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Ground-Water Quality and Effects of Poultry Confined Animal Feeding Operations on Shallow Ground Water, Upper Shoal Creek Basin, Southwest Missouri, 2000

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By Douglas N. Mugel

Abstract

Forty-seven wells and 8 springs were sampled in May, October, and November 2000 in the upper Shoal Creek Basin, southwest Missouri, to determine if nutrient concentrations and fecal bacteria densities are increasing in the shallow aquifer as a result of poultry confined animal feeding operations (CAFOs). Most of the land use in the basin is agricultural, with cattle and hay production dominating; the number of poultry CAFOs has increased in recent years. Poultry waste (litter) is used as a source of nutrients on pasture land as much as several miles away from poultry barns.

Most wells in the sample network were classified as "P" wells, which were open only or mostly to the Springfield Plateau aquifer and where poultry litter was applied to a substantial acreage within 0.5 mile of the well both in spring 2000 and in several previous years; and "Ag" wells, which were open only or mostly to the Springfield Plateau aquifer and which had limited or no association with poultry CAFOs. Water-quality data from wells and springs were grouped for statistical purposes as P1, Ag1, and Sp1 (May 2000 samples) and P2, Ag2, and Sp2 (October or November 2000 samples).

The results of this study do not indicate that poultry CAFOs are affecting the shallow ground water in the upper Shoal Creek Basin with respect to nutrient concentrations and fecal bacteria densities. Statistical tests do not indicate that P wells sampled in spring 2000 have statistically larger concentrations of nitrite plus nitrate or fecal indicator bacteria densities than Ag wells sampled during the same time, at a 95-percent confidence level. Instead, the Ag wells had statistically larger concentrations of nitrite plus nitrate and fecal coliform bacteria densities than the P wells.

The results of this study do not indicate seasonal variations from spring 2000 to fall 2000 in the concentrations of nutrients or fecal indicator bacteria densities from well samples. Statistical tests do not indicate statistically significant differences at a 95-percent confidence level for nitrite plus nitrate concentrations or fecal indicator bacteria densities between either P wells sampled in spring and fall 2000, or Ag wells sampled in spring and fall 2000. However, analysis of samples from springs shows that fecal streptococcus bacteria densities were statistically smaller in fall 2000 than in spring 2000 at a 95-percent confidence level.

Nitrite plus nitrate concentrations in spring 2000 samples ranged from less than the detection level [0.02 mg/L (milligram per liter) as nitrogen] to 18 mg/L as nitrogen. Seven samples from three wells had nitrite plus nitrate concentrations at or larger than the maximum contaminant level (MCL) of 10 mg/L as nitrogen. The median nitrite plus nitrate concentrations were 0.28 mg/L as nitrogen for P1 samples, 4.6 mg/L as nitrogen for Ag1 samples, and 3.9 mg/L as nitrogen for Sp1 samples.

Fecal coliform bacteria were detected in 1 of 25 P1 samples and 5 of 15 Ag1 samples. *Escheri-*

chia coli (*E. coli*) bacteria were detected in 3 of 24 P1 samples and 1 of 13 Ag1 samples. Fecal streptococcus bacteria were detected in 8 of 25 P1 samples and 6 of 15 Ag1 samples. Bacteria densities in samples from wells ranged from less than 1 to 81 col/100 mL (colonies per 100 milliliters) of fecal coliform, less than 1 to 140 col/100 mL of *E. coli*, and less than 1 to 130 col/100 mL of fecal streptococcus. Fecal indicator bacteria densities in samples from springs were substantially larger than in samples from wells. In Sp1 samples, bacteria densities ranged from 12 to 3,300 col/100 mL of fecal coliform, 40 to 2,700 col/100 mL of *E. coli*, and 42 to 3,100 col/100 mL of fecal streptococcus.

INTRODUCTION

The number of poultry confined animal feeding operations (CAFOs) in the upper Shoal Creek Basin (fig. 1) has increased since the late 1980's. By 2000, an estimated 377 active poultry barns were in the basin, of which about 75 percent were used for the production of broilers (chickens raised from chicks to approximately 4 1/2 pounds; Schumacher, 2001). A poultry CAFO normally consists of two to eight large poultry barns. Approximately 21,000 broilers are produced in each barn five to six times per year, for an estimated annual production of 33 million chickens (Schumacher, 2001). The remaining poultry barns are used for the production of about 300,000 turkeys annually. The production process consists of raising the chickens or turkeys for several weeks until they are shipped to market, removing the poultry litter (poultry waste and sawdust base) from the poultry barns, and repeating the process. The litter is spread on pasture land as a source of nutrients, or composted for later application. The field application of poultry litter may occur near the poultry barns and as much as several miles away.

The Springfield Plateau aquifer is the shallow aquifer throughout most of the upper Shoal Creek Basin and supplies most of the rural domestic water. Alluvial deposits along Shoal Creek and its tributaries form a thin and narrow aquifer. There is concern that nutrient concentrations and fecal bacteria densities in shallow ground water in the upper Shoal Creek Basin may be increasing because of poultry CAFOs. In 1999, the Missouri Department of Natural Resources (MDNR), Division of Environmental Quality, Water Pollution Control Program and the U.S. Environmental Protection Agency (USEPA) entered into a cooperative agreement with the U.S. Geological Survey (USGS) to investigate the shallow ground-water quality in the upper Shoal Creek Basin, and to determine if nutrient concentrations and fecal bacteria densities are increasing in the shallow aquifer in the upper Shoal Creek Basin in areas of poultry CAFOs.

The wells sampled for this study were limited to existing domestic and commercial wells. Therefore, the wells in the sample network were characterized by variations and uncertainties in well and casing depth, age, and litter application, and the presence of other environmental factors. Although the emphasis of the study was on the water quality of wells open to the Springfield Plateau aquifer, one alluvial well, three wells open to a substantial part of the deeper and confined Ozark aquifer, and eight springs discharging from the Springfield Plateau aquifer also were sampled. Eighty-seven samples were collected from 47 wells and 8 springs in May, October, and November 2000. Data are presented for physical properties, fecal indicator bacteria densities, concentrations of chemical constituents, and nitrogen isotopic composition. The data analysis included an assessment of seasonal variations in nutrient concentrations and fecal indicator bacteria densities, from spring 2000 to fall 2000. This report presents the results of the study.

Previous Studies

The relation between poultry CAFOs and ground-water quality of the upper Shoal Creek Basin has not been studied previously except for the sampling of some springs in conjunction with surface-water studies. The quality of surface water of the upper Shoal Creek Basin has been previously studied because of the concern that large fecal coliform densities and nutrient concentrations in Shoal Creek may be related to the increase in the number of commercial poultry CAFOs. Shoal Creek is an important source of drinking water for the cities of Joplin and Neosho, both downstream from the study area (fig. 1). The stream also is used for recreation, industrial water supply, irrigation, and livestock watering. The MDNR began ambient water-quality monitoring at two surface-water sites in the upper Shoal Creek Basin in 1992; the monitoring included measurements of nutrient concentrations and fecal indicator bacteria densities. Between 1992 and 1998, fecal coliform bacteria densities at a site on Shoal Creek at State Highway 97 (fig. 1) had a median of 320

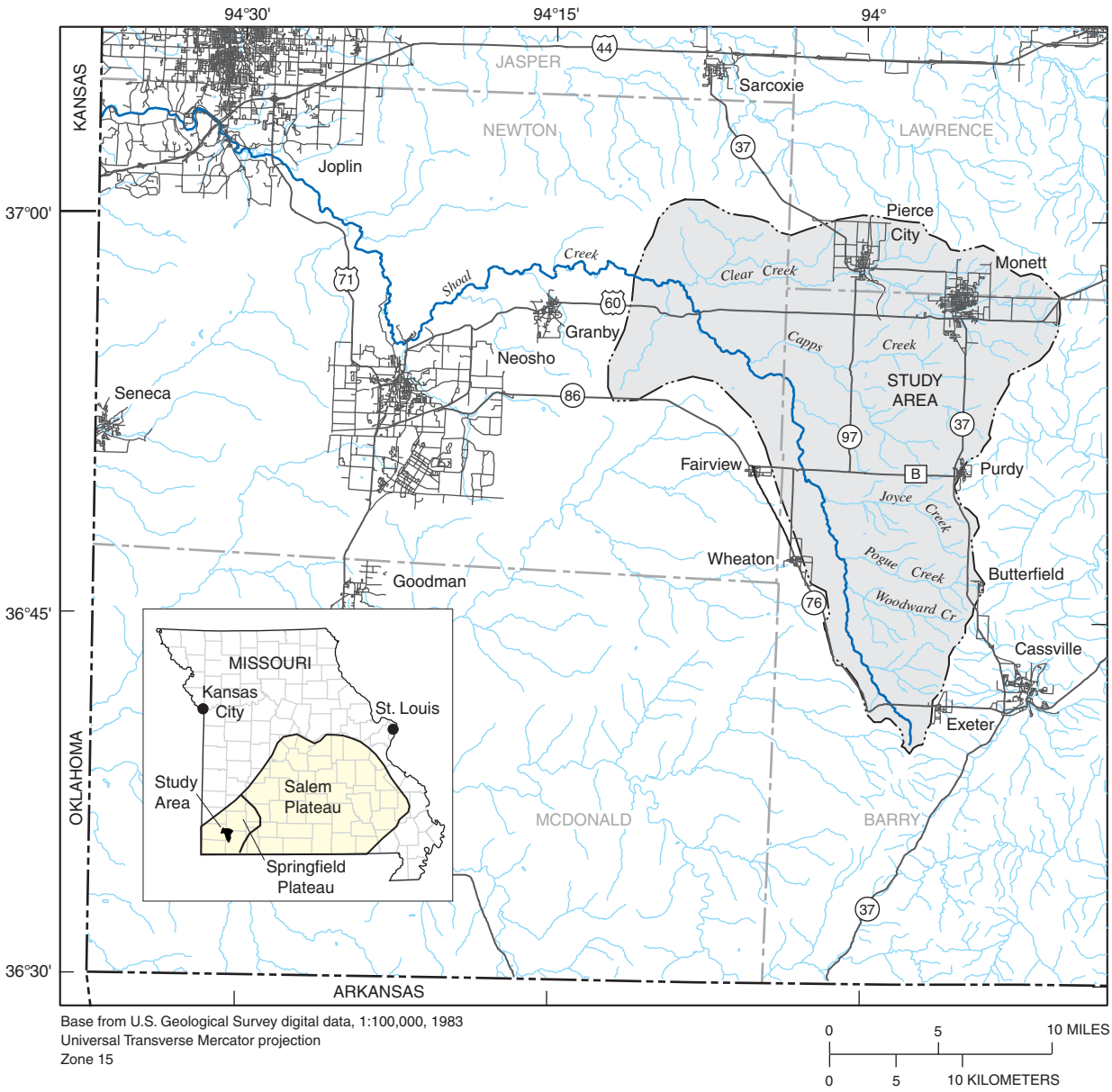

Figure 1. Location of the upper Shoal Creek Basin study area.

col/100 mL (colonies per 100 milliliters; Schumacher, 2001). Concentrations of total nitrite plus nitrate as nitrogen and total phosphorus averaged 3.15 and 0.17 mg/L (milligrams per liter). In 1995, a 5-year study was initiated by the MDNR and USEPA focusing on reducing nutrient concentrations in the upper Shoal Creek Basin (Schumacher, 2001). Monthly water-quality samples were collected at six surface-water sites and four springs. As part of the study, the Natural Resources Conservation Service (NRCS) provided technical assistance to poultry operators to develop nutrient management plans and implement Best Management Plans (BMPs). A 5-year Special Area Land Treatment (SALT) project began in 1998 in the upper Shoal Creek Basin (Schumacher, 2001). This cooperative project between the MDNR, NRCS, Missouri Department of Conservation (MDOC), University of Missouri Extension office, and local farmers and poultry producers includes water-quality sampling of six surface-water sites and four springs, mostly in the Capps Creek Basin (fig. 1).

From 1999 to 2000, the USGS conducted a study of the water quality of Shoal Creek and its principal tributaries in the upper Shoal Creek Basin (Schumacher, 2001). More than 170 water samples were collected during 13 months from a network of 17 sites, including 5 springs. Analyses of stream samples from that study indicated that base-flow concentrations of total nitrite plus nitrate as nitrogen in Shoal Creek (mean of 2.90 mg/L) were significantly larger than base-flow concentrations of total nitrite plus nitrate as nitrogen in other Missouri streams (mean of 1.02 mg/L). The report stated that, at base-flow conditions, most of the total nitrite plus nitrate discharged by Shoal Creek was from nonpoint sources and that nearly all the total phosphorus discharged by Shoal Creek was from effluent from a municipal wastewater treatment plant. Median fecal coliform densities at two sites on Shoal Creek were 277 and 400 col/100 mL. Historical data were also examined and the study concluded that an apparent trend of increasing fecal coliform densities with increasing time at one of the sites on Shoal Creek was, in part, related to a general trend of increasing discharge in Shoal Creek in response to an increase in annual precipitation, and not necessarily land-use changes or changes in the number of CAFOs in the basin.

Acknowledgments

The author thanks the owners of wells and springs in Barry, Lawrence, and Newton Counties, Missouri, who provided information about the wells and springs, the land use near the wells, and gave permission to sample the wells and springs. Their cooperation was instrumental in the completion of this study. Appreciation also is extended to Mr. Dan Philbrick and Mrs. Kari Rhoades of the Barry County NRCS for their help in the selection of wells for sampling.

DESCRIPTION OF THE STUDY AREA

The study area is the upper 233 mi^2 (square miles; Schumacher, 2001) of the Shoal Creek Basin in parts of Barry, Lawrence, and Newton Counties in southwest Missouri (fig. 1). The largest density of poultry CAFOs in the Shoal Creek Basin is in this area. The upper Shoal Creek Basin is in the Springfield Plateau of the Ozark Plateaus physiographic province.

