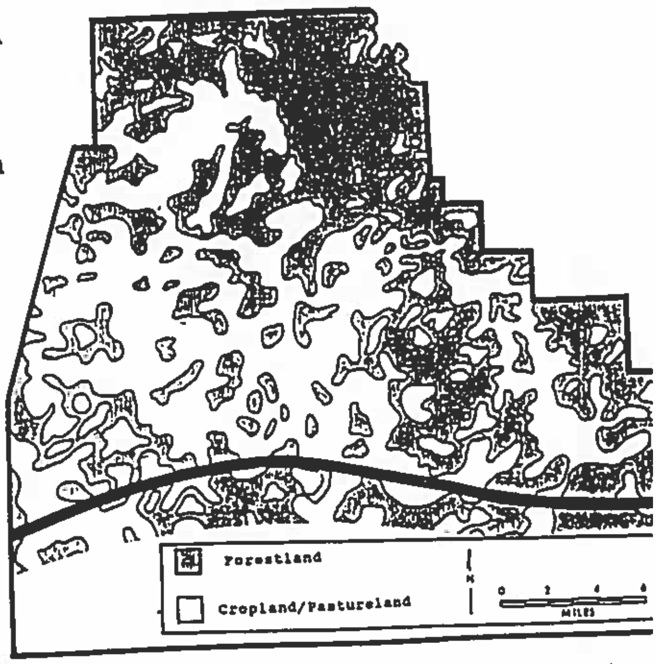

Figure 4: Land use distribution in study area (adapted from USGS 1976 and SCS 1986 da

Physiography

The three distinct plateaus of the area (figure 2) have surface exposure of strata ranging from Lower Ordovician to Pennsylvanian age as shown by the generalized stratigraphic section in figure 5. The Salem Plateau has the lowest average elevation of approximately 1000 feet above mean sea level. As reported by Imes and Emmett (1990) this plateau surface is coincident with the exposure of Ordovician rocks. These limestones and dolomites exhibit a rough topography that has resulted from being deeply cut by numerous streams.

Separating the Salem Plateau from the higher Springfield Plateau is the northward facing Eureka Springs escarpment. This escarpment is most prominent near Eureka Springs where it reaches a height of 400 feet (Croneis,1930).

With an elevation of 1000 to 1500 (Croneis, 1930) the Springfield Plateau has an erosional surface that coincides with the exposure of limestone and chert of the Mississippian Boone Formation. In the western part of the area the plateau surface is gently undulating and relief is generally less than 100 feet (Croneis, 1930).

The irregular Boston Mountain escarpment divides the Springfield Plateau from the Boston Mountain Plateau. This escarpment rises above the plateau by about 700 feet (Imes & Emmett, 1990) to the highest elevations (1900 to 2400 feet above mean sea level) in the Ozark Highlands (Croneis, 1930). Areas of highly dissected Pennsylvanian rocks occur throughout the southern portion of the study area. This dissection by major streams has caused some valleys to attain depths in excess of 500 feet.

Resistant Pennsylvanian sandstones form the erosional surface of the Boston Mountain Plateau. Alternating hard sandstone beds and soft shale beds form a bench and bluff type of topography in many areas (Purdue, 1916).

GEOLOGIC SETTING

Structure

Across Madison County the Northern Arkansas structural platform (Chinn and Konig, 1973) consists of subtle folds trending about N 30 E (Quinn, 1959). Dips vary within the study area from 1 to 3 degrees or 20 to 50 feet per mile (Caplin, 1960).

Stratigraphy

A sedimentary section that is approximately 2,500 feet thick rests on the Precambrian basement rocks across northern Madison County. It consists mainly of Cambrian, Ordovician, and Mississippian carbonates, shales, and sandstones. Pennsylvanian shales, sandstones and thin limestones are restricted to the area of the Boston Mountain Plateau except as erosional outliers (Caplin, 1960).

Lower Ordovician Cotter and Powell Formations are located in the Kings River Valley and are representative of the oldest exposed rocks in the study area. Across the northern half of the study area, exposure of the Springfield Plateau is dominated by the Mississippian Boone Formation.

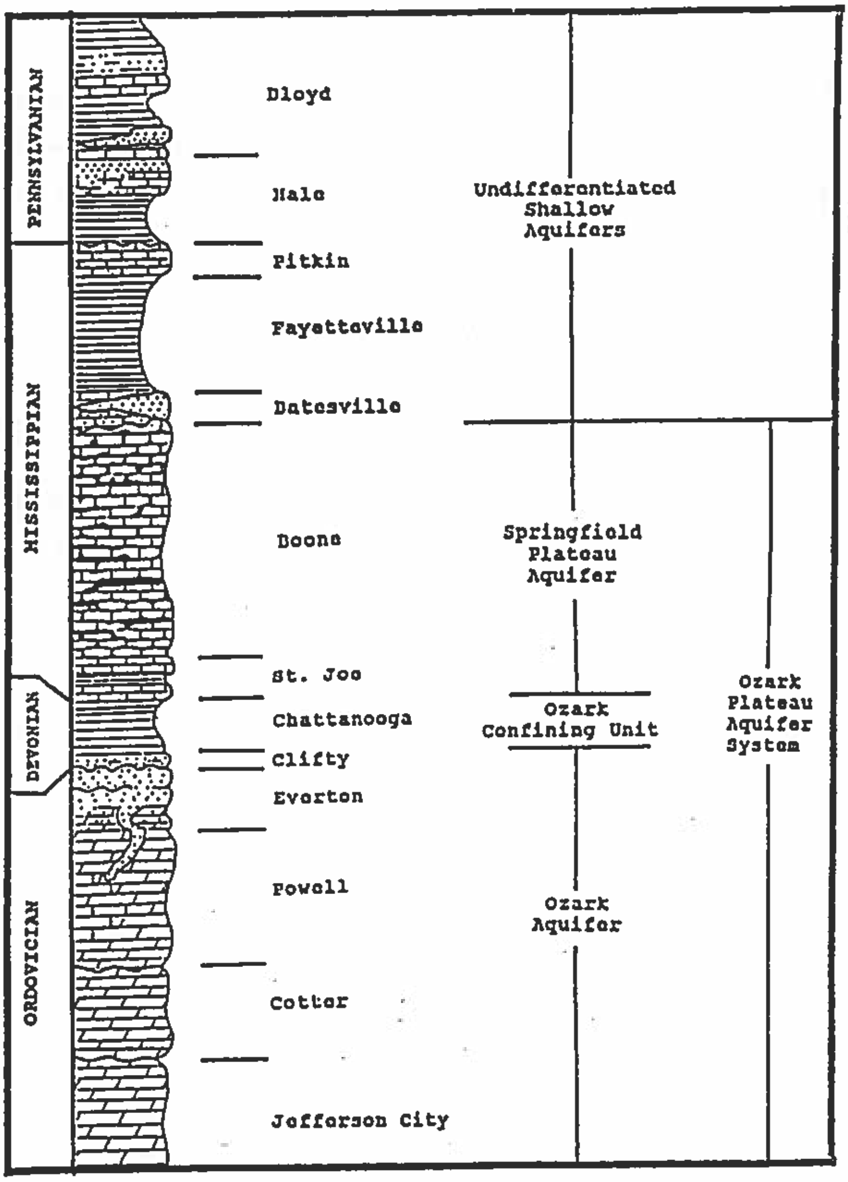

Figure 5: Generalized stratigraphic section of exposed rock units and hydrologic units in the study area.

The Clifty and Chattanooga Formations of Devonian age are exposed only in areas where the overlying Boone has been removed by erosion. An extensive area devoid of Devonian sediments exist in the north-east to north-central region of the study area. In this area, Mississippian rocks lay unconformably on those of Ordovician age (Terry, 1977).

Soils

Soils of the Nixa-Clarksville-Noark type are predominant throughout the Northern two-thirds of the study area. These soils are derived from the weathering of the Boone Limestone as shown in figure 5. Members of this combination soil type are described as deep, gently sloping to very steep, moderately to excessively drained very cherty soils (USDA, 1986). Properties of various soil types present across the plateaus of northern Arkansas are shown in Appendix A, Table A-1.

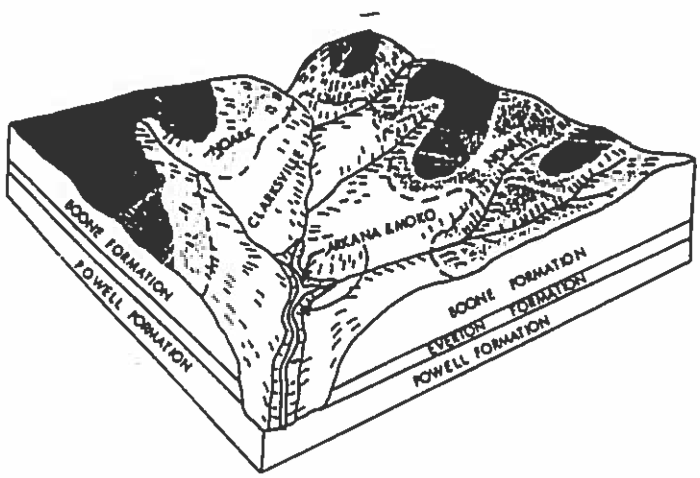

Figure 6: Soil pattern and parent material in Clarksville-Nixa-Noark unit.

An area of Tonti-Peridge-Captina type soil covers the flatter-lying upland areas in the Western part of the above area (USDA, 1986). Also derived from the Boone Limestone, they are very cherty but with a much gentler slope (3-8%) allowing more loamy material in the residuum.

The majority of the remainder of the study area is covered with Enders-Leesburg type soils. Soils are formed from the weathering of the sandstones and shales of the Pennsylvanian Atoka rocks on the ridgetops and steep (from 3-40%) slopes. Many of the upland areas here are capped with Steprock-Linker-Mountainburg type soils having a well drained, loamy gravelly, stoney composition.

Major drainages of the area are covered with an alluvium that can be grouped into Ceda-Leadville-Cleoria type (USDA, 1986). These are deep, level to gently-sloping, moderately well drained, loamy, gravelly, cobbly soils derived from sandstones, shales and limestones.

HYDROGEOLOGIC SETTING

OZARK AQUIFER

In the study area the Ozark aquifer can be roughly divided into two broad aquifer units. The lowermost unit consists of the sandy dolomites and dolomites of the Lower Ordovician Roubidoux, Gasconade and Gunter (descending order) Formations. Yields of 300 to 600 gpm (Lamonds, 1972) are encountered by municipal and agricultural users of aquifers in this unit. In this study no wells sampled were from depths sufficient to encounter these Formations.

The upper unit consists of sandstones and carbonates of the Lower to Middle Ordovician Everton, Powell, Cotter, and Jefferson City (descending order) Formations. Hydraulic conductivity values for this unit in the study area to range from $0.05*10^{-6}$ to $0.50*10^{-6}$ ft/sec. The transmissivity values are in the range of 0.1 to 0.5 ft^2/sec (Imes an Emmett, 1990). These ranges are due to the heterogeneous, anisotropic nature of the various lithologies.

Recharge for the Ozark aquifer is from infiltration of precipitation in outcrop areas and from leakage through the overlying units. Flow is north-northeast from the upland areas between major rivers toward valleys where the water discharges as stream base flow (Imes and Emmett, 1990). Yields from these Middle Ordovician rocks range from 5 to 10 gpm and may approach 50 gpm when larger solution channels are encountered (Lamonds, 1972). Water in this unit is typically of a calcium-magnesium bicarbonate type that are moderately hard to very hard (Hem, 1985) with values ranging from 95 to 235 mg/L as $CaCO_3$ according to Lamonds (1972) and from 114 to 345 mg/L $CaCO_3$ (Austin, 1991) as shown in Appendix B, Table B-2.

Cotter and Powell Dolomite

The oldest exposed rocks in the study area are from the

Cotter Dolomite Formation (Purdue, 1916 and Croenis, 1930) which disconformably underlies the Powell Limestone Formation. The Cotter Formation is exposed only in the region of the Salem Plateau as either a fine-grained, light-tan rock or a more massive, medium-gray rock. Sandstone is present in minor amounts as a sandy dolomite and as a thin basal sandstone (Croenis, 1930).

