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Sources and Occurrences of Nonpoint-Source Chemicals in Groundwater, Jackson Purchase Region, Kentucky

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Abstract

Nitrate concentrations that exceed U.S. Environmental Protection Agency drinking-water standards have been reported in Jackson Purchase Region groundwater since the 1960's. More recently, other nonpoint-source chemicals such as pesticides and volatile organic compounds have also been found. The sources of these chemicals and the pathways by which they reach domestic groundwater supplies must be determined to protect human health and to design effective land-management practices.

To investigate the occurrence of nonpoint-source chemicals in Jackson Purchase groundwater, 60 wells were selected on the basis of geographic location, hydrostratigraphic unit penetrated, and well type (bored or drilled); distances to row crops, known septic systems, and active and abandoned feedlots were recorded for each well. Groundwater was sampled in the spring and fall of 2005 for field measurements, water properties, major and minor solutes, nutrients, metals, pesticides, volatile organic compounds, caffeine, and bacteria.

Nitrate concentrations exceeded EPA maximum contaminant levels in three wells, and exceeded half the MCL in three other wells. High nitrate concentrations were found mainly in samples from shallow wells in the Continental Gravel hydrostratigraphic unit near row crops. The combination of the permeable gravel and proximity to fertilizer applications makes these wells highly susceptible to nitrate contamination. Pesticides and caffeine were most commonly detected in Continental Gravel samples, but also in other units throughout the area. Total coliform bacteria were found throughout the region from all hydrostratigraphic units and all well types. High nitrate concentrations and detectable caffeine and pesticides are most often found in shallow wells regardless of whether the well was drilled or bored. Shallow wells, bored wells, and those near septic systems were most likely to produce water containing total coliform bacteria, however.

The occurrence of high nitrate concentrations and detectable amounts of pesticides and caffeine shows that groundwater contamination is occurring in the Jackson Purchase. Land management practices that take into account the different hydrologic properties of hydrostratigraphic units and bored wells' greater susceptibility to annular leakage are needed to protect groundwater quality from further degradation. The occurrence of total coliform bacteria in groundwater samples indicates contamination of either the well or water delivery system (or both) or the water-producing aquifer. More extensive testing is needed to determine exactly where the bacteria reside.

This study was one of the first to consider well types and distances to potential sources of nonpoint groundwater contaminants with water-chemistry investigations. Future

studies of nonpoint-source groundwater contamination must first establish that pollutants are not entering the well via local pathways such as leaky well casings or near-wellhead surface sources of chemicals, but rather that the local or regional groundwater system is affected. Second, future studies must carefully document distances from wells to potential sources of contaminants. In many cases this will require historical investigations to locate abandoned confined-animal feeding operations or on-site waste-disposal systems.

Introduction

High nitrate concentrations are common in groundwater in the Jackson Purchase Region (Morgan, 1964, 1966; Lambert, 1964, 1965, 1966a, b; Kentucky Division of Water, 2000; Hansen, 1966, 1967; Davis and others, 1973; Conrad and others, 1999; Beck and others, 2005a). Nitrate-nitrogen concentrations exceed the U.S. Environmental Protection Agency maximum contaminant level of 10 mg/L at 64 of 193 Jackson Purchase wells on record in the Kentucky Groundwater Data Repository (accessed June 2008), operated and maintained by the Kentucky Geological Survey. Groundwater Data Repository records also show the presence of orthophosphate, pesticides, metals, bacteria, and caffeine in Jackson Purchase groundwater at levels that suggest a human origin.

The sources of these chemicals and the pathways by which they reach groundwater must be determined to protect the health of the many citizens and farm livestock who rely on groundwater for domestic and public water supplies in this region. Such assessments are complicated, however, because nonpoint-source contaminants have multiple sources (Table 1).

Nitrogen and phosphorus nutrients occur naturally at low concentrations and also have human sources such as fertilized crop fields, waste from confined-animal feedlots, leaky on-site waste-disposal systems, and fertilizer used on lawns and gardens. Herbicides and insecticides do not occur naturally; typical human sources include agricultural applications and use around houses, gardens, and lawns. Elevated concentrations of metals may have natural sources such as ore deposits, but can also be released from feedlot waste, leaky waste-disposal systems, and house and farm environments. Bacteria are naturally present in soils and groundwater; however, potentially harmful amounts are typically associated with feedlots, septic systems, and households. Caffeine in groundwater is not a hazard, but is a useful marker of human influence. Any of these chemicals can enter a groundwater supply through regional aquifer contamination; local contamination around households, septic systems, or feedlots; or by transport from land surface to groundwater via improperly constructed or damaged wells.

This study evaluated relations between nonpoint-source chemicals in groundwater, hydrostratigraphic units, well types, and land use to determine the sources and pathways that allow contaminants to reach Jackson Purchase wells. The results can be used to design best management practices to reduce or eliminate nonpoint-source contamination of groundwater.

Jackson Purchase Region

The Jackson Purchase Region consists of the eight westernmost Kentucky counties (Fig. 1) bounded by the Mississippi, Ohio, and Tennessee

Table 1. Potential sources of nonpoint-source contaminants and the areas affected.

Source (Area Affected)	*Nutrients (Fertilizer)*	*Pesticides (Insecticides and Herbicides)*	*Metals, Total Dissolved Solids*	*Bacteria*	*Caffeine*
cultivated crops (regional)	X	X			
feedlots (local)	X		X	X	
septic systems (local)	X		X	X	X
residential use (local)	X	X	X	X	X
leaky wellbore (immediate)	X	X	X	X	

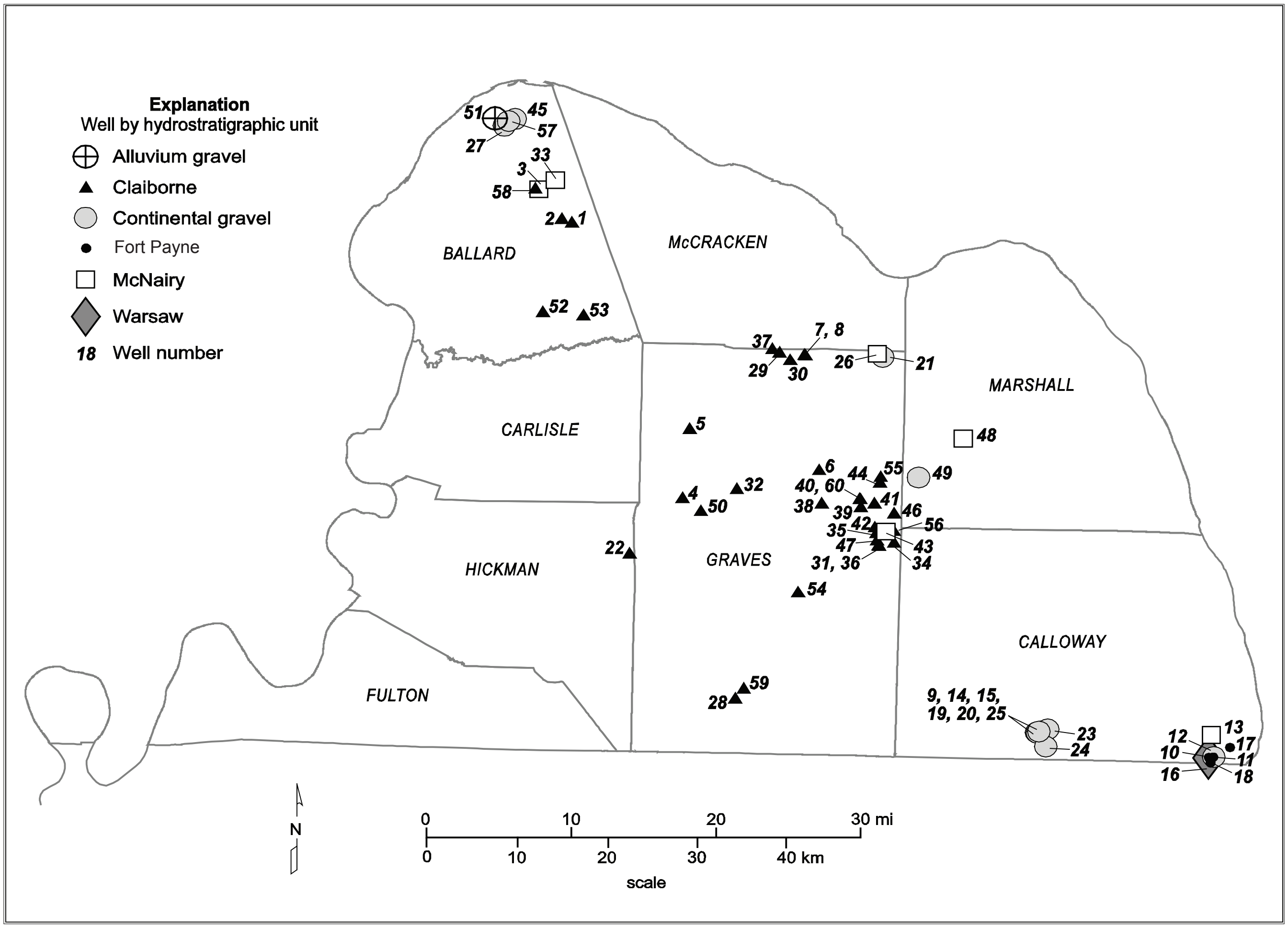

Figure 1. Well locations, well numbers, and hydrostratigraphic units sampled in this study.

Rivers and the Kentucky-Tennessee border. The topography is gently rolling hills and broad, shallow valleys, with steep bluffs along the Tennessee and Mississippi Rivers. The climate is humid-continental, with approximately 45 in. of precipitation a year and monthly average temperatures that range from 37°F in January to about 80°F in July (Davis and others, 1973).

The Jackson Purchase Region occupies the northern tip of the Mississippi Embayment, a syncline that plunges south toward the Gulf of Mexico. Late Cretaceous to Holocene sediments are a few hundred feet thick along the northern and eastern edges of the embayment and reach a maximum thickness of nearly 1,800 ft in the southwestern Jackson Purchase. These semiconsolidated sediments rest unconformably on basement Paleozoic rocks and are separated from the older strata by a discontinuous gravel layer (Davis and others, 1973). In Kentucky, groundwater supplies suitable for domestic or light industrial use are provided by the gravel deposits on top of the Paleozoic limestones. These are, in ascending order, the Cretaceous McNairy Formation; the Eocene Claiborne Group, Cockfield Formation, and Jackson Formation; continental Pliocene river terrace gravel (referred to as Continental Gravel in this report); and alluvial gravel along the Mississippi, Ohio, and Tennessee Rivers (Davis and others, 1973).

Selection of Sampling Sites

After reviewing well records from the Kentucky Division of Water and the Kentucky Groundwater Data Repository, 60 sites were selected on the basis of location, well construction, and hydrostratigraphic unit (Fig. 1, Table 2). Site visits confirmed that the wells were accessible and that the owner would allow sampling. Proximity to sep-

Table 2. Well numbers, descriptions, hydrostratigraphic units, and proximity to potential nonpoint chemical sources. NA=none in sight. AKGWA= Assembled Kentucky Ground Water Database.

Well Number	*AKGWA Number*	*Depth (ft)*	*Diameter (in.)*	*Screened Interval (ft)*	*Hydrostratigraphic Unit*	*Distance to Row Crop (ft)*	*Distance to Septic System (ft)*	*Distance to Active Feedlot (ft)*
1	00002553	130.0	4	120–130	Claiborne	140	170	NA
2	00006541	104.0	4	98–104	Claiborne	105	162	NA
3	00057508	270.0	4	250–270	McNairy	100	96	NA
4	00061186	250.0	4	240–250	Claiborne	80	100	NA
5	00061241	172.0	4	162–172	Claiborne	NA	170	NA
6	00061190	160.0	4	150–160	Claiborne	NA	80	70
7	00055661	100.0	4	90–100	Claiborne	> 200	160	NA
8	00014369	95.0	4	85–95	Claiborne	> 200	40	NA
9	00001207	54.0	4	44–54	Continental Gravel	164	84	NA
10	00061242	130.0	4	unknown	Fort Payne	> 200	120	NA
11	00061250	140.0	4	unknown	Fort Payne	> 200	50	NA
12	00051482	52.0	24	none	Continental Gravel	> 200	NA	NA
13	00044334	101.0	4	unknown	McNairy	140	120	NA
14	00061243	42.0	24	none	Continental Gravel	> 200	54	NA
15	00061244	20.3	24	none	Continental Gravel	> 200	50	NA
16	00051481	35.0	24	none	Warsaw	> 200	105	NA
17	00001201	141.0	6	118–141	Fort Payne	> 200	140	NA
18	00041894	190.0	6	75–190	Fort Payne	NA	NA	NA
19	00031287	75.0	4	65–75	Continental Gravel	> 200	160	55
20	00020717	60.0	4	40–60	Continental Gravel	180	80	NA
21	00051475	47.0	24	none	Continental Gravel	> 200	140	NA
22	00048761	260.0	4	240–260	Claiborne	NA	NA	NA
23	00042377	32.0	24	none	Continental Gravel	100	NA	NA
24	00044344	100.0	4	90–100	Continental Gravel	90	75	NA
25	00042386	37.0	24	none	Continental Gravel	> 200	81	NA
26	00061189	280.0	4	270–280	McNairy	> 200	NA	NA
27	00045131	66.0	4	56–66	Continental Gravel	10	240	NA
28	00051841	200.0	4	180–200	Claiborne	> 200	NA	50
29	00019601	220.0	4	200–220	Claiborne	> 200	NA	NA
30	00049054	185.0	4	175–185	Claiborne	NA	NA	NA
31	00030068	130.0	4	120–130	Claiborne	NA	70	NA
32	00061245	205.0	4	195–205	Claiborne	NA	63	NA
33	00028287	320.0	4	300–320	McNairy	180	159	NA
34	00045890	83.0	4	70–83	Claiborne	> 200	72	NA
35	00030806	65.0	4	55–65	Claiborne	NA	60	NA
36	00050244	115.0	4	105–115	Claiborne	> 200	105	NA
37	00043120	150.0	4	140–150	Claiborne	30	156	NA
38	00015335	265.0	4	245–265	Claiborne	> 200	75	NA
39	00035610	250.0	4	240–250	Claiborne	> 200	102	NA
40	00061187	21.0	36	none	Claiborne	> 200	60	NA

Table 2. Well numbers, descriptions, hydrostratigraphic units, and proximity to potential nonpoint chemical sources. NA=none in sight. AKGWA= Assembled Kentucky Ground Water Database.

