**Arkansas Water Resources Center**

# NITRATE CONCENTRATIONS OF GROUND WATER FROM LIMESTONE AND DOLOMITIC AQUIFERS IN THE NORTHEASTERN WASHINGTON COUNTY AREA, ARKANSAS

Submitted to:

Arkansas Department of Pollution Control & Ecology

**MSC-68**

1990

By


Kenneth F. Steele, Principal Investigator
Arkansas Water Resources Center
University of Arkansas
Fayetteville, Arkansas 72701

And

William K. McCalister, Research Assistant
Department of Geology
University of Arkansas
Fayetteville, Arkanas 72701

TABLE OF CONTENTS

LIST OF TABLES

## LIST OF FIGURES

# NITRATE CONCENTRATIONS OF GROUND WATER FROM LIMESTONE AND DOLOMITIC AQUIFERS IN THE NORTHEASTERN WASHINGTON COUNTY AREA, ARKANSAS

K. F. Steele and W. K. McCalister
Arkansas Water Resources Research Center
and Department of Geology
113 Ozark Hall
University of Arkansas
Fayetteville, AR 72701

## Abstract

The Ozark Region of Arkansas is a major poultry-producing area of the United States. Large quantities of poultry waste are spread as fertilizer on thin soils of pastureland overlying limestone and dolomitic aquifers. Because these aquifers provide domestic water supplies for the rural population and are susceptible to contamination from surface water, there is concern that nitrate leached from poultry litter is polluting the ground water. In response to this concern, well water from a major poultry-producing area was compared with that from a forested area in the northeastern Washington County area, Arkansas. Although nitrate concentration of the well water from the poultry producing area (2.83 mg/L as nitrogen) is about 10 times that of springs in the forested area, it is considerably below the drinking water limits of 10 mg/L set by the U.S. Environmental Protection Agency. The shallow Boone-St. Joe aquifer contains about twice as much nitrate as the deeper Everton aquifer. Expansion of poultry production in this region requires implementation of best management practices in order to protect the ground water from nitrate pollution.

## Introduction

Although nitrate contamination of water by commercial fertilizers and feed lots has been extensively investigated (e.g. Beck et al., 1985; Pionke and Urban, 1985; Mc Leod and Hegg, 1984; Hill, 1982; Burden, 1982; Khaleel et al., 1980; Spalding et al., 1978; Sommerfeldt et al., 1973; Groba and Hahn, 1972; Lorimar et al., 1972; Walker et al., 1972; and Gillham and Webber, 1969), very little research has been conducted on the effects of land application of poultry litter (Adamski and Steele, 1988; Wolf et al., 1988; Magette et al., 1988; Gilmour et al., 1987; Giddens and Barnett, 1980; and Liebhardt et al., 1979). Arkansas is the national leader in broiler production and in 1988 produced over 900 million birds (broilers, turkeys and hens)(Arkansas Agricultural Statistics Service, 1989).

A majority of Arkansas' poultry production is in the Ozark Region of the northwestern portion of the state. Brittle limestone which readily fractures forms the bedrock for most of this region. Fractures and solution-enlarged fractures provide ready access for surface water to enter the aquifer (Figure 1). Fractures and thin soils combined make limestone aquifers susceptible to contamination from surface sources.

Poultry litter (manure and associated bedding material such as sawdust) has long been recognized as a valuable source of ni-

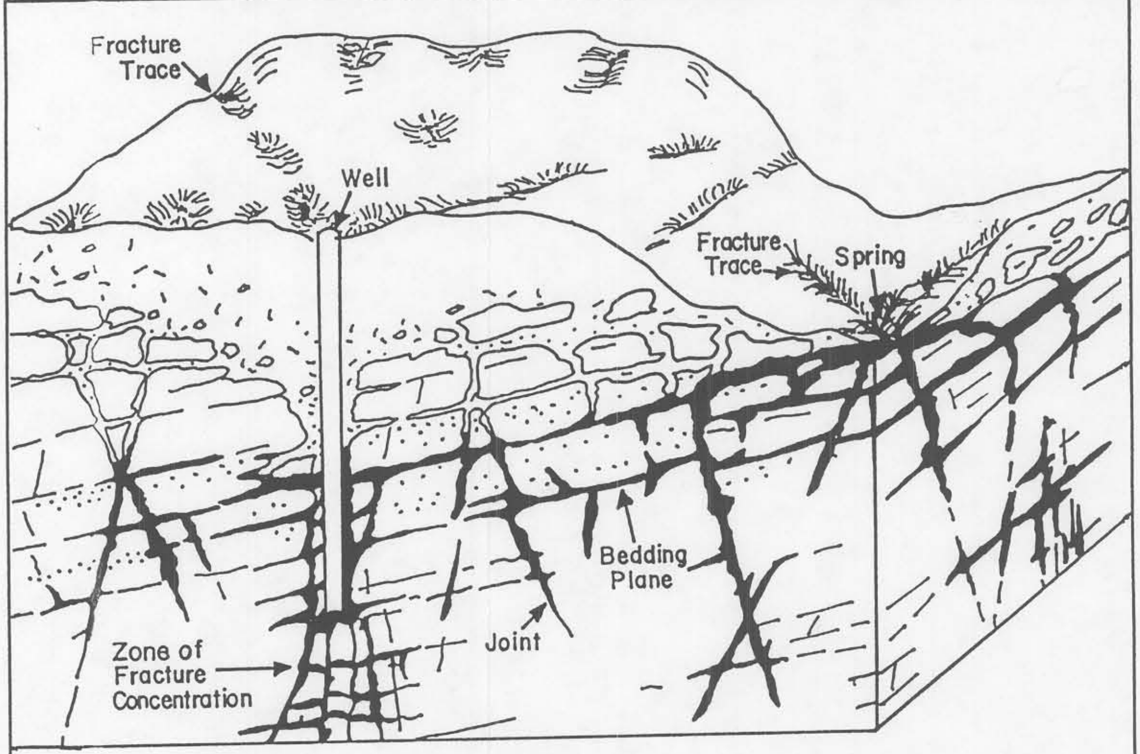


Figure 1. Schematic diagram showing the relationship of a spring and a high-yield water well to fracture and bedding planes.

trate fertilizer and is applied to pastureland in northwestern Arkansas. Because of this practice, beef cattle production is associated with land to which poultry litter has been applied. There is concern that nitrate from poultry litter and cattle manure in excess of plant cover requirements could be leached through the soil and pollute the ground water.

Two studies specifically designed to analyze the effects of land-applied poultry wastes on ground water quality in northwestern Arkansas have been conducted. One study focused on springs issuing from the Boone-St. Joe Formation during 1986-1987 (Adamski and Steele, 1988), and the second study in 1989 (reported here) focused on wells completed in the Boone-St. Joe and Everton aquifers.

More detailed information for this project is available in McCalister (1990). Two publications associated with this project are in press (Steele et al., 1990a and Steele et al., 1990b).

## Study Area and Land Use

The northeastern Washington County area was used for the present study and for the earlier study by Adamski and Steele (1988) (Figure 2) to investigate the effect of poultry litter on ground water nitrate concentrations because: (1) it is one of the highest density poultry-producing areas in the United States and (2) the limestone aquifers of the area, especially the Boone-St. Joe, are susceptible to contamination from surface sources. In 1988, Washington County produced 113,635,000 broilers, 2,316,000 turkeys, 121,000 beef cattle (Arkansas Agricultural Statistics Service, 1989) and 2,053,000 hens (Washington County Extension Service, personal communication, 1990).

For this investigation, a smaller study area which overlapped a portion of the first study area (Adamski and Steele, 1988) was used. For both studies, experimental and control subareas were defined (Figures 2 and 3). The location of the wells and site numbers used for this study are shown in Figure 3. The two subareas are adjacent and, with the exception of land use practices, have similar geology, meteorology and hydrogeology.

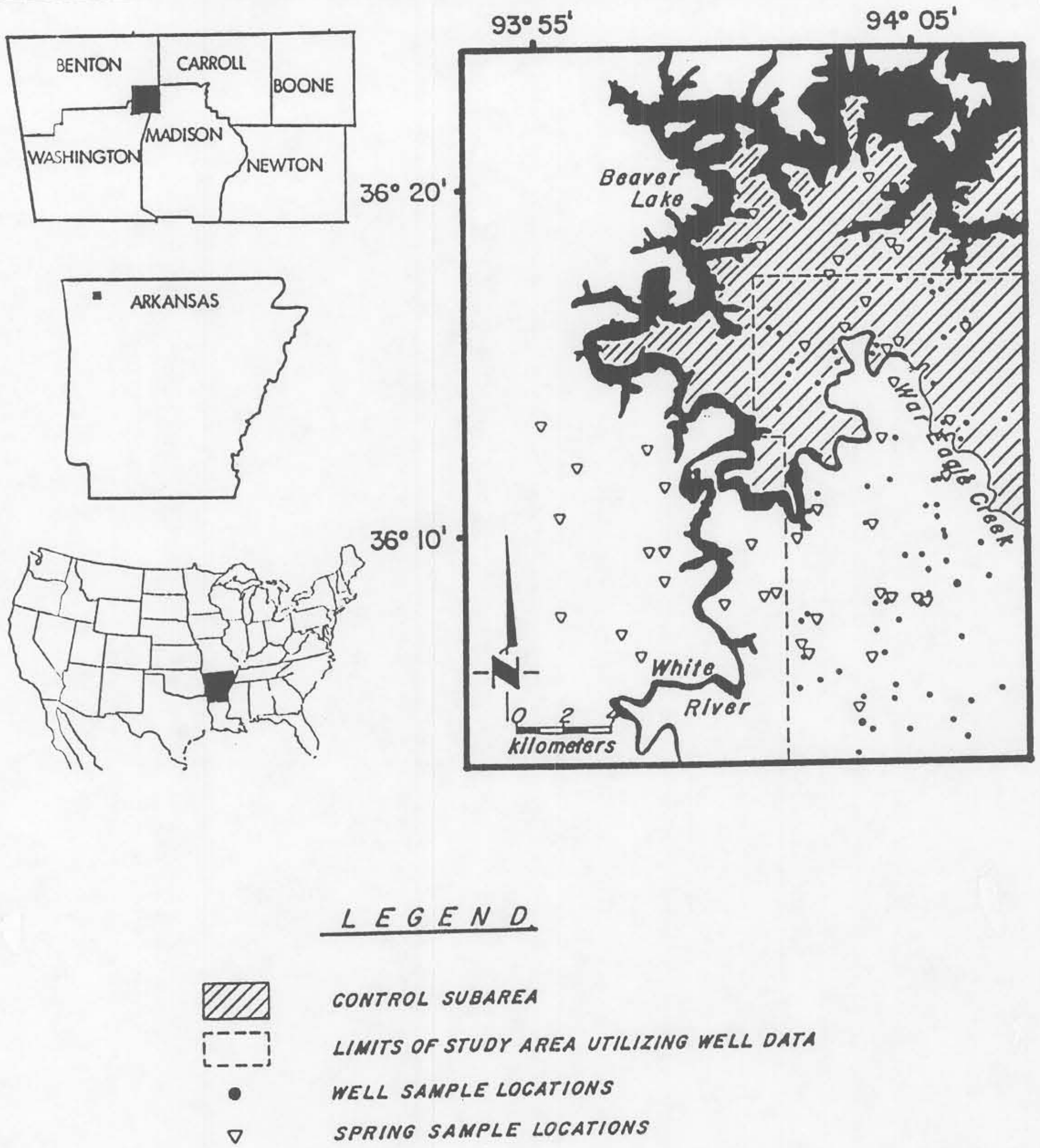


Figure 2. Location of well sites for this study and for springs used by Adamski and Steele (1988).