Climate

The upper Shoal Creek Basin has a temperate climate characterized by warm, humid summers and cool, wet winters. Climatological stations are maintained by the National Oceanic and Atmospheric Administration (NOAA) at Cassville and Monett (fig. 1). The mean annual (2000) temperature at Monett is 55.6 ^{o}F (degrees Fahrenheit), and ranged from a minimum of 17 ^{o}F to a maximum of 105 ^{o}F during the sampling period from May through November 2000 (National Oceanic and Atmospheric Administration, 2000a, 2000b). The mean annual precipitation at Monett is 43.63 in. (inches). Precipitation during 2000 at the Monett station, expressed as departure from average, is shown in figure 2. Drought conditions existed at the Monett station for approximately 10 months before the first set of samples was collected in May 2000 (Schumacher, 2001). From May through July 2000, precipitation at the Monett station was near or greater than average. Precipitation was less than average from August through October, when the second set of samples was collected, and was greater than average in November, when the third set of samples was collected. From May 2000 through November 2000, precipitation

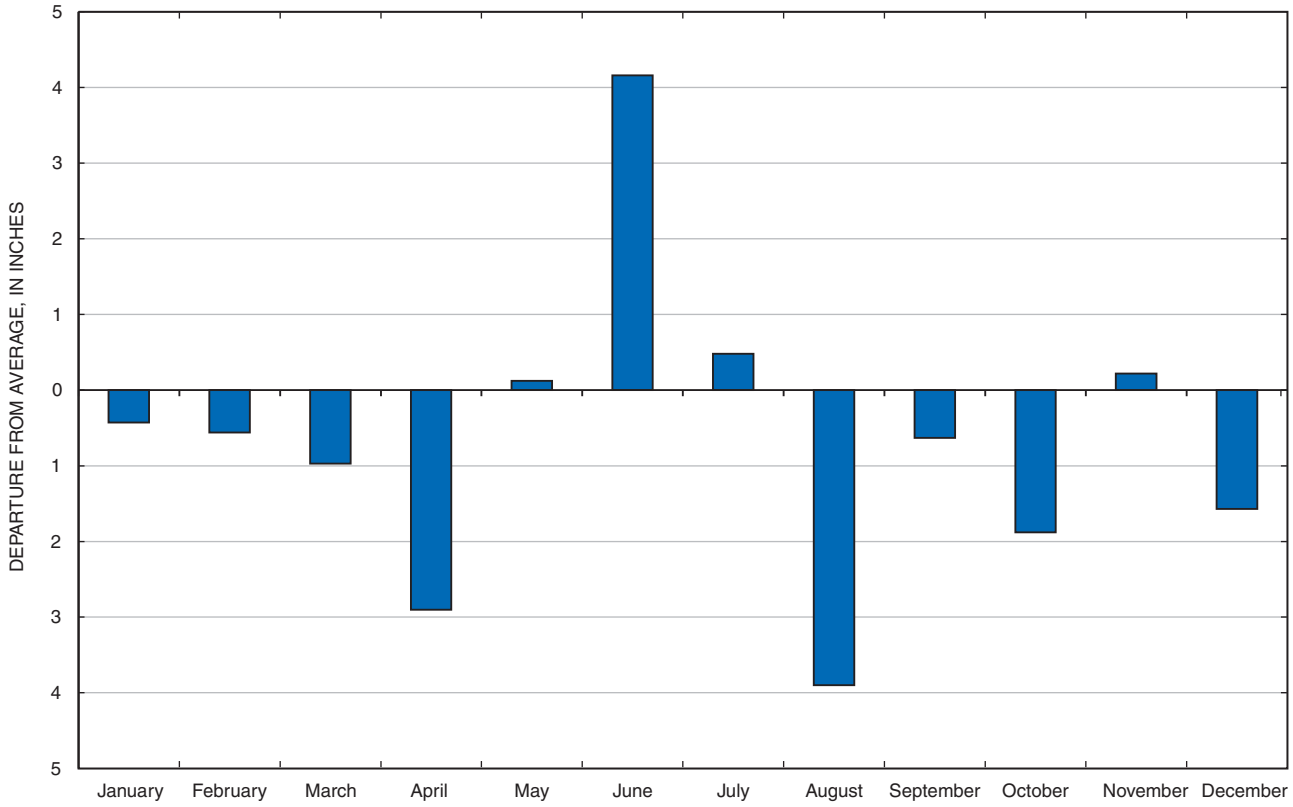

Figure 2. Departure from average monthly precipitation at Monett, Missouri, 2000 (data from the National Oceanic and Atmospheric Administration, 2000a).

at the Monett station was 27.52 in., which was 1.43 in. less than the long-term average of 28.95 in. for that period.

Topography

The topography in the upper Shoal Creek Basin is one of gently rolling hills, except near streams where the local relief can be steeper. A notable feature of the upper Shoal Creek Basin is its asymmetry, with Shoal Creek occupying a position west of the basin center (fig. 3). Elevations in the study area range from 1,060 ft (feet) at the most downstream point on Shoal Creek to more than 1,570 ft in the southern part of the basin.

Geohydrologic Setting

The upper Shoal Creek Basin is underlain mostly by uplifted Mississippian rocks that define the Springfield Plateau (fig. 1) of the Ozark Plateaus physiographic province. Stream dissection of uplifted sedimentary strata has produced a dendritic drainage pattern. A hydrostratigraphic column for the upper Shoal Creek Basin is shown in figure 4.

The oldest sedimentary strata in the upper Shoal Creek Basin are Upper Cambrian and Ordovician formations that are mostly dolostone or cherty dolostone with lesser sandstone and shale. These strata have a cumulative thickness of as much as 1,700 ft (Imes, 1990b, 1990c, 1990d), and do not crop out in the upper Shoal Creek Basin. Devonian, Mississippian, and locally Pennsylvanian formations overlie the Ordovician formations (Thompson, 1986, 1993, 1995). The Upper Devonian Chattanooga Shale is discontinuous and does not crop out in the study area. It occurs mostly in the southern part of Barry County, where it probably is only a few feet thick. Overlying the Chattanooga Shale are Mississippian formations of the Kinderhookian Series, which also do not crop out in the study area. These are the Bachelor Formation, a thin (1 ft or less) sandstone that may be absent in part of the study

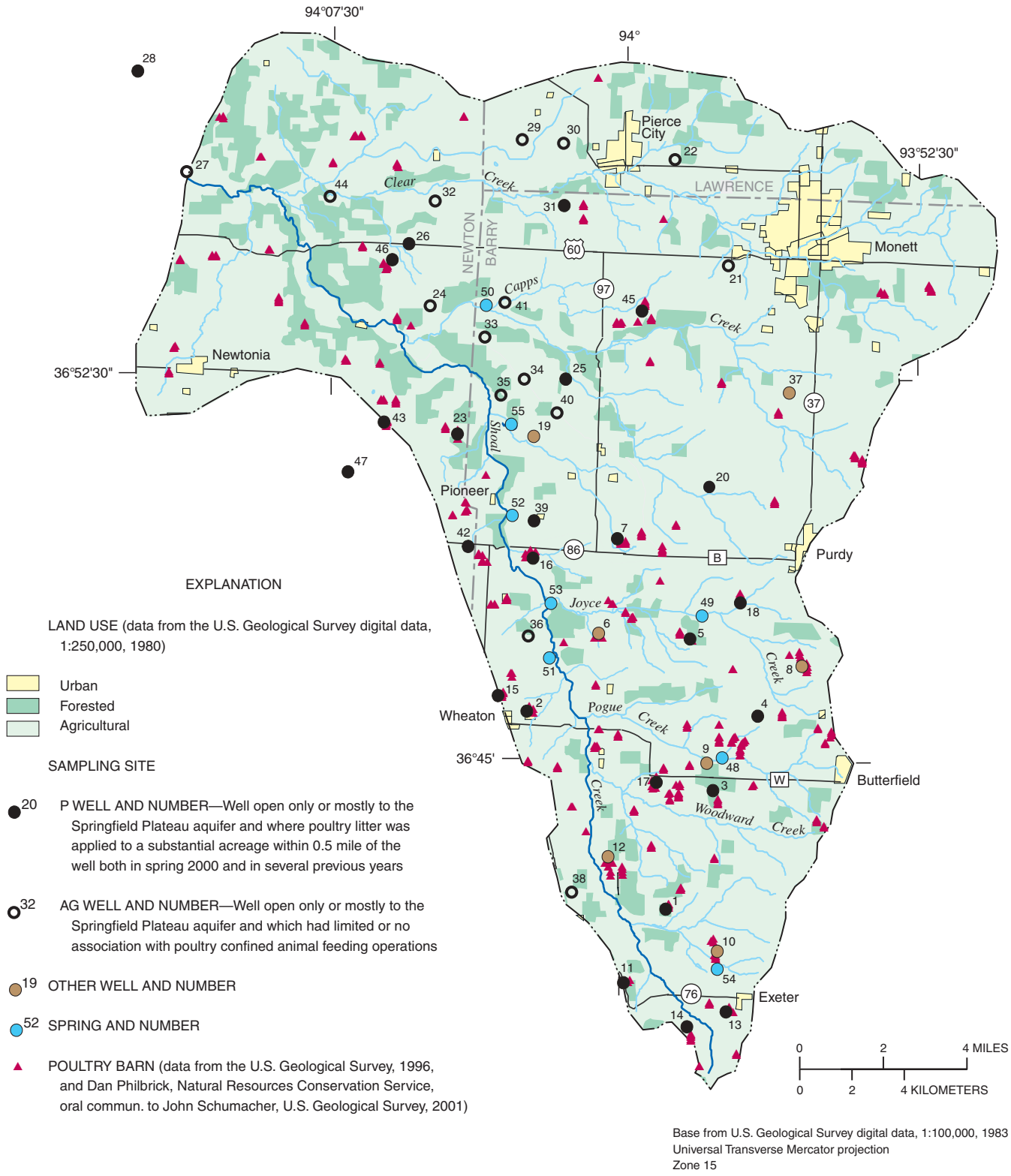

Figure 3. Land use, location of U.S. Geological Survey sampling sites, and distribution of poultry confined animal feeding operations in the study area.

TIME-STRATIGRAPHIC UNIT			ROCK-STRATIGRAPHIC UNIT	REGIONAL GEOHYDROLOGIC UNIT
ERA	SYSTEM	SERIES		
PALEOZOIC	PENNSYLVANIAN		Undifferentiated	Western Interior Plains confining system
	MISSISSIPPIAN	Meramecian	Undifferentiated	Springfield Plateau aquifer
		Osagean	Burlington-Keokuk Limestone Elsey Formation Reeds Spring Formation Pierson Limestone	
		Kinderhookian	Chouteau Group Northview Formation Compton Limestone Bachelor Formation	Ozark confining unit
	DEVONIAN	Upper	Chattanooga Shale	
	ORDOVICIAN	Canadian	Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite	Ozark aquifer
	CAMBRIAN	Upper	Eminence Dolomite Potosi Dolomite	
			Elvins Group Derby-Doerun Dolomite Davis Formation	St. Francois confining unit
			Bonneterre Formation Reagan Sandstone	St. Francois aquifer
PRECAMBRIAN			Precambrian igneous and metamorphic rocks	Basement confining unit

Figure 4. Hydrostratigraphic column of bedrock units for the upper Shoal Creek Basin, southwest Missouri (modified from Imes, 1990a; stratigraphic nomenclature follows that of the Missouri Geological Survey and Resource Assessment Division, formerly known as the Missouri Division of Geology and Land Survey).

area, and the Chouteau Group. The Chouteau Group consists of the Compton Limestone, a fine-grained limestone as much as 12 ft thick, and the Northview Formation, which is a shale or siltstone ranging from less than 5 ft to about 10 ft thick in the study area.

Mississippian formations of the Osagean Series (Thompson, 1986, 1995) form the bedrock throughout most of the upper Shoal Creek Basin. Osagean Series formations are the Pierson Limestone and the Reeds Spring and the Elsey Formations, which are cherty limestones, and the less cherty limestone of the Burlington-Keokuk Limestone (usage follows nomenclature of the Missouri Geological Survey and Resource Assessment Division, formerly know as the Missouri Division of Geology and Land Survey). The Grand Falls Chert is a discontinuous chert-rich facies of the Reeds Spring Formation, Elsey Formation, and Keokuk Limestone. It is exposed along and in the streambed of Shoal Creek in the southern part of the upper Shoal Creek Basin where it forms shoals, riffles, and small waterfalls. Small springs and seeps discharge above the Grand Falls Chert (Schumacher, 2001). The cumulative thickness of the Osagean Series is as much as 300 ft in the upper Shoal Creek Basin. Undifferentiated Mississippian limestones of the Meramecian Series form the bedrock in a few places in the northern part of the upper Shoal Creek Basin. A few outliers of Pennsylvanian sandstone and shale also occur in the northern part of the upper Shoal Creek Basin (Missouri Division of Geology and Land Survey, 1979).

The geohydrologic units that occur in the upper Shoal Creek Basin are, from the surface down, the Western Interior Plains confining system, Springfield Plateau aquifer, Ozark confining unit, Ozark aquifer, St. Francois confining unit, St. Francois aquifer, and Basement confining unit (fig. 4). The geohydrologic unit of greatest interest to this study is the Springfield Plateau aquifer, which is the uppermost geohydrologic unit in all but a few places in the northern part of the upper Shoal Creek Basin where Pennsylvanian rocks crop out. It comprises the formations of the Mississippian Osagean Series and Meramecian Series. Wells producing from 5 to 20 gal/min (gallons per minute) are common, and well yields may locally be much larger (Imes and Smith, 1990). Most wells in the upper Shoal Creek Basin are open to the Springfield Plateau aquifer. Its lower surface is defined by the top of the Ozark confining unit, which dips to the northwest generally at less than 1^{o} (degree; Imes, 1990e). Because the land surface also generally slopes to the northwest, the thickness of the Springfield Plateau aquifer does not vary appreciably from southeast to northwest in the study area, but varies more locally because of topographic changes, from about 200 ft along parts of Shoal Creek to almost 400 ft at some topographic highs. Most of the precipitation that penetrates the soil layer and reaches the water table flows through the Springfield Plateau aquifer and discharges at springs and through the streambed of Shoal Creek and its tributaries. The depth to water measured in eight wells that probably are open only to the Springfield Plateau aquifer ranged from 28.3 to 153.3 ft below land surface (table 1).

