

Kentucky Geological Survey
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**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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Technical Level



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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 north-eastern 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 fac-

tors 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 storm-water 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 mi² (Fig. 1). The Kentucky River originates in the

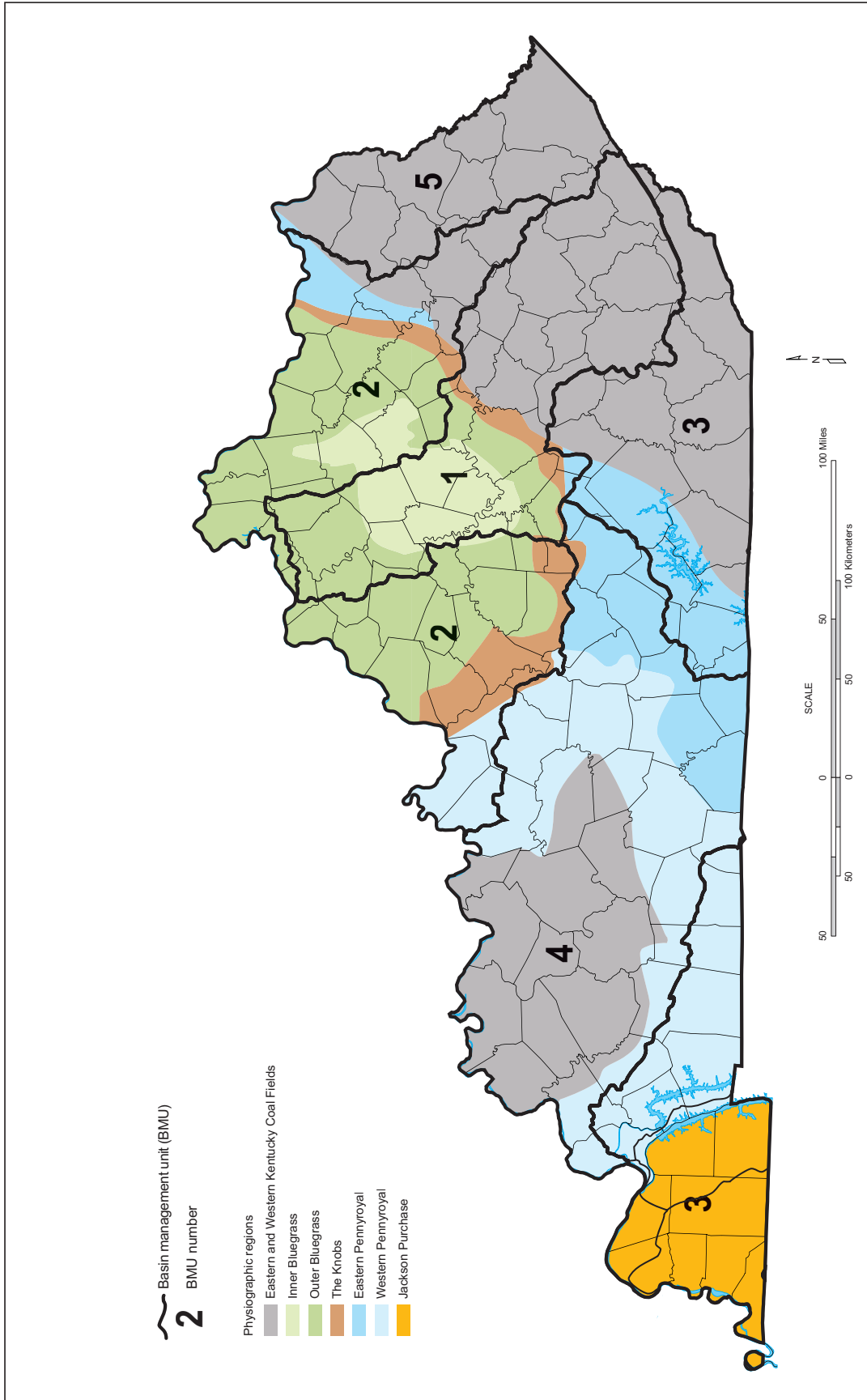


Figure 1. Locations of major river watersheds, physiographic regions, and basin management units. This study summarizes groundwater-quality data from basin management units 1, 2, and 5.

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 mi², 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 mi². 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 ur-

ban 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 mi² 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 west 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 Hydrogeologic 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 practic-

es, 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 ($\text{PO}_4\text{-P}$)," "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 μ S	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.

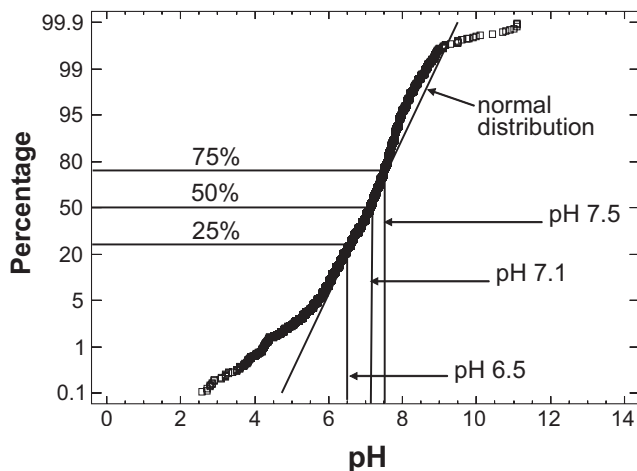


Figure 2. Cumulative data plot for all pH values reported in Kentucky groundwater.

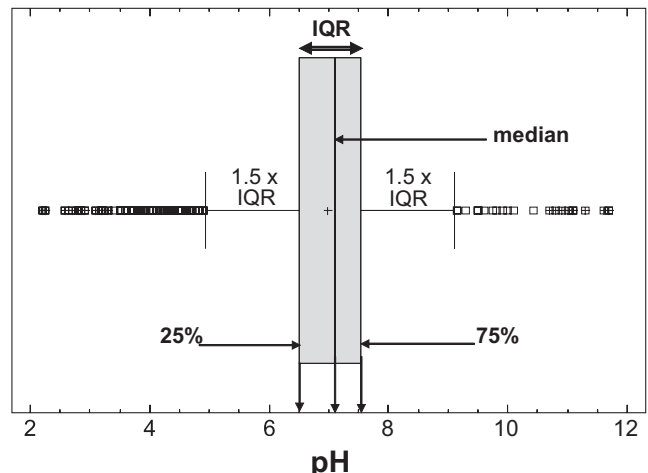


Figure 3. Box-and-whisker plot for all pH values reported in Kentucky groundwater.

Results

Water Properties

pH. The property pH (negative base-10 logarithm of hydrogen ion activity in moles per liter) is one of the most fundamental water-quality parameters. It is easily measured, indicates whether water will be corrosive or will precipitate scale, determines the solubility and mobility of most dissolved constituents, and provides a good indication of the types of minerals groundwater has reacted with as it flows from recharge to discharge area or sample site. For these reasons it is one of the most important parameters that describe groundwater quality.

The pH of neutral (neither acidic nor basic) water varies with temperature. For example, the neutral pH of pure water at 25°C (77°F) is 7.0. The neutral pH of pure water at 30°C (86°F) and 0°C (32°F) is 6.9 and 7.5, respectively (Hem, 1985). Solutes, including dissolved gases, also affect pH. Rain that has equilibrated with atmospheric carbon dioxide has a pH of about 5.6 (Hem, 1985). Streams and lakes in humid regions such as Kentucky typically have pH values between 6.5 and 8. Soil water in contact with decaying organic material can have values as low as 4, and the pH of water that has reacted with iron sulfide minerals in coal or shale can be even lower. In the absence of coal and associated iron sulfide minerals, the pH of groundwater typically ranges from about 6.0 to 8.5, depending on the type of soil and rock contacted. Reactions between groundwater and sandstones result in pH values between about 6.5 and 7.5, whereas groundwater flowing through carbonate strata can have values as high as 8.4.

There are no health-based drinking water standards for pH. Very high or very low pH values can lead to high dissolved concentrations of some metals for which there are drinking-water standards and associated health effects, however. Water with pH higher than 8.5 or lower than 6.5 can produce staining, etching, or scaling. Therefore, the Environmental Pro-

tection Agency has established a secondary standard (SMCL) for pH of 6.5 to 8.5.

The data repository contained 4,388 pH values from 828 sites in the study area (Table 4). The pH data are generally similar in BMU's 1, 2, and 5. The median values in each basin management unit are within 0.5 pH unit of each other, and the interquartile ranges are similar. Minimum pH values are also similar, but the maximum values are quite different.

Cumulative data plots (Figs. 4–6) show some differences between basin management units. BMU 1 has many values less than 6.5 and greater than 8.5 (Fig. 4), whereas samples from BMU 2 and BMU 5 show many values less than 6.5 but very few values greater than 8.5 (Figs. 5–6). The pH values from BMU 2 are more tightly clustered about the median than values from the other basin management units (Fig. 5).

Distribution of sampled sites through the project area is very uneven (Fig. 7). The Eastern Kentucky Coal Field and Western Pennyroyal Regions are more

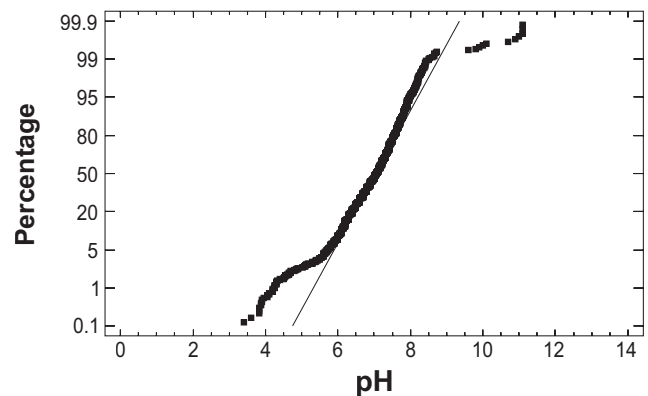


Figure 4. Cumulative plot of pH values from BMU 1.

densely sampled than the other regions. This sample-site distribution in part reflects differences in groundwater use throughout the area. The map also shows that pH values vary considerably in the Eastern Kentucky Coal Field but are more uniform in the carbonate

settings of the Inner Bluegrass, Outer Bluegrass, and Western Pennyroyal Regions. Values less than 6.5 are restricted to the Eastern Kentucky Coal Field and Knobs Regions; pH values greater than 8.5 are rare outside the Eastern Kentucky Coal Field.

Grouping pH values by physiographic region (Fig. 8) shows the variability within the Eastern Kentucky Coal Field relative to the other regions.

Table 4. Summary of pH values (standard pH units). SMCL: 6.5 to 8.5.

	BMU 1	BMU 2	BMU 5
Values	2,005	778	1,605
Maximum	11.6	8.6	10.4
75th percentile	7.5	7.7	7.4
Median	7.1	7.4	6.9
25th percentile	6.5	7.2	6.4
Minimum	2.3	2.8	2.6
Interquartile range	1.0	0.5	1.0
Sites	288	278	262
Sites < 6.5	112	35	87
Sites > 8.5	8	2	2

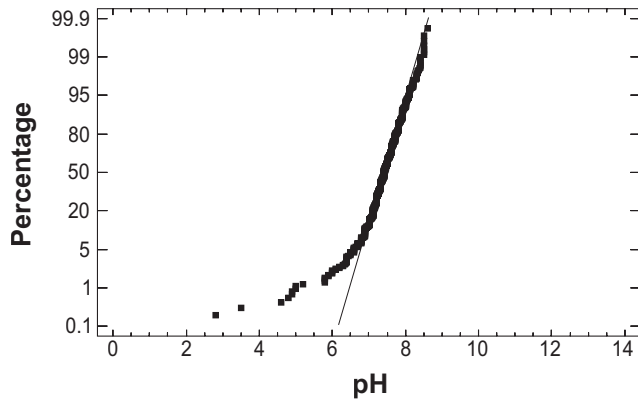


Figure 5. Cumulative plot of pH values from BMU 2.

Samples from the Eastern Kentucky Coal Field produce the highest and lowest pH values reported and the greatest range of pH values. Also, the interquartile range of values is greater for groundwater from the Eastern Kentucky Coal Field than for water from other regions. This pattern is probably the result of the lithologic heterogeneity in the coal fields, whereas bedrock type in the other regions is less variable. The lithologically similar Inner and Outer Bluegrass and Eastern and Western Pennyroyal Regions have similar interquartile ranges.

Group pH values by major watershed (Fig. 9) shows the greatest variability in the Kentucky River watershed, which drains the Eastern Kentucky Coal Field, Knobs, and Inner and Outer Bluegrass Regions.

Groundwater from wells generally has somewhat lower and more variable pH values than groundwater from springs (Fig. 10). Wells also show more pH values greater than 8.5 than springs, probably because wells are more common in the lithologically heterogeneous Eastern Kentucky Coal Field, whereas springs are more common in the carbonate Bluegrass and Pennyroyal Regions.

Shallow wells show a greater range of pH values than deeper wells (Fig. 11), suggesting that groundwater in intermediate and deep flow systems has equili-

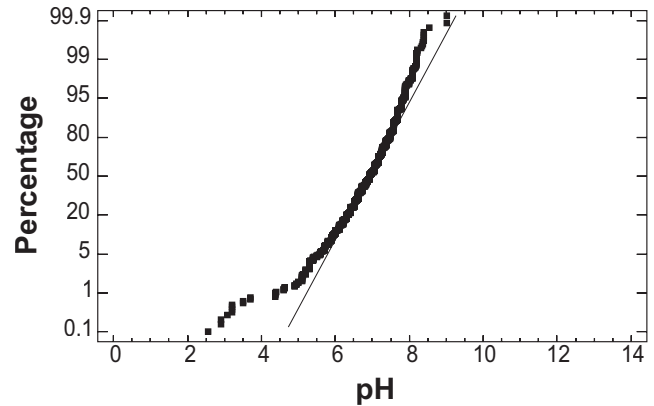


Figure 6. Cumulative plot of pH values from BMU 5.

brated with bedrock, whereas shallower groundwater systems have not.

In summary, sample-site distribution for pH is not uniform throughout the project area. The Eastern Kentucky Coal Field and Western Pennyroyal Regions are relatively well sampled, whereas large parts of the Inner and Outer Bluegrass have not been sampled. Groundwater pH values and ranges of values are more closely related to physiographic region and underlying bedrock lithology than to basin management unit or watershed. Groundwater in the predominantly carbonate regions is nearly neutral, and pH values show relatively little scatter. In the Eastern Kentucky Coal Field, where bedrock lithology is more heterogeneous, most groundwater is near neutral to slightly acidic, but there is a much wider range of values. In general, pH values reflect bedrock geology rather than nonpoint-source effects. The pH of springs and shallow wells is much more variable than the pH observed in intermediate and deep wells. The decrease in variability of pH with sample depth shows that groundwater in intermediate and deep flow systems has equilibrated with bedrock to a greater extent than groundwater in springs and shallow wells.

A statewide summary of pH data (Fisher, 2002b) can be viewed on the KGS Web site (kgsweb.uky.edu/olops/pub/kgs/ic06_12.pdf).

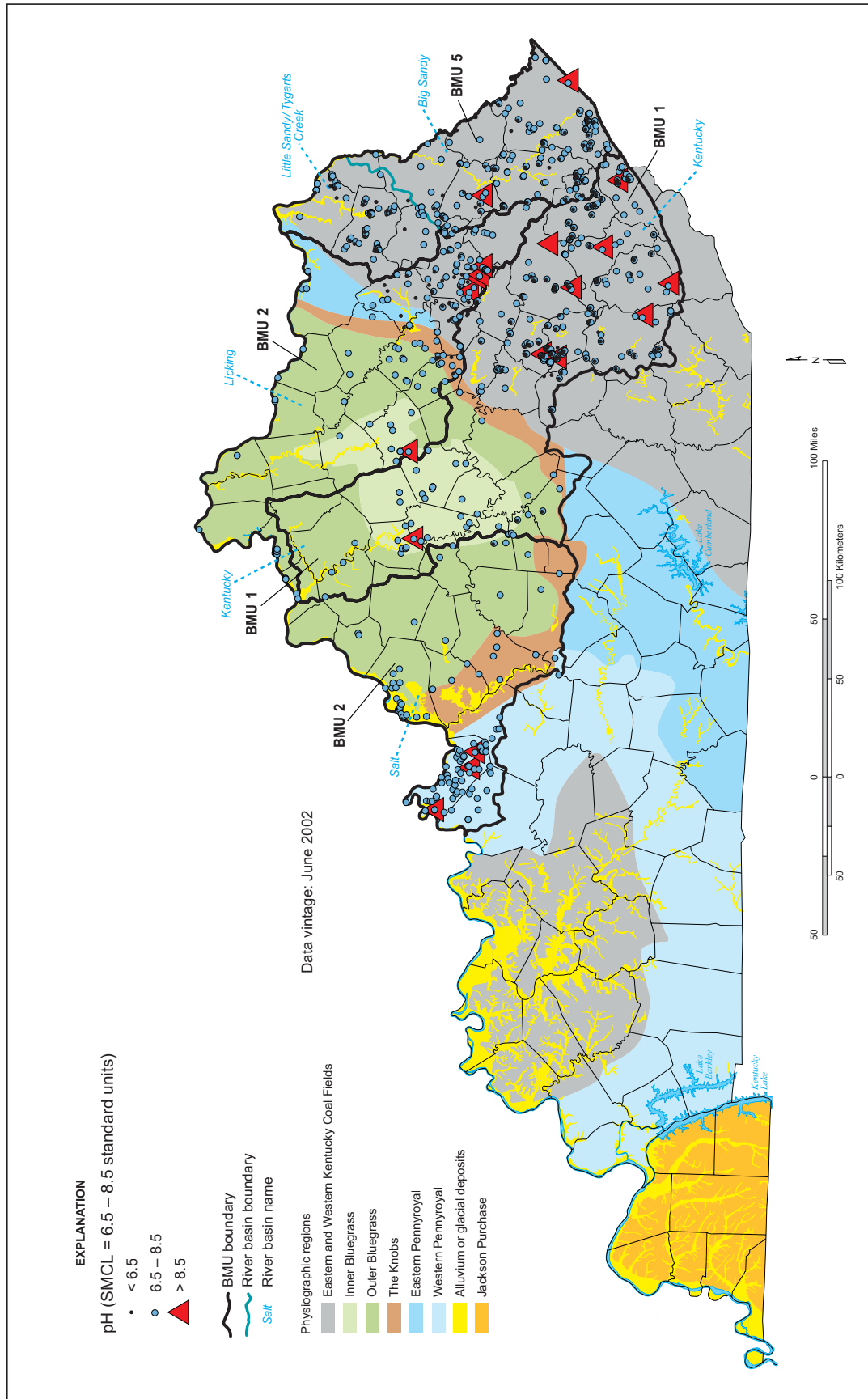


Figure 7. Locations of sampled sites and ranges of pH values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

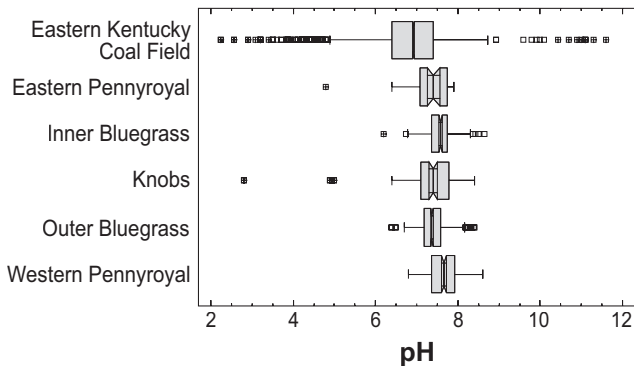


Figure 8. Summary of pH values grouped by physiographic region.

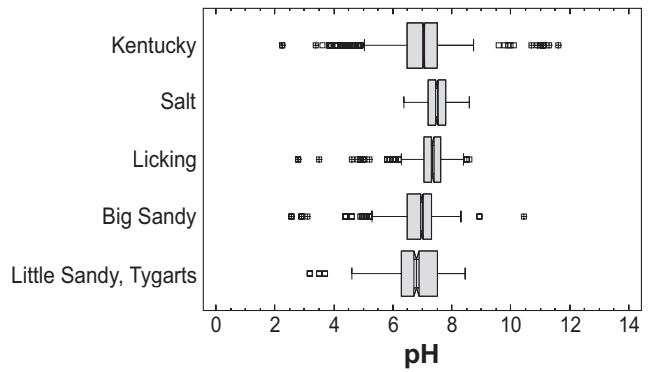


Figure 9. Summary of pH values grouped by major watershed.

