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Arkansas Water Resources Center

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

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

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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-

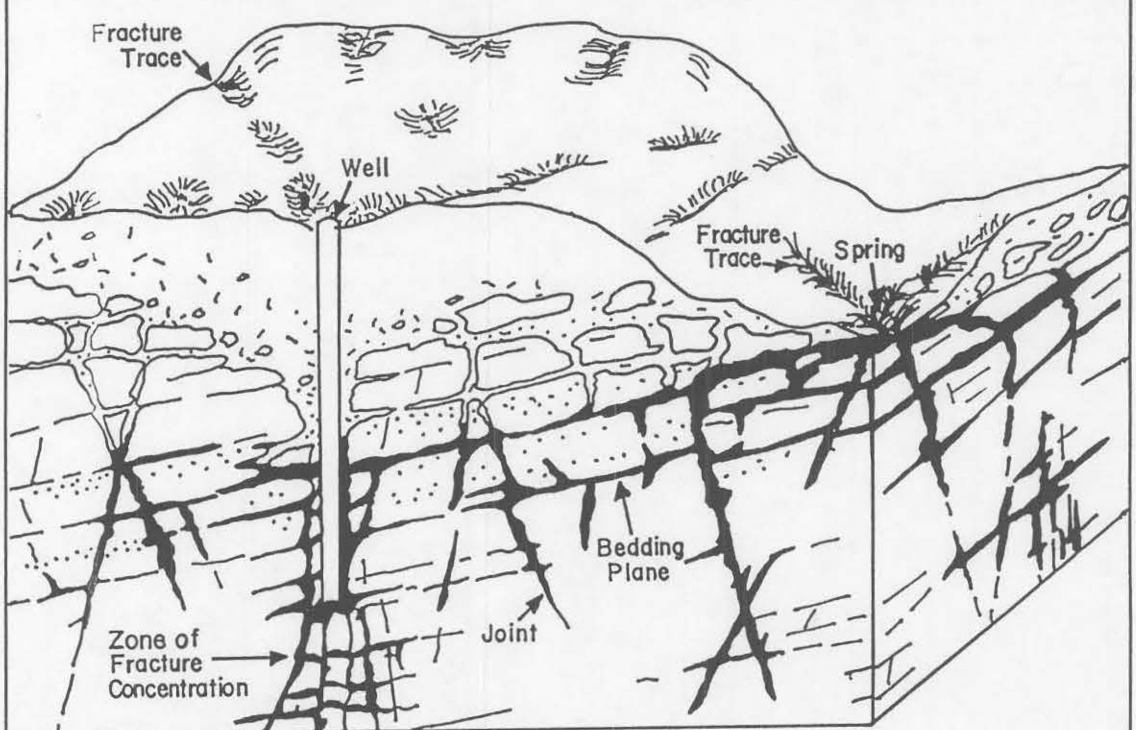

Figure 1. Schematic diagram showing the relationship of a spring and a high-yield water well to fracture and bedding planes.

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.