In 1989 about 6,000,000 broilers and 44,000 turkeys were produced and 171,000 hens were housed in the 140 $km^2$ experimental subarea. These fowl are estimated to have produced a total of $23.5 \times 10^6$ kg of waste which would yield about 382,000 kg of total nitrogen. Even if 50% of the nitrogen in the animal wastes may have volatilized (U.S. Department of Agriculture, 1975), an appreciable amount of nitrogen was spread on pastureland in the experimental subarea. A 145 $km^2$ portion of an adjacent wildlife

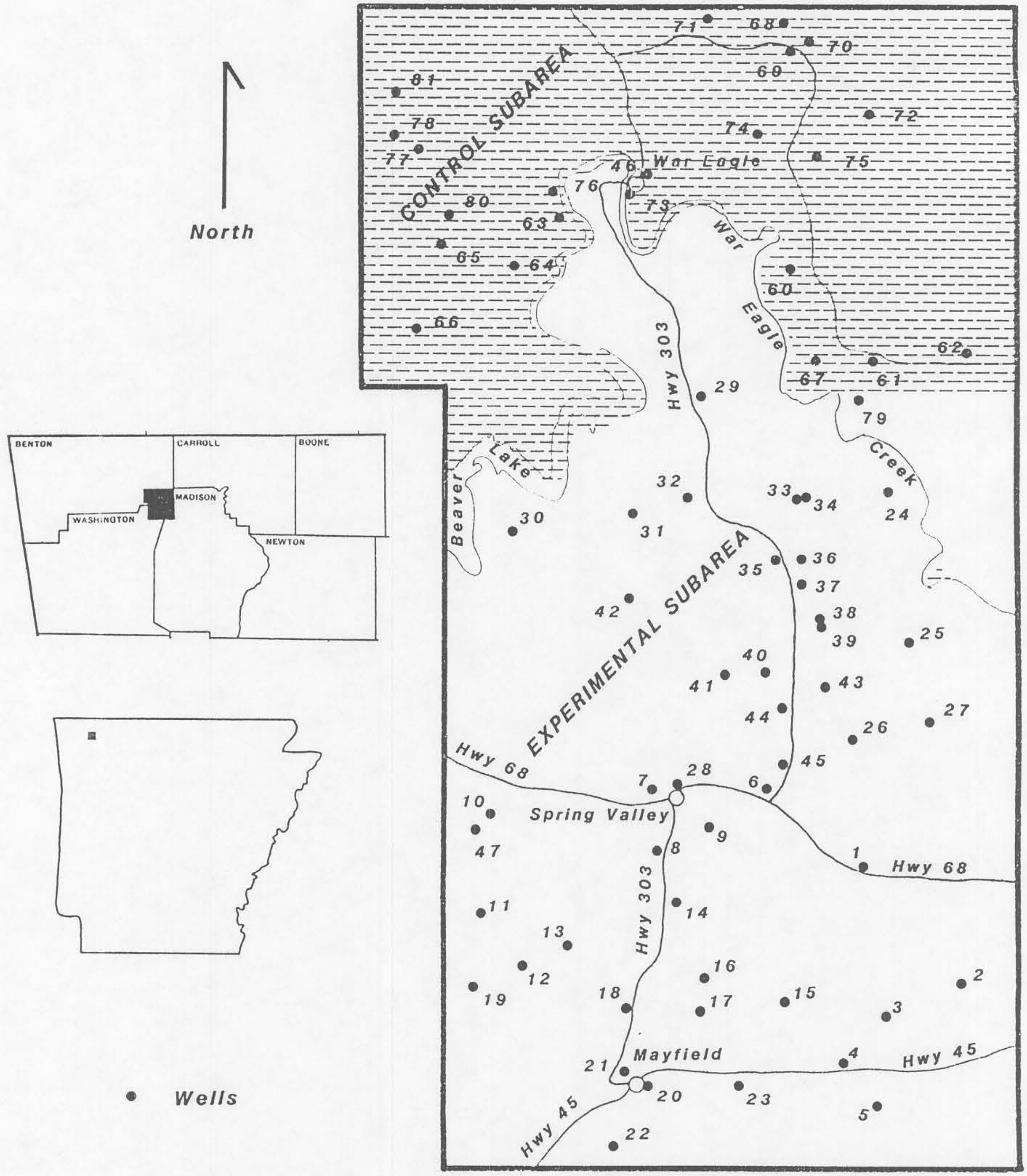


Figure 3. Well sites and numbers used in this study. See Appendix I for more precise location of wells.

management area was used as the control subarea (shaded portion of Figure 2).

The 1800 beef cattle and dairy cows in the experimental subarea of this study are estimated to have produced 20 x $10^6$ kg of waste which would yield about 170,000 kg of total nitrogen. Another source of nitrate to ground water is septic tank effluent. All the houses in this rural area use septic tank systems for treating domestic wastewater. The 475 septic tanks in the experimental subarea are estimated to have produced a total of only 954,000 kg of waste which would yield about 6,000 kg of total nitrogen.

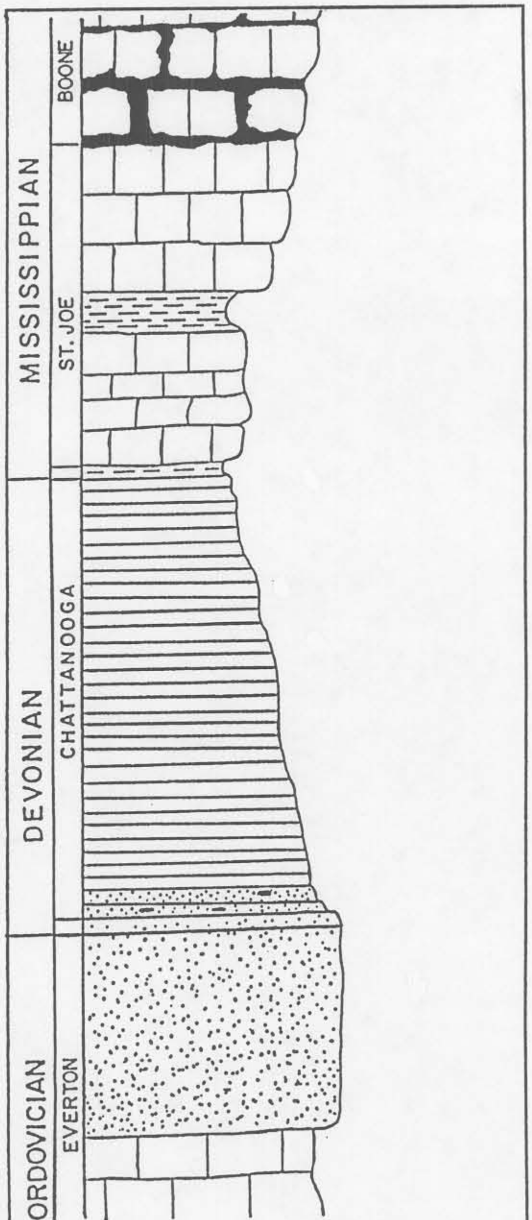


Figure 4. Schematic stratigraphic column for northwest Arkansas (from Manger and Borengasser, 1979).

## Geology

Soils are typically thin (maximum thickness of 1.8 meters) and are moderately to slowly permeable (Harper et al., 1969). The bed rock of the study area is dominantly cherty limestone (Boone Formation); however, minor areas of shale and sandstone exist as erosional remnants. The Boone Formation overlies the St. Joe Formation (limestone) and together the two form a single aquifer in this area (Figure 3). Based on well-driller reports, the thickness of the aquifer ranges from 35 to 85 meters in this area. The relatively impermeable Chattanooga Shale Formation (about 18 meters thick) underlies the Boone-St. Joe aquifer in the study area. The Everton Formation is a complex of intertonguing dolomite, limestone and sandstone. The Kings River Sandstone Member of the Everton is important hydrologically in the study area (Figure 4).

## Hydrogeology

Water wells completed in the Boone-St. Joe and Everton aquifers are used in approximate equal frequency in the study area. Both the Boone-St. Joe and Everton wells are used for domestic supplies; however, the Everton aquifer is preferred for poultry and cattle farming because it provides greater water yields. Everton wells in the study area are typically completed in the Kings River Sandstone Member of the Everton Formation (Figure 4).

The primary permeability of the Boone limestone is less than $7.4 \times 10^{-6}$ meters/day (Van den Huevel, 1979); however, secondary porosity developed by dissolution along joints, fractures, faults and bedding planes (Figure 1), result in much higher permeability values, 0.005 to 5.1 meters/day. These secondary permeability values were calculated from transmissivity values (Ogden, 1980) using the average thickness of the Boone-St. Joe aquifer in the study area. This variable permeability is directly related to variability of secondary porosity development; that is, the presence of fractures and the extent of chemical solutioning of fracture and bedding plane surfaces.

Although the Boone-St. Joe Formation is characterized by solution channels in the study area, there are some sinkholes, caves and disappearing streams in the region. The thin soils of the area combined with secondary porosity and permeability (Figure 1), limit natural purification of recharge water and make the Boone-St. Joe aquifer susceptible to contamination from surface water.

Typically, Boone-St. Joe wells have low yields (about 12 liters/minute); whereas, many springs have discharges at least one order larger. All springs in the study area issue from the Boone-St. Joe aquifer. Springs are typically associated with solution enlarged fracture or bedding planes; whereas, wells typically intersect smaller, less enlarged fractures. The larger solution channels associated with spring systems should make springs more susceptible to contamination from the surface than wells. However, wells drilled on solution enlarged fractures produce high-yield wells (as shown in Figure 1). These rare high-yield wells are similar to springs in terms of susceptibility to surface contamination because they are also located on the larger ground water channels.

## Methodology

Wells were flushed for at least three well volumes prior to sample collection. Samples were collected during different seasons in order to compare nitrate concentrations for "wet" (fall) and "dry" (summer and winter) seasons. A "wet" season is defined as a period of major recharge of the aquifer.

Elevation of each well was determined from well locations on U.S. Geological 7.5 degree topographic maps and well depth was obtained from well owners. These data, as well as elevation of the base of the well and the primary aquifer for each well are listed in Appendix I. See section on Comparison of Shallow and Deep Wells for discussion of the method used to determine the aquifer for each well.

Samples were stored and analyzed by the colorimetric--cadmium reduction method (U.S. Environmental Protection Agency, 1983). Samples were analyzed for nitrate+nitrite and reported as mg/L nitrogen. In this paper, *nitrate+nitrite as nitrogen* will be referred to simply as *nitrate*. Analyses of U.S. Environmental Protection Agency standard solutions (0.37 mg/L) were within 95% confidence limits of the true value (0.40 mg/L). Repetitive analyses (5) yielded a standard deviation 0.02 for a 0.40 mg/L concentration sample. The largest difference for duplicate analyses was 12.91 and 13.54 mg/L. Data for individual wells and sampling date are given in Appendix II by season.