The Ozark confining unit (fig. 4) is beneath the Springfield Plateau aquifer and comprises formations that are less permeable than the Springfield Plateau aquifer. It ranges from less than 20 ft to as much as 40 ft thick in the southernmost part of the upper Shoal Creek Basin. The confining unit is more than 60 percent shale in the southernmost part of the basin, and is less than 40 percent shale throughout most of the rest of the basin (Imes, 1990e). The Ozark confining unit impedes ground-water movement between the overlying Springfield Plateau aquifer and the underlying Ozark aquifer. In the Springfield area, approximately 40 mi (miles) northeast of the study area, a downward potentiometric hydraulic head difference of as much as 130 ft exists between the Springfield Plateau aquifer and the Ozark aquifer (Imes, 1989). Water-level measurements from this study are not sufficient to quantify the hydraulic head difference between these units in the study area, but widely spaced regional data indicate that a downward vertical-flow component probably exists in upland areas and that an upward vertical-flow component may exist along Shoal Creek and its principal tributaries (Imes, 1990d, 1990f).

The Ozark aquifer is beneath the Ozark confining unit and is a more productive aquifer than the Springfield Plateau aquifer. It comprises Ordovician and some Upper Cambrian formations (fig. 4). Wells open to the Ozark aquifer produce from 15 to 700 gal/min, and possibly more than 1,000 gal/min (Imes and Smith, 1990). Municipal wells in southern Missouri commonly produce from the Ozark aquifer, as do some commercial and domestic wells. Some wells in the upper Shoal Creek Basin are open to the Ozark aquifer, and some are open to both the Ozark aquifer and the Springfield Plateau aquifer. The Ozark aquifer ranges from about 1,100 to 1,400 ft thick in the upper Shoal Creek Basin (Imes, 1990d). The depth to water was

Table 1. Site type, well-construction data, and water-level data for wells in the sample network

[OZA, Ozark aquifer; mm/dd/yyyy, month, day, year; P, poultry well open only or mostly to Springfield Plateau aquifer, with poultry litter application in spring 2000 and in previous years; SPA, Springfield Plateau aquifer; --, no data; SPA/OZA, Springfield Plateau aquifer and Ozark aquifer; P(old), poultry well open only or mostly to Springfield Plateau aquifer, with poultry litter application only in years prior to 2000; P(deep), poultry well too deep to be open only or mostly to the Springfield Plateau aquifer; approx, approximate value provided by well owner; ?, questionable; >, greater than; Ag(deep), agriculture well too deep to be open only or mostly to the Springfield Plateau aquifer; Ag, agriculture well open only or mostly to Springfield Plateau aquifer; ALLUV, alluvium; all depths in feet below land surface]

Well number	Site type	Well depth	Casing depth	Aquifer open to well	Estimated interval of well open to OZA (feet)	Depth to water	Date of water-level measurement (mm/dd/yyyy)
1	P	200	105	SPA	0	66.2	05/02/2000
2	P	357	85	SPA	0	--	--
3	P	370	--	SPA/OZA	20	--	--
4	P	110	--	SPA	0	81.8	05/03/2000
5	P	330	84	SPA	0	153.3	05/09/2000
6	P(old)	323	126	SPA	0	--	--
7	P	430	150	SPA/OZA	90	152.1	05/05/2000
8	P(deep)	approx 550	--	OZA	all ?	>300	05/03/2000
9	P(old)	280	--	SPA	0	--	--
10	P(old)	approx 70	--	SPA	0	28.3	05/03/2000
11	P	270	--	SPA	0	--	--
12	P(old)	280	60	SPA	0	--	--
13	P	approx 350	--	SPA/OZA	20	--	--
14	P	approx 375	--	SPA/OZA	100	--	--
15	P	232	80	SPA	0	--	--
16	P	310	126	SPA/OZA	65	64.6	05/09/2000
17	P	approx 330	--	SPA	0	149.0	05/04/2000
18	P	approx 350	--	SPA/OZA	50	--	--
19	Ag(deep)	330	260	OZA	70	50.3	05/17/2000
20	P	330	84	SPA/OZA	20	116.3	05/18/2000
21	Ag	382	169	SPA/OZA	30	--	--
22	Ag	425	35	SPA/OZA	50	90.3	05/18/2000
23	P	200	80	SPA	0	109.2	05/10/2000
24	Ag	approx 180	--	SPA	0	--	--
25	P	400	--	SPA/OZA	100	--	--
26	P	approx 250	--	SPA	0	--	--
27	Ag	27	--	ALLUV	0	--	--
28	P	365	105	SPA	0	--	--
29	Ag	90	--	SPA	0	--	--
30	Ag	156	--	SPA	0	--	--
31	P	180	--	SPA	0	--	--
32	Ag	approx 250	--	SPA	0	--	--
33	Ag	360	approx 50	SPA/OZA	80	--	--
34	Ag	--	--	SPA ?	0	--	--
35	Ag	--	--	SPA ?	0	57.0	05/11/2000
36	Ag	--	--	SPA ?	0	--	--
37	P(deep)	540	--	SPA/OZA	220	--	--
38	Ag	200	--	SPA	0	--	--
39	P	100	--	SPA	0	--	--
40	Ag	approx 300	--	SPA	0	--	--
41	Ag	100	approx 20	SPA	0	--	--
42	P	450	--	SPA/OZA	100	--	--
43	P	approx 250	--	SPA	0	--	--
44	Ag	150	--	SPA	0	--	--
45	P	270	--	SPA	0	64.0	05/18/2000
46	P	440	--	SPA/OZA	120	--	--
47	P	285	--	SPA	0	--	--

measured in two wells that probably are open only to the Ozark aquifer. These depths were 50.3 and more than 300 ft below land surface (table 1).

Land Use

Approximately 84 percent of the land in the upper Shoal Creek Basin is used for agriculture (fig. 2; Schumacher, 2001). The remainder of the land is either forested (13 percent) or urban (3 percent). Most of the agricultural land is pasture used for cattle and hay production, with a much smaller amount under cultivation. The number of cattle in the study area is estimated at about 25,000 (Schumacher, 2001). Poultry CAFOs have become an important business activity in the upper Shoal Creek Basin in recent years. An average of less than two poultry barns per square mile are in the upper Shoal Creek Basin; the distribution of barns is uneven. Poultry barns normally are in clusters of two to eight barns per CAFO, and the number of barns in the southern part of the basin is greater than in the northern part of the basin (fig. 3). Also, each barn may affect a large area with respect to nutrient loading, because poultry litter commonly is spread on pasture land as much as several miles away.

Poultry litter applied to pasture land is an important source of nutrient loading in the upper Shoal Creek Basin. An estimated 2.7 million pounds each of nitrogen and phosphate are produced by poultry CAFOs in the basin each year (Schumacher, 2001). An estimated 3.8 million pounds of nitrogen loading and 1.9 million pounds of phosphate loading per year can be attributed to cattle in the upper Shoal Creek Basin (Schumacher, 2001). Commercial fertilizer, which is spread on pasture land, also contributes to nutrient loading. Although commercial fertilizer use has declined in recent years, it represents about 27 percent of the total nitrogen loading and 16 percent of the total phosphate loading in the basin (Schumacher, 2001). About 28 percent of the total nitrogen loading and 47 percent of the total phosphate loading can be attributed to poultry CAFOs. About 39 percent of the total nitrogen loading and 33 percent of the total phosphate loading can be attributed to cattle. Another source of nutrient loading is human wastes from rural septic systems. Although this is small compared to other sources, human wastes can be an important source of contamination in rural water supplies. Nutrients and pathogens released from septic systems can migrate into the aquifer and contaminate a nearby water supply, particularly down a well if the casing is too shallow or is corroded.

SAMPLING AND ANALYSIS METHODS

The possible effects of poultry CAFOs on ground-water quality in the upper Shoal Creek Basin were evaluated by comparing water-quality data from wells in different land-use areas. Ground-water samples were collected in May, October, and November 2000. Water-quality data were analyzed using statistical tests to determine if significant differences between data groups existed.

Sample Network

A well inventory consisting of door-to-door interviews with well owners was conducted in April 2000 to establish a network of wells. Priority was given to permitted wells for which the Missouri Geological Survey and Resource Assessment Division (GSRAD) had ownership and well-construction records, and wells belonging to owners suggested by the staff of the Barry County NRCS office. Well owners were asked for construction information (well and casing depth and age of well) if not already available, information regarding poultry CAFOs at or near the well, and whether or not poultry litter was applied to fields near the well. Forty-seven wells were selected for inclusion in the sample network, two of which were short distances outside the boundary of the upper Shoal Creek Basin (fig. 3). The wells in the sample network were domestic or commercial (serving as water supplies for poultry CAFOs). Most wells were shallow enough to be open to the Springfield Plateau aquifer, or mostly to the Springfield Plateau aquifer in cases where the open interval also included the Ozark aquifer (table 1). The open intervals of three wells (wells 8, 19, and 37) were completely, or at least one-half, in the Ozark aquifer. One well (well 27), a dug well that was open to the alluvial aquifer along Shoal Creek, was included in the sample network because the alluvial aquifer is the shallowest aquifer present at that setting. Documented well depth information was lacking for many wells, but most well owners were able to provide an approximate depth. However, most well owners could not provide an approximate depth of casing in their well.

The wells that were selected for the sample network are classified into two main land-use categories: 31 "poultry" wells where there is an association with poultry CAFOs, and 16 "agriculture" wells with a limited or no association with poultry CAFOs. These two land-use categories and well-construction data were used to assign wells to a "site type" (table 1). The poultry wells were classified into 3 site types: 25 "P" wells, 4 "P(old)" wells, and 2 "P(deep)" wells. The P wells are those open only or mostly to the Springfield Plateau aquifer, where the application of poultry litter occurred to a substantial acreage (generally several tens of acres or more) within a 0.5 mi radius of the well (the application usually was much closer to the well) both in spring 2000 and in several previous years. The P(old) wells are similar to P wells except that the poultry litter was applied only in years before 2000. The P(deep) wells are similar to P wells except they are too deep to be open mostly to the Springfield Plateau aquifer. Agriculture wells were classified into two site types: 15 "Ag" wells that are open only or mostly to the Springfield Plateau aquifer, and 1 "Ag(deep)" well that is too deep to be open mostly to the Springfield Plateau aquifer. Variations in land use, such as the amount of applied litter, the proximity of the applied litter to the wells, and well construction, such as well and casing depths (which were unknown for some wells), resulted in variations within site types. Most of the poultry wells are in the southern part of the study area, and most of the agriculture wells are in the northern part of the study area (fig. 3), reflecting the geographic distribution of poultry CAFOs in the upper Shoal Creek Basin.

Eight springs (site type Sp; table 2, at the back of this report) also were selected for inclusion in the sample network to provide additional information about shallow ground water in the upper Shoal Creek Basin. The springs were not differentiated based on land use because the catchment area of at least some of the springs is probably large enough to include poultry and non-poultry areas. Five of these springs were sampled by the USGS in 1999 (Schumacher, 2001).

Sample Collection

The first set of samples was collected in May 2000 when all 47 wells and 8 springs were sampled (table 2). All samples were analyzed for total nutrients and the fecal indicator bacteria fecal coliform, *Escherichia coli* (*E. coli*), and fecal streptococcus. Total nutrients included nitrite plus nitrate, nitrite, ammonia, phosphorus, and orthophosphorus. Twenty-two wells and all springs also were sampled for dissolved major (calcium, magnesium, potassium, sodium, chloride, fluoride, and sulfate) and trace (boron and strontium) ions. Of these 22 wells, 13 were P wells, 6 were Ag wells, and 1 each was a P(old), P(deep), and Ag(deep) well. Field alkalinity titrations were performed for each well and spring sample. A sample also was collected from each well to analyze for the presence of optical brighteners using a scanning spectrofluorophotometer at the USGS office in Rolla, Missouri. This analysis was performed because optical brighteners can be present in septic systems, and their presence in a water sample would indicate that septic effluent was present in the well water. No optical brighteners were detected in any of the samples. The depth to water was measured in 14 wells before the pump was turned on by lowering an electric tape down the well until a probe at the end of the tape made contact with the water surface. The depth to water ranged from 28 to more than 300 ft below land surface (table 1), and was estimated at approximately 5 ft below land surface for well 27, which is open to alluvium.

The second set of samples was collected in October 2000. Fifteen wells and all springs that were sampled in May were sampled again in October (table 2). Nine of the wells were P wells, and six of the wells were Ag wells. Emphasis was placed on wells that had detections of fecal indicator bacteria, particularly fecal coliform or *E. coli*, or large concentrations of total nitrite plus nitrate in May. Each of the eight wells with at least 1 col/100 mL of fecal coliform or *E. coli* bacteria in May was sampled again in October. Four wells that had only fecal streptococcus bacteria in May were sampled in October, and seven wells that had only fecal streptococcus bacteria in May were not sampled in October. All three wells with total nitrite plus nitrate concentrations at or larger than the USEPA Maximum Contaminant Level (MCL) of 10 mg/L as nitrogen in May (two of which also had fecal coliform or *E. coli* bacteria, or both) were sampled in October. Two wells that had no fecal indicator bacteria and that had small concentrations of nitrite plus nitrate in May also were sampled in October. Four targeted wells could not be sampled in October for various reasons. All samples collected in October were analyzed for total nutrients, fecal indicator bacteria, and dissolved major and trace ions. Field alkalinity titrations also were performed. Samples also were collected to test for the presence of the human pathogen *E. coli* O157:H7 by incubating an

additional bacteria plate with mEndo-LES agar at 37 ^{o}C (degrees Celsius) for approximately 24 hours. Shiny-metallic colonies that grew on the mEndo-LES agar were transferred to a McConkey Sorbitol plus MUG agar plate using a sterile toothpick, and incubated at 37 ^{o}C for approximately 8 hours.