The average thickness reported by Caplin (1960) in adjacent Carroll county was 200 feet. There is some thinning to the west and Staley (1962) reported a total thickness between 90-100 feet in the White River Valley adjacent to northwestern Madison County.

Caplin (1960) described the Powell Formation as a light-gray, crystalline, shaley dolomite. Within the beds of dolomite and limy dolomite are scattered layers of shaley dolomite and dark oolitic chert. Croenis (1930) gives the thickness of the Powell Formation in surrounding Carroll and Benton Counties at 150-200 feet; thus this general thickness can be expected in Madison County.

Solution channels and fractures in the dolomite make this an important aquifer when yields from overlying formations is insufficient. Throughout both the Cotter dolomite and the Powell dolomite, zones of secondary porosity are also host for aquifers.

Everton Formation

Unconformably resting on the Powell Formation are the sandstones and sandy limestones of the Middle-Ordovician Everton Formation. The uppermost fine-grained limestone makes up only a small portion of the formation in northwestern Washington County as reported by McCalister (1990). The only exposure in the study area according to Willard (1962) is represented by the Kings River Member in the Salem Plateau region. This member is a fine-to medium-grained, calcareous sandstone which may be up to 40 feet thick (Staley, 1962). Thickness of this unit reported by Frezon and Glick (1959) increases toward the south from a beveled edge in far northern Arkansas.

Clifty-Sylamore Sandstones

The Ordovician rocks are overlain by the Middle Devonian Clifty sandstone and the Upper Devonian basal Sylamore sandstone member of the Chattanooga shale. Erosional surfaces make distinguishing the Ordovician Everton sandstone and the Devonian Sylamore/Clifty sandstones difficult due to similar lithologies and erratic distribution (Hall, 1978). The Clifty Formation has been reported to reach a maximum thickness of 20 feet but it is thinner at most locations. The Sylamore Sandstone is not continuous at the base of the Chattanooga and ranges from 0-20 feet throughout the area

(Wise and Caplin, 1979 and Hairston, 1990).

Wise and Caplin (1979) described the Sylamore and the Clifty as fine- to coarse-grained, light brown to white, rounded, quartzarenites. The sands of the Everton-Clifty-Sylamore comprise the uppermost confined aquifer of the Ozark Aquifer System. Where the overlying Boone Formation does not yield a sufficient quantity of water the Everton serves as an important aquifer (Widmann, 1982).

OZARK CONFINING UNIT

Chattanooga Shale

Where present the relatively impermeable, fissile, black-to-darkbrown, Chattanooga Shale is the barrier to the confined aquifers below and is referred to as the Ozark Confining Unit (Imes and Emmett, 1990). The carbonaceous Chattanooga shale may contain small concretions of siderite or pyrite (Duncan, 1983). The shale ranges from 10-35 feet thick in most areas, with localized thickness up to 70 feet along the western edge of the county as reported by

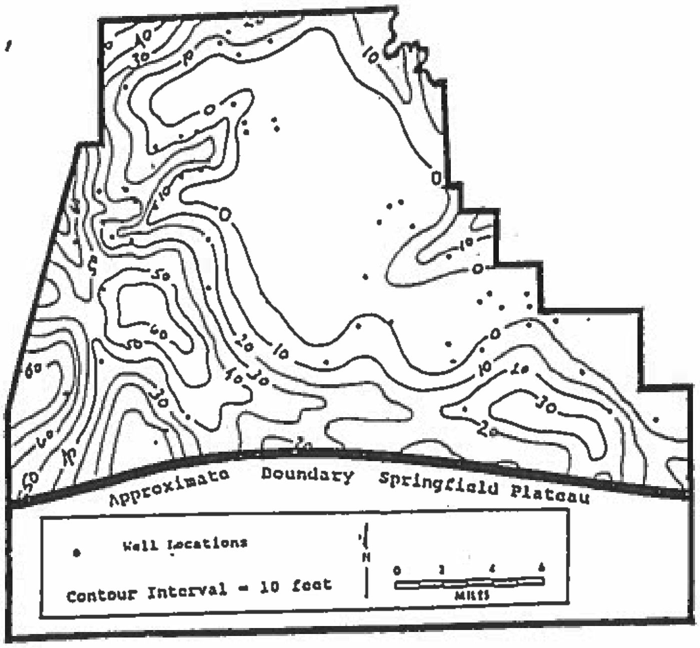

Figure 7: Isopach map of the Chattanooga Shale.

Manger and Shanks (1977). Imes and Emmett (1990) report the vertical conductivity of the confining unit to be in the range from 1.0 to $1.9*10^{-8}$ ft/ sec. Freeze and Glick (1959), Terry (1977), and Wise and Caplin (1979) showed an area in the north-central part of Madison County to be devoid of Chattanooga shale due to erosion across areas of a structural or topographic high existing in the Ordovician strata. A thorough investigation based on water well data indicated this area larger than previously described (figure 7).

SPRINGFIELD PLATEAU AQUIFER

Where present the shallow Springfield Plateau aquifer is the most frequently used in the study area. In western Madison County it ranges from semi-confined to unconfined or absent in the Salem Plateau area. In the limestones of the Mississippian Boone-St. Joe Formation solution channels form oriented along fractures and bedding planes. Imes and Emmett (1990) report the average lateral conductivity to be $2.5*10^{-4}$ ft/sec and transmissivity values ranging from 0.04 to 0.08 ft^2/sec across the study area.

The Springfield Plateau aquifer, referred to as the Boone-St.Joe aquifer by others, gets its recharge from infiltration of precipitation. The aquifer is under water table conditions and flow direction is generally a reflection of local topography, fracture orientation, and local geology. Discharge is through springs and streams in the area. In areas where the Ozark Confining Unit is absent there can be significant discharge to the confined aquifers below.

Wells in this aquifer are adequate for domestic use generally yielding between 2 to 5 gpm although those intersecting larger solution channels may reach 25 to 50 gpm (Lamonds, 1972). Water typically is a calcium-bicarbonate type that is moderately hard to very hard (Hem, 1985).

St.Joe Formation

The Mississippian Age St. Joe Formation rests unconformably on the Chattanooga Shale (Staley, 1962; Hall, 1978). Thicknesses between 6 to 84 feet were reported by McFarland (1975) and Shanks (1976) for the four formal members recognized in Arkansas as composing the St. Joe Formation. The basal Bachelor Member is described by Post (1982) as composed of limestone, shale, and phosphatic sandstone. The Compton and Pierson Members are both persistent and resistant fine-grained, unsorted, grain-supported, crinozoan-bryozoan calcarenites (Manger and Shanks, 1977; Liner, 1979). McFarland (1975) recognized the Northview Member to be made up of shales and argillaceuos limestone. Both shale members form reentrants in outcrop.

Boone Formation

The St. Joe-Boone contact is conformable. The presence of the first persistent chert delineates the contact according to McFarland (1975). Additional criteria added by Shanks (1976) an Manger and Shanks (1977) are: (1) a thin calcareous shale and (2) a facies change from a grain-dominated interval to a mud-dominated one.

The Boone Formation throughout the study area is divided into informal units rather than the formal members recognized in southern Missouri. These informal units are based on the development of dark penecontemporaneous chert and fine-grained lithologies in the lower part and light, later diagenetic chert and coarser grained lithologies in the upper portion of the section (Liner, 1979).

UNDIFFERENTIATED SHALLOW AQUIFERS

Sands, shales and limestones of late Mississippian and Pennsysvanian age make up the rugged Boston Mountain Plateau. The shales are highly jointed and fractured resulting in infiltration from precipitation. The sands are typically calcareous quartzarenites and serve as perched aquifers. Typically these zones are isolated from one another and serve only as localized aquifers. Flow is generally low (1 to 5 gpm) and depletion during periods of low recharge/discharge is common.

These isolated aquifers have water types ranging from calcium-bicarbonate to sodium-calcium-bicarbonate and are generally very hard (Austin,1991). The total dissolved solids, which can be approximated by multiplying the specific conductance by 0.65 (Hem, 1970), in some of these aquifers exceeds the 500 ppm value established by the Drinking Water Standards. Mean values for T.D.S. are from 468 ppm (wet season) to 533 ppm (dry season). Values for specific conductivity are shown in Appendix B, Table B-2.

Fayetteville Shale

The Fayetteville shale rests unconformably on the underlying Boone Formation, or on the Batesville Formation where it is present. The unit is a black, fissile, carbonaceous shale containing numerous septerian concretions and ranges in thickness from 125-200 feet thick (Hairston, 1989) across the southern portion of the study area. Near the top of the unit is the calcareous bluff-forming Wedington Sandstone Member. Thickness ranges from 40 feet along the western edge of the county to 0 feet as it pinches out toward the eastern part of Madison County (Hairston, 1989).

Pitkin Formation

The Pitkin Formation is the uppermost unit of the Mississippian Period within the study area. It is a coarse-grained, bioclastic oolitic limestone. The formation is up to 60 feet thick in the southern portion of the area, where present, and is truncated northward by the overlying unconformity (Zachary, 1979).

METHODOLOGY

Representive samples of the ground water in the rural areas of the study area were collected from domestic wells.

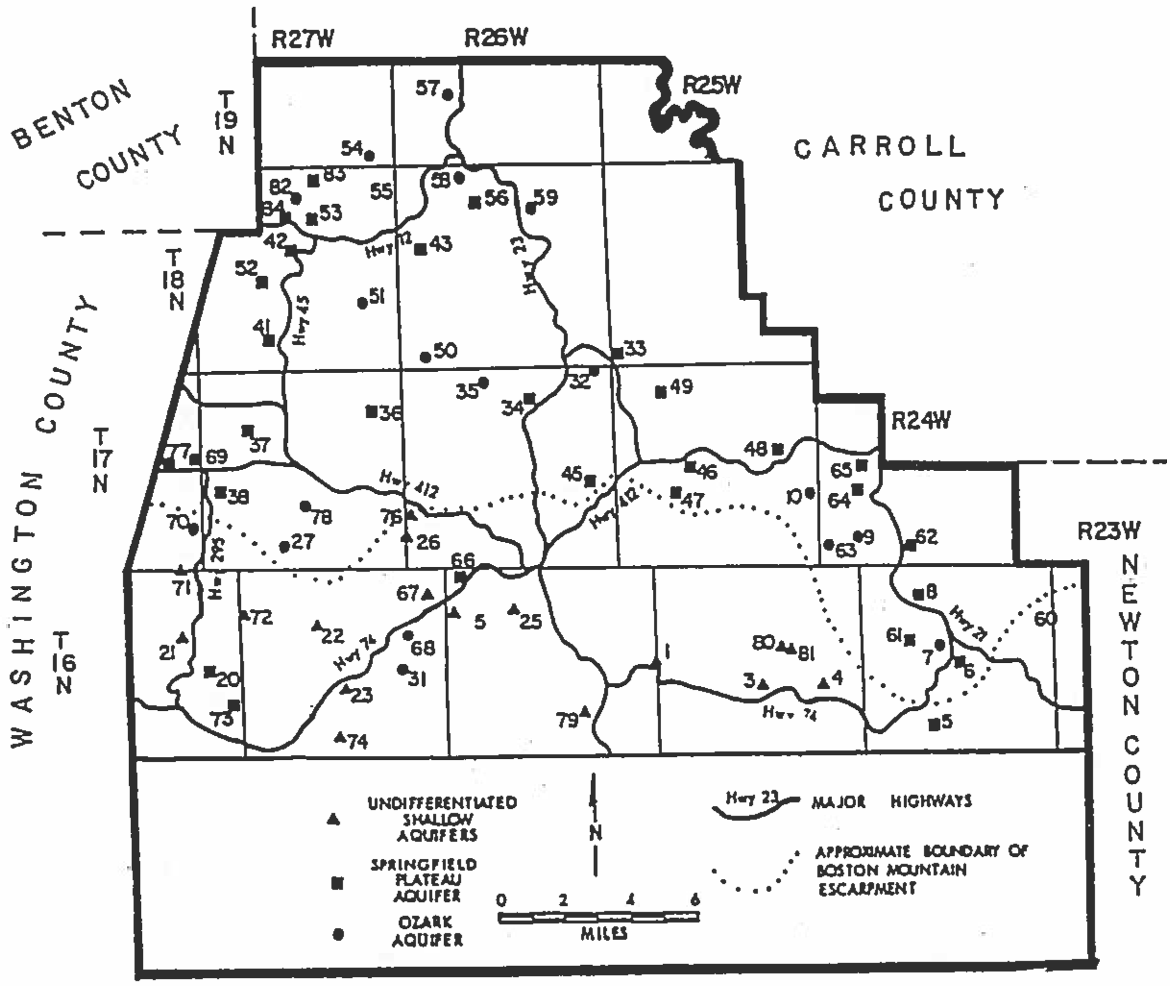

Figure 8: Location map of study area in northern Madison County, Arkansas showing wells sampled.