Well Number	*AKGWA Number*	*Depth (ft)*	*Diameter (in.)*	*Screened Interval (ft)*	*Hydrostratigraphic Unit*	*Distance to Row Crop (ft)*	*Distance to Septic System (ft)*	*Distance to Active Feedlot (ft)*
41	00053989	170.0	4	160–170	Claiborne	NA	200	NA
42	00045920	200.0	4	184–200	Claiborne	NA	NA	105
43	00040389	536.0	4	516–536	McNairy	> 200	NA	NA
44	00000705	94.0	4	88–94	Claiborne	40	68	NA
45	00061181	60.0	6	unknown	Continental Gravel	50	50	NA
46	00004375	180.0	4	170–180	Claiborne	> 200	39	NA
47	00036379	148.0	4	138–148	Claiborne	> 200	81	NA
48	00045936	280.0	4	270–280	McNairy	> 200	120	NA
49	00045405	38.0	24	none	Continental Gravel	> 200	30	NA
50	00059631	165.0	4	155–165	Claiborne	200	NA	NA
51	00012674	36.0	6	26–36	alluvium gravel	> 200	171	NA
52	00034315	170.0	4	150–170	Claiborne	> 200	NA	NA
53	00057470	220.0	4	210–220	Claiborne	> 200	54	NA
54	00062164	200.0	4	190–200	Claiborne	170	125	NA
55	00062168	130.0	4	120–130	Claiborne	> 200	NA	NA
56	00003532	94.0	24	none	Claiborne	20	39	NA
57	00055180	80.0	4	55–75	Continental Gravel	75	NA	NA
58	00061185	95.0	4	85–95	Claiborne	80	NA	NA
59	00061249	210.0	4	200–210	Claiborne	> 200	195	NA
60	00051801	75.0	4	55–75	Claiborne	> 200	109	NA

tic systems, active and abandoned confined-animal feeding operations, and row crops was recorded during the site visit. Proximity to abandoned confined-animal feeding operations and waste-disposal systems is potentially significant but difficult to determine. Well depths ranged from 20 to 536 ft; well diameters ranged from 4 to 36 in. Hydrostratigraphic intervals sampled and their characteristics are summarized in Table 3.

Both bored and drilled wells were selected to determine whether susceptibility to contamination varied between well types. Bored wells are particularly common in Marshall and Calloway Counties. Because the shallow sands and gravels there do not produce enough groundwater for domestic use, these larger-diameter wells are used to store water between times of high demand.

Properly constructed drilled wells consist of a 4- to 6-in.-diameter continuous PVC casing whose upper 20 ft of annular space is grouted to prevent contamination from surface spills or to prevent shallow, contaminated groundwater from reaching the well inlet (Fig. 2a). Well integrity is compromised if the annular seal does not isolate the screened interval from shallow groundwater or if the PVC casing is cracked (Fig. 2b).

Bored wells are 24 to 36 in. in diameter, consisting of 3-ft sections of cement tile casings stacked on each other. The upper annular portion should be sealed with concrete grout, bentonite, or other impermeable material, whereas the deeper section should be encased in a gravel pack (Fig. 3a). These wells are susceptible to contamination if shallow groundwater leaks through cracks in the annular seal or the joints between each tile section (Fig. 3b). The upper annular space of older bored wells may be filled with well cuttings, which do not prevent surface water or shallow groundwater from mixing with deeper groundwater.

Table 3. Hydrostratigraphic units, hydrologic properties, number of wells, screened intervals, and well diameters in each unit.

Hydrostratigraphic Unit	*Hydrologic Characteristics*	*Number of Wells*	*Screened Interval (ft)*	*Well Diameter (in.) and Number of Wells*
alluvium gravel	Thick deposits may yield sufficient water for domestic, stock, and irrigation use. Water quality is generally good; high nitrate concentrations have been reported. (Hansen, 1967)	1	36.0	6 (1)
Continental Gravel	Thick deposits may yield sufficient water for domestic or stock use. Water is moderately hard; high nitrate concentrations have been reported. (Lambert, 1964; Hansen, 1967)	14	20.3–100.0	4 (6) 6 (1) 24 (7)
Claiborne Group	Thick sands of the Claiborne Group are potentially the most productive regional aquifers; high nitrate concentrations have been reported. (Morgan, 1964; Hansen, 1966; Lambert, 1966b; Davis and others, 1973)	34	21.0–265.0	4 (32) 24 (1) 36 (1)
McNairy Formation	Yields plentiful water supplies for domestic use to small-diameter drilled wells and most large-diameter or bored wells. Yields may be as high as several hundred gallons per minute; high nitrate concentrations have been reported. (Lambert, 1964, 1966b; Morgan, 1964)	6	101.0–536.0	4 (6)
Fort Payne Formation	May yield large quantities of groundwater from chert rubble zones and from solution channels in the limestone. (Lambert, 1964, 1966a)	4	130.0–190.0	4 (2) 6 (2)
Warsaw Limestone	May yield large quantities of groundwater for domestic and public supplies from chert rubble zones and a lesser amount from solution channels in limestone; yields greater than 100 gal/min have been reported. (Lambert, 1965, 1966a)	1	35.0	24 (1)

Methodology

Sampling Schedule

Wells were sampled for a full suite of analyses, except for bacteria, by Kentucky Geological Survey personnel in the spring (April 19–June 28, 2005), when rainfall, groundwater recharge, and agricultural chemical applications were high, and again in the fall (September 12–October 4, 2005), when precipitation, recharge, and chemical application rates were low. Bacteria samples were collected by Kentucky Division of Water personnel on September 13–14, 2005. All sampling dates are presented in Beck (2010).

Sample-Collection Methods

All groundwater samples were collected in accordance with U.S. Geological Survey guidelines for sampling and collecting (U.S. Geological Survey, 1980). They were collected from an outside faucet after the well was purged with the existing submersible pump and after field measurements (pH, temperature, and conductivity) stabilized. Field measurements were recorded using a Horiba[1] U-22 water-quality monitoring system with a flow-through chamber. The Horiba U-22 was calibrated daily during sampling using procedures prescribed by the manufacturer.

Sample splits were prepared in the field and transported to the laboratory in properly sterilized bottles. For dissolved-constituent analysis, samples were filtered by using a peristaltic pump to pump water from a designated bucket through Tygon tubing and a high-capacity in-line filter (0.45-µm pore size). New Tygon tubing and a new filter were used for each sample. The bucket was rinsed once with 10 percent hydrochloric acid, three times with distilled water, and once with tap water between each filtering. If preservation was required, the samples were preserved at the time of collection and kept at a temperature of 4°C until delivered to

[1]The use of trade or product names is for descriptive purposes only and does not imply endorsement by the Kentucky Geological Survey.

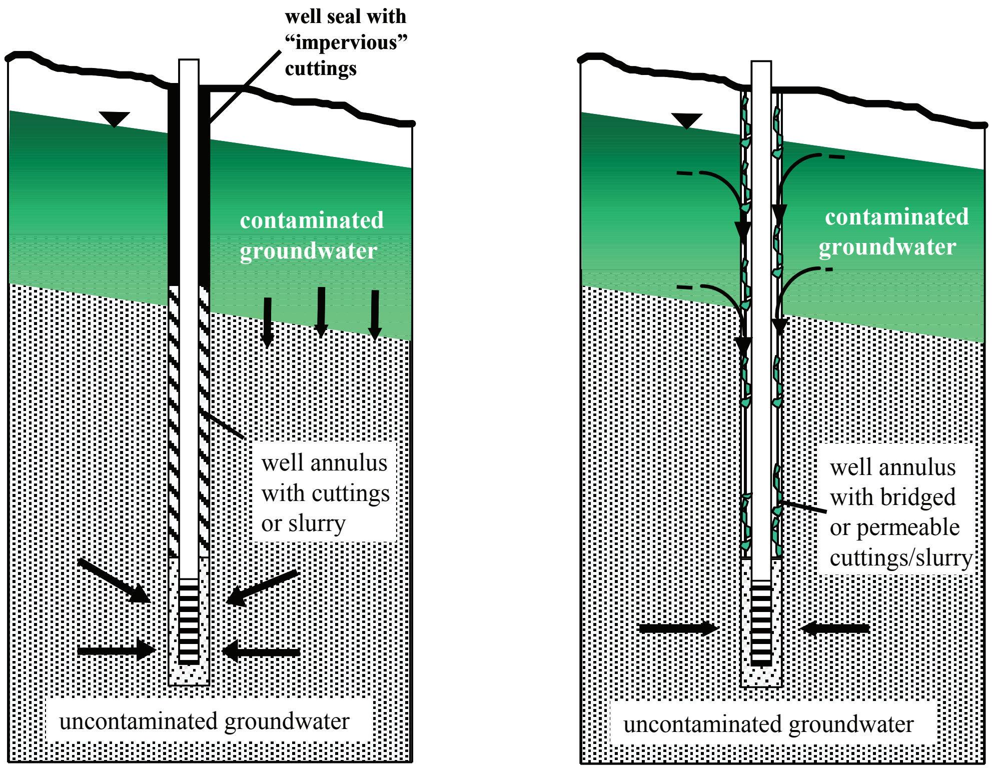

Figure 2. Schematic diagram of a (a) properly constructed drilled well and (b) leaky drilled well. Modified from Beck and others (2005a) with permission of the University of Kentucky Cooperative Extension Service.

the laboratory. Information on sample bottles and preservation is in Beck (2010).

For bacteria samples, the plumbing system was flushed for approximately 10 min before sample bottles were filled. Each bottle was placed on ice and delivered to the laboratory within 6 hr of collection.

Analytical Methods

Analyses were performed at the Western Kentucky Regional Laboratory (bacteria), Kentucky Geological Survey and Environmental Research and Training Laboratory (nitrogen isotopes), and Kentucky Division of Environmental Services Laboratory (complete suite of nonpoint-source analyses). All analyses were performed in accordance with either EPA or analytical methods widely approved in the literature (Beck, 2010).

Results

Detailed groundwater data associated with this project are presented in Beck (2010). In addition, the resulting data are stored in the Kentucky Division of Water groundwater database and the Kentucky Groundwater Data Repository.

Total Dissolved Solids

Total dissolved solids is the total mass of material remaining after a volume of water is evaporated to dryness. Water with more than about 500 mg/L of total dissolved solids has an objectionable taste and may not be suitable for drinking or cooking. Water samples collected in this study have total dissolved solids values that range from 20 to 712 mg/L, as shown in Figure 4, a box and whisker diagram. In this type of diagram, used to illustrate results of all analyses in this project, boxes enclose the central 50 percent of the data, whiskers extend 1.5 times the range of the central box, and outliers are plotted as individual symbols. The vertical line through each box shows the median value for that group, and the plus sign shows the average value. Only one sample (from well 57, completed at 80 ft in the Continental Gravel) exceeded 500 mg/L. There was no systematic increase in total dissolved

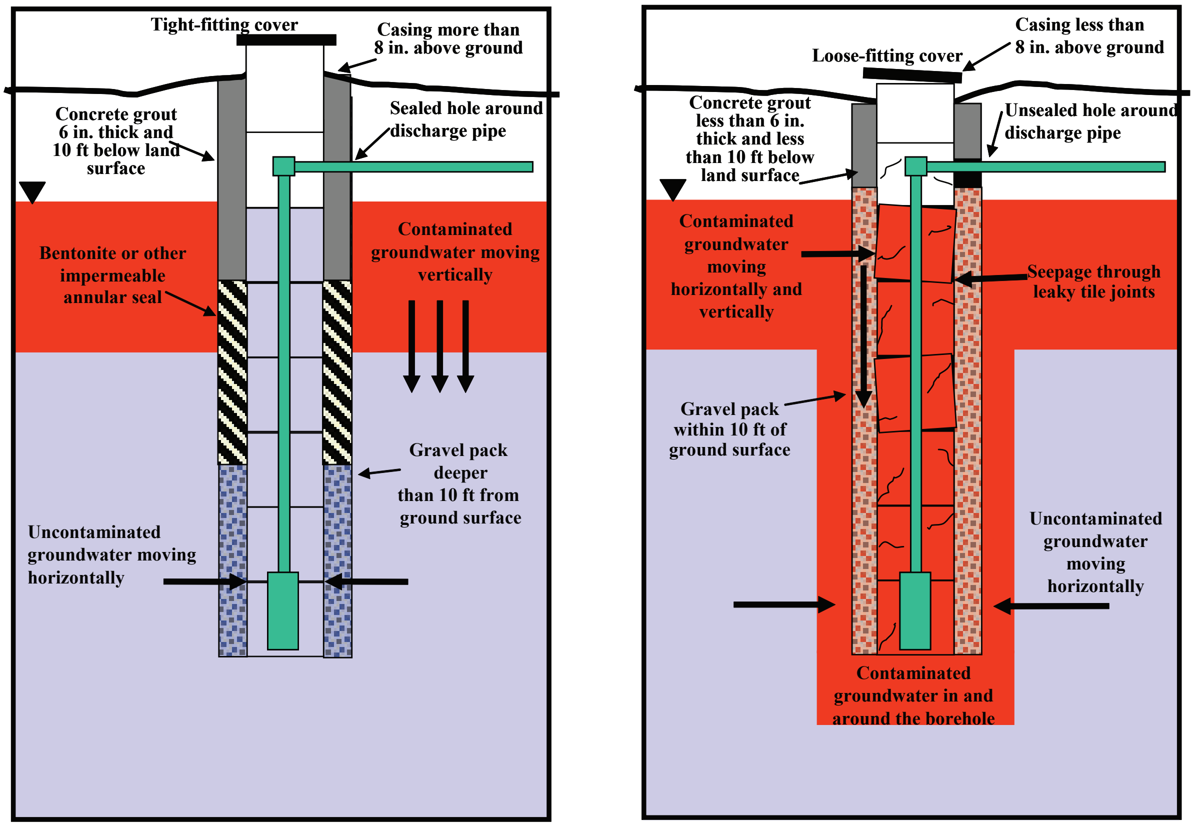

Figure 3. Schematic diagram of a (a) properly constructed bored well and (b) leaky bored well. Modified from Beck and others (2005a) with permission of the University of Kentucky Cooperative Extension Service.

solids with depth, either for all samples or within any individual unit.

pH

Acidity or alkalinity of a substance is measured as pH. Under uncontaminated conditions, pH values for water range from about 5.5 (pure water in equilibrium with air) to 8.5 (water in equilibrium with calcium carbonate, as found in carbonate aquifers).