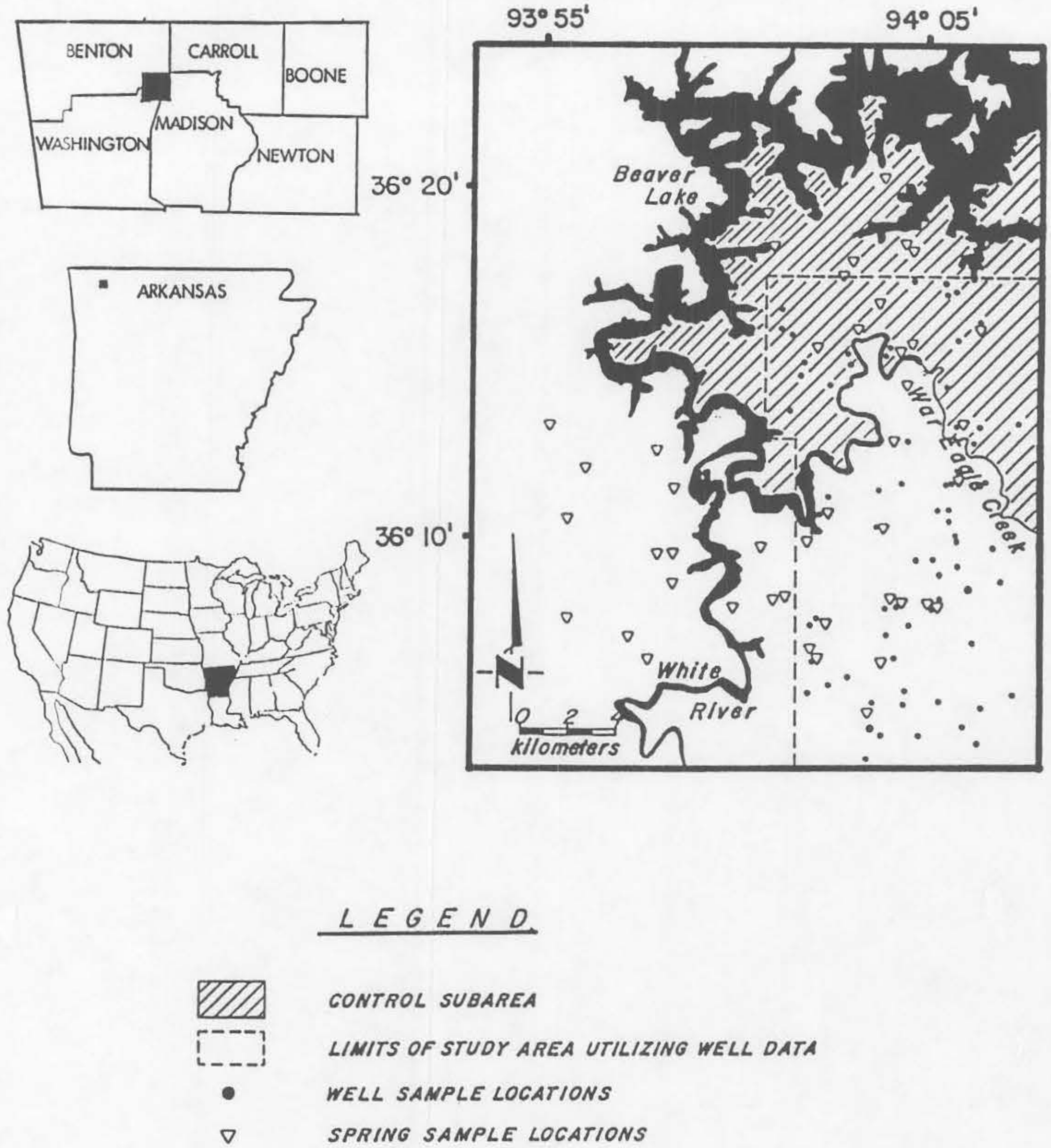

Figure 2. Location of well sites for this study and for springs used by Adamski and Steele (1988).

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 23.5×10^6 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