A third set of samples was collected in November 2000. Six wells and two springs were sampled to determine the nitrogen isotopic composition (table 2), which can be used to differentiate between nitrate derived from commercial fertilizer and nitrate derived from human or animal wastes. The wells that were sampled were among those with moderate or large concentrations of nitrite plus nitrate in previous samples, and they also were selected to provide geographic diversity. Samples for nitrogen isotopic composition analysis were collected by filtering water through a 0.45-µm (micrometer) filter into a 1-L (liter) polyethylene bottle and were chilled to 4 ^{o}C. Except for one well (well 23) for which a bacteria sample also was collected, the only other sample collected was for total nutrient concentrations.

The process of sampling a well began by turning on the water for at least 10 minutes until physical properties (temperature, specific conductance, and pH) were stable. Once stability was achieved, the values of these properties and the concentration of dissolved oxygen were recorded, and samples were collected. Chlorinated water was avoided to prevent false negative bacteria results. Discharge measurements or flow estimates were made for springs, and samples were collected as close to the spring orifice as possible. The sample for the determination of total nitrite plus nitrate, total nitrite, total ammonia, and total orthophosphorus was placed in an amber 125-mL (milliliter) polyethylene bottle and chilled to 4 ^{o}C. The sample for total phosphorus was placed in a 125-mL clear polyethylene bottle, preserved to pH less than 2 with sulfuric acid, and chilled to 4 ^{o}C. Samples for dissolved major and trace ions were collected in a 3-L Teflon bottle, from which water was filtered through a 0.45 µm pore-size disposable capsule filter using a peristaltic pump. The filtered water was placed in a 250-mL clear polyethylene bottle and a 250-mL clear polyethylene acid-washed bottle. Nitric acid was added to the acid-washed bottle to bring the pH to less than 2. Alkalinity, bicarbonate, and carbonate were determined by titrating 0.16 N (normal) sulfuric acid into 25 mL of sample water. Quality-assurance samples also were collected. Three duplicate samples were collected in May, one during each week of the sampling event, and one duplicate sample was collected in each of the October and November sample events. Three blanks were also collected in May, and one each in October and November. Blank samples were prepared by filling sample containers with inorganic-free water prepared by the USGS National Water Quality Laboratory in Lakewood, Colorado, and preserving and shipping the samples in the same manner as regular samples. Bacteria samples were collected in sterilized 500-mL polyethylene bottles from an outside faucet or hydrant in most cases, but occasionally from an inside kitchen faucet when a suitable outside sampling point was not available. The sampling point was flame-sterilized before sample collection where possible, but in some cases, such as a kitchen faucet or where the outside faucet was close to vinyl siding that could be damaged by a flame, a chlorine solution was sprayed on the sampling point. The sample was placed on ice until processing, which occurred within 4 hours of collection. Processing was by the membrane filter technique according to methods described in Myers and Wilde (1997). Sample aliquots of 50 or 100 mL, or both, were used for the wells, and aliquots of the same volume but also as small as 1 mL were used for the springs. Daily blanks were prepared using 100 mL of sterile buffer solution and processed in the same manner as a sample. No fecal indicator bacteria colonies grew from any of the daily blanks.

Statistical Analysis

A statistical analysis of the water-quality data was performed to determine if the fecal indicator bacteria densities and total nitrite plus nitrate concentrations were larger in P wells than in Ag wells and to determine if there were any seasonal differences between samples collected in spring 2000 and fall 2000. Although the water-quality data for all site types are presented in table 2, only the data for P and Ag wells were used for statistical hypothesis tests and summary statistics (table 3). Water-quality data for two wells a short distance outside the basin (fig. 3) also were used in the statistical tests and summary statistics because of similar land use and geohydrology. Samples were grouped using the suffix “1” for spring (May 2000) samples (P1, Ag1, and Sp1) and the suffix “2” for fall (October or November 2000) samples (P2, Ag2, and Sp2). Only the well samples collected in spring 2000 (P1 and Ag1) were used to determine if the total nitrite plus nitrate concentrations and fecal indicator

DESCRIPTIONS OF ABBREVIATIONS AND REPORTING UNITS FOR PHYSICAL PROPERTIES, CHEMICAL CONSTITUENTS, FECAL INDICATOR BACTERIA, AND NOTATIONS USED IN TABLE 3

Abbreviation	Description
T	Temperature, in degrees Celsius
SC	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius
DO	Dissolved oxygen, in milligrams per liter
pH	In standard units
NO_{2t}+NO_{3t}	Total nitrite plus nitrate as nitrogen, in milligrams per liter
NO_{2t}	Total nitrite as nitrogen, in milligrams per liter
NH_{3t}	Total ammonia as nitrogen, in milligrams per liter
P_t	Total phosphorus, in milligrams per liter
PO_{4t}	Total orthophosphorus as phosphorus, in milligrams per liter
FC	Fecal coliform density, in colonies per 100 milliliters
E. coli	*Escherichia coli* density, in colonies per 100 milliliters
FS	Fecal streptococcus density, in colonies per 100 milliliters
$Alk_{(it)}$	Total acid neutralizing capacity, incremental titration, in milligrams per liter
$HCO_{3(it)}$	Bicarbonate, total, incremental titration, in milligrams per liter
$CO_{3(it)}$	Carbonate, total, incremental titration, in milligrams per liter
Solids	Dissolved solids, in milligrams per liter
Hard	Hardness, total, in milligrams per liter as $CaCO_3$
Ca	Calcium, dissolved, in milligrams per liter
Mg	Magnesium, dissolved, in milligrams per liter
K	Potassium, dissolved, in milligrams per liter
Na	Sodium, dissolved, in milligrams per liter
Cl	Chloride, dissolved, in milligrams per liter
F	Fluoride, dissolved, milligrams per liter
SO_4	Sulfate, dissolved, in milligrams per liter
B	Boron, dissolved, in micrograms per liter
Sr	Strontium, dissolved, in micrograms per liter
P	Poultry well open only or mostly to the Springfield Plateau aquifer, with poultry litter application in spring 2000 and in previous years
P1	Data for P well sampled in May 2000 and used for statistical tests
N	Number
<	Less than
STD	Standard deviation
P2	Data for P well sampled in October or November 2000 and used for statistical tests
Ag	Agriculture well open only or mostly to the Springfield Plateau aquifer
Ag1	Data for Ag well sampled in May 2000 and used for statistical tests
Ag2	Data for Ag well sampled in October or November 2000 and used for statistical tests
Sp	Spring
Sp1	Data for spring sampled in May 2000 and used for statistical tests
Sp2	Data for spring sampled in October or November 2000 and used for statistical tests

Table 3. Summary statistics of physical properties, concentrations of chemical constituents, and fecal indicator bacteria densities for sample groups

Site type	Sample group		T	SC	DO	pH	NO_{2i} + NO_{3i}	NO_{2i}	NH_{3i}	P_t	PO_{4i}	FC	*E. coli*	FS	$Alk_{(f)}$
P	P1	N (samples)	25	25	24	25	25	25	25	25	25	25	24	25	25
		N (detections)	25	25	20	25	16	0	12	2	3	1	3	8	25
		Minimum	14.9	233	0	6.85	<.02	<.01	<.01	<.02	<.01	<1	<1	<1	104
		Maximum	17.1	557	8.8	7.95	18	<.01	.22	.03	.19	72	140	77	223
		Median	15.6	348	3.3	7.50	.28	<.01	<.01	<.02	<.01	<1	<1	<1	170
		Mean	15.7	360	3.3	7.46	2.6	<.01	.03	<.02	.02	3	6	6	172
		STD	.6	87	3.1	.29	4.2	0	.04	0	.04	14	29	18	39
P	P2	N (samples)	12	12	11	12	12	12	12	12	12	9	9	9	9
		N (detections)	12	12	9	12	8	0	7	0	3	0	0	2	9
		Minimum	15	250	0	6.91	<.02	<.01	<.01	<.02	<.01	<1	<1	<1	111
		Maximum	18.1	568	6.9	7.90	17	<.01	.04	<.02	.03	<1	<1	59	217
		Median	15.8	352	4.5	7.48	1.4	<.01	.02	<.02	<.01	<1	<1	<1	173
		Mean	15.9	369	3.2	7.44	3.5	<.01	.02	<.02	<.01	<1	<1	7	165
		STD	.8	106	2.9	.34	5.1	0	.01	0	.01	0	0	20	42
Ag	Ag1	N (samples)	15	15	12	15	15	15	15	15	15	15	13	15	15
		N (detections)	15	15	12	15	14	0	1	3	4	5	1	6	15
		Minimum	13.9	260	.1	6.42	<.02	<.01	<.01	<.02	<.01	<1	<1	<1	109
		Maximum	16.5	506	9	7.49	12	<.01	.02	.03	.03	81	45	130	280
		Median	15.4	408	6.6	7.26	4.6	<.01	<.01	<.02	<.01	<1	<1	<1	174
		Mean	15.3	388	6.2	7.16	4.8	<.01	<.01	<.02	<.01	9	3	23	174
		STD	.6	90	2.5	.31	3.1	0	0	0	.01	22	12	46	48
Ag	Ag2	N (samples)	7	7	4	7	7	7	7	7	7	6	6	6	6
		N (detections)	7	7	4	7	7	1	5	0	6	3	3	5	6
		Minimum	15.1	273	3	6.61	1.0	<.01	<.01	<.02	<.01	<1	<1	<1	125
		Maximum	18.8	540	6.0	7.60	13	.01	.04	<.02	.04	15	15	150	216
		Median	15.4	415	4.0	7.26	6.3	<.01	.02	<.02	.02	2	6	6	163
		Mean	16.2	441	4.3	7.11	6.1	<.01	.02	<.02	.03	5	6	29	165
		STD	1.6	98	1.3	.33	4.2	0	.01	0	.01	7	7	59	35
Sp	Sp1	N (samples)	7	8	8	8	8	8	8	8	8	7	5	8	8
		N (detections)	7	8	8	8	8	1	7	3	8	7	5	8	8
		Minimum	13.5	294	2.6	6.50	2.9	<.01	<.01	<.02	<.01	12	40	42	114
		Maximum	16.5	385	11.6	7.38	6.4	.01	.04	.14	.06	3,300	2,700	3,100	154
		Median	14.1	318	6.3	6.94	3.9	<.01	.02	<.02	.02	470	1,100	445	128
		Mean	14.5	329	6.2	6.92	4.2	<.01	.02	.04	.03	1,172	1,268	911	131
		STD	1.0	33	2.8	.26	1.2	0	.01	.04	.02	1,332	1,122	1,124	12
Sp	Sp2	N (samples)	8	8	8	8	8	8	8	8	8	8	8	6	8
		N (detections)	8	8	8	8	8	4	7	1	8	7	8	6	8
		Minimum	14.6	278	3	6.58	2.7	<.01	<.01	<.02	.01	<1	16	16	124
		Maximum	16.9	420	6	7.12	6.4	.02	.05	.04	.05	840	2,000	260	183
		Median	15.7	363	4.5	6.91	4.0	.01	.03	<.02	.03	50	33	35	155
		Mean	15.6	359	4.7	6.91	4.3	.01	.03	<.02	.03	176	336	82	155
		STD	.7	42	.9	.17	1.3	0	.02	.01	.01	281	694	95	22

Table 3. Summary statistics of physical properties, concentrations of chemical constituents, and fecal indicator bacteria densities for sample groups—Continued