In this study, pH values ranged from 5.5 to 8.1 (Fig. 5). The highest values occurred in Fort Payne samples, whereas the widest range of values occurred in McNairy samples. No sample exceeded the upper limit of the EPA national secondary drinking-water standard of 8.5; however, 68 percent of samples were lower than 6.5, the lower limit recommended by the EPA. These samples were from all hydrostratigraphic units except the Fort Payne. There

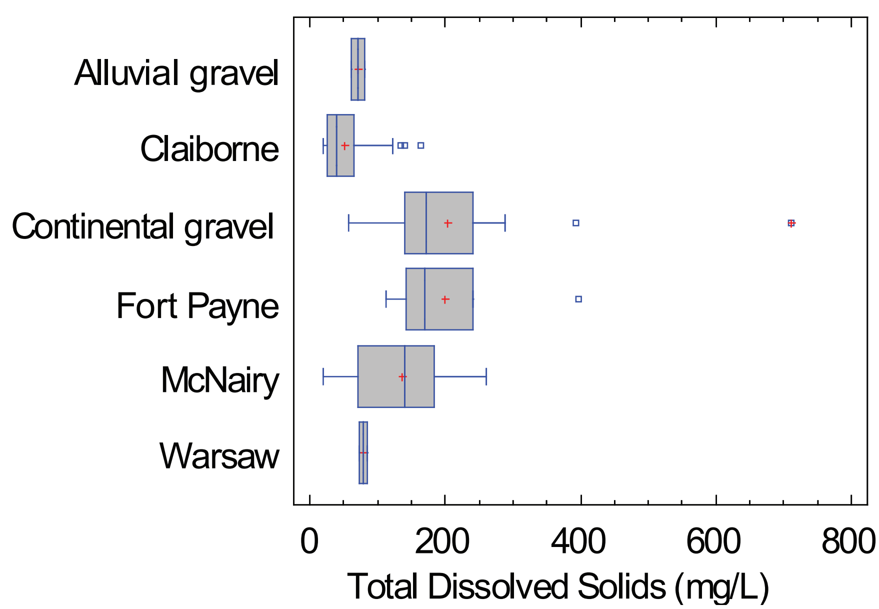

Figure 4. Total dissolved solids values grouped by hydrostratigraphic unit.

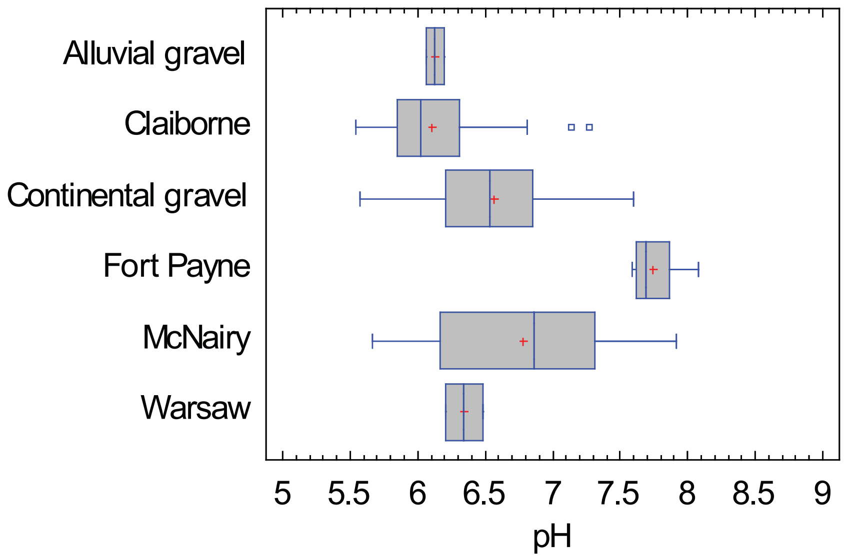

Figure 5. pH values grouped by hydrostratigraphic unit.

was no systematic change in pH with depth, either for all samples or within any individual unit.

Water Types

Natural waters can be classified into various chemical types on the basis of predominant cations and anions. Some water types are directly related to aquifer mineralogy; for example, a calcium-bicarbonate water results from dissolution of carbonate minerals in a limestone aquifer.

Waters in mixed-lithology aquifers generally have mixed water types. Fort Payne and Warsaw samples are predominantly calcium-bicarbonate waters; other samples are mixed water types (Table 4, Fig. 6).

Nitrate-Nitrogen

Nitrate in groundwater has both natural (dissolved atmospheric nitrogen or natural organic material) and man-made (fertilizer, animal waste, or leaking septic systems) sources. Nitrate concentrations greater than 10 mg/L can cause illness or death in infants. Long-term exposure to nitrate levels above the MCL can cause diuresis (increased starchy deposits and hemorrhaging of the spleen in adults) (U.S. Environmental Protection Agency, 2006). For these reasons, EPA has set a maximum contaminant level of 10 mg/L for nitrate in drinking water. Concentrations between 5 and 10 mg/L are cause for concern and continued monitoring to ensure they do not reach harmful levels. Nitrate concentrations in samples collected for this study ranged from 0.011 to 19.2 mg/L (Table 5; samples with nitrate greater than 5 mg/L are marked for easier reference).

Table 4. Water types produced from each hydrostratigraphic unit.

Unit	*Predominant Water Type*
alluvium gravel	$Ca-Mg-Na-SO_4$
Claiborne	mixed
Continental Gravel	mixed; includes Na-Cl
Fort Payne	$Ca-HCO_3$
McNairy	mixed
Warsaw	$Ca-HCO_3$

Samples from the Continental Gravel have the highest nitrate concentrations, whereas samples from Fort Payne, McNairy, and Warsaw units have the lowest concentrations (Fig. 7). Twenty-seven samples exceeded 2 mg/L, 15 samples exceeded 5 mg/L, and six exceeded the MCL of 10 mg/L. All samples with concentrations higher than 5 mg/L of nitrate were from the Continental Gravel, but not all Continental Gravel groundwaters have high nitrate concentrations.

Samples with concentrations exceeding 10 mg/L were found in a small cluster in northern Ballard County, whereas samples with concentrations of 5 to 10 mg/L were found in a small cluster in southern Calloway County (Fig. 8).

The highest nitrate concentrations were from wells less than 100 ft deep (Fig. 9), although not all shallow samples had high nitrate concentrations.

Water with more than 5 mg/L of nitrate was produced from both drilled and bored wells, whereas water with more than 10 mg/L was produced only from drilled wells (Fig. 10). All samples with more than 5 mg/L were produced from the Continental Gravel, regardless of well diameter (Table 6).

Samples from the Claiborne and McNairy units did not show any systematic change in nitrate concentration with proximity to row crops (Fig. 11). Samples from the Continental Gravel that

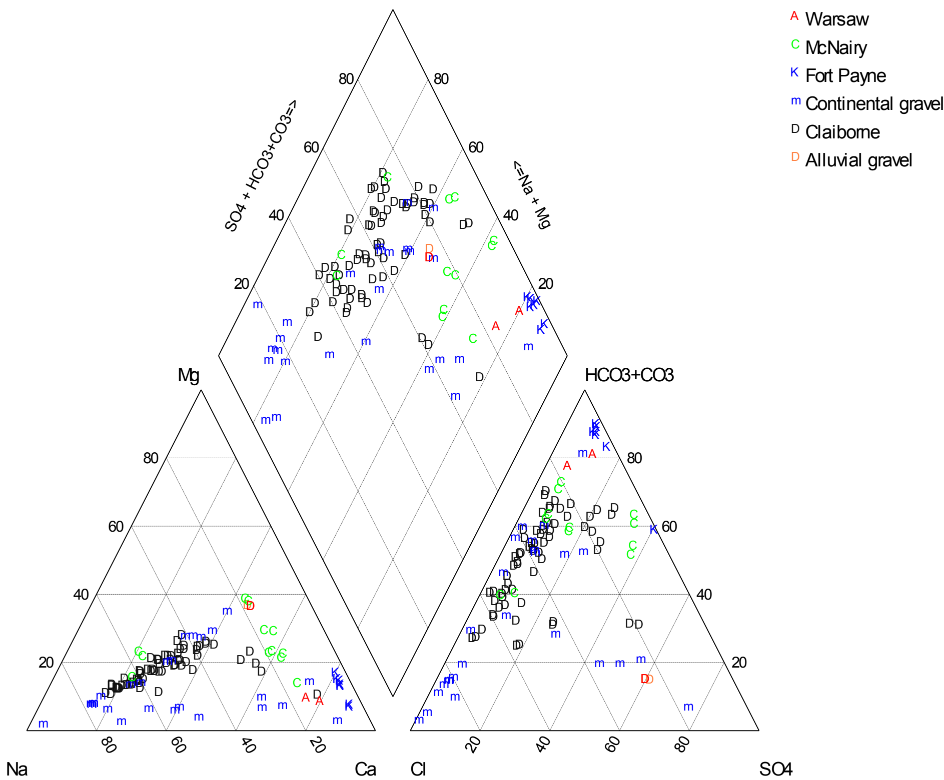

Figure 6. Ternary plot of major cation and anion composition of water samples.

were less than 80 ft from row crops had higher nitrate concentrations than those farther away, however.

Samples were collected in both spring and fall to evaluate whether spring fertilizer applications directly affected nitrate concentrations. Seasonal variations (spring concentration minus fall concentration) were near zero for samples from the alluvium gravel, Claiborne, Fort Payne, McNairy, and Warsaw units, and generally less than zero (i.e., fall concentrations were higher than spring concentrations) in Continental Gravel samples (Fig. 12).

Comparison of seasonal nitrate variations versus spring concentration for individual samples (Fig. 13) showed essentially no variation for most wells. Five wells (4, 20, 25, 45, and 57), all completed in the Continental Gravel, showed marked deviations from zero seasonal variation. In four of the five cases, fall nitrate concentrations were greater than spring concentrations. Samples with both low and high nitrate concentrations have seasonal variations greater than 1 mg/L (Fig. 13). There was no clear association between seasonal nitrate variation and well depth, well diameter, well type, or distance to row crops.

Nitrogen Isotope Compositions

The isotope composition of nitrogen is a useful indicator of the origin of nitrate (Choi and others, 2003). Nitrogen has two stable isotopes: ^{14}N and ^{15}N. Stable isotope compositions are reported in del units (δ, in per mil or parts per thousand), which compare the isotope composition of a sample to a standard. For nitrogen, the standard is air. The nitrogen in fertilizer is extracted from the atmosphere during manufacturing and has a $\delta^{15}N$ value of 0 ±2 per mil, whereas human or animal waste has a $\delta^{15}N$ value of 15 ±10 per mil (Eby, 2004, p. 193). These two end-members are readily distinguished. When dissolved nitrate is converted to nitrogen gas under reducing conditions (denitrification), however, the $\delta^{15}N$ value of residual dissolved nitrate-nitrogen increases and can reach values approaching that of animal or human waste. Mixing nitrate from fertilizer and waste sources can also result in intermediate $\delta^{15}N$ values.

The nitrogen isotope composition of nitrate ($\delta^{15}N$) was measured in nine samples, all from the Continental Gravel aquifer (Table 7). Results show two groups of samples. Those with $\delta^{15}N$ values less than 6 per mil and NO_3-N concentrations less than

Table 5. Spring and fall nitrate concentrations.

Well Number	*AKGWA Number*	*Season*	*Unit*	*Well Depth (ft)*	*Well Diameter (in.)*	*Nitrate-N (mg/L)*
1	00002553	spring	Claiborne	130.0	4	0.725
1	00002553	fall	Claiborne	130.0	4	0.831
2	00006541	spring	Claiborne	104.0	4	1.320
2	00006541	fall	Claiborne	104.0	4	1.320
3	00057508	spring	McNairy	270.0	4	0.033
3	00057508	fall	McNairy	270.0	4	< 0.025
4	00061186	spring	Claiborne	250.0	4	0.465
4	00061186	fall	Claiborne	250.0	4	0.453
5	00061241	spring	Claiborne	172.0	4	1.320
5	00061241	fall	Claiborne	172.0	4	1.100
6	00061190	spring	Claiborne	160.0	4	0.260
6	00061190	fall	Claiborne	160.0	4	0.268
7	00055661	spring	Claiborne	100.0	4	0.053
7	00055661	fall	Claiborne	100.0	4	0.030
8	00014369	spring	Claiborne	95.0	4	0.060
8	00014369	fall	Claiborne	95.0	4	0.023
9	00001207	spring	Continental Gravel	54.0	4	6.800
9	00001207	fall	Continental Gravel	54.0	4	7.140
10	00061242	spring	Fort Payne	130.0	4	0.060
10	00061242	fall	Fort Payne	130.0	4	0.015
11	00061250	spring	Fort Payne	140.0	4	0.036
12	00051482	spring	Continental Gravel	52.0	24	0.472
13	00044334	spring	McNairy	101.0	4	0.490
13	00044334	fall	McNairy	101.0	4	0.447
14	00061243	spring	Continental Gravel	42.0	24	5.960
14	00061243	fall	Continental Gravel	42.0	24	8.130
15	00061244	spring	Continental Gravel	20.3	24	4.810
16	00051481	spring	Warsaw	35.0	24	0.465
16	00051481	fall	Warsaw	35.0	24	0.355
17	00001201	spring	Fort Payne	141.0	6	0.103
17	00001201	fall	Fort Payne	141.0	6	0.088
18	00041894	spring	Fort Payne	190.0	6	0.066
18	00041894	fall	Fort Payne	190.0	6	0.038
19	00031287	spring	Continental Gravel	75.0	4	4.400
19	00031287	fall	Continental Gravel	75.0	4	4.550
20	00020717	spring	Continental Gravel	60.0	4	0.296
20	00020717	fall	Continental Gravel	60.0	4	8.070
21	00051475	spring	Continental Gravel	47.0	24	0.629
21	00051475	fall	Continental Gravel	47.0	24	0.670
22	00048761	spring	Claiborne	260.0	4	0.119
22	00048761	fall	Claiborne	260.0	4	0.091

Table 5. Spring and fall nitrate concentrations.

