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Assessment of Row Crop, Alfalfa, and Pasture Field Practices on Groundwater Quality in an Upland Bedrock Setting, Henderson County, Kentucky: Report of Soil- and Water-Quality Data

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Abstract

An assessment of how present agricultural practices have influenced shallow groundwater and soil quality was conducted on a 540-acre farm in north-central Henderson County. Groundwater- and soil-quality data were collected from row crop (corn and soybean), alfalfa, and pasture fields. In addition to the field settings, groundwater and soil data were collected from the existing farmyard and an abandoned feedlot. Groundwater samples were analyzed for pH, specific conductance, temperature, oxidation-reduction potential, metals, anions, nutrients, herbicides, and various isotopes. Soil samples were analyzed for pH, bioavailable phosphorus, potassium, calcium, magnesium, zinc, organic matter, total nitrogen, and inorganic nitrogen (nitrate-N). Soil- and groundwater-quality data are presented in the appendices.

Introduction

This report presents the results of quality analyses for surface-water, vadose-water, and groundwater samples collected from monitoring wells and seeps on a farm in an upland bedrock setting in the Western Kentucky Coal Field. It also contains rock- and soil-core data, monitoring-well construction details, precipitation data, and groundwater elevations. The upland bedrock setting (loess overlying bedrock) is one of the major hydrogeologic settings in the Western Kentucky Coal Field. Prior to this research, no comprehensive study of the transport and fate of agriculturally related chemicals had been done in this setting in Kentucky. Funding

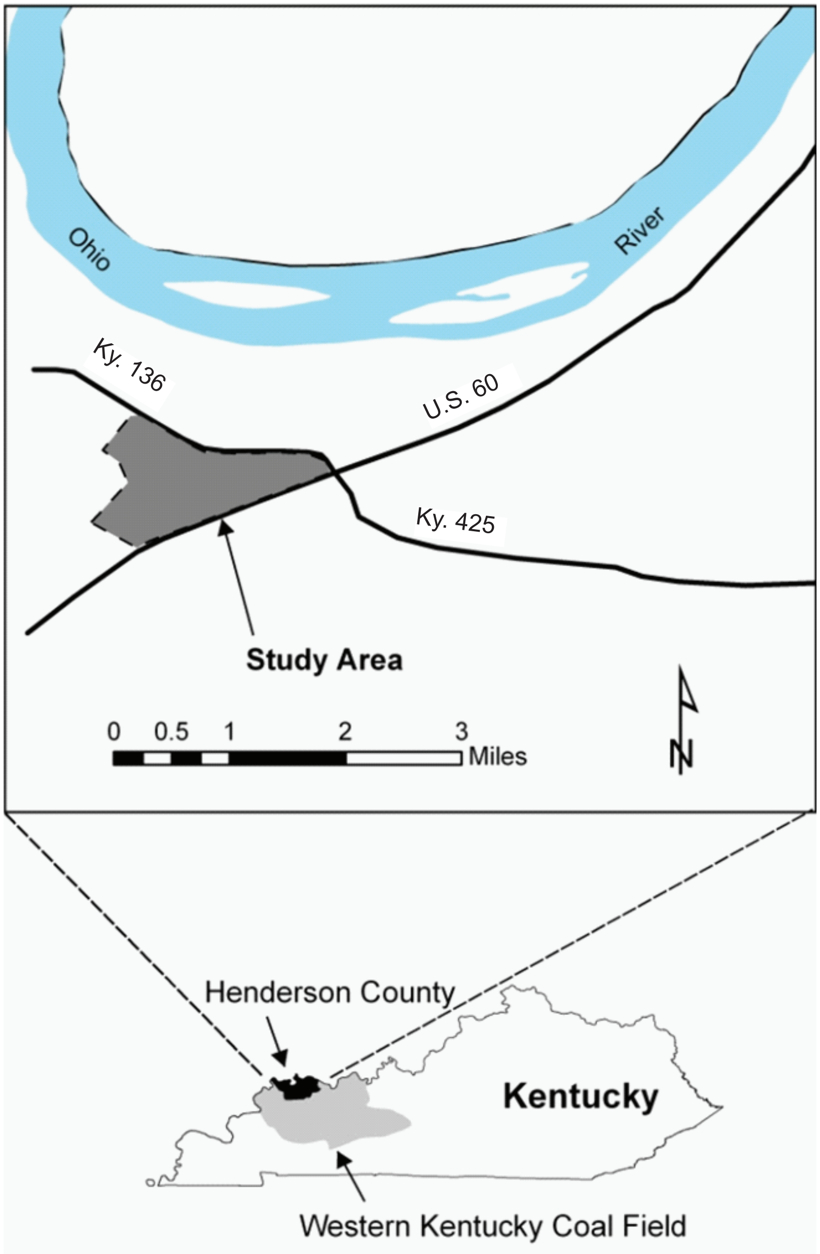

Figure 1. Location of the Keach farm in Henderson County, Ky.

for this research was provided in part by the University of Kentucky's College of Agriculture through the Senate Bill 271 Research and Education Program. Previous reports describing water-quality monitoring at this site were submitted to the UK College of Agriculture. This report covers work completed during phase I (1995–2002). Work completed during phases II (1998–2001) and III (2002–present) is presented in Beck and others (in press a, b), respectively. The dates for the phases overlap because phase I continued while phases II and III were implemented.

Study Site

The study area is a 540-acre farm (referred to as the Keach farm) located in north-central Henderson County approximately 5 mi west of downtown Henderson (Fig. 1), in the Wilson 7.5-minute quadrangle (Johnson, 1973). The Keach farm is located in an upland bedrock setting in the Western Kentucky Coal Field with moderately thick loess (17 to 35 ft) of Pleistocene age overlying bedrock (shale and channel-fill sandstone) of Pennsylvanian age. Western Kentucky Coal Field upland bedrock settings are characterized by broad ridges with shallow, wide valleys. The two dominant loess-derived soil series are Memphis and Loring. Memphis soils are well drained, whereas Loring soils are well to moderately well drained and typically have a fragipan (layer of semiconsolidated soil particles that retard water infiltration between 26 and 42 in. below land surface (Converse and Cox, 1967).

Rock and Soil Core Descriptions

Prior to monitoring-well installation, eight split-spoon soil cores were collected from the soil surface through the loess until the core tubing was stopped by hard rock (bedrock refusal). The cores were taken in two groups. The first six were under agricultural fields, and the Memphis and Loring silt loams were represented. These two soils were sampled under each of three agricultural land uses (three different cropping patterns): corn (row-crop rotation), alfalfa (forage row-crop rotation), and long-term pasture (Fig. 2). The second group of two cores was taken in a long-abandoned dairy feedlot area and in the present-day farmyard area (Fig. 2). Both cores were located in a Memphis silt loam.

In addition to the eight soil cores, one rock core was collected, which extended through the loess and underlying channel-fill sandstone. The rock core was terminated once shale was encountered. Coordinates, surface elevation, depth to bedrock, and total depth of the soil and rock cores are presented in Table 1. Coordinates are in decimal degrees and based on the North American datum 1983 (NAD 83). Elevations are recorded as feet above sea level. The rock core description is presented in Table 2.

Soil Core Data

At the time of collection, soil cores were subdivided into 1-ft increments and placed in brown paper bags to be transported to a freezer, where the samples remained until analyzed. Samples were air-dried and crushed to pass a 2-mm sieve. The soil cores were analyzed in two laboratories. Particle size (silt, clay, and sand) and inorganic nitrogen (ammonium and nitrate) were analyzed in the Chemical and Physical Edaphology Laboratory of the University of Kentucky Department of Plant and Soil Sciences. All other soil analyses (pH, bioavailable phosphorus, potassium, calcium, magnesium, zinc, organic matter, total nitrogen) were conducted in the University of Kentucky Regulatory Services Laboratory. All laboratory analyses were performed in accordance with analytical methods widely accepted in the literature. Table 3 lists the analyses performed and methods used.

Particle-size data for the eight soil cores are listed in Appendix A. When possible, particle size and chemical analysis were determined for 1-ft intervals of core. Missing intervals indicate that soil samples were not collected because of inadequate sample volume or cross contamination occurred during the coring process. Appendix B contains all of the chemical data related to the eight soil cores. Organic matter was calculated as percentage of carbon multiplied by 1.72, which gives the percentage of organic matter of the soil sample. Total nitrogen is presented as lb/acre.

Well and Seep Descriptions

Water-quality data were collected from 25 wells. Twenty-one of them are monitoring wells installed by a Kentucky certified monitoring-well driller according to Kentucky monitoring-well regulations (Kentucky Department of Environmental Protection, 1991). The remaining four wells (DW01, DW02, DW03, and DW04) are domestic water wells that existed prior to this research. Twenty of the monitoring wells were installed in three agricultural field settings (corn, alfalfa, and pasture) at various depths, and one monitoring well (DW05) was installed in the center of the present-day farmyard (Fig. 3). Wells DW03 and DW04 are located on the present-day farmyard, whereas wells DW01 and DW02 are located on an abandoned farmyard (Fig. 3).

In each of the corn and pasture settings, a nest of four wells was installed in a Loring soil and a Memphis soil. For the alfalfa field, because of budget constraints, a well nest was installed in a Loring soil only. Each nest contained a well installed in four distinct hydrogeologic zones: root zone, paleosol, bedrock surface, and bedrock aquifer. Monitoring well DW05 was installed in the bedrock aquifer. With the exception of well DW05, all

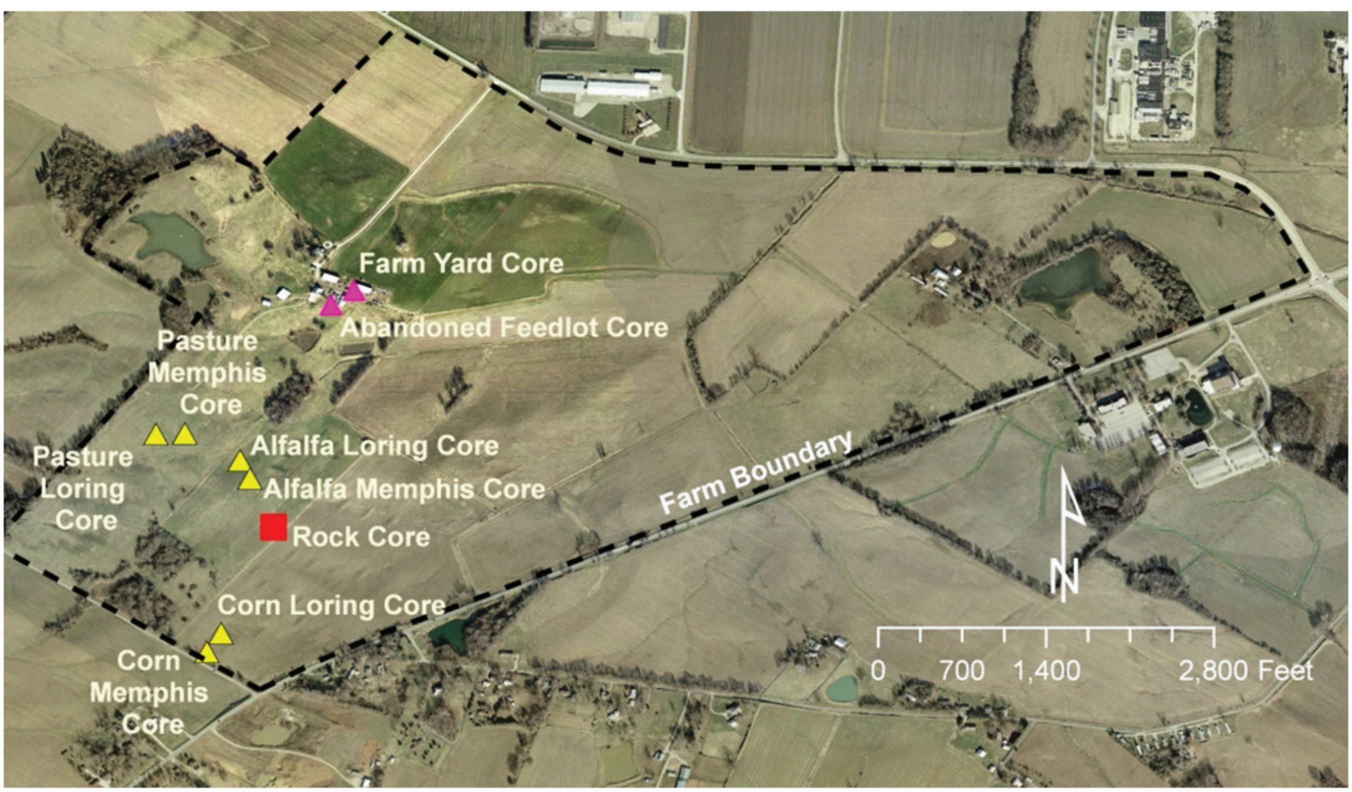

Figure 2. Locations of rock and soil cores at the Keach farm.

Table 1. Coordinates, surface elevation, depth to bedrock, and total depth of Keach farm soil and rock cores.

Core	*Latitude*	*Longitude*	*Elevation (ft above sea level)*	*Depth to Bedrock (ft)*	*Total Depth (ft)*
Corn Memphis	37.791442	–87.673264	443.4	25.0	27.25
Corn Loring	37.791867	–87.672937	435.8	19.5	20.00
Pasture Memphis	37.796456	–87.673769	450.4	29.0	35.50
Pasture Loring	37.796436	–87.674434	434.4	12.5	18.00
Alfalfa Loring	37.795837	–87.672503	436.1	18.5	27.30
Alfalfa Memphis	37.795420	–87.672280	451.0	26.5	31.00
Abandoned feedlot	37.799410	–87.670420	426.4	31.0	33.20
Farmyard	37.799742	–87.669902	434.4	33.0	34.60
Rock core	37.794290	–87.671740	455.0	29.5	111.15

of the monitoring wells were constructed using 2-in.-diameter PVC casing. Each well was screened differently, depending on the targeted hydrogeologic zone. Well DW05 was constructed as an open borehole well with an 8-in.-diameter PVC surface casing. Descriptive well and seep names, corresponding AKGWA (Assembled Kentucky Ground Water Database) numbers, coordinates, elevations, total depths, and screen or open borehole intervals of each well are presented in Table 4. Coordinates and elevations were determined using GPS equipment and recorded as decimal degrees based on NAD 83. Elevations are recorded as feet above sea level. The total drilled depths of each well are reported in feet from ground surface. Detailed construction diagrams for each monitoring well are shown in Appendix C.

The four domestic wells (DW01, DW02, DW03, and DW04) were installed in the bedrock aquifer. Wells DW01, DW02, and DW03 were constructed as open borehole wells with 8-in.-diameter steel surface casing. Well DW04 is a 48-in.-diameter, brick-lined, hand-dug well. Coordinates, elevations, total depths, and open borehole intervals of each well are presented in Table 4. Because these four wells were constructed prior to the enactment of current water-well regulations, the construction methods are unknown. Therefore, there are no well-construction diagrams for these four wells.

Surface-water data presented in this report represent samples collected from four seeps formed in the loess along the top of a fragipan. Three of the four seeps are located in the same fields as the field monitoring wells (Fig. 3). The additional seep is located just north of monitoring well DW05 in the northern part of the study area (Fig. 3).

Water-Quality Data

Water-quality data is divided into three categories: surface water, vadose water, and groundwater. Vadose-water and groundwater data are associated with monitoring and domestic wells. Therefore, to simplify data presentation, they are shown together. Surface-water data are associated with the seeps.

Vadose- and Groundwater Data

Vadose- and groundwater data were collected from the Keach farm monitoring and domestic wells from September 1995 through May 2002. Field measurements collected during sampling were pH, specific conductance, temperature, dissolved oxygen, and oxidation-reduction potential, all in accordance with U.S. Geological Survey guidelines for sampling and collecting groundwater (U.S. Geological Survey, 1980). Well purging and sample collecting differed between wells, depending on well design. Root-zone wells were purged and sampled using a peristaltic pump. The peristaltic pump was connected to a 3/16-in. inside-diameter hard plastic tubing that ran to the bottom of the storage cup below the screen. Separate tubing was designated for each root-zone well and stored inside the well casing between sampling events. Paleosol and bedrock-surface wells were purged and sampled using a 2-in.-diameter submersible Fultz pump.[1] Bedrock-aquifer wells, including DW01, DW02, and DW05, were purged and sampled using a 2-in.-diameter submersible Grundfos Redi-Flo pump. All pumps and tubing were rinsed thoroughly with distilled water between purging and sampling events. Domestic wells DW03 and DW04 were purged and sampled using existing submersible pumps.

Field measurements (specific conductance, pH, temperature, and dissolved oxygen) were recorded using a Horiba U-10 water-quality monitoring system with a flow-through chamber. Oxidation-reduction potential was recorded using an Orion ORP electrode and field meter. For the field monitoring wells (DW05, DW01, and DW02), measurements were recorded after purging three well volumes and measurements stabilized. Domestic wells DW03 and DW04 were pumped until

Table 2. Rock core description (by David Williams, Kentucky Geological Survey).

From (ft)	*To (ft)*	*Thickness (ft)*	*Description*
0.00	29.50	29.50	Loess.
29.50	30.50	1.00	Reddish brown sandstone with iron stains, fine-grained and angular, micaceous, friable.
30.50	30.80	0.30	White sandstone with reddish brown iron staining, fine-grained and angular, micaceous, rooted.
30.80	31.50	0.70	Light gray sandstone, mottled, fine-grained and angular, micaceous.
31.50	36.50	5.00	Light yellowish brown sandstone, fine-grained and angular to subrounded, micaceous and carbonaceous with feldspar grains present, porous and wet.
36.50	41.50	5.00	Light yellow-gray to brown sandstone; coarsens downward from fine- to medium-grained; iron staining present; porous.
41.50	51.50	10.00	Light gray sandstone with iron staining present, fine- to medium-grained, micaceous and carbonaceous with scattered feldspar grains, porous.
51.50	54.45	2.95	Light yellowish sandstone with light gray and reddish brown streaks, fine- to medium-grained, subangular to subrounded; feldspar grains present with some disseminated carbonaceous material; crossbedded, porous.
54.45	56.50	2.05	Light gray sandstone, medium- to coarse-grained with light yellow mottling, micaceous, abundant red and purple grains.
56.50	61.10	4.60	Light gray sandstone with brownish red to light yellowish brown staining along crossbeds, medium-grained and subangular to subrounded, micaceous with some feldspar, friable and porous.
61.10	63.65	2.55	Light gray sandstone with yellowish brown streaks and mottling, medium-grained, subangular, well sorted, friable; very little mica present.
63.65	63.85	0.20	Light yellowish brown sandstone, coarse-grained, subangular, well sorted.
63.85	67.25	3.40	Weathered light gray shale with yellowish brown streaks, silty and micaceous, scattered plant fragments.
67.25	71.25	4.00	Light gray sandstone with yellowish brown mottling, fine-grained and angular, scattered coal clasts, vertical fracture throughout segment; thick ironstone band at 68.95 ft.
71.25	74.20	2.95	Reddish brown sandstone, fine grained and subangular; some mica and claystone clasts.
74.20	74.40	0.20	Light tan claystone, silty, soft and plastic.
74.40	77.30	2.90	Light reddish brown to light gray sandstone with iron staning and mottling, fine-grained and subangular, micaceous.
77.30	78.80	1.50	Beige sandstone with iron staining along bedding planes, very fine-grained, micaceous; crossbedding and planar bedding present.
78.80	81.10	2.30	Light brownish gray sandstone, fine- to medium-grained, subangular, well sorted, micaceous; coal fragments present; crossbedded.
81.10	85.05	3.95	Light brownish gray sandstone with scattered reddish brown staining, fine- to medium-grained and subangular, micaceous with coal and claystone fragments present, crossbedded; thick ironstone band at base.
85.05	86.20	1.15	Dark gray shale with very thin sandstone laminations, carbonaceous.
86.20	86.60	0.40	Light gray sandstone, subangular, well sorted, medium-grained.

Table 2. Rock core description (by David Williams, Kentucky Geological Survey).			
From (ft)	*To (ft)*	*Thickness (ft)*	*Description*
86.60	92.15	5.55	Reddish brown sandstone, subangular, well sorted, medium-grained, micaceous with coal and claystone fragments, crossbedded; thick ironstone band at base.
92.15	94.35	2.20	Light gray sandstone, subangular, well sorted, fine-grained, micaceous with coal laminations at base.
94.35	94.60	0.25	Reddish brown sandstone, subangular, fine-grained, low-angle crossbedding.
94.60	96.20	1.60	Light gray sandstone with reddish brown staining, subangular and medium-grained, micaceous with coal and plant fragments.
96.20	97.30	1.10	Reddish brown sandstone, subangular, well sorted, medium-grained; coal spar at base.
97.30	102.75	5.45	Light gray sandstone, subangular, well sorted, fine- to coarse-grained, micaceous; abundant coal spar and shale clasts present; crossbedded and porous.
102.75	104.75	2.00	Lag conglomerate, mix of elongated (3/4 to 2 in.) fragments of sandstone, shale, hard sandy shale, and coal clasts in matrix of hard sandy shale and sandstone; breaks apart readily.
104.75	105.33	0.58	Medium gray shale, hard and tacky.
105.33	105.40	0.07	Light gray claystone, soft and plastic.
105.40	105.45	0.05	Siderite band.
105.45	107.50	2.05	Dark gray shale, hard, fissile, breaks readily along horizontal surfaces; siderite band at 106.90–106.95 ft; coal laminations.
107.50	108.07	0.57	Coal, thin-banded clairain; minor pyrite on cleat surfaces; base sharp.
108.07	108.28	0.21	Dark gray claystone, soft and crumbly, rooted.
108.28	111.15	2.87	Medium gray siltstone, very argillaceous, rooted, disseminated siderite in base.

measurements stabilized. All field instruments were calibrated daily during sampling using procedures prescribed by the manufacturers.

All laboratory analyses were in accordance with either U.S. Environmental Protection Agency methods or methods widely accepted in the literature. Sample splits were prepared in the field and transported to the lab in properly sterilized bottles. For dissolved-constituent analysis, filtration was performed in the field using high-capacity in-line filters (0.45-µm pore size). If sample preservation was required by analysis protocol, the samples were preserved at the time of collection and kept at a temperature of 4°C until delivered to the appropriate laboratory.

Table 3. Laboratory analytical methods conducted on soil samples.		
Analyte	*Method*	*Laboratory*
Particle size	Suspension sedimentation and pipette extraction (Gee and Bauder, 1986)	Chemical and Physical Edaphology
pH	Glass electrode in a 1:1 soil:water suspension	UK Regulatory Services
Bioavailable phosphorus, calcium, potassium, magnesium, zinc	Mehlich III extraction (Mehlich, 1984)	UK Regulatory Services
Organic matter and total nitrogen	Dry combustion (Bradstreet, 1965; Nelson and Sommers, 1996)	UK Regulatory Services
Inorganic nitrogen (ammonium and nitrate)	Colorimetry (Technicon Corp., 1965) and Greiss-Ilosvay method (Keeney and Nelson, 1982)	Chemical and Physical Edaphology

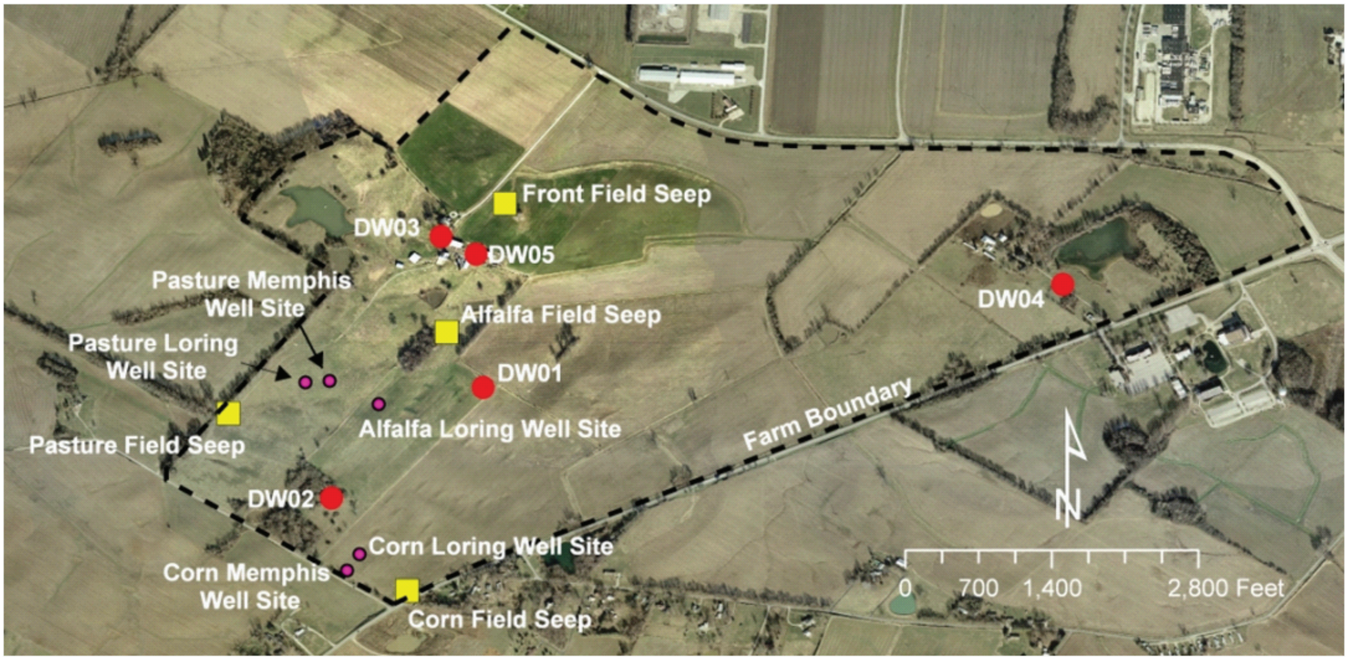

Figure 3. Locations of monitoring wells, domestic wells, and seeps at the Keach farm.

Water analyses were performed in four laboratories: Kentucky Geological Survey, Kentucky Division of Environmental Services, University of Waterloo Environmental Isotope Laboratory (Ontario, Canada), and KGS Western Kentucky office. Table 5 lists the analyses performed, methods used, and required sample preservation for the KGS, Division of Environmental Services, and University of Waterloo laboratories. Table 6 lists the same information for the Western Kentucky office laboratory. Because funding and goals changed during the project, the list of analytes changed also. Therefore, not all analytes listed in Tables 5 and 6 appear throughout the water-quality data tables.

Vadose- and Groundwater Data Format

All data tables are formatted similarly. The "<" symbol indicates a concentration below the indicated method detection limit (MDL). Data were checked for quality, and suspect laboratory results were reanalyzed to verify reported values. Monitoring well ALBA was drilled at a later date, and therefore has fewer water-quality data.

Appendix D contains field-measurement data (pH, specific conductance, dissolved oxygen, temperature, and oxidation-reduction potential) for all wells. Problems occasionally occurred with field instruments, and when identified, the resulting measurements were not included. The second column of the field measurement data tables for the root-zone and paleosol wells is titled "Well Conditions" and either "dry" or "wet" is indicated for each sampling event. "Dry" means no water was in the storage cup during the sampling event. "Wet" means water was in the storage cup, but there may not have been enough after purging for a complete sample.

Appendix E contains inorganic anion data (chloride, sulfate, fluoride, bromide, alkalinity, bicarbonate, and carbonate) for all wells. Chloride and bromide samples were analyzed using two different methods, identified in Tables 5 and 6. Shaded cells in the chloride and bromide columns indicate that the samples were analyzed using an ion selective electrode.

Appendix F contains nutrient data (nitrate-nitrogen, orthophosphate, orthophosphate-phosphorous, ammonia, ammonia-nitrogen, nitrite-nitrogen, total organic carbon) for all wells. Nitrate-nitrogen samples were analyzed using two different methods, which are identified in Tables 5 and 6. Shaded cells in the nitrate-nitrogen column indicate that the water sample was analyzed using an ion selective electrode. Appendix G contains total metals and dissolved total metals data for all wells.

This phase of the project performed analyses to detect a wide range of pesticides. Appendices H and I contain pesticide data analyzed using gas chromatography and enzyme-linked immunosorbent assay, respectively, for all wells. Two gas-chromatography methods were used: electron-capture detection and nitrogen-phosphorus detection. The method used to analyze each pesticide is indicated in Appendix H.

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

Table 4. Abbreviations, coordinates, surface elevation, total depth, and screen or borehole interval for Keach farm monitoring wells, domestic wells, and seeps.

Well Name	*Well Name Abbreviation*	*AKGWA[1] Number*	*Latitude*	*Longitude*	*Surface Elevation (ft above sea level)*	*Total Depth (ft)*	*Screen or Open Bore-hole Interval (ft)*
Alfalfa Loring root zone	ALRZ	8003-1071	37.795823	–87.672503	433.28	10.32	3.76–5.26
Alfalfa Loring paleosol	ALPS	8003-1070	37.795837	–87.672503	433.28	13.71	10.71–13.71
Alfalfa Loring bedrock surface	ALBS	8003-1069	37.795867	–87.672503	433.28	29.33	19.33–29.33
Alfalfa Loring bedrock aquifer	ALBA	8002-6954	37.795805	–87.672449	433.28	63.00	43.00–63.00
Alfalfa field seep	ASEEP	9000-2469	37.797699	–87.670679	405.92	0.00	surface
Corn Loring root zone	CLRZ	8003-1065	37.791867	–87.672903	434.64	9.96	3.40–4.90
Corn Loring paleosol	CLPS	8003-1066	37.791867	–87.672920	434.64	15.87	7.81–10.81
Corn Loring bedrock surface	CLBS	8003-1067	37.791867	–87.672937	434.64	29.93	19.93–29.93
Corn Loring bedrock aquifer	CLBA	8003-1068	37.791867	–87.672955	434.64	63.35	43.35–63.35
Corn Memphis root zone	CMRZ	8003-1061	37.791442	–87.673229	441.86	9.80	3.25–14.86
Corn Memphis paleosol	CMPS	8003-1062	37.791442	–87.673246	442.19	19.92	11.86–14.86
Corn Memphis bedrock surface	CMPBS	8003-1063	37.791442	–87.673264	442.19	35.14	25.14–35.14
Corn Memphis bedrock aquifer	CMBA	8003-1064	37.791442	–87.673281	442.19	79.77	59.77–79.77
Corn field seep	CSEEP	9000-2471	37.790906	–87.671708	418.38	0.00	surface
Pasture Loring root zone	PLRZ	8003-1076	37.796436	–87.674458	434.50	9.89	3.33–4.83
Pasture Loring paleosol	PLPS	8003-1077	37.796436	–87.674434	434.48	16.06	8.00–11.00
Pasture Loring bedrock surface	PLBS	8003-1078	37.796418	–87.674440	434.66	23.61	13.61–23.61
Pasture Loring bedrock aquifer	PLBA	8003-1081	37.796374	–87.674373	434.56	62.28	42.28–62.28
Pasture Memphis root zone	PMRZ	8003-1072	37.796456	–87.673736	450.49	10.13	3.57–5.07
Pasture Memphis paleosol	PMPS	8003-1073	37.796456	–87.673754	450.46	25.78	17.72–20.72
Pasture Memphis bedrock surface	PMBS	8003-1074	37.796456	–87.673769	450.36	39.12	29.12–39.12
Pasture Memphis bedrock aquifer	PMBA	8003-1075	37.796416	–87.673742	450.43	87.91	67.91–87.91
Pasture field seep	PSEEP	9000-2470	37.795560	–87.676390	407.24	0.00	surface
Domestic well 01	DW01	0005-1555	37.796242	–87.669718	436.67	50.50	35.00–50.50[2]
Domestic well 02	DW02	0005-1559	37.793339	–87.673685	447.08	72.50	35.00–72.50[2]
Domestic well 03	DW03	0005-1556	37.800209	–87.670819	429.95	60.55	30.00–60.55[2]
Domestic well 04	DW04	0005-1557	37.798954	–87.654535	416.69	45.55	0.00–45.55[3]
Domestic well 05	DW05	0004-6214	37.799742	–87.669902	434.40	75.00	46.00–75.00[2]
Front field seep	FSEEP	9000-2472	37.801077	–87.669149	404.55	0.00	surface

[1]Assembled Kentucky Ground Water Database
[2]Open borehole intervals
[3]Well is brick-lined

Table 5. Analyses, methods, and preservation for KGS, Division of Environmental Services, and University of Waterloo laboratories.

Analyte	*Method*	*Preservative*	*Laboratory*
Total metals and total dissolved metals: aluminum magnesium antimony manganese arsenic nickel barium phosphorus beryllium potassium boron selenium cadmium silicon calcium silver chromium sodium cobalt strontium copper sulfur gold thallium iron tin lead vanadium lithium zinc	EPA 200.7 and SW846-6010A, B inductively coupled plasma	filter for dissolved metals, nitric acid, 4°C	KGS
chloride bromide sulfate fluoride nitrate-nitrogen	SW846-9056	4°C	KGS
nitrite-nitrogen	EPA 354.1	4°C	KGS
orthophosphate	EPA 365.3	filter, 4°C	KGS
ammonia-nitrogen	SM 4500 NH_3F	sulfuric acid, 4°C	KGS
pesticides	SW846-8081 and -8141, GC ECD and NPD	4°C	KGS
pesticides	ELISA	4°C	KGS
alkalinity	EPA 310.1	4°C	KGS
bicarbonate and carbonate	calculated	4°C	KGS
caffeine and metabolites	DES 5220 (Ky. Div. of Environmental Services, 2006), DES 6230 (Ky. Div. of Environmental Services, 2005)	4°C	Kentucky Division of Environmental Services
tritium (enriched)	Liquid scintillation counting (Drimmie and others, 1991)	none	University of Waterloo
nitrogen-15 and oxygen-18	Flatt and Heemskerk (1997)	filtered, $HgCl_2$	University of Waterloo

Appendix J contains caffeine and isotope data for all wells. The analyte 1,7-dimethylzanthine is a metabolite of caffeine. Nitrogen ($^{15}N/^{14}N$) and oxygen ($^{18}O/^{16}O$) isotope ratios were analyzed from the groundwater nitrate molecule and are represented as NO_3-$\delta^{15}N$ and NO_3-$\delta^{18}O$, respectively.

Surface-Water Data

Surface-water data were collected from corn-, pasture-, alfalfa-, and front-field seeps. Field measurements sampled pH, specific conductance, temperature, dissolved oxygen, and oxidation-reduction potential, all in accordance with U.S. Geological Survey guidelines for sampling and collecting (U.S. Geological Survey, 1980). Seeps were sampled using a peristaltic pump and Tygon tubing. The tubing was lowered into the flowing water as close to the water source (point of water exiting the ground) as possible. New tubing was used for

Table 6. Analyses, methods, and preservation for Western Kentucky office laboratory.

Analyte	*Method*	*Preservative*
chloride	Orion Research Inc. (1996a)	4°C
nitrate-nitrogen	Orion Research Inc. (1996b)	4°C
bromide	Cole Parmer Instrument Co. (no date)	4°C

each seep and sampling event. Specific conductance, pH, temperature, and dissolved oxygen were recorded using a Horiba U-10 water-quality monitoring system with a flow-through chamber. Oxidation-reduction potential was recorded using an Orion ORP electrode and field meter. Field measurements were recorded and samples were collected after measurements stabilized. All field instruments were calibrated daily during sampling using calibration procedures prescribed by the manufacturers.

All laboratory analyses were performed in accordance with either U.S. Environmental Protection Agency or analytical methods widely accepted in the literature. Sample splits were prepared in the field and transported to the lab in properly sterilized bottles. For dissolved constituent analysis, filtration was performed in the field using high-capacity in-line filters (0.45-µm pore size). If sample preservation was required by analysis protocol, the samples were preserved at the time of collection and kept at a temperature of 4°C until delivered to the appropriate laboratory. Analytical methods and laboratories were the same as those used for the vadose- and groundwater samples (Tables 5 and 6). Because funding and goals changed during the project, the list of analytes changed also. Therefore, not all analytes listed in Tables 5 and 6 appear throughout the surface-water-quality data tables.

Surface-Water Data Format

All data tables are formatted similarly. The “<” symbol indicates a concentration below the indicated MDL. Data were checked for quality, and suspect laboratory results were reanalyzed to verify reported values.

Appendix K contains field-measurement data (pH, specific conductance, dissolved oxygen, temperature, and oxidation-reduction potential) for all seeps. Problems occasionally occurred with field instruments, and when identified, the resulting measurements were not included. The second column of the field measurement data tables is titled “Seep Conditions” and either “dry” or “flowing” is indicated for each sampling event. “Dry” means water was not flowing or that the flow volume was insufficient for a complete sample. “Flowing” means water was flowing at the time of sampling.

Appendix L contains inorganic anion data (chloride and sulfate) for all seeps. Chloride samples were analyzed using two different methods, which are identified in Tables 5 and 6. Shaded cells in the chloride column indicate that the sample was analyzed using an ion selective electrode.

Appendix M contains nutrient data (nitrate-nitrogen, orthophosphate, orthophosphate-phosphorous, ammonia, ammonia-nitrogen, nitrite-nitrogen, total organic carbon) for all seeps. Nitrate-nitrogen samples were analyzed using two different methods, which are identified in Tables 5 and 6. Shaded cells in the nitrate-nitrogen column indicate that the sample was analyzed using an ion selective electrode.

This phase of the project performed analyses to detect a wide range of pesticides. Appendices N and O contain pesticide data analyzed using gas chromatography and enzyme-linked immunosorbent assay, respectively, for all seeps. Two gas-chromatography methods were used: electron-capture detection and nitrogen-phosphorous detection. The method used to analyze each pesticide is indicated in Appendix N.

Groundwater-Elevation Data

Groundwater-level elevations were manually measured during each sampling event and periodically between sampling events. A downhole electronic water-level indicator that measures the depth to water from a consistent measuring point, the top of the well casing unless otherwise indicated, was used.

Groundwater-level elevations for all of the bedrock-surface and bedrock-aquifer monitoring wells (DW01, DW02, DW03, DW04, and DW05) are shown in Appendix P. Elevations are reported in feet above sea level. Monitoring well ALBA was drilled at a later date, and therefore has fewer records.

Also included in this report is one year of real-time water-level measurements collected in wells CMBA and CLBA. These measurements were made by installing downhole electronic pressure transducers that measured the gauge pressure above the transducer, translating pressure into feet above the measurement point. Real-time data were collected from August 1997 through August 1998. The results of those measurements are reported in Appendix Q as feet above sea level.

Rain Data

Rainfall data were collected on site from October 26, 1995, through May 31, 2002. Data were collected by a tipping-bucket rain gauge connected to a Telog pulse-recording data logger. The data logger did not record data unless a pulse from the tipping-bucket was sent to the recorder. Therefore, there are records only for days with rainfall.

Rainfall data are found in Appendix R. The first column is the date of measurement in mm/dd/yy format. The second column is the amount of daily rainfall in inches. The third column is cumulative rainfall. The data tables are categorized by year and the cumulative totals are zeroed at the beginning of each year.

Monitoring-Well Termination and Additional Data

In June 2002, all corn-, alfalfa-, and pasture-field wells were plugged by a Kentucky certified monitoring-well driller according to Kentucky monitoring-well regulations (Kentucky Department of Environmental Protection, 1991). Sampling of domestic wells DW01, DW02, and DW04 was discontinued at the end of phase I (2002). All data associated with the field-setting wells, seeps, and domestic wells DW01, DW02, and DW04 are presented in this report. Sampling of domestic well DW03 and monitoring well DW05 continued through phase III (June 2002–present). Additional groundwater-quality data associated with wells DW03 and DW05 are presented in reports for phase II (Beck and others, in press a) and phase III (Beck and others, in press b).

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