Although the contract for this project only required nitrate analyses, other analyses were made. These analyses also are reported in Appendix II. Calcium, magnesium, potassium and sodium are utilized in determining the primary aquifer for well water. Calcium and magnesium were analyzed by atomic absorption spectrophotometry using a nitrous oxide-acetelyene flame. Potassium and sodium were analyzed by flame photometry using a hydrogen-air flame. Prior to the analyses of these cations, cesium chloride was added to the sample to produce a concentration of 1000 mg/L cesium.

Comparison of Experimental and Control Subareas

The experimental wells discussed in this section are all from the Boone-St. Joe aquifer, that is there are no Everton wells utilized in this discussion (see section on Comparison of Shallow and Deep Wells for method of determining the aquifer. Experimental wells have higher average seasonal concentrations of nitrate (2.44 to 3.04 mg/L) than control wells (1.62 to 1.78 mg/L) (Table 1). The difference in nitrate concentration of ground water between the experimental and control subareas is most evident

Table 1. Comparison of control and experimental subarea seasonal average nitrate concentrations for wells and springs in the northeastern Washington County area. Nitrate concentrations are mg/L nitrate+nitrite as nitrogen. Standard deviations are given in [ ]. Number of sites is given in ( ).

| | Control Subarea | | Experimental Subarea | |
|---|---|---|---|---|
| Season | Wells* | Springs# | Wells | Springs# |
| Fall | 1.62 [2.18] (4) | 0.40 [0.70] (18) | 2.44 [2.04] (20) | 2.58 [1.74] (30) |
| Winter | -- -- | 0.16 [0.18] (10) | 3.04 [2.34] (26) | 2.73 [2.16] (14) |
| Spring | 1.78 [2.38] (8) | 0.02 [0.01] (8) | 2.90 [3.06] (26) | 3.23 [1.63] (12) |
| Annual | 1.72 [2.29] (12) | 0.25 [0.40] (36) | 2.83 [2.51] (72) | 2.76 [1.82] (56) |

*Considered contaminated, see text.
#Data from Adamski and Steele (1988).

using the data from springs (Adamski and Steele, 1988). The average seasonal concentrations for experimental springs range from 2.58 to 3.23 mg/L nitrate; whereas, the average seasonal concentrations for control springs range from 0.02 to 0.40 mg/L (Table 1). These differences for the Boone-St. Joe aquifer experimental and control subareas (both wells and springs) are statistically significant (using the non-parametric Wilcoxon two-sample test with a 0.05 alpha).

The smaller difference between control and experimental wells compared to springs is probably the result of some contamination of the control wells (Table 1). The wells used for this study were domestic wells which may be contaminated by runoff from barnyards, lawns and/or by septic tank effluent. This observation suggests: (1) that it is difficult to obtain "true" control wells in a relatively shallow limestone aquifer because of anthropogenic effects, and (2) that some of the ground water contamination in the experimental subarea is from sources other than poultry litter and cattle manure. Nitrate concentrations of spring water (0.14 to 0.33 mg/L) from other regional relatively pristine areas (mostly forested with very low population) of similar hydrogeology (Table 2), confirms that samples of ground

Table 2. Comparison of seasonal nitrate concentrations of springs from the control subarea with springs from other pristine areas. Concentrations are mg/L nitrate+nitrite expressed as nitrogen. The numbers in ( ) are the number of sites collected. Control subarea data are for the three seasons in Table 1.

| | Other Pristine Areas Of The Region | | |
|---|---|---|---|
| Control Subarea | Ponca* | Rush* | Zinc* |
| 0.40 (18) | 0.14 | 0.33 | 0.30 |
| 0.16 (10) | (48) | (52) | (43) |
| 0.02 (8) | | | |

*Steele (1983)

water from the control subarea should be less than 0.40 mg/L nitrate rather than the 1.62 and 1.78 mg/L observed for control wells (Table 1).

Although there are statistically higher concentrations of nitrate (about 14 times) in ground water in the Boone-St. Joe aquifer from experimental subareas than for the control springs, these concentrations are considerably below the drinking water limit of 10 mg/L set by the U.S. Environmental Protection Agency (1985). There is concern that the soil and vegetation in most of northwestern Arkansas have more than sufficient available nitrogen present for growth. It is probable that much of the nitrogen in any additional litter applied to the land may be leached into the ground water and significantly increase nitrate concentrations.

## Comparison of Nitrate Concentrations from Wells and Springs

Table 1 indicates springs had slightly higher nitrate concentrations than wells for the Boone-St. Joe aquifer in the experimental subarea during the spring and fall seasons, and wells had higher concentrations during the winter. These differences may not be meaningful because spring and well samples were collected in different years (1986-1987 and 1989, respectively). Environmental conditions (for example timing and amount of litter application and amount of recharge) could have been different for the two study periods. Thus, there is no irrefutable evidence from this study that springs are more susceptible to contamination than wells, as hypothesized earlier. As noted previously, for the shallow Boone-St. Joe limestone aquifer the proximity of control wells to human activities may result in more contamination of wells because control springs were not located near human activity.

## Seasonal Variations

Spring is the season expected to have the highest ground water nitrate concentrations for several reasons. It is the season when: (1) most of the poultry litter is applied to the land, (2) heavy spring rains cause major recharge to the aquifer and (3) there is little nitrate uptake by vegetation because most of it is still dormant. These conditions are consistent with greater movement of nitrate into the ground water system during this season. It is interesting to note that the spring season indeed has the highest average nitrate concentration for both wells and springs (Table 1), even though samples were collected during different years. Despite this logical explanation for higher nitrate values occurring in the spring (Table 1), comparison of the well data by the non-parametric Kuskal-Wallis statistical test (0.05 alpha) supports the null hypothesis that there are no differences among the seasons. The Kuskal-Wallis test was used rather than the Wilcoxon two-sample test because it is a multiple-sample test that allows simultaneous comparison of all three seasons.

Comparison of Shallow and Deep Wells

Both Boone-St. Joe and Everton wells were sampled in the experimental subarea. The two aquifers are utilized with about equal frequency in the study area. Wells drilled through the Boone-St. Joe and Chattanooga Formations into the Everton are only cased through the soil and about 3 meters into the bedrock (total depth about 6 meters or less). Therefore, wells completed in the Everton aquifer may have ground water contributions from the overlying formations. Because of uncertainty in water source, regional dip of the aquifers and unreliability of owner reported wells depths, geochemical data also were used to assign the primary aquifer for each well (Appendix I).

Based on water well-drillers records, the top of the Chattanooga Formation averages 57 meters (187 feet) below land surface in the study area, and the median depth of wells used for this study is 56.7 meters (186 feet) (Appendix I). The wells were divided into two groups, those less than 186 feet deep and those greater than 186 feet as an approximation of water source (Boone-St. Joe and Everton, respectively). Trilinear plots of these two groups (Figures 5 and 6) show that the wells with depths less than 186 feet have a higher percentage of calcium the well water than those with greater depth. The Boone-St. Joe aquifer (predominantly limestone and chert) would be expected to have higher calcium percentages than the Everton aquifer which tends to be dolomitic. The dolomitic character of the Everton aquifer is especially well demonstrated by higher magnesium percentages in Figure 6. Based on the clustering of shallow wells (less than 186 feet deep) with calcium percentages greater than 85 in Figure 5 wells with these percentages are considered to have the Boone-St. Joe aquifer as their primary aquifer. The remainder of the wells in Figures 5 and 6 have less than 85 percent calcium and 2 to 40 percent magnesium. Although the lower values for these samples suggest mixing of ground water from the Everton (and Chatttanooga) Formations with that from Boone-St. Joe aquifer, wells with less than 85% calcium are classed as Everton. This geochemical classification avoids problems associated with mixing of aquifer waters in a well and other problems noted above.

Nitrate concentrations for the deeper Everton aquifer (1.51 mg/L) are about half that for the shallow Boone-St. Joe aquifer (2.83 mg/L) (Table 3). These differences are statistically significant (0.05 alpha) using the Wilcoxon two-sample test. Apparently, the Everton aquifer is less susceptible to contamination because of the overlying relatively impermeable Chattanooga Shale Formation.

Table 3. Comparison of mean nitrate concentrations (mg/L) for Boone-St. Joe (shallow) and Everton (deep) experimental wells. Standard deviation is in [ ] and the number of wells is given in ( ).

| Season | Shallow Wells | Deep Wells |
|---|---|---|
| Winter | 3.04 [2.34] (20) | 1.45 [4.45] (23) |
| Spring | 2.90 [3.06] (26) | 1.59 [4.33] (18) |
| Fall | 2.44 [2.04] (26) | 1.51 [5.10] (18) |
| Annual | 2.83 [2.51] (72) | 1.51 [4.61] (59) |

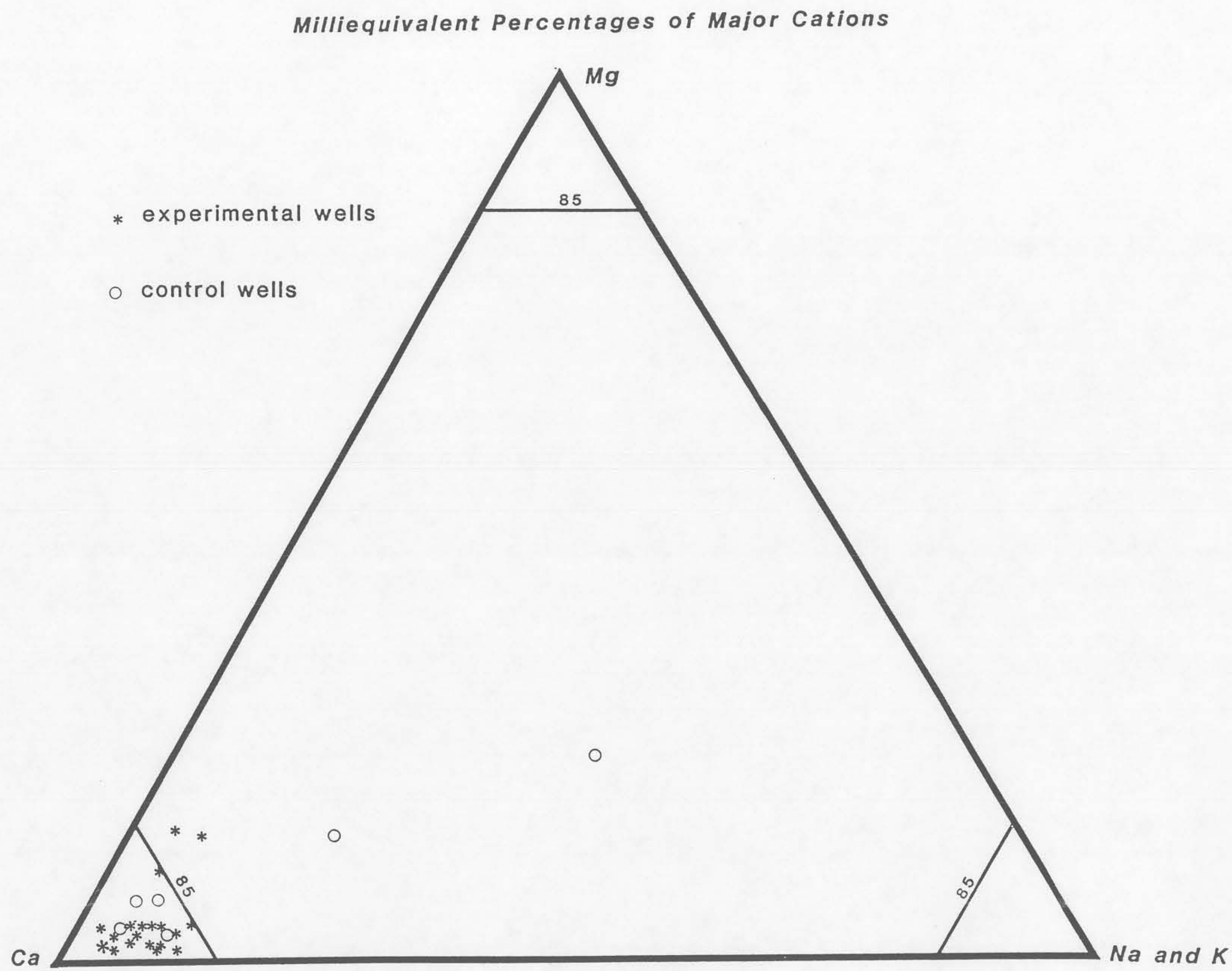


Figure 5. Plot of the milliequivalent percentages of calcium, magnesium and sodium+potassium for wells with depths less than 186 feet (nominally the Boone-St. Joe aquifer).