The original plan of sampling the area with a 9 mi^2 grid was modified by geographical features that tended to localize the populated areas. The forested areas in figure 4 coincides with the modified distribution of sampled wells shown in figure 8.

A total of 58 wells were sampled during the spring "wet" season. Samples from this period being indicative of a significant recharge period. Ninety-five percent (55) of the wells were resampled during the "dry" summer season. These samples being from a period of low recharge to discharge.

Field Techniques

To minimize the problems of contamination associated with plumbing, samples were obtained from the closest outlet to the well. All wells were purged three to ten minutes in order to empty the holding tank and most were flushed approximately three well volumes.

Samples were collected at each site in two 1000 mL polypropolene bottles. These bottles had been rinsed with de-ionized water until the conductance was below 2 µS/cm prior to each days collection. One of the bottles of unfiltered water was used at the wellsite to determine the temperature, conductance, pH, and total alkalinity.

Temperature was determined using a mercury thermometer. Conductance was measured using a YSI model 33 conductivity meter. Conductances values were converted to specific conductance at 25° C. A Markson model 88 pH meter along with a Cole-Palmer model 5685-45 pH probe were used for determining pH. Titration of a 10 mL sample to the bromocreosol/methyl red end point with 0.02 N H_2SO_4 was used to determine total alkalinity.

The other bottle was immediately placed on ice and returned to the Geochemistry Laboratory, University of Arkansas, at the end of each days collection for filtration.

Laboratory Techniques

The chilled samples were filtered through a 0.45 um pore-sized cellulose-acetate membrane and divided into three portions. A 500 mL portion was refrigerated at 4° C to be analyzed within 28 days for sulfate (SO_4) and chloride (Cl). A 250 mL aliquot to be used for the cations was acidified with 1.0 ml of HNO_3 to a pH of 2 or less. The remaining 250 mL of the filtered sample was stored in a new plastic bottle. This sample was used for nitrate plus nitrite (as-N) and ammonia (NH_4 and NH_3) was acidified with 1.0 mL of 1:1 H_2SO_4 to a pH of 2 or less and refrigerated at 4°C. Time constraints established by the Environmental Protection Agency of 28 days maximum holding time were observed for the nitrogen analysis (E.P.A., 1988).

Analysis for nitrate plus nitrite, for the wet season samples, followed Hach Company procedures (Hach, 1984). A reformulation of Hach's NitraVer VI reagent necessitated the neutralization of the dry season samples to a pH of 7.0 +/- 0.1 by using (NaOH) sodium hydroxide. Concentrations of these samples were adjusted to compensate for the change in volume during titration.

Standard solutions for nitrate analysis were prepared according to Standard Methods and calibration curves were established. Daily sample blanks from filtered de-ionized water were prepared and treated in the same manner as the samples. These blanks were used to remove any variances from reagents used.

A Bausch & Lomb Spectronic 20 Colorimeter was used to determine the transmittance of the nitrate and ammonia samples. Values below (12%) transmittance required dilution and were re-analyzed. The concentrations for the diluted samples were determined from the dilution factor used.

Calcium and magnesium were analyzed by atomic absorption spectrophotometry (Perkin Elmer Corporation, 1973; American Public Health Association, 1985). To minimize ionization interference in the flame, cesium chloride (final concention of 1000 mg/L) was added to the samples. Other parameters were determined (Appendix B) and are discussed in Austin (1991).

Quality-Control

Duplicate samples were analyzed as part of the quality-control program for analytical accuracy. Appendix C, Table C-1 lists these duplicates and data for determining the standard deviation from duplicate analysis. Of the 58 samples analyzed during the wet season, eight (14%) were run as duplicates. From 65 dry season samples, nine (14%) were selected to be duplicates. A single pooled precision value of (+/- 0.05) for both seasons was calculated based on the method of Skoog and West (1974).

$$\text{Pooled Standard Deviation} = \sqrt{\frac{\text{Sum of squares of deviation from mean}}{\text{Number of degrees of freedom}}}$$

Field duplicates along with trip blanks were analyzed as further quality-control measures. Field duplicates consisted of duplicate samples collected in the field. Deionized water from the laboratory, taken to the field and then treated in the same manner as a sample served as trip blanks. These values are tabulated in Appendix C, Table C-2.

Various known NO_3 concentrations were used to spike selected samples. These spiked samples were analyzed with the same procedure as other nitrate samples and are tabulated in Appendix C, Table C-3.

The percent deviation (%D), the percent recovery (%R) and the relative standard deviation (RSD) were calculated from the values obtained by the procedure outlined by Adams (1990). A mean percent recovery (%R) of 98.9 and a relative standard deviation for the %R of +/- 6.99 was determined for the spiked samples.

Additional quality-control was ensured by analysis of blind samples provided by the E.P.A. and by determining cation-anion balances for all samples. Results of analysis of the blind samples were within the 95% confidence interval of acceptability for all parameters except potassium. This value was within the 90% interval and is given with the other parameters listed in Appendix C, Table C-4. Differences between the cations (calcium, magnesium, sodium and potassium) and the anions (chloride, sulfate, alkalinity and nitrate) in milliequivalents per liter were determined for all samples. The percent difference between the cation and anions concentrations are listed in Appendix B, Table B-2.

RESULTS

Depth of the wells in the study were obtained from the well owners. Locations and elevations were obtained from U.S. Geological Survey 7.5 minute quadrangle maps. This surface information; the appproximate subsurface datum of the total depth; and the individual nitrate values for each well during each season (figure 9) were used for initial identification of the aquifer.

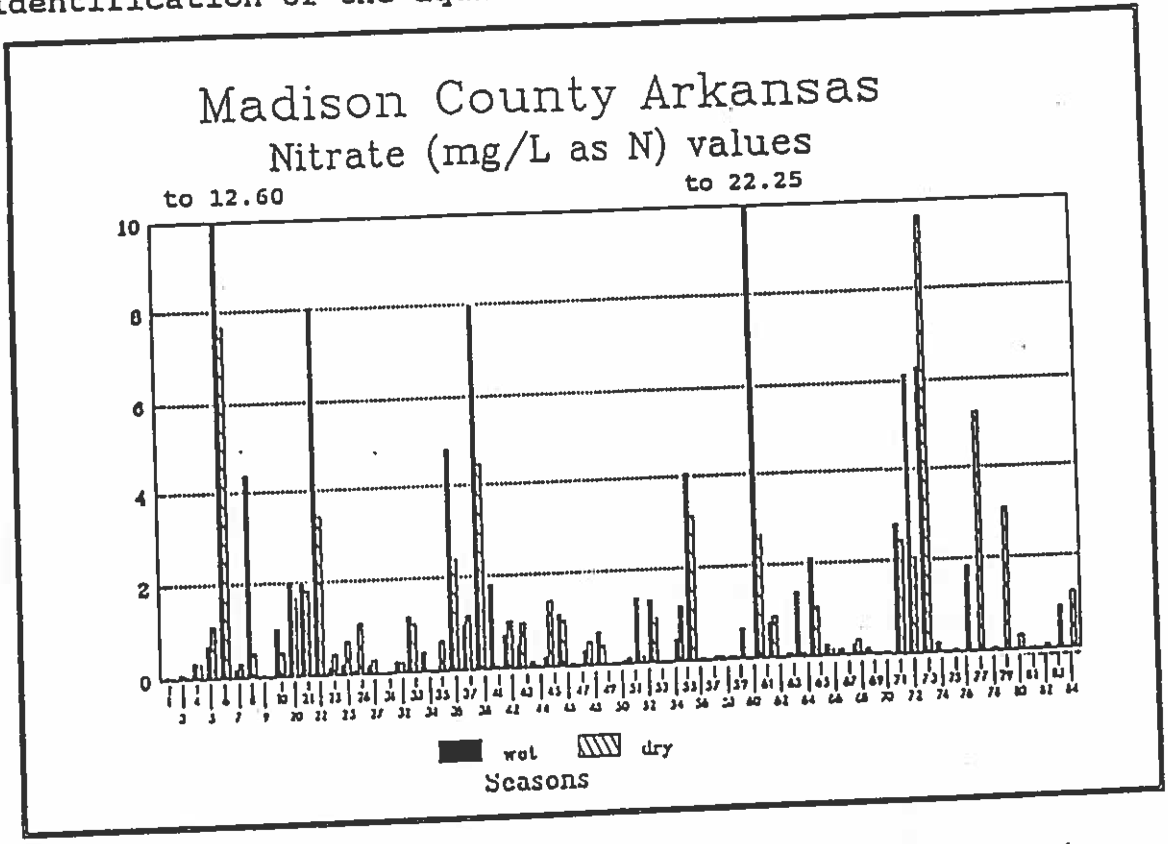

Figure 9: Seasonal comparison of wells sampled during both wet and dry seasons in Madison County.

This initial identification was refined by using Mg/Ca ratios (meq/L) for each well during each season. Contribution of water from the deeper, dolomitic Ozark aquifer will cause this ratio to be higher than the ratio observed for the more shallow, limey Springfield Plateau aquifer. However, a high Mg/Ca ratio (meq/L) is also present in waters that are contributed from the shallow undifferentiated aquifers above the Springfield Plateau aquifer.

Incorporation of well datum depths with subsurface structure and isopachous maps of the Ozark Confining Unit (Austin, 1991) along with examination of other data from chemical analysis confirmed the aquifer identification. Wells from the undifferentiated shallow aquifers, although from depths comparable to the Springfield Plateau aquifer, have 19.3 (wet season) to 17.7 (dry season) times the sodium values and 2.8 (wet season) to 6.9 (dry season) times the sulfate values as the Springfield Plateau aquifer as shown in Table 1.

	Seasonal Mean Values									
	Well Depth (ft)		Mg/Ca Ratio (meq/L)		Sulfate (mg/L as SO4)		Chloride (mg/L as Cl)		Sodium (mg/L as Na)	
	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
Undifferentiated Shallow Aquifers	(12) 136.7	(16) 136.5	(12) 0.6853 [0.29]	(16) 0.5893 [0.22]	(12) 35.13 [29.67]	(16) 57.98 [63.51]	(12) 39.65 [31.50]	(16) 44.19 [41.16]	(12) 97.77 [111.41]	(16) 118.36 [155.97]
Springfield Plateau Aquifer	(28) 144.7	(31) 133.4	(28) 0.0928 [0.08]	(31) 0.1008 [0.09]	(28) 12.52 [6.56]	(31) 8.42 [7.12]	(28) 10.31 [9.54]	(31) 8.18 [5.10]	(28) 5.06 [9.40]	(31) 6.07 [10.34]
Ozark Aquifer	(15) 500.9	(17) 465.5	(15) 0.5278 [0.19]	(17) 0.5648 [0.22]	(15) 23.57 [42.68]	(17) 20.45 [24.22]	(15) 4.75 [2.65]	(17) 3.84 [2.29]	(15) 9.76 [13.75]	(17) 10.06 [14.37]

Table 1: Comparison of seasonal mean Depth, Mg/Ca Ratios, Sulfate, Chloride, and Sodium values for aquifers of northern Madison County (Austin, 1991). ( ) indicate number of wells sampled; [ ] indicate sandard deviation.

These sodium-calcuim-bicarbonate type results are similar to those obtained by Grubbs (1974) for water from wells completed in the Fayetteville Shale of southern Washington County.

Higher nitrate values were present in the wells sampled during recharge (wet season) than those resampled during discharge (dry season). Of the 58 wells sampled, 46 (79.4%) had higher values in the wet season compared to 12 (20.6%) with higher values in the dry season. This suggests that more nitrate contamination is introduced into the aquifers during major recharge periods.