Well Number	AKGWA Number	Season	Unit	Well Depth (ft)	Well Diameter (in.)	Nitrate-N (mg/L)
23	00042377	spring	Continental Gravel	32.0	24	6.980
23	00042377	fall	Continental Gravel	32.0	24	6.800
24	00044344	spring	Continental Gravel	100.0	4	7.050
24	00044344	fall	Continental Gravel	100.0	4	7.260
25	00042386	spring	Continental Gravel	37.0	24	0.983
25	00042386	fall	Continental Gravel	37.0	24	4.880
26	00061189	spring	McNairy	280.0	4	< 0.025
26	00061189	fall	McNairy	280.0	4	0.011
27	00045131	spring	Continental Gravel	66.0	4	13.300
27	00045131	fall	Continental Gravel	66.0	4	13.200
28	00051841	spring	Claiborne	200.0	4	4.240
28	00051841	fall	Claiborne	200.0	4	4.180
29	00019601	spring	Claiborne	220.0	4	1.050
29	00019601	fall	Claiborne	220.0	4	0.993
30	00049054	spring	Claiborne	185.0	4	0.067
30	00049054	fall	Claiborne	185.0	4	0.057
31	00030068	spring	Claiborne	130.0	4	0.659
31	00030068	fall	Claiborne	130.0	4	0.674
32	00061245	spring	Claiborne	205.0	4	0.155
32	00061245	fall	Claiborne	205.0	4	0.145
33	00028287	spring	McNairy	320.0	4	0.073
33	00028287	fall	McNairy	320.0	4	0.054
34	00045890	spring	Claiborne	83.0	4	3.760
34	00045890	fall	Claiborne	83.0	4	3.870
35	00030806	spring	Claiborne	65.0	4	0.508
35	00030806	fall	Claiborne	65.0	4	0.520
36	00050244	spring	Claiborne	115.0	4	0.602
36	00050244	fall	Claiborne	115.0	4	0.670
37	00043120	spring	Claiborne	150.0	4	0.575
37	00043120	fall	Claiborne	150.0	4	0.576
38	00015335	spring	Claiborne	265.0	4	0.124
38	00015335	fall	Claiborne	265.0	4	0.097
39	00035610	spring	Claiborne	250.0	4	0.214
39	00035610	fall	Claiborne	250.0	4	0.207
40	00061187	spring	Claiborne	21.0	36	1.100
40	00061187	fall	Claiborne	21.0	36	0.955
42	00045920	spring	Claiborne	200.0	4	0.028
42	00045920	fall	Claiborne	200.0	4	< 0.025
43	00040389	spring	McNairy	536.0	4	0.039
43	00040389	fall	McNairy	536.0	4	< 0.025
44	00000705	spring	Claiborne	94.0	4	1.990

Table 5. Spring and fall nitrate concentrations.						
Well Number	*AKGWA Number*	*Season*	*Unit*	*Well Depth (ft)*	*Well Diameter (in.)*	*Nitrate-N (mg/L)*
44	00000705	fall	Claiborne	94.0	4	1.980
45	00061181	spring	Continental Gravel	60.0	6	12.300
45	00061181	fall	Continental Gravel	60.0	6	15.100
46	00004375	spring	Claiborne	180.0	4	0.976
46	00004375	fall	Claiborne	180.0	4	0.968
47	00036379	spring	Claiborne	148.0	4	0.868
47	00036379	fall	Claiborne	148.0	4	0.811
48	00045936	spring	McNairy	280.0	4	< 0.025
48	00045936	fall	McNairy	280.0	4	< 0.025
49	00045405	spring	Continental Gravel	38.0	24	1.060
49	00045405	fall	Continental Gravel	38.0	24	1.180
50	00059631	spring	Claiborne	165.0	4	1.660
50	00059631	fall	Claiborne	165.0	4	1.560
51	00012674	spring	alluvium gravel	36.0	6	3.200
51	00012674	fall	alluvium gravel	36.0	6	2.820
52	00034315	spring	Claiborne	170.0	4	1.460
52	00034315	fall	Claiborne	170.0	4	1.510
53	00057470	spring	Claiborne	220.0	4	0.125
53	00057470	fall	Claiborne	220.0	4	0.112
54	00062164	spring	Claiborne	200.0	4	0.550
54	00062164	fall	Claiborne	200.0	4	0.518
55	00062168	spring	Claiborne	130.0	4	1.600
55	00062168	fall	Claiborne	130.0	4	1.670
56	00003532	spring	Claiborne	94.0	24	1.190
56	00003532	fall	Claiborne	94.0	24	1.160
57	00055180	spring	Continental Gravel	80.0	4	19.200
57	00055180	fall	Continental Gravel	80.0	4	13.300
58	00061185	spring	Claiborne	95.0	4	2.320
58	00061185	fall	Claiborne	95.0	4	2.340
59	00061249	spring	Claiborne	210.0	4	0.389
59	00061249	fall	Claiborne	210.0	4	0.356
60	00051801	spring	Claiborne	75.0	4	0.941
60	00051801	fall	Claiborne	75.0	4	0.938

9 mg/L were found in Calloway County, whereas those with $\delta^{15}N$ values greater than 6 per mil and NO_3-N concentrations greater than 12 mg/L were found in Ballard County (Table 6, Fig. 14). Samples with $\delta^{15}N$ less than 6 per mil showed no trend with depth, whereas samples with $\delta^{15}N$ greater than 6 per mil showed an increase with depth (Fig. 15).

Orthophosphate-Phosphorus

Phosphorus is a common element in rocks and soils, and is generally present in uncontaminated water at low concentrations. Phosphorus is a component of sewage and fertilizers, and elevated concentrations can produce algal blooms and remove dissolved oxygen from lakes and streams. Phosphorus can occur in water in several chemi-

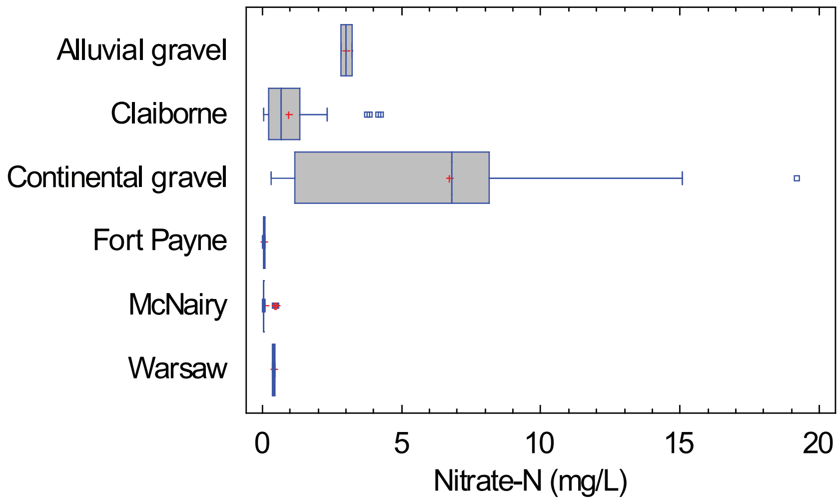

Figure 7. Nitrate concentrations grouped by hydrostratigraphic unit.

cal forms, the most common being orthophosphate (PO_4). Orthophosphate concentrations greater than 0.04 mg/L may cause eutrophication in surface waters (an influx of nutrients required for the growth of aquatic plants); however, there is no water-quality standard for orthophosphate in groundwater.

Orthophosphate was detected in 15 of 115 samples (Table 8), most commonly in groundwater from the Claiborne units (Fig. 16). Concentrations are generally low regardless of well depth (Fig. 17). The highest concentration (0.145 mg/L) was found in the McNairy Formation at a depth of 270 ft. There was no apparent correlation between orthophosphate concentrations and distance to row crops or distance to septic systems.

Metals

Total and dissolved concentrations of arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc generally ranged from low to below analytical detection limits (Table 9), with no systematic relation between concentration and hydrostratigraphic unit or depth. No sample approached maximum contaminant levels

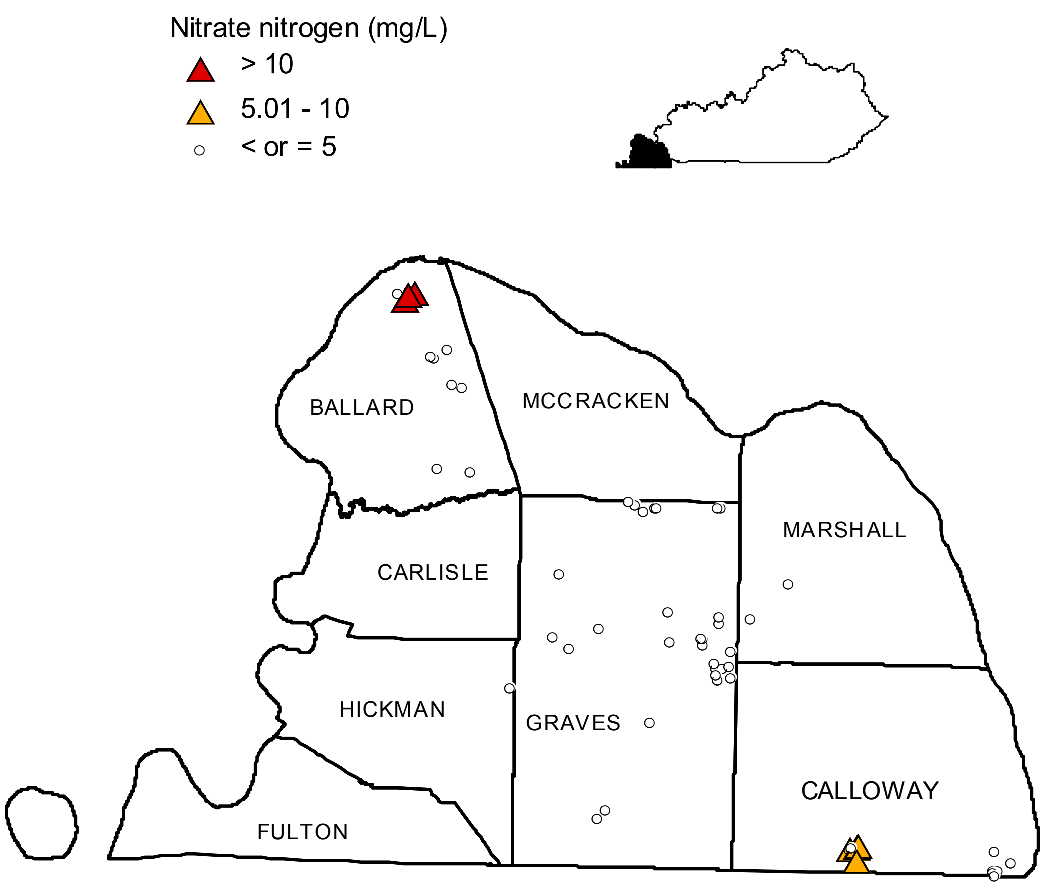

Figure 8. Well locations and ranges of nitrate concentrations.

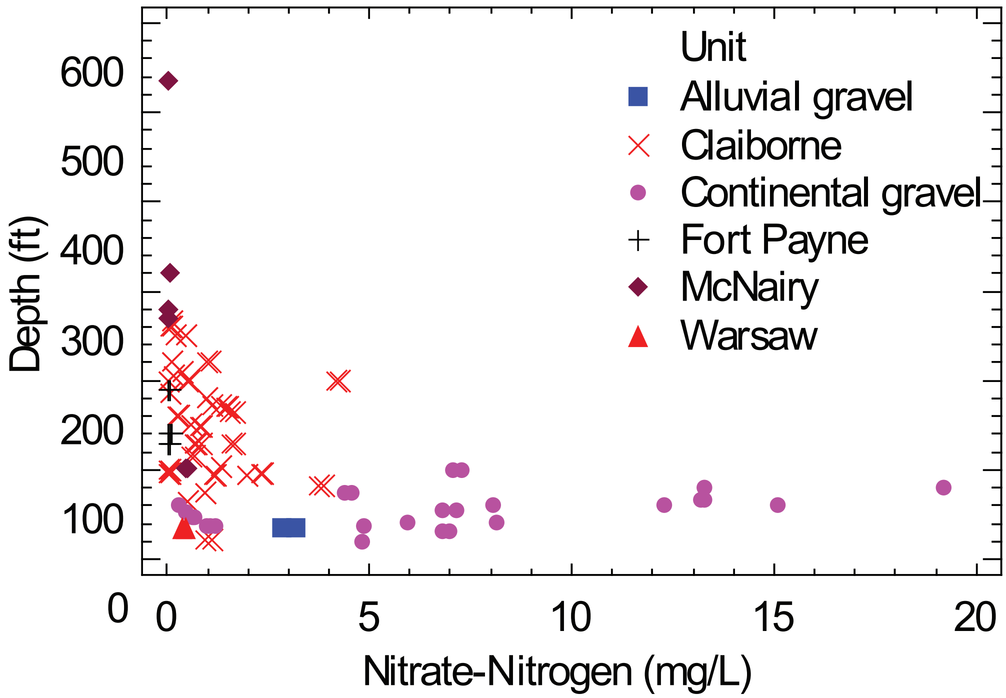

Figure 9. Nitrate concentrations versus depth.

for drinking water. Iron and manganese concentrations were such that they could cause aesthetic problems for domestic use but were within normal ranges for groundwater.

Pesticides

Pesticides are synthetic chemicals used to control weeds and insects on cultivated fields and urban landscapes. At high enough concentrations, pesticides can threaten the health of humans and animals. Because they do not occur naturally, any pesticides in groundwater means contaminants were transported from ground surface to the groundwater system.