Site type	Sample group		$HCO_{3(lf)}$	$CO_{3(lf)}$	Solids	Hard	Ca	Mg	K	Na	Cl	F	SO_4	B	Sr
P	P1	N (samples)	25	25	13	13	13	13	13	13	13	13	13	13	13
		N (detections)	25	25	13	13	13	13	13	13	13	1	13	13	13
		Minimum	127	0	131	130	30	1.8	.4	1.6	1.1	<.10	1.8	3.6	23
		Maximum	272	0	254	260	100	22	2.2	11	21	.12	14	11	270
		Median	207	0	179	180	51	13	1.1	3.7	4.2	<.10	7.2	6.3	51
		Mean	210	0	190	189	55	12.4	1.1	4.4	6.9	<.10	7.1	7.0	69
		STD	47	0	40	43	21	6.0	.5	3.1	6.6	.01	4.4	2.6	63
P	P2	N (samples)	9	9	9	9	9	9	9	9	9	9	9	9	9
		N (detections)	9	9	9	9	9	9	9	9	9	2	9	9	9
		Minimum	135	0	59	110	28	1.2	.3	1.9	1.2	<.10	.6	2.9	22
		Maximum	265	0	256	260	100	21	1.9	7.4	14	.14	12	22	100
		Median	211	0	174	170	41	14	.8	2.7	2.0	<.10	7.1	5.4	59
		Mean	201	0	166	168	48	12.0	1.0	3.5	3.8	.11	6.2	9.6	61
		STD	52	0	59	51	21	7.2	.6	1.7	4.2	.02	4.1	7.6	23
Ag	Ag1	N (samples)	15	15	6	6	6	6	6	6	6	6	6	6	6
		N (detections)	15	15	6	6	6	6	6	6	6	0	6	6	6
		Minimum	133	0	143	140	53	1.2	.6	2.4	3.6	<.10	.8	4.7	28
		Maximum	342	0	241	260	86	11	6.9	12	27	<.10	29	38	120
		Median	212	0	207	190	69	4	1.1	2.9	8.5	<.10	4.1	6.2	55
		Mean	213	0	200	193	69	4.5	2.0	5.4	12.4	<.10	8.0	11.2	63
		STD	59	0	36	42	13	3.5	2.4	4.2	9.7	0	10.5	13.2	32
Ag	Ag2	N (samples)	6	6	6	6	6	6	6	6	6	6	6	6	6
		N (detections)	6	6	6	6	6	6	6	6	6	0	6	6	6
		Minimum	152	0	141	130	47	1.3	.5	2.6	1.3	<.10	1.3	5	38
		Maximum	263	0	247	260	86	11	5.4	12	24	<.10	19	37	110
		Median	199	0	198	175	65	4	1.5	5.4	10.4	<.10	4.7	6.5	62
		Mean	200	0	196	183	67	4.4	2.0	6.4	11.5	<.10	6.4	11.2	64
		STD	43	0	45	50	16	3.4	1.8	3.5	7.3	0	6.6	12.7	26
Sp	Sp1	N (samples)	8	8	8	8	8	8	8	8	8	8	8	8	8
		N (detections)	8	8	8	8	8	8	8	8	8	0	8	8	8
		Minimum	139	0	146	140	52	1.6	1	2.8	7	<.10	1.9	4.8	36
		Maximum	188	0	192	170	63	6.2	3.1	19	41	<.10	6.5	8.2	68
		Median	156	0	157	150	55	2	1.7	5.2	10.5	<.10	3.6	5.9	47
		Mean	160	0	164	150	56	2.7	1.8	6.6	14.0	<.10	3.7	6.1	47
		STD	15	0	18	11	4	1.6	.6	5.2	11.1	0	1.4	1.1	10
Sp	Sp2	N (samples)	8	8	8	8	8	8	8	8	8	8	8	8	8
		N (detections)	8	8	8	8	8	8	8	8	8	<.10	8	8	8
		Minimum	151	0	156	140	52	1.3	.9	3.5	7.5	<.10	1.7	4.6	36
		Maximum	224	0	203	200	76	6.3	1.8	20	48	<.10	5.8	8.5	65
		Median	189	0	183	165	60	2	1.3	5.3	9.9	<.10	2.5	5.6	45
		Mean	189	0	183	165	62	2.9	1.3	7.1	13.8	<.10	2.8	5.9	48
		STD	27	0	18	19	8	1.6	.3	5.3	12.0	0	1.4	1.2	9

bacteria densities were larger in P wells than in Ag wells. Samples collected in fall 2000 (P2 and Ag2) were not used for this purpose because they were intentionally collected from wells with some of the largest total nitrite plus nitrate concentrations and fecal indicator bacteria densities in the spring, and inclusion of these data with the spring data might produce biased results. Only data for wells sampled in both the spring and the fall were used to test for seasonal changes in wells; data from wells sampled in the spring without corresponding fall data were not used. Generally, samples collected from wells in October were used as fall data, but samples collected in November were used in the four cases where a sample for total nitrite plus nitrate analysis was collected in November and not in October. Seasonal changes also were evaluated for springs using Sp1 and Sp2 data groups.

The computer software SYSTAT (SPSS Inc., 1998) was used for the preparation of boxplots and computation of summary statistics, and for statistical hypothesis tests. Bacteria densities reported as "less than" a specific number of colonies per 100 milliliters were converted to 0 col/100 mL for statistical calculations. Three exceptions to this were two cases with less than 100 col/100 mL and 1 case with less than 20 col/100 mL. These data were discarded. For one spring sample, the data reported as "greater than" 1,000 col/100 mL was changed to 1,000 col/100 mL. Fecal indicator bacteria data for some samples contained a remark code indicating a non-ideal bacteria count; these data were treated in the same way as other data. For analytical data reported as less than the laboratory detection level, the data were changed to the detection level.

Data for sample groups were tested for normality using a two-tailed Lillefors test (SPSS Inc., 1998) before conducting statistical hypothesis tests for total nitrite plus nitrate concentrations and fecal indicator bacteria densities. The data for most sample groups were not normally distributed, and nonparametric statistical hypothesis tests were, therefore, used. Data groups were considered significantly different if the probability (p-value) for a test was less than 5 percent (less than 0.05). A p-value less than 0.05 indicates that there is a less than 5 percent chance (95 percent confidence level) that the observed difference occurs by chance. The nonparametric Mann-Whitney test (SPSS Inc., 1998) was used to test for differences between P1 and Ag1 data. The Mann-Whitney test is the Kruskal-Wallis test using only two sample groups (SPSS Inc., 1998). Several statistical tests were used to test for seasonal differences between P1 and P2 data, Ag1 and Ag2 data, and Sp1 and Sp2 data. The Mann-Whitney test was used for grouped data. The nonparametric Wilcoxan signed-rank test (SPSS Inc., 1998) and the nonparametric sign test (SPSS Inc., 1998; Helsel and Hirsch, 1992) were used with paired data. The results of the Mann-Whitney test and the sign test were in agreement with respect to rejecting or not rejecting the null hypothesis that there were no differences and generally were more conservative in this respect than results from the Wilcoxan signed-rank test. For these reasons, results from the Mann-Whitney test and the sign test were used to interpret seasonal differences.

Correlation tables of water-quality data were prepared using SYSTAT to calculate the Spearman's rank-order correlation coefficient (Helsel and Hirsch, 1992; SPSS Inc., 1998). The Spearman's rank-order correlation coefficient is the Pearson correlation coefficient computed on ranked data. The Spearman's rank-order correlation coefficients for combined P1 and Ag1 samples and for Sp1 samples are given in tables 4 and 5.

GROUND-WATER QUALITY

The ground-water quality of the upper Shoal Creek Basin can be described in terms of general geochemistry (physical properties and major inorganic constituents) and constituents that are important from a human health standpoint (nutrients and fecal indicator bacteria). Water-quality data collected for this study are listed in table 2. Comparisons between sample groups (P1, Ag1, and so forth) are facilitated by the summary statistics for these data (minimum, maximum, median, mean, and standard deviation; table 3).

Major Inorganic Constituents

The ground water represented by all the samples collected in this study is of the calcium bicarbonate type, as shown in a trilinear diagram of major inorganic constituents (fig. 5). Calcium bicarbonate water is typical of ground water from a limestone aquifer such as the Springfield Plateau aquifer. Water from a dolostone aquifer, such as the Ozark aquifer, also can be calcium bicarbonate water, but the amount of magnesium, as the second most common cation, would be larger in most cases. Samples from approximately one-third (16) of

DESCRIPTIONS OF ABBREVIATIONS AND REPORTING UNITS FOR PHYSICAL PROPERTIES, CHEMICAL CONSTITUENTS, FECAL INDICATOR BACTERIA, AND NOTATIONS USED IN TABLES 4 AND 5

Abbreviation	Description
P	Poultry well open only or mostly to the Springfield Plateau aquifer, with poultry litter application in spring 2000 and in previous years
P1	Data for P well sampled in May 2000 and used for statistical tests
Ag	Agriculture well open only or mostly to the Springfield Plateau aquifer
Ag1	Data for Ag well sampled in May 2000 and used for statistical tests
Sp	Spring
Sp1	Data for spring sampled in May 2000 and used for statistical tests
SC	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius
DO	Dissolved oxygen, in milligrams per liter
pH	In standard units
NO_{2t}+NO_{3t}	Total nitrite plus nitrate as nitrogen, in milligrams per liter
NH_{3t}	Total ammonia as nitrogen, in milligrams per liter
P_t	Total phosphorus, in milligrams per liter
PO_{4t}	Total orthophosphorus as phosphorus, in milligrams per liter
FC	Fecal coliform density, in colonies per 100 milliliters
E. coli	*Escherichia coli* density, in colonies per 100 milliliters
FS	Fecal streptococcus density, in colonies per 100 milliliters
$Alk_{(it)}$	Total acid neutralizing capacity, incremental titration, in milligrams per liter
$HCO_{3(it)}$	Bicarbonate, total, incremental titration, in milligrams per liter
Solids	Dissolved solids, in milligrams per liter
Hard	Hardness, total, in milligrams per liter as $CaCO_3$
Ca	Calcium, dissolved, in milligrams per liter
Mg	Magnesium, dissolved, in milligrams per liter
K	Potassium, dissolved, in milligrams per liter
Na	Sodium, dissolved, in milligrams per liter
Cl	Chloride, dissolved, in milligrams per liter
F	Fluoride, dissolved, milligrams per liter
SO_4	Sulfate, dissolved, in milligrams per liter
B	Boron, dissolved, in micrograms per liter
Sr	Strontium, dissolved, in micrograms per liter
--	No data

Table 4. Spearman's rank-order correlation coefficients for physical properties, concentrations of chemical constituents, and fecal indicator bacteria densities for combined P1 and Ag1 samples

	SC	DO	pH	$NO_{2i} + NO_{3i}$	NH_{3i}	P_t	PO_{4t}	FC	*E. coli*	FS	$Alk_{(t)}$	$HCO_{3(t)}$
SC	1											
DO	.361	1										
pH	-.738	-.723	1									
$NO_{2i} + NO_{3i}$	.776	.708	-.868	1								
NH_{3i}	-.360	-.524	.522	-.68	1							
P_t	.170	.205	-.136	.243	-.272	1						
PO_{4t}	.202	.180	-.141	.128	.092	.734	1					
FC	.450	.400	-.478	.524	-.272	.468	.340	1				
E. coli	.397	.164	-.351	.405	-.187	.686	.540	.728	1			
FS	-.213	-.098	.084	-.057	.176	.304	.177	.331	.546	1		
$Alk_{(t)}$	.782	-.040	-.308	.286	.020	.051	.199	.149	.257	-.122	1	
$HCO_{3(t)}$	.783	-.038	-.309	.291	.020	.034	.186	.149	.257	-.122	.999	1
Solids	.948	.216	-.558	.602	-.208	.102	.148	.414	.351	-.189	.881	.882
Hard	.954	.201	-.578	.622	-.221	.120	.195	.370	.376	-.145	.911	.913
Ca	.894	.601	-.852	.871	-.511	.170	.075	.450	.398	-.138	.568	.574
Mg	-.234	-.773	.653	-.656	.526	-.273	.011	-.415	-.352	-.214	.214	.211
K	.087	-.171	.001	.208	-.084	-.102	-.334	.353	.187	.299	-.134	-.127
Na	.529	.512	-.566	.700	-.541	.273	-.033	.471	.258	-.134	.078	.075
Cl	.774	.723	-.888	.894	-.622	.205	.122	.471	.257	-.229	.305	.301
F	-.210	-.211	.304	-.286	.320	-.086	-.108	-.086	-.059	-.128	-.117	-.117
SO_4	-.252	-.515	.546	-.389	.239	-.222	-.299	-.139	-.327	-.236	-.213	-.214
B	-.237	-.425	.476	-.307	.268	-.119	-.299	.077	-.047	.209	-.083	-.085
Sr	.133	-.275	.202	-.023	.361	-.153	-.118	.320	.187	.136	.096	.106

	Solids	Hard	Ca	Mg	K	Na	Cl	F	SO_4	B	Sr
SC											
DO											
pH											
$NO_{2i} + NO_{3i}$											
NH_{3i}											
P_t											
PO_{4t}											
FC											
E. coli											
FS											
$Alk_{(t)}$											
$HCO_{3(t)}$											
Solids	1										
Hard	.969	1									
Ca	.803	.786	1								
Mg	-.106	-.043	-.600	1							
K	.117	.088	.026	-.096	1						
Na	.456	.358	.594	-.543	.289	1					
Cl	.630	.606	.808	-.575	.132	.797	1				
F	-.070	-.212	-.210	.070	-.094	.211	-.210	1			
SO_4	-.086	-.235	-.377	.328	.505	.029	-.289	.351	1		
B	-.036	-.120	-.345	.212	.682	-.050	-.307	.258	.711	1	
Sr	.289	.177	.007	.100	.680	.195	-.057	.398	.636	.622	1

Table 5. Spearman's rank-order correlation coefficients for physical properties, concentrations of chemical constituents, and fecal indicator bacteria densities for Spt samples

	SC	DO	pH	$NO_{21} + NO_{31}$	NH_{31}	P_t	PO_{4t}	FC	*E. coli*	FS	$Alk_{(t)}$	$HCO_{3(t)}$
SC	1											
DO	.718	1										
pH	.300	-.051	1									
$NO_{21} + NO_{31}$	.600	.975	-.100	1								
NH_{31}	-.894	-.344	-.447	-.224	1							
P_t	.783	.803	-.224	.671	-.500	1						
PO_{4t}	.667	.553	.205	.359	-.459	.803	1					
FC	.200	.821	-.300	.900	.224	.447	.154	1				
E. coli	.100	.667	0	.800	.224	.112	-.103	.900	1			
FS	.200	.821	-.300	.900	.224	.447	.154	1	.900	1		
$Alk_{(t)}$	.700	.667	.300	.500	-.447	.783	.975	.300	.100	.300	1	
$HCO_{3(t)}$	.700	.667	.300	.500	-.447	.783	.975	.300	.100	.300	1	1
Solids	1	.718	.300	.600	-.894	.783	.667	.200	.100	.200	.700	.700
Hard	.738	.189	.105	0	-.825	.648	.640	-.369	-.580	-.369	.527	.527
Ca	.667	.395	-.205	.205	-.574	.860	.789	-.051	-.410	-.051	.667	.667
Mg	.900	.564	.600	.500	-.894	.447	.410	.100	.200	.100	.500	.500
K	.800	.975	0	.900	-.447	.894	.718	.700	.500	.700	.800	.800
Na	.700	.154	.700	.100	-.894	.112	.154	-.300	-.100	-.300	.200	.200
Cl	.700	.154	.700	.100	-.894	.112	.154	-.300	-.100	-.300	.200	.200
F	--	--	--	--	--	--	--	--	--	--	--	--
SO_4	.700	.667	.300	.500	-.447	.783	.975	.300	.100	.300	1	1
B	.700	.667	.300	.500	-.447	.783	.975	.300	.100	.300	1	1
Sr	.667	.763	.103	.616	-.344	.860	.947	.462	.205	.462	.975	.975