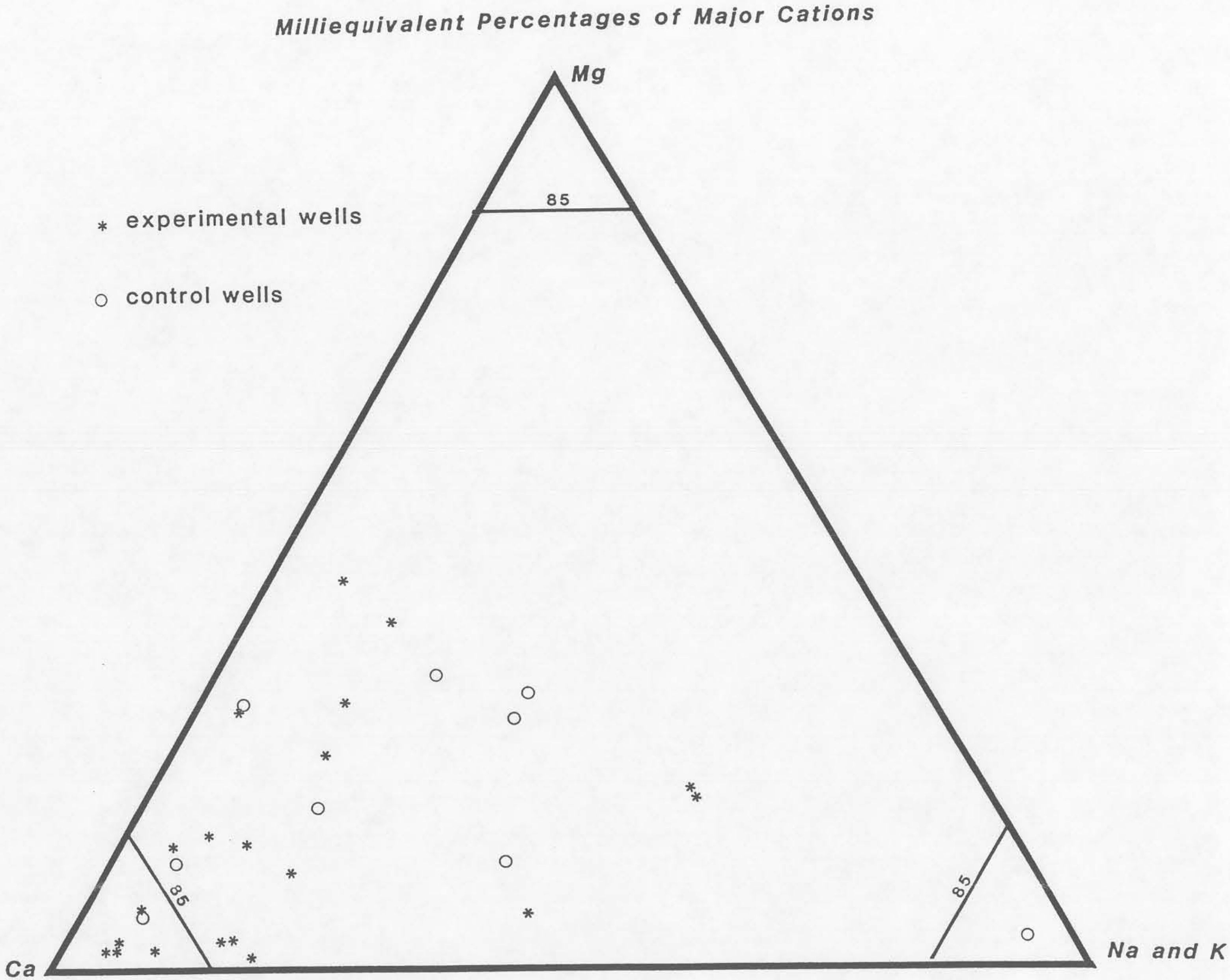


Figure 6. Plot of the milliequivalent percentages of calcium, magnesium and sodium+potassium for wells with depths greater than 186 feet (nominally the Everton aquifer).

## Conclusions

The results of this study indicate that there are significantly higher annual average concentrations of nitrate for ground water in the experimental subarea (2.83 mg/L) compared to the control subarea (0.25 mg/L). Because cattle graze on the pastureland on which the poultry litter is applied and because there are domestic septic tank systems in the same area, it is difficult to quantitatively distinguish the amount of nitrate contributed to the ground water from poultry litter versus the amount of nitrate contributed from other sources. This problem is further complicated by differences in rates of nitrogen mineralization and volatization of the different nitrate sources. However, because of the much greater annual abundance of nitrogen from poultry litter (209,000 kg) compared to cattle manure (114,300 kg) and human wastes (10,700 kg), it appears reasonable to attribute the greatest amount of contamination to poultry litter. The higher nitrate concentrations for wells (2.83 mg/L) in the shallow Boone-St. Joe aquifer than the deeper Everton aquifer (1.51 mg/L) indicate that Boone-aquifer is more susceptible to surface contamination.

The results of this investigation indicate the need for additional research on the land application of poultry litter in terms of amounts, rates, timing of application (regarding season and meteorological conditions), soil type, slope, and vegetation. Research of this type would provide data for development of Best Management Practices (BMPs) for farmers not only in the Ozark Region, but also other limestone regions.

Poultry production is an important economic base for the Ozark Region and implementation of BMPs and alternate uses of poultry litter should allow expansion of the poultry industry while at the same time minimizing the effect of litter on ground water nitrate concentrations. Utilized properly, poultry litter can be a valuable resource for the region.

## Acknowledgements

Reviews of portions of this report by J.V. Brahana and D.R. Edwards are gratefully acknowledged. Their comments and suggestions were very helpful in revision of the manuscript. C.R. Smith and A.Y. Austin III prepared several of the figures in this paper. Funding for the project was supplied by the Arkansas Department of Pollution Control and the Arkansas Water Resources Research Center.

## References

Adamski JC and Steele KF (1988) Agricultural land use effects on ground water quality in the Ozark Region. In: Agricultural Impacts on Ground Water Conference. Nat Water Well Assoc, Dublin Ohio, 593-614

Arkansas Agricultural Statistics Service (1989) Arkansas Agricultural Statistics 1988. Arkansas Agricultural Experiment Station, Fayetteville Arkansas

Beck BF, Asmussen L and Leonard R (1985) Relationship of geology, physiography, agriculture, and groundwater quality in southwest Georgia. Ground Water 23:527-634

Burden RJ (1982) Nitrate contamination of New Zealand aquifers. New Zealand Jour Sciences 25:205-220

Giddens J and Barnett AP (1980) Soil loss and microbiological quality of runoff from land treated with poultry litter. J Environ Qual 9:518-520

Gilmour JT, Wolf DC and Gale PM (1987) Estimating potential ground and surface water pollution from land application of poultry litter. Pub No 128 Ark Water Resources Research Center, Uni of Arkansas, Fayetteville Arkansas 36 p

Gillham RW and Webber LR (1969) Nitrogen contamination of groundwater by barnyard leachates. Water Poll Control Fed Jour 41:1752-1762

Groba E and Hahn J (1972) Variation of groundwater chemistry by anthropogenic factors in northwest Germany. Internat Geol Cong Pub 270-281

Harper MD, Phillips, WW and Haley GJ (1969) Soil Survey of Washington Country, Arkansas. US Dept of Agriculture, U.S. Government Printing Office, Washington DC, 94 p

Hill AR (1982) Nitrate distribution in the groundwater of the Alliston Region of Ontario, Canada. Ground Water 20:696-802

Khaleel R, Reddy KR and Overcash MR (1980) Transport of potential pollutants in runoff water from land areas receiving animal wastes: a review. Water Research 14:421-436

Leidy, VA and Morris EE (1990 in press) Hyrogeology and quality of ground water in the Boone Formation and Cotter Dolomite in karst terrain of northwestern Boone County, Arkansas

Liebhardt WC, Golt C and Turpin J (1979) Nitrate and ammonium concentrations of ground water resulting from poultry manure applications. J Environ Qual 8:212-215

Lorimar JC, Mielke, LN, Elliot LF, and Ellis JR (1972) Nitrate concentrations in groundwater beneath a beef cattle feedlot. Water Resources Bull 8:999-1005

Magette WL, Brinsfield RB and Hrebenach DA (1988) Water quality impacts of land applied broiler litter. Paper No 88-2050 presented at the Annual Summer Meeting of the Amer Soc Agri Engineers, Rapid City South Dakota June 26-29

Manger WL and Borengasser M (1978) Devonian-Lower Mississippian lithostratigraphy, Northwest Arkansas. Arkansas Academy of Science, Field Trip Guidebook 13 p

McCalister WK (1990) The effects of land applied animal wastes on ground water chemistry in northwest Arkansas. Unpub MS Thesis, Uni of Arkansas, Fayetteville Arkansas 123 p

Mc Leod RV and Hegg RO (1984) Pasture runoff water quality from application of inorganic and organic nitrogen sources. J Environ Qual 13:122-126

Ogden AE (1980) Hydrogeologic and geochemical investigation of the Boone-St. Joe Limestone Aquifer in Benton County, Arkansas. Pub No 68 Ark Water Resources Research Center, Uni of Arkansas, Fayetteville Arkansas, 133 p

Pionke HB and Urban JB (1985) The effect of agriculture land use on groundwater quality in a small Pennsylvanian watershed. Ground Water 23:68-80

Spalding RF, Gromly JR, Curtiss BH, and Exner ME (1978) Nonpoint nitrate contamination of groundwater in Merrick County, Nebraska. Ground Water 16:86-95

Sommerfeldt TG, Pittman UJ, and Milne RA (1973) Effect of feedlot manure on soil and water quality. J Environ Qual 2:423-427

Steele KF, McCalister WK, and Adamski, JC (1990a in press) Nitrate and bacteria contamination of limestone aquifers in poultry/cattle producing areas of northwestern Arkansas, USA. Environmental Contamination

Steele, KF, McCalister WK, and Adamski, JC (1990b in press) Potential Nitrate Pollution of Ground Water in Limestone Terrain by Poultry Litter, Ozark Region, U.S.A. In: Nitrate Contamination: Exposure, Consequence and Control, Springer-Verlag, New York

Steele, KF, Widmann RK, Wickliff DS and Parr DL (1985) The effect of rainstorm events on spring water chemistry in a limestone terrane. In: Proceedings of the Southern Regional Ground Water Conference, Nat Water Well Assoc, Worthington Ohio, 50-66

Steele, KF (1983) Chemistry of the springs of the Ozark Mountains, northwestern Arkansas. Pub No 98, Ark Water Resources Research Center, Uni of Arkansas, Fayetteville Arkansas 48 p

U.S. Environmental Protection Agency (1985) National primary drinking water regulations: synthetic organic chemicals, inorganic chemicals and microorganisms; proposed rule. Fed Register 50:46934-47022

U.S. Environmental Protection Agency (1983) Methods for Chemical Analysis of Water and Wastes. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati Ohio, 430.2-5 p

Van den Huevel, P. (1979) Petrography of the Boone Formation, Northwest Arkansas. Unpub MS Thesis, Uni of Arkansas, Fayetteville Arkansas 75 p

Walker WH, Peck TR and Lembke WD (1972) Farm ground water nitrate pollution--a case study. Presented at the Amer Soc Civil Engineers Meeting in Houston Texas Preprint 1842

Wolf DC, Gilmour JT and Gale PM (1988) Estimating potential ground and surface water pollution from land application of poultry litter--II. Pub No 137, Ark Water Resources Research Center, Uni of Arkansas, Fayetteville Arkansas 34 p

# APPENDIX I

Primary aquifer, location, elevation, depth and base of well by subarea.