Samples were collected and analyzed for alachlor, atrazine, cyanazine, glyphosate, metolachlor, and simazine in the spring, and were collected and analyzed for 2,4-D in both spring and fall. Concentrations generally ranged from low to below detection; no pesticide concentration approached EPA drinking-water standards. One or more pesticides were detected in 13 of the 60 wells, however (Table 10). Atrazine was found in nine wells, 2,4-D in five, metolachlor in three, alachlor in two, and simazine in two. Cyanazine and glyphosate were not detected.

Seven of the wells with detectable pesticide concentrations were completed in the Continental Gravel, compared to three in the Claiborne, two in the McNairy, and one in alluvium gravel (Table 10). Two wells (23 and 56) yielded detectable amounts of four pesticides. Both of these wells were 24-in. bored wells. Well 23 is 32 ft deep and completed in the Continental Gravel, whereas well 56 is 94 ft deep and completed in the Claiborne. Two other wells yielded detectable amounts of two pesticides: well 19 is a 4-in. drilled well completed

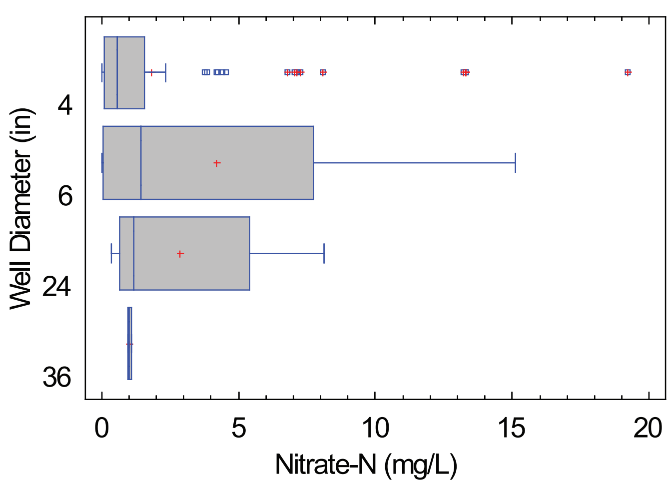

Figure 10. Nitrate concentrations grouped by well diameter. With with diameters of 4 and 6 in. are drilled, and wells of 24 and 36 in. are bored.

Table 6. Summary of nitrate concentrations (mg/L) grouped by hydrostratigraphic unit and well diameter.

Unit	*4 in.*	*6 in.*	*24 in.*	*36 in.*
alluvium gravel	none	2.820–3.200	none	none
Claiborne	0.023–4.240	none	1.160–1.190	0.955–1.100
Continental Gravel	0.296–19.200	12.300–15.100	0.472–8.130	none
Fort Payne	0.015–0.060	0.038–0.103	none	none
McNairy	0.011–0.490	none	none	none
Warsaw	none	none	0.355–0.465	none

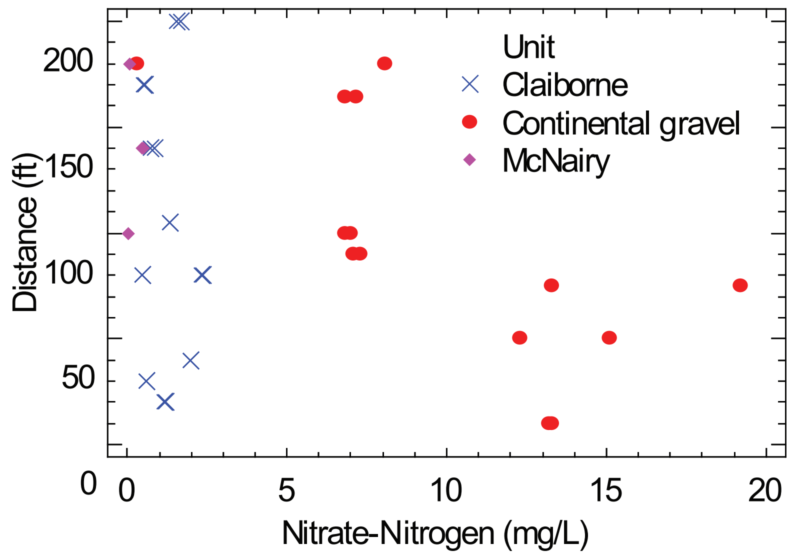

Figure 11. Nitrate concentration versus distance to row crops.

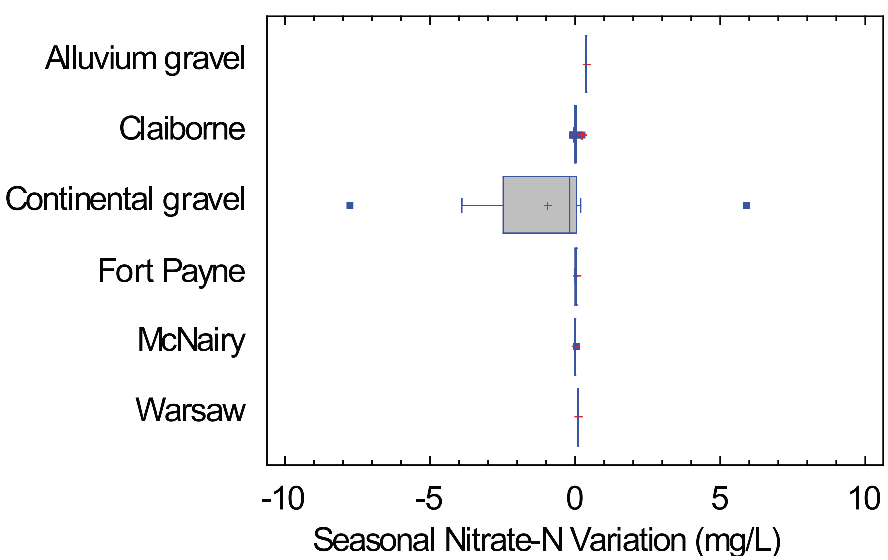

Figure 12. Seasonal variations in nitrate concentration grouped by hydrostratigraphic unit.

at 75 ft in the Continental Gravel and well 24 is a 4-in. drilled well completed at 100 ft in the Continental Gravel.

The highest pesticide concentrations were found in groundwater from the Continental Gravel (Fig. 18), in wells less than 100 ft deep (Fig. 19). Pesticides were detected in wells as deep as 320 ft, however, and throughout the region (Fig. 20). There was no correlation between pesticide concentration and distance to row crops or distance to septic systems. Bored and drilled wells had the same range of pesticide concentrations; however, pesticides were detected in

40 percent of bored wells (four detections out of 10 wells) versus 18 percent of drilled wells (nine detections out of 50 wells).

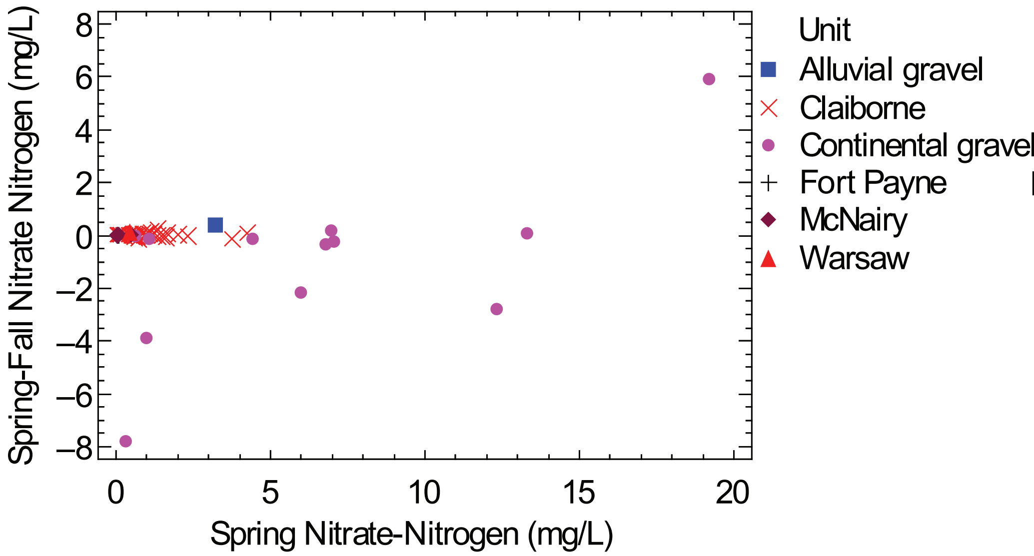

Figure 13. Seasonal variations in nitrate concentration versus spring concentration.

Volatile Organic Chemicals

Volatile organic chemicals are synthetic hydrocarbons used in manufacturing and are an important component of gasoline and other petroleum products. As with pesticides, the presence of volatile organic compounds in groundwater indicates contamination from human sources. The chemicals benzene, ethylbenzene, methyl-tert-butyl ether (MTBE), toluene, and total xylenes are the most commonly found volatile organic chemicals in surface- and groundwater systems, originating from fuel spills or leaking storage tanks.

Benzene, ethylbenzene, MTBE, toluene, and total xylenes were measured in 116 samples. One sample from a 140-ft-deep well in the Fort Payne (well 11) yielded groundwater with 0.000582 mg/L of toluene; no other groundwater samples had detectable concentrations of these volatile organic chemicals. This value is very close to the analytical detection limit of 0.0005 mg/L, and is suspect because no other volatile organic chemical was found in the sample.

Caffeine

Caffeine is a stimulant found in coffee, tea, soft drinks, some foods, and medicines. Because it is used in products intended for human consumption, it is a specific indicator of the presence of domestic waste or wastewater in groundwater. Caffeine was detected in 16 of 60 samples, ranging from 0.000048 to 0.000194 mg/L (Table 11).

Groundwater from the Claiborne (10 detections) and Continental Gravel (three detections) contained approximately equal concentrations of caffeine, whereas samples from the McNairy (three detections) had lower concentrations (Fig. 21). Most samples with detectable caffeine were from wells

Table 7. Nitrogen isotope composition of nitrate in selected samples.

Well Number	*AKGWA Number*	*County*	*NO_3-N (mg/L)*	*$\delta^{15}N$ (per mil)*
14	00061243	Calloway	8.13	5.7
15	00061244	Calloway	4.81	3.8
17	00001207	Calloway	7.14	4.6
19	00031287	Calloway	4.55	4.6
23	00042377	Calloway	6.80	5.1
24	00044344	Calloway	7.26	3.8
27	00045131	Ballard	13.20	9.2
45	00061181	Ballard	15.10	7.5
57	00055180	Ballard	13.30	12.6

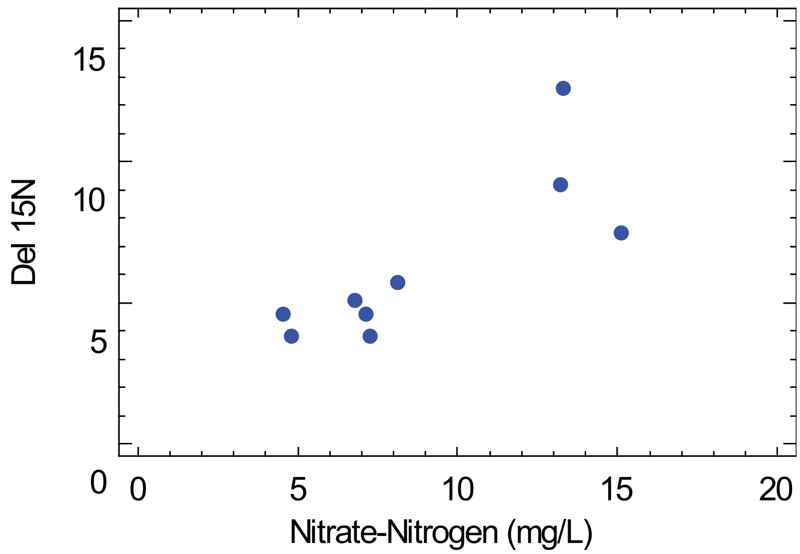

Figure 14. Nitrate concentration versus nitrogen isotopic composition. All samples were from the Continental gravel.

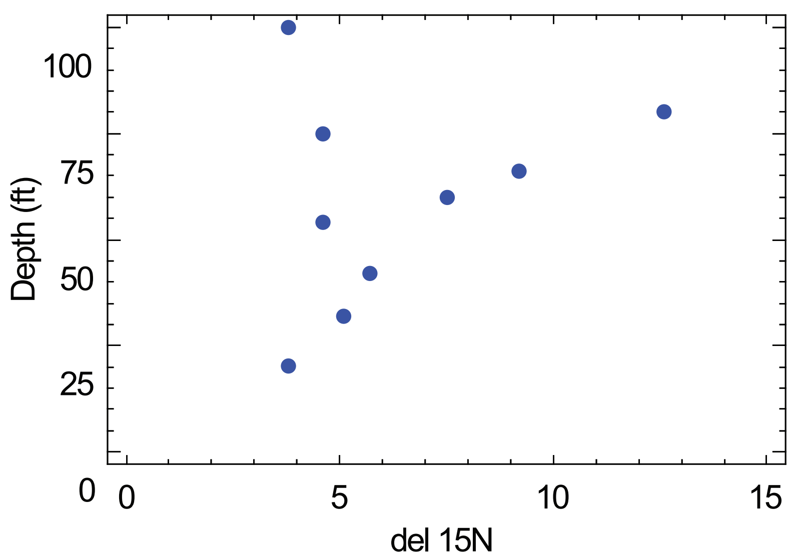

Figure 15. Nitrate isotope compositions plotted versus depth. All samples were from the Continental gravel.

less than 300 ft deep; however, one groundwater sample from a 356-ft-deep well contained caffeine (Fig. 22). Caffeine was detected in wells throughout the region (Fig. 23).

Bacteria

Coliform bacteria is a widely used indicator of waste contamination in water supplies because they occur in the intestines and feces of warm-blooded animals, including humans. Total coliform refers to a large group of bacteria, fecal coliform refers to a particular type of coliform that occurs in feces, and *E. coli* is a special subgroup of fecal coliform bacteria. Total coliform bacteria are more readily measured than fecal coliform and *E. coli,* so total coliform counts are used as an indicator of contamination. Although not likely to cause illness, total coliform bacteria indicate that other disease-causing pathogens may be present and that additional testing is needed. *E. coli* bacteria can cause illness, and if found in groundwater, fecal contamination has almost certainly occurred.