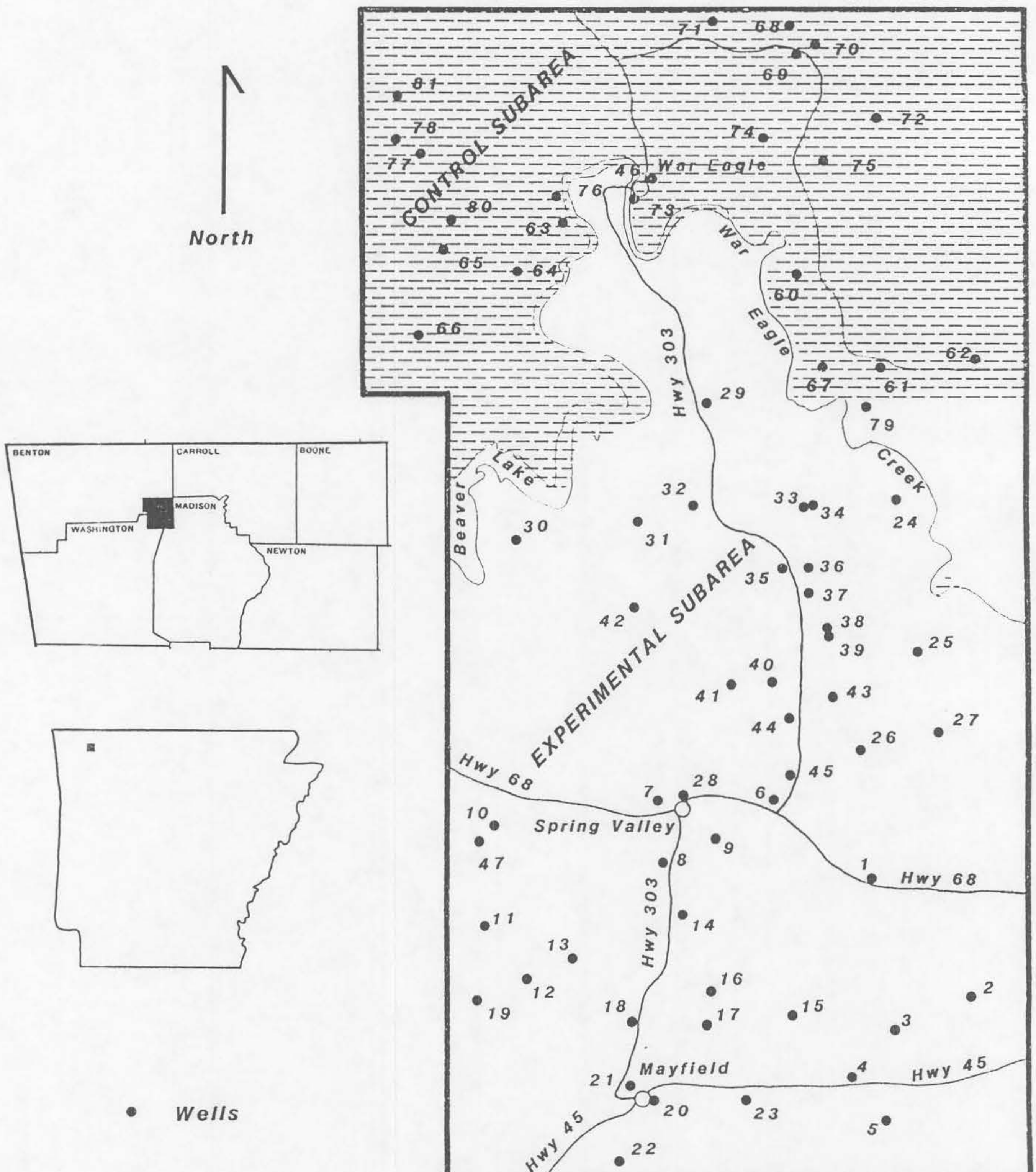

Figure 3. Well sites and numbers used in this study. See Appendix I for more precise location of wells.

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.

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

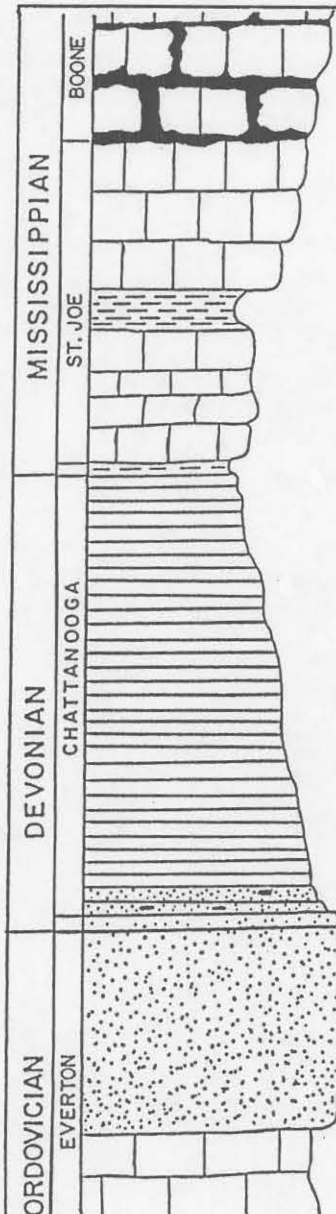

Figure 4. Schematic stratigraphic column for northwest Arkansas (from Manger and Borengasser, 1979).

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 7.4×10^{-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.

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)

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.