**WELLS IN THE EXPERIMENTAL SUBAREA**

| Well # | Primary Aquifer 1 | Location | Elevation (ft amsl) 2 | Depth (ft) | Well Base (ft amsl) |
|---|---|---|---|---|---|
| * 1 | bbb | 17-27-06CCD | 1360 | 0 | 1360 |
| 2 | bbb | 17-17-08CDC | 1330 | 87 | 1243 |
| 3 | eee | 17-27-18ADC | 1305 | 200 | 1105 |
| 4 | bbb | 17-27-18CCC | 1380 | 100 | 1280 |
| 5 | bbe | 17-27-19BDB | 1365 | 104 | 1260 |
| 6 | ebe | 17-28-01BAC | 1310 | 70 | 1240 |
| 7 | bbb | 17-28-02BAB | 1320 | 25 | 1295 |
| 8 | bbe | 17-28-02CBD | 1280 | 125 | 1155 |
| 9 | eee | 17-28-02DAB | 1380 | 300 | 1080 |
| 10 | bbb | 17-28-04ACB | 1300 | 180 | 1120 |
| 11 | bbb | 17-28-09BDB | 1320 | 150 | 1170 |
| 12 | eee | 17-28-09DCC | 1300 | 280 | 1020 |
| 13 | eee | 17-28-10CBD | 1240 | 357 | 883 |
| 14 | bbb | 17-28-11BDB | 1200 | 100 | 1100 |
| 15 | bbb | 17-28-13BAD | 1335 | 75 | 1260 |
| 16 | bbb | 17-28-14ABA | 1310 | 200 | 1110 |
| 17 | eee | 17-28-14ACB | 1265 | 300 | 965 |
| 18 | bbb | 17-28-15ADC | 1245 | 70 | 1175 |
| 19 | bbb | 17-28-16BAB | 1170 | 40 | 1130 |
| 20 | bbe | 17-28-22AAD | 1180 | 38 | 1142 |
| 21 | ee- | 17-28-22ABA | 1200 | 90 | 1110 |
| 22 | bbb | 17-28-22ACD | 1240 | 200 | 1040 |
| 23 | eeb | 17-28-23AAA | 1365 | 177 | 1188 |
| 24 | bbb | 18-27-19BAA | 1210 | 190 | 1020 |
| 25 | bee | 18-27-30DAB | 1365 | 235 | 1130 |
| 26 | eee | 18-27-31CBA | 1400 | 197 | 1203 |
| 27 | eee | 18-27-31DAD1 | 1380 | 690 | 690 |
| 28 | bbb | 17-28-02BAA | 1320 | 50 | 1270 |
| 29 | eee | 18-28-14ABA | 1330 | 350 | 980 |
| 30 | eee | 18-28-21ACC | 1340 | 300 | 1040 |
| 31 | bbb | 18-28-22ADA | 1360 | 340 | 1020 |
| 32 | eee | 18-28-23ABB | 1370 | 450 | 920 |
| 33 | bbe | 18-28-24ABC1 | 1380 | 100 | 1280 |
| 34 | ebe | 18-28-24ABC2 | 1380 | 370 | 1010 |
| 35 | bbb | 18-28-24CDA | 1370 | 120 | 1250 |
| 36 | bbb | 18-28-24DCB | 1380 | 140 | 1240 |
| 37 | beb | 18-28-25ABB | 1370 | 250 | 1120 |
| 38 | eee | 18-28-25ADC1 | 1380 | 530 | 850 |
| 39 | bbe | 18-28-25ADC2 | 1380 | 104 | 1276 |
| 40 | eee | 18-28-25CCD | 1380 | 300 | 1080 |
| 41 | bbb | 18-28-26DDC | 1365 | 180 | 1185 |
| 42 | eee | 18-28-27AAC | 1340 | 220 | 1120 |
| 43 | bee | 18-28-36AAB | 1380 | 200 | 1180 |
| 44 | bbe | 18-28-36ABC | 1395 | 150 | 1245 |
| 45 | bbb | 18-28-36CCA | 1380 | 150 | 1230 |
| * 46 | eeb | 19-28-34DDD | 1160 | 100 | 1060 |
| * 47 | bbb | 17-28-04BDC | 1200 | 0 | 1200 |

**WELLS IN THE CONTROL SUBAREA**

| Well # | Primary Aquifer 1 | Location | Elevation (ft amsl) 2 | Depth (ft) | Well Base (ft amsl) |
|---|---|---|---|---|---|
| 60 | -ee | 18-27-01DBC | 1200 | 100 | 1100 |
| 61 | -be | 18-27-07CAD | 1220 | 300 | 920 |
| 62 | -ee | 18-27-08CAD | 1240 | 270 | 970 |
| * 63 | -bb | 18-28-03BBB | 1180 | 0 | 1180 |
| 64 | -ee | 18-28-04DBC | 1320 | 356 | 964 |
| 65 | -ee | 18-28-05ADD | 1240 | 164 | 1076 |
| 66 | -bb | 18-28-08ACB | 1180 | 180 | 1000 |
| * 67 | -bb | 18-28-12DDB | 1200 | 130 | 1070 |
| 68 | -bb | 19-28-25ACB | 1440 | 186 | 1254 |
| 69 | -ee | 19-28-25ACC1 | 1420 | 507 | 913 |
| 70 | -ee | 19-28-25ACC2 | 1430 | 396 | 1034 |
| 71 | -ee | 19-28-26ABA | 1360 | 1360 | 0 |
| * 72 | -bb | 19-28-31BAB | 1415 | 130 | 1285 |
| 73 | -ee | 19-28-34DDC | 1140 | 150 | 990 |
| 74 | -ee | 19-28-36BDB | 1400 | 600 | 800 |
| 75 | -bb | 19-28-36DAB | 1380 | 122 | 1258 |
| 76 | -ee | 18-28-34CCC | 1260 | 200 | 1060 |
| 77 | -ee | 19-28-32ACC | 1430 | 590 | 840 |
| 78 | -ee | 19-28-32BDA | 1420 | 495 | 925 |
| 79 | --e | 18-27-18BBD | 1260 | 180 | 1080 |
| 80 | --e | 18-28-05AAD | 1240 | 187 | 1053 |
| 81 | --e | 19-28-29CCA | 1300 | 175 | 1125 |

* these designated wells with water treatment systems and/or springs were excluded from statistical analysis

1 "b" refers to primary ground-water contribution from the Boone and St. Joe Formations, "e" refers to the Everton and Chattanooga Formations. The letter designations are in order from winter, spring, and fall. The symbol "-" represents no sample for that particular season.

2 "ft amsl" refers to feet above mean sea level

APPENDIX II

Chemical analyses and date of collection

by season and subarea.

pH is in pH units, temperature (temp) is in Celsius degrees, conductance (cond) is in micro-Siemens/centimeter, total alkalinity (alk) is mg/L as $CaCO_3$, nitrate+nitrate ($NO_3$) and all other analyses are mg/L.

Winter Analysis - Experimental Subarea

| Well | Date | pH | Temp | Cond | Alk | NO3 | NH3 |
|---|---|---|---|---|---|---|---|
| 1 | 2-26-89 | 6.3 | 12.5 | 398 | 178 | 5.73 | 0.00 |
| 2 | 2-26-89 | 6.7 | 12.5 | 349 | 190 | 1.54 | 0.00 |
| 3 | 2-26-89 | 7.6 | 15.0 | 307 | 148 | 0.00 | 0.00 |
| 4 | 2-26-89 | 7.3 | 16.0 | 309 | 150 | 2.95 | 0.03 |
| 5 | 2-26-89 | 6.8 | 6.0 | 293 | 133 | 4.71 | 0.00 |
| 6 | 3-11-89 | 7.2 | 15.0 | 486 | 300 | 0.00 | 0.04 |
| 7 | 2-25-89 | 7.1 | 12.0 | 373 | 165 | 5.01 | 0.00 |
| 8 | 2-25-89 | 7.3 | 10.0 | 420 | 196 | 4.03 | 0.00 |
| 9 | 2-25-89 | 7.2 | 11.0 | 396 | 198 | 0.00 | 0.00 |
| 10 | 2-25-89 | 7.5 | 11.5 | 338 | 148 | 1.09 | 0.01 |
| 11 | 3-02-89 | 6.8 | 15.0 | 442 | 235 | 0.56 | 0.05 |
| 12 | 2-25-89 | 7.6 | 14.5 | 437 | 233 | 0.16 | 0.12 |
| 13 | 2-25-89 | 6.6 | 12.0 | 379 | 138 | 18.50 | 0.00 |
| 14 | 2-25-89 | 7.2 | 10.0 | 276 | 123 | 3.13 | 0.00 |
| 15 | 2-26-89 | 7.1 | 13.0 | 465 | 210 | 5.73 | 0.00 |
| 16 | 2-26-89 | 7.2 | 15.5 | 480 | 190 | 6.28 | 0.00 |
| 17 | 2-26-89 | 7.5 | 15.0 | 407 | 215 | 0.00 | 0.00 |
| 18 | 2-25-89 | 7.1 | 13.5 | 353 | 146 | 7.70 | 0.00 |
| 19 | 3-02-89 | 7.2 | 9.0 | 283 | 133 | 1.07 | 0.09 |
| 20 | 2-25-89 | 6.2 | 12.0 | 314 | 175 | 1.22 | 0.00 |
| 21 | 2-25-89 | 6.8 | 14.0 | 436 | 209 | 0.00 | 0.05 |
| 22 | 3-12-89 | 7.4 | 14.0 | 423 | 215 | 3.28 | 0.03 |
| 23 | 2-26-89 | 7.3 | 13.5 | 309 | 155 | 1.83 | 0.00 |
| 24 | 3-03-89 | 7.0 | 8.5 | 287 | 140 | 0.75 | 0.06 |
| 25 | 3-03-89 | 6.9 | 13.0 | 568 | 275 | 5.37 | 0.02 |
| 26. | 3-11-89 | 7.2 | 16.5 | 475 | 265 | 0.00 | 0.15 |
| 27 | 3-03-89 | 7.5 | 14.0 | 348 | 175 | 0.02 | 0.10 |
| 28 | 3-03-89 | 7.2 | 14.0 | 358 | 150 | 5.28 | 0.07 |
| 29 | 3-02-89 | 7.0 | 15.0 | 255 | 100 | 0.46 | 0.03 |
| 30 | 3-12-89 | 7.4 | 18.0 | 386 | 210 | 0.05 | 0.12 |
| 31 | 3-12-89 | 7.3 | 14.0 | 174 | 85 | 0.84 | 0.02 |
| 32 | 3-02-89 | 7.0 | 14.5 | 455 | 190 | 1.17 | 0.07 |
| 33 | 3-02-89 | 6.8 | 15.0 | 468 | 200 | 2.66 | 0.06 |
| 34 | 3-02-89 | 6.8 | 13.0 | 421 | 208 | 0.02 | 0.07 |
| 35 | 3-02-89 | 6.7 | 9.0 | 357 | 180 | 0.79 | 0.04 |
| 36 | 3-02-89 | 7.0 | 17.0 | 383 | 198 | 0.42 | 0.05 |
| 37 | 3-02-89 | 6.2 | 13.0 | 274 | 103 | 5.77 | 0.05 |
| 38 | 3-03-89 | 6.9 | 13.5 | 227 | 100 | 2.47 | 0.05 |
| 39 | 3-11-89 | 7.2 | 16.5 | 370 | 208 | 0.00 | 0.07 |
| 40 | 3-03-89 | 6.8 | 14.0 | 367 | 190 | 0.00 | 0.24 |
| 41 | 3-03-89 | 7.3 | 13.5 | 319 | 165 | 1.22 | 0.02 |
| 42 | 3-02-89 | 7.2 | 14.0 | 398 | 203 | 0.00 | 0.03 |
| 43 | 3-03-89 | 6.8 | 13.5 | 334 | 205 | 0.00 | 0.03 |
| 44 | 2-26-89 | 6.2 | 6.5 | 304 | 110 | 4.12 | 0.00 |
| 45 | 2-26-89 | 6.8 | 12.0 | 419 | 195 | 6.55 | 0.02 |
| 46 | 3-11-89 | 6.6 | 5.0 | 684 | 245 | 0.00 | 0.01 |
| 47 | 3-09-89 | 7.6 | 22.0 | 308 | 160 | 1.83 | 0.02 |

Winter Analysis - Experimental Subarea

| Well | Cl | Ca | Mg | Na | K |
|---|---|---|---|---|---|
| 1 | 11.50 | 84 | 1.55 | 3.29 | 2.01 |
| 2 | 3.75 | 78 | 3.00 | 3.00 | 0.45 |
| 3 | 5.75 | 48 | 13.00 | 3.57 | 0.06 |
| 4 | 5.00 | 68 | 0.65 | 3.43 | 0.28 |
| 5 | 8.25 | 54 | 1.80 | 4.86 | 1.64 |
| 6 | 7.00 | 98 | 8.00 | 6.01 | 0.17 |
| 7 | 9.75 | 72 | 1.90 | 3.71 | 1.89 |
| 8 | 6.75 | 82 | 2.90 | 11.00 | 0.47 |
| 9 | 3.50 | 50 | 10.25 | 29.10 | 0.28 |
| 10 | 9.50 | 70 | 1.75 | 4.86 | 0.39 |
| 11 | 20.00 | 96 | 1.00 | 4.29 | 0.47 |
| 12 | 18.75 | 22 | 10.75 | 81.71 | 3.39 |
| 13 | 16.00 | 66 | 1.70 | 12.90 | 0.67 |
| 14 | 7.75 | 54 | 1.40 | 2.70 | 2.01 |
| 15 | 12.75 | 96 | 2.50 | 6.61 | 2.17 |
| 16 | 16.25 | 96 | 2.30 | 5.81 | 2.29 |
| 17 | 7.75 | 60 | 7.75 | 30.05 | 0.35 |
| 18 | 8.50 | 74 | 1.60 | 2.50 | 0.99 |
| 19 | 11.00 | 58 | 1.45 | 2.70 | 1.36 |
| 20 | 12.25 | 70 | 3.10 | 4.57 | 0.47 |
| 21 | 6.50 | 74 | 8.00 | 7.22 | 0.67 |
| 22 | 11.25 | 90 | 0.85 | 2.80 | 0.59 |
| 23 | 4.00 | 58 | 5.25 | 2.80 | 0.34 |
| 24 | 10.25 | 50 | 3.70 | 2.70 | 0.87 |
| 25 | 17.75 | 116 | 6.00 | 6.01 | 0.35 |
| 26 | 15.75 | 78 | 13.00 | 11.95 | 0.39 |
| 27 | 9.25 | 20 | 7.75 | 71.00 | 3.11 |
| 28 | 12.25 | 68 | 1.60 | 4.00 | 1.77 |
| 29 | 4.50 | 32 | 10.00 | 4.86 | 1.08 |
| 30 | 5.75 | 46 | 12.75 | 73.57 | 3.19 |
| 31 | 9.00 | 34 | 0.50 | 3.57 | 0.11 |
| 32 | 31.75 | 76 | 8.50 | 14.81 | 0.67 |
| 33 | 27.50 | 96 | 0.90 | 6.81 | 0.67 |
| 34 | 22.75 | 72 | 8.50 | 16.88 | 1.64 |
| 35 | 8.75 | 76 | 0.85 | 3.57 | 0.43 |
| 36 | 8.50 | 76 | 1.10 | 2.70 | 0.35 |
| 37 | 10.50 | 50 | 0.95 | 5.60 | 0.40 |
| 38 | 12.00 | 40 | 0.50 | 8.02 | 0.23 |
| 39 | 8.75 | 82 | 0.70 | 6.41 | 1.16 |
| 40 | 7.75 | 42 | 21.00 | 11.95 | 0.35 |
| 41 | 5.25 | 70 | 1.65 | 2.00 | 0.35 |
| 42 | 7.25 | 48 | 24.25 | 9.03 | 0.28 |
| 43 | 4.25 | 80 | 3.25 | 9.23 | 0.40 |
| 44 | 11.50 | 56 | 1.50 | 7.62 | 0.79 |
| 45 | 13.25 | 88 | 1.25 | 6.01 | 1.16 |
| 46 | 10.00 | 106 | 24.50 | 8.02 | 0.59 |
| 47 | 8.25 | 66 | 0.85 | 3.29 | 0.51 |

Spring Analysis - Experimental Subarea

| Well | Date | pH | Temp | Cond | Alk | NO3 | NH3 |
|---|---|---|---|---|---|---|---|
| 1 | 5-12-89 | 6.7 | 14.0 | 392 | 185 | 4.09 | 0.00 |
| 2 | 5-12-89 | 7.4 | 14.0 | 398 | 210 | 0.70 | 0.00 |
| 3 | 5-12-89 | 7.6 | 15.0 | 334 | 180 | 0.00 | 0.00 |
| 4 | 5-14-89 | 6.7 | 19.0 | 333 | 185 | 1.85 | 0.00 |
| 5 | 5-12-89 | 7.3 | 14.0 | 385 | 175 | 3.72 | 0.14 |
| 6 | 5-11-89 | . | . | . | . | 1.94 | 0.00 |
| 7 | 5-11-89 | 7.3 | 14.5 | 405 | 185 | 4.00 | 0.00 |
| 8 | 5-12-89 | 7.0 | 15.0 | 401 | 205 | 2.83 | 0.00 |
| 9 | 5-11-89 | 7.4 | 15.0 | 388 | 235 | 0.00 | 0.00 |
| 10 | 5-15-89 | 6.6 | 17.0 | 348 | . | 1.09 | 0.00 |
| 11 | 5-12-89 | 7.2 | 14.0 | 410 | 215 | 0.61 | 0.00 |
| 12 | 5-13-89 | 7.4 | 15.5 | 372 | 213 | 0.04 | 0.23 |
| 13 | 5-13-89 | 7.4 | 15.0 | 461 | 140 | 18.01 | 0.00 |
| 14 | 5-12-89 | 7.2 | 14.0 | 298 | 163 | 1.47 | 0.00 |
| 15 | 5-15-89 | . | 14.0 | 485 | 215 | 4.46 | 0.00 |
| 16 | 5-15-89 | . | 15.5 | 480 | 175 | 14.63 | 0.00 |
| 17 | 5-15-89 | 7.0 | 16.0 | 338 | 180 | 0.00 | 0.00 |
| 18 | 5-12-89 | 7.0 | 15.0 | 376 | 170 | 3.78 | 0.00 |
| 19 | 5-12-89 | 7.3 | 14.5 | 319 | 158 | 0.96 | 0.11 |
| 20 | 5-12-89 | 6.8 | 14.0 | 361 | 170 | 1.30 | 0.00 |
| 21 | 5-12-89 | 6.8 | 15.0 | 431 | 220 | 0.00 | 0.18 |
| 22 | 5-12-89 | 7.0 | 16.0 | 516 | 205 | 2.26 | 0.00 |
| 23 | 5-12-89 | 7.6 | 15.0 | 334 | 168 | 1.07 | 0.00 |
| 24 | 5-16-89 | 7.7 | 17.0 | 284 | 140 | 2.00 | 0.00 |
| 25 | 5-16-89 | 6.7 | 16.0 | 569 | 268 | 0.33 | 0.00 |
| 26 | 5-11-89 | 7.2 | 15.0 | 486 | 273 | 0.00 | 0.09 |
| 27 | 5-11-89 | 8.0 | 16.6 | 322 | 190 | 0.00 | 0.17 |
| 28 | 5-11-89 | 7.7 | 15.5 | 348 | 170 | 5.02 | 0.00 |
| 29 | 5-16-89 | 6.9 | 18.5 | 292 | 125 | 0.00 | 0.00 |
| 30 | 5-16-89 | 6.9 | 15.5 | 366 | 180 | 0.00 | 0.00 |
| 31 | 5-16-89 | 7.3 | 17.0 | 185 | 75 | 0.72 | 0.00 |
| 32 | 5-16-89 | 7.2 | 16.5 | 504 | 245 | 0.63 | 0.14 |
| 33 | 5-16-89 | 6.8 | 15.5 | 486 | 220 | 3.29 | 0.00 |
| 34 | 5-16-89 | 6.7 | 16.0 | 486 | 215 | 3.34 | 0.00 |
| 35 | 5-15-89 | 6.5 | 22.0 | 349 | 215 | 1.05 | 0.00 |
| 36 | 5-15-89 | 6.9 | 26.5 | 372 | 218 | 0.31 | 0.00 |
| 37 | 5-11-89 | 6.6 | 16.5 | 211 | 95 | 5.17 | 0.00 |
| 38 | 5-11-89 | 6.3 | 15.5 | 246 | 105 | 3.29 | 0.00 |
| 39 | 5-19-89 | 6.8 | 16.0 | 391 | 205 | 0.07 | 0.00 |
| 40 | 5-11-89 | 7.7 | 16.0 | 350 | 235 | 0.00 | 0.09 |
| 41 | 5-11-89 | 7.7 | 15.5 | 312 | 190 | 1.09 | 0.34 |
| 42 | 5-16-89 | 6.8 | 15.0 | 394 | 160 | 0.00 | 0.21 |
| 43 | 5-11-89 | 6.8 | 16.5 | 410 | 270 | 0.00 | 0.00 |
| 44 | 5-11-89 | 7.1 | 16.0 | 338 | 165 | 0.00 | 0.16 |
| 45 | 5-15-89 | 6.6 | 17.0 | 371 | 180 | 8.65 | 0.00 |
| 46 | 5-16-89 | 7.0 | 14.5 | 491 | 250 | 4.38 | 0.00 |
| 47 | 5-12-89 | 7.3 | 20.0 | 337 | 183 | 0.00 | 0.00 |