Sampling for bacteria presents special challenges because they can be present in the plumbing system that delivers groundwater, the well that collects groundwater, or in the aquifer itself. Simply finding bacteria in a groundwater sample does not distinguish which of these potential sources is contaminated. Confirming that the aquifer contains bacteria requires a two-step procedure. First, the well and all plumbing lines that supply water to the sample collection point must be thoroughly cleaned, disinfected, and flushed with fresh groundwater, and only then should the sample be taken, using sterile equipment and proper protocol. Such sampling was beyond the scope of this work; therefore, the presence of bacteria only indicates that they are somewhere in the system, not necessarily in the aquifer.

Samples for total coliform bacteria counts were collected from all wells in the fall. Twenty-nine of the 60 wells produced water with some total coliform bacteria present (Table 12). One sample, from well 15, a bored well completed in the Continental Gravel, had measurable *E. coli* bacteria. Total coliform bacteria were found approximately equally in samples collected from the Claiborne and Continental Gravel; smaller amounts were found in the McNairy and Warsaw (Fig. 24). Most bacteria-containing groundwater was produced from wells less than 300 ft deep; however, one water sample from a depth of 536 ft also contained bacteria (Fig. 25).

Table 8. Summary of orthophosphate concentrations (mg/L). Only values greater than analytical detection limits are shown.

Well Number	*AKGWA Number*	*Sample Date*	*PO_4-P (mg/L)*	*Depth (ft)*	*Well Diameter (in.)*	*Unit*
51	00012674	4/25/2005	0.033	36.0	6	alluvium gravel
8	00014369	5/2/2005	0.040	95.0	4	Claiborne
42	00045920	4/19/2005	0.074	200.0	4	Claiborne
42	00045920	9/13/2005	0.069	200.0	4	Claiborne
28	00051841	9/20/2005	0.013	200.0	4	Claiborne
58	00061185	4/25/2005	0.055	95.0	4	Claiborne
58	00061185	9/19/2005	0.035	95.0	4	Claiborne
54	00062164	4/25/2005	0.028	200.0	4	Claiborne
45	00061181	4/25/2005	0.034	60.0	6	Continental Gravel
15	00061244	5/2/2005	0.033	20.3	24	Continental Gravel
17	00001201	5/10/2005	0.034	141.0	6	Fort Payne
17	00001201	10/4/2005	0.029	141.0	6	Fort Payne
3	00057508	4/25/2005	0.145	270.0	4	McNairy
3	00057508	9/19/2005	0.050	270.0	4	McNairy
26	00061189	5/2/2005	0.030	280.0	4	McNairy

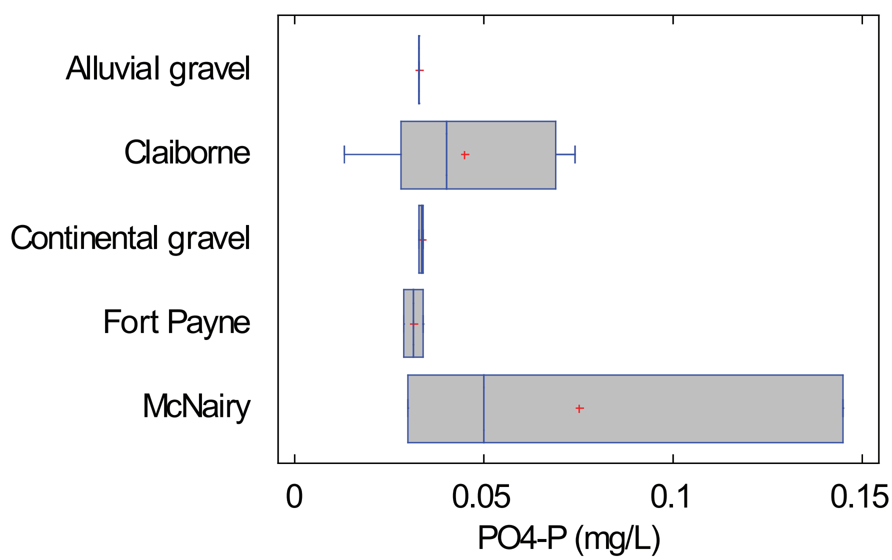

Figure 16. Orthophosphate concentrations grouped by hydrostratigraphic unit.

The highest total coliform counts were found in wells less than 100 ft from septic systems (Fig. 26) and at locations throughout the region (Fig. 27).

Because large-diameter bored wells are used to store water for peak use, they might be more likely to have bacteria than smaller-diameter drilled wells, where water has a shorter residence time. All bored wells had detectable total coliform bacteria, and four of the nine bored wells (44 percent) had counts of more than 200.5, the maximum measurable value. Only 20 of 49 drilled wells (41 percent) had detectable bacteria, and four of 49 drilled wells (8 percent) had counts of more than 200.5 per 100 ml (Fig. 28).

Conclusions

The major-ion chemistry of all water samples is normal for the hydrogeologic setting and climate of the Jackson Purchase Region. Salinity is generally low, water types are variable, and pH values are within normal ranges expected for relatively fresh groundwater in mixed carbonate/siliciclastic aquifers. Concentrations of phosphate, metals, and volatile organic compounds are within natural ranges and do not pose a health threat or signify significant contamination of the groundwater. High nitrate concentrations and detectable amounts of pesticides, caffeine, and bacteria are present throughout the region, however.

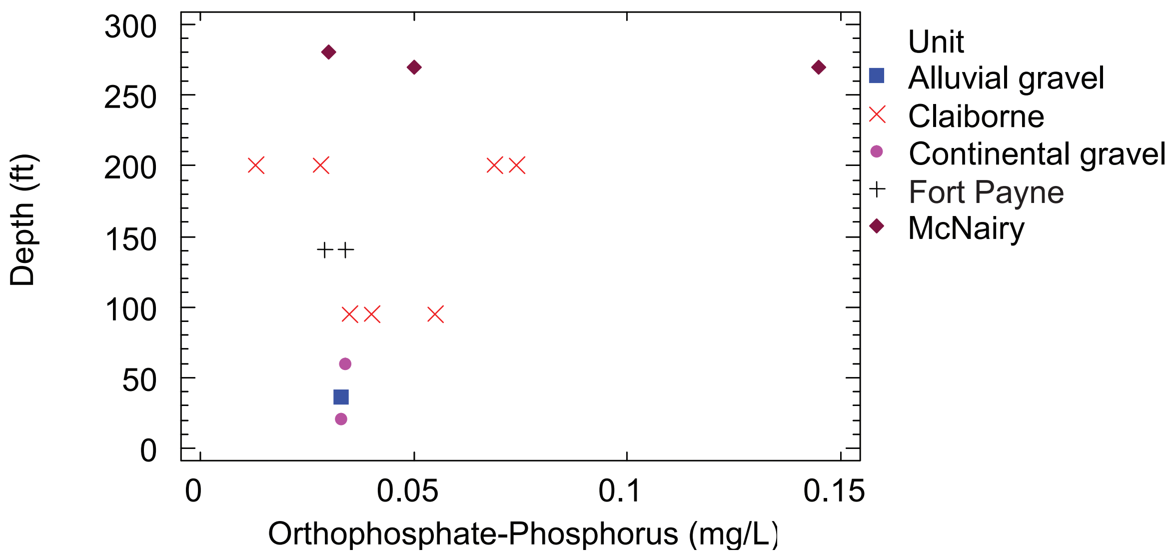

Figure 17. Orthophosphate concentration versus well depth.

Table 9. Summary of maximum metals concentrations. NA=does not apply.

Element	*Number of Samples*	*Number of Detections*	*Maximum Concentration (mg/L)*	*MCL (mg/L)*	*Unit with Maximum Concentration*
arsenic	241	31	0.000966	0.010	McNairy
barium	241	241	0.000354	2.0	Claiborne
cadmium	241	0	< 0.000800	0.005	NA
chromium	241	40	0.008920	0.1	Claiborne
copper	241	240	0.332000	none	Claiborne
iron	241	36	11.500000	none	McNairy
lead	241	127	0.022600	none	Claiborne
manganese	241	151	0.265000	none	McNairy
mercury	120	3	0.000069	0.002	Continental Gravel
nickel	241	126	0.015200	none	Claiborne
selenium	241	48	0.003100	0.05	Continental Gravel
silver	241	4	0.001980	none	McNairy
zinc	241	11	0.453000	none	Fort Payne

Nitrate-Nitrogen

Nitrate concentrations are greater than expected in many cases: 27 of the 116 samples had concentrations greater than 2 mg/L, 15 had concentrations greater than 5 mg/L, and six had concentrations greater than the maximum contaminant level of 10 mg/L. All samples with concentrations more than 5 mg/L are from shallow groundwaters from the Continental Gravel hydrostratigraphic unit. Not all shallow Continental Gravel samples have high nitrate concentrations, however, nor do nearby wells in other units have nitrate concentrations as high.

Groundwaters with nitrate concentrations greater than 10 mg/L (wells 27, 45, and 57) are shallow (less than 80 ft deep) drilled wells that produce water from the Continental Gravel and are less than 75 ft from row crops. These similarities suggest that fertilizer is the nitrogen source and nitrate concentrations are high because of the shallow depth of the hydrostratigraphic unit, permeability of the unit, and proximity to fertilized crops. These

Table 10. Summary of pesticide concentrations. Only values greater than analytical detection limits are listed.						
Map Number	*AKGWA Number*	*Pesticide*	*Concentration (mg/L)*	*Depth (ft)*	*Diameter (in.)*	*Unit*
9	00001207	atrazine	0.0006560	54	4	Continental Gravel
13	00004334	atrazine	0.0000556	101	4	McNairy
14	00061243	atrazine	0.0001420	42	24	Continental Gravel
19	00031287	atrazine	0.0006330	75	4	Continental Gravel
19	00031287	metolachlor	0.0002280	75	4	Continental Gravel
23	00042377	2,4-D	0.0000553	32	24	Continental Gravel
23	00042377	alachlor	0.0000262	32	24	Continental Gravel
23	00042377	atrazine	0.0004470	32	24	Continental Gravel
23	00042377	metolachlor	0.0006940	32	24	Continental Gravel
24	00044344	atrazine	0.0007950	100	4	Continental Gravel
24	00044344	simazine	0.0000330	100	4	Continental Gravel
25	00042386	atrazine	0.0003280	37	24	Continental Gravel
27	00045131	2,4-D	0.0000892	66	4	Continental Gravel
33	00028287	2,4-D	0.0000448	320	4	McNairy
34	00045890	atrazine	0.0001020	83	4	Claiborne
39	00035610	2,4-D	0.0000832	250	4	Claiborne
51	00012674	2,4-D	0.0000801	36	6	alluvium gravel
56	00003532	alachlor	0.0000884	94	24	Claiborne
56	00003532	atrazine	0.0001400	94	24	Claiborne
56	00003532	metolachlor	0.0000774	94	24	Claiborne
56	00003532	simazine	0.0001730	94	24	Claiborne

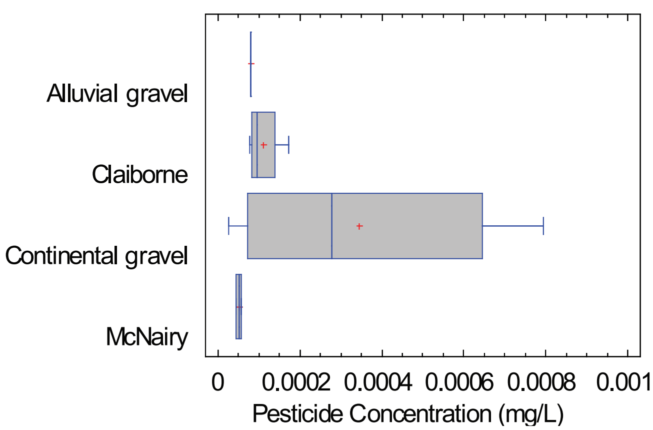

Figure 18. Summary of pesticide concentrations grouped by hydrostratigraphic unit. All pesticides are included; however, only values greater than analytical detection limits are shown.

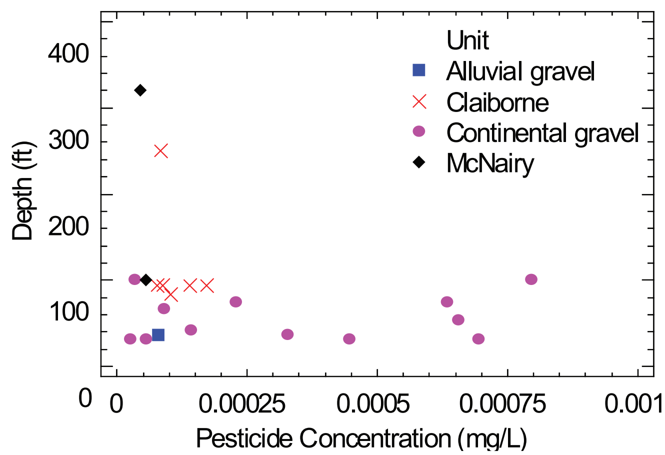

Figure 19. Detected pesticide concentration versus well depth.

samples have enriched nitrogen isotope compositions relative to fertilizer and trend of increasing $\delta^{15}N$ with depth, suggesting that denitrification has occurred as nitrate is transported from fields to the sampled interval.