	Solids	Hard	Ca	Mg	K	Na	Cl	F	SO_4	B	Sr
SC											
DO											
pH											
$NO_{21} + NO_{31}$											
NH_{31}											
P_t											
PO_{4t}											
FC											
E. coli											
FS											
$Alk_{(t)}$											
$HCO_{3(t)}$											
Solids	1										
Hard	.738	1									
Ca	.667	.892	1								
Mg	.900	.527	.308	1							
K	.800	.369	.564	.600	1						
Na	.700	.527	.154	.900	.200	1					
Cl	.700	.527	.154	.900	.200	1	1				
F	--	--	--	--	--	--	--	--			
SO_4	.700	.527	.667	.500	.800	.200	.200	--	1		
B	.700	.527	.667	.500	.800	.200	.200	--	1	1	
Sr	.667	.460	.684	.410	.872	.051	.051	--	.975	.975	1

the wells (wells 1, 2, 5, 6, 7, 8, 13, 16, 17, 19, 20, 26, 39, 45, 46, and 47) had a magnesium milliequivalent concentration larger than 25 percent of the total major cation (calcium, magnesium, sodium, and potassium) milliequivalent concentration. The calcium to magnesium milliequivalent ratio for these samples ranged from 1.4 to 2.6, which is characteristic of ground water from a mixed limestone and dolostone sequence (White, 1988). Although some dolostone may be present in the Springfield Plateau aquifer, the magnesium content may indicate contact with or a contribution of ground water from the Ozark aquifer. Based on well depth data (table 1), 2 of these 16 wells (wells 8 and 19) probably are open mostly or only to the Ozark aquifer, and at least part of the open interval of 5 other wells (wells 7, 13, 16, 20, and 46) is in the Ozark aquifer. Based on well depth data, the other nine wells are open only to the Springfield Plateau aquifer. It is possible that the well depth data for these wells are inaccurate, or that because the interpretation of the depth to the top of the Ozark aquifer is based on widely spaced data (Imes, 1990d), the top of the Ozark aquifer may be higher than is thought, and the wells may be at least partially open to the Ozark aquifer. Also, upward movement of ground water from the Ozark aquifer to the Springfield Plateau aquifer is possible along Shoal Creek and its principal tributaries.

The trilinear diagram (fig. 5) also shows that the dominant anion is bicarbonate, but that samples from 2 P wells (4 and 11), 2 Ag wells (27 and 44), and spring

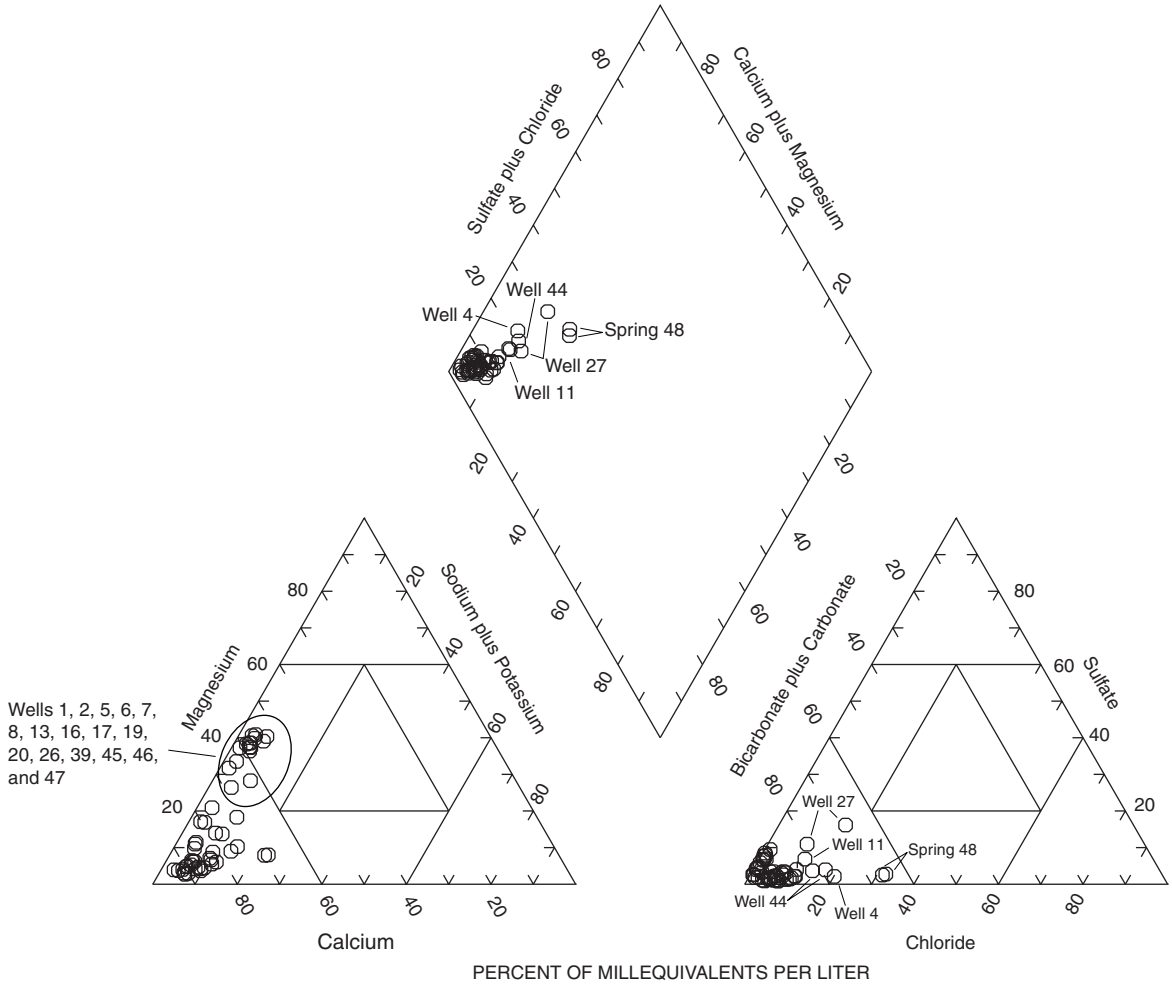

Figure 5. Trilinear diagram of major inorganic constituents in well and spring samples.

48 had a larger concentration of chloride or sulfate than other samples. Chloride and sulfate in wells may indicate contamination from a septic system. Spring 48 is less than 2 mi west of a site where liquid waste from a poultry processing plant is sprayed on pasture land, and about 3 mi west of the town of Butterfield (fig. 3). The catchment area of spring 48 is not known, but may include these areas.

Nutrients

The total nutrient data and summary statistics by sample group (P1, P2, Ag1, Ag2, Sp1, and Sp2) are given in tables 2 and 3. The concentrations of nitrite plus nitrate are essentially that of nitrate, because the nitrite concentration was less than the detection level in most samples, and was small when it was detected (maximum of 0.02 mg/L as nitrogen with a detection level of 0.01 mg/L as nitrogen). Ammonia was detected more frequently than nitrite (12 of 25 P1 samples and 7 of 8 Sp1 samples, but only 1 of 15 Ag1 samples). However, ammonia concentrations were small when it was detected (all but one value was less than 0.1 mg/L, with a detection level of 0.01 mg/L). The ammonia concentration in the May 2000 sample from well 13 was 0.22 mg/L, which was anomalously large relative to the other data. Phosphorus also was infrequently detected (2 of 25 P1 samples, 3 of 15 Ag1 samples, and 3 of 8 Sp1 samples), and concentrations were small when detected (maximum of 0.14 mg/L, with a detection level of 0.02 mg/L). Orthophosphorus was detected somewhat more frequently than phosphorus (3 of 25 P1 samples, 4 of 15 Ag1 samples, and 8 of 8 Sp1 samples), but also was at small concentrations when detected (all but one sample was less than 0.1 mg/L, with a detection level of 0.01 mg/L). The maximum detection of 0.19 mg/L was for the May 2000 sample from well 13, the same sample with the largest ammonia concentration.

Total nitrite plus nitrate frequently was detected (16 of 25 P1 samples, 14 of 15 Ag1 samples, and 8 of 8 Sp1 samples). Nitrite plus nitrate concentrations ranged from less than the detection level (0.02 mg/L as nitrogen) to 18 mg/L as nitrogen (well 23). Seven samples from three wells (2 Ag wells and 1 P well) had nitrite plus nitrate concentrations at or larger than the MCL of 10 mg/L as nitrogen, and several other sample concentrations were slightly less than the MCL. Boxplots of nitrite plus nitrate as nitrogen concentrations for sample groups P1, Ag1, Sp1, and Sp2 are shown in figure 6. The boxplots show that the median nitrite plus nitrate concentrations for Ag1 samples (4.6 mg/L as nitrogen) and Sp1 samples (3.9 mg/L as nitrogen) were larger than that for P1 samples (0.28 mg/L as nitrogen). A Mann-Whitney test between Ag1 and P1 samples indicates that a significant difference ($p = 0.011$) exists for nitrite plus nitrate concentrations at a 95-percent confidence level, meaning that, statistically, nitrite plus nitrate concentrations were significantly larger in Ag1 samples than P1 samples.

Both the Mann-Whitney test ($p = 0.837$) and the sign test ($p = 0.125$) did not indicate a significant difference in nitrite plus nitrate concentration between P1 and P2 samples at a 95-percent confidence level. Also, both the Mann-Whitney test ($p = 0.848$) and the sign test ($p = 1$) did not indicate a significant difference in nitrite plus nitrate concentrations between Ag1 and Ag2 samples at a 95-percent confidence level. The median concentration for springs increased only slightly from spring to fall 2000 (3.9 mg/L as nitrogen for Sp1 samples, and 4.0 mg/L as nitrogen for Sp2 samples), and both the Mann-Whitney test ($p = 0.875$) and the sign test ($p = 0.725$) did not indicate a significant difference between Sp1 and Sp2 samples at a 95-percent confidence level.

The Spearman's rank-order correlation coefficients between nitrite plus nitrate concentrations and other constituent concentrations are listed in table 4 for samples collected from wells in May 2000 (combined P1 and Ag1 samples) and in table 5 for Sp1 samples. Strong correlations exist between combined P1 and Ag1 nitrite plus nitrate concentrations and chloride concentration (0.894) and between combined P1 and Ag1 nitrite plus nitrate concentrations and calcium concentration (0.871). Nitrite plus nitrate and chloride may be correlated because both can occur in large concentrations in animal and human wastes. A correlation exists between Sp1 nitrite plus nitrate concentrations and potassium concentration (0.9), both of which can occur in large concentrations in animal and human wastes, and in commercial fertilizer.

Fecal Indicator Bacteria

Nine of 25 P1 samples, 7 of 15 Ag1 samples, and all 8 Sp1 samples had at least 1 col/100 mL of at least one fecal indicator bacteria (tables 2, 3). Fecal coliform bacteria were detected in 1 of 25 P1 samples and 5 of 15 Ag1 samples. *E. coli* bacteria were detected in 3 of 24 P1 samples and 1 of 13 Ag1 samples. Fecal streptococcus bacteria were detected in 8 of 25 P1 samples

and 6 of 15 Ag1 samples. For P1 samples, bacteria densities ranged from less than 1 to 72 col/100 mL of fecal coliform, less than 1 to 140 col/100 mL of *E. coli*, and less than 1 to 77 col/100 mL of fecal streptococcus. For Ag1 samples, bacteria densities ranged from less than 1 to 81 col/100 mL of fecal coliform, less than 1 to 45 col/100 mL of *E. coli*, and less than 1 to 130 col/100 mL of fecal streptococcus. Fecal indicator bacteria densities in samples from springs were substantially larger than densities in samples from wells. For Sp1 samples, bacteria densities ranged from 12 to 3,300 col/100 mL of fecal coliform, 40 to 2,700 col/100 mL of *E. coli*, and 42 to 3,100 col/100 mL of fecal streptococcus. Boxplots for all three fecal indicator bacteria for sample groups P1, Ag1, Sp1, and Sp2 are shown in figure 6.

A Mann-Whitney test for fecal coliform bacteria indicates that a significant difference exists ($p = 0.016$) between Ag1 and P1 samples at a 95-percent confidence level. This result and the fact that more Ag1 samples had detections of fecal coliform bacteria than P1 samples (table 3; fig. 7) indicate that statistically more fecal coliform bacteria were in Ag1 samples than P1 samples. Although it appears that there was slightly more *E. coli* bacteria in P1 samples than Ag1 samples and slightly more fecal streptococcus bacteria in Ag1 samples than P1 samples (fig. 7), Mann-Whitney tests do not indicate significant differences ($p = 0.679$ for *E. coli*; $p = 0.431$ for fecal streptococcus) at a 95-percent confidence level.