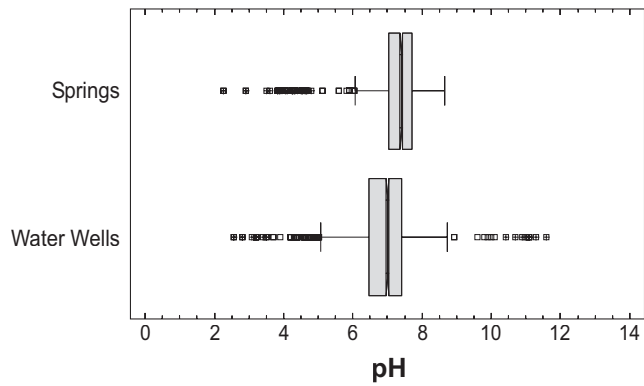


Figure 10. Comparison of pH values from wells and springs.

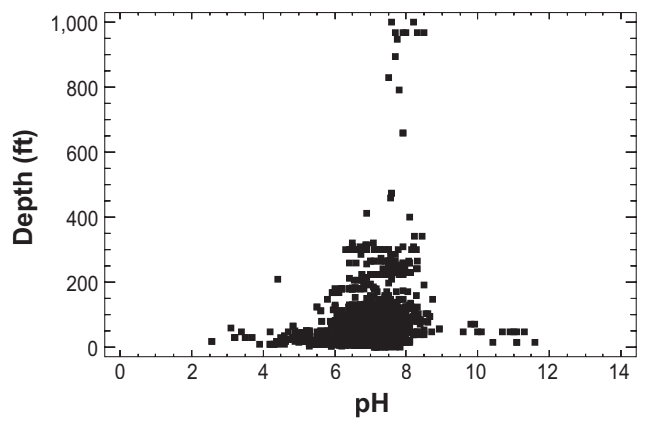


Figure 11. Plot of pH values versus well depth.

Total Dissolved Solids. Total dissolved solids is the sum of all dissolved chemicals in water expressed as mg/L. TDS can be calculated by adding all the solute concentrations from a complete chemical analysis or measured as the weight of the residue remaining after a known volume of water has been evaporated to dryness. TDS typically increases with sample depth or the distance that groundwater has traveled from recharge area to sample site.

TDS values are a general indicator of the suitability of groundwater for various uses (Mazor, 1991, p. 94-95):

Potable water: up to 500 mg/L TDS

Slightly saline water: adequate for drinking and irrigation (500 to 1,000 mg/L TDS)

Medium saline water: potable only in cases of need; may be used for some crops and aquaculture (1,000 to 2,500 mg/L TDS)

Saline water: adequate for aquaculture and industrial use (2,500 to 5,000 mg/L TDS)

Brackish water: 5,000 to 35,000 mg/L TDS (the salinity of seawater)

Brine: TDS greater than 35,000 mg/L

The EPA has set an SMCL of 500 mg/L for total dissolved solids. Water having values greater than 500 mg/L has an unpleasant taste and may stain objects or precipitate scale.

The Kentucky Groundwater Data Repository contained 1,185 reports of total dissolved solids at 230 sites in the project area (Table 5). Nearly all samples and sites yielded potable water; the 75th percentile value

Table 5. Summary of total dissolved solids values (mg/L). SMCL: 500 mg/L.

	BMU 1	BMU 2	BMU 5
Values	599	441	145
Maximum	60,364	18,000	2,880
75th percentile	406	442	414
Median	320	358	298
25th percentile	254	234	222
Minimum	0	10	60
Interquartile range	152	208	192
Sites	82	86	62
Sites > 500 mg/L	24	16	19

for each basin management unit is less than 500 mg/L. Only 59 of 230 sites (26 percent) yielded groundwater with more than 500 mg/L total dissolved solids.

Cumulative data plots (Figs. 12-14) show some differences between the basin management units. A break in slope at about 100 mg/L suggests two different populations of data in BMU 1 (Fig. 12). More than 95 percent of the values from BMU 2 follow a normal distribution, whereas values from BMU 5 show a distribution typical of a positively skewed data set.

The distribution of sampled sites is densest in the Eastern Kentucky Coal Field and Inner Bluegrass, and least dense in the Outer Bluegrass (Fig. 15), a consequence of variations in groundwater use in the project area.

Groundwater from the Eastern Kentucky Coal Field has the highest TDS values, the greatest number of values greater than 1,000 mg/L, and the largest spread in the central 50 percent of the data (Fig. 16). Samples from the Eastern and Western Pennyroyal and the Inner Bluegrass Regions have the smallest spread in the central 50 percent of the reported values.

Grouping total dissolved solids values by major watershed (Fig. 17) shows that all watersheds have about the same range and magnitude of values for the central 50 percent of the data. There are many more values greater than 1,000 mg/L reported from the Kentucky River watershed than from any other major river basin, however.

Groundwater from wells has a somewhat higher median value of total dissolved solids than groundwater from springs (Fig. 18), although the ranges are quite similar.

With the exception of a few high-TDS reports from shallow wells, there is no systematic trend of total dissolved solids with well depth (Fig. 19).

In summary, more than 75 percent of the groundwater sampled in the project area is potable in terms of TDS, although there are exceptions in each basin management unit, physiographic region, and major watershed. Saline to brackish groundwater is most likely to be encountered in the Eastern Kentucky Coal Field. Total dissolved solids values are generally similar in each basin management unit and each major river watershed. There are systematic differences in the data for each physiographic region, however. This indicates that total dissolved solids values are controlled more by the bedrock geologic differences between physiographic regions than by the geographic differences between basin management units or major watersheds. There is no clear evidence that nonpoint-source chemicals are influencing regional trends in total dissolved solids values.

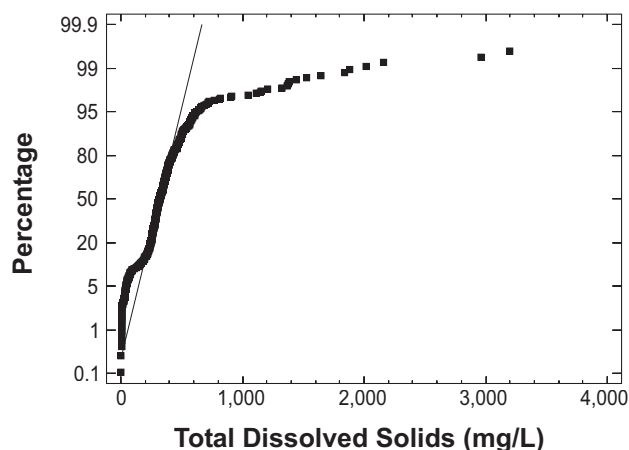


Figure 12. Cumulative plot of total dissolved solids values from BMU 1. Two values greater than 4,000 mg/L were omitted for clarity.

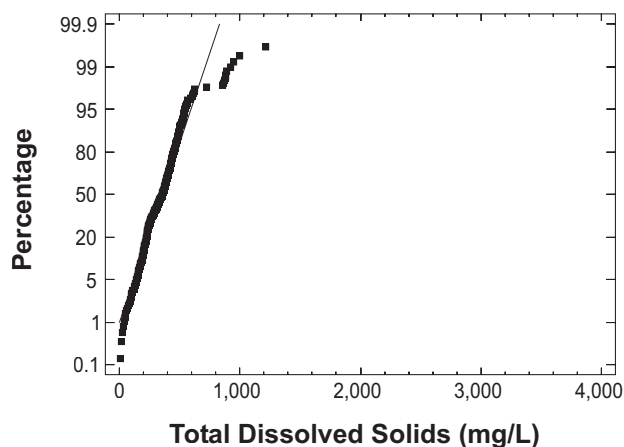


Figure 13. Cumulative plot of total dissolved solids values from BMU 2. One value greater than 4,000 mg/L was omitted for clarity.

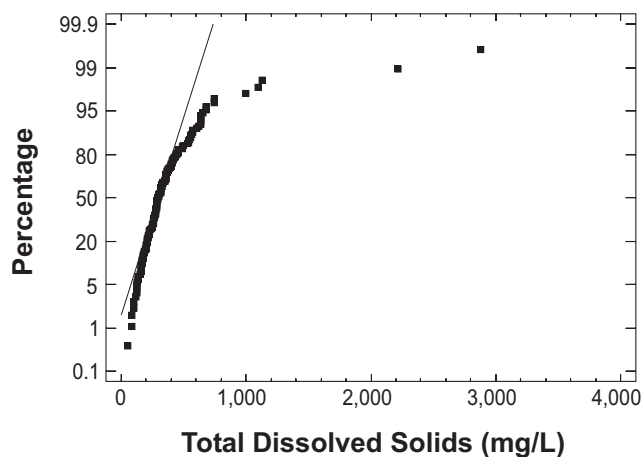


Figure 14. Cumulative plot of total dissolved solids values from BMU 5. No values exceeded 4,000 mg/L.

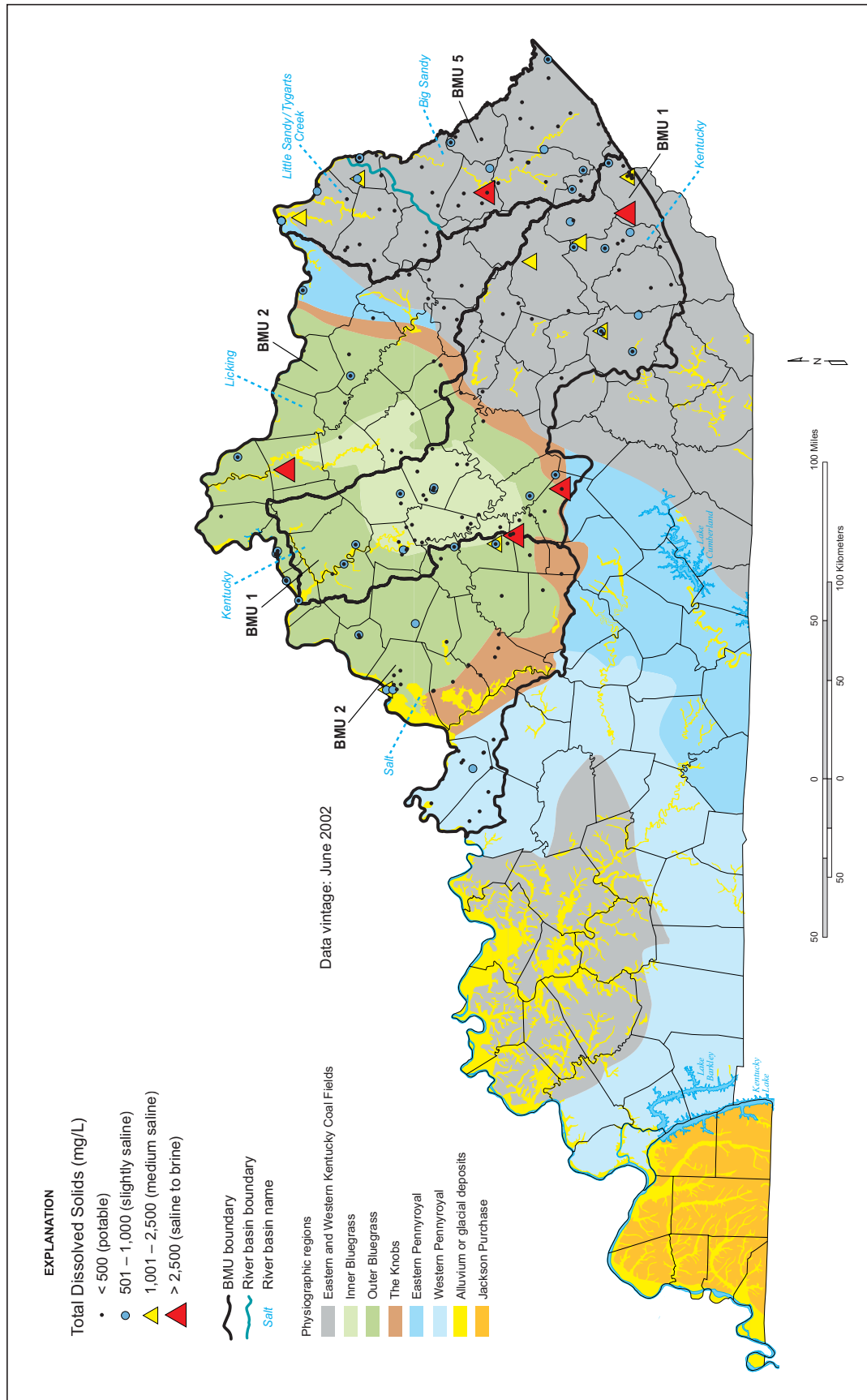


Figure 15. Locations of sampled sites and ranges of total dissolved solids values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

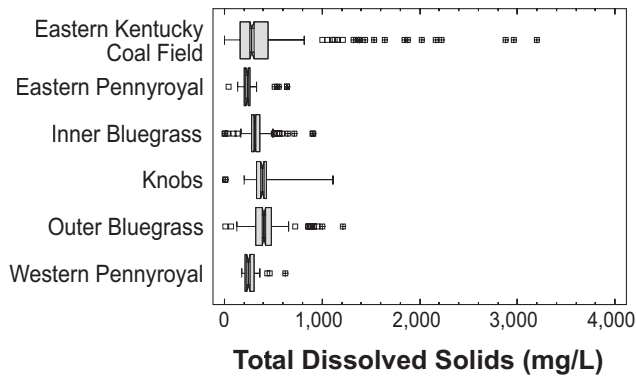


Figure 16. Summary of total dissolved solids values grouped by physiographic region.

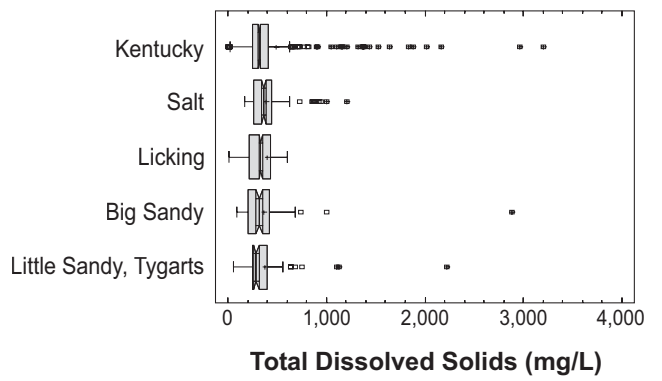


Figure 17. Summary of total dissolved solids values grouped by major watershed.

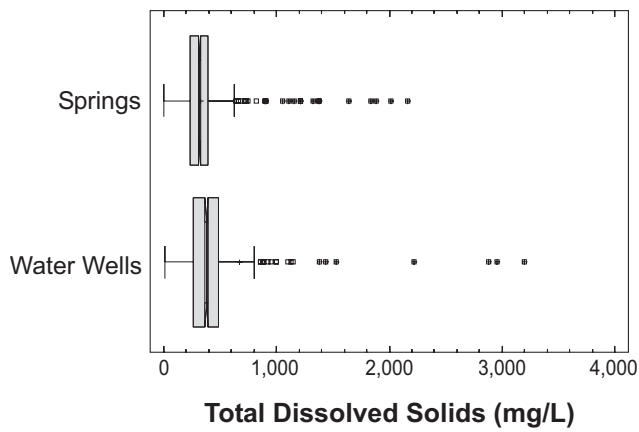


Figure 18. Comparison of total dissolved solids values from wells and springs.

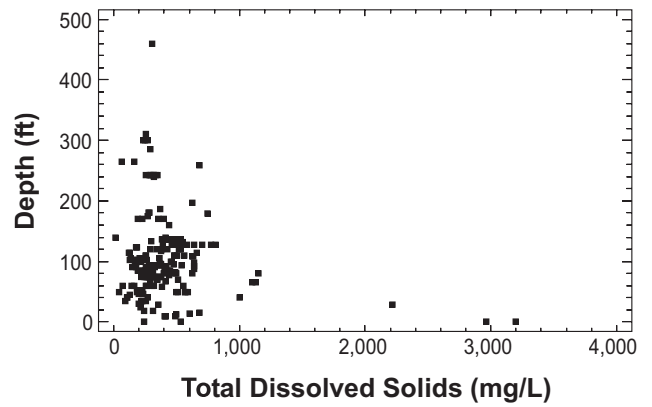


Figure 19. Plot of total dissolved solids values versus well depth.

Specific Electrical Conductance. Specific electrical conductance, also referred to as conductivity, is a measure of the ease with which water conducts an electrical current. It is an indirect measure of water quality and is proportional to total dissolved solids concentrations. Specific electrical conductance is a quick and simple measurement to make in the field, and provides a relative comparison of water quality if the samples being compared have nearly the same temperature and predominant cations and anions (for example, sodium and chloride or calcium and bicarbonate).

Conductance is reported in micromhos per centimeter at 25°C, or the numerically equivalent microSiemens per centimeter ($\mu\text{S}/\text{cm}$) in the International System of Units (Hem, 1985). Because conductance does not directly indicate water quality, there are no health or water-use standards based on this parameter.

The data repository contained 10,874 conductance measurements from 4,628 sites in the project area (Table 6). This large number of measurements is the result of the extensive field sampling program associated with the National Uranium Resource Evaluation project (Smith, 2001). Values range from 0 to 205,000 $\mu\text{S}/\text{cm}$. Groundwater from BMU 2 has higher 75th percentile, median, and 25th percentile conductance values and a larger interquartile range than groundwater from the rest of the project area.

The data distributions for the lowest 95 percent of the measured values are similar for the three basin management units (Figs. 20–22). Few groundwater samples from BMU 2 have conductance values greater than 50,000 $\mu\text{S}/\text{cm}$, whereas such values are more common in BMU 1 and BMU 5. The data distribution for BMU 2 (Fig. 21) has a distinct break in slope at about 20,000 $\mu\text{S}/\text{cm}$, which suggests that two different populations are included in the data set.

There are many more sampled sites in the southern half of the project area, below approximately 38°N latitude, than in the northern half (Fig. 23), because sampling for the National Uranium Resource Evaluation program did not extend north of this line. Sites where conductance exceeded 10,000 $\mu\text{S}/\text{cm}$ are more

common in the Eastern Kentucky Coal Field than in the other regions.

The median conductance value and interquartile range of values is higher for measurements from sites in the Knobs Region than in any other region (Fig. 24). This is because 10 sites in the Knobs Region have yielded high-conductance samples on 48 occasions; the number of high conductance values is large, but the number of sites producing that water is small. Samples from the Eastern Kentucky Coal Field have the lowest median value, whereas samples from the Inner Bluegrass and Western Pennyroyal Regions have the smallest interquartile range. Nearly all of the conductance values are less than 4,000 $\mu\text{S}/\text{cm}$.

Grouping the measurements by major river basin (Fig. 25) shows the Licking River watershed to have the highest median, interquartile range, and 75th percentile values. Nearly all of the conductance values in the project area are less than 4,000 $\mu\text{S}/\text{cm}$, however.

Groundwater from wells has higher median values and interquartile range than groundwater from springs (Fig. 26), as well as many more reported values greater than 4,000 $\mu\text{S}/\text{cm}$.

The vast majority of the conductance values from wells are less than 10,000 $\mu\text{S}/\text{cm}$, and within that group there is a general trend toward lower values with increasing well depth (Fig. 27). There is considerable scatter in the data, however.

In summary, conductance is an indirect indicator of groundwater quality, related to salinity or total dissolved solids, but not a direct measure of either. There are no health-based standards or aesthetic effects associated with high conductance values. Conductance values are as high as 205,000 $\mu\text{S}/\text{cm}$ in the project area. There is little systematic regional variation, however. More than 97 percent of the reported values are less than 5,000 $\mu\text{S}/\text{cm}$, and more than 98 percent of the reported values are less than 10,000 $\mu\text{S}/\text{cm}$. The highest conductance values reported in the project area are from wells deeper than 600 ft. There are no clear indications of nonpoint-source effects on conductance values in the project area.

Table 6. Summary of conductance values ($\mu\text{S}/\text{cm}$).

	BMU 1	BMU 2	BMU 5
Values	3,601	5,119	2,154
Maximum	142,000	172,000	205,000
75th percentile	530	1,480	580
Median	350	710	325
25th percentile	195	450	195
Minimum	0	0	0
Interquartile range	335	1,030	385
Sites	1,753	1,827	1,04

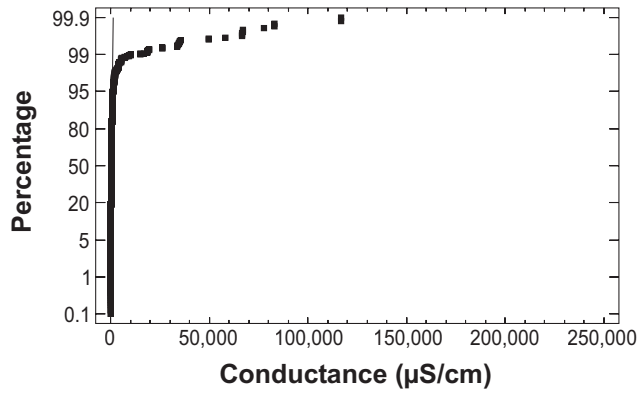


Figure 20. Cumulative plot of conductance values from BMU 1. The highest 0.1 percent of values is omitted so that the central 99.8 percent of the data can be presented more clearly.