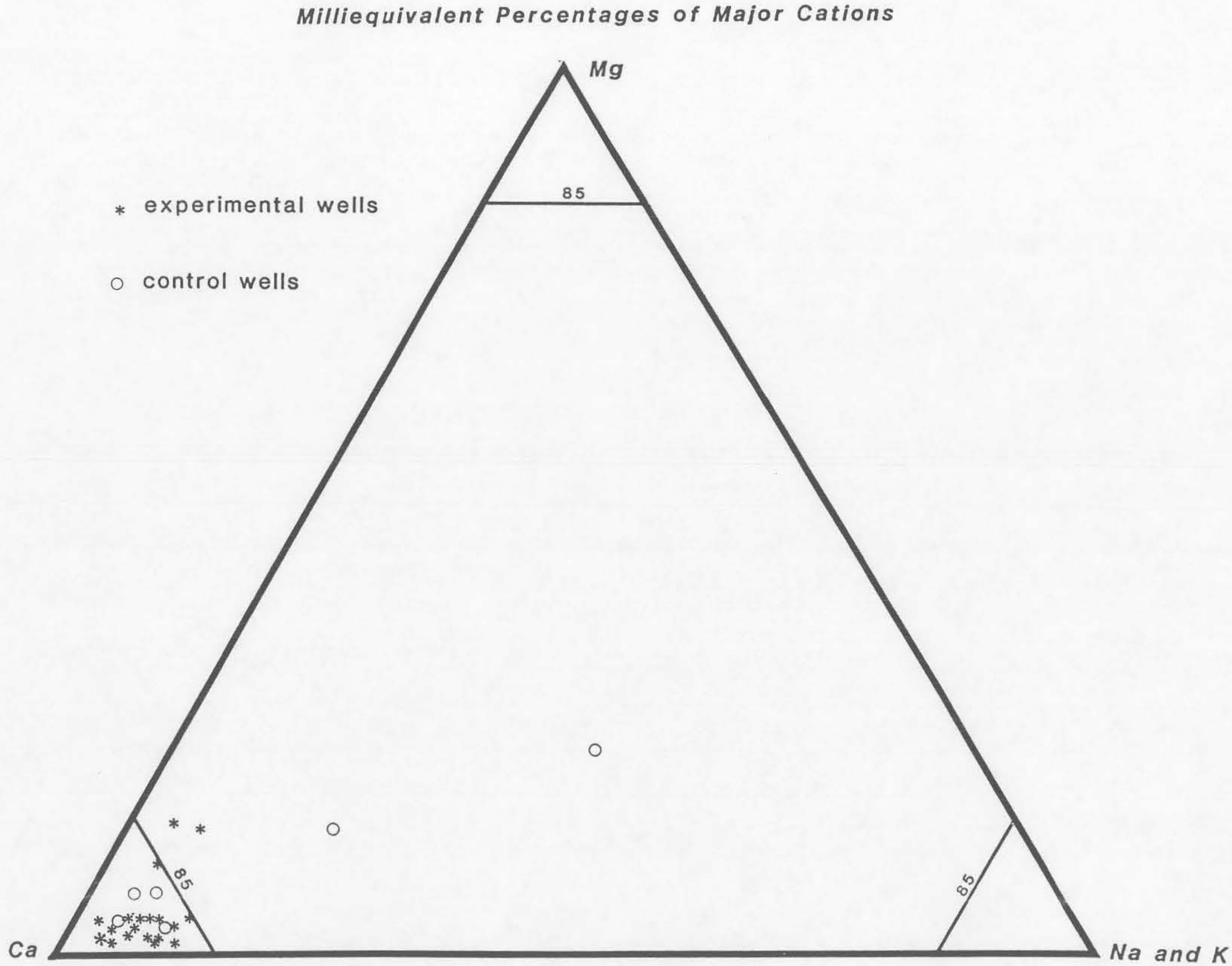

Figure 5. Plot of the milliequivalent percentages of calcium, magnesium and sodium+potassium for wells with depths less than 186 feet (nominally the Boone-St. Joe aquifer).