Samples with 5 to 10 mg/L of nitrate (wells 9, 14, 20, 23, and 24) are from drilled or bored wells that produce water from the Continental Gravel and are less than 100 ft deep; also, four of the five wells are less than 180 ft from row crops. As above,

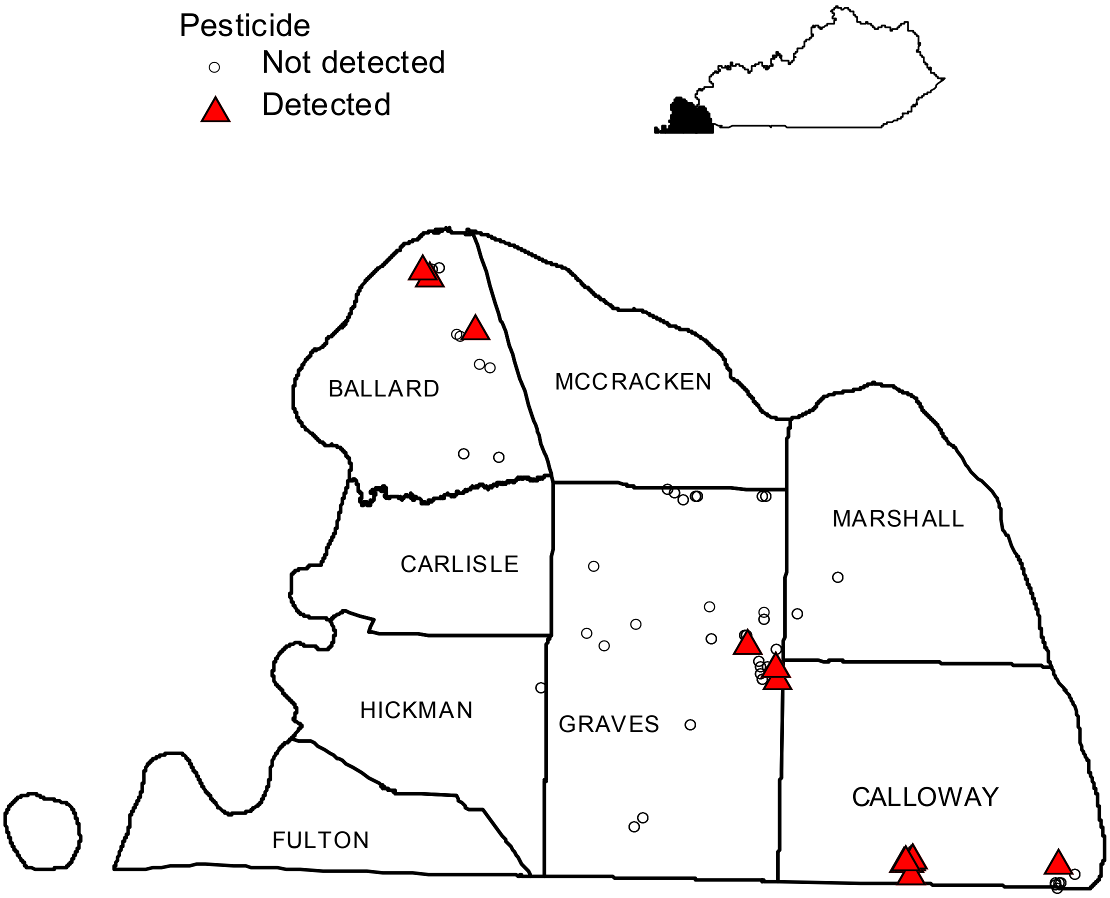

Figure 20. Well locations and sites where pesticides were detected.

Table 11. Summary of maximum caffeine concentrations.

Well Number	*AKGWA Number*	*Caffeine (mg/L)*	*Well Diameter (in.)*	*Well Depth (ft)*	*Unit*
6	61190	0.0000876	4	160	Claiborne
31	30068	0.0000726	4	130	Claiborne
37	43120	0.0001540	4	150	Claiborne
38	15335	0.0001010	4	265	Claiborne
40	61187	0.0000897	36	21	Claiborne
40	61187	0.0001940	36	21	Claiborne
47	36379	0.0001420	4	148	Claiborne
50	59631	0.0000976	4	165	Claiborne
52	34315	0.0000557	4	170	Claiborne
53	57470	0.0000493	4	220	Claiborne
12	51482	0.0000488	24	52	Continental Gravel
25	42386	0.0000639	24	37	Continental Gravel
27	45131	0.0000480	4	80	Continental Gravel
3	57508	0.0000544	4	270	McNairy
26	61189	0.0001400	4	280	McNairy
43	40389	0.0000488	4	536	McNairy

these shared properties suggest that fertilizer is the nitrogen source, and that nitrate is found because of the shallow depth and permeability of the hydrostratigraphic unit. These wells are farther from row crops than the group of wells with nitrate concentrations higher than 10 mg/L, accounting for the more moderate concentrations. Nitrogen isotope signatures are somewhat enriched relative to the value expected for fertilized, suggesting denitrification has occurred.

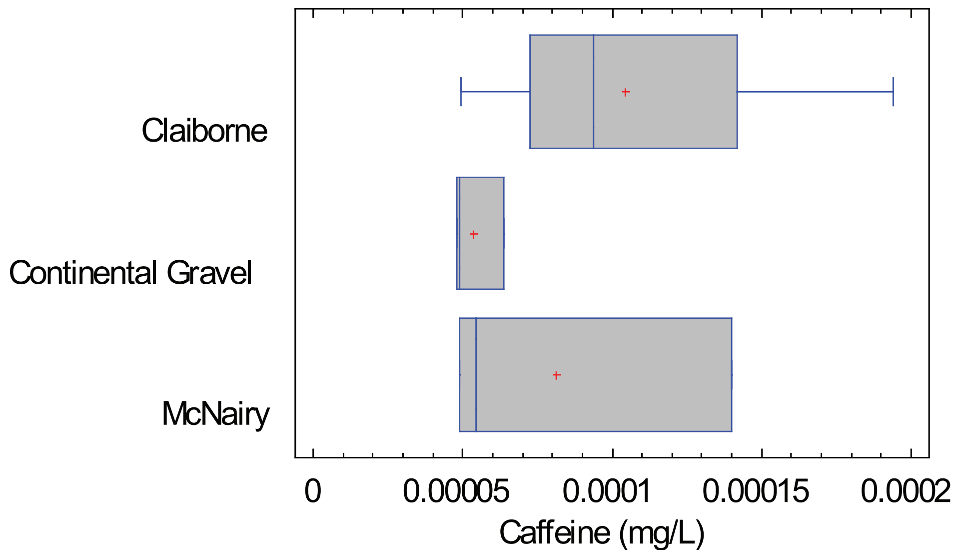

Figure 21. Summary of caffeine concentrations grouped by hydrostratigraphic unit. Only values greater than analytical detection limits are shown.

Seasonal variations in nitrate concentrations are generally near zero for most wells. Only samples from the Continental Gravel showed seasonal variations greater than 1 mg/L. In four cases the seasonal variation (spring concentration minus fall concentration) was less than 1 mg/L, and in one case the variation was greater than 1 mg/L. Because fertilizer is applied to crops in the spring, groundwater sampled in the spring would be expected to have higher nitrate concentrations than groundwater sampled in the fall. Cases where fall concentrations exceed spring concentrations are interpreted as showing a travel-time lag from surface application to groundwater sample point.

Most of the wells that produce high-nitrate groundwater are drilled, rather than bored. This is attributed to the distribution of drilled versus bored wells in the sample area rather than to differences in well integrity. Groundwater most prone to high nitrate concentrations (found in shallow wells in the Continental Gravel near row crops) was sampled from drilled wells; bored wells in the Continental Gravel (wells 12,

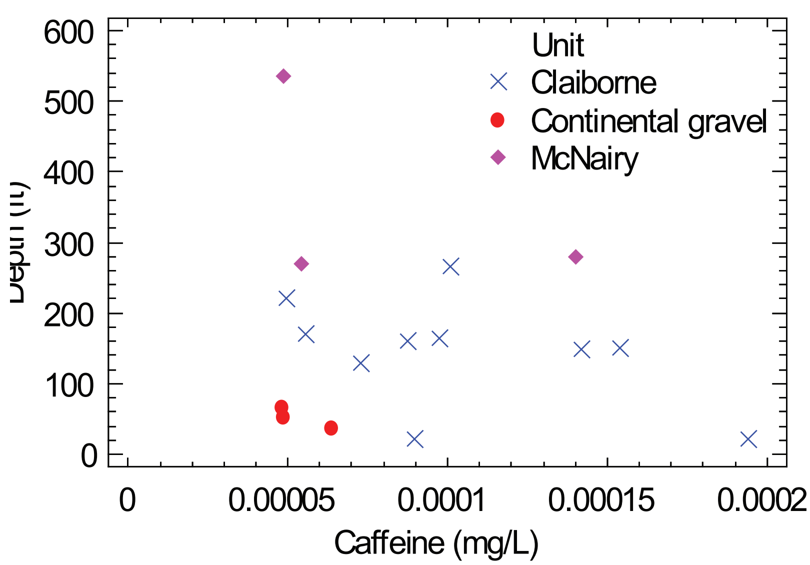

Figure 22. Detected caffeine concentrations versus well depth.

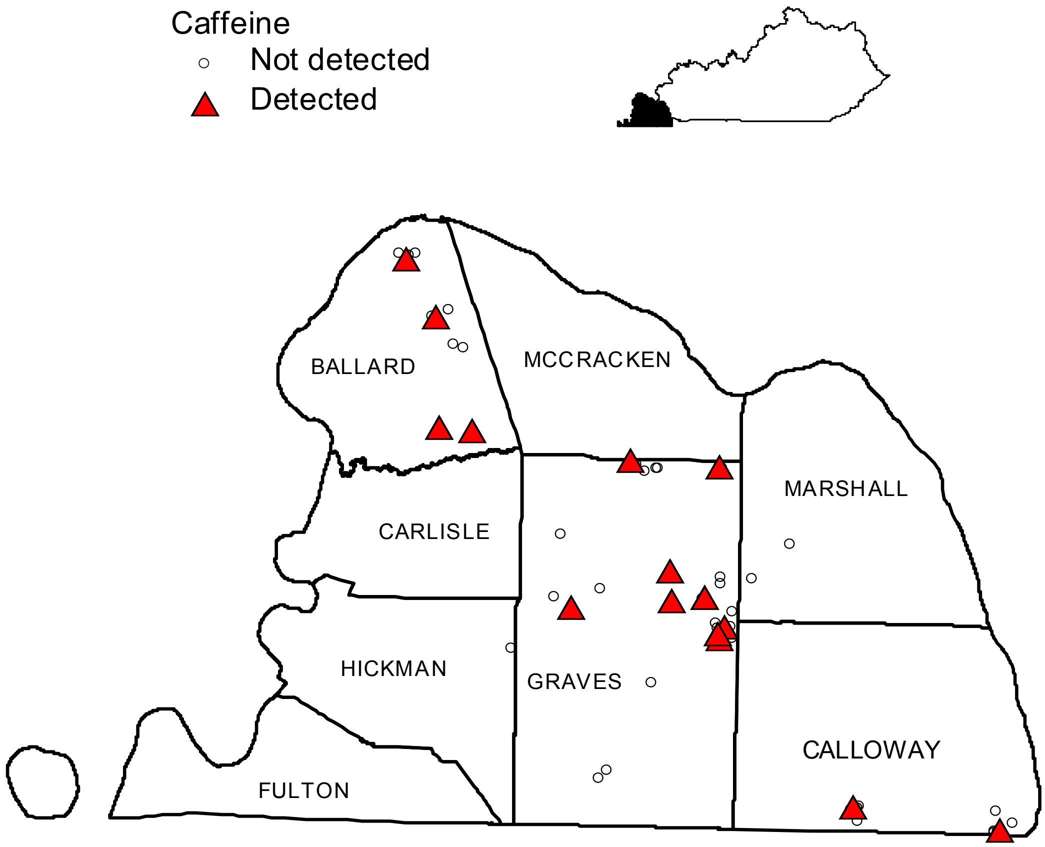

Figure 23. Well locations and sites where caffeine was detected.

15, 21, and 49) are all more than 200 ft from the nearest row crops.

Not all wells producing from the Continental Gravel have high nitrate concentrations, indicating that contamination does not extend throughout the entire hydrostratigraphic unit. Apparently, the denitrification and sorption on aquifer materials restrict transport of nitrate throughout the unit. This study does not indicate that proximity to feedlots or septic systems affects nitrate concentrations.

Pesticides

Pesticides were found at low concentrations in 13 wells located throughout the Jackson Purchase. They were detected in both drilled and bored wells. Water from the Continental Gravel most commonly contained detectable amounts of pesticides, predominantly atrazine. Most of the pesticide detections occurred in wells less than 100 ft deep, although groundwater from depths of 250 ft (well 39 in the Claiborne) and 320 ft (well 33 in the McNairy) also contained pesticides. There was no correlation between pesticide detection and distance to either row crops or septic systems.

Caffeine

Caffeine was present in 16 of the 60 wells sampled. It was found most commonly in the Claiborne and Continental Gravel, less frequently in the McNairy, in all well types, and without preference for any particular geographic location. Caffeine was found most commonly in wells less than 300 ft deep, although one sample from 536 ft contained the stimulant. No relation was found between caffeine and distance to row crops or septic systems.

Bacteria

Total coliform bacteria were found in 29 of 60 wells located throughout the Jackson Purchase, in both drilled and bored wells, and in all hydrostratigraphic units except the alluvium gravel. Bacteria were found mostly in wells less than 300 ft deep, although one sample from 536 ft had detectable total coliform bacteria. There was no relation between

Table 12. Summary of samples that contained total coliform bacteria.

Well Number	*AKGWA Number*	*Total Coliform (Counts per 100 ml)*	E. coli	*Depth (ft)*	*Diameter (in.)*	*Unit*
1	2553	> 200.5	0	130	4	Claiborne
3	57508	144.5	0	270	4	McNairy
5	61241	12.4	0	172	4	Claiborne
14	61243	> 200.5	0	42	24	Continental Gravel
15	61244	56.0	2	20	24	Continental Gravel
16	51481	8.7	0	35	24	Warsaw
19	31287	50.4	0	75	4	Continental Gravel
20	20717	94.5	0	60	4	Continental Gravel
21	51475	45.3	0	47	24	Continental Gravel
22	48761	5.3	0	260	4	Claiborne
23	42377	47.8	0	32	24	Continental Gravel
25	42386	> 200.5	0	37	24	Continental Gravel
28	51841	34.4	0	200	4	Claiborne
31	30068	129.8	0	130	4	Claiborne
32	61245	73.8	0	205	4	Claiborne
34	45890	101.3	0	83	4	Claiborne
35	30806	> 200.5	0	65	4	Claiborne
40	61187	> 200.5	0	21	36	Claiborne
41	53989	69.7	0	170	4	Claiborne
43	40389	3.1	0	536	4	McNairy
45	61181	7.5	0	60	6	Continental Gravel
46	4375	> 200.5	0	180	4	Claiborne
47	36379	36.4	0	148	4	Claiborne
48	45936	7.5	0	280	4	McNairy
49	45405	> 200.5	0	38	24	Continental Gravel
52	34315	165.5	0	170	4	Claiborne
53	57470	7.5	0	220	4	Claiborne
56	3532	165.2	0	94	24	Claiborne
57	55180	> 200.5	0	80	4	Continental Gravel

total coliform bacteria and distance to row crops. The highest counts were found in wells within 100 ft of known septic systems, however. One sample from a 20-ft-deep bored well in the Continental Gravel contained *E. coli*.