Bacteria densities for individual wells (fig. 7) appear to indicate a decrease from spring to fall 2000 for all three fecal indicator bacteria. Mann-Whitney tests and sign tests, however, do not show a statistically significant difference at a 95-percent confidence level between P1 and P2 samples or Ag1 and Ag2 samples for any of the three fecal indicator bacteria. A few p-values were small enough to indicate a significant difference at a 90-percent confidence level, but this difference is not considered a strong enough indication of significance for the purpose of this study. These p-values are 0.066 for the Mann-Whitney test for *E. coli* bacteria for P1 and P2 samples, 0.090 for the Mann-Whitney test for fecal streptococcus bacteria for P1 and P2 samples, and 0.062 for the sign test for fecal coliform bacteria for Ag1 and Ag2 samples. A decrease in all fecal indicator bacteria seems to occur in springs from the spring to the fall 2000 (figs. 6, 8). However, only fecal streptococcus bacteria densities were significantly smaller in the fall than the spring at a 95-percent confidence level (Mann-Whitney test, $p = 0.02$; sign test, $p = 0.031$). Although a significant seasonal difference at a 95-percent confidence level is indicated for fecal coliform bacteria by the sign test ($p = 0.016$), a significant difference does not appear to exist based on the Mann-Whitney test ($p = 0.105$). Also, the result for the sign test ($p = 0.062$), but not the Mann-Whitney test ($p = 0.117$), was small enough to indicate a significant seasonal difference for *E. coli* bacteria in springs at a 90-percent confidence level, but this also was not considered a strong enough indication of significance.

Wells and springs sampled in October 2000 were analyzed for the presence of the human pathogen *E. coli* O157:H7 bacteria. A total of 15 wells and 8 springs were tested. No colonies of *E. coli* O157:H7 bacteria grew in any of the samples.

Spearman's rank-order correlation coefficients for wells sampled in spring 2000 (combined P1 and Ag1 samples; table 4) show a moderate positive correlation (0.728) between fecal coliform and *E. coli* bacteria, but not for other pairs of fecal indicator bacteria. Also, no correlation is noted between any of the fecal indicator bacteria and either nitrite plus nitrate or chloride concentrations for wells sampled in spring 2000. Strong positive correlations (0.900 to 1) exist for all pairs of fecal indicator bacteria for springs sampled in spring 2000 (table 5). Also, all three fecal indicator bacteria were positively correlated (0.800 to 0.900) with nitrite plus nitrate and potassium concentrations for springs sampled in spring 2000, but no correlation with chloride concentrations was indicated.

Nitrogen Isotopic Composition

The isotopic composition of nitrogen in a sample is expressed in terms of its $\delta^{15}N$ value:

$$\delta^{15}\text{N (in per mil)} = \left(\frac{R_{sample}}{R_{standard}} - 1\right) \times 10^3,$$

where R is the atomic $^{15}N/^{14}N$ ratio (Heaton, 1986). The $\delta^{15}N$ values for commercial fertilizer are close to 0 per mil, whereas the $\delta^{15}N$ values for human sewage or animal waste are typically in the +10 to +20 per mil range (Heaton, 1986). Thus, relative nitrogen isotope abundance can be used to distinguish between commercial fertilizer and human or animal waste. The eight nitrogen isotope samples that were collected for this study represent only a cursory look at nitrogen isotopic composition in the ground water in the upper Shoal Creek Basin. The $\delta^{15}N$ values for this study ranged from 7.2 to 9.1 per mil for six wells and from 5.2 to 5.8 per mil for two springs (table 2). These values may indicate a mixing of animal or human

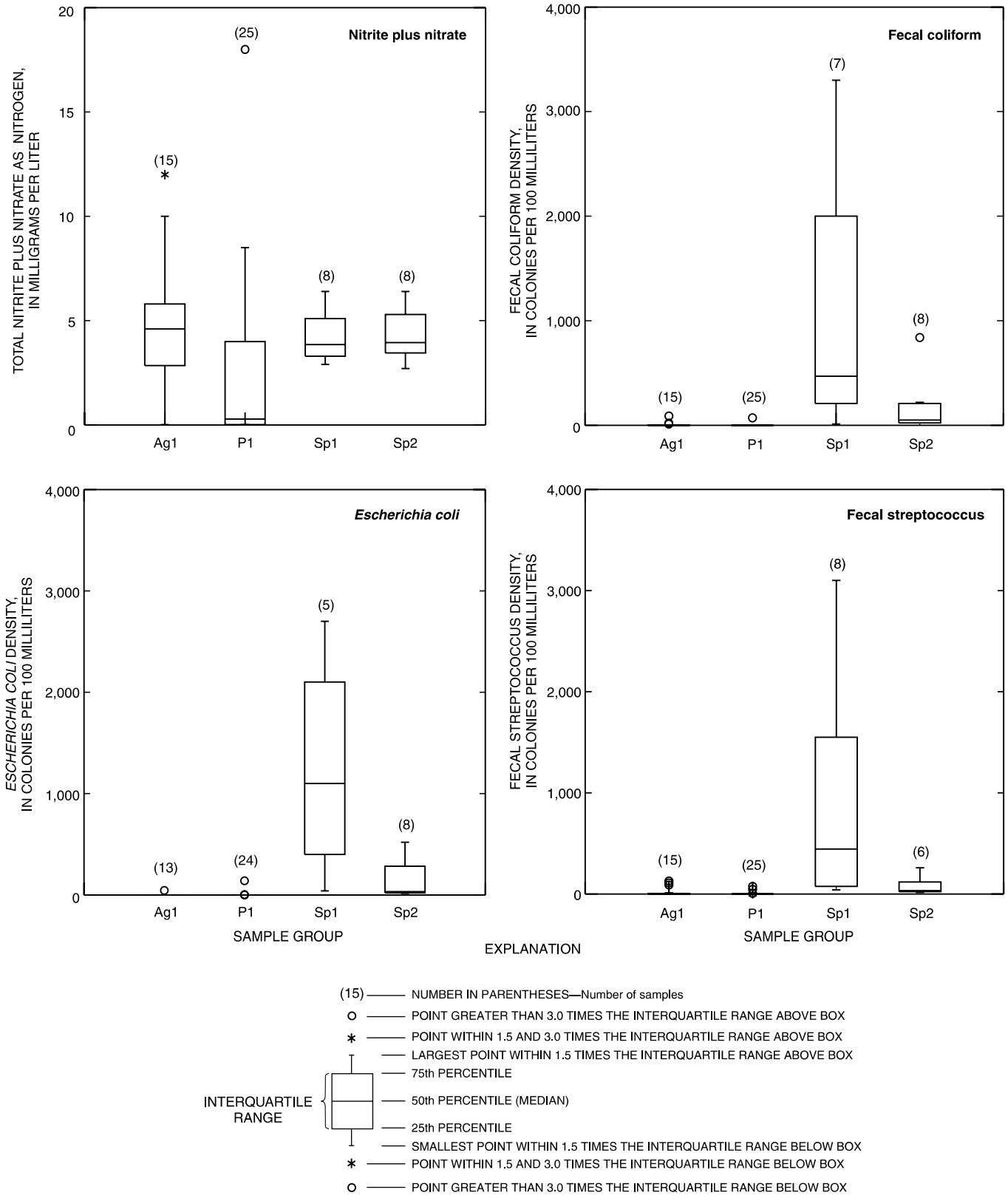

Figure 6. Distribution of nitrite plus nitrate concentrations and fecal indicator bacteria densities for well and spring sample groups.

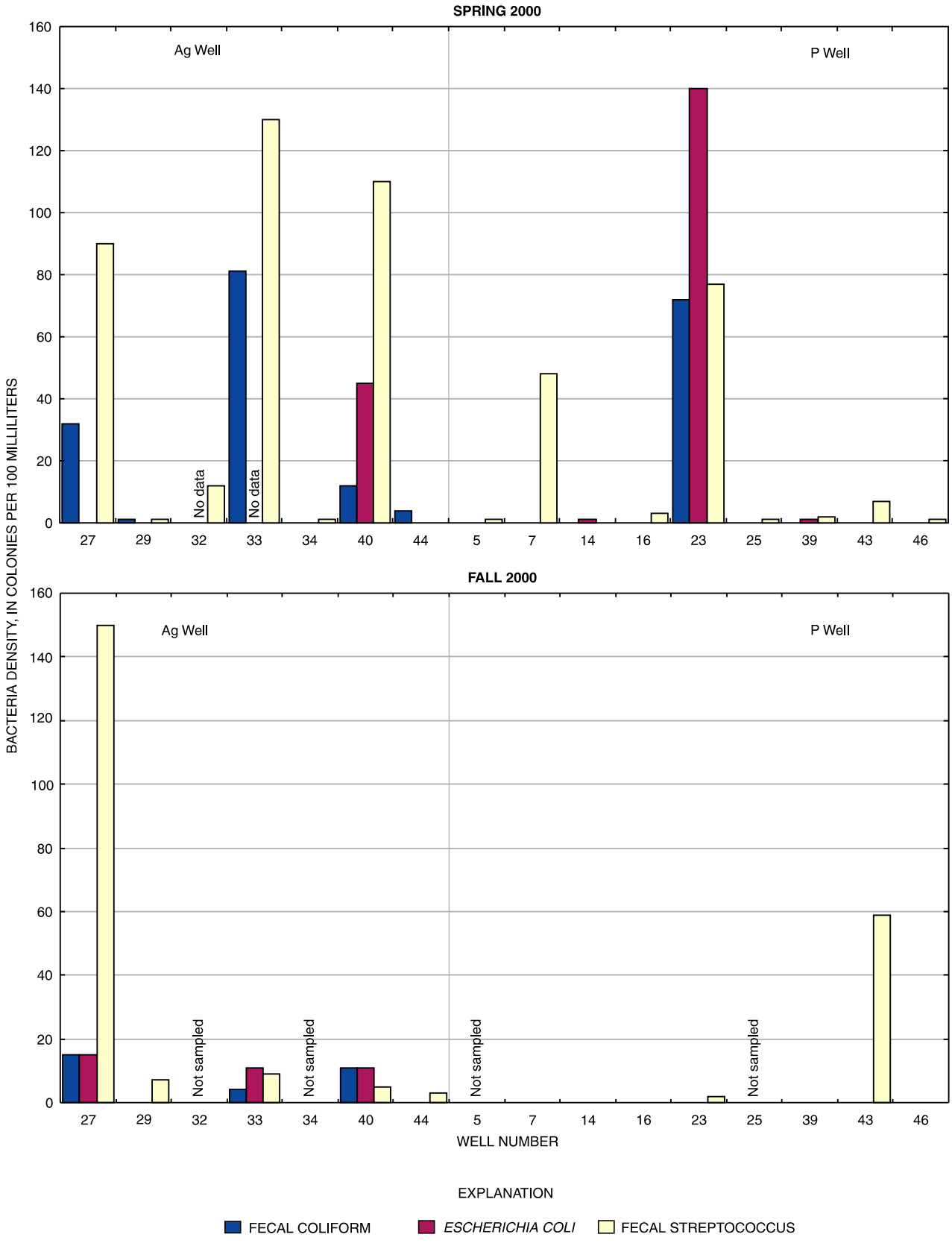

Figure 7. Fecal indicator bacteria densities for wells with at least one colony per 100 milliliters of fecal indicator bacteria.

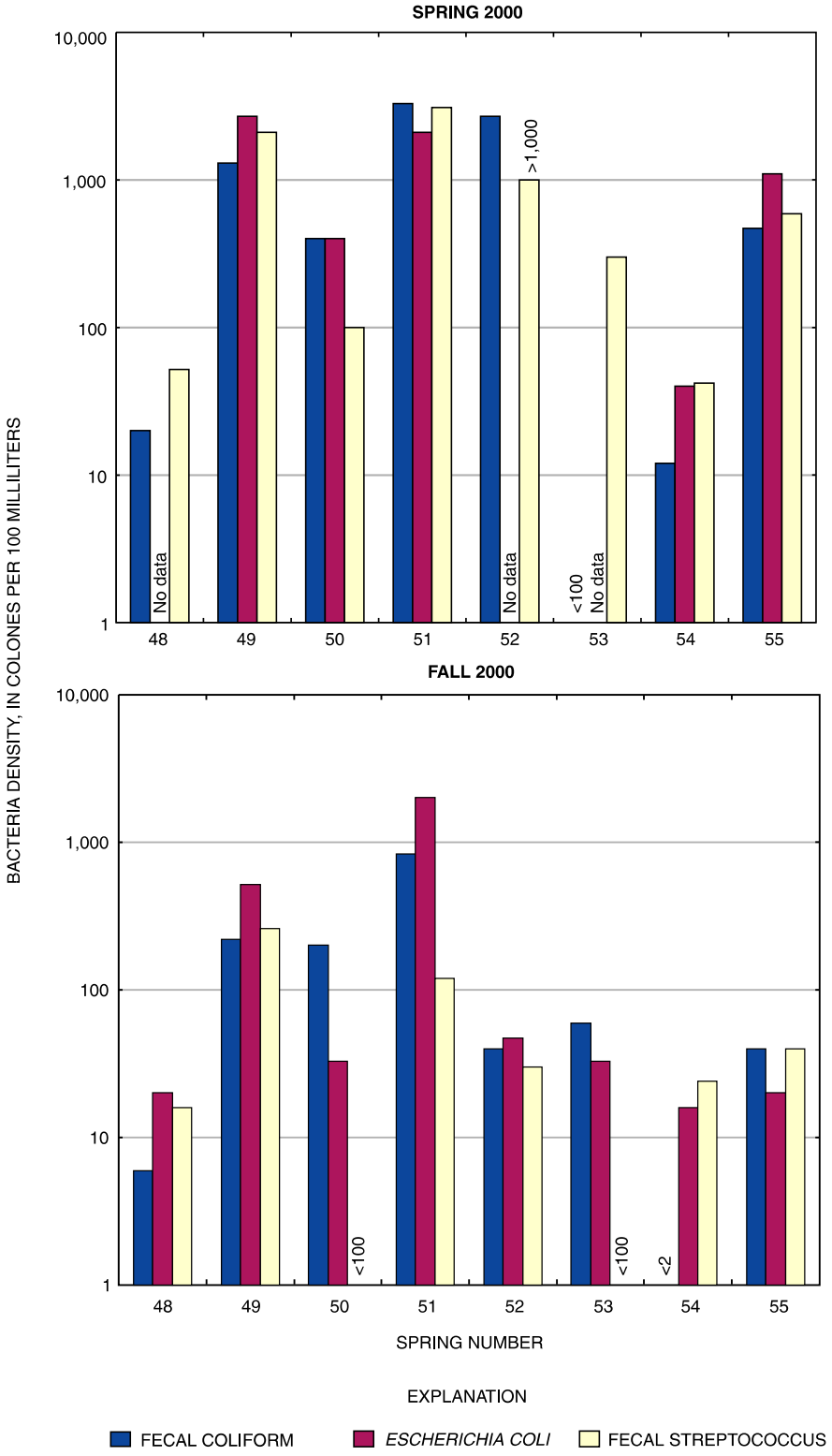

Figure 8. Fecal indicator bacteria densities in springs sampled in spring 2000 and fall 2000.

wastes and commercial fertilizer. The values for the P wells (7.2 to 9.1per mil) do not appear to differ from the Ag wells (7.2 and 7.4 per mil).