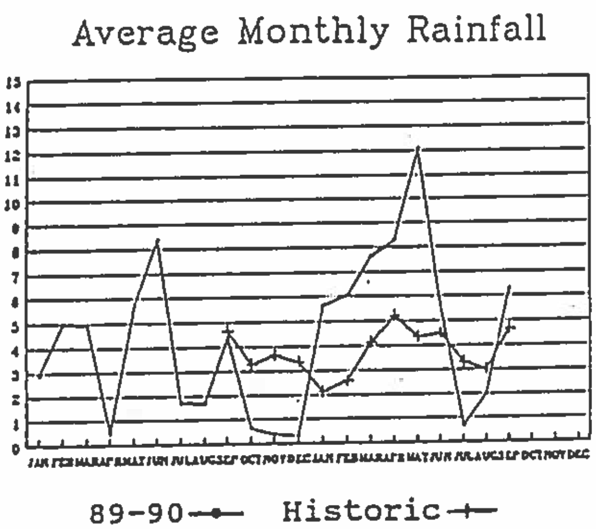

Figure 10:
Average historical rainfall versus rainfall during collection period (U. of A. Agriculture and S.C.S. historic data).

For this study, wet season samples were collected between May 21 and June 5, 1990, and dry season collection from July 23 to August 1, 1990. Monthly rainfall totals for this period are shown in figure 10.

The shallow undifferentiated aquifers showed higher (1.68 to 0.92 mg/L) nitrate concentrations during the wet season than in the dry season. The percent of wells having nitrate levels above the mean values for each season varied only slightly from 33.3% (wet) to 37.5% (dry). The seasonal comparison of nitrate values from wells in these undifferentiated shallow aquifers are shown in Figure 11.

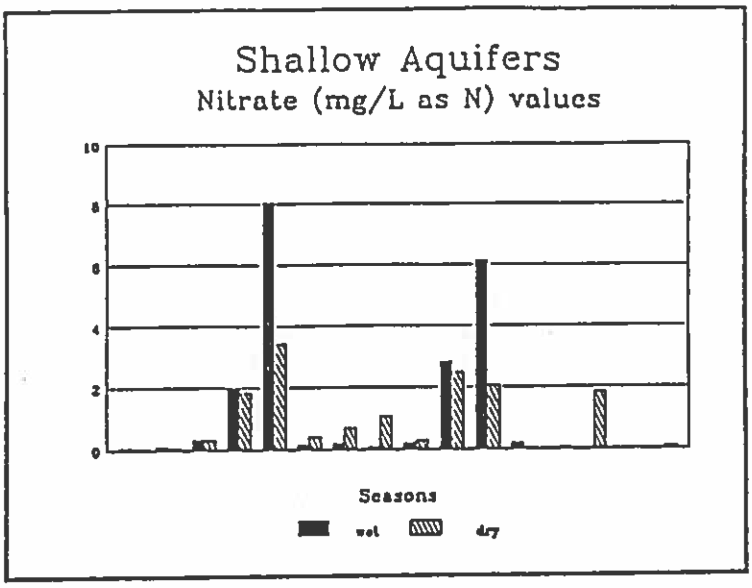

Figure 11: Seasonal comparison of wells completed in the Undifferentiated Shallow Aquifers.

Seasonal comparison between sampling periods for the Springfield Plateau Aquifer showed greater concentrations during the wet (recharge) season (2.89 to 1.79 mg/L) as shown in Table 2. Of the 28 wells completed in this aquifer only two had nitrate levels greater than Safe Drinking Water Limits of 10 mg/L as N (E.P.A., 1985) during the wet season. Seven wells (25.0%) were above the mean value (2.89 mg/L). During the dry (discharge) season, none of the 31 wells sampled from this aquifer were above the EPA limit and only eight wells (25.8%) were over the mean value (1.79 mg/L).

Figure 12 shows the nitrate concentrations in this aquifer.

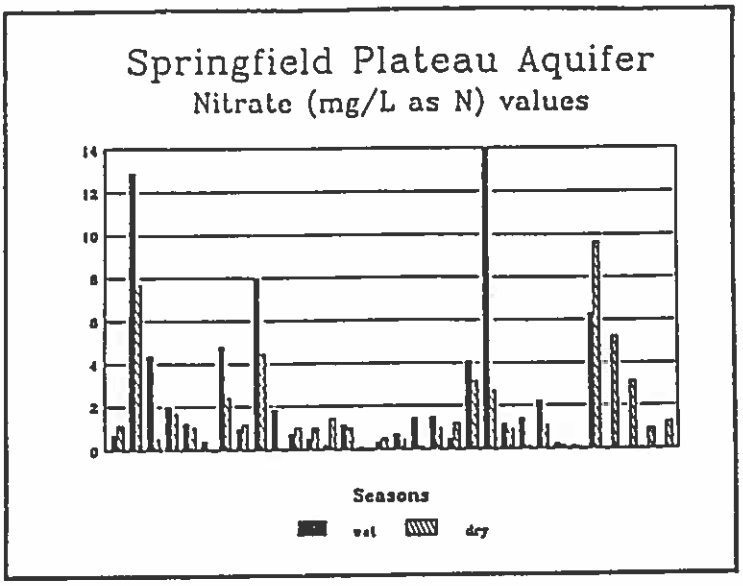

Figure 12: Seasonal comparison of wells completed in the Springfield Plateau Aquifer.

The deeper Ozark Aquifer had much lower concentrations of nitrate and very small variation between seasons. The mean values for the wet and dry seasons were 0.13 to 0.16 mg/L, respectively. The highest value of nitrate in this aquifer for both seasons was 1.00 mg/L as shown in figure 13. Lower concentrations of nitrate in the deeper Ozark aquifer are due to both surface and subsurface controls. The more rugged terrain where Ordovician rocks crop out would indicate more forestland (figure 4) and therefore less potential for contamination. Also, where it is present, the relatively impermeable Chattanooga Shale restricts water movement between the aquifers.

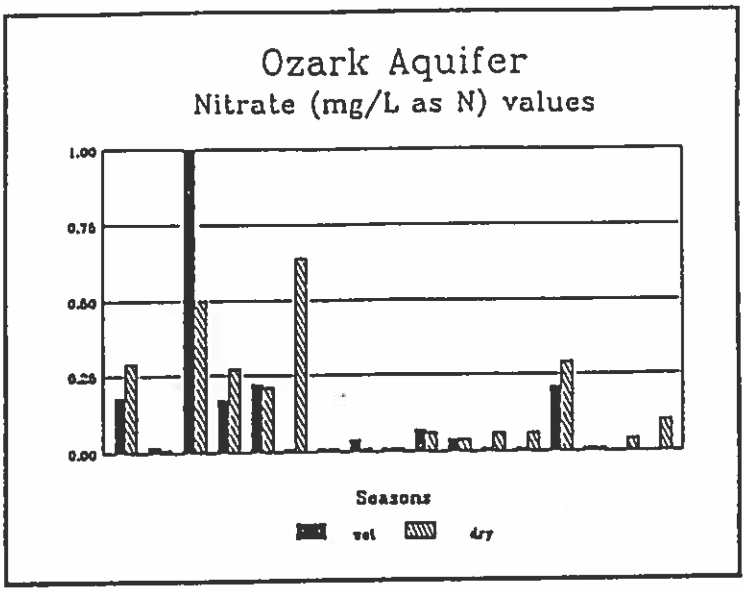

Figure 13: Seasonal comparison of wells completed in the Ozark Aquifer.

COMPARISON OF NITRATE DATA

Ground water in northwestern Arkansas has been investigated for the effects of nitrate contamination by the Arkansas Water Resources Research Center and the University of Arkansas Geology Department in several previous studies (Leidy, 1988; Adamski and Steele, 1988; McCalister, 1989; Steele and McCalister, 1990 and 1991; Steel et al., 1990). Two of these studies focused on the water quality of the shallow Springfield Aquifer in Washington County adjacent to the study area. A third concentrated on the water quality of deeper Ozark Aquifer in Boone County east of the study area. A study similar to the scope of this one is being conducted in Benton County (Smith, 1991). A comparison of the nitrate plus nitrite concentrations and Mg/Ca (meq/L) ratios for these studies are listed in Table 2.

	Springfield Plateau Aquifer				Ozark Aquifer			
	NO_3 wet	NO_3 dry	Mg/Ca (meq/L) wet	Mg/Ca (meq/L) dry	NO_3 wet	NO_3 dry	Mg/Ca (meq/L) wet	Mg/Ca (meq/L) dry
Madison County	(28) 2.89 [4.46]	(31) 1.79 [2.09]	0.09	0.10	(15) 0.13 [0.28]	(17) 0.16 [0.18]	0.53	0.56
Benton County[1]	(52) 2.63 [4.64]	(52) 1.80 [1.95]	0.07	0.06	(16) 0.11 [0.12]	(16) 0.15 [0.29]	0.64	0.62
NE Washington Co.[2]	(26) 2.90 [3.06]	(20) 2.44 [2.04]	0.04	0.04	(18) 1.59 [4.33]	(18) 1.51 [5.10]	0.28	0.24
Boone County[3]	(14) 2.10 [2.78]	(14) 2.78 [3.53]	0.06	0.08	(16) 0.27 [0.49]	(16) 0.44 [0.82]	0.72	0.79

1. Smith (in progress)
2. McCalister (1989)
3. Laidy (1988)

Table 2: Comparison of seasonal mean nitrate plus nitrite (mg/L as N) and Mg/Ca (meq/L) ratios with related studies in northwest Arkansas. ( ) indicates number sampled; [ ] indicates standard deviation.

The wet season Springfield Plateau aquifer results for Madison, Benton, Boone and northeastern (NE) Washington Counties are similar. Although the dry season values for Madison and Benton Counties are similar, these values are lower than those in NE Washington County and Boone County. The most likely explanation for the differences in mean nitrate concentrations is the difference in sampling periods. Madison and Benton Counties were sampled during the same seasons in 1990 and thus the hydrological conditions would be expected to be similar. However, the other studies were conducted as much as three years before and therefore the hydrological conditions could have been different. Another difference for the NE Washington County study is the higher density poultry production there. Also the Boone County data are based on springs; whereas, the Madison, Benton and NE Washington County data are based on wells.

All of the studies indicate lower nitrate values for the deeper Ozark aquifer. The slightly higher value for dry season values in two of the four studies may be indicative of the lag time necessary for contaminants introduced into the shallow aquifer to reach the deeper aquifers. Note that the area of dense poultry production (NE Washington County) has higher nitrate values than the other study areas for the Ozark aquifer.

CONCLUSION

Water from the undifferentiated shallow aquifers has lower nitrate values than the underlying Springfield Plateau aquifer. The steep slopes of the rugged terrain making any form of land use impractical is the likely explanation for these low values. Although it typically has lower nitrate levels, this water may be high in total dissolved solids due to assimulation of sodium, chloride, and/or sulfate from contact with the Fayetteville Shale.

The water in the Springfield Plateau aquifer (Boone-St.Joe aquifer) can be more readily contaminated from pollution sources such as chicken houses, land application of animal waste, or domestic septic tanks than the water in either the deeper Ozark aquifer or the more shallow undifferentiated aquifers. However, the Ozark aquifer appears to exhibit seasonal variations which indicates that it is not completely isolated from the shallow aquifers and that the potential for contamination exists. Seasonal mean (mg/L as N) nitrate levels in ground water in northern Madison County are similar to those for surrounding counties as shown if Table 2 and are generally below the drinking water standards.

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APPENDIX A

Classification properties for soil types across plateau region of northern Arkansas

Table A-1. Classification properties for soil types across plateau region of northern Arkansas (modified after Madison County soil survey 1986).

Soil Type	Average % Clay	Average Slope	Permeability (in/hr)	Soil Capacity (in/hr)	Reservoir Usage	Absorption Fields
Nixa	5-30	3-15	0.06-2.00	0.03-0.10	slight	severe (slowperc
Clarks-ville	10-20	20-50	0.60-6.00	0.05-0.12	severe (seepage)	severe (slope)
Noark	30-40	8-45	0.60-2.00	0.06-0.14	mod-sev (seepage)	moderate (slope)
Tonti	20-40	3-8	0.60-2.00	0.01-0.22	slight	severe (slowperc
Peridge	20-60	1-3	0.60-2.00	0.09-0.24	moderate (seepage)	moderate (slowperc
Capita	20-35	1-3	0.06-2.00	0.05-0.20	slight	severe (wetness)
Enders	20-45	3-40	<0.06-2.00	0.10-0.22	severe (slope)	severe (slowperc
Leesburg	10-40	3-20	0.60-2.00	0.12-0.22	moderate (seepage)	moderate (slowperc
Steprock-Linker-Mtnburg.	15-40	1-8	0.60-6.00	0.08-0.20	mod-sev (slope)	severe (floodin
Ceda-Leadville-Cleoria	10-25	1-8	0.60-20.0	0.07-0.22	mod-sev (slope)	severe (depth)

Where:

Permeability = Rate of downward movement of water when soil is saturated.