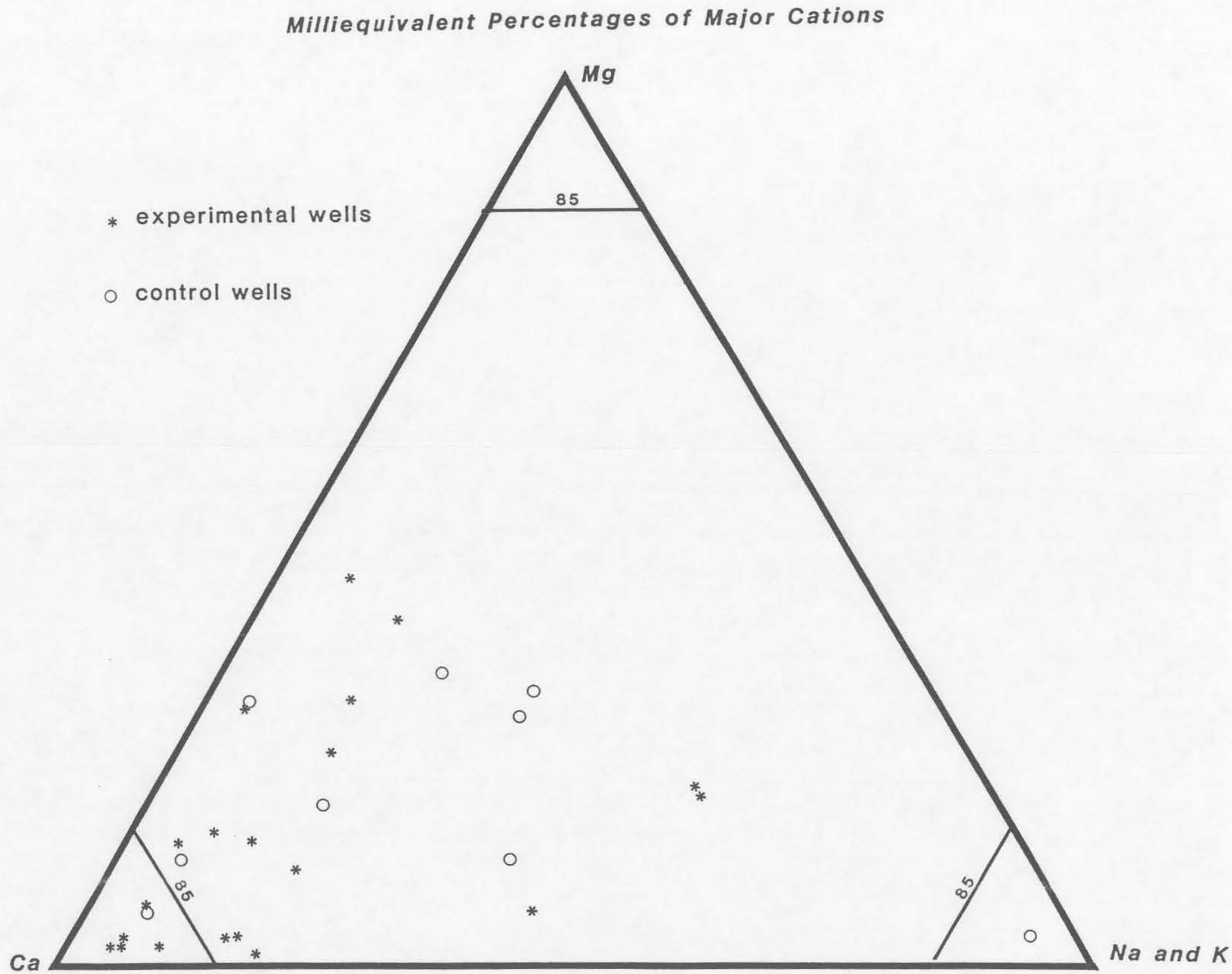

Figure 6. Plot of the milliequivalent percentages of calcium, magnesium and sodium+potassium for wells with depths greater than 186 feet (nominally the Everton aquifer).

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.

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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	0.09
40	5-11-89	7.7	16.0	350	235	0.00	0.34
41	5-11-89	7.7	15.5	312	190	1.09	0.21
42	5-16-89	6.8	15.0	394	160	0.00	0.00
43	5-11-89	6.8	16.5	410	270	0.00	0.16
44	5-11-89	7.1	16.0	338	165	8.65	0.00
45	5-15-89	6.6	17.0	371	180	4.38	0.00
46	5-16-89	7.0	14.5	491	250	0.00	0.00
47	5-12-89	7.3	20.0	337	183	1.30	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