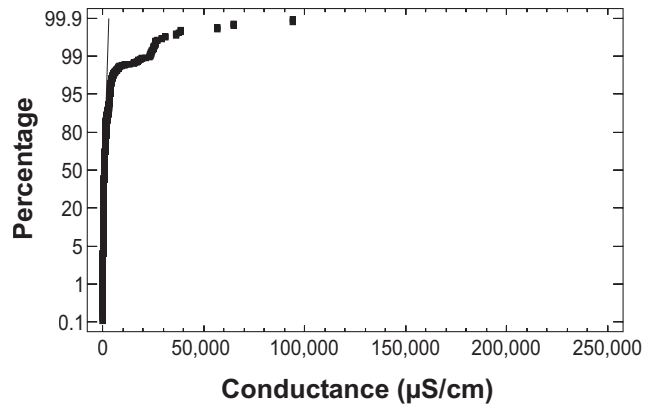


Figure 21. Cumulative plot of conductance values from BMU 2. The highest 0.1 percent of values is omitted so that the central 99.8 percent of the data can be presented more clearly.

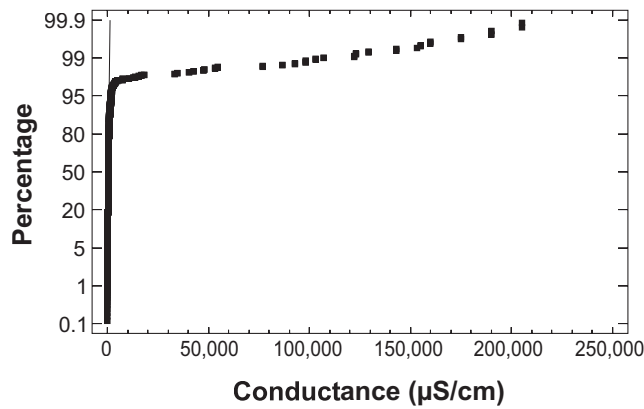


Figure 22. Cumulative plot of conductance values from BMU 5. The highest 0.1 percent of values is omitted so that the central 99.8 percent of the data can be presented more clearly.

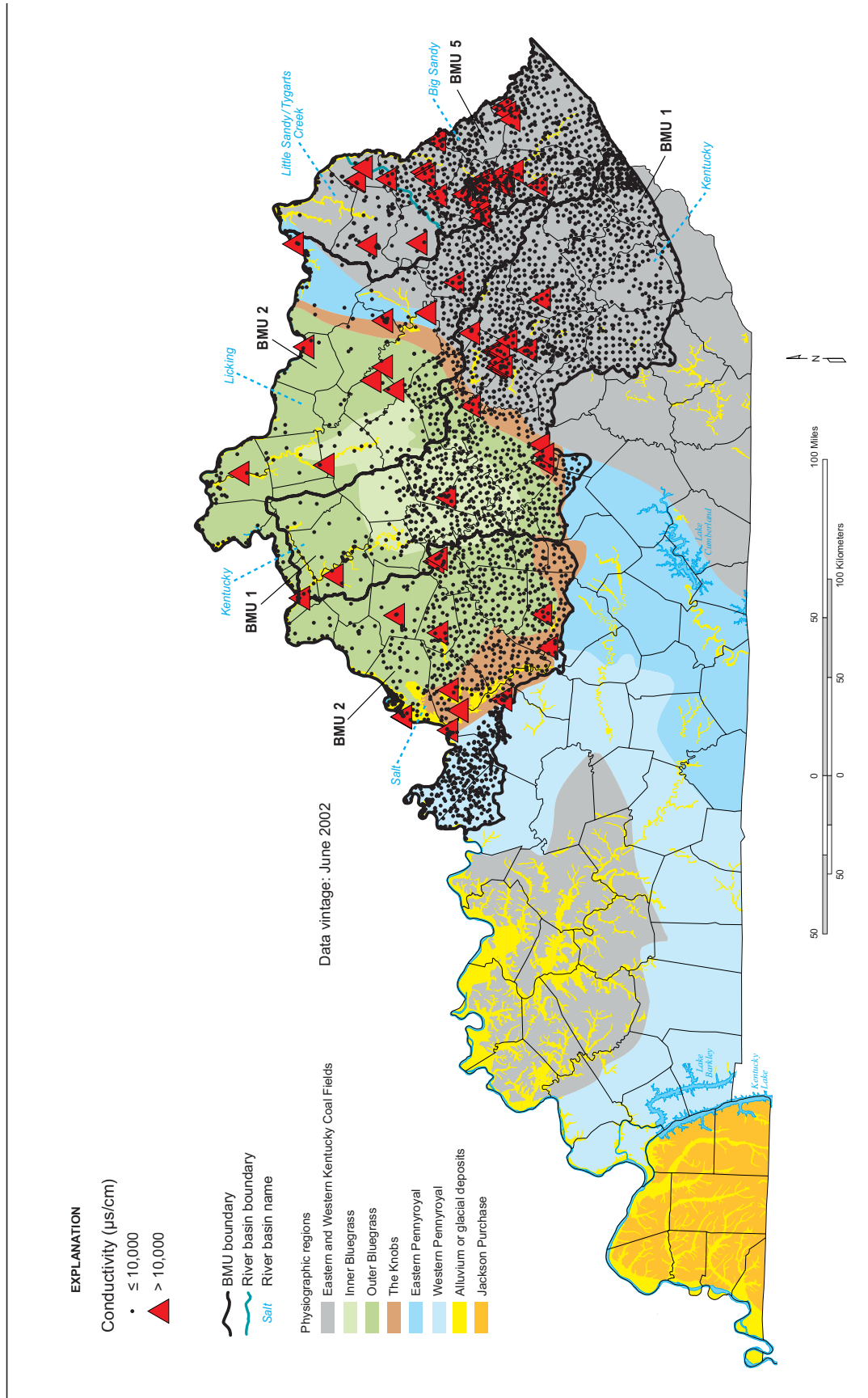


Figure 23. Locations of sampled sites and ranges of conductance values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

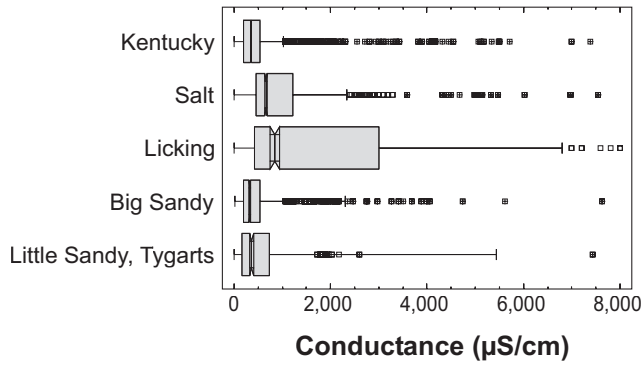


Figure 24. Summary of conductance values grouped by physiographic region. Higher values have been omitted to better show the majority of the data.

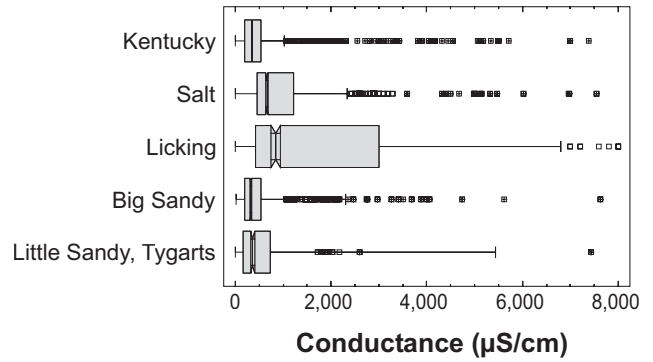


Figure 25. Summary of conductance values grouped by major river watershed. Higher values have been omitted to better show the majority of the data.

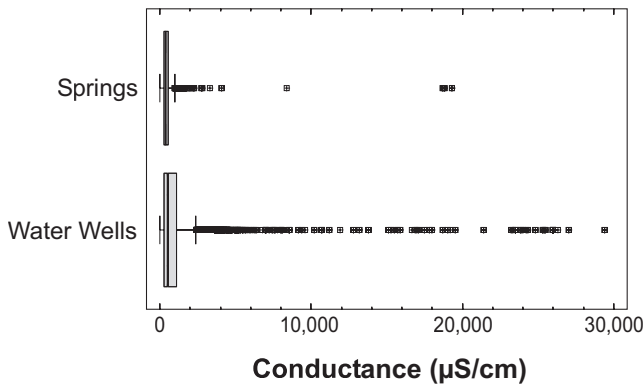


Figure 26. Comparison of conductance values from wells and springs. Higher values have been omitted to better show the majority of the data.

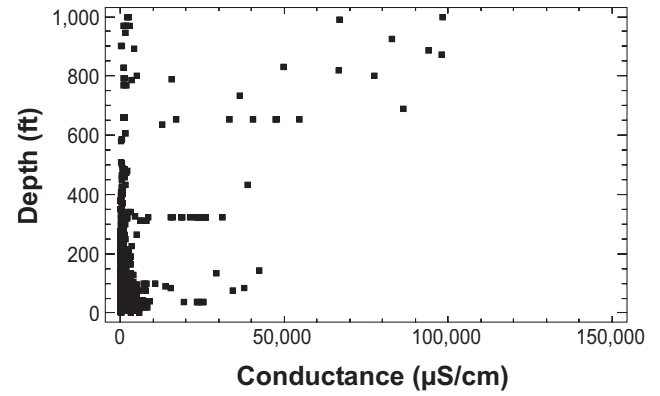


Figure 27. Plot of conductance values versus well depth.

Hardness. Hardness is the capacity of water to precipitate an insoluble residue when soap is used, and to form a scale on containers when water evaporates. Hard water reduces the ability of soap and detergents to clean clothes; leaves a sticky film on skin, clothes, and hair; and deposits scale in water heaters, boilers, and industrial equipment.

Because calcium and magnesium are largely responsible for the behavior of soap in water, hardness is usually defined as the concentrations of calcium and magnesium expressed as an equivalent amount of calcium carbonate:

$$\text{Hardness (mg/L calcium carbonate equivalent)} = 2.5 \text{ Ca (mg/L)} + 4.1 \text{ Mg (mg/L)}$$

Table 7 shows a frequently used classification of hardness in water supplies (U.S. Geological Survey, 2006).

Table 7. Hardness classification of water supplies.

Hardness Category	Concentration (mg/L)
Soft	0–17
Slightly hard	18–60
Moderately hard	61–120
Hard	121–180
Very hard	> 180

Calcium and magnesium concentrations from the data repository were combined according to the above equation to produce a total of 1,550 groundwater hardness values at 436 sites in the project area. Because most sites were sampled and analyzed more than once, the calculated hardness values for individual samples at a site were averaged to give the number of sites meeting various water-quality criteria (Table 8). Hard to very hard water is predominant in each basin management unit. Soft to moderately hard water is uncommon, except in BMU 5, where 69 of 137 sites produced such water.

Cumulative data plots (Figs. 28–30) show that hardness values greater than 10,000 mg/L are present in each BMU. More than 95 percent of the values are less than 1,000 mg/L, however. Basin management

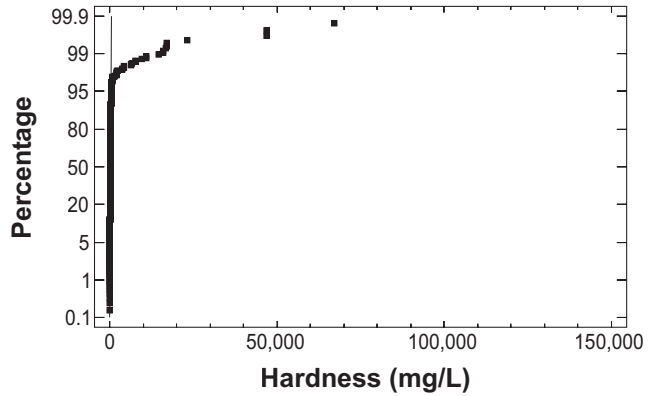


Figure 28. Cumulative plot of hardness values from BMU 1.

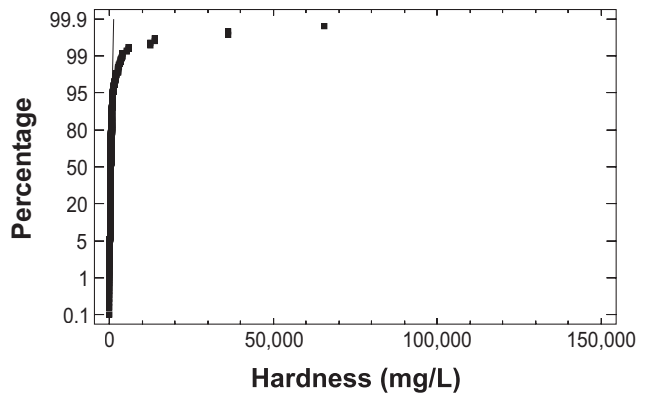


Figure 29. Cumulative plot of hardness values from BMU 2.

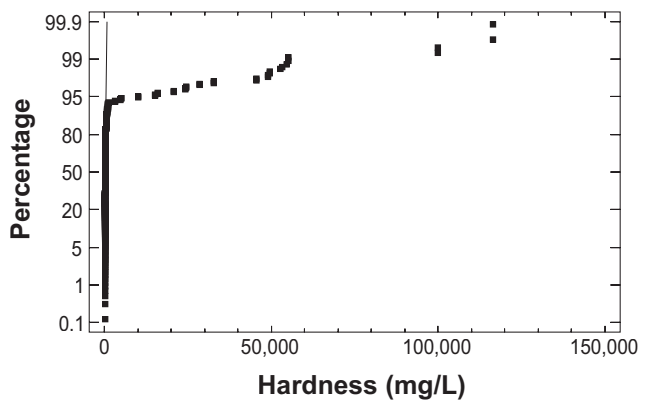


Figure 30. Cumulative plot of hardness values from BMU 5.

Table 8. Summary of the number of sites in various hardness categories.

	BMU 1	BMU 2	BMU 5
Values	339	937	274
Sites	100	199	137
Sites with soft water	2	1	3
Sites with slightly hard water	13	4	23
Sites with moderately hard water	10	8	43
Sites with hard water	13	6	25
Sites with very hard water	62	180	43

unit 5 has the hardest water and the greatest number of values that exceed 10,000 mg/L.

The distribution of sampled sites is extremely uneven throughout the project area (Fig. 31). In the Licking River watershed, the northeastern half of basin management unit 2, 72 sites are located mostly in the Ohio River alluvium and the Inner Bluegrass Region; very few sites in the interior of the watershed have been sampled. The eastern part of the Eastern Kentucky Coal Field and the northern parts of the Salt and Kentucky River watersheds are also more densely sampled than the other parts of the project area. Hard to very hard water is found throughout, but soft to moderately hard water is rare outside of the Eastern Kentucky Coal Field.

The Outer Bluegrass Region has the highest median hardness value and the largest interquartile range (Fig. 32). The Eastern Kentucky Coal Field has the lowest (softest) median value, whereas the Inner Bluegrass Region has the smallest interquartile range.

Grouping the hardness values by major watershed (Fig. 33) shows that samples from the Salt River Basin have the highest median value and largest interquartile range, whereas samples from the Kentucky River watershed have the smallest interquartile range (least variability within the central 50 percent of the data). Groundwater from the Big Sandy River watershed has the lowest median value.

Groundwater from wells has higher median hardness, larger spread of the central 50 percent of values, and more very high hardness values than water from springs (Fig. 34).

The hardest water is reported from wells deeper than 600 ft (Fig. 35). The trend of the majority of reported values is to decrease with well depth, however.

In summary, the distribution of sites at which water hardness could be calculated is very uneven throughout the project area. Water hardness is strongly related to bedrock geology, however, and so can be predicted in areas where there has been no sampling. Groundwater in the Inner Bluegrass and Western Pennyroyal Regions, which are underlain by limestone strata, is typically hard to very hard. Groundwater in the lithologically heterogeneous Eastern Kentucky Coal Field has highly variable hardness. Hard to very hard water occurs at more than 75 percent of the sites in the project area. Although groundwater is typically hard to very hard throughout the project area, few sites have hardness values greater than 1,000 mg/L. For such sites, water softeners can remove much of the calcium and magnesium that cause hardness problems. No significant effect of nonpoint-source chemicals is indicated because water hardness values correspond closely with bedrock geology.

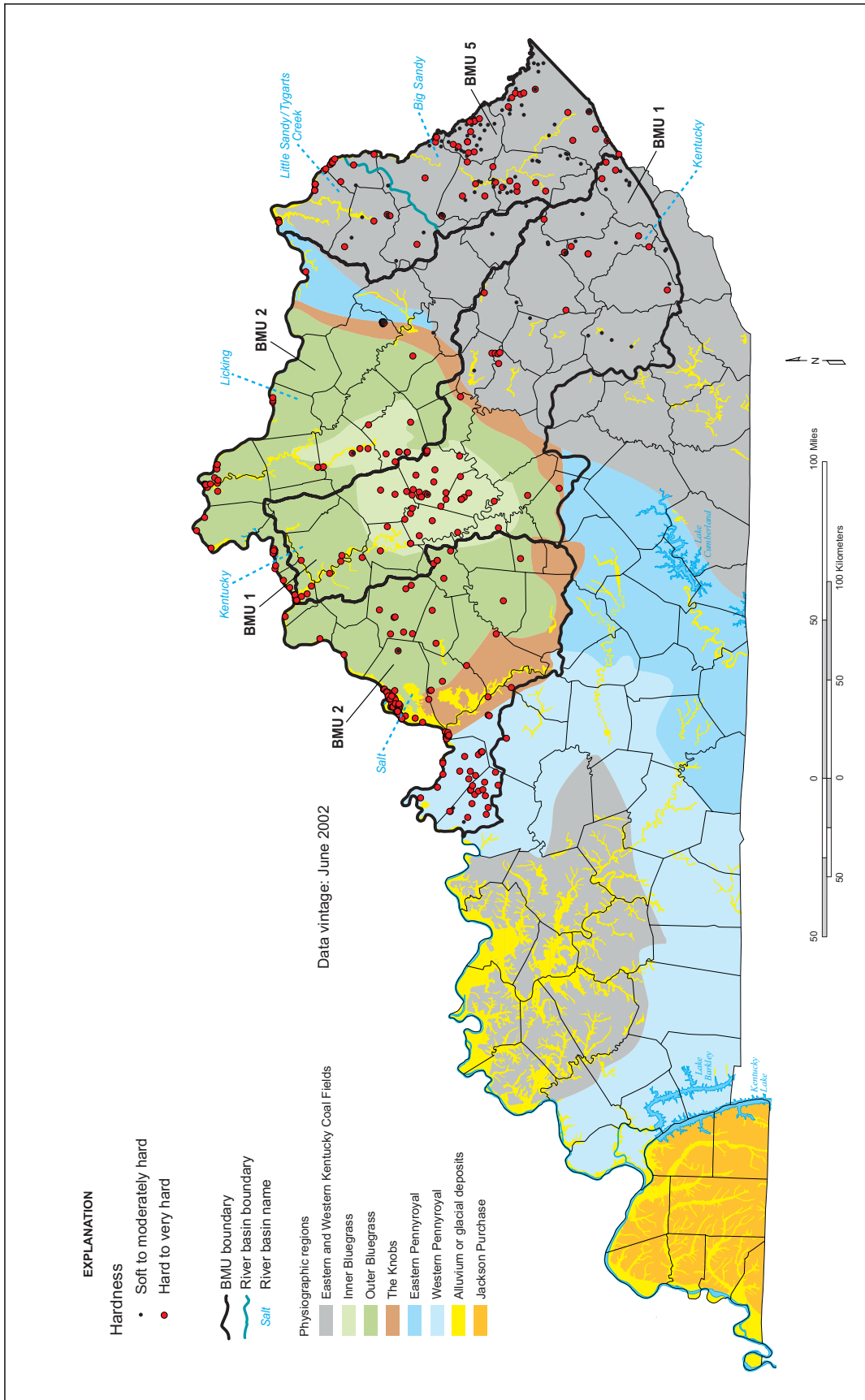


Figure 31. Locations of sampled sites and ranges of hardness values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

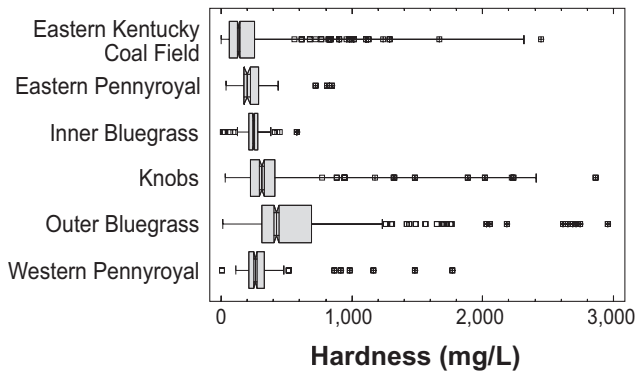


Figure 32. Summary of hardness values grouped by physiographic region. Higher values have been omitted to better show the majority of the data.