Spring Analysis - Experimental Subarea

| Well | Cl | Ca | Mg | Na | K |
|---|---|---|---|---|---|
| 1 | 10.50 | 82 | 1.45 | 3.67 | 1.77 |
| 2 | 2.75 | 76 | 5.50 | 4.33 | 0.32 |
| 3 | 5.75 | 54 | 14.00 | 3.75 | 0.03 |
| 4 | 4.25 | 70 | 0.55 | 3.40 | 0.26 |
| 5 | 15.50 | 76 | 1.30 | 9.35 | 1.28 |
| 6 | 5.75 | 76 | 3.00 | 2.50 | 0.15 |
| 7 | 10.25 | 80 | 2.20 | 3.80 | 1.91 |
| 8 | 7.00 | 86 | 2.25 | 9.35 | 0.58 |
| 9 | 3.50 | 52 | 10.00 | 43.85 | 0.08 |
| 10 | 9.00 | 72 | 2.00 | 5.00 | 0.58 |
| 11 | 7.50 | 88 | 0.95 | 2.90 | 0.48 |
| 12 | 15.00 | 28 | 12.25 | 59.23 | 3.48 |
| 13 | 19.75 | 76 | 1.90 | 15.16 | 0.79 |
| 14 | 7.50 | 64 | 1.40 | 3.13 | 1.70 |
| 15 | 12.25 | 106 | 2.55 | 9.15 | 2.40 |
| 16 | 15.25 | 96 | 1.85 | 4.33 | 2.11 |
| 17 | 5.50 | 62 | 8.25 | 10.00 | 0.05 |
| 18 | 7.00 | 80 | 1.85 | 2.50 | 2.06 |
| 19 | 9.50 | 62 | 1.80 | 4.07 | 1.35 |
| 20 | 9.00 | 74 | 1.45 | 4.20 | 0.52 |
| 21 | 6.75 | 80 | 8.50 | 7.50 | 0.18 |
| 22 | 12.50 | 90 | 1.10 | 3.80 | 0.76 |
| 23 | 4.50 | 60 | 6.75 | 3.13 | 0.36 |
| 24 | 5.50 | 56 | 2.85 | 2.50 | 1.00 |
| 25 | 10.25 | 106 | 12.75 | 10.69 | 0.61 |
| 26 | 13.50 | 94 | 10.25 | 6.50 | 0.08 |
| 27 | 5.00 | 24 | 10.00 | 51.54 | 3.06 |
| 28 | 9.25 | 76 | 1.70 | 3.40 | 1.81 |
| 29 | 3.25 | 36 | 11.75 | 9.54 | 1.56 |
| 30 | 4.50 | 48 | 11.50 | 5.45 | 14.15 |
| 31 | 7.00 | 32 | 0.45 | 3.53 | 0.10 |
| 32 | 29.25 | 80 | 7.75 | 22.50 | 0.82 |
| 33 | 23.75 | 102 | 1.00 | 10.50 | 0.82 |
| 34 | 22.25 | 98 | 0.95 | 7.00 | 0.15 |
| 35 | 5.00 | 84 | 1.20 | 2.80 | 0.44 |
| 36 | 5.75 | 86 | 1.15 | 2.80 | 0.71 |
| 37 | 7.00 | 40 | 0.80 | 8.77 | 0.22 |
| 38 | 12.50 | 44 | 0.50 | 11.46 | 0.20 |
| 39 | 6.00 | 78 | 0.75 | 9.92 | 1.32 |
| 40 | 6.25 | 40 | 20.25 | 13.50 | 0.10 |
| 41 | 3.25 | 68 | 1.60 | 1.90 | 0.52 |
| 42 | 8.00 | 42 | 22.75 | 6.50 | 0.08 |
| 43 | 3.50 | 52 | 3.40 | 50.00 | 0.91 |
| 44 | 10.50 | 70 | 1.90 | 9.92 | 0.97 |
| 45 | 9.50 | 80 | 1.15 | 8.58 | 1.07 |
| 46 | 10.50 | 2 | 0.00 | 117.74 | 0.05 |
| 47 | 6.75 | 74 | 0.90 | 3.67 | 0.70 |

Spring Analysis - Control Subarea

| Well | Date | pH | Temp | Cond | Alk | NO3 | NH3 |
|---|---|---|---|---|---|---|---|
| 60 | 5-18-89 | 6.7 | 16.0 | 291 | 80 | 7.09 | 0.00 |
| 61 | 5-18-89 | 6.9 | 16.0 | 314 | 130 | 0.86 | 0.00 |
| 62 | 5-18-89 | 7.4 | 16.0 | 338 | 165 | 0.00 | 0.33 |
| 63 | 5-23-89 | 6.2 | 16.0 | 190 | 90 | 0.30 | 0.00 |
| 64 | 5-19-89 | 7.0 | 16.0 | 445 | 220 | 0.04 | 0.18 |
| 65 | 5-19-89 | 7.2 | 16.5 | 692 | 370 | 0.12 | 0.58 |
| 66 | 5-19-89 | 7.3 | 15.0 | 249 | 115 | 1.60 | 0.00 |
| 67 | 5-18-89 | 6.7 | 15.5 | 630 | 210 | 15.07 | 0.00 |
| 68 | 5-18-89 | 6.9 | 15.5 | 366 | 130 | 5.90 | 0.00 |
| 69 | 5-18-89 | 7.0 | 17.5 | 373 | 185 | 0.09 | 0.51 |
| 70 | 5-18-89 | 6.8 | 15.0 | 352 | 168 | 0.04 | 0.00 |
| 71 | 5-23-89 | 7.2 | 16.5 | 317 | 160 | 0.14 | 0.11 |
| 72 | 5-18-89 | 7.1 | 16.0 | 296 | 145 | 0.00 | 0.09 |
| 73 | 5-16-89 | 6.2 | 15.0 | 376 | 100 | 0.00 | 0.00 |
| 74 | 5-17-89 | 6.9 | 15.0 | 243 | 100 | 0.00 | 0.00 |
| 75 | 5-18-89 | 7.2 | 15.0 | 218 | 100 | 0.54 | 0.00 |
| 76 | 5-23-89 | 7.0 | 16.0 | 433 | 193 | 0.09 | 0.33 |
| 77 | 5-24-89 | 7.8 | 16.5 | 451 | 225 | 0.06 | 0.09 |
| 78 | 5-24-89 | 6.9 | 20.0 | 423 | 145 | 4.17 | 0.00 |

Spring Analysis - Control Subarea

| Well | Cl | Ca | Mg | Na | K |
|---|---|---|---|---|---|
| 60 | 9.00 | 36 | 4.45 | 9.54 | 5.87 |
| 61 | 8.75 | 58 | 2.70 | 3.40 | 1.49 |
| 62 | 3.25 | 34 | 14.50 | 14.84 | 4.64 |
| 63 | 4.50 | 38 | 1.00 | 2.00 | 0.58 |
| 64 | 2.50 | 66 | 11.25 | 17.74 | 3.42 |
| 65 | 3.50 | 58 | 22.75 | 68.06 | 9.78 |
| 66 | 4.00 | 48 | 2.15 | 2.00 | 1.07 |
| 67 | 23.00 | 118 | 2.85 | 11.65 | 1.21 |
| 68 | 9.75 | 66 | 3.20 | 4.73 | 0.20 |
| 69 | 5.00 | 34 | 14.00 | 25.00 | 6.63 |
| 70 | 7.25 | 52 | 14.25 | 3.53 | 0.28 |
| 71 | 7.50 | 28 | 13.75 | 24.19 | 3.06 |
| 72 | 4.00 | 60 | 1.25 | 2.20 | 0.32 |
| 73 | 68.50 | 34 | 1.30 | 38.89 | 0.52 |
| 74 | 4.25 | 36 | 3.25 | 2.40 | 0.85 |
| 75 | 4.50 | 42 | 0.95 | 1.80 | 0.76 |
| 76 | 3.50 | 22 | 11.00 | 75.00 | 6.85 |
| 77 | 12.00 | 4 | 1.95 | 112.50 | 1.91 |
| 78 | 22.00 | 52 | 7.25 | 45.83 | 1.07 |