Soil Capacity = Quantity of water that soil is capable of storing for use by plants.

Slight = Soil properties and site features are generally favorable.

Moderate = Soil properties or site facilities are not favorable and special planning is needed to overcome limitations.

Severe = Soil properties or site features are so unfavorable or so difficult to overcome that special design, increase in costs and increased maintanence is required.

APPENDIX B

B-1. Results of chemical analysis for wells sampled presented by aquifer.

B-2. Completion datum and Mg/Ca(meq/L) ratios used in aquifer determination. Datum indicates total depth of well in feet above sea level. Percent difference is equal to the difference between cations and anions divided by the sum of the total ions multiplied by 100.

Undifferentiated Shallow Aquifers (wet season)

Sample Number	Date Collected	Well Location	TEMP (°C)	Spec. Cond. (µs/cm)	pH	Alkalinity (mg/L as CaCO3)	Nitrate (mg/L as N)	Ammonia (mg/L as N)	Sulfate (mg/L as SO4)	Chloride (mg/L as Cl)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Mg/Ca Ratio (meq/L)
1	5/21/90	16N/25wabd24	18.00	467.51	7.40	268.18	0.05	0.00	10.00	62.00	5.50	13.95	36.00	1.05	0.3710
3	5/21/90	16N/25Wdcb22	18.50	508.08	7.10	277.27	0.09	0.00	36.00	94.00	10.25	10.80	8.00	1.80	0.1890
4	5/21/90	16N/25Wabd26	16.00	102.64	6.40	27.27	0.32	0.00	6.50	11.00	10.50	3.15	4.20	0.80	0.4720
21	5/22/90	16N/28Waca14	16.50	439.32	6.70	145.45	1.96	0.00	12.25	37.50	35.25	11.70	28.50	1.65	0.5140
22	5/22/90	16N/27Wbda16	17.50	529.91	7.00	222.73	8.04	0.00	20.25	65.00	20.00	25.80	15.50	0.95	0.6540
23	5/22/90	16N/27Wbdb28	18.00	375.16	7.10	168.18	0.16	0.00	38.25	12.00	9.25	7.35	58.00	1.50	1.0090
25	5/22/90	16N/26Waab08	17.00	427.29	6.80	27.27	0.21	0.00	26.50	21.50	96.75	14.85	32.00	0.80	1.1380
26	5/22/90	16N/27Wdcb25	18.50	1,392.93	8.30	531.82	0.08	0.00	125.00	19.00	52.25	12.60	275.00	1.95	1.0930
67	6/4/90	16N/26Wacd12	18.00	1,846.94	8.50	795.45	0.11	0.00	33.00	2.00	20.25	1.05	300.00	0.85	0.8650
71	6/5/90	16N/28Waca02	17.00	584.28	6.10	113.64	2.81	0.00	48.50	35.50	81.50	10.50	70.00	0.60	0.4870
72	6/5/90	16N/27Wdbc07	16.50	668.54	6.10	145.45	6.13	0.01	30.75	44.00	85.00	15.90	58.00	0.80	0.5960
74	6/5/90	16N/27Wbac33	18.00	1,298.63	8.40	536.36	0.21	0.00	34.50	5.00	49.25	2.47	288.00	0.95	0.8140
		Number	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
		Mean Values	17.46	720.10	7.16	271.59	1.68	0.00	35.13	34.04	39.65	10.84	97.77	1.14	0.6835
		Stan.Dev.	0.80	490.58	0.81	223.89	2.59	0.00	29.67	26.95	31.50	6.56	111.41	0.44	0.29

Undifferentiated Shallow Aquifers (dry season)

Sample Number	Date Collected	Well Location	TEMP (°C)	Spec. Cond. (µs/cm)	pH	Alkalinity (mg/L as CaCO3)	Nitrate (mg/L as N)	Ammonia (mg/L as N)	Sulfate (mg/L as SO4)	Chloride (mg/L as Cl)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Mg/Ca Ratio (meq/L)
1	7/23/90	16N/25wabd24	18.50	485.24	7.30	240.91	0.03	0.00	11.94	4.50	60.00	14.25	27.75	0.95	0.3910
3	7/23/90	16N/25Wdcb22	21.00	552.19	7.10	227.27	0.05	0.00	36.50	10.00	96.00	11.70	7.25	1.90	0.2010
4	7/23/90	16N/25Wabd26	21.00	211.13	6.40	68.18	0.31	0.00	9.75	11.00	25.00	7.20	6.40	1.20	0.4750
21	7/26/90	16N/28Waca14	20.50	536.08	6.70	163.64	1.83	0.00	26.90	54.00	41.00	14.10	47.00	1.15	0.5670
22	7/25/90	16N/27Wbda16	18.50	433.86	7.20	186.36	3.43	0.00	15.75	12.75	55.00	19.50	13.80	0.74	0.5840
23	7/25/90	16N/27Wbdb28	20.50	396.04	7.00	154.55	0.42	0.00	33.60	8.00	15.00	8.10	56.00	1.80	0.8900
25	7/25/90	16N/26Waab08	18.00	432.88	5.40	22.73	0.69	0.00	27.35	101.00	21.50	14.25	33.00	0.74	1.0920
26	7/26/90	16N/27Wdcb25	19.50	1,385.55	7.20	559.09	1.07	0.01	19.40	50.25	28.50	14.40	288.00	1.80	0.8330
67	7/25/90	16N/26Wacd12	19.00	1,377.91	8.80	668.18	0.03	0.00	42.90	20.75	3.00	1.50	292.00	1.15	0.8240
71	7/26/90	16N/28Waca02	18.50	673.63	6.30	172.73	2.48	0.00	72.00	81.75	59.00	14.55	63.00	0.60	0.4060
72	7/26/90	16N/27Wdbc07	17.00	708.22	6.60	186.36	2.05	0.00	66.85	92.00	66.00	21.90	58.00	0.65	0.5470
74	7/25/90	16N/27Waac33	18.00	1,356.34	8.30	581.82	0.02	0.00	34.60	48.50	7.00	1.80	304.00	1.15	0.4240
75	7/25/90	16N/26Wbbd07	17.00	596.08	7.40	304.55	0.04	0.00	20.00	10.75	66.00	14.85	48.50	1.50	0.3710
76	7/25/90	16N/27Wabc25	18.50	1,358.68	6.80	254.55	1.83	0.01	236.60	153.75	160.00	50.40	60.00	1.30	0.5190
80	7/30/90	16N/25Wbbd23	18.00	808.03	6.70	254.55	0.30	0.00	173.60	25.00	124.00	52.20	13.00	1.50	0.6940
81	7/30/90	16N/25Wbbd23	20.00	2,155.89	7.60	590.91	0.20	0.01	< 3.00	23.00	27.40	10.20	576.00	1.90	0.6110
		Number	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
		Mean Values	18.97	841.73	7.05	289.77	0.92	0.00	57.98	44.19	53.40	16.93	118.36	1.25	0.5893
		Stan.Dev.	1.27	511.37	0.77	192.09	1.04	0.00	63.51	41.61	41.83	14.02	155.97	0.43	0.22

Table B-1. Results of chemical analysis for wells sampled in shallow aquifers; Madison County, Arkansas.

Springfield Plateau Aquifer (wet season)

Sample Number	Date Collected	Well Location	TEMP (°C)	Spec. Cond. (µs/cm)	pH	Alkalinity (mg/L as CaCO3)	Nitrate (mg/L as N)	Ammonia (mg/L as N)	Sulfate (mg/L as SO4)	Chloride (mg/L as Cl)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Mg/Ca Ratio (meq/L)
5	5/21/90	16N/24Wcbd28	17.00	70.82	6.50	13.64	0.69	0.00	4.75	9.75	6.50	1.35	3.00	2.70	0.3420
6	5/21/90	16N/24Wbcc15	17.00	377.71	7.50	177.27	12.90	0.00	< 3.00	11.00	76.00	1.35	2.70	0.95	0.0290
8	5/21/90	16N/24Wbcc09	18.00	424.80	7.00	172.73	4.35	0.00	25.75	13.00	75.00	2.10	10.50	1.20	0.0460
20	5/22/90	16N/28Waca23	18.50	557.17	6.90	295.45	1.97	0.00	9.00	18.00	59.00	3.00	5.00	1.35	0.0840
33	5/23/90	17N/25Wbac06	16.00	156.99	7.00	72.73	1.19	0.00	< 3.00	7.25	28.50	1.05	1.95	0.95	0.0610
34	5/23/90	17N/26Waac10	15.00	113.72	6.60	50.00	0.41	0.00	< 3.00	4.50	22.00	1.20	1.45	1.05	0.0900
36	5/23/90	17N/27Wbbd12	17.00	257.32	6.50	122.73	4.80	0.00	3.50	6.75	46.00	1.65	3.10	3.00	0.0590
37	5/23/90	17N/27Wdcd08	16.00	317.59	7.40	163.64	0.96	0.00	5.50	7.25	67.00	0.90	2.15	0.55	0.0220
38	5/23/90	17N/27Wbdc19	17.50	385.18	7.10	177.27	7.95	0.00	< 3.00	14.00	70.00	1.20	5.60	0.95	0.0280
41	5/26/90	18N/27Wdbd28	16.50	325.91	6.50	159.09	1.81	0.00	4.00	7.25	62.00	1.50	3.00	1.80	0.0400
42	5/26/90	18N/27Wdaa16	17.00	349.39	6.10	172.73	0.70	0.01	< 3.00	9.75	61.00	4.50	6.25	0.40	0.1220
43	5/26/90	18N/26Wbac16	16.00	277.74	6.40	145.45	0.48	0.00	< 3.00	5.25	54.00	1.65	3.80	2.25	0.0500
45	5/29/90	16N/26Wddb21	20.00	318.41	7.50	177.27	0.20	0.00	7.00	5.75	56.00	5.85	3.00	1.05	0.1720
46	5/29/90	17N/25Wdca16	18.50	525.20	7.20	250.00	1.10	0.00	15.00	18.25	82.00	13.80	11.00	0.55	0.2770
47	5/29/90	17N/25Waab20	17.00	649.20	7.20	227.27	0.05	0.01	24.75	54.00	96.00	4.65	21.00	1.20	0.0800
48	5/29/90	17N/25Wcba13	18.00	420.18	7.20	209.09	0.31	0.00	< 3.00	3.75	85.00	0.90	1.45	0.40	0.0170
49	5/29/90	17N/25Wbcc05	19.00	377.23	7.50	209.09	0.68	0.00	4.00	5.75	65.00	2.85	13.00	0.95	0.0720
52	5/29/90	18N/27Wbdc21	16.00	239.10	7.20	109.09	1.40	0.00	< 3.00	10.00	39.00	1.80	6.38	0.65	0.0760
53	5/31/90	18N/27Wbcc10	14.50	262.68	6.90	122.73	1.34	0.00	< 3.00	5.25	49.00	1.20	1.95	1.20	0.0400
55	5/31/90	18N/26Wbcc06	17.50	128.39	6.50	54.55	0.47	0.00	9.25	3.50	19.00	1.50	2.40	2.00	0.1300
56	5/31/90	18N/26Wcba04	15.50	140.49	6.30	40.91	4.05	0.00	8.00	5.50	20.00	1.50	2.45	2.70	0.1240
61	6/4/90	16N/24Wbbb16	17.00	596.08	6.70	172.73	22.25	0.00	9.75	18.50	55.00	2.25	5.15	1.68	0.0570
62	6/4/90	17N/24Wbdd33	18.00	376.31	7.20	209.09	0.73	0.00	< 3.00	4.75	73.00	4.35	1.95	0.55	0.0980
64	6/4/90	17N/24Wddd18	19.00	374.97	7.00	177.27	1.38	0.00	< 3.00	5.00	74.00	0.90	1.65	0.55	0.0200
65	6/4/90	17N/24Wdda18	18.00	364.77	6.90	177.27	2.10	0.00	< 3.00	6.50	76.00	0.90	2.15	0.55	0.0200
66	6/4/90	16N/26Waca06	24.50	98.94	6.50	31.82	0.22	0.00	8.00	4.25	12.50	1.65	2.15	1.20	0.2180
69	6/5/90	17N/27Wccc18	17.00	483.95	6.70	268.18	0.12	0.01	12.25	8.00	88.00	9.30	8.50	0.40	0.1740
73	6/5/90	16N/27Wbac36	17.00	488.67	6.80	209.09	6.28	0.02	13.50	16.25	90.00	2.70	9.00	1.70	0.0490
		Number	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00
		Mean Values	17.43	337.82	6.91	156.01	2.89	0.00	12.52	10.31	57.38	2.77	5.06	1.23	0.0928
		StanDev.	1.83	150.59	0.37	71.29	4.68	0.00	6.56	9.54	24.53	2.81	4.40	0.73	0.08

Table B-1 (continued). Results of chemical analysis for wells sampled in Springfield Plateau Aquifer; Madison County, Arkansas.