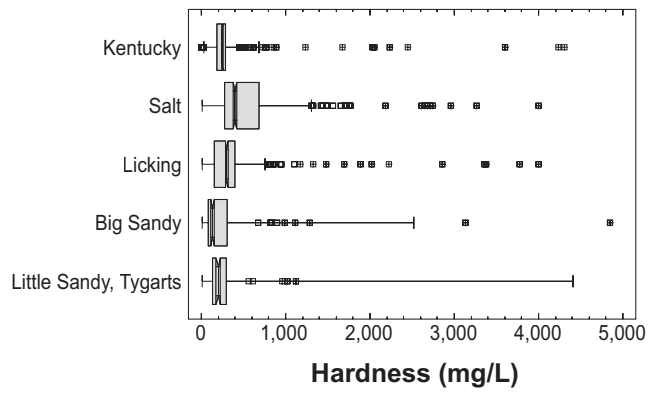


Figure 33. Summary of hardness values grouped by major watershed. Higher values have been omitted to better show the majority of the data.

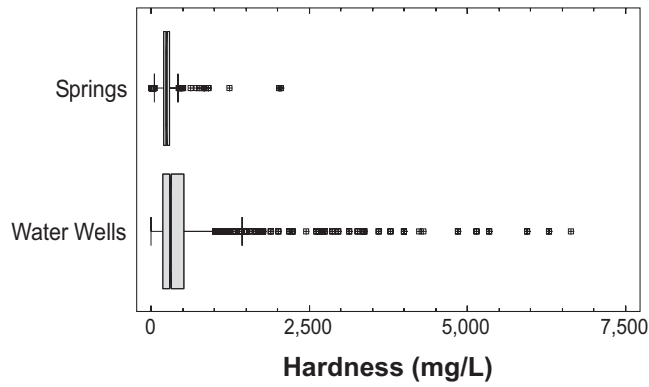


Figure 34. Comparison of hardness values from wells and springs. Higher values have been omitted to better show the majority of the data.

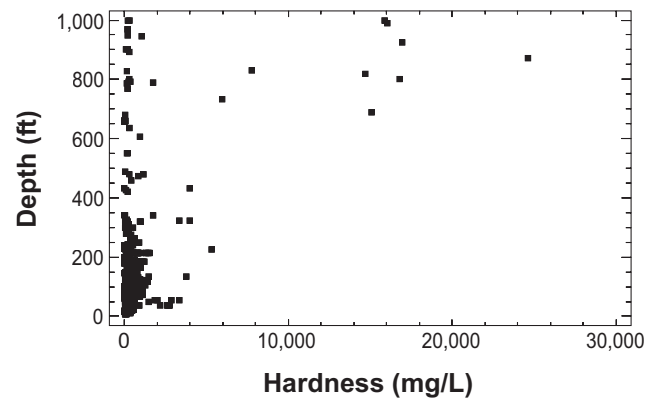


Figure 35. Plot of hardness values versus well depth.

Total Suspended Solids. Particulate material is reported as total suspended solids. TSS values are typically higher in groundwater samples from karst springs, where turbulent water flow can transport fine material such as clays and particulate organic material; from uncased wells that have been vigorously stirred during purging prior to sample collection; or from wells that intercept a fracture or karst conduit, where turbulent flow may occur. TSS measurements also include any precipitate that formed in the sample bottle after collection.

There are no health or cosmetic standards for total suspended solids in water. Some metals and pesticides are preferentially sorbed onto or included in the matrix of suspended material, however, so water high in total suspended solids may also contain important amounts of metals, which may have health or safety implications. Also, high amounts of suspended material can clog plumbing systems and stain clothing and water containers. The Kentucky Pollution Discharge Elimination System recommends that TSS levels be less than 35 mg/L.

The project area contains 1,223 reports of total suspended solids from 245 sites (Table 9). Maximum values in each basin man-

Table 9. Summary of total suspended solids values (mg/L). KPDES recommendation: < 35 mg/L.

	BMU 1	BMU 2	BMU 5
Values	599	439	185
Maximum	1,520	680	125
75th percentile	6	5	5
Median	3	3	3
25th percentile	3	3	1
Minimum	0	< 1	< 1
Interquartile range	3	2	4
Sites	81	82	82
Sites > 35 mg/L	15	10	3

< means analytical result reported as less than the stated analytical detection limit

agement unit are quite high. Only 40 total suspended solids values from 28 sites exceed 35 mg/L, however.

Cumulative data distribution curves for the three basin management units are very similar (Figs. 36–38).

Site distribution is sparse and uneven throughout the project area (Fig. 39). This is probably because total suspended solids is not considered a critical parameter in determining groundwater quality.

In no physiographic region (Fig. 40) or major watershed (Fig. 41) does the 75th percentile of values exceed 10 mg/L. The largest interquartile range is found in the Salt River watershed of the Western Pennyroyal Region.

Groundwater from springs is more likely to produce turbid water (high TSS) than groundwater from wells (Fig. 42). Of the 28 sites that produce water

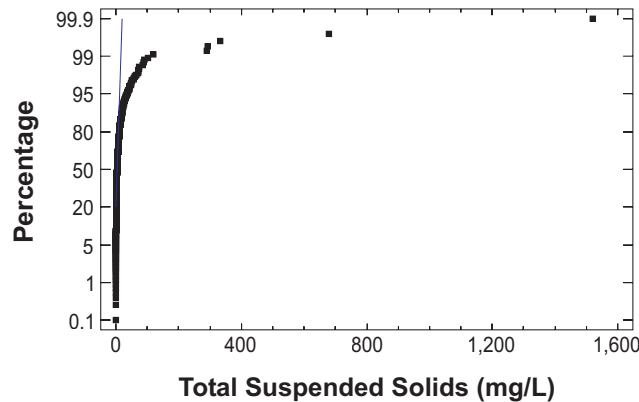


Figure 36. Cumulative plot of total suspended solids values from BMU 1.

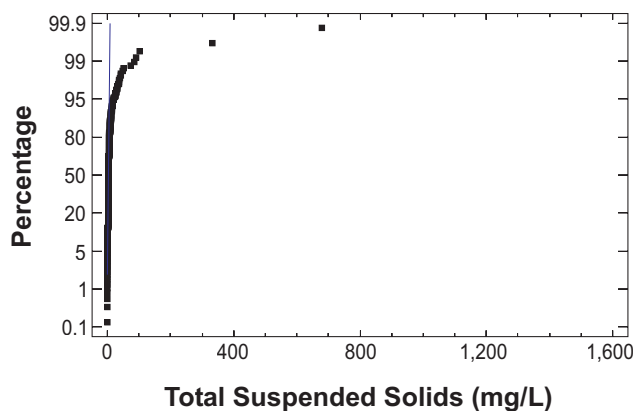


Figure 37. Cumulative plot of total suspended solids values from BMU 2.

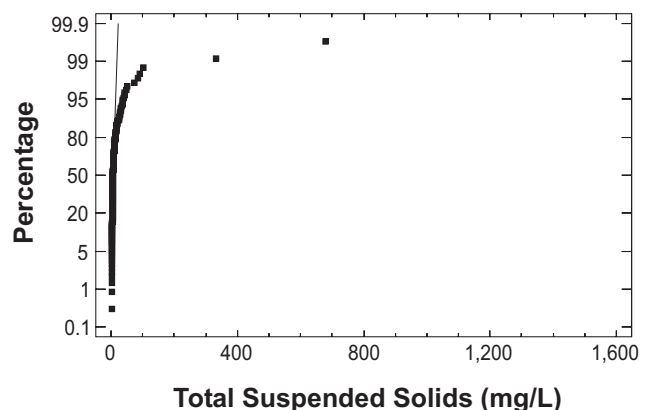


Figure 38. Cumulative plot of total suspended solids values from BMU 5.

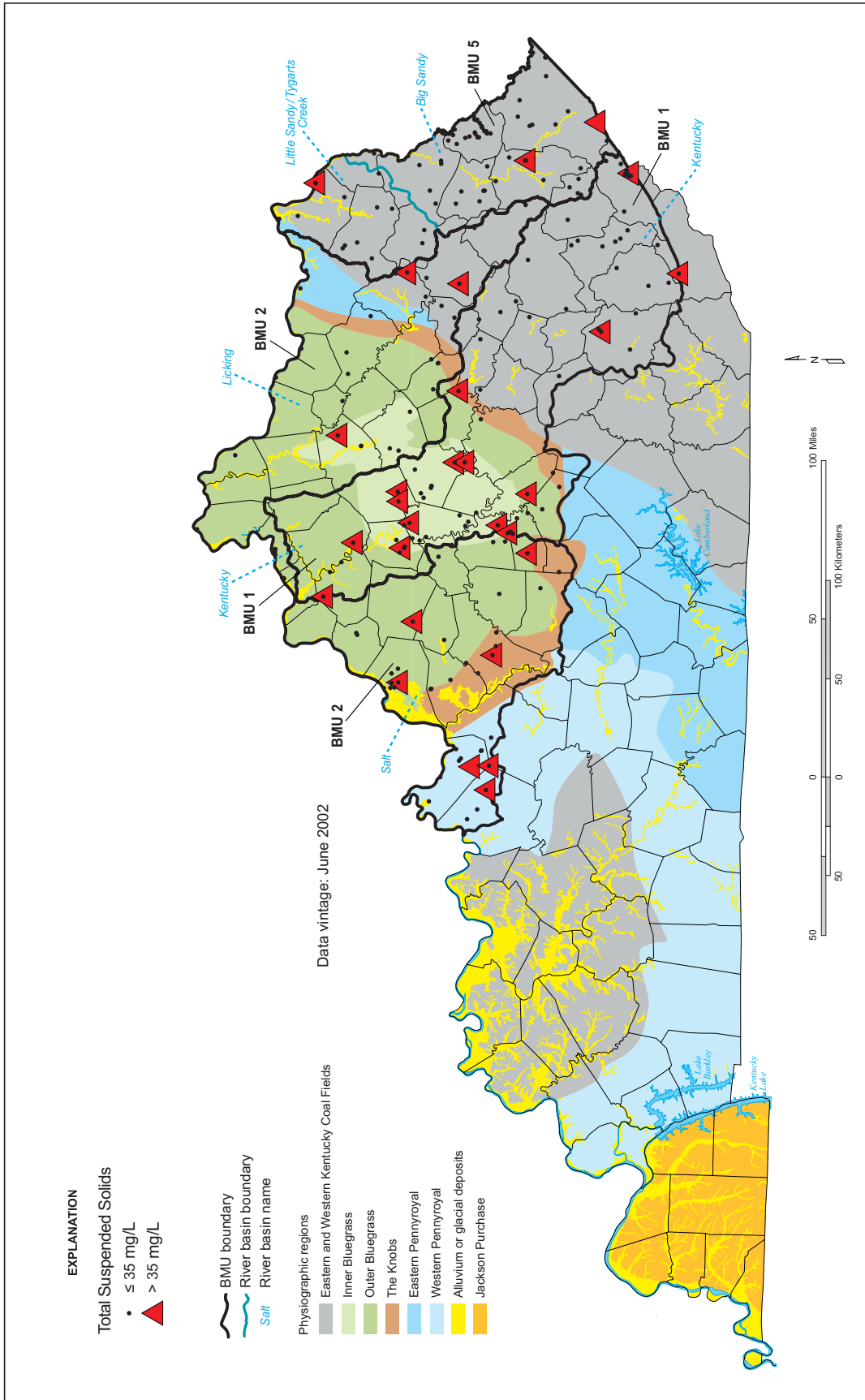


Figure 39. Locations of sampled sites and ranges of total suspended solids values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

having more than 35 mg/L total suspended solids, 24 are springs and only four are wells. Shallow wells are more likely to produce turbid water than deeper wells (Fig. 43).

In summary, total suspended solids values generally do not present problems for groundwater use in the project area. Only 40 of 1,223 measurements from

28 of 245 sites exceed the DOW-recommended value of 35 mg/L. Twenty-four of the 28 sites at which this value is exceeded are springs, where turbulent flow and transport of suspended solids is expected. There is no evidence of a nonpoint-source contribution to groundwater at the sampled sites.

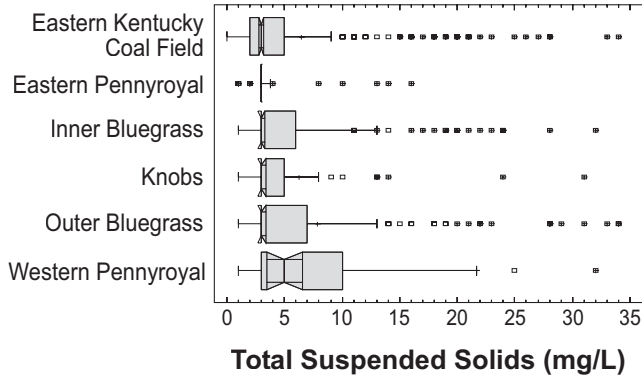


Figure 40. Summary of total suspended solids values grouped by physiographic region. Higher values have been omitted to better show the majority of the data.

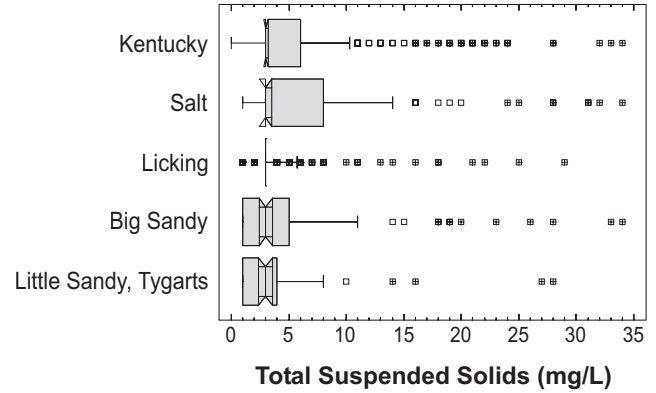


Figure 41. Summary of total suspended solids values grouped by major watershed. Higher values have been omitted to better show the majority of the data.

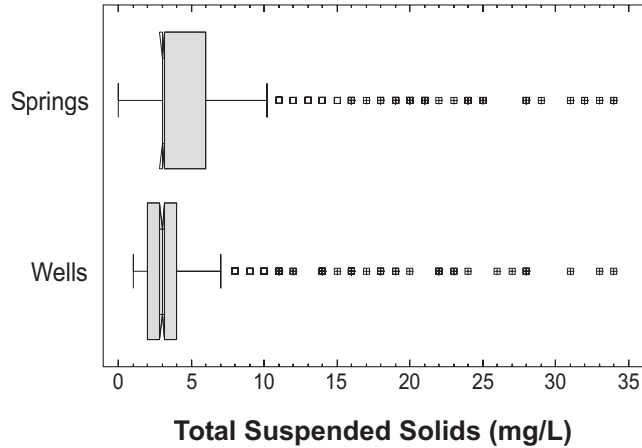


Figure 42. Comparison of total suspended solids values from wells and springs.

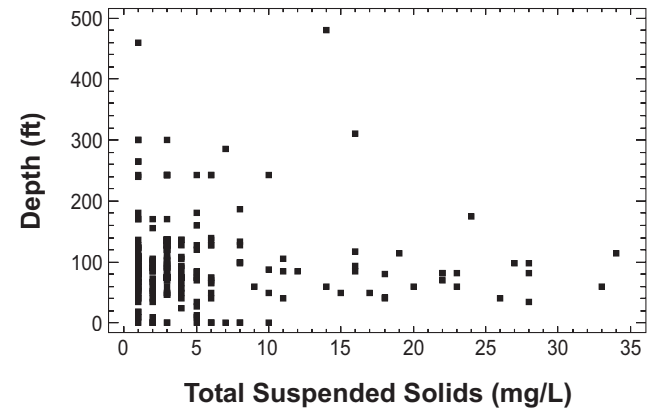


Figure 43. Plot of total suspended solids values versus well depth.

Inorganic Anions

Chloride. Chloride (Cl) is present in most natural groundwater in low to moderate amounts. It is a highly conservative anion; once in solution it is not involved in oxidation/reduction reactions, does not precipitate out as low-solubility minerals, and is not readily sorbed onto the aquifer matrix. In Kentucky groundwater, the main sources of chloride are interstitial fluids in shales and brackish groundwater that is commonly encountered at depth in the coal fields (Wunsch, 1993) and the Pennyroyal Region (Hopkins, 1966). Nonpoint sources include leaking oil or gas wells, road salt, confined animal-feeding operations, and defective septic waste-disposal systems.

There are no health-related standards for chloride. The EPA has set a secondary maximum contaminant level of 250 mg/L for chloride because water containing more than this amount has an unpleasant taste that makes it unsuitable for domestic use.

The data repository contained 10,029 chloride measurements from 4,665 sites in the project area (Table 10). The maximum value in each basin management unit exceeds 100,000 mg/L.

Table 10. Summary of chloride values (mg/L). SMCL: 250 mg/L.

	BMU 1	BMU 2	BMU 5
Values	3,327	4,878	1,824
Maximum	121,000	141,000	184,880
75th percentile	19	44	31.2
Median	7.4	17	9.8
25th percentile	3.7	6.4	3.9
Minimum	0	0	0
Interquartile range	15.3	37.6	27.3
Sites	1,742	1,825	1,098
Sites > 250 mg/L	74	119	69

Such high values are exceptional, however; 75 percent of the measured values are less than 45 mg/L and 50 percent are less than 17 mg/L.

Data distributions for the three basin management units have a similar shape (Figs. 44–46) with a sharp break in slope at a chloride value less than 250 mg/L.

Sample-site density is much greater in the southern half of the study area than in the northern half (Fig. 47), because sampling for the National Uranium Resource Evaluation project did not extend into the northern part of the state. The percentage of sites where chloride exceeds 250 mg/L is approximately the same in each basin management unit and shows no relation to river basin or physiographic region.

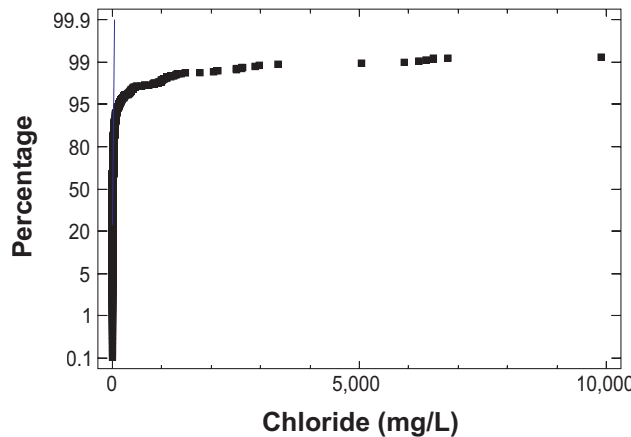


Figure 44. Cumulative plot of chloride values from BMU 1. Higher values were excluded for clarity.

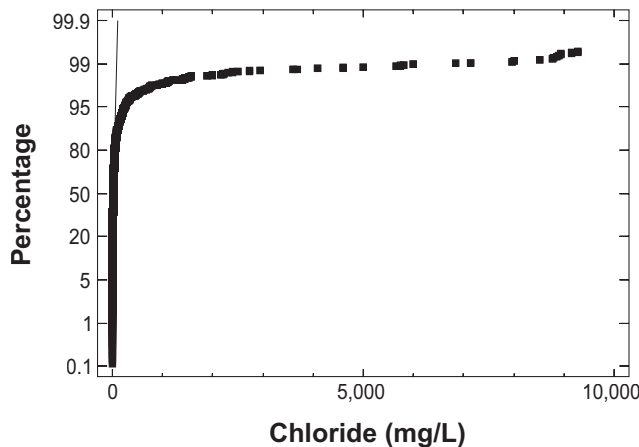


Figure 45. Cumulative plot of chloride values from BMU 2. Higher values were excluded for clarity.