Summary

Unnaturally high nitrate concentrations and detectable amounts of pesticides, caffeine, and bacteria were found in groundwater throughout the Jackson Purchase Region. In some cases, nitrate levels were high enough to pose health hazards.

High nitrate occurred in wells in the Continental Gravel that are near row crops. The combination of relatively high permeability and shallow depth of the gravel and proximity to fields where fertilizers were used allowed nitrate to reach the screened intervals of these wells. Whether a well was drilled or bored was not a major factor in high nitrate concentrations. Because of its high permeability and shallow depth, the Continental Gravel was highly susceptible to nonpoint-source contamination; therefore, special management practices

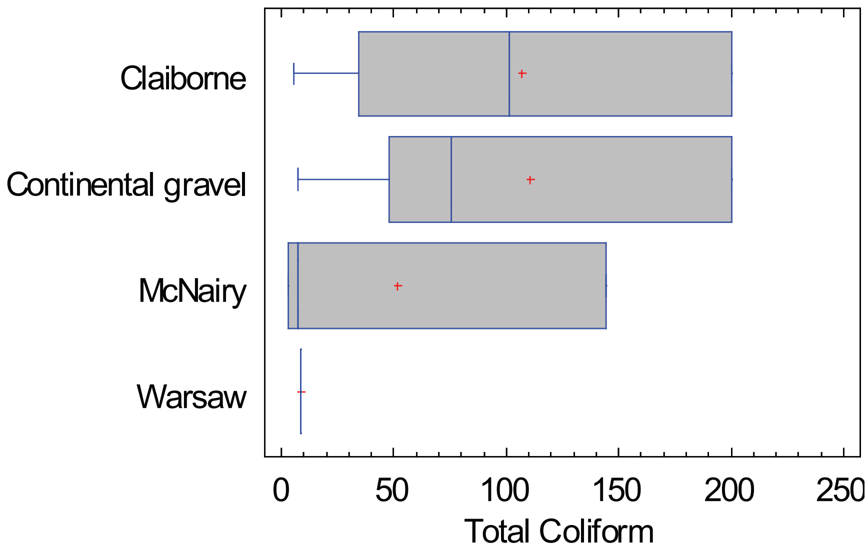

Figure 24. Summary of detected total coliform bacteria counts grouped by hydrostratigraphic unit.

are needed to protect groundwater quality in this unit.

Pesticides and caffeine in groundwater do not pose an immediate health threat and do not restrict water use; however, their presence indicates that human activity is affecting the groundwater system. These chemicals were most commonly found in the Continental Gravel, but also in other units. They were more commonly found in shallow wells, regardless of well type. No direct relation was found between presence of these chemicals and proximity to crops or septic systems, probably because the chemicals are mobile in groundwater systems and can be transported long distances. The occurrence of detectible amounts of pesticides in groundwater results from the widespread use of these chemicals in both agricultural and urban environments and the mobility of the chemicals. The widespread detection of caffeine results from leaking or improperly designed on-site wastewater disposal systems.

Total coliform bacteria were widely found in all types of wells and from all hydrostratigraphic units. Wells less than 250 ft deep, those within 100 ft of known septic systems, and bored wells were most likely to have bacteria. The sampling methods used in this study were not adequate to determine whether bacteria reside in the regional aquifer system or in the local well and water-delivery system. Well owners are urged to have their water supplies tested for bacteria periodically and to follow recommended procedures for decontaminating private wells (Beck and Henken, 2004) to ensure safe drinking water.

The presence of nonpoint-source contaminants demonstrates that Jackson Purchase groundwater quality has been degraded and that more effective land-management practices are needed to prevent further impacts. The most likely causes of regional groundwater degradation are the overuse or untimely use of pesticides and fertilizers in both agricultural and domestic settings and improper construction or poor maintenance of septic systems.

Well integrity is very likely a factor in groundwater contamination in some cases. Previous studies (Beck and others, 2005a, b) have shown that damaged wells and those with faulty annulus seals allow contaminants to leak into a well and possibly into the regional aquifer. Bored wells, which have large annulus volumes and potentially impaired annular seals, are

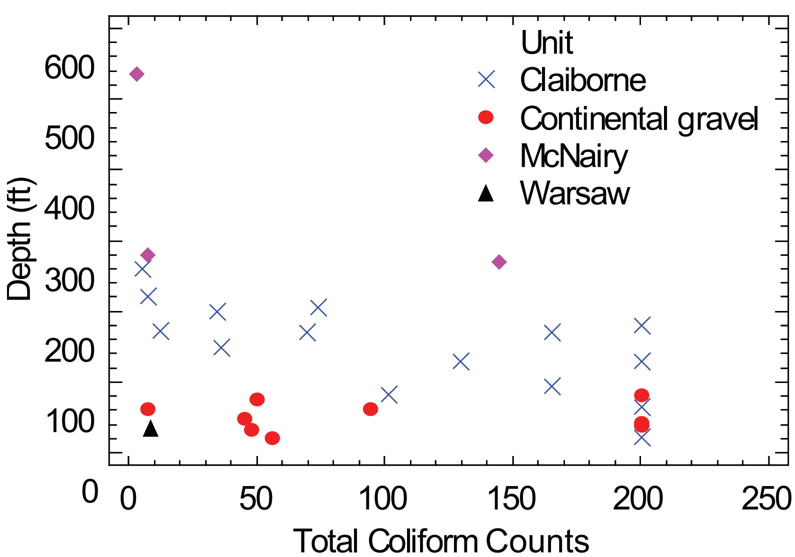

Figure 25. Detected total coliform bacteria counts versus well depth. Counts reported as greater than 200.5 per 100 ml are plotted at 200.5.

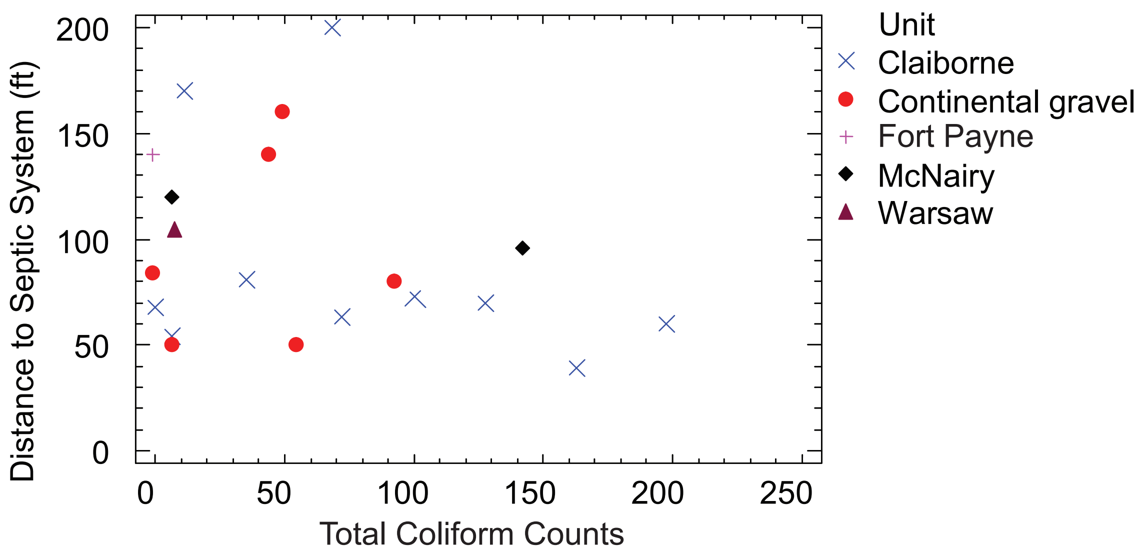

Figure 26. Detected total coliform counts versus distance to septic system. Counts reported as greater than 200.5 per 100 ml are plotted at 200.5.

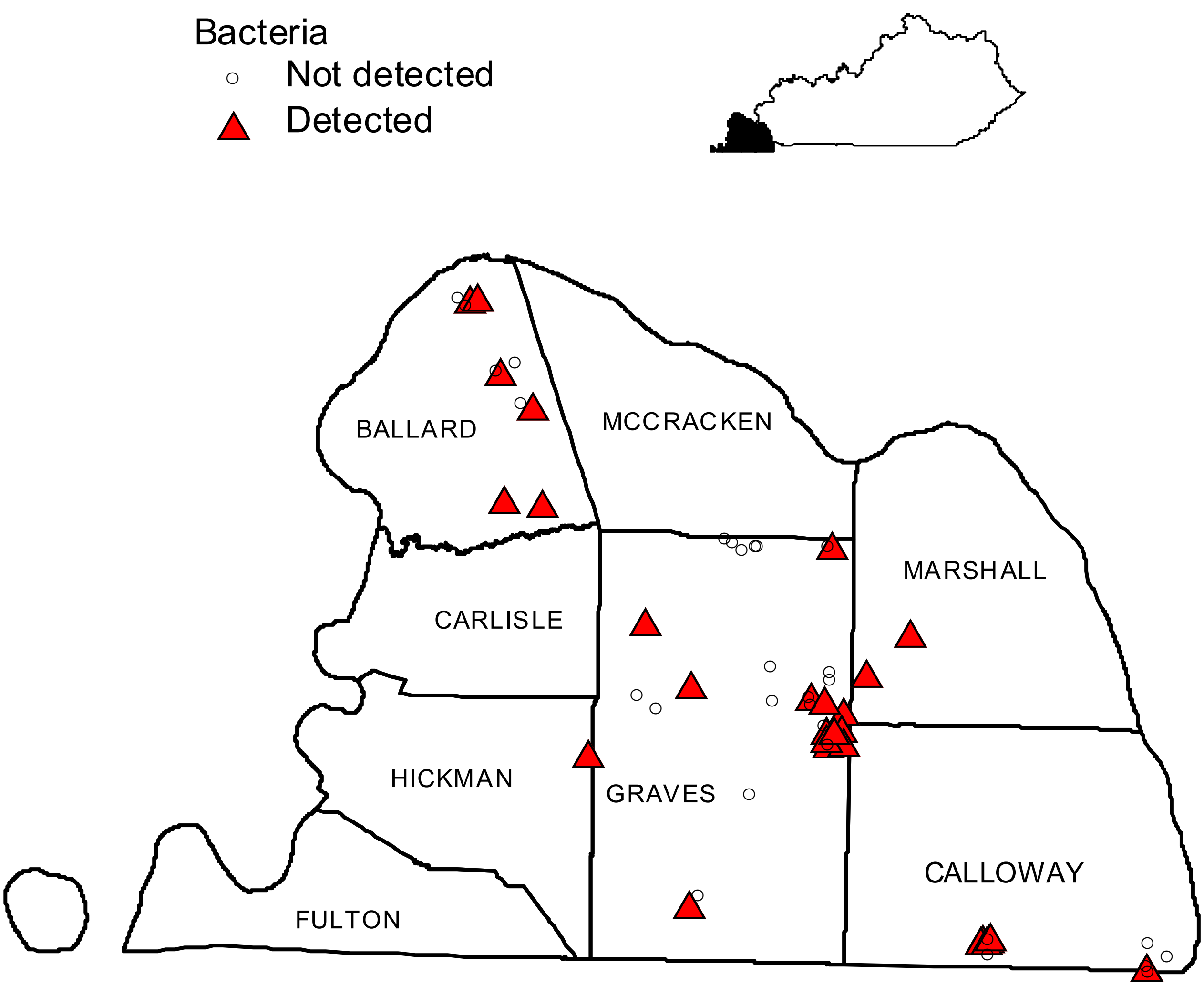

Figure 27. Well locations and sites where total coliform bacteria were detected.

particularly susceptible to such leakage. Whether water in the domestic plumbing system, wellbore, or regional aquifer is affected by nonpoint-source chemicals and bacteria can best be determined by drilling monitoring wells near contaminated wells and testing the water under strict sampling protocols.

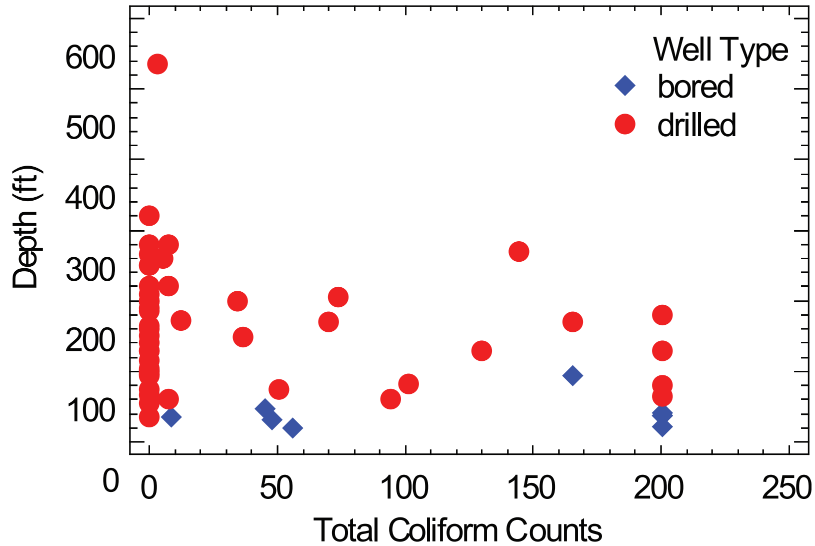

Figure 28. Total coliform counts versus depth and grouped by well type. Counts reported as greater than 200.5 per 100 ml are plotted at 200.5.

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