Springfield Plateau Aquifer (dry season)

Sample Number	Date Collected	Well Location	TEMP (°C)	Spec. Cond. (µs/cm)	pH	Alkalinity (mg/L as CaCO3)	Nitrate (mg/L as N)	Ammonia (mg/L as N)	Sulfate (mg/L as SO4)	Chloride (mg/L as Cl)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Mg/Ca Ratio (meq/L)
5	7/23/90	16N/24Wcbd28	20.50	82.05	6.10	13.64	1.10	0.00	7.65	9.75	8.50	1.65	2.70	2.50	0.3200
6	7/23/90	16N/24Wbcc15	17.00	389.52	7.30	145.45	7.68	0.00	< 3.00	7.50	76.00	1.20	2.00	0.65	0.0260
8	7/23/90	16N/24Wbcc09	22.00	312.93	7.00	150.00	0.51	0.00	< 3.00	3.00	58.00	3.30	2.45	2.05	0.0940
20	7/26/90	16N/28Waca23	20.50	481.37	7.20	227.27	1.67	0.01	17.15	7.75	93.00	2.25	1.68	0.53	0.0380
33	7/30/90	17N/25Wbac06	17.50	161.07	7.50	72.73	1.03	0.01	< 3.00	6.75	30.00	0.90	2.00	0.74	0.0490
34	7/30/90	17N/26Waac10	16.00	223.40	6.80	100.00	0.03	0.00	< 3.00	5.25	43.00	1.05	2.45	0.80	0.0400
36	7/26/90	17N/27Wbbd12	18.50	302.56	6.60	150.00	2.40	0.01	< 3.00	7.75	56.00	1.80	4.35	2.40	0.0530
37	7/26/90	17N/27Wdcd08	18.50	382.49	7.10	163.64	1.15	0.00	5.75	6.00	75.00	1.05	2.15	0.48	0.0230
38	8/1/90	17N/27Wbdc19	17.50	402.68	7.10	177.27	4.45	0.01	< 3.00	15.25	79.00	1.35	7.00	1.15	0.0280
41	7/31/90	18N/27Wdbd28	16.00	323.63	7.40	159.09	0.04	0.00	8.30	4.75	58.00	3.75	10.80	1.80	0.1070
42	7/31/90	18N/27Wdaa16	18.00	311.67	7.20	168.18	1.00	0.00	< 3.00	9.75	62.00	4.95	7.60	0.38	0.1320
43	7/31/90	18N/26Wbac16	18.50	368.19	7.10	163.64	0.96	0.00	< 3.00	4.00	72.00	2.85	3.90	5.00	0.0650
45	7/30/90	16N/26Wddb21	22.00	387.19	7.40	163.64	1.41	0.00	5.40	6.25	67.00	7.20	3.25	0.65	0.1770
46	7/30/90	17N/25Wdca16	19.50	586.62	7.00	254.55	0.97	0.00	19.00	26.75	104.00	11.40	7.00	0.53	0.1810
48	7/30/90	17N/25Wcba13	19.00	370.45	7.00	200.00	0.48	0.00	< 3.00	3.50	75.00	1.35	1.20	0.48	0.0300
49	7/30/90	17N/25Wbcc05	18.00	394.78	7.40	190.91	0.40	0.00	16.60	3.50	55.00	9.90	11.80	2.10	0.2970
52	7/31/90	18N/27Wbdc21	18.50	356.23	7.90	186.36	0.15	0.00	15.00	6.50	25.50	3.40	57.50	1.55	0.2200
53	7/31/90	18N/27Wbcc10	15.50	348.18	7.10	159.09	0.94	0.00	< 3.00	6.25	70.00	1.65	2.70	1.15	0.0450
55	8/1/90	18N/26Wbcc06	19.00	234.92	6.70	109.09	1.17	0.00	< 3.00	15.25	39.00	0.90	8.00	0.53	0.0380
56	8/1/90	18N/26Wcba04	17.00	295.09	6.30	131.82	3.14	0.00	< 3.00	7.75	54.00	1.65	5.00	2.10	0.0500
61	7/23/90	16N/24Wbbb16	19.00	446.13	6.90	126.36	2.67	0.00	9.55	7.50	91.50	1.42	2.10	0.80	0.0260
62	7/23/90	17N/24Wbdd33	17.50	375.84	7.20	195.45	0.89	0.00	< 3.00	4.50	74.00	4.20	1.68	0.53	0.0940
64	7/23/90	17N/24Wddd18	17.50	373.50	7.20	177.27	0.08	0.00	< 3.00	3.50	76.00	1.95	2.00	0.60	0.0420
65	7/23/90	17N/24W18dda	17.50	394.51	7.20	163.64	1.04	0.01	< 3.00	4.25	83.00	1.20	2.00	0.53	0.0240
66	7/25/90	16N/26Waca06	23.00	140.36	6.40	59.09	0.11	0.01	11.30	5.25	20.00	2.55	4.40	1.68	0.2100
69	7/25/90	17N/27Wccc18	18.00	551.77	7.50	295.45	0.01	0.01	18.40	10.00	86.00	9.60	24.00	0.30	0.1840
73	8/1/90	16N/27Wbac36	18.00	517.14	7.30	204.55	9.63	0.01	13.82	15.50	58.00	3.15	5.30	2.10	0.0530
77	7/25/90	17N/28Wccc13	18.50	405.32	7.40	195.45	5.24	0.00	< 3.00	8.00	82.00	1.20	3.25	0.53	0.0240
79	7/30/90	16N/26Wcbd26	19.00	570.36	7.30	200.00	3.10	0.00	74.25	18.50	93.00	14.32	12.00	1.35	0.2540
83	8/1/90	18N/27Wccd03	19.00	406.60	7.40	181.82	0.90	0.00	< 3.00	7.00	74.00	6.90	3.00	0.88	0.1540
84	7/31/90	18N/27Wada09	16.50	346.21	7.00	159.09	1.21	0.00	< 3.00	6.25	68.00	1.95	2.45	1.15	0.0470
		Number	31.00	31.00	31.00	31.00	31.00	31.00	31.00	31.00	31.00	31.00	31.00	31.00	31.00
		Mean Values	18.47	363.31	7.10	164.66	1.79	0.00	8.42	8.18	66.15	3.61	6.70	1.23	0.1008
		Stan.Dev.	1.71	114.14	0.37	53.58	2.20	0.00	17.12	5.10	23.18	3.41	10.34	0.95	0.09

Table B-1 (continued). Results of chemical analysis for wells sampled in Springfield Plateau Aquifer; Madison County, Arkansas.

Ozark Aquifer (wet season)

Sample Number	Date Collected	Well Location	TEMP (°C)	Spec. Cond. (µs/cm)	pH	Alkalinity (mg/L as CaCO3)	Nitrate (mg/L as N)	Ammonia (mg/L as N)	Sulfate (mg/L as SO4)	Chloride (mg/L as Cl)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Mg/Ca Ratio (meq/L)
7	5/21/90	16N/24Waaa16	18.00	300.13	7.30	195.45	0.18	0.00	18.80	9.00	58.00	12.75	10.00	0.80	0.3620
9	5/21/90	17N/24Wbcd33	17.00	363.55	7.80	172.73	0.02	0.00	11.00	3.75	52.00	13.50	6.00	1.20	0.4280
10	5/21/90	17N/24Wbac19	18.50	436.15	7.10	195.45	1.00	0.00	12.50	6.25	67.50	11.75	7.40	1.50	0.2870
27	5/22/90	16N/27Waca33	18.00	438.65	7.20	231.82	0.17	0.00	16.25	6.25	66.00	12.30	12.50	2.10	0.3070
32	5/23/90	18N/26Wddd36	18.00	360.15	7.30	186.36	0.22	0.00	17.50	2.50	38.50	20.85	3.10	6.50	0.8930
35	5/23/90	17N/26Wcad04	18.50	305.99	7.40	168.18	< 0.01	0.00	10.50	2.75	39.00	15.90	2.70	2.60	0.6720
50	5/29/90	18N/26Wbbc32	19.00	298.17	7.70	159.09	< 0.01	0.00	6.25	2.75	40.00	14.40	5.30	1.35	0.5930
51	5/29/90	18N/27Wdca23	18.00	311.67	7.60	168.18	0.04	0.02	< 3.00	3.25	39.00	15.30	3.00	1.50	0.6470
54	5/31/90	19N/27Wbdb36	18.50	456.70	7.20	200.00	< 0.01	0.00	3.00	4.25	75.00	13.80	2.40	0.40	0.3030
57	5/31/90	19N/26Wbcb21	19.00	408.85	7.10	204.55	0.04	0.00	14.25	3.00	65.00	13.50	1.55	1.65	0.3420
58	5/31/90	19N/26Wbda32	17.50	394.51	7.20	190.91	0.07	0.00	16.00	2.75	52.00	19.20	2.15	2.70	0.6090
59	5/31/90	18N/26Wadc03	17.00	342.30	7.30	163.64	0.04	0.00	21.00	3.00	43.00	19.50	0.70	1.20	0.7470
63	6/4/90	17N/24Wadc31	18.50	433.86	7.20	222.73	< 0.01	0.00	13.50	3.50	66.00	14.40	6.20	0.40	0.3600
68	6/4/90	16N/26Wddd11	18.00	438.65	6.80	209.09	0.21	0.00	14.75	2.00	41.00	18.60	28.00	1.35	0.7480
70	6/5/90	17N/27Wcad30	17.00	826.25	7.30	277.27	< 0.01	0.00	78.25	6.25	85.50	32.10	55.00	0.95	0.6190
		Number	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
		Mean Values	18.03	407.71	7.30	196.36	0.13	0.00	23.57	4.75	55.17	16.52	9.76	1.75	0.5278
		Stan.Dev.	0.64	124.58	0.24	29.98	0.28	0.00	42.68	2.65	14.62	4.59	13.75	1.43	0.19

Ozark Aquifer (dry season)

Sample Number	Date Collected	Well Location	TEMP (°C)	Spec. Cond. (µs/cm)	pH	Alkalinity (mg/L as CaCO3)	Nitrate (mg/L as N)	Ammonia (mg/L as N)	Sulfate (mg/L as SO4)	Chloride (mg/L as Cl)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Mg/Ca Ratio (meq/L)
7	7/23/90	16N/24Waaa16	20.50	306.33	7.60	168.18	0.29	0.00	10.85	8.00	49.00	7.95	5.00	0.74	0.2670
9	7/23/90	17N/24Wbcd33	17.00	368.27	7.60	159.09	< 0.01	0.00	14.40	2.50	53.00	13.80	5.30	1.38	0.4290
10	7/23/90	17N/24Wbac19	21.00	427.67	7.30	181.82	0.50	0.00	19.40	3.50	62.00	13.30	7.25	1.70	0.3540
27	7/26/90	16N/27Waca33	19.50	430.19	7.20	218.18	0.27	0.00	16.15	3.75	59.00	15.30	12.00	2.60	0.4270
32	7/30/90	18N/26Wddd36	19.00	372.71	7.50	163.64	0.21	0.00	16.50	2.25	41.00	18.90	3.18	6.95	0.7600
35	7/30/90	17N/26Wcad04	18.50	319.69	7.50	145.45	0.64	0.02	15.60	2.00	40.00	15.75	2.45	2.60	0.6490
50	7/31/90	18N/26Wbbc32	19.50	312.87	7.70	140.91	0.03	0.00	13.30	2.00	39.00	13.50	3.80	1.75	0.5700
51	7/31/90	15N/27Wdca23	18.50	319.69	7.50	154.55	0.13	0.00	13.55	4.00	39.00	15.75	3.10	1.80	0.6606
54	6/1/90	19N/27Wbdb36	19.00	449.51	7.30	240.91	< 0.01	0.00	< 3.00	3.50	76.00	13.05	3.00	0.48	0.2830
57	8/1/90	19N/26Wbcb21	19.00	412.24	7.40	195.45	< 0.01	0.00	15.85	2.00	66.00	13.65	2.00	1.75	0.3410
58	8/1/90	19N/26Wbda32	17.50	396.85	7.40	200.00	0.06	0.00	18.00	2.50	56.00	19.80	2.20	2.80	0.5830
59	8/1/90	18N/26Wadc03	17.00	351.75	7.60	172.73	0.04	0.00	20.70	2.00	46.00	20.10	0.78	1.35	0.7200
63	7/23/90	17N/24Wadc31	18.00	427.10	7.30	204.55	0.06	0.01	16.70	2.75	68.00	15.30	5.00	0.33	0.3710
68	7/25/90	16N/26Wddd11	17.50	402.68	6.70	195.45	0.29	0.01	13.70	10.50	41.00	19.80	27.50	1.30	0.7960
70	7/26/90	17N/27Wcad30	18.00	692.60	7.40	272.73	0.01	0.00	115.00	5.50	75.00	21.30	59.50	0.78	0.4650
78	7/26/90	17N/27Waaa28	20.50	339.15	7.50	172.73	0.04	0.00	11.00	5.50	35.00	21.60	5.00	0.30	1.0170
82	7/31/90	18N/27Waad09	19.00	299.30	7.90	131.82	0.10	0.00	17.00	3.00	24.00	13.20	24.00	0.88	0.9060
		Number	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00
		Mean Values	18.76	389.92	7.45	183.42	0.16	0.00	20.45	3.84	51.12	16.00	10.06	1.74	0.5648
		Stan.Dev.	1.16	89.48	0.26	35.72	0.18	0.01	24.22	2.29	14.45	3.60	14.37	1.50	0.22

Table B-1 (continued). Results of chemical analysis for wells sampled in Ozark Aquifer; Madison County, Arkansas.

Undifferentiated Shallow Aquifers (wet season)

Sample Number	Date Collected	Well Location	Well Depth (ft)	Elevation (ft)	Datum T.D (ft)	Mg/Ca Ratio (meq/L)	Hardness (mg/L as CaCO3)	Percent Difference Cations / Anions
1	5/21/90	16N/25wabd24	350.00	1,640.00	1,290.00	0.3710	212.20	0.93
3	5/21/90	16N/25Wdcb22	22.00	1,445.00	1,423.00	0.1890	279.28	-4.17
4	5/21/90	16N/25Wabd26	25.00	1,420.00	1,395.00	0.4720	40.42	1.92
21	5/22/90	16N/28Waca14	80.00	1,590.00	1,510.00	0.5140	141.72	-0.31
22	5/22/90	16N/27Wbda16	200.00	1,760.00	1,560.00	0.6540	268.28	4.92
23	5/22/90	16N/27Wbdb28	32.00	1,345.00	1,313.00	1.0090	60.13	-7.41
25	5/22/90	16N/26Waab08	220.00	1,700.00	1,480.00	1.1380	114.64	-1.51
26	5/22/90	16N/27Wdcb25	150.00	1,560.00	1,410.00	1.0930	99.16	-2.49
67	6/4/90	16N/26Wacd12	171.00	1,430.00	1,259.00	0.8650	9.31	-12.82
71	6/5/90	16N/28Waca02	130.00	1,635.00	1,505.00	0.4870	131.80	0.62
72	6/5/90	16N/27Wdbc07	125.00	1,621.00	1,496.00	0.5960	175.19	0.02
74	6/5/90	16N/27Waac33	135.00	1,350.00	1,215.00	0.8140	22.63	0.66
		Number	12					
		Mean Value	136.67	1,541.33	1,404.67	0.6835	129.56	-1.64

Undifferentiated Shallow Aquifers (dry season)

Sample Number	Date Collected	Well Location	Well Depth (ft)	Elevation (ft)	Datum T.D. (ft)	Mg/Ca Ratio (meq/L)	Hardness (mg/L as CaCO3)	Percent Difference Cations / Anions
1	7/23/90	16N/25Wabd24	350.00	1,640.00	1,290.00	0.3910	208.43	2.70
3	7/23/90	16N/25Wdcb22	22.00	1,445.00	1,423.00	0.2010	287.97	5.20
4	7/23/90	16N/25Wabd26	25.00	1,420.00	1,395.00	0.4750	92.02	7.23
21	7/26/90	16N/28Waca14	80.00	1,590.00	1,510.00	0.5670	160.31	-0.48
22	7/25/90	16N/27Wbda16	200.00	1,760.00	1,560.00	0.5840	217.45	5.97
23	7/25/90	16N/27Wbdb28	32.00	1,345.00	1,313.00	0.8900	70.71	-0.95
25	7/25/90	16N/26Waab08	220.00	1,700.00	1,480.00	1.0920	112.18	-2.33
26	7/26/90	16N/27Wdcb25	150.00	1,560.00	1,410.00	0.8330	130.29	0.88
67	7/25/90	16N/26Wacd12	171.00	1,430.00	1,259.00	0.8240	13.65	-5.85
71	7/26/90	16N/28Waca02	130.00	1,635.00	1,505.00	0.4060	207.16	-2.44
72	7/26/90	16N/27Wdbc07	125.00	1,621.00	1,496.00	0.5470	254.79	-0.33
74	7/25/90	16N/27Waac33	135.00	1,350.00	1,215.00	0.4240	24.88	0.11
75	7/25/90	16N/26Wbbd07	54.00	1,450.00	1,396.00	0.3710	225.89	-0.35
76	7/25/90	16N/27Wabc25	150.00	1,560.00	1,410.00	0.5190	606.64	1.63
80	7/30/90	16N/25Wbbd23	60.00	1,750.00	1,690.00	0.6940	524.02	8.59
81	7/30/90	16N/25Wbbd23	280.00	1,750.00	1,470.00	0.6110	110.57	38.01
		Number	16.00					
		Mean Values	136.50	1,562.88	1,426.38	0.5893	202.94	3.60

Table B-2. Completion datum and Mg/Ca (meq/L) ratios used in aquifer determination.

Springfield Plateau Aquifer (wet season)

Sample Number	Date Collected	Well Location	Well Depth (ft)	Elevation (ft)	Datum T.D. (ft)	Mg/Ca Ratio (meq/L)	Hardness (mg/L as CaCO3)	Percent Difference Cations / Anions
5	5/21/90	16N/24Wcbd28	25.00	1,400.00	1,375.00	0.3420	21.79	-1.41
6	5/21/90	16N/24Wbcc15	150.00	1,380.00	1,230.00	0.0290	195.54	0.51
8	5/21/90	16N/24Wbcc09	50.00	1,360.00	1,310.00	0.0460	196.11	0.38
20	5/22/90	16N/28Waca23	145.00	1,282.00	1,137.00	0.0840	159.80	-31.01
33	5/23/90	17N/25Wbac06	165.00	1,385.00	1,220.00	0.0610	75.56	-1.11
34	5/23/90	17N/26Waac10	SPRING	1,270.00	1,270.00	0.0900	59.92	6.33
36	5/23/90	17N/27Wbbd12	20.00	1,250.00	1,230.00	0.0590	121.77	-2.06
37	5/23/90	17N/27Wdcd08	24.00	1,335.00	1,311.00	0.0220	171.19	-0.39
38	5/23/90	17N/27Wbdc19	75.00	1,385.00	1,310.00	0.0280	179.92	-1.90
41	5/26/90	18N/27Wdbd28	120.00	1,225.00	1,105.00	0.0400	161.15	-0.76
42	5/26/90	18N/27Wdaa16	191.00	1,450.00	1,259.00	0.1220	170.95	0.18
43	5/26/90	18N/26Wbac16	100.00	1,480.00	1,380.00	0.0500	141.77	0.61
45	5/29/90	16N/26Wddb21	110.00	1,280.00	1,170.00	0.1720	163.99	-5.04
46	5/29/90	17N/25Wdca16	225.00	1,395.00	1,170.00	0.2770	261.58	-0.36
47	5/29/90	17N/25Waab20	250.00	1,370.00	1,120.00	0.0800	259.07	-3.10
48	5/29/90	17N/25Wcba13	100.00	1,450.00	1,350.00	0.0170	216.19	1.93
49	5/29/90	17N/25Wbcc05	370.00	1,500.00	1,130.00	0.0720	174.19	-3.56
52	5/29/90	18N/27Wbdc21	260.00	1,390.00	1,130.00	0.0760	104.88	-1.27
53	5/31/90	18N/27Wbcc10	52.00	1,280.00	1,228.00	0.0400	127.42	1.45
55	5/31/90	18N/26Wbcc06	34.00	1,510.00	1,476.00	0.1300	53.65	-5.56
56	5/31/90	18N/26Wcba04	65.00	1,460.00	1,395.00	0.1240	56.15	4.24
61	6/4/90	16N/24Wbbb16	120.00	1,350.00	1,230.00	0.0570	146.73	-9.60
62	6/4/90	17N/24Wbdd33	234.00	1,340.00	1,106.00	0.0980	200.34	-1.90
64	6/4/90	17N/24Wddd18	510.00	1,480.00	970.00	0.0200	188.69	2.71
65	6/4/90	17N/24Wdda18	245.00	1,440.00	1,195.00	0.0200	193.69	3.52
66	6/4/90	16N/26Waca06	45.00	1,375.00	1,330.00	0.2180	38.02	-2.34
69	6/5/90	17N/27Wccc18	308.00	1,370.00	1,062.00	0.1740	258.13	-1.95
73	6/5/90	16N/27Wbac36	60.00	1,265.00	1,205.00	0.0490	236.07	1.25
		Number	28.00					
		Mean Values	144.75	1,373.46	1,228.71	0.0928	154.80	-1.79

Table B-2 (continued). Completion datum and Mg/Ca (meq/L) ratios used in aquifer determination.

Springfield Plateau Aquifer (dry season)

Sample Number	Date Collected	Well Location	Well Depth (ft)	Elevation (ft)	Datum T.D. (ft)	Mg/Ca Ratio (meq/L)	Hardness (mg/L as CaCO3)	Percent Difference Cations / Anions
5	7/23/90	16N/24Wcbd28	25.00	1,400.00	1,375.00	0.3200	28.02	1.44
6	7/23/90	16N/24Wbcc15	150.00	1,380.00	1,230.00	0.0260	194.92	11.11
8	7/23/90	16N/24Wbcc09	50.00	1,360.00	1,310.00	0.0940	158.53	4.43
20	7/26/90	16N/28Waca23	145.00	1,282.00	1,137.00	0.0380	254.23	0.88
33	7/30/90	17N/25Wbac06	165.00	1,385.00	1,220.00	0.0490	78.69	1.20
34	7/30/90	17N/26Waac10	SPRING	1,270.00	1,270.00	0.0400	111.81	5.45
36	7/26/90	17N/27Wbbd12	20.00	1,250.00	1,230.00	0.0530	147.38	-0.22
37	7/26/90	17N/27Wdcd08	24.00	1,335.00	1,311.00	0.0230	191.81	5.49
38	8/1/90	17N/27Wbdc19	75.00	1,385.00	1,310.00	0.0280	203.04	4.76
41	7/31/90	18N/27Wdbd28	120.00	1,225.00	1,105.00	0.1070	160.38	3.95
42	7/31/90	18N/27Wdaa16	191.00	1,450.00	1,259.00	0.1320	175.30	2.50
43	7/31/90	18N/26Wbac16	100.00	1,480.00	1,380.00	0.0650	191.69	10.42
45	7/30/90	16N/26Wddb21	110.00	1,280.00	1,170.00	0.1770	197.02	4.54
46	7/30/90	17N/25Wdca16	225.00	1,395.00	1,170.00	0.1810	306.74	2.17
48	7/30/90	17N/25Wcba13	100.00	1,450.00	1,350.00	0.0300	193.04	-1.53
49	7/30/90	17N/25Wbcc05	370.00	1,500.00	1,130.00	0.2970	178.09	-1.88
52	7/31/90	18N/27Wbdc21	260.00	1,390.00	1,130.00	0.2200	77.69	-0.85
53	7/31/90	18N/27Wbcc10	52.00	1,280.00	1,228.00	0.0450	181.77	-0.66
55	8/1/90	18N/26Wbcc06	34.00	1,510.00	1,476.00	0.0380	101.19	-4.27
56	8/1/90	18N/26Wcba04	65.00	1,460.00	1,395.00	0.0500	141.77	4.02
61	7/23/90	16N/24Wbbb16	120.00	1,350.00	1,230.00	0.0260	234.57	7.58
62	7/23/90	17N/24Wbdd33	234.00	1,340.00	1,106.00	0.0940	202.22	0.92
64	7/23/90	17N/24Wddd18	510.00	1,480.00	970.00	0.0420	198.00	6.14
65	7/23/90	17N/24Wdda18	245.00	1,440.00	1,195.00	0.0240	212.42	12.82
66	7/25/90	16N/26Waca06	45.00	1,375.00	1,330.00	0.2100	60.46	-3.52
69	7/25/90	17N/27Wccc18	308.00	1,370.00	1,062.00	0.1840	254.36	-2.72
73	8/1/90	16N/27Wbac36	60.00	1,265.00	1,205.00	0.0530	257.92	4.46
77	7/25/90	17N/28Wccc13	105.00	1,350.00	1,245.00	0.0240	209.92	1.49
79	7/30/90	16N/26Wcbd26	100.00	1,330.00	1,230.00	0.2540	291.21	2.61
83	8/1/90	18N/27Wccd03	77.00	1,300.00	1,223.00	0.1540	213.29	7.63
84	7/31/90	18N/27Wada09	50.00	1,290.00	1,240.00	0.0470	178.00	5.21
		Number	31.00					
		Mean Values	133.39	1,366.35	1,232.97	0.1008	180.18	3.08

Table B-2 (continued). Completion datum and Mg/Ca (meq/L) ratios used in aquifer determination.

Ozark Aquifer (wet season)

Sample Number	Date Collected	Well Location	Well Depth (ft)	Elevation (ft)	Datum T.D. (ft)	Mg/Ca Ratio (meq/L)	Hardness (mg/L as CaCO3)	Percent Difference Cations / Anions
7	5/21/90	16N/24Waaa16	200.00	1,375.00	1,175.00	0.3620	197.28	-1.06
9	5/21/90	17N/24Wbcd33	650.00	1,510.00	860.00	0.4280	185.35	3.43
10	5/21/90	17N/24Wbac19	500.00	1,525.00	1,025.00	0.2870	216.93	4.43
27	5/22/90	16N/27Waca33	701.00	1,531.00	830.00	0.3070	215.43	-1.74
32	5/23/90	18N/26Wddd36	500.00	1,580.00	1,080.00	0.8930	181.74	-2.07
35	5/23/90	17N/26Wcad04	330.00	1,295.00	965.00	0.6720	162.69	-2.36
50	5/29/90	18N/26Wbbc32	393.00	1,460.00	1,067.00	0.5930	159.04	1.61
51	5/29/90	18N/27Wdca23	801.00	1,450.00	649.00	0.6470	160.23	-0.39
54	5/31/90	19N/27Wbdb36	456.00	1,560.00	1,104.00	0.3030	244.08	3.70
57	5/31/90	19N/26Wbcb21	760.00	1,730.00	970.00	0.3420	217.85	0.86
58	5/31/90	19N/26Wbda32	598.00	1,585.00	987.00	0.6090	208.72	2.00
59	5/31/90	18N/26Wadc03	700.00	1,600.00	900.00	0.7470	187.45	0.93
63	6/4/90	17N/24Wadc31	300.00	1,390.00	1,090.00	0.3600	224.04	-0.02
68	6/4/90	16N/26Wddd11	325.00	1,560.00	1,235.00	0.7480	178.76	0.70
70	6/5/90	17N/27Wcad30	300.00	1,265.00	965.00	0.6190	345.36	-0.09
		Number	15.00					
		Mean Values	500.93	1,494.40	993.47	0.5278	205.66	0.66

Ozark Aquifer (dry season)

Sample Number	Date Collected	Well Location	Well Depth (ft)	Elevation (ft)	Datum T.D. (ft)	Mg/Ca Ratio (meq/L)	Hardness (mg/L as CaCO3)	Percent Difference Cations / Anions
7	7/23/90	16N/24Waaa16	200.00	1,375.00	1,175.00	0.2670	155.10	7.50
9	7/23/90	17N/24Wbcd33	650.00	1,510.00	860.00	0.4290	189.08	7.24
10	7/23/90	17N/24Wbac19	500.00	1,525.00	1,025.00	0.3540	209.53	4.61
27	7/26/90	16N/27Waca33	701.00	1,531.00	830.00	0.4270	210.23	0.56
32	7/30/90	18N/26Wddd36	500.00	1,580.00	1,080.00	0.7600	179.99	3.82
35	7/30/90	17N/26Wcad04	330.00	1,295.00	965.00	0.6490	164.58	3.16
50	7/31/90	18N/26Wbbc32	393.00	1,460.00	1,067.00	0.5700	152.85	2.53
51	7/31/90	18N/27Wdca23	801.00	1,450.00	649.00	0.6606	162.08	-0.20
54	8/1/90	19N/27Wbdb36	456.00	1,560.00	1,104.00	0.2830	243.51	1.75
57	8/1/90	19N/26Wbcb21	760.00	1,730.00	970.00	0.3410	220.97	3.62
58	8/1/90	19N/26Wbda32	598.00	1,585.00	987.00	0.5830	221.18	2.35
59	8/1/90	18N/26Wadc03	700.00	1,600.00	900.00	0.7200	197.41	1.67
63	7/23/90	17N/24Wadc31	300.00	1,390.00	1,090.00	0.3710	232.73	3.86
68	7/25/90	16N/26Wddd11	325.00	1,560.00	1,235.00	0.7960	183.68	5.08
70	7/26/90	17N/27Wcad30	300.00	1,265.00	965.00	0.4680	274.83	1.15
78	7/26/90	17N/27Waaa28	300.00	1,515.00	1,215.00	1.0170	176.06	-0.44
82	7/31/90	18N/27Waad09	100.00	1,300.00	1,200.00	0.9060	114.12	4.97
		Number	17.00					
		Mean Values	465.53	1,484.18	1,018.65	0.5648	193.41	3.13

Table B-2 (continued). Completion datum and Mg/Ca (meq/L) ratios used in aquifer determination.

APPENDIX C

Quality-Control/ Quality-Assurance

Table C-1: Nitrate plus nitrite (mg/L as N) values obtained during duplicate analysis of samples from Madison County, Arkansas.

Sample Number	Initial Conc.	Duplicate Conc.	Mean Value	Sum Squares of Dev.
6w	12.950	13.050	13.000	0.00500
24w	0.140	0.160	0.150	0.00020
35w	0.030	0.030	0.030	0.00000
43w	0.590	0.800	0.695	0.22000
48w	0.510	0.480	0.495	0.00450
53w	1.600	1.690	1.645	0.00405
59w	0.050	0.040	0.045	0.00050
65w	1.120	1.080	1.100	0.00080
23d	0.416	0.330	0.373	0.00370
33d	1.030	1.102	1.066	0.00259
36d	2.400	2.394	2.397	0.00002
53d	0.941	0.968	0.955	0.00037
58d	0.060	0.047	0.054	0.00009
61d	2.669	2.854	2.762	0.00171
69d	0.012	0.015	0.014	0.00001
78d	0.042	0.032	0.037	0.00005
83d	0.903	0.869	0.886	0.00057

Pooled standard deviation (wet season) = +/- 0.064
Pooled standard deviation (dry season) = +/- 0.032
Pooled standard deviation (both seasons) = +/- 0.049

Table C-2: Nitrate plus nitrite (mg/L) values obtained from field duplicates and trip blanks from Madison County, Arkansas.

Sample Number	Initial Conc.	Duplicate Conc.	Mean Value	Percent Difference
20	1.97	1.81	1.89	4.23
38	4.63	4.85	4.74	1.27
69	0.03	0.03	0.03	0.00
70	< 0.01	< 0.01	< 0.01	0.00
77	2.73	2.93	2.83	3.53

Blank Number	Concentration
1	< 0.01
2	< 0.01
3	< 0.01
4	< 0.01
5	< 0.01

Table C-3: Relative standard deviation of spiked nitrate plus nitrite (mg/L as N) samples from Madison County, Arkansas.

Sample Number	UN-SP	CON-SP	TH-SP	EX-SP	%D	%R
3	0.046	0.300	0.323	0.344	+6.50	106.50
7	0.290	0.250	0.540	0.490	-9.20	90.80
23	0.416	0.300	0.508	0.487	+2.10	102.10
23	0.416	0.120	0.453	0.415	-3.80	96.20
25	0.690	0.250	0.940	0.909	-3.30	96.70
27	0.273	0.300	0.435	0.468	+3.30	103.30
27	0.273	0.250	0.523	0.598	-14.30	85.70
32	0.210	0.120	0.330	0.315	+0.70	100.70
32	0.210	0.300	0.510	0.480	+7.40	107.40
52	0.148	0.200	0.348	0.396	+13.80	113.80
58	0.060	0.250	0.310	0.335	+2.50	102.50
59	0.039	0.250	0.289	0.266	-2.40	97.60
69	0.012	0.300	0.306	0.256	-4.90	96.10
69	0.012	0.120	0.128	0.054	-7.40	92.60
78	0.042	0.300	0.320	0.269	-5.10	94.90
80	0.297	0.200	0.497	0.466	-3.10	96.90

$\overline{\%R}$ = 98.90
RSD = 6.99

Where:

UN-SP = Concentration of original sample.
CON-SP = Concentration of the spike.
TH-SP = Theoretical concentration of the spiked sample.
EX-SP = Experimental concentration of the spiked sample.
%D = Percent deviation of experimentally determined spiked samples.

$$\frac{(EX\text{-}SP)-(TH\text{-}SP)}{(TH\text{-}SP)} * (100)$$

%R = Percent recovery of the spiked sample.
= 100 + (%D)
$\overline{\%R}$ = Mean value of %R.
s = Standard deviation of %R.
RSD = Relative standard deviation of percent recoveries.
= (s)/($\overline{\%R}$) * 100

Table C-4: E.P.A. quality-control assurance samples for mineral analysis (mg/L)

Parameter	True Value	Experimental Value	95% Confidence interval	Difference
Total Alk.	27.30	27.29	24.10--30.50	0.01
Sulfate	20.00	18.65	16.30--23.10	1.35
Chloride	52.10	50.00	48.20--55.40	2.10
Nitrate	1.59	1.45	1.43-- 1.71	0.14
Calcium	20.00	19.50	17.50--22.20	0.50
Magnesium	5.00	5.25	4.18-- 5.62	0.25
Sodium	20.00	20.00	17.80--22.30	0.00
Potassium	5.00	4.15	4.17-- 5.71	0.85

APPENDIX D

Sample collection field checklist

SAMPLE COLLECTION CHECK-LIST

LOCATION INFORMATION

DATE COLLECTED: ____________________ SAMPLE NUMBER: ___________

WELL LOCATION: ____________________ SURFACE ELEVATION: ______

LAND OWNER: ____

____

____

WELL INFORMATION

AGE OF WELL: ____________________ TYPE OF CASING USED: ___________

DEPTH OF WELL: ____________________ DEPTH TO WATER TABLE: __________

AMOUNT OF FLOW: ____________________

ODORS AND/OR MINERALIZATION: ____________________ DISTANCE/DIRECTION TO SEPTIC SYSTEM: ______________

____

____

FIELD TESTS

TEMPERATURE: ____________________ CONDUCTIVITY: ____________

ALKALINITY: ____________________ pH: ____________

LOCAL GEOLOGY-OUTCROPS: ____

NOTES/MAP: