Groundwater Quality in Watersheds of the Kentucky River, Salt River, Licking River, Big Sandy River, Little Sandy River, and Tygarts Creek (Kentucky Basin Management Units 1, 2, and 5)

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Abstract

The Kentucky Geological Survey, University of Kentucky, and the Kentucky Division of Water (of the Kentucky Environmental and Public Protection Cabinet) are evaluating groundwater quality throughout the commonwealth to determine regional conditions, assess impacts of nonpoint-source pollutants, establish a basis for detecting changes, and provide essential information for environmental-protection and resource-management decisions.

These evaluations are being conducted in stages. Under the Kentucky Watershed management Framework, Kentucky's 12 major river basins and tributaries of the Ohio River were grouped into five basin management units (BMU's). A previous report summarized and evaluated groundwater quality in BMU 3 (watersheds of the Upper Cumberland River, Lower Cumberland River, Tennessee River, the Jackson Purchase Region, and adjacent Ohio River tributaries). That report is available on the KGS Web site (www.uky.edu/KGS/water/RI_15/). This report summarizes results of analyses of groundwater samples from wells and springs in BMU 1 (Kentucky River watershed and adjacent Ohio River tributaries), BMU 2 (Salt River and Licking River watersheds and adjacent Ohio River tributaries), and BMU 5 (Big Sandy River, Little Sandy River, and Tygarts Creek watersheds, and adjacent Ohio River tributaries).

Analytical results for selected water properties, major and minor inorganic ions, metals, nutrients, pesticides, and volatile organic chemicals were retrieved from the Kentucky Groundwater Data Repository. The repository is maintained by the Kentucky Geological Survey and contains reports received from the Division of Water's Ambient Groundwater Monitoring Program as well as data from investigations by the U.S. Geological Survey, U.S. Environmental Protection Agency, U.S. Department of Energy, Kentucky Geological Survey, Kentucky Division of Pesticide Regulation, and other agencies. The Kentucky Division of Water provided water-quality standards. Statistics such as the number of measurements reported, the number of sites sampled, quartile concentration values, and the number of sites at which water-quality standards were met or exceeded are used to summarize the data. Maps show sampled locations and sites where water-quality standards were met or exceeded. Cumulative data plots are used to show concentration distributions

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in each basin management unit. Box-and-whisker diagrams compare values between physiographic regions, major watersheds, wells and springs, and total versus dissolved metal concentrations. Plots of analyte concentrations versus well depth compare groundwater quality in shallow, intermediate, and deep groundwater flow systems.

Table A1 summarizes the findings. General water-quality properties, inorganic anions, and metals are primarily controlled by natural factors such as bedrock lithology. Some exceptionally high values of conductance, hardness, chloride, and sulfate may be affected by nearby oil and gas production or improperly sealed oil and gas wells, leaking waste-disposal systems, or other man-made factors, and some exceptionally low pH values probably result from acid mine drainage. Nitrate concentrations show a strong contribution from agricultural and waste-disposal practices, whereas orthophosphate and total phosphorus concentrations are largely determined

Table A1. Summary of evidence for nonpoint-source impacts on groundwater quality in basin management units 1, 2, and 5.

	Parameter	No Strong Evidence for Widespread Nonpoint-Source Impact	Evidence for Some Nonpoint-Source Impact	Evidence for Definite Nonpoint-Source Impact
Water Properties	Conductance	X		
	Hardness	X		
	pH	X		
	Total dissolved solids	X		
	Total suspended solids	X		
Inorganic Ions	Chloride	X		
	Sulfate	X		
	Fluoride	X		
Metals	Arsenic	X		
	Barium	X		
	Iron	X		
	Manganese	X		
	Mercury	X		
Nutrients	Ammonia-nitrogen		X	
	Nitrate-nitrogen			X
	Nitrite-nitrogen		X	
	Orthophosphate	X		
	Total phosphorus	X		
Pesticides	2,4-D		X	
	Alachlor		X	
	Atrazine		X	
	Cyanazine		X	
	Metolachlor		X	
	Simazine		X	
Volatile Organic Compounds	Benzene		X	
	Ethylbenzene		X	
	Toluene		X	
	Xylenes		X	
	MTBE		X	

[1] Methyl tertiary-butyl ether

by the chemical composition of limestone bedrock and coal strata. Synthetic organic chemicals such as pesticides and refined volatile organic compounds do not occur naturally in groundwater. Although these chemicals rarely exceed water-quality criteria in the project area, the detection of these man-made chemicals in springs and shallow wells indicates there has been some degradation of groundwater quality. Monitoring of these synthetic, potentially health-threatening chemicals should continue, and efforts to protect the groundwater resources from them should be a priority for the commonwealth of Kentucky.

Introduction

Purpose

Evaluating groundwater quality is essential for determining its suitability for various uses and the sources of dissolved chemicals, and because regional groundwater quality provides a sensitive indicator of the general condition of the natural environment. This report summarizes groundwater quality in the northeastern part of Kentucky (watersheds of the Kentucky River, Salt River, Licking River, Big Sandy River, Little Sandy River, and Tygarts Creek, and Ohio River tributaries adjacent to those watersheds). Similar reports on groundwater quality in the southwestern part of Kentucky were previously completed (Fisher and others, 2004).

Goals

The goals of this report are to summarize regional values for a group of groundwater-quality parameters and to determine whether nonpoint-source chemicals have affected groundwater systems. The results identify natural and anomalous concentrations of dissolved chemicals, show areas where nonpoint-source chemicals have entered the groundwater system and implementation of best management practices are needed, provide information for Kentucky Division of Water watershed assessment reports, provide groundwater-quality data to the DOW's Groundwater Protection program, help the DOW's Wellhead Protection program set priorities to protect areas and activities, and provide critical information for long-term protection and management of water resources.

Background

Evaluating groundwater quality is particularly important in Kentucky because groundwater use is extensive and will continue to be so. The 1990 census data and recent DOW estimates indicate that approximately 60 percent of public water-supply companies use groundwater as a sole or contributing water source, more than 25 percent of the population uses groundwater for domestic purposes, and more than 226 million gallons of groundwater are consumed daily by individuals, municipalities, utilities, businesses, and farms. Groundwater will continue to be important to Kentuckians because economic and logistical factors make replacing groundwater with surface-water supplies expensive or impractical in rural areas, and because some cities along the Ohio River are turning to groundwater from alluvial deposits for urban water supplies. An estimated 400,000 Kentuckians will still depend on private, domestic water supplies in the year 2020 (Kentucky Geological Survey, 1999).

Both natural and man-made processes affect groundwater quality. The major natural processes that contribute cations, anions, metals, nutrients, and sediment to groundwater are dissolution of atmospheric gases as rain falls through the atmosphere, dissolution of soil particles and physical transport of chemicals and sediment as rainfall flows across the land surface, dissolution of soil gases and reactions with inorganic and organic material in the soil zone above the water table, and reactions with gases, minerals, and organic material beneath the water table.

Groundwater quality is also affected by human activities that contribute synthetic organic chemicals such as pesticides, fertilizers, and volatile organic compounds, as well as cations, anions, metals, nutrients, and sediment, to the water system. Nearly all activities that threaten surface waters and aquatic ecosystems also endanger groundwater systems. Agriculture, confined animal-feeding operations, forestry, mining, oil and gas production, waste disposal, and urban stormwater runoff can deliver pesticides, fertilizers, nutrients, metals, and hydrocarbons to groundwater.

Previous Investigations

Numerous reports covering the study area or nearby areas describe the hydrology, groundwater resources, and general water quality of the study area. Few address the issue of nonpoint-source contamination, however. In the 1960's and early 1970's, the U.S. Geological Survey published reconnaissance studies of the geology, groundwater supplies, and general groundwater quality in Kentucky. These reports include a Hydrologic Atlas series, which was made in conjunction with the Kentucky Geological Survey; each atlas covers from two to 10 counties across the state (except in the Jackson Purchase area, which had coverage for each 7.5-minute quadrangle). Each atlas includes three sheets showing geology, lithology, and availability of groundwater. The atlases have been scanned and are currently available online (www.uky.edu/KGS/water/library/USGSHA.html). The Kentucky Geological Survey developed a series of county groundwater-resource reports based on the USGS Hydrologic Atlases. Each report (www.uky.edu/KGS/water/library/webintro.html) contains from 16 to 31 pages of information on geology, hydrogeologic characteristics of aquifers, available water supplies, and availability of groundwater for public consumption. Older but more comprehensive groundwater-resource reports related to this study area cover the Bluegrass Region (Hendrickson and Krieger, 1964; Faust, 1977), Eastern Kentucky Coal Field (Price and others, 1962), and the Mississippian Plateau Region (Brown and Lambert, 1963), herein referred to as the Eastern and Western Pennyroyal Regions. These reports considered major and minor inorganic ions and nitrate; other nutrients, metals, and synthetic organic chemicals were not considered. Sprinkle and others (1983) summarized general groundwater quality throughout Kentucky. The Kentucky Geological Survey (1999) summarized groundwater supply and general groundwater quality throughout the state for the Groundwater Resource Development Commission (kgsweb.uky.edu/download/wrs/GWTASK1.PDF). Carey and others (1993) surveyed selected groundwater-quality parameters, including nutrients and pesticides, in private groundwater supplies.

Two other sources of largely uninterpreted analytical data contributed significantly to the database used here. Faust and others (1980) summarized the results of cooperative groundwater investigations involving KGS and other State, Federal, and local agencies. The National Uranium Resource Evaluation program provided a large source of analyses of groundwater, surface water, and stream sediments (Smith, 2001). Digital records from both these reports are stored in the Kentucky Groundwater Data Repository and were used in this report.

DOW interpreted the results of expanded groundwater monitoring in BMU 2 as a contract report (Webb and others, 2003). The data used in that report are included in the larger data sets used here.

Project Area

The DOW Watershed Management Framework (Kentucky Division of Water, 1997) grouped Kentucky's major river basins into five basin management units (Fig. 1). This project covers watersheds of the Kentucky River (BMU 1), Salt and Licking Rivers (BMU 2), and the Big Sandy River, Little Sandy River, and Tygarts Creek (BMU 5).

The project area includes six of Kentucky's physiographic regions: Eastern Kentucky Coal Field, the Knobs, Eastern and Western Pennyroyal, Outer Bluegrass, and Inner Bluegrass (Fig. 1). Each region is distinguished by unique bedrock type, topography, and soil types (McDowell, 1986; Newell, 1986). This framework is important to understanding groundwater quality because it has a controlling effect on the natural occurrences of major and minor inorganic solutes and metals. It also strongly influences land use, urban and commercial development, and the potential use of nutrients, pesticides, and volatile organic compounds.

The Eastern Kentucky Coal Field is characterized by deeply incised sandstone, shale, and coal strata that are essentially horizontal throughout most of the area but are steeply inclined to nearly vertical along the Pine Mountain Overthrust Fault in southeastern Kentucky. Steep hillsides separate narrow, flat river valleys from sharp, sinuous mountain crests. Valley slopes are typically fractured and covered by rock fragments and weathered material; soils are generally thin except in river valleys (Newell, 1986).

The Eastern and Western Pennyroyal Regions consist mainly of thick, horizontally bedded limestone with minor thin shales. The Pennyroyal surface is characterized by karst features such as sinkholes and springs, connected by underground solution channels and caves. Soils are composed of insoluble residue that remains as the carbonate rocks weather.

The Knobs Region is a narrow belt separating the Eastern Pennyroyal Region from the Outer Bluegrass Region. It is characterized by conical, flat-topped hills composed mostly of shale and siltstone, topped by more resistant cap rock. Soils are thin except where the lower slopes of knobs merge with alluvium in valley bottoms.

The Inner and Outer Bluegrass Regions are gently rolling to relatively flat lowlands, underlain with interbedded limestones and shales. The regions display well-developed karst features such as sinkholes, springs, underground streams, and caves. Soils in the Inner Bluegrass are generally thick and phosphatic, whereas soils in the Outer Bluegrass range from thick and rich over limestones to thin and clayey over shales (Newell, 1986).

Basin Management Unit 1: Kentucky River Watershed

The Kentucky River watershed (basin management unit 1) includes the Inner and Outer Bluegrass, Knobs, Eastern Pennyroyal, and Eastern Kentucky Coal Field Regions, and covers an area of about 6,975 mi^2 (Fig. 1). The Kentucky River originates in the

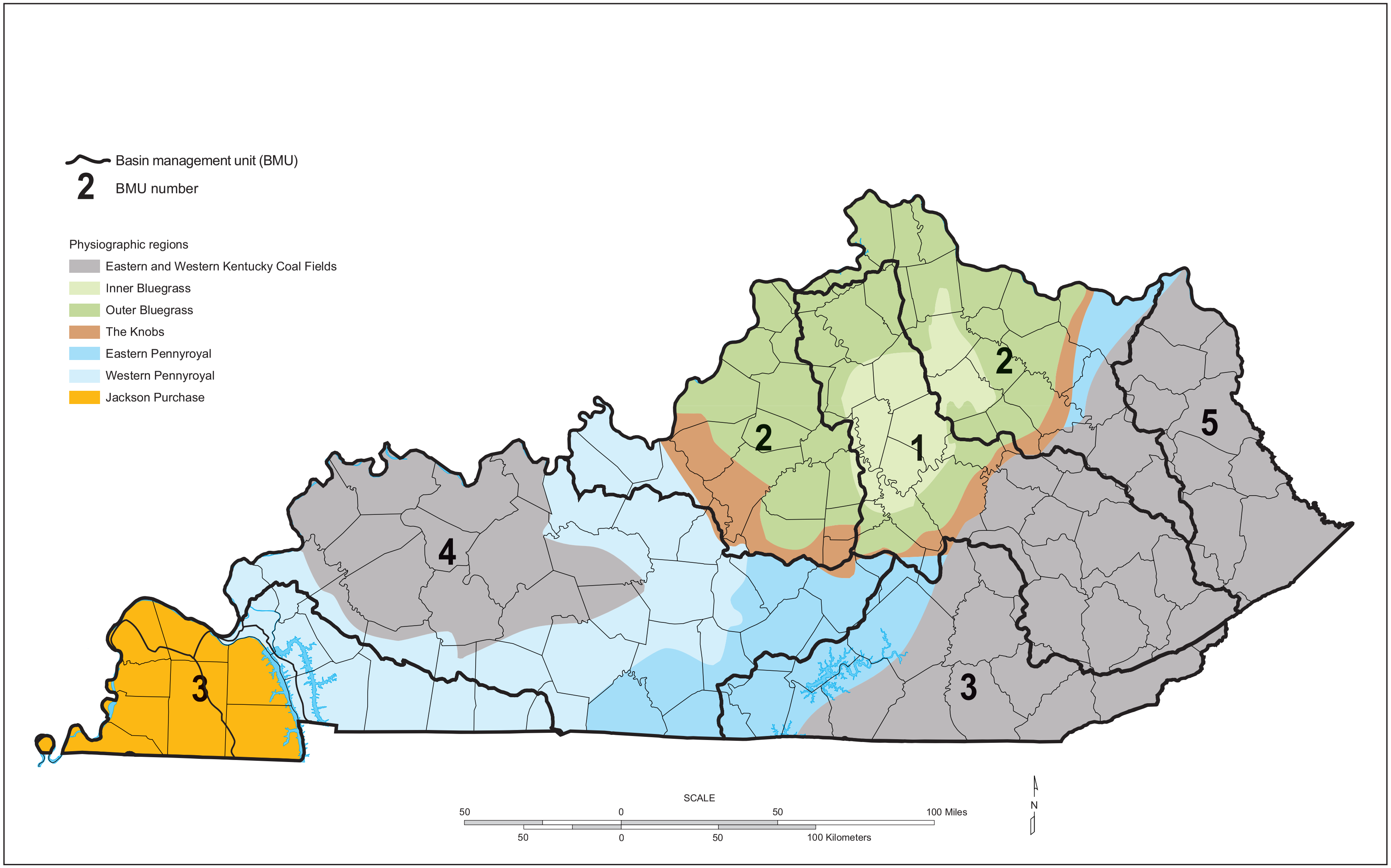

Figure 1. Locations of major river watersheds, physiographic regions, and basin management units. This study summarizes groundwater-quality data from basin management units 1, 2, and 5.

mountains of the Eastern Kentucky Coal Field and flows northwest through the Knobs and the Outer and Inner Bluegrass Regions to join the Ohio River near Carrollton in Carroll County. The total length of the river in the basin is approximately 405 mi. The main stem of the Kentucky River extends approximately 255 mi through 14 locks and dams.

Land uses and nonpoint-source chemical threats to groundwater quality in BMU 1 include oil and gas production; active and abandoned coal mines; leaking sewage-disposal systems; straight pipes (household sewage dumped directly into streams or rivers); deforested areas in the Eastern Kentucky Coal Field; and farm land, urban centers, and confined animal-feeding operations (Kentucky Division of Water, 2000). Groundwater is particularly vulnerable to nonpoint-source contamination in the karst regions of the Bluegrass because of the well-developed network of sinkholes, caves, and springs.

BMU 1 includes all or parts of Anderson, Bell, Boone, Bourbon, Boyle, Breathitt, Carroll, Casey, Clark, Clay, Estill, Fayette, Floyd, Franklin, Gallatin, Garrard, Grant, Harlan, Harrison, Henry, Jackson, Jessamine, Kenton, Knott, Knox, Laurel, Lee, Leslie, Letcher, Lincoln, Madison, Magoffin, Menifee, Mercer, Montgomery, Morgan, Owen, Owsley, Perry, Pike, Powell, Rockcastle, Scott, Shelby, Trimble, Wolfe, and Woodford Counties.

Basin Management Unit 2: Salt River and Licking River Watersheds

Basin management unit 2 consists of the Licking River and Salt River watersheds and adjacent Ohio River tributaries. The Licking River has headwaters in the mountains of Magoffin County in the Eastern Kentucky Coal Field and flows northwest toward the Ohio River. The Licking River flows through the Eastern Pennyroyal and Knobs Regions into the Outer and Inner Bluegrass Regions and enters the Ohio River between Newport and Covington. The Licking River Basin drains approximately 3,710 mi^2, and provides a source of drinking water for nearly 80 percent of the population in the basin.

Although the Salt River Basin is west of the Kentucky River Basin, it is also included in BMU 2. This basin drains approximately 4,155 mi^2. The Salt River itself is nearly 150 mi long and flows northwest, emptying into the Ohio River near West Point in northern Hardin County in the Fort Knox Military Reservation.

Land uses and nonpoint-source threats in BMU 2 are varied. Agricultural land accounts for approximately 57 percent of the region; forest land accounts for approximately 30 percent, and residential and urban land account for the remainder (Kentucky Division of Water, 2001). The major nonpoint-source threats are fertilizers, pesticides, animal wastes, mine drainage, runoff from mine spoil, leaking septic systems, and urban stormwater runoff.

BMU 2 includes all or parts of Anderson, Bath, Boone, Bourbon, Boyle, Bracken, Breathitt, Breckinridge, Bullitt, Campbell, Carroll, Carter, Casey, Clark, Elliott, Fayette, Fleming, Floyd, Gallatin, Grant, Green, Greenup, Hardin, Harrison, Henry, Jefferson, Johnson, Kenton, Knott, Larue, Lewis, Lincoln, Magoffin, Marion, Mason, Meade, Menifee, Mercer, Montgomery, Morgan, Nelson, Nicholas, Oldham, Pendleton, Powell, Robertson, Rowan, Scott, Shelby, Spencer, Taylor, Trimble, Washington, and Wolfe Counties.

Basin Management Unit 5: Big Sandy River, Little Sandy River, and Tygarts Creek Watersheds

Basin management unit 5 includes watersheds of the Big Sandy and Little Sandy Rivers and Tygarts Creek. This basin covers approximately 4,610 mi^2 in the Eastern Kentucky Coal Field. The Big Sandy River forms the northeastern boundary between Kentucky and West Virginia, and flows northwest to Boyd County, where it joins the Ohio River near Catlettsburg. The Little Sandy River flows northeast in the northern half of BMU 5, and joins the Ohio River near the town of Greenup in Greenup County. Tygarts Creek is east of and roughly parallel to the Little Sandy River, and flows into the Ohio River in northern Greenup County.

Land uses and nonpoint-source chemical threats to groundwater quality in BMU 5 include oil and gas production, active and abandoned coal mines, leaking sewage-disposal systems, deforested areas in the Eastern Kentucky Coal Field, and confined animal-feeding operations (Kentucky Division of Water, 2000). The major nonpoint-source threats are mine drainage, runoff from mine spoil, leaking septic systems, straight pipes, fertilizers, pesticides, and animal wastes.

BMU 5 includes all or parts of Boyd, Carter, Elliott, Floyd, Greenup, Johnson, Knott, Lawrence, Letcher, Lewis, Magoffin, Martin, Morgan, Pike, and Rowan Counties.

Hydrogeologic Unit Codes

The U.S. Geological Survey has assigned Hydrologic Unit Codes to watersheds to identify regions, subregions, accounting units, and cataloging units (U.S. Geological Survey, 1988). The HUC designations of watersheds in BMU's 1, 2, and 5 are listed in Tables 1 and 2.

Table 1. Watershed names and six-digit HUC designations for basin management units 1, 2, and 5.

Six-digit HUC	HUC 6 Name	BMU
051002	Kentucky River	1
050902	areas along the Ohio River	2
051001	Licking River	2
051401	Salt River, Rolling Fork River, and Ohio River	2
050702	Big Sandy River	5
050901	Tygarts Creek, Little Sandy River, and Ohio River	5

Table 2. Watershed names and eight-digit HUC designations for basin management units 1, 2, and 5.

Eight-digit HUC	HUC 8 Name	BMU
05100201	North Fork Kentucky River	1
05100202	Middle Fork Kentucky River	1
05100203	South Fork Kentucky River	1
05100204	Kentucky River–Red River	1
05100205	Lower Kentucky River	1
05090201	Ohio River–Kinniconick Creek	2
05090203	Ohio River–Gunpowder Creek	2
05100101	Licking River	2
05100102	South Fork Licking River	2
05140101	Ohio River–Little Kentucky River–Harrods Creek	2
05140102	Salt River	2
05140103	Rolling Fork River	2
05140104	Ohio River–Sinking Creek	2
05070201	Big Sandy River	5
05070202	Upper Levisa Fork	5
05070203	Levisa Fork	5
05070204	Blaine Creek	5
05090103	Tygarts Creek–Ohio River	5
05090104	Little Sandy River	5

Groundwater Sensitivity Regions

The vulnerability of groundwater to nonpoint-source contamination varies geographically across Kentucky, and vertically at any given location, in response to both natural and man-made factors.

Among the most important natural controls on the transport of pollutants to the groundwater system are physiography (principally the topography, relief, land slope, and presence or absence of sinkholes or caves); soil type and thickness; bedrock type; bedrock structure (principally the bedrock porosity and permeability and the presence or absence of faults, fractures, or solution conduits); and depth to groundwater. Overprinted on the natural environment are man-made factors such as the type of land use, nature and amount of chemicals applied to agricultural and urban landscapes, wastewater and sewage-disposal practices, and the effects of resource extraction (principally oil and gas production and coal mining).

Recognizing the need to develop a flexible program for groundwater protection, DOW developed a method for rating and delineating regions of different groundwater sensitivity (Ray and O'dell, 1993) and published a map showing the various groundwater sensitivity regions throughout the commonwealth (Ray and others, 1994). Ray and O'dell (1993) concluded that the natural factors controlling the potential for contamination of the shallowest aquifer can be assessed from three factors: the potential ease and speed of vertical infiltration, the maximum potential flow velocity, and the potential for dilution by dispersion after a chemical enters the aquifer.

Groundwater sensitivity to nonpoint-source contamination generally decreases with depth as a result of the same factors: infiltration is slower and more tortuous, allowing for degradation and dilution of the chemicals; flow velocities in deep groundwater systems are slower, allowing for additional degradation and dilution of nonpoint-source chemicals; and dispersion and dilution are greater, because deep groundwater systems contain water from large recharge areas.

Within the study area, the sensitivity of shallow groundwater to nonpoint-source contamination can best be summarized by physiographic region (Ray and others, 1994). The uppermost groundwater system is moderately sensitive in the Knobs and the Eastern Kentucky Coal Field, but highly to extremely sensitive in the Eastern Pennyroyal and Inner and Outer Bluegrass Regions.

Local groundwater sensitivity may be very different from these regional assessments, but local conditions cannot be assessed in this regional summary of groundwater quality. Well depth is an approximate indicator of whether a shallow, intermediate, or deep groundwater system is being sampled. Two factors limit the usefulness of well depth as an indicator of groundwater systems, however. First, many wells have no depth recorded, are uncased throughout much of their length and thus collect water from various depths, or are drilled deeper than needed to serve as a water-storage system. Second, a shallow well may actually tap a deep groundwater flow system if the well is located near the discharge region of the groundwater flow system.

Methods

Recorded groundwater analyses were extracted from the Kentucky Groundwater Data Repository. The intent was to extract and summarize analyses of samples that are representative of regional groundwater quality, and to avoid reports from wells or springs that were known or suspected of being contaminated by local conditions. For this reason, samples collected for the Resource Conservation and Recovery Act, Solid Waste, or Underground Storage Tank regulatory programs were excluded. Even so, some of the anomalous values that were included in the resulting data sets may represent local or point-source contamination because there was no basis in the data reports for excluding those results. Determining whether these results are naturally occurring extreme values, inaccurate data entries, or are the result of pollutants would require reviewing the original sample collection reports or visiting the site. Those activities are beyond the scope of this project.

Analytical results from wells deeper than 1,000 ft were excluded because such deep wells are not generally used for domestic water supplies. Some deep samples may have been included in the data sets used here if well depths were not recorded, however.

The following steps were taken to summarize and evaluate the analytical data.

1. **Query the repository database for reports of analyses.** Analytical reports were selected for groundwater-quality constituents that either determine the suitability of the water for various uses, provide geochemical signatures that characterize the regional groundwater flow system, have recognized or suspected impacts on human health, or record the impacts of nonpoint-source contaminants on groundwater. The parameters selected were:

   Water properties: pH, total dissolved solids, conductance, hardness, and total suspended solids
   Inorganic anions: chloride, fluoride, sulfate
   Metals: arsenic, barium, iron, manganese, mercury
   Nutrients: ammonia, nitrate, nitrite, orthophosphate, total phosphorus
   Pesticides: alachlor, atrazine, cyanazine, metolachlor, simazine
   Volatile organic compounds: benzene, ethylbenzene, toluene, xylenes, MTBE

   Both dissolved concentrations (measured from a sample that had been filtered to remove suspended particulate material) and total concentrations (measured from an unfiltered sample) were retrieved from the database for metals.

   Many of the analytes of interest have been reported under a variety of names, and not all analytical results are identified by unique CAS numbers (Chemical Abstract Service registry numbers), so queries were written to return all variations of the analyte name. For example, phosphorus measurements are reported as "orthophosphate," "orthophosphate-P (PO_4-P)," "phosphate," "phosphate-total," "phosphate-ortho," "phosphorus," "phosphorus-ortho," "phosphorus-total," "phosphorus-total by ICP," and "phosphorus-total dissolved." The results were inspected to ensure that each resulting data set contained the appropriate chemical species. All reported analytical units were converted to milligrams per liter.

   Each sample site was assigned a basin management unit number, six-digit HUC number, major watershed name, and physiographic region designation so that the data could be grouped into these categories. GIS coverages of six-digit HUC's and physiographic regions were obtained from the KGS Web site (www.uky.edu/KGS/gis/).

2. **Delete records that do not provide useful information.** The Environmental Protection Agency has established maximum contaminant levels for chemicals that present health risks. Some analytical results in the groundwater data repository were reported only as "less than" a detection limit, where the detection limit was greater than the MCL. These records do not provide useful analytical data for this report and so were eliminated from the data sets.
3. **Count the number of analytical results and the number of sites sampled for each constituent.** Many wells and springs were sampled more than once, so there may be more than one reported concentration for an analyte at a particular site. The number of individual sites was determined by counting unique location identification numbers associated with the analytical records.
4. **Determine quartile values.** Water-quality data are generally positively skewed; that is, concentrations are not symmetrically distributed about a mean value and there are some extremely high values. The combined effect of a non-normal distribution and extreme outlier values is that parametric statistical measures such as mean and standard deviation do not efficiently describe the data. Nonparametric statistical measures such as quartile values and interquartile range provide a better description of the data population (see Helsel and Hirsch, 1992, for example).

   The quartile values are:

   zero quartile value: the minimum value; all other values are greater

   first quartile value: the value that is greater than 25 percent of all values

   second quartile value: the median value; greater than 50 percent of all values

   third quartile value: the value that is greater than 75 percent of all values

   fourth quartile value: the maximum value

   Maximum and minimum concentrations may be anomalous, but the median value and the interquartile range (range of values between the first and third quartile values, also equal to the central 50 percent of the data) provide an efficient summary of the data. Many analytical results are censored data; that is, they are reported as less than a detection limit rather than as an accurately measured concentration. The preferred treatment of censored data depends on the purpose of the analysis. For example, the EPA has established guidelines for treating censored data in Resource Conservation and Recovery Act investigations (U.S. Environmental Protection Agency, 1992). The goals of this report are to summarize ambient groundwater quality and to locate regions affected or threatened by nonpoint-source contamination. Therefore, censored data were treated as if the analyte concentration was equal to the detection limit, but the censored data were ranked below actual measurements at that value when quartile values were determined. For example, a value reported as less than a detection limit of 0.0004 mg/L was ranked below a measured value of 0.0004 mg/L and above a measured value of 0.0003 mg/L for the quartile determinations.
5. **Determine the number of sites at which measurements exceeded water-quality standards.** Because many samples may have been analyzed from a particular well or spring over time, the number of sites at which parameters exceed critical values is a better indicator of regional groundwater quality than the number of measurements that exceed those values. Water-quality standards were provided by DOW (Table 3).
6. **Map sample sites and use various symbols to represent concentration ranges and to show where MCL or other critical values were exceeded.** Maps show sample site locations, site distributions, concentration ranges, and areas where concentrations exceed MCL's or other critical values. Maps also reveal whether analyte values are randomly distributed or are related to watersheds, physiography, or land use.

   Maps were generated using ArcView GIS 3.1. At the scale used in this report and depending on symbol size and shape, sites within a few hundred feet of each other may not be resolved as separate locations. Therefore, the maps are useful for illustrating the general location of sites where various criteria are met or exceeded, but they may not provide an accurate count of those sites. All maps are projected on the NAD 83 datum.
7. **Use summary tables, probability plots, and box-and-whisker diagrams to summarize and illustrate the data and to compare analytical results between watersheds, physiographic**

Table 3. Parameters and water-quality standards used for data summaries.

	Parameter	Standard (mg/L unless otherwise noted)	Source
Water Properties	Conductance	10,000 µS	No MCL or SMCL; approximately corresponds to brackish water
	Hardness (calcium and magnesium)	Soft: 0–17 Slightly hard: 18–60 Moderately hard: 61–120 Hard: 121–180 Very hard: > 180	U.S. Geological Survey
	pH	6.5–8.5 pH units	SMCL
	Total dissolved solids	500	SMCL
	Total suspended solids	35	KPDES
Inorganic Ions	Chloride	250	SMCL
	Sulfate	250	SMCL
	Fluoride	4.0	MCL
Metals	Arsenic	0.010	MCL
	Barium	2.0	MCL
	Iron	0.3	SMCL
	Manganese	0.05	SMCL
	Mercury	0.002	MCL
Nutrients	Ammonia-nitrogen	0.110	DEP
	Nitrate-nitrogen	10.0	MCL
	Nitrite-nitrogen	1.0	MCL
	Orthophosphate-phosphorus	0.04	Texas surface-water standard
	Total phosphorus	0.1	NAWQA
Pesticides	2,4-D	0.007	MCL
	Alachlor	0.002	MCL
	Atrazine	0.003	MCL
	Cyanazine	0.001	HAL
	Metolachlor	0.1	HAL
	Simazine	0.004	MCL
Volatile Organic Compounds	Benzene	0.005	MCL
	Ethylbenzene	0.7	MCL
	Toluene	1.0	MCL
	Xylenes	10	MCL
	MTBE	0.050	DEP

MCL: Maximum contaminant level allowed by EPA in drinking water. Higher concentrations may present health risks.
SMCL: Secondary maximum contaminant level (EPA). Higher concentrations may degrade the sight, smell, or taste of the water.
NAWQA: National Water-Quality Assessment Program, U.S. Geological Survey. Higher concentrations may promote eutrophication.
HAL: Health advisory level. Higher concentrations may present concerns for human health.
KPDES: Kentucky Pollution Discharge Elimination System. Standard set for water-treatment facilities.
DEP: Kentucky Department for Environmental Protection risk-based concentration. Higher concentrations may present health risks.

regions, or other groupings. Summary tables list the number of measurements and sites, quartile values, and the number of sites where concentrations exceed MCL's or other standard values for each BMU.

Normal probability plots (cumulative data plots) (Fig. 2) show the distribution of values as a percentage of the total number of analytical results. They provide an easy way to identify outlier values. The cumulative data plots in this report exclude the highest and lowest 0.1 percent of the values so that extremely high or low values do not compress the display of the majority of the data. Therefore, probability plots of data sets that contain more than 1,000 measurements do not show the absolute maximum and minimum values. Each plot also includes a straight line that shows the locus of points along which the data would fall if the measurements were normally distributed.

Box-and-whisker diagrams (Fig. 3) show the median value and the interquartile range, and illustrate how clustered or scattered analytical results are. The box extends from the first quartile value to the third quartile value, thereby including the central 50 percent of the data. Either a center line or notches within the box shows the median value. Whiskers extend from each edge of the box a distance of 1.5 times the interquartile range. Values that are more than 1.5 times the interquartile range are shown as squares; values that are more than 3.0 times the interquartile range above the third quartile value or below the first quartile value are shown as squares with plus signs through them. The presence of far outside points indicates suspect values or a highly skewed distribution. Probability plots and box-and-whisker plots were generated using Statgraphics Plus for Windows v. 4.1.

The general approach for each analyte is:

1. Define the analyte; summarize common natural sources, uses, and potential contaminant sources; list relevant water-quality criteria; and describe how excessive amounts affect water use and human health.
2. Summarize analytical reports from BMU's 1, 2, and 5 by constructing summary data tables and cumulative data plots.
3. Show sample-site distribution and sites where water-quality standards are met or exceeded by mapping sample sites and concentration ranges.
4. Summarize data for each physiographic region and major watershed by constructing box-and-whisker plots.
5. Compare data by site type (well versus spring) and sample type (total versus dissolved) by constructing box-and-whisker plots.
6. Evaluate the impact on shallow (less than 200 ft), intermediate (200 to 500 ft), and deep (greater than 500 ft) groundwater flow systems by plotting concentrations versus well depth.
7. Summarize probable causes of observed concentrations and distribution of values.

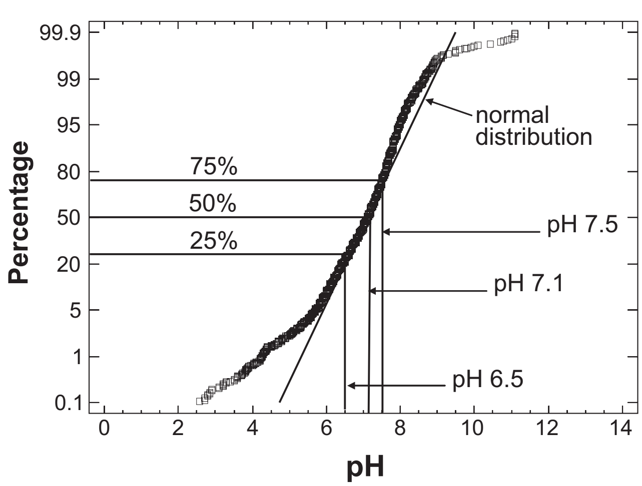

Figure 2. Cumulative data plot for all pH values reported in Kentucky groundwater.

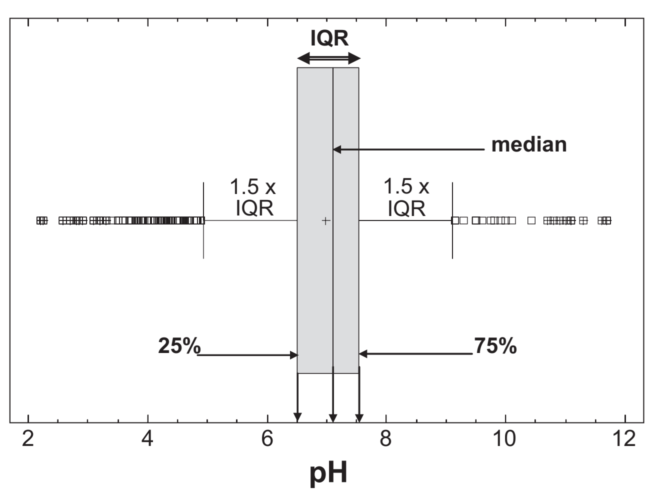

Figure 3. Box-and-whisker plot for all pH values reported in Kentucky groundwater.