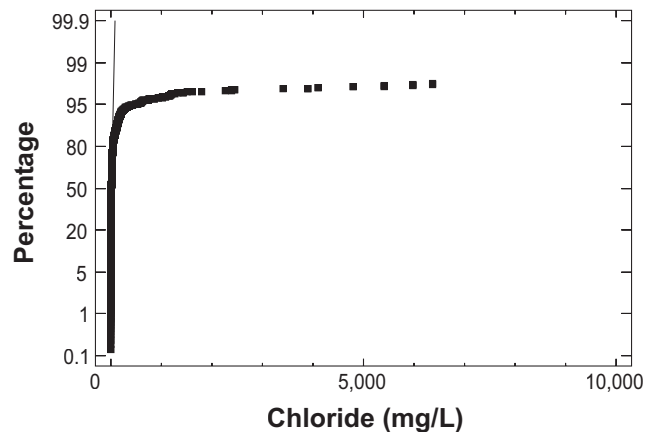


Figure 46. Cumulative plot of chloride values from BMU 5. Higher values were excluded for clarity.

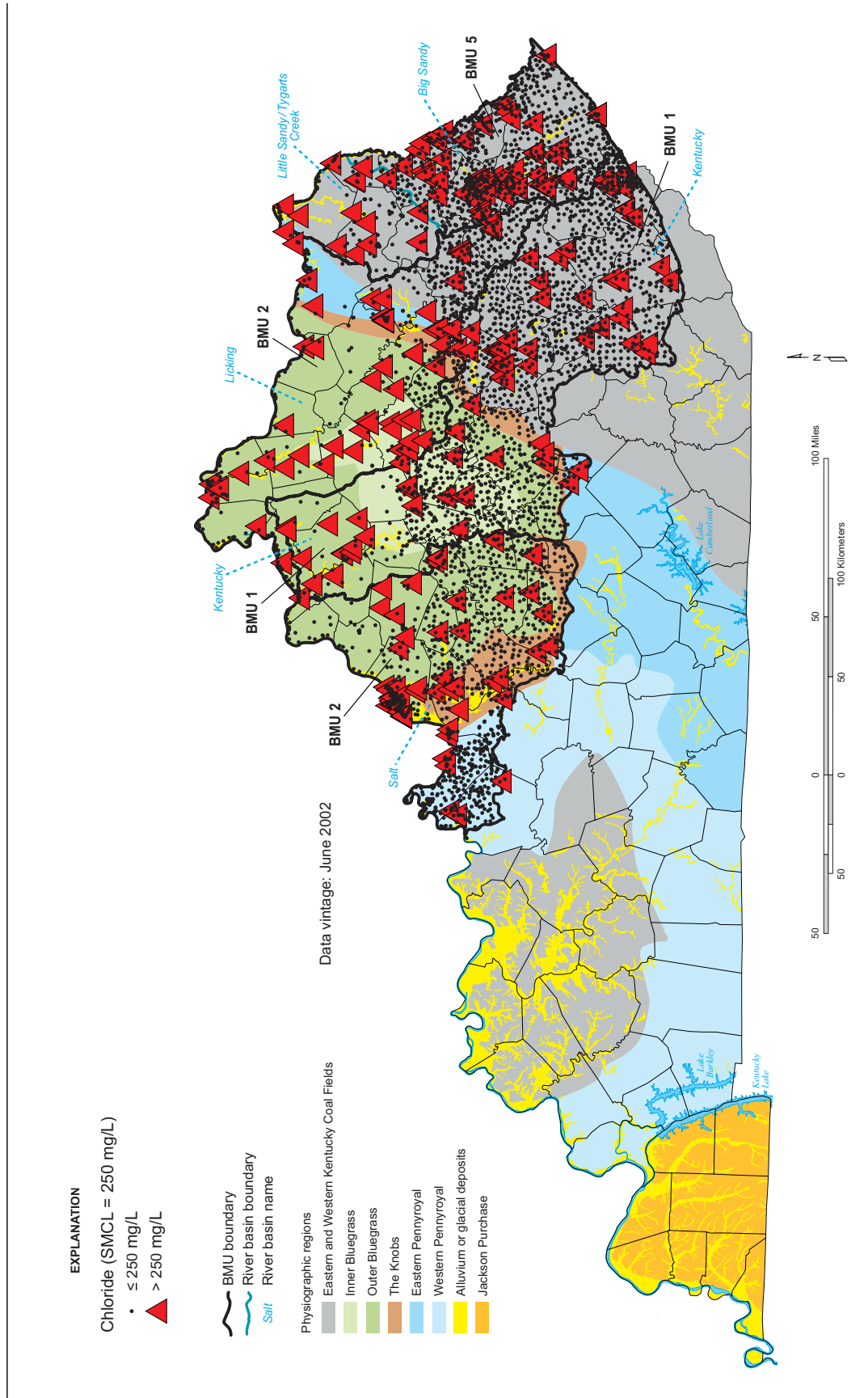


Figure 47. Locations of sampled sites and ranges of chloride values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

The median and 75th percentile chloride concentrations are well below 250 mg/L in every physiographic region (Fig. 48) and major watershed (Fig. 49).

Samples from wells have a higher median value, 75th percentile value, and larger interquartile range of chloride concentrations than samples from springs (Fig. 50).

Chloride concentrations are greatest in wells shallower than about 250 ft, with a general trend of lower concentrations at depths of about 500 ft (Fig. 51). Some deeper samples have concentrations that exceed 250 mg/L.

In summary, chloride concentrations in excess of 100,000 mg/L are found throughout the project area, but are uncommon and do not appear to be controlled by basin management unit, physiographic region, or major watershed. Higher chloride concentrations are found in wells than in springs, and shallow wells (less than 200 ft) are more likely to have high chloride concentrations than deep wells. The occurrence of high chloride concentrations in shallow wells might suggest an impact from nonpoint sources, possibly road salt applied in the winter. That cannot be clearly demonstrated with the available information, however.

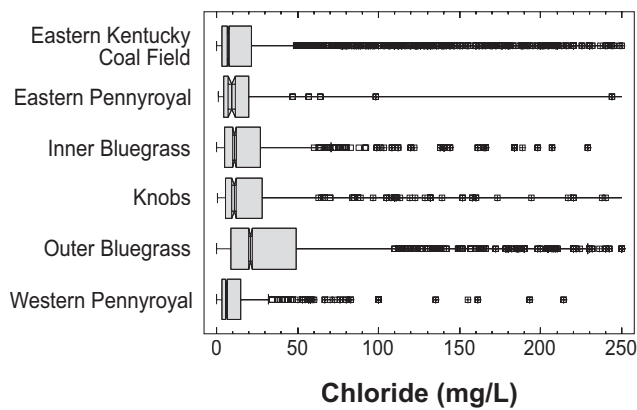


Figure 48. Summary of chloride values grouped by physiographic region. Higher values were excluded for clarity.

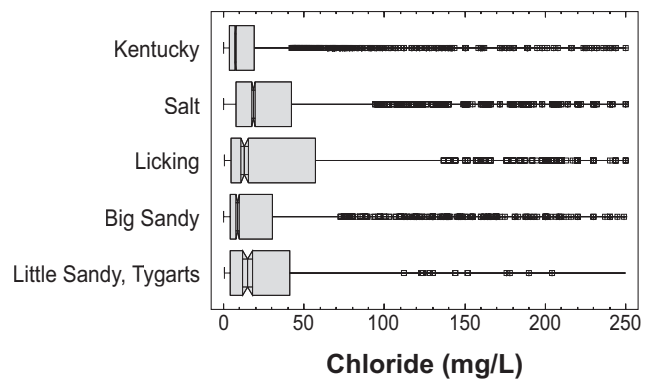


Figure 49. Summary of chloride values grouped by major watershed. Higher values were excluded for clarity.

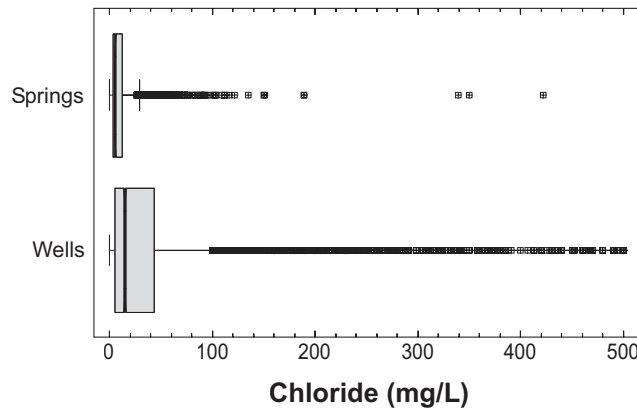


Figure 50. Summary of chloride values for wells and springs. Higher values were excluded for clarity.

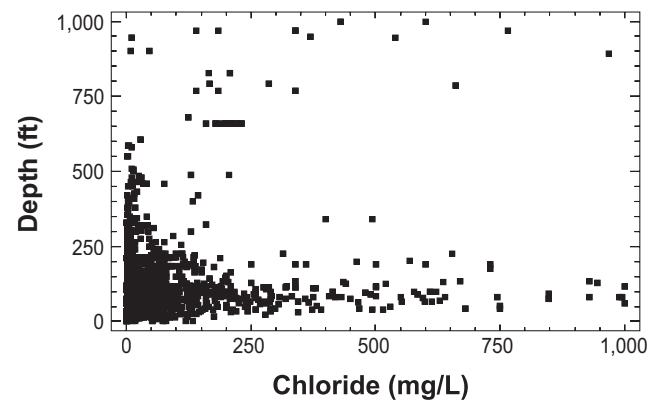


Figure 51. Plot of chloride values versus well depth. Higher values were excluded for clarity.

Sulfate. Sulfate (SO₄) is a major anion in most groundwater. The most common natural sources of sulfate in the project area are oxidation of iron sulfide minerals in coal or shale, and dissolution of the calcium-sulfate minerals gypsum or anhydrite in carbonate strata.

There is no primary drinking-water standard for sulfate. The EPA has set a secondary standard of 250 mg/L because water containing more than 250 mg/L of sulfate has an unpleasant taste that makes it unsuitable for domestic use. Water having sulfate concentrations greater than about 500 mg/L is a mild laxative.

There are 11,607 sulfate measurements reported from 2,611 sites in the project area (Table 11). The high-

Table 11. Summary of sulfate values (mg/L). SMCL: 250 mg/L.

	BMU 1	BMU 2	BMU 5
Values	4,078	4,383	3,146
Maximum	1,740	3,200	2,749
75th percentile	63	211	66.7
Median	27	66	26.8
25th percentile	12	28.7	7
Minimum	0	0	0
Interquartile range	51	182.3	59.7
Sites	738	1,121	752
Sites > 250 mg/L	70	149	76

est values for maximum, 75th percentile, median, and 25th percentile are found in BMU 2, which also contains the largest number of sites that exceed 250 mg/L (Table 11).

Distributions of sulfate concentrations are generally similar in each basin management unit (Figs. 52–54). Most values in each BMU are less than 250 mg/L; however, groundwater from BMU 2 has more sulfate concentrations greater than 250 mg/L than water from BMU 1 or BMU 5.

The distribution of sampled sites varies throughout the project area (Fig. 55). The Eastern Kentucky Coal Field, Inner Bluegrass, and Western Pennyroyal Regions are more densely sampled than the Outer Bluegrass Region of the Licking River watershed. Sites where sulfate concentrations exceed 250 mg/L occur mainly in the Outer Bluegrass Region of the Licking River watershed. Sites where sulfate concentrations exceed 250 mg/L occur mainly in the Outer Bluegrass Region of the Salt River watershed and the Eastern Kentucky Coal Field Region of the Kentucky River and Big Sandy River watersheds (Figs. 56–57).

Groundwater samples from wells and springs have nearly the same median sulfate concentration

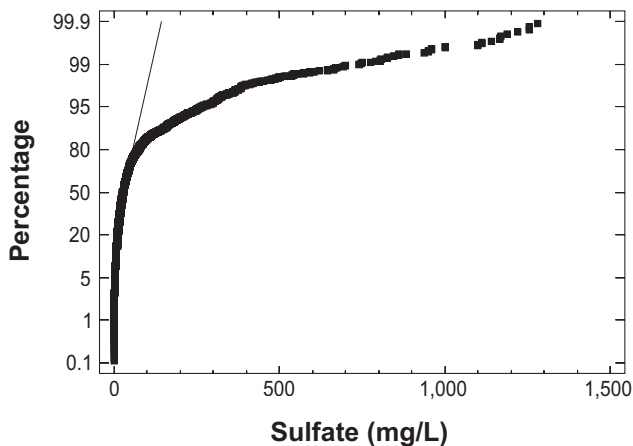


Figure 52. Cumulative plot of sulfate values in BMU 1. Higher values were excluded for clarity.

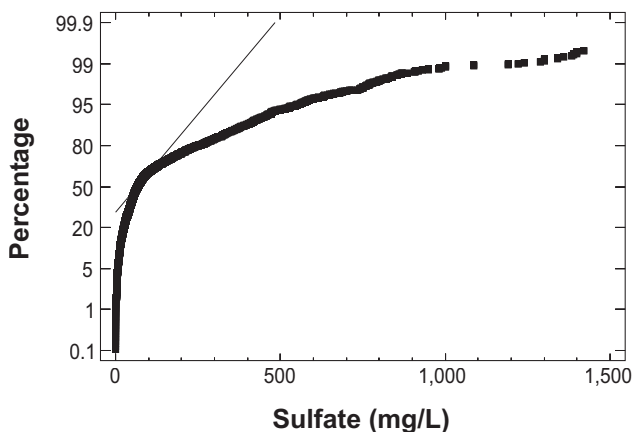


Figure 53. Cumulative plot of sulfate values in BMU 2. Higher values were excluded for clarity.

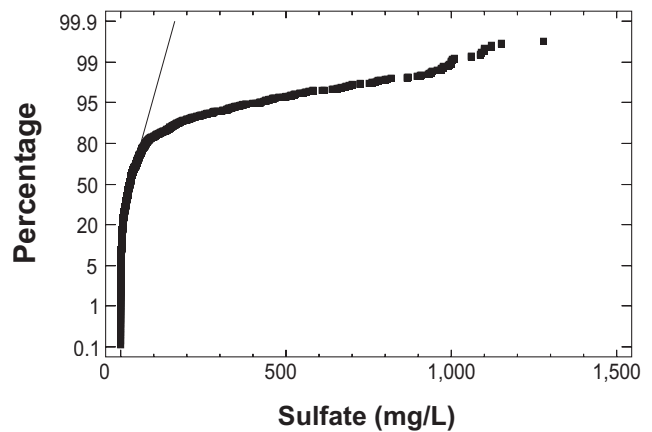


Figure 54. Cumulative plot of sulfate values in BMU 5. Higher values were excluded for clarity.

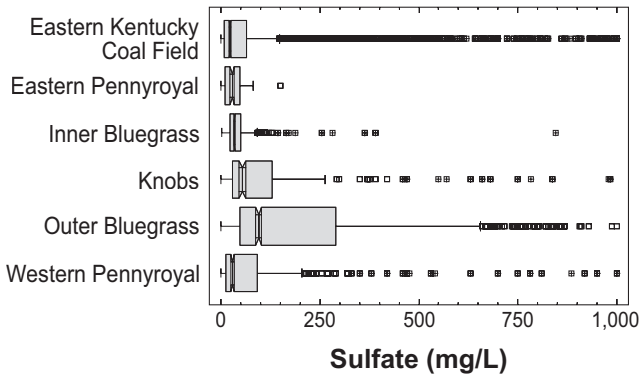


Figure 56. Summary of sulfate values grouped by physiographic region. Higher values were excluded for clarity.

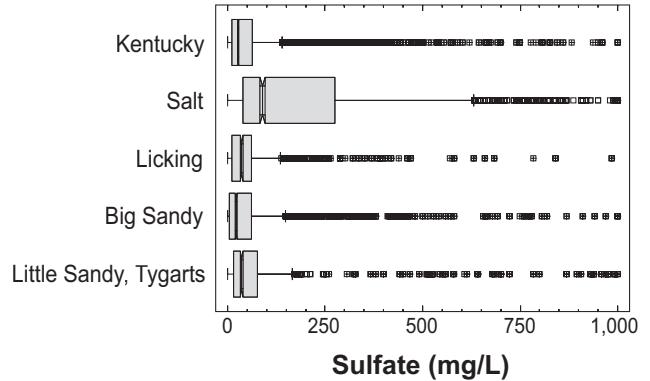


Figure 57. Summary of sulfate values grouped by major watershed. Higher values were excluded for clarity.

(Fig. 58). Water from wells has a higher 75th percentile value, larger interquartile range, and more values that exceed 250 mg/L than water from springs, however.

The highest sulfate concentrations occur in shallow wells (Fig. 59). Sulfate concentrations decrease with well depth.

In summary, most wells and springs in the project area contain sulfate concentrations that are below the secondary standard of 250 mg/L. Higher values are found most commonly in the Eastern Kentucky Coal Field, Outer Bluegrass, and Western Pennyroyal Regions. Wells produce high-sulfate water more com-

monly than springs, and shallow wells are more likely to have high sulfate concentrations than deeper wells. The distribution of sulfate concentrations greater than 250 mg/L suggests that natural sources mask any nonpoint-source effects. High sulfate concentrations are expected in the coal fields, where oxidation of iron sulfide minerals in shale and coal produces sulfate, and in carbonate strata such as occurs in the Outer Bluegrass and Western Pennyroyal, where the sulfate-bearing minerals gypsum and anhydrite are widely distributed.

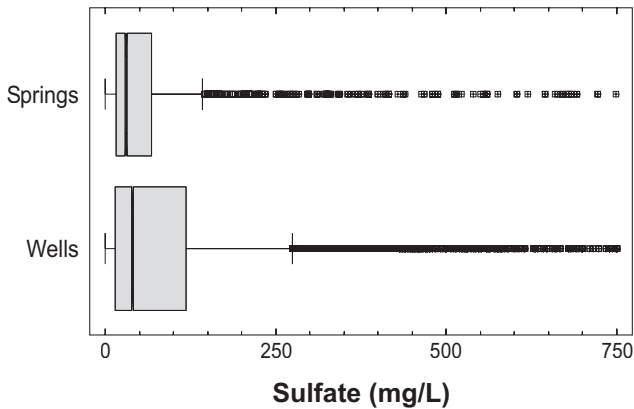


Figure 58. Comparison of sulfate values from wells and springs. Higher values were excluded for clarity.

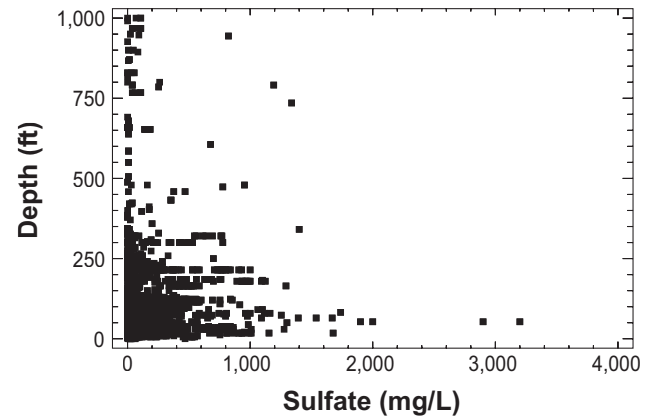


Figure 59. Plot of sulfate values versus well depth. Higher values were excluded for clarity.

Fluoride. Fluoride (F) is a minor anion, usually present in concentrations of less than about 1 mg/L in groundwater. Natural sources of fluoride include the mineral fluorite, which is common in carbonate rocks. The major man-made sources are discharges from fertilizer and aluminum production facilities.

Because of the proven value of fluoride in maintaining healthy teeth and bones, fluoride is added to public water supplies in Kentucky. The concentration in public water is maintained at approximately 1 mg/L. Although fluoride has a beneficial effect at low concentrations, at higher concentrations it may cause pain and weakness of the bones, and staining or mottling of teeth. For these reasons, the Environmental Protection Agency has established a maximum contaminant level of 4 mg/L of fluoride in public drinking water.

Fluoride in Kentucky groundwater has been measured in 6,897 samples from 3,498 sites (Table 12). The maximum value in each basin management unit greatly exceeds 4 mg/L, but concentrations above the MCL are rare. The 75th percentile and median values in each basin management unit are less than 1.0 mg/L (Table 12).

The distribution of reported fluoride concentrations is similar in BMU's 1, 2, and 5. More than 99 percent of all measured values in each basin management unit are less than 4 mg/L (Figs. 60-62).

Sample-site density is much greater in the southern half of the project area than in the northern part (Fig. 63), because sampling for the National Uranium Resource Evaluation project did not extend into north-

Table 12. Summary of fluoride values (mg/L). MCL: 4.0 mg/L.

	BMU 1	BMU 2	BMU 5
Values	2,585	3,220	1,092
Maximum	64.8	73.0	10.0
75th percentile	0.22	0.3	0.3
Median	0.13	0.13	0.164
25th percentile	0.08	0.1	0.1
Minimum	0	0	0
Interquartile range	0.14	0.2	0.2
Sites	1,355	1,400	743
Sites > 4.0 mg/L	11	7	2

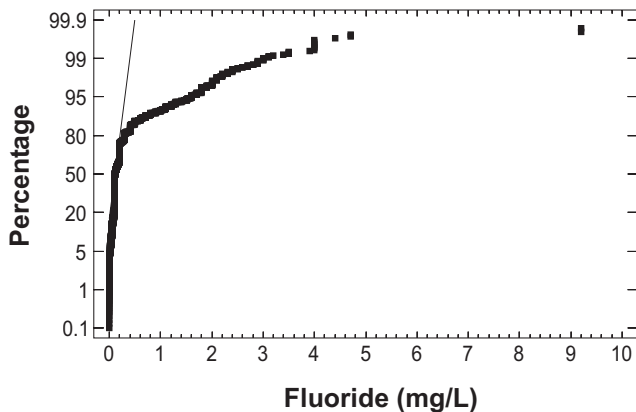


Figure 60. Cumulative plot of fluoride values from BMU 1. Higher values were excluded for clarity.

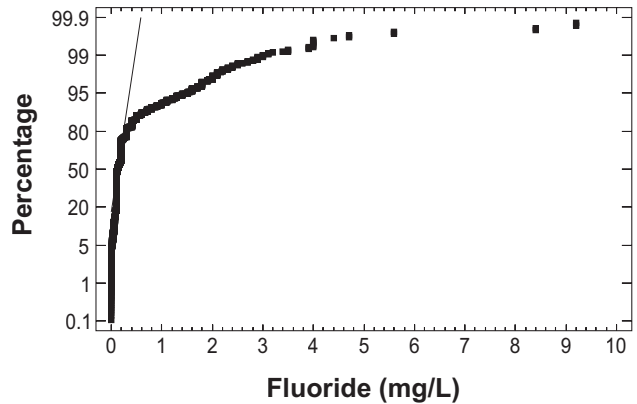


Figure 61. Cumulative plot of fluoride values from BMU 2. Higher values were excluded for clarity.

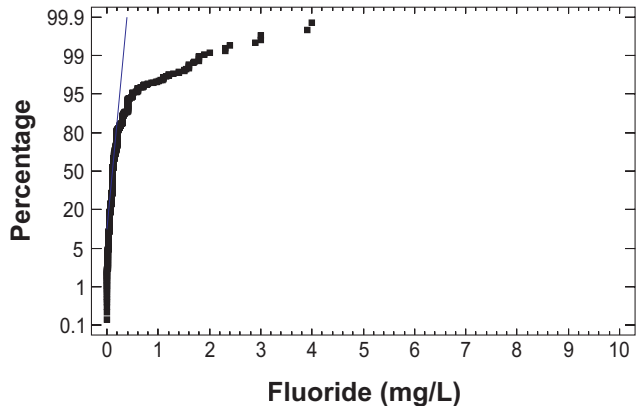


Figure 62. Cumulative plot of fluoride values from BMU 5. Higher values were excluded for clarity.

ern Kentucky. Sites where fluoride exceeds 2 mg/L or 4 mg/L do not appear to be concentrated in any particular physiographic region or watershed, but are randomly distributed throughout the region.

Groundwater samples from the Western Pennyroyal Region have the largest range of interquartile values (Fig. 64). The range of interquartile values from all other regions is much less than 1.0 mg/L, suggest-

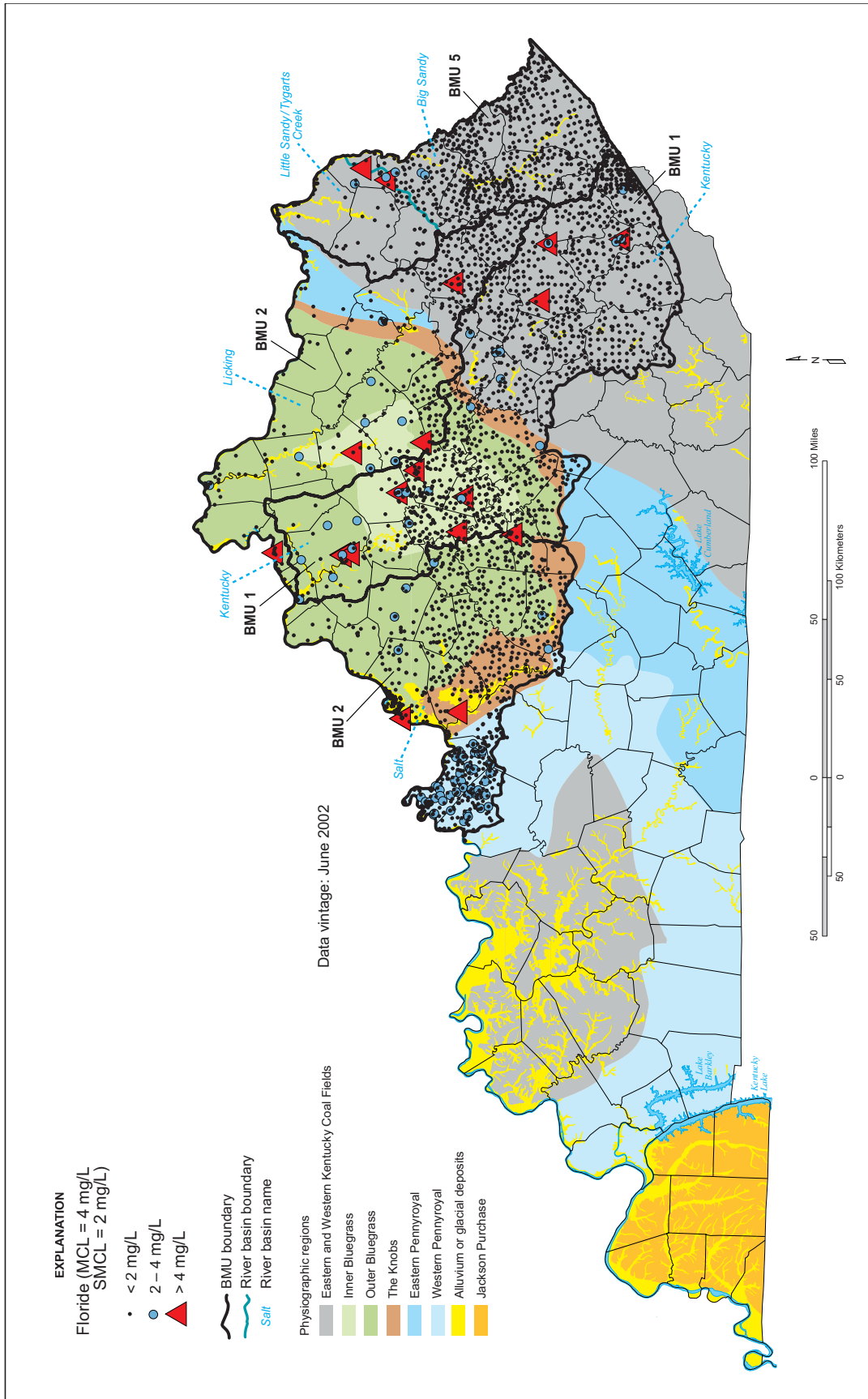


Figure 63. Locations of sampled sites and ranges of fluoride values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

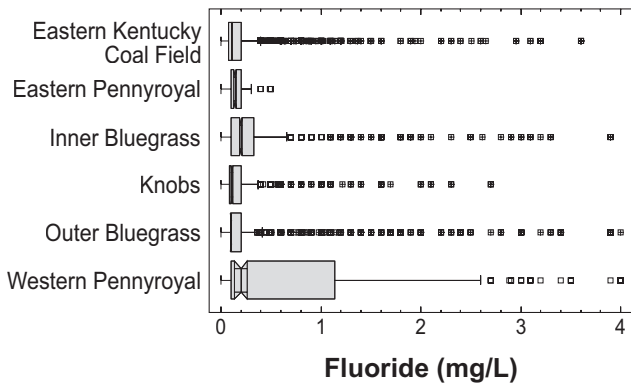


Figure 64. Summary of fluoride values grouped by physiographic region. Higher values were excluded for clarity.

ing either stronger geochemical control on fluoride concentrations or an absence of naturally occurring fluoride in the area.

More than 75 percent of all fluoride concentrations in each river basin are less than 1 mg/L (Fig. 65).

Total and dissolved fluoride concentrations are very similar, as expected, because fluoride is not associated with suspended solids (Fig. 66).

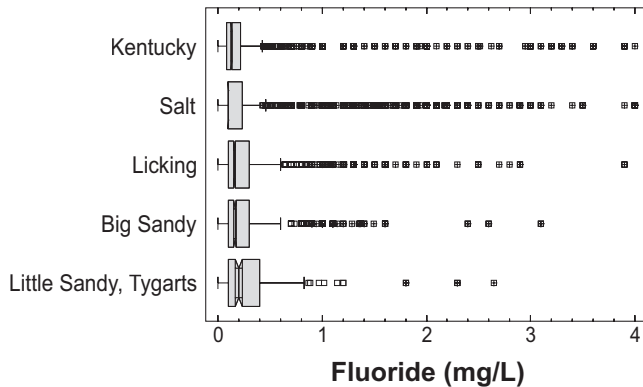


Figure 65. Summary of fluoride values grouped by major watershed. Higher values were excluded for clarity.

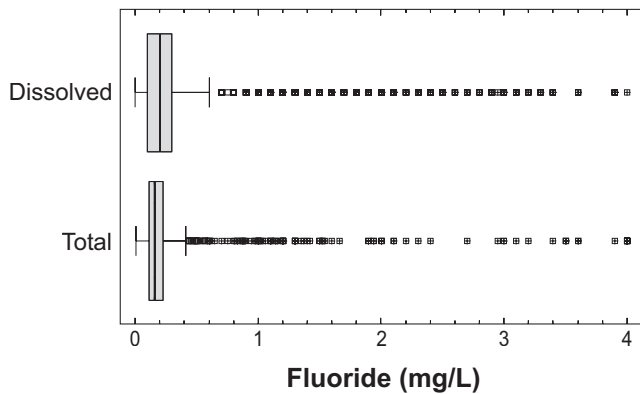


Figure 66. Comparison of total and dissolved fluoride values. Higher values were excluded for clarity.

Groundwater samples from wells and springs have nearly the same median fluoride value and interquartile range, although higher fluoride concentrations may be found in well water (Fig. 67).

Fluoride concentrations show no strong trend with well depth (Fig. 68).

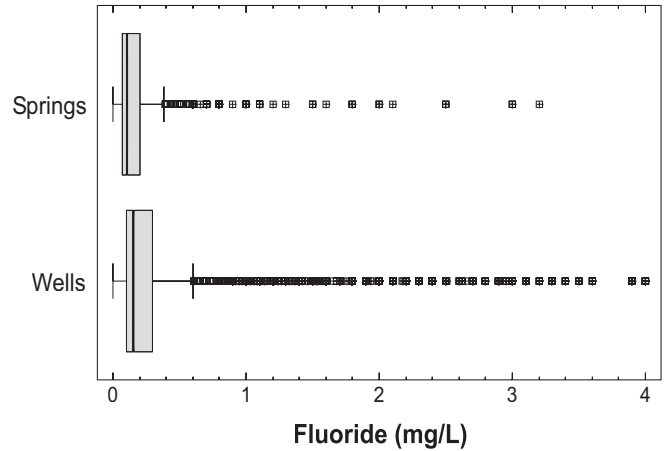


Figure 67. Comparison of fluoride values from wells and springs. Higher values were excluded for clarity.

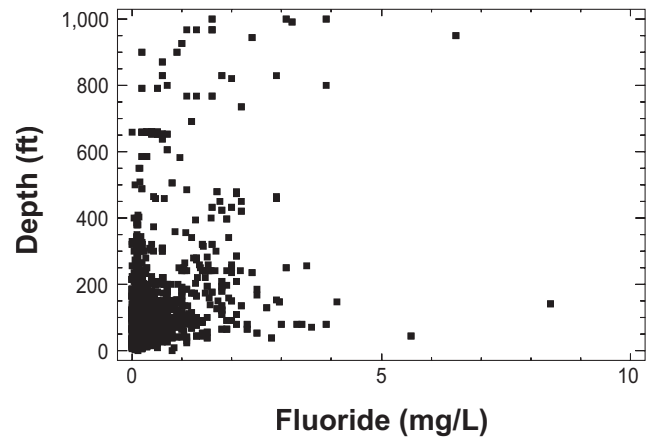


Figure 68. Plot of fluoride values versus well depth. Higher values were excluded for clarity.

In summary, fluoride concentrations less than the MCL of 4.0 mg/L predominate throughout the project area. A few groundwater samples contain more than 4.0 mg/L of fluoride, but they are widely scattered and show no strong correlation with physiographic region or major river watershed. The fluoride concentrations that exceed the MCL probably result from natural variations in bedrock composition rather than the effects of nonpoint-source contamination.

A statewide summary of fluoride data (Conrad and others, 1999a) can be viewed on the KGS Web site (kgsweb.uky.edu/olops/pub/kgs/ic01_12.pdf).

Metals

Arsenic. Arsenic (As) is a naturally occurring element found in low concentrations in rocks, soils, water, plants, and animals (Nriagu, 1994a, b; U.S. EPA, 1998). In Kentucky, arsenic is commonly found in pyrite or arsenopyrite minerals associated with coal deposits and black shales. Arsenic is released when iron sulfides oxidize during weathering. Once released, arsenic is readily sorbed onto iron oxides and iron oxyhydroxides. This sorption can limit dissolved arsenic concentrations in groundwater, but can produce high arsenic concentrations in unfiltered groundwater samples that contain suspended particulate material (total arsenic concentrations).

Arsenic is used as a wood preservative and in paints, dyes, metals, drugs, soaps, semiconductors, animal feed additives, and herbicides. From 1860 through 1910, arsenic was heavily used in embalming fluids. It was banned in 1910 because it interfered with investigations into suspected poisoning deaths; but old graveyards may still be a source of arsenic in groundwater (Fetter, 1993). Waste-disposal sites and landfills may be sources of arsenic contamination because of the materials disposed of there, and coal burning can release arsenic to the atmosphere. Hydrocarbons from leaking underground storage tanks can dissolve iron oxide minerals in soils, thus releasing naturally occurring arsenic to the environment (Welch and others, 2000). Metal-reducing bacteria, as well as changes in

oxidation conditions as a result of pumping, also can affect arsenic concentrations in the vicinity of a well.

Long-term exposure to arsenic in drinking water has been linked to health problems such as cancer of the skin, bladder, lungs, kidneys, nasal passages, liver, and prostate. Arsenic has also been linked to damage of the cardiovascular, pulmonary, immunological, neurological, and endocrine systems. Because of these health effects, the Environmental Protection Agency set the maximum contaminant level for arsenic in drinking water at 50 ppb (or 0.05 mg/L) in 1974. In 2001, the EPA announced that this MCL would be lowered to 10 ppb (0.01 mg/L). Water-supply systems had to meet the new MCL beginning January 1, 2006.

Sites identified as monitoring wells by the Kentucky Division of Water's well-identification numbering system were excluded from the data set used here because, although not explicitly identified as part of an underground storage tank investigation, these wells may have been installed to check for leaking hydrocarbon storage tanks. Because hydrocarbons can dissolve iron oxides from soils, arsenic results from these sites may not represent regional background conditions.

Because the new MCL is 0.01 mg/L, measurements that had a detection limit greater than 0.01 mg/L provide no useful information. Therefore, such values are not included in the following discussion. Removing these measurements leaves 1,858 reported arsenic concentrations at 308 sites (Table 13).

Table 13. Summary of arsenic values (mg/L). MCL: 0.010 mg/L.

	BMU 1	BMU 2	BMU 5
Values	869	697	290
Maximum	0.076	0.265	0.038
75th percentile	< 0.002	< 0.002	< 0.002
Median	< 0.002	< 0.002	< 0.002
25th percentile	< 0.002	< 0.002	< 0.002
Minimum	< 0.0005	< 0.0005	< 0.0005
Interquartile range	N/A	N/A	N/A
Sites	92	110	106
Sites > 0.010 mg/L	1	3	5

< means analytical result reported as less than the stated analytical detection limit

The maximum value in each basin management unit exceeds the MCL. Nine of 308 sites produced groundwater that had an arsenic concentration greater than 0.01 mg/L, and 94 percent of the values are reported as less than analytical detection.

Cumulative plots of values (Figs. 69–71) are similar for the three basin management units. More than 95 percent of the arsenic concentrations are less than 0.01 mg/L.

There are relatively few sites in the Outer Bluegrass Region where arsenic was measured, compared to the Inner Bluegrass, Eastern Kentucky Coal Field, and Western Pennyroyal Regions (Fig. 72). Sites where arsenic exceeds the MCL of 0.01 mg/L are not concentrated in any region or major watershed.

The highest arsenic concentrations are found in the Outer Bluegrass Region (Fig. 73) and the Kentucky River watershed (Fig. 74).

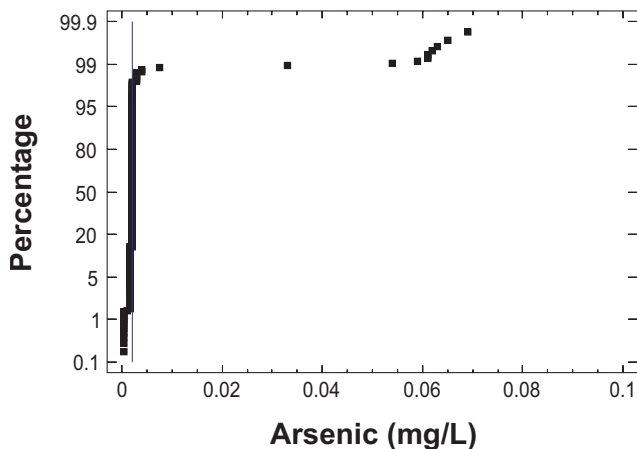


Figure 69. Cumulative plot of arsenic values from BMU 1.

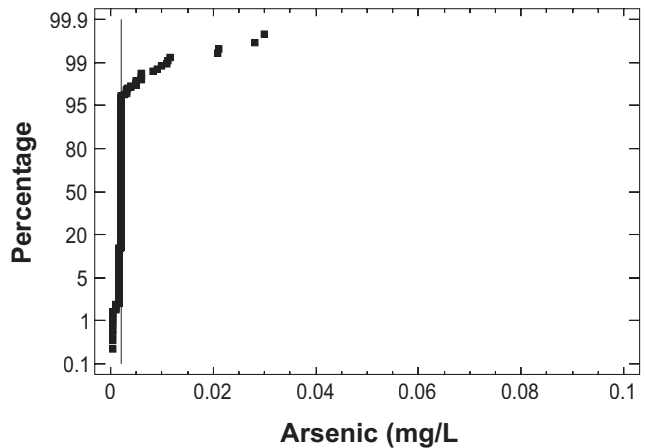


Figure 70. Cumulative plot of arsenic values from BMU 2. One value of 0.265 mg/L was excluded for clarity.

Total (unfiltered sample) and dissolved (filtered sample) arsenic concentrations have the same distribution of values (Fig. 75), indicating that significant amounts of arsenic have not adsorbed on suspended material in the project area.

Arsenic concentrations from wells reach higher values than groundwater from springs (Fig. 76).

The highest arsenic concentrations in wells are found at depths of about 100 ft (Fig. 77).

In summary, arsenic is present at very low concentrations in groundwater throughout the project area. Only nine of 308 sites produced groundwater with arsenic concentrations that exceeded the MCL, and these sites are not predominantly in any one physiographic region or major river watershed. Therefore, nonpoint-source contamination with respect to arsenic in groundwater does not seem to be occurring in the project area. A statewide summary of arsenic data (Fisher, 2002a) can be viewed on the KGS Web site (kgsw eb.uky.edu/olops/pub/kgs05_12.pdf).