EFFECTS OF CONFINED ANIMAL FEEDING OPERATIONS

The results of this study do not indicate that poultry CAFOs are causing an increase of nutrient concentrations and fecal bacteria densities in the shallow ground water in the upper Shoal Creek Basin. This conclusion is based on statistical tests that do not show that P wells sampled in spring 2000 have significantly larger concentrations of nitrite plus nitrate or fecal indicator bacteria densities than Ag wells sampled in spring 2000 at a 95-percent confidence level. On the contrary, the Ag wells had significantly ($p < 0.05$) larger concentrations of nitrite plus nitrate and fecal coliform bacteria densities than the P wells. Many samples contained nitrite plus nitrate concentrations larger than the reporting level of 0.02 mg/L as nitrogen, and several were near or larger than the MCL of 10 mg/L as nitrogen. Few samples had concentrations of the nutrients ammonia, phosphorus, or orthophosphorus substantially larger than the detection level. The well with the largest ammonia and orthophosphorus concentration (well 13) is a commercial P well, suggesting that the poultry CAFO near that well could be a source of these nutrients in the well water.

The results of this study do not indicate seasonal variations from spring 2000 to fall 2000 in the concentrations of nutrients or fecal indicator bacteria densities for well samples. This conclusion is based on statistical tests that indicate no significant difference at a 95-percent confidence level for nitrite plus nitrate concentrations or fecal indicator bacteria densities between either P wells sampled in the spring and fall 2000, or Ag wells sampled in the spring and fall 2000. However, analysis of samples from springs shows that fecal streptococcus bacteria densities were significantly smaller in fall 2000 than in spring 2000 at a 95-percent confidence level. These conclusions regarding seasonal differences are based on a small set of sample results over a limited period of time; analysis of a larger set of sample results over a longer period of time would provide a better assessment of seasonal trends.

The larger nitrite plus nitrate concentrations and fecal coliform bacteria densities in Ag1 samples compared to P1 samples may be the result of variables not considered in this study. For example, more cattle possibly are in the northern part of the basin where most of the Ag wells are located, more commercial fertilizer may be applied to pasture in the northern part of the basin, or the larger nitrite plus nitrate concentrations may be a relic of the application of fertilizer to row crops in the past. The limited nitrogen isotope data do not resolve this because mixed animal or human wastes and commercial fertilizer sources are indicated by the data. The interpretation of sample results is complicated by the fact that the well network consisted of existing wells rather than monitoring wells with known and consistent construction, knowledge of past and present poultry litter application, and limited effects from other environmental factors, such as septic tanks, which also may be sources of nitrite plus nitrate and fecal indicator bacteria. Instead, the well network was characterized by variations and uncertainties in well and casing depth, age, and poultry litter application, and some wells were close to a septic tank. As a group, the Ag wells may be more susceptible to septic tank contamination than P wells because all the Ag wells are domestic wells and all but one (well 29) are close (within about 100 ft) to a septic tank. Fifteen of the 25 P wells are domestic wells. The remaining 10 P wells (wells 1, 2, 5, 7, 13, 15, 17, 23, 43, and 47) are commercial wells supplying water to poultry CAFOs, and only one is close to a septic tank. Also, the construction of commercial wells may make them generally less susceptible to shallow sources of contamination than domestic wells. Most commercial wells were constructed relatively recently and, therefore are more likely to be in compliance with MDNR regulations that the casing be a minimum of 80 ft deep (Missouri Division of Geology and Land Survey, 1996), the condition of the casing is more likely to be good, and the wells may be deeper than most domestic wells. Domestic wells vary in depth and condition of casing, and because most are older than commercial wells, they are more likely to have shallow or corroded casing, or both, which increases the possibility of contamination from shallow sources, including septic tanks. The 16 wells with a magnesium milliequivalent concentration greater than 25 percent of the total cation milliequivalent concentration (fig. 5) generally were less affected by surficial contaminants than other wells. Except for one nitrite plus nitrate concentration of 4 mg/L as nitrogen, the largest nitrite plus nitrate concentration of the 16 wells was 1.6 mg/L as nitrogen, and 10 concentrations were less than the detection level of 0.02 mg/L. Although 4 of the 16 wells had at least 1 col/100 mL of

fecal indicator bacteria, the only bacteria detected was fecal streptococcus. Thirteen of these 16 wells are P wells, and 1 each is a P(old) well, P(deep) well, and an Ag(deep) well. Water from these 16 wells would be expected to be relatively uncontaminated if the large magnesium concentrations means that the wells are open at least partly to the deeper, dolomitic Ozark aquifer. However, the well-construction data indicate that 9 of the 16 wells are not open to the Ozark aquifer. As has been noted, these construction data may be incorrect, or there may be dolostone in the predominantly limestone Springfield Plateau aquifer.

Although an environmental bias in the well sample network may exist, consisting of a larger percentage of Ag wells having the potential to be affected by septic tank effluent, as compared to P wells, it is unclear if this bias is strong enough to affect the statistically based conclusions of this study. Where all 15 Ag wells are domestic wells, and all but one have a greater potential than most commercial wells to be affected by septic effluent, a substantial part of the P wells (15 of 25) also are domestic wells. Also, samples from four wells that plot outside the cluster of other wells at the bicarbonate vertex of the trilinear diagram (fig. 5) because of larger chloride or sulfate concentrations (which may indicate septic contamination), two are P wells (wells 4 and 11) and two are Ag wells (wells 27 and 44). The four wells had detections of fecal indicator bacteria or large nitrite plus nitrate concentrations (ranging from 7.5 to 10 mg/L for 3 wells), or both.

SUMMARY

The upper Shoal Creek Basin, approximately 233 mi^2 (square miles) in size, is in parts of Barry, Lawrence, and Newton Counties in southwest Missouri. Agriculture, the predominant land use in the upper Shoal Creek Basin, primarily is pasture for cattle and hay production. Poultry confined animal feeding operations (CAFOs) have become an important land use in the upper Shoal Creek Basin in recent years. The litter removed from poultry barns is spread on pasture land to provide a source of nutrients. There is concern that the large increase in the number of poultry CAFOs in the basin since the late 1980's may have caused an increase in nutrient concentrations and fecal bacteria densities in ground water.

The surficial Springfield Plateau aquifer ranges from about 200 ft (feet) thick along parts of Shoal Creek to almost 400 ft thick at some topographic highs. Most wells in the upper Shoal Creek Basin are open to the Springfield Plateau aquifer. The Ozark confining unit, which is as much as 40 ft thick, occurs beneath the Springfield Plateau aquifer, and is composed of formations that are less permeable than the Springfield Plateau aquifer. The Ozark aquifer occurs beneath the Ozark confining unit, and ranges from about 1,100 to 1,400 ft thick in the upper Shoal Creek Basin.

A well inventory was conducted in April 2000 to establish a network of wells to sample. Forty-seven wells were selected. Most of the wells were classified as 1 of 2 site types that are wells open only or mostly to the Springfield Plateau aquifer: 25 "P" (for poultry) wells where the application of poultry litter occurred to a substantial acreage (generally several tens of acres or more) within a 0.5 mi (mile) radius of the well (the application was usually much closer to the well) both in spring 2000 and in several previous years, and 15 "Ag" (for agriculture) wells with a limited or no association with poultry CAFOs. Eight springs (site type Sp) also were selected for inclusion in the sample network.

All 47 wells and 8 springs were sampled in May 2000 for total nutrients and fecal indicator bacteria [fecal coliform, *Escherichia coli* (*E. coli*), and fecal streptococcus]. Twenty-two of the wells and all springs also were sampled for dissolved major and trace ions. Fifteen wells and all eight springs were sampled again in October 2000 for total nutrients, fecal indicator bacteria, and dissolved major and trace ions. Emphasis was placed on wells that had previous detections of fecal indicator bacteria, particularly fecal coliform or *E. coli* bacteria, or large concentrations of nitrite plus nitrate as nitrogen in May 2000. Samples also were collected to test for the presence of the human pathogen *E. coli* O157:H7. Five wells and one spring were sampled in November 2000 to determine nutrient concentrations and nitrogen isotopic composition. For a statistical analysis of the water-quality data, samples were grouped using the suffix "1" for spring (May 2000) samples (P1, Ag1, and Sp1) and the suffix "2" for fall (October or November 2000) samples (P2, Ag2, and Sp2).

Nitrite plus nitrate frequently was detected (16 of 25 P1 samples, 14 of 15 Ag1 samples, and 8 of 8 Sp1 samples). Concentrations ranged from less than the detection level of 0.02 mg/L (milligram per liter) as nitrogen to 18 mg/L as nitrogen. Seven samples from three wells had nitrite plus nitrate concentrations at or larger than the Maximum Contaminant Level (MCL) of 10 mg/L as nitrogen, and several other sample concen-

trations were slightly less than the MCL. The median nitrite plus nitrate concentrations for Ag1 samples (4.6 mg/L as nitrogen) and Sp1 samples (3.9 mg/L as nitrogen) were larger than that for P1 samples (0.28 mg/L as nitrogen). A Mann-Whitney test indicated that nitrite plus nitrate concentrations were significantly larger in Ag1 samples than P1 samples, at a 95-percent confidence level. Both the Mann-Whitney test and the sign test for nitrite plus nitrate concentrations did not indicate a significant seasonal difference between P1 and P2 samples, Ag1 and Ag2 samples, or Sp1 and Sp2 samples, at a 95-percent confidence level.

Fecal coliform bacteria was detected in 1 of 25 P1 samples and 5 of 15 Ag1 samples. *E. coli* bacteria was detected in 3 of 24 P1 samples and 1 of 13 Ag1 samples. Fecal streptococcus bacteria were detected in 8 of 25 P1 samples and 6 of 15 Ag1 samples. Bacteria densities ranged from less than 1 to 81 col/100 mL (colonies per 100 milliliters) of fecal coliform, less than 1 to 140 col/100 mL of *E. coli*, and less than 1 to 130 col/100 mL of fecal streptococcus. Fecal indicator bacteria densities in samples from springs were substantially larger than densities in samples from wells. For Sp1 samples, bacteria densities ranged from 12 to 3,300 col/100 mL of fecal coliform, 40 to 2,700 col/100 mL of *E. coli*, and 42 to 3,100 col/100 mL of fecal streptococcus. A Mann-Whitney test indicated that statistically, at a 95-percent confidence level, more fecal coliform bacteria were in Ag1 samples than P1 samples. No statistical differences between P1 and Ag1 samples were detected for *E. coli* or fecal streptococcus bacteria. Statistical tests did not indicate a significant seasonal difference at a 95-percent confidence level between P1 and P2 samples, or Ag1 and Ag2 samples, for any of the three fecal indicator bacteria. A significant seasonal difference for springs at a 95-percent confidence level is indicated only for fecal streptococcus bacteria, with Sp1 densities larger than Sp2 densities. No colonies of *E. coli* O157:H7 bacteria grew on any of the plates from the October samples. The eight $\delta^{15}N$ values for this study ranged from 7.2 to 9.1 per mil for six wells and from 5.2 to 5.8 per mil for two springs, possibly indicating a mixing of animal or human wastes and commercial fertilizer.

The results of this study do not indicate that poultry CAFOs are causing an increase of nutrient concentrations and fecal bacteria densities in the shallow ground water in the upper Shoal Creek Basin. Statistical tests do not indicate that P wells sampled in spring 2000 have significantly larger nitrite plus nitrate concentrations or fecal indicator bacteria densities than Ag wells sampled in spring 2000 at a 95-percent confidence level. On the contrary, the Ag wells had significantly larger nitrite plus nitrate concentrations and fecal coliform bacteria densities than the P wells.

The results of this study also do not indicate seasonal variations from spring 2000 to fall 2000 in the concentrations of nutrients or fecal indicator bacteria densities from well samples. Statistical tests do not indicate significant differences at a 95-percent confidence level for nitrite plus nitrate concentrations or fecal indicator bacteria densities between either P wells sampled in spring and fall 2000 or Ag wells sampled in spring and fall 2000. However, analysis of samples from springs shows that fecal streptococcus bacteria densities were significantly smaller in fall 2000 than in spring 2000 at a 95-percent confidence level.

The statistically significant result that the Ag1 samples had larger nitrite plus nitrate concentrations and fecal coliform bacteria densities than the P1 samples may be the result of variables not considered in this study. For example, more cattle possibly are in the northern part of the basin where most of the Ag wells are located, more commercial fertilizer may be applied to pasture in the northern part of the basin, or the larger nitrite plus nitrate concentrations may be a relic of the application of fertilizer to row crops in the past. As a group, the Ag wells may be more susceptible to septic contamination than P wells, because all the Ag wells are domestic wells and all but one are close (within about 100 ft) to a septic tank. Although this may indicate an environmental bias in the well sample network, it is unclear if this bias is strong enough to affect the statistically based conclusions of this study. Where all 15 Ag wells are domestic wells, a substantial part (15 of 25) of the P wells also are domestic wells.

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