Groundwater Quality in Watersheds of the Big Sandy River, Little Sandy River, and Tygarts Creek (Kentucky Basin Management Unit 5)

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Abstract

The Kentucky Geological Survey and the Kentucky Division of Water are evaluating groundwater quality throughout the commonwealth to determine regional conditions, assess impacts of nonpoint-source contaminants, provide a baseline for tracking changes, and provide essential information for environmental-protection and resource-management decisions. These evaluations include summarizing existing regional groundwater-quality data and reporting the results of expanded, focused groundwater collection programs in specific areas. This report summarizes groundwater sampling and analysis in Kentucky basin management unit 5 (watersheds of the Big Sandy River, Little Sandy River, and Tygarts Creek in eastern Kentucky).

Thirty wells and springs were sampled quarterly between the fall of 2002 and the summer of 2003. Temperature, pH, and conductance were measured at the sample site, and concentrations of a selected group of major and minor inorganic ions, metals, nutrients, pesticides, and volatile organic chemicals were measured at the Kentucky Division of Environmental Services laboratory. The new analytical data were combined with groundwater-quality records retrieved from the Kentucky Groundwater Data Repository. This 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 results of 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. Statistical measures such as the number of measured concentrations reported, the number of sites sampled, quartile values (maximum 75th percentile, median, 25th percentile, and minimum), and the number of sites at which water-quality standards were exceeded were used to summarize the data, and probability plots were used to illustrate the distribution of reported concentrations. Maps were used to show well and spring locations and sites where water-quality standards were met or exceeded. Box-and-whisker diagrams were used to compare values between major watersheds, water from wells versus water from springs, and total versus dissolved metal concentrations. Plots of concentrations versus well depth were used to compare groundwater quality in shallow, intermediate, and deep groundwater flow systems.

Table A1 summarizes the findings. Water properties, inorganic anions, and metals are primarily controlled by natural factors such as bedrock lithology. Some exceptionally high values of conductance, chloride, and sulfate may be affected by nearby oil and gas production, leaking waste-disposal systems, or other human factors, and some exceptionally low pH values may in-

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dicate acid mine drainage. Ammonia and nitrate concentrations indicate a probable contribution from nutrient applications and waste-disposal practices. Synthetic organic chemicals such as pesticides and refined volatile organic compounds do not occur naturally. Although these chemicals rarely exceed water-quality criteria in the project area, their detection indicates there has been some degradation of groundwater quality. The occurrence of these synthetic chemicals should continue to be monitored, and renewed efforts are needed to protect the groundwater resource.

Table A1. Summary of nonpoint-source effects on groundwater quality in basin management unit 5.

	Parameter	No Strong Evidence for Nonpoint-Source Impact on Groundwater Quality	Some Evidence for Nonpoint-Source Impact on Groundwater Quality	Clear Evidence for Nonpoint-Source Impact on Groundwater Quality
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[1]		X	

[1] Methyl tertiary-butyl ether

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. In this report we summarize groundwater quality in the northeastern part of Kentucky (Kentucky basin management unit 5, consisting of watersheds of the Big Sandy River, Little Sandy River, and Tygarts Creek).

Goals

The goals of this project were to summarize the concentrations of a select group of groundwater-quality parameters in the project area, and to evaluate whether nonpoint-source chemicals have entered the groundwater system. This was accomplished by selecting approximately 30 wells and springs that had not been previously sampled, collecting a groundwater sample from each site quarterly over a 12-month period, and having the samples analyzed by the Kentucky Division of Environmental Services laboratory. Those analytical results were combined with other data obtained from the Kentucky Groundwater Data Repository and compared to criteria selected by the Division of Water. The results provide a basis for identifying natural and anomalous concentrations of dissolved chemicals as well as areas where nonpoint-source chemicals have entered the groundwater system and where the implementation of best management practices is needed. The results also supply information for the Division of Water's watershed assessment reports, add groundwater-quality data to the Division's Groundwater Protection Program, help the Division's Wellhead Protection Program set priorities for protection 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 Division of Water 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 in rural areas expensive or impractical, 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. 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 stormwater runoff can deliver pesticides, fertilizers, nutrients, metals, and hydrocarbons to groundwater.

Previous Investigations

Several earlier reports describe the hydrology, groundwater resources, and general water quality of the study area. None 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 developed in conjunction with the Kentucky Geological Survey. Each atlas covers from two to 10 counties across the state, except in the Jackson Purchase Region, which had an atlas for each 7.5-minute quadrangle. Each atlas includes three sheets showing geology, lithology, and groundwater availability. The atlases have been digitally 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. These reports (www.uky.edu/KGS/water/library/webintro.html) contain from 16 to 31 pages per county of information on geology, hydrogeologic characteristics of aquifers, available water supplies, and availability of groundwater for public consumption. Price and others (1962) published a comprehensive groundwater resource report for the Eastern Kentucky Coal Field. This report covered only major and minor inorganic ions and nitrate, however; 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 Water 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 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 was a large source of analyses of groundwater, surface water, and stream sediments (Smith, 2001). Data from both these reports are stored in the Kentucky Groundwater Data Repository and were used in this report.

Project Area

The Division of Water's Watershed Management Framework grouped Kentucky's river basins into five basin management units (BMU's; Fig. 1). The current project area is BMU 5 (Big Sandy River, Little Sandy River, and Tygarts Creek, and adjacent tributaries of the Ohio River).

With the exception of the extreme northern tip of BMU 5, the project area is in the Eastern Kentucky Coal Field physiographic region (Fig. 1). This region 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).

Basin Management Unit 5

Basin management unit 5 includes watersheds of the Big Sandy River, Little Sandy River, and Tygarts Creek (Fig. 2). This area covers approximately 4,610 mi^2. 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 include oil and gas production, leaking sewage disposal systems, and runoff from active and abandoned coal mines, deforested areas, and confined animal-feeding operations (Kentucky Division of Water, 2000).

BMU 5 includes all or parts of the following 15 counties: Boyd, Carter, Elliott, Floyd, Greenup, Johnson, Knott, Lawrence, Letcher, Lewis, Magoffin, Martin, Morgan, Pike, and Rowan.

Hydrologic 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, 1976). The HUC designations of watersheds in BMU 5 are listed in Tables 1 and 2.

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 human 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 human factors such as the type of land use, the type 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, the Division of Water 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 the potential ease and speed of vertical infiltration, the maximum potential flow

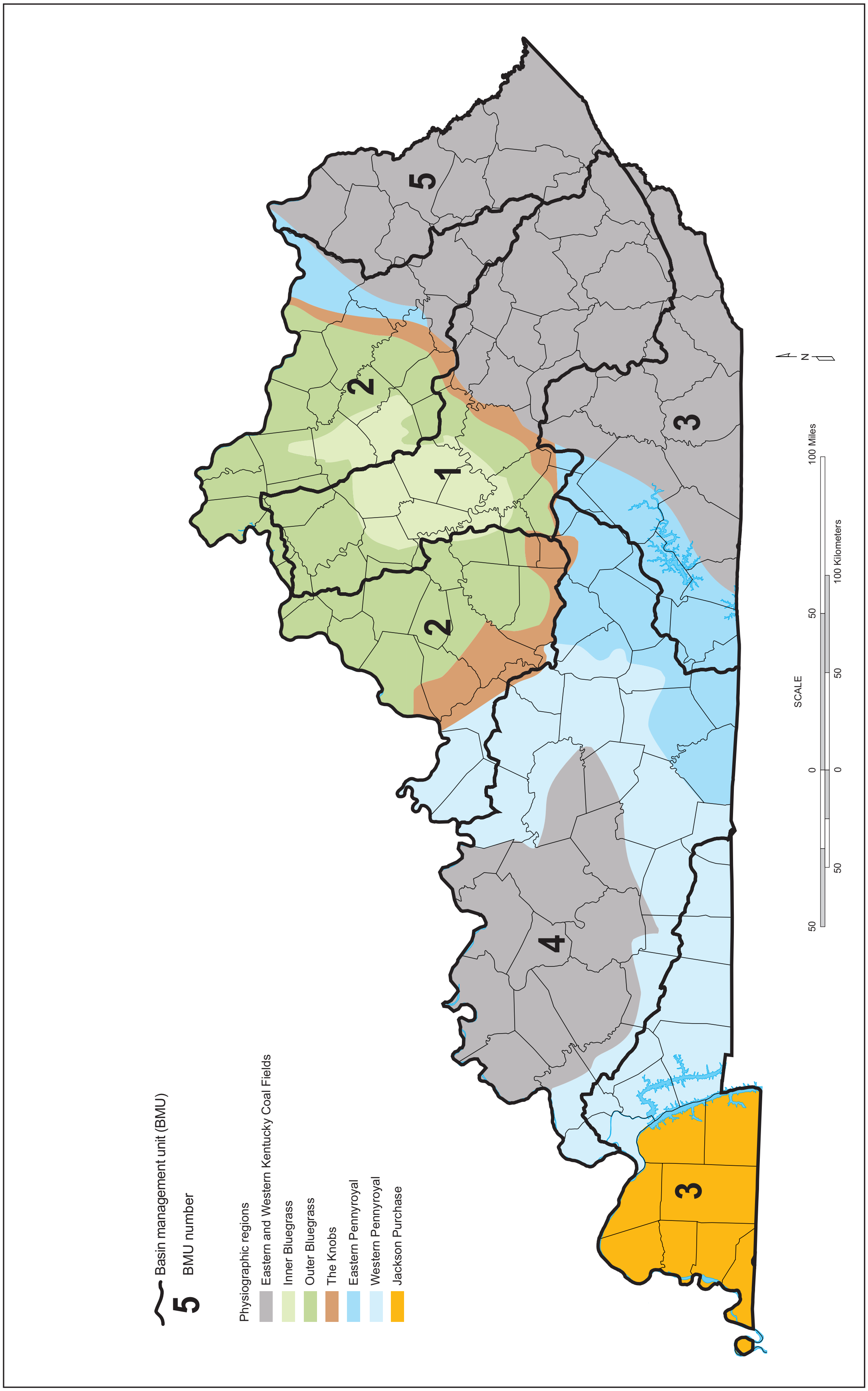

Figure 1. Major watersheds, physiographic regions, and basin management units in Kentucky.

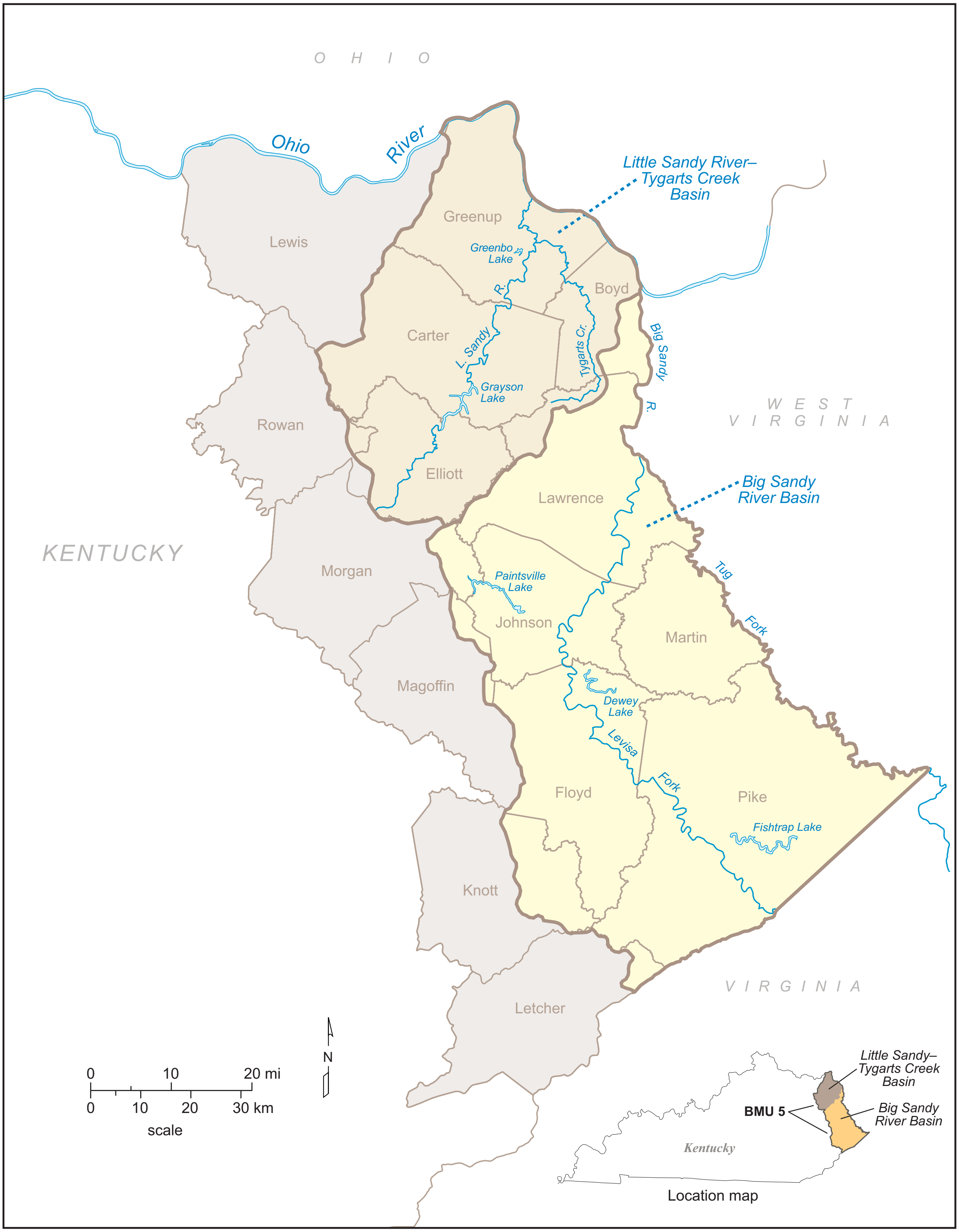

Figure 2. Major watersheds and counties in basin management unit 5.

Table 1. Watershed names and six-digit HUC designations for basin management unit 5.

Six-Digit HUC	HUC 6 Name	Area (mi^2)
050702	Big Sandy River	2,290
050901	Tygarts Creek, Little Sandy River, Ohio River	2,320

Table 2. Watershed names and eight-digit HUC designations for basin management unit 5.

Eight-Digit HUC	HUC 8 Name	Area (mi^2)
05070201	Big Sandy River	478
05070202	Upper Levisa Fork	359
05070203	Levisa Fork	1,116
05070204	Big Sandy River, Blaine Creek	337
05090103	Ohio River, Tygarts Creek	438
05090104	Little Sandy River	726

velocity, and the potential for dilution by dispersion within the subsurface.

Ray and others (1994) concluded that the uppermost groundwater system is moderately sensitive to contamination in the Eastern Kentucky Coal Field, relative to the rest of the state. Groundwater sensitivity to nonpoint-source contamination generally decreases with depth because infiltration is slower and more tortuous, allowing for degradation and dilution of the chemicals; flow velocities are also slower, allowing for additional degradation of chemicals. And dispersion and dilution are greater because deep groundwater systems contain water from large recharge areas.

Local groundwater sensitivity may be very different from these regional assessments, but local conditions cannot be assessed in this regional summary. 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 system, 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

Site Selection

The groundwater sampling program is intended to represent the various physiographic, geologic, land-use, and demographic settings in the river basins. Resource limitations preclude drilling new wells; therefore, candidate sites were selected from existing wells and springs. The site selection process followed three steps.

1. Each 7.5-minute quadrangle in BMU 5 was assigned a number, and 30 numbers were drawn at random. To be eligible for selection, the center of each quadrangle had to fall within BMU 5. Quadrangles in which groundwater monitoring was currently being performed were not considered. If there were no suitable wells or springs in the selected quadrangle, an adjacent quadrangle was selected.
2. Within each selected quadrangle, potential sample sites were ranked according to type, use, condition, and accessibility. Large springs were preferred over wells because such springs collect water from large basin areas and are more sensitive to nonpoint-source pollution. Public wells or nonregulated public springs used for domestic purposes were chosen over private wells or wells used for livestock or irrigation. Springs protected from surface runoff and properly constructed wells were preferred to avoid sample contamination. Readily accessible springs and wells were selected over sites in remote locations or sites with limited access.
3. Final site selections were made only after field inspection to ensure that seasonal monitoring was feasible and after obtaining permission from owners. Sample sites are listed in Table 3.

Sample Collection

Samples were collected in the fall, winter, spring, and summer from November 2002 through September 2003. Conductance, temperature, and pH were measured at each site and recorded in a field log book. Meters and electrodes were calibrated using standard

Table 3. Sites used for monitoring.

Quadrangle	County	AKGWA[1]	Latitude	Longitude	Well Depth (ft)
Adams	Lawrence	0001-0545	38.068889	–82.665556	180
Argillite	Greenup	0003-2501	38.419862	–82.840755	100
Belfry	Pike	0003-2502	37.601577	–82.317562	80–100
Blaine	Lawrence	0004-6810	38.027778	–82.820000	105
Boltsfork	Boyd	0003-2503	38.258743	–82.710555	90–100
Burnaugh	Boyd	0003-2504	38.277265	–82.592570	170
Dorton	Pike	0003-2505	37.308668	–82.541591	50–60
Grahn	Carter	9000-2567	38.368571	–83.107085	spring
Grayson	Carter	0003-2506	38.272225	–82.906884	80
Inez	Martin	0005-0406	37.794139	–82.522083	90
Isonville	Elliott	0004-3781	38.070021	–83.121917	265
Jamboree	Pike	0003-2507 & 0001-8874	37.476373	–82.185014	102
Jenkins East	Pike	0003-2508	37.208845	–82569746	59
Kite	Knott	0003-2509	37.344662	–82.781904	35
Lancer	Floyd	0003-2510	37.659130	–82.644453	60
Martin	Floyd	0003-2511	37.505902	–82.781273	> 100
Mazie	Lawrence	0003-8804	38.003611	–82.896389	435(?)
Meta	Pike	0003-2512	37.612601	–82.411734	60
Millard	Pike	0003-2513	37.440980	–82.464534	35
Milo	Martin	0003-2514	37.935280	–82.533764	108
Offutt	Johnson	0001-2311	37.761111	–82.691389	75
Oil Springs	Johnson	0000-5743	37.801944	–82.891389	115
Olive Hill	Carter	9000-2570	38.303746	–83.202611	spring
Paintsville	Johnson	0003-2515	37.776712	–82.831102	103
Portsmouth	Greenup	0003-2516	38.636771	–82.941586	65
Redbush	Johnson	0003-2517	37.910626	–82.900877	160–180
Sitka	Lawrence	0003-2518	37.883641	–82.831211	120–125
Wayland	Knott	9000-2573	37.386964	–82.828231	mine
Wesleyville	Carter	0003-2521	38.435811	–83.138423	40
Willard	Carter	0003-2520	38.203626	–82.917586	98

buffer solutions and cleaned after each use according to manufacturers' specifications.

Samples for measurement of chemical constituents were collected and preserved as necessary for laboratory analysis. All materials that contacted the sample were either new, disposable equipment, or were decontaminated prior to and after each use. Sample containers were labeled with the site name and well or spring identification number, collection date and time, analysis requested, preservation method, and collector's initials.

Bacteria were not sampled for logistical reasons. Sample collection trips visited six to 12 sites over a 1- to 2-day period, commonly in remote regions. The short holding time for bacteria (6 hours for fecal coliform, 24 hours for total coliform) prohibited collecting aliquots for bacterial analysis and delivering them to a laboratory within the holding time, while maintaining sampling efficiency for all other parameters.

Duplicate samples were collected for at least 10 percent of all samples in order to check reproducibility and provide QA/QC control. One duplicate sample was submitted with each batch of samples. Field blanks of deionized water were collected, filtered, and preserved in the same manner as a sample and submitted once per quarter.

Sample containers, preservation methods, and holding-time requirements are outlined in the Kentucky Division of Water's "Standard Operating Procedures for Nonpoint Source Surface Water Quality Monitoring Projects," prepared by the Water Quality Branch. Sampling personnel completed a chain-of-custody record developed in conjunction with the Kentucky Division of Environmental Services laboratory for each sample. Specific sample-collection methods are documented in the project QA/QC plan, which was approved by the Division of Water before sampling began. The approved QA/QC plan is attached as Appendix A.

Sample Analysis

All samples were delivered to the Kentucky Division of Environmental Services laboratory for analysis. Major and minor inorganic solutes, dissolved and total metals, nutrients, pesticides, and volatile organic chemicals were determined according to EPA-approved laboratory procedures. The analytical results were entered into the Kentucky Department for Environmental Protection's Consolidated Groundwater Database and copied to the Kentucky Groundwater Data Repository at the Kentucky Geological Survey.

Data Analysis and Evaluation

Analytical results from both the current sampling program and from earlier investigations were combined for this report. Previous results of groundwater analyses were extracted from the Kentucky Groundwater Data Repository. The intent was to extract and summarize analyses of samples that were representative of regional groundwater quality, and to avoid reports from wells or springs that were known to be 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 values that were included in the resulting data sets may represent local or point-source contamination because there was nothing in the data reports to identify these samples as part of a regulatory program. Determining whether anomalous results are naturally occurring extreme values, inaccurate data entries, or the result of point-source pollution would require collecting and analyzing new samples from the site, which is 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.

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 parameters that have recognized impacts on human health, determine the suitability of the water for domestic use, provide geochemical signatures that characterize the regional groundwater system, or record the impacts of nonpoint-source contaminants on groundwater. The parameters selected were:

   Water properties: pH, total dissolved solids, conductance, hardness, total suspended solids

   Inorganic anions: chloride, fluoride, sulfate

   Metals: arsenic, barium, iron, manganese, mercury

   Nutrients: ammonia, nitrate, nitrite, orthophosphate, total phosphate

   Pesticides: 2,4-D, alachlor, atrazine, cyanazine, metolachlor, simazine

   Volatile organic compounds: benzene, ethylbenzene, toluene, MTBE (methyl tertiary-butyl ether).

   Some of the analytes of interest have been reported under a variety of names, and not all analytical results are identified by unique CAS (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 data set contained the appropriate chemical species. All reported analytical units were converted to milligrams per liter.

   Each sample site was assigned a six-digit HUC number and major watershed name so that the data could be grouped into these categories. GIS coverages of six-digit HUC's and watershed names were obtained from the KGS Web site (www.uky.edu/KGS/gis/intro.html).
2. **Delete records that do not provide useful information.** The U.S. Environmental Protection Agency has established maximum contaminant levels for many 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 data for this report and so were eliminated from the data sets.
3. **Count the number of analytical results and sample sites for each constituent.** Most wells and springs were sampled more than once, so several concentrations may have been reported for an analyte at a single site. The number of 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 some values are extremely high. 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 adequately describe the data. Nonparametric statistical measures such as quartile values and

interquartile range provide a better description of the data population (see, for example, Helsel and Hirsch, 1992).

The quartile values used in this report 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 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, 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, 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 regional groundwater quality and to locate areas 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 quartile determination.

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 the Division of Water (Table 4).
6. **Map site locations and show concentration ranges.** Maps show sample-site locations, site distribution, concentration ranges, and areas where concentrations exceeded MCL's or other critical values. Maps also reveal whether analyte values were randomly distributed or were 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 thousand feet of each other may not be resolved as separate locations. Therefore, the maps show the locations of sites where various criteria are met or exceeded, but may not provide an accurate count of those sites. All maps are projected on NAD 83.
7. **Use summary tables, probability plots, and box-and-whisker diagrams to summarize the data and compare results between watersheds or other groupings.** Summary tables list the number of measurements and sites, quartile values, and the number of sites where concentrations exceeded critical values. Probability plots (cumulative data plots; Fig. 3) show values sorted from smallest to largest plotted versus percentage of the total number of analytical results. They provide an easy way to read percentile values, to identify extreme (outlier) values, and to answer questions such as: what is the probability that a new sample in this region will exceed a particular value? The cumulative data plots in this report exclude the highest 0.1 percent of the values so that extremely high values do not compress the display of the majority of the data. Therefore, probability plots may not show the absolute maximum value.

   Box-and-whisker diagrams (Fig. 4) show the median value and interquartile range, and illustrate how clustered or scattered the data are. The box extends from the first quartile value to the third quartile value, including the central 50 percent of the data. A center line or notches within the box show 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.

Table 4. 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	0.07	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 (U.S. Environmental Protection Agency). Concentrations higher than the MCL may present health risks.
SMCL: Secondary maximum contaminant level (U.S. Environmental Protection Agency). Concentrations greater than the SMCL may degrade the sight, smell, or taste of water.
NAWQA: National Water-Quality Assessment Program (U.S. Geological Survey). Higher concentrations may promote algal growth and eutrophication.
HAL: Health advisory level. Higher concentrations may have an impact on 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.

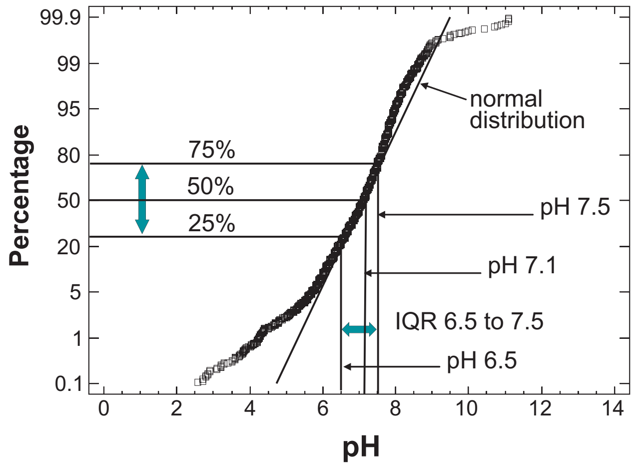

Figure 3. Example of a cumulative data plot, showing all pH values reported in Kentucky groundwater.

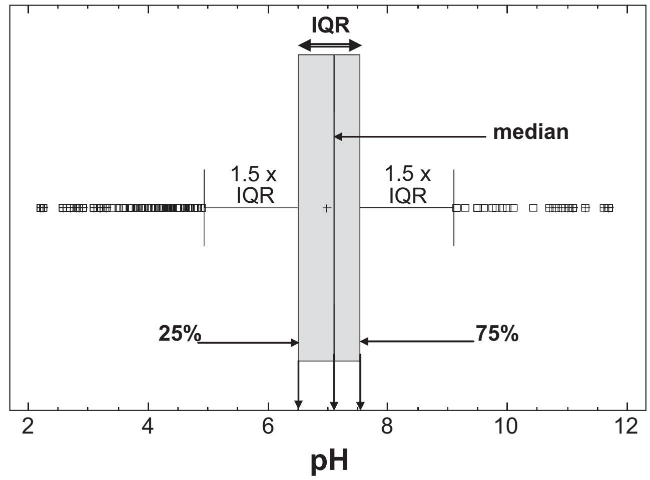

Figure 4. Example of a box-and-whisker plot showing all pH measurements reported in Kentucky groundwater.

The approach for each analyte was:

1. Define the analyte; summarize 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 results by constructing summary data tables and cumulative data plots.
3. Show sample-site distribution and sites where water-quality standards were met or exceeded on maps.
4. Summarize data for each watershed by constructing box-and-whisker plots.
5. Compare data by site type (wells versus springs) and sample type (total versus dissolved metals) 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 systems by plotting concentrations versus well depth.
7. Summarize probable causes of observed concentrations and distribution of values.