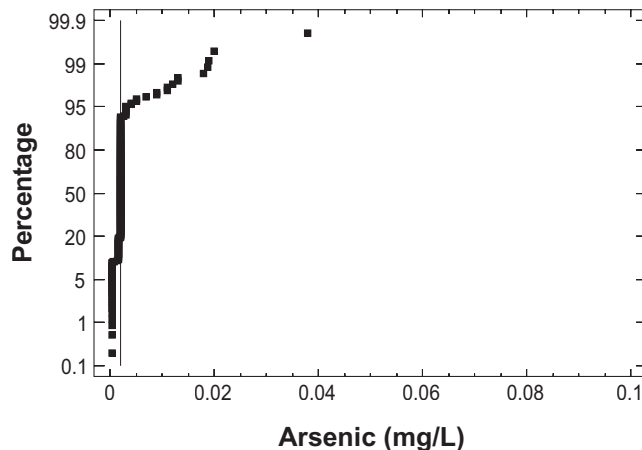


Figure 71. Cumulative plot of arsenic values from BMU 5.

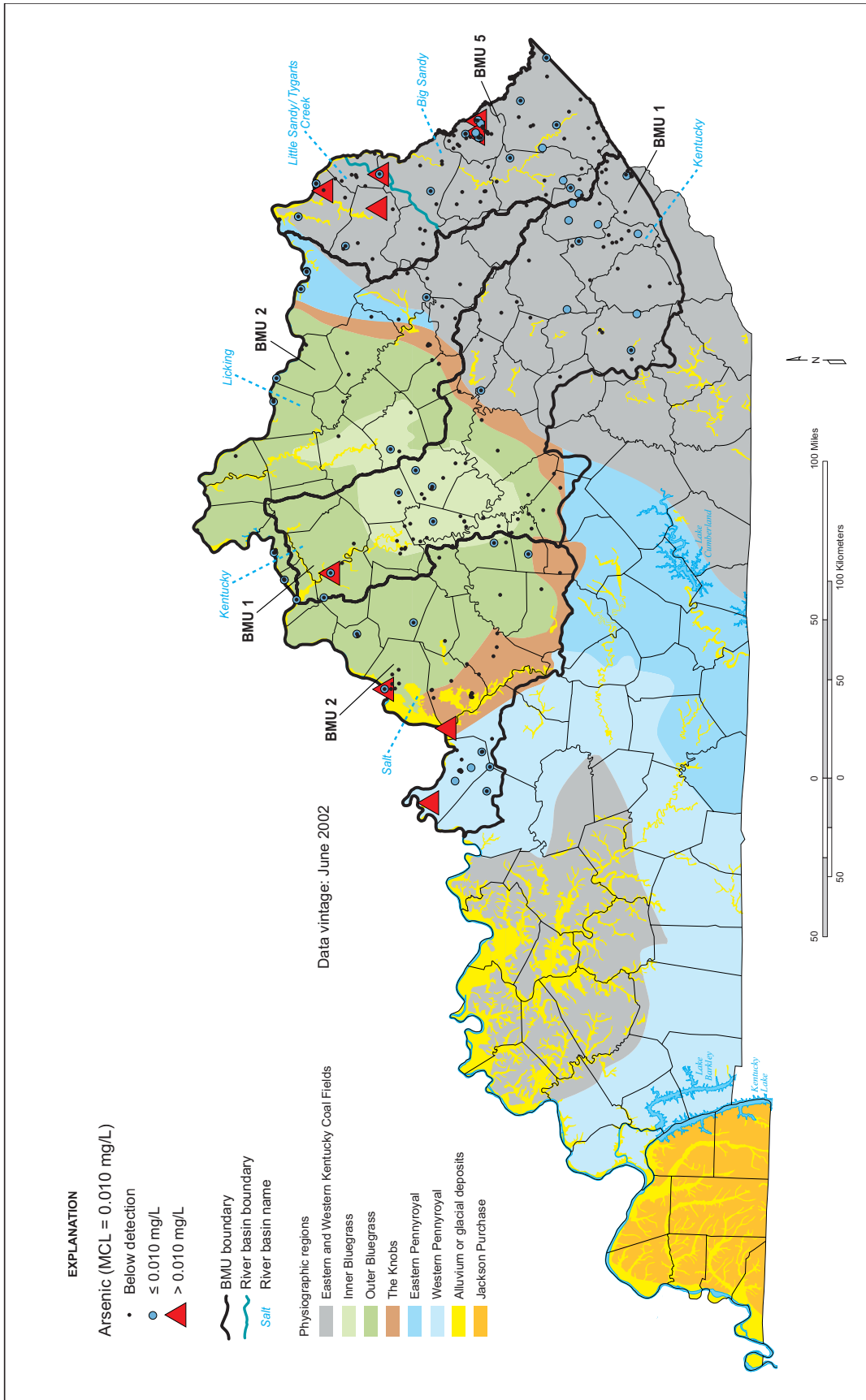


Figure 72. Locations of sampled sites and ranges of arsenic values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

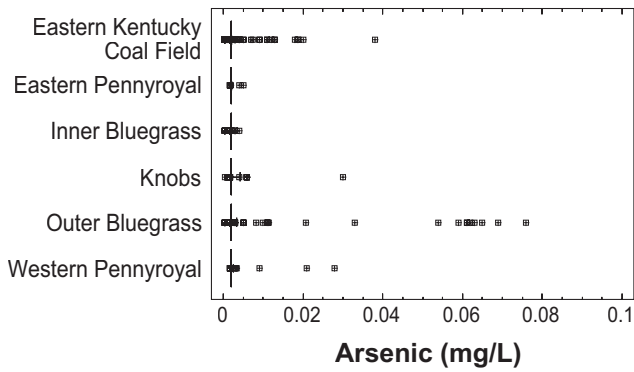


Figure 73. Summary of arsenic values grouped by physiographic region. One value of 0.265 mg/L in the Knobs Region was excluded for clarity.

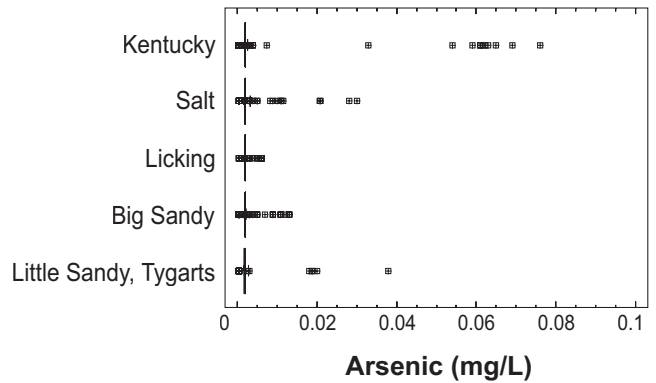


Figure 74. Summary of arsenic values grouped by major watershed. One value of 0.265 mg/L in the Salt River watershed was excluded for clarity.

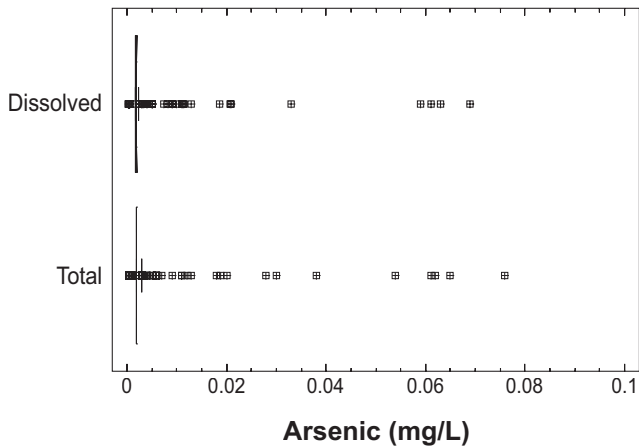


Figure 75. Comparison of total and dissolved arsenic values. One value of 0.265 mg/L total arsenic was excluded for clarity.

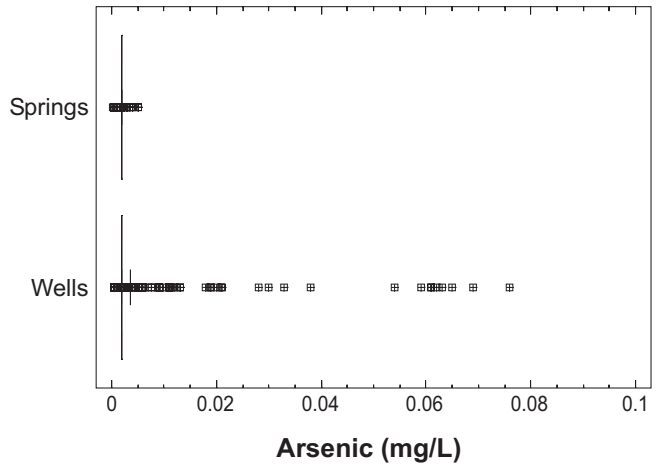


Figure 76. Comparison of arsenic values from wells and springs. One value of 0.265 mg/L arsenic from a well was excluded for clarity.

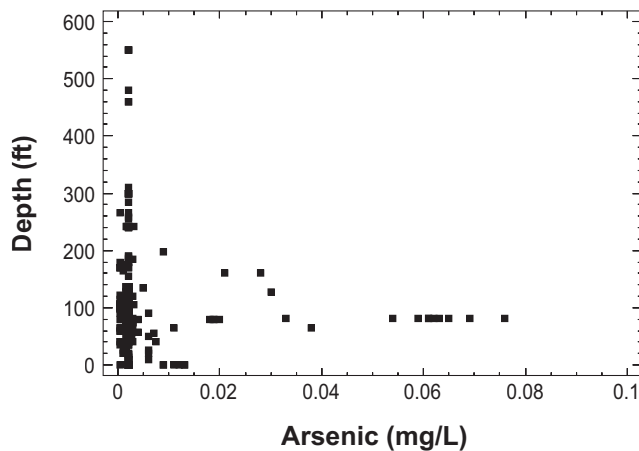


Figure 77. Plot of arsenic values versus well depth.

Barium. Barium (Ba) is an alkaline earth element that occurs naturally as the mineral barite (BaSO₄), which is common in both sandstone and carbonate strata. Barium is used in electronic components, metal alloys, bleaches, dyes, fireworks, ceramics, and glass, and as an additive to drilling fluids used in oil and gas wells. Barium may be released to soil and water from the discharge of drilling wastes, or from leaking landfills where barium-containing materials were discarded.

The EPA has set the MCL for barium at 2 mg/L. Short-term exposure to higher barium concentrations can cause gastrointestinal problems and muscular weakness, whereas long-term exposure can cause high blood pressure.

The data repository contained 2,579 barium measurements from 654 sites in the project area (Table 14). Although maximum values in each basin management unit are quite high, the 75th percentile values are well below 1 mg/L throughout the region. Only 21 of 654 sites yielded groundwater that had more than 2 mg/L of barium.

Data distributions (Figs. 78–80) show the same general trend, with more than 95 percent of the values being less than 2 mg/L. Data distributions for BMU 2 (Fig. 79) and BMU 5 (Fig. 80) have a sharp break in

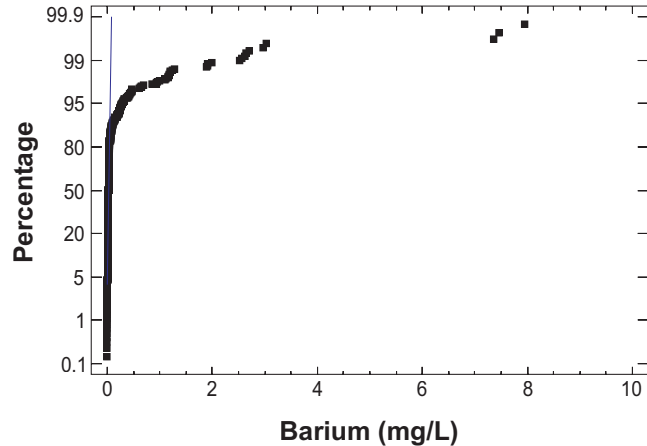


Figure 78. Cumulative plot of barium values from BMU 1.

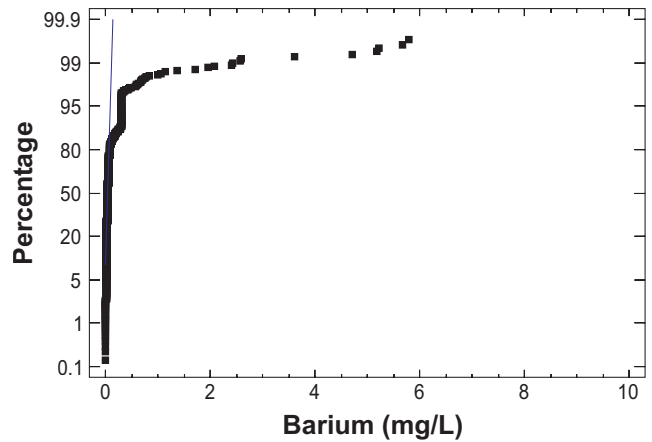


Figure 79. Cumulative plot of barium values from BMU 2. Two values were excluded for clarity.

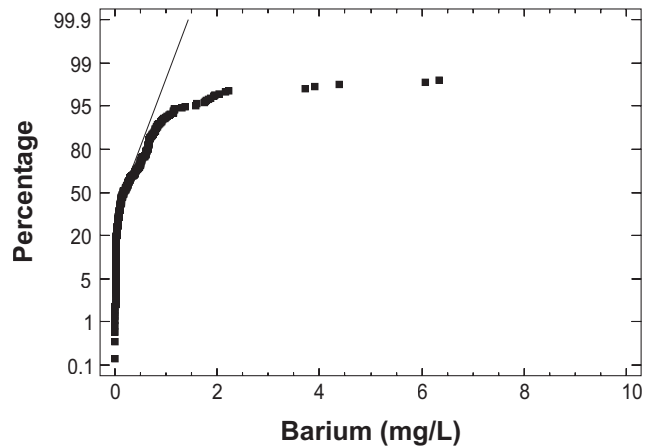


Figure 80. Cumulative plot of barium values from BMU 5. Nine values were excluded for clarity.

slope, which may indicate that two distinct populations are represented.

The distribution of sampled sites (Fig. 81) shows a greater density in the Eastern Kentucky Coal Field, Inner Bluegrass, and Western Pennyroyal Regions. Eleven of the 21 sites where barium exceeded the MCL are in the Eastern Kentucky Coal Field.

Table 14. Summary of barium values (mg/L). MCL: 2.0 mg/L.

	BMU 1	BMU 2	BMU 5
Values	1,027	1,122	430
Maximum	8.69	79.8	100.0
75th percentile	0.43	0.07	0.59
Median	0.03	0.04	0.16
25th percentile	0.02	0.03	0.04
Minimum	0.00	0.00	0.00
Interquartile range	0.41	0.04	0.55
Sites	143	344	167
Sites > 2.0 mg/L	2	11	8

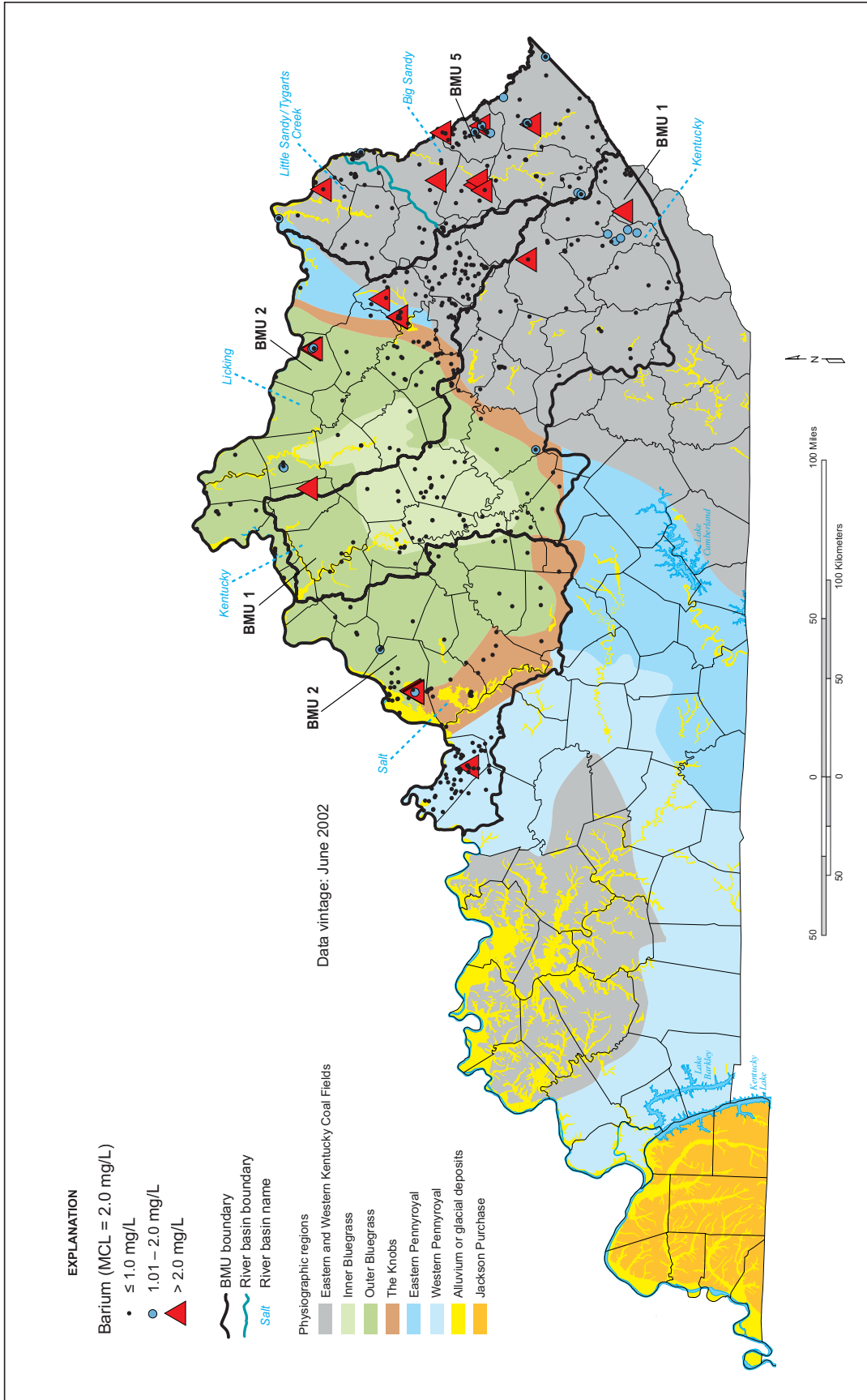


Figure 81. Locations of sampled sites and ranges of barium values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

Values greater than the MCL are found primarily in the Eastern Kentucky Coal Field (Kentucky, Licking, and Big Sandy River watersheds) and the Outer Bluegrass Region (Salt River watershed) (Figs. 82–83).

Barium concentrations in total (unfiltered) samples have a larger interquartile range than concentra-

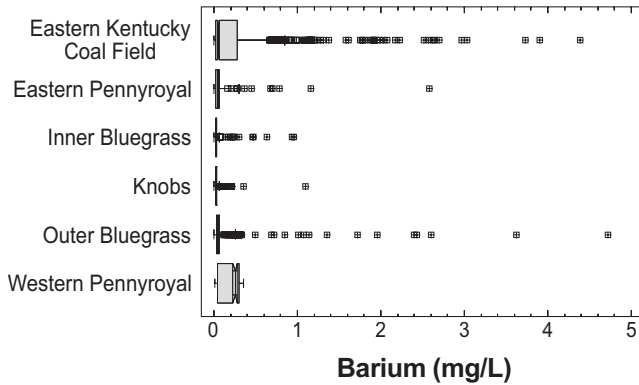


Figure 82. Summary of barium values grouped by physiographic region. Higher values were excluded for clarity.

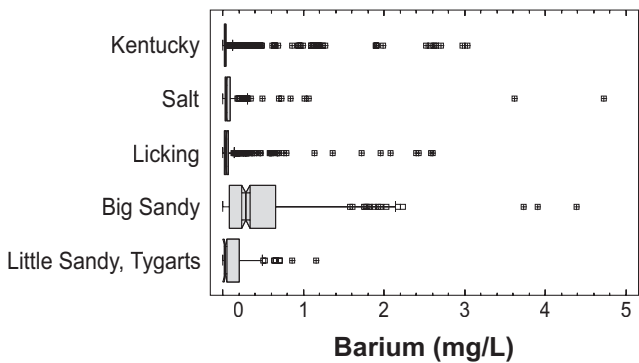


Figure 83. Summary of barium values grouped by major watershed. Higher values were excluded for clarity.

tions from dissolved (filtered) samples, and more values greater than 2 mg/L (Fig. 84).

Barium concentrations from wells have a larger interquartile range than concentrations from springs (Fig. 85). No samples from springs had a barium concentration above the MCL.

The highest barium concentrations are found in wells that are less than 100 ft deep (Fig. 86).

In summary, 21 of 654 sites yielded groundwater that contained more than 2 mg/L barium in the project area. All these sites were shallow wells in the Eastern Kentucky Coal Field. Wunsch (1991) reported similar observations from 130 wells in the Eastern Kentucky Coal Field, and attributed the barium concentrations greater than 1.0 mg/L primarily to a mixing of deep, barium-rich brines with shallow groundwater. Naturally occurring barite is another probable source of the barium concentrations observed. Strong influence of

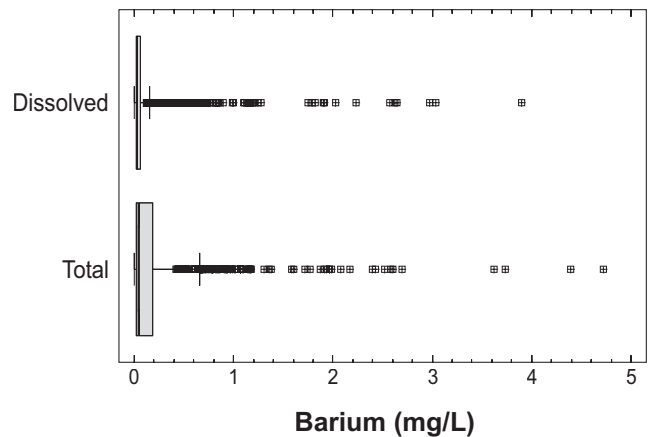


Figure 84. Comparison of total and dissolved barium values. Nine values of total barium were excluded for clarity.

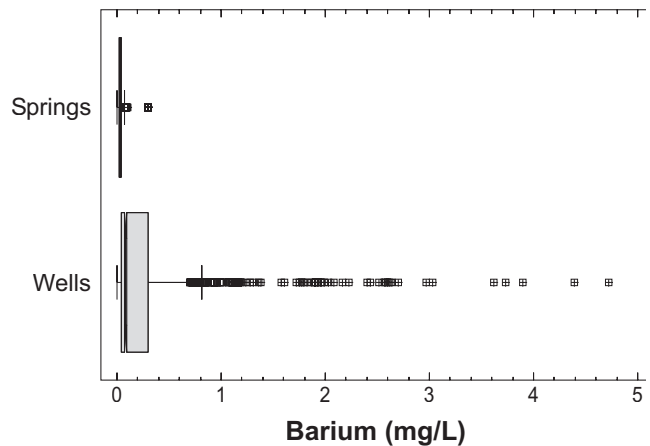


Figure 85. Comparison of barium values from wells and springs. Nine values from wells were excluded for clarity.

man-made, nonpoint sources of barium contamination are not suggested by the observed barium concentrations.

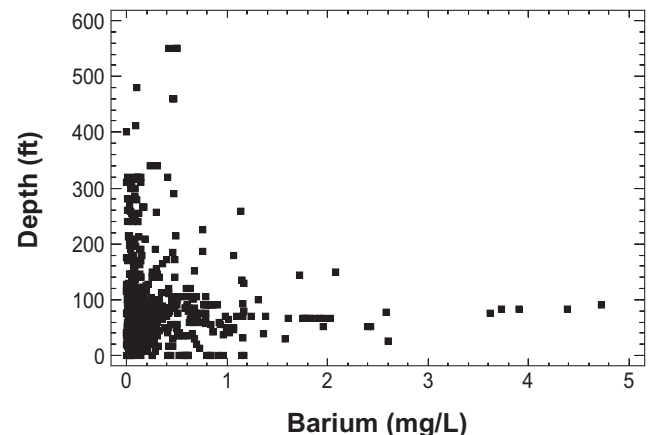


Figure 86. Plot of barium values versus well depth.

Mercury. Mercury (Hg) is a liquid metal found in natural deposits as ores containing other elements. Forest fires, coal combustion products, disposal of mercury-containing products such as electric lights and switches, computers, and blood pressure gauges contribute mercury to the environment. Electrical products such as dry-cell batteries, fluorescent lightbulbs, switches, and other control equipment account for 50 percent of mercury used. Combustion of fossil fuels, metal smelters, cement manufacture, municipal landfills, sewage, and metal refining operations are significant sources of mercury in the environment. When mercury from such sources is acted on by bacteria, some of it is converted to methylmercury, a much more toxic form of mercury. At high doses, mercury is a strong neurotoxin that causes demyelination¹, delayed nerve conduction, and kidney damage. Because of its toxicity, the EPA has set an MCL for mercury at 0.002 mg/L.

The Kentucky Groundwater Data Repository contained 1,587 mercury analyses from 430 sites from the project area (Table 15, Fig. 87). No measured mercury concentration exceeded the MCL of 0.002 mg/L.

Only 21 of the 430 sites had values above analytical detection. Most of these were in the Western Pennyroyal Region of the Salt River watershed. Four of these sites are springs and 17 are wells. Three of these values were dissolved mercury and 18 were measurements of total mercury. The highest reported value was 0.00095 mg/L, well below the MCL of 0.002 mg/L.

Because so few values of mercury were above analytical detection limits, no further analysis was performed.

In summary, mercury was detected in 21 of 430 sites in the project area. The maximum mercury concentration reported was 0.00095 mg/L, less than half of the MCL. Detections were more common in unfiltered samples, suggesting that mercury was adsorbed onto suspended material rather than in true solution. Most of the sites where mercury was detected are located in the Western Pennyroyal Region of the Salt River watershed, BMU 2. This concentration of mercury detections most likely indicates either a geologic control or the influence of atmospheric fallout.

Table 15. Summary of mercury values (mg/L). MCL: 0.002 mg/L.

	BMU 1	BMU 2	BMU 5
Values	622	731	235
Maximum	< 0.002	< 0.002	0.00095
75th percentile	< 0.00005	<0.0001	< 0.00005
Median	< 0.00005	< 0.00005	< 0.00005
25th percentile	< 0.00005	< 0.00005	< 0.00005
Minimum	< 0.00005	< 0.00005	< 0.00005
Interquartile range	N/A	N/A	N/A
Sites	100	221	109
Sites > 0.002 mg/L	0	0	0

< means analytical result reported as less than the stated analytical detection limit

¹Destruction or loss of material that acts as a sheath around nerves.

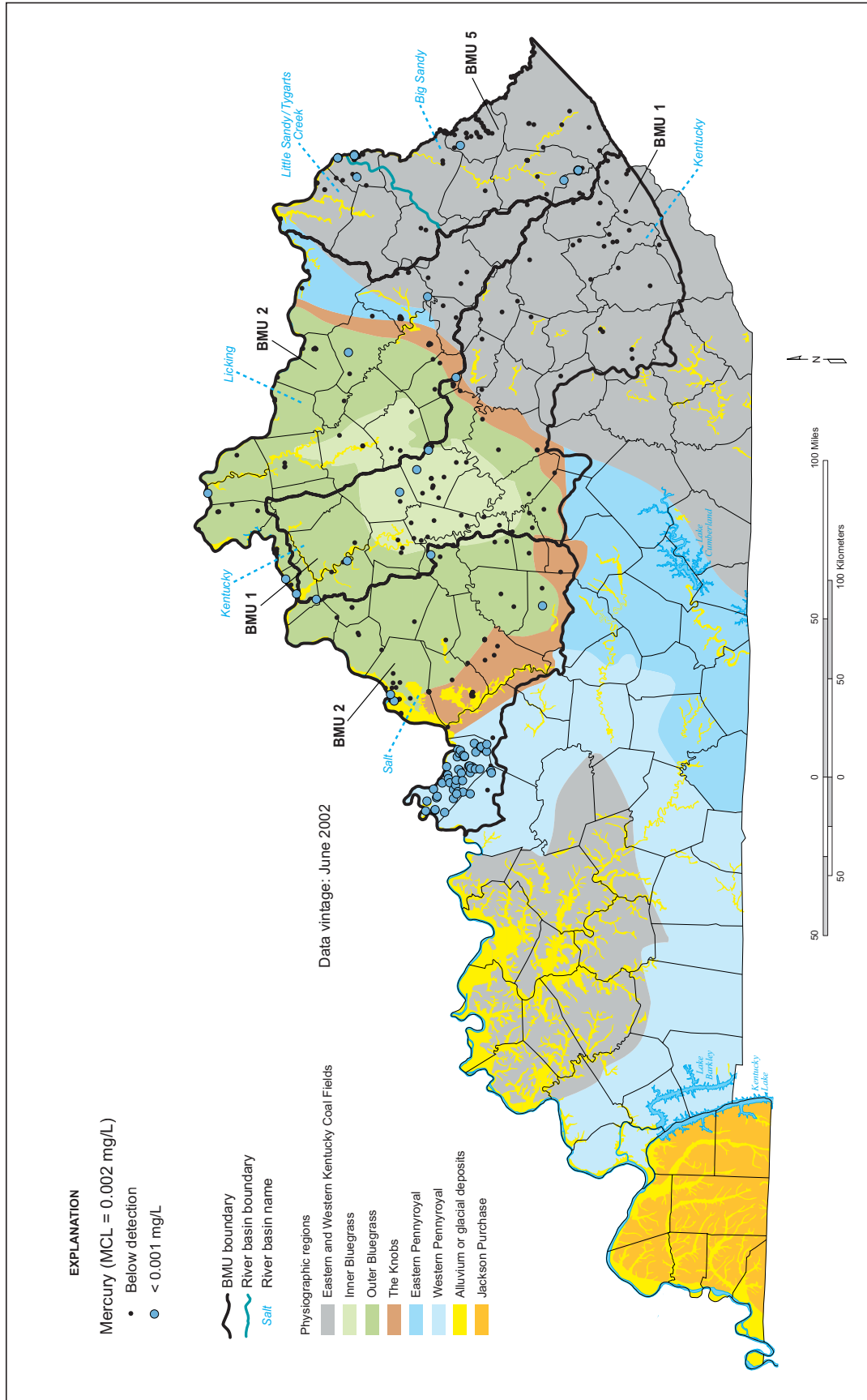


Figure 87. Locations of sampled sites and ranges of mercury values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

Iron. Iron (Fe) is a naturally occurring metal that is widely present in groundwater. Iron can occur in either an oxidized (ferric) or reduced (ferrous) state. At normal groundwater pH values, ferric iron is rapidly precipitated as an iron oxide, iron hydroxide, iron oxyhydroxide (rust), or poorly crystalline to amorphous material. Under reduced conditions, however, ferrous iron is stable and will remain in groundwater. There is no EPA primary drinking-water standard for iron in water supplies because there are no identified serious health threats posed by it. There is, however, a secondary standard of 0.3 mg/L for iron because concentrations above this level produce objectionable odor, taste, color, staining, corrosion, and scaling.

The data repository contained 11,288 iron measurements from 2,629 sites in the project area (Table 16). Iron concentrations are quite high; more than half of the sites in each basin management unit produced groundwater that has iron concentrations above the secondary standard.

The distribution of reported iron concentrations is similar in the three basin management units (Figs. 88–90).

Sample-site density is greatest in the Eastern Kentucky Coal Field and lowest in the eastern part of the Outer Bluegrass Region (Fig. 91). Values above the

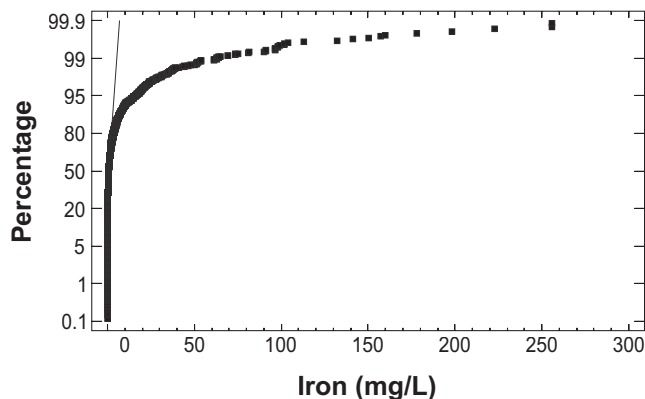


Figure 88. Cumulative plot of iron values in BMU 1. Higher values were excluded for clarity.

SMCL are found throughout the project area and are most common in the Eastern Kentucky Coal Field, western part of the Outer Bluegrass, and Western Pennyroyal Regions.

Samples from the Eastern Kentucky Coal Field and the Outer Bluegrass Regions have the highest iron concentrations and the largest range of values,

Table 16. Summary of iron values (mg/L). SMCL: 0.3 mg/L.

	BMU 1	BMU 2	BMU 5
Values	4,394	3,187	3,707
Maximum	735	9,660	1,500
75th percentile	1.0	1.9	2.76
Median	0.23	0.26	0.60
25th percentile	0.05	0.04	0.14
Minimum	0.00	0.00	0.00
Interquartile range	0.95	1.86	2.62
Sites	751	1,055	823
Sites > 0.3 mg/L	523	599	641

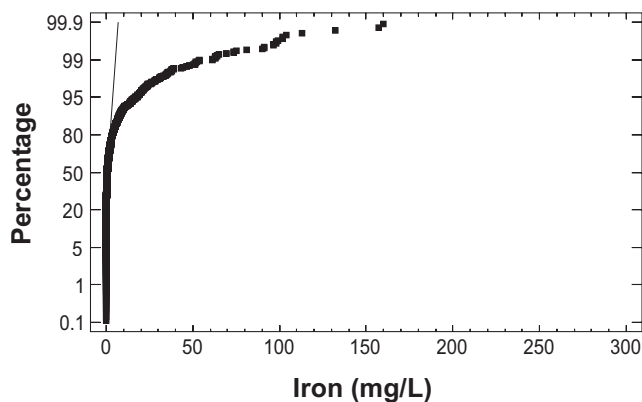


Figure 89. Cumulative plot of iron values from BMU 2. Higher values were excluded for clarity.

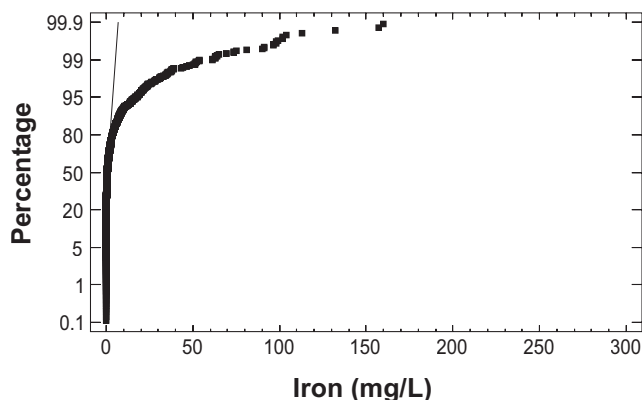


Figure 90. Cumulative plot of iron values from BMU 5. Higher values were excluded for clarity.

whereas sites from the Inner Bluegrass and Western Pennyroyal Regions have the lowest concentrations and smallest range of values (Fig. 92).

Samples from the Licking River watershed have the lowest median value and smallest interquartile range of iron concentrations (Fig. 93). Samples from the Salt River, Big Sandy River, Little Sandy River, and Tygarts Creek watersheds have high median values, a large interquartile range, and a large number of iron concentrations greater than 5 mg/L.

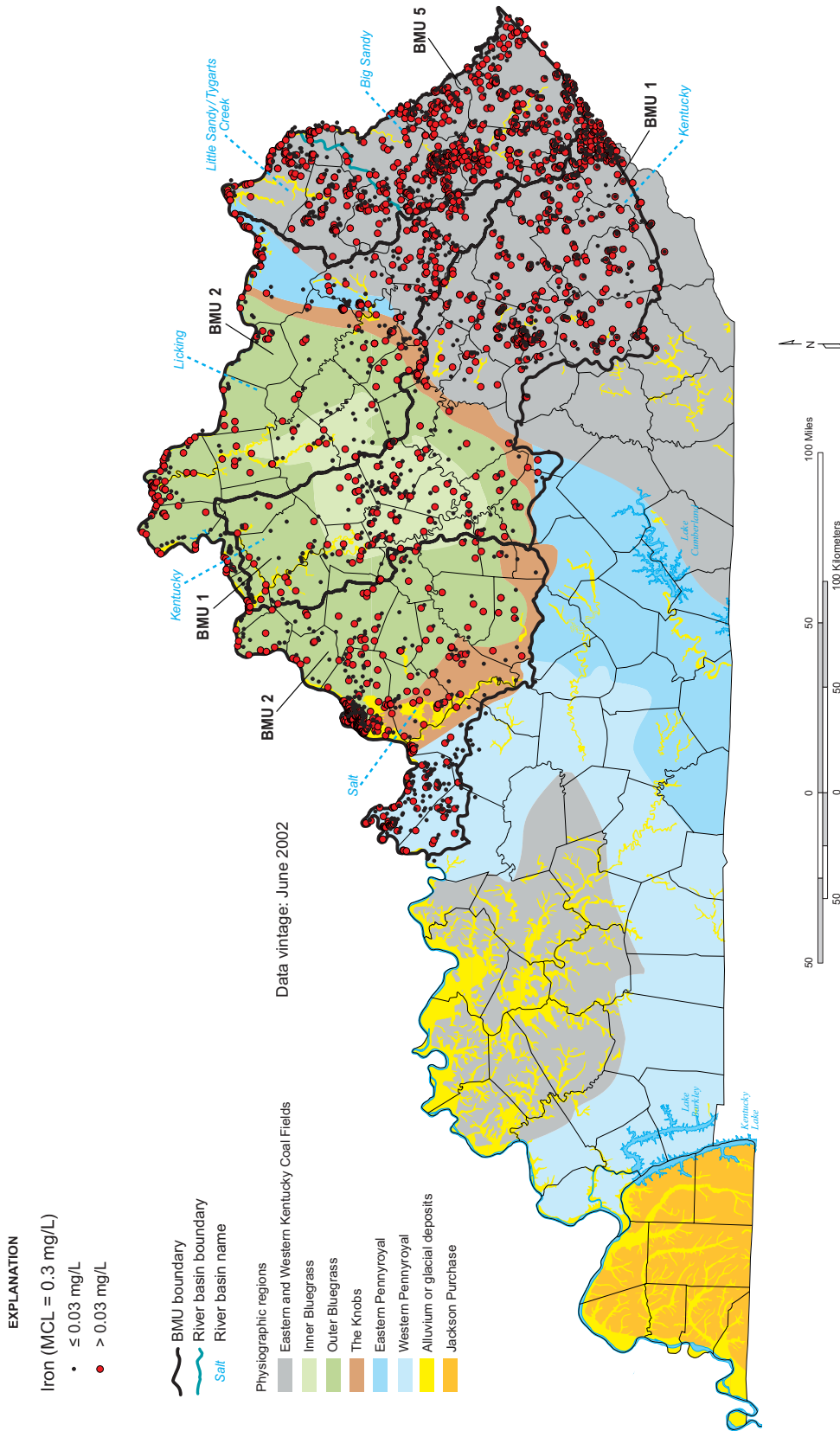


Figure 91. Locations of sites and ranges of iron values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

Total iron concentrations (unfiltered samples) have a higher median value and greater interquar-

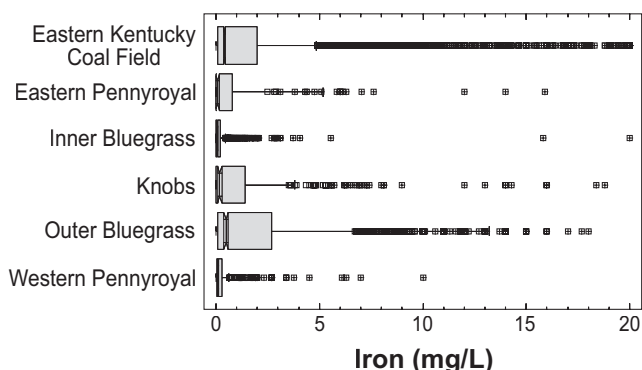


Figure 92. Summary of iron values grouped by physiographic region. Higher values were excluded for clarity.

tile range than dissolved iron concentrations (filtered samples), suggesting that some of the reported iron is associated with suspended solids (Fig. 94).

Groundwater from springs is generally much lower in iron than water from wells (Fig. 95).

High iron concentrations are found more commonly in wells that are less than 100 ft deep; deeper wells typically have much lower iron concentrations (Fig. 96).

In summary, iron concentrations that are high enough to produce staining and objectionable taste are common in groundwater throughout the project area. High iron concentrations are especially common in the Eastern Kentucky Coal Field and western part of the Outer Bluegrass Region. Total iron concentrations are higher than dissolved concentrations, indicating that iron is also present in suspended material. Wells have higher iron concentrations than springs, probably because many springs in this area are in carbonate bedrock, which is naturally lower in iron than sandstones and shales.