Fall Analysis - Experimental Subarea

| Well | Date | pH | Temp | Cond | Alk | NO3 | NH3 |
|---|---|---|---|---|---|---|---|
| 1 | 9-16-89 | 6.5 | 16.5 | 399 | 190 | 5.13 | 0.00 |
| 2 | 9-22-89 | 7.2 | 15.5 | 390 | 210 | 0.89 | 0.00 |
| 3 | 9-15-89 | 7.2 | 15.5 | 336 | 170 | 0.00 | 0.00 |
| 4 | 9-18-89 | 7.3 | 20.0 | 347 | 175 | 1.85 | 0.00 |
| 5 | 9-15-89 | 6.6 | 16.0 | 421 | 180 | 5.19 | 0.00 |
| 6 | 9-16-89 | 7.3 | 15.5 | 474 | 260 | 0.00 | 0.00 |
| 7 | 9-16-89 | 7.0 | 18.0 | 459 | 215 | 5.19 | 0.00 |
| 8 | 9-15-89 | 7.5 | 19.0 | 438 | 238 | 0.11 | 0.00 |
| 9 | 9-15-89 | 7.4 | 16.5 | 399 | 215 | 0.04 | 0.00 |
| 10 | 9-16-89 | 6.8 | 17.0 | 354 | 195 | 0.75 | 0.00 |
| 11 | 9-16-89 | 7.4 | 15.0 | 407 | 220 | 0.94 | 0.00 |
| 12 | 9-16-89 | 7.8 | 16.0 | 688 | 350 | 0.15 | 0.07 |
| 13 | 9-16-89 | 7.4 | 15.0 | 467 | 125 | 21.61 | 0.00 |
| 14 | 9-15-89 | 6.7 | 15.5 | 336 | 175 | 1.55 | 0.00 |
| 15 | 9-15-89 | 6.8 | 14.0 | 528 | 230 | 3.02 | 0.00 |
| 16 | 9-15-89 | 6.9 | 17.0 | 411 | 180 | 3.33 | 0.00 |
| 17 | 9-15-89 | 7.3 | 16.5 | 657 | 338 | 0.02 | 0.00 |
| 18 | 9-16-89 | 7.0 | 17.0 | 498 | 240 | 7.53 | 0.00 |
| 19 | 9-16-89 | 7.7 | 18.0 | 323 | 145 | 1.14 | 0.00 |
| 20 | 9-15-89 | 6.7 | 16.0 | 368 | 175 | 1.14 | 0.00 |
| 22 | 9-18-89 | 6.9 | 15.5 | 432 | 210 | 2.05 | 0.00 |
| 23 | 9-15-89 | . | 15.5 | 318 | 160 | 1.55 | 0.00 |
| 24 | 9-19-89 | 7.7 | 21.5 | 300 | 160 | 1.58 | 0.00 |
| 25 | 9-19-89 | 7.2 | 16.0 | 516 | 285 | 0.39 | 0.00 |
| 26 | 9-18-89 | 7.1 | 16.0 | 486 | 270 | 0.04 | 0.00 |
| 27 | 9-18-89 | 7.7 | 16.5 | 340 | 180 | 0.02 | 0.00 |
| 28 | 9-16-89 | 7.0 | 15.5 | 474 | 248 | 4.51 | 0.00 |
| 29 | 9-18-89 | 7.5 | 21.0 | 308 | 155 | 0.00 | 0.00 |
| 30 | 9-18-89 | 7.8 | 18.0 | 334 | 203 | 0.15 | 0.09 |
| 31 | 9-18-89 | 7.9 | 20.5 | 177 | 90 | 0.55 | 0.00 |
| 32 | 9-18-89 | 7.0 | 16.0 | 474 | 235 | 0.15 | 0.03 |
| 33 | 9-19-89 | 7.3 | 15.0 | 492 | 245 | 3.34 | 0.00 |
| 34 | 9-19-89 | 7.4 | 16.0 | 409 | 215 | 0.25 | 0.00 |
| 35 | 9-19-89 | . | 19.5 | 379 | 210 | 0.53 | 0.00 |
| 36 | 9-22-89 | 7.4 | 21.5 | 374 | 190 | 0.39 | 0.00 |
| 37 | 9-16-89 | 6.7 | 15.5 | 336 | 150 | 5.51 | 0.00 |
| 38 | 9-16-89 | 6.8 | 15.5 | 348 | 155 | 4.38 | 0.00 |
| 39 | 9-23-89 | 7.2 | 14.0 | 373 | 205 | 0.00 | 0.00 |
| 40 | 9-19-89 | 7.7 | 16.5 | 375 | 225 | 0.00 | 0.07 |
| 41 | 9-19-89 | 7.5 | 16.0 | 314 | 180 | 1.14 | 0.00 |
| 42 | 9-19-89 | 7.4 | 15.5 | 426 | 248 | 0.00 | 0.00 |
| 43 | 9-16-89 | 7.3 | 19.5 | 411 | 230 | 0.00 | 0.00 |
| 44 | 9-16-89 | . | 19.0 | 466 | 160 | 18.06 | 0.00 |
| 45 | 9-19-89 | 7.3 | 19.5 | 401 | 210 | 4.81 | 0.00 |
| 46 | 9-18-89 | 7.3 | 16.0 | 498 | 255 | 0.02 | 0.00 |
| 47 | 9-23-89 | 7.1 | 15.5 | 378 | 180 | 1.61 | 0.00 |

Fall Analysis - Experimental Subarea

| Well | Cl | Ca | Mg | Na | K |
|---|---|---|---|---|---|
| 1 | 12.50 | 78 | 1.80 | 5.14 | 3.32 |
| 2 | 5.25 | 78 | 3.75 | 3.57 | 0.49 |
| 3 | 7.75 | 50 | 15.00 | 4.17 | 0.06 |
| 4 | 5.75 | 74 | 0.75 | 5.00 | 0.30 |
| 5 | 17.50 | 84 | 1.10 | 29.17 | 0.94 |
| 6 | 6.80 | 96 | 8.00 | 5.56 | 0.11 |
| 7 | 12.50 | 86 | 2.50 | 5.83 | 5.00 |
| 8 | 6.75 | 40 | 9.25 | 9.79 | 1.56 |
| 9 | 4.75 | 50 | 10.25 | 5.63 | 0.30 |
| 10 | 9.25 | 70 | 2.00 | 5.29 | 0.55 |
| 11 | 10.25 | 88 | 1.00 | 2.78 | 0.52 |
| 12 | 29.00 | 20 | 7.75 | 146.88 | 3.17 |
| 13 | 22.00 | 78 | 2.00 | 15.94 | 0.75 |
| 14 | 9.75 | 66 | 1.70 | 5.71 | 3.57 |
| 15 | 14.00 | 104 | 2.45 | 5.42 | 2.45 |
| 16 | 12.50 | 84 | 1.25 | 6.43 | 1.30 |
| 17 | 16.25 | 38 | 7.50 | 128.13 | 2.41 |
| 18 | 10.50 | 102 | 2.80 | 3.57 | 1.81 |
| 19 | 10.25 | 64 | 2.00 | 5.43 | 2.37 |
| 20 | 12.00 | 76 | 1.55 | 30.21 | 0.61 |
| 22 | 18.75 | 84 | 1.55 | 5.42 | 0.83 |
| 23 | 5.25 | 64 | 4.50 | 2.50 | 0.36 |
| 24 | 7.25 | 58 | 2.95 | 2.44 | 1.04 |
| 25 | 7.25 | 96 | 12.25 | 6.04 | 0.43 |
| 26 | 12.25 | 74 | 17.00 | 12.78 | 0.55 |
| 27 | 6.00 | 26 | 11.50 | 68.75 | 3.34 |
| 28 | 11.50 | 100 | 2.30 | 6.57 | 2.62 |
| 29 | 5.50 | 34 | 12.75 | 11.56 | 2.57 |
| 30 | 10.75 | 28 | 13.50 | 56.25 | 3.60 |
| 31 | 8.50 | 30 | 0.55 | 2.89 | 0.04 |
| 32 | 30.25 | 74 | 7.50 | 30.00 | 0.83 |
| 33 | 24.75 | 100 | 1.00 | 38.54 | 0.83 |
| 34 | 17.25 | 60 | 10.00 | 34.29 | 2.45 |
| 35 | 7.75 | 80 | 1.00 | 4.00 | 0.55 |
| 36 | 7.25 | 76 | 1.10 | 2.56 | 0.49 |
| 37 | 9.00 | 66 | 0.90 | 5.42 | 0.19 |
| 38 | 17.50 | 54 | 1.20 | 15.63 | 0.43 |
| 39 | 6.25 | 78 | 0.75 | 32.29 | 0.94 |
| 40 | 7.25 | 42 | 19.50 | 16.43 | 0.55 |
| 41 | 4.50 | 68 | 2.20 | 1.89 | 0.52 |
| 42 | 5.25 | 48 | 26.50 | 7.22 | 0.07 |
| 43 | 4.25 | 74 | 4.25 | 13.33 | 0.58 |
| 44 | 14.50 | 84 | 2.65 | 41.67 | 1.11 |
| 45 | 11.25 | 80 | 1.20 | 5.63 | 1.07 |
| 46 | 8.50 | 76 | 1.00 | 5.29 | 0.75 |
| 47 | 8.50 | 76 | 1.00 | 5.29 | 0.75 |

Fall Analysis - Control Subarea

| Well | Date | pH | Temp | Cond | Alk | NO3 | NH3 |
|---|---|---|---|---|---|---|---|
| 60 | 9-21-89 | 7.1 | 16.5 | 322 | 125 | 7.63 | 0.00 |
| 61 | 9-21-89 | 7.1 | 15.5 | 354 | 190 | 0.97 | 0.00 |
| 62 | 9-21-89 | 7.9 | 16.5 | 317 | 205 | 0.02 | 0.16 |
| 63 | 9-23-89 | 6.9 | 15.0 | 261 | 140 | 0.21 | 0.00 |
| 64 | 9-22-89 | 7.3 | 15.5 | 300 | 230 | 0.07 | 0.13 |
| 65 | 9-23-89 | 6.8 | 14.5 | 688 | 390 | 0.19 | 0.38 |
| 66 | 9-22-89 | 7.5 | 15.0 | 303 | 145 | 1.27 | 0.00 |
| 67 | 9-21-89 | 7.1 | 15.5 | 672 | 255 | 12.91 | 0.00 |
| 68 | 9-21-89 | 7.3 | 16.5 | 334 | 140 | 4.80 | 0.00 |
| 69 | 9-21-89 | 7.4 | 16.5 | 334 | 198 | 0.09 | 0.27 |
| 70 | 9-21-89 | 7.2 | 16.5 | 346 | 190 | 0.00 | 0.00 |
| 71 | 9-21-89 | 7.8 | 19.5 | 324 | 180 | 0.07 | 0.05 |
| 72 | 9-21-89 | 7.4 | 17.0 | 284 | 170 | 0.04 | 0.00 |
| 73 | 9-23-89 | 6.3 | 16.0 | 498 | 75 | 0.04 | 0.00 |
| 74 | 9-21-89 | 7.4 | 15.5 | 222 | 130 | 0.00 | 0.00 |
| 75 | 9-21-89 | 7.2 | 15.0 | 206 | 125 | 0.37 | 0.00 |
| 76 | 9-23-89 | 7.4 | 15.5 | 468 | 280 | 0.11 | 0.27 |
| 77 | 9-23-89 | 8.2 | 15.5 | 462 | 260 | 0.17 | 0.00 |
| 78 | 9-23-89 | 7.7 | 17.0 | 458 | 225 | 1.88 | 0.00 |
| 79 | 9-21-89 | 7.7 | 16.5 | 346 | 200 | 0.09 | 0.03 |
| 80 | 9-23-89 | 7.2 | 15.5 | 630 | 375 | 0.15 | 0.43 |
| 81 | 9-23-89 | 7.3 | 19.5 | 357 | 185 | 0.04 | 0.00 |

Fall Analysis - Control Subarea

| Well | Cl | Ca | Mg | Na | K |
|---|---|---|---|---|---|
| 60 | 12.00 | 44 | 5.25 | 10.63 | 7.96 |
| 61 | 10.50 | 66 | 3.10 | 8.29 | 1.81 |
| 62 | 4.25 | 32 | 14.25 | 15.63 | 4.58 |
| 63 | 6.00 | 50 | 1.45 | 2.67 | 0.61 |
| 64 | 4.50 | 56 | 10.50 | 17.14 | 4.20 |
| 65 | 5.50 | 56 | 21.50 | 7.08 | 9.81 |
| 66 | 4.75 | 58 | 2.45 | 1.56 | 1.11 |
| 67 | 26.25 | 120 | 3.20 | 10.00 | 1.33 |
| 68 | 11.25 | 62 | 3.20 | 4.00 | 0.11 |
| 69 | 6.75 | 32 | 13.75 | 5.00 | 7.04 |
| 70 | 9.75 | 50 | 14.00 | 3.29 | 0.19 |
| 71 | 8.00 | 26 | 13.00 | 26.04 | 3.23 |
| 72 | 4.75 | 58 | 1.15 | 2.11 | 0.24 |
| 73 | 108.25 | 38 | 1.55 | 56.25 | 0.63 |
| 74 | 5.25 | 40 | 3.25 | 2.33 | 0.86 |
| 75 | 6.25 | 40 | 0.95 | 1.89 | 0.80 |
| 76 | 4.00 | 22 | 11.25 | 75.00 | 7.04 |
| 77 | 14.75 | 6 | 2.00 | 128.13 | 1.96 |
| 78 | 17.50 | 32 | 5.50 | 70.31 | 1.44 |
| 79 | 5.25 | 20 | 11.50 | 89.58 | 3.12 |
| 80 | 5.00 | 48 | 18.75 | 71.88 | 9.26 |
| 81 | 9.75 | 62 | 7.50 | 7.29 | 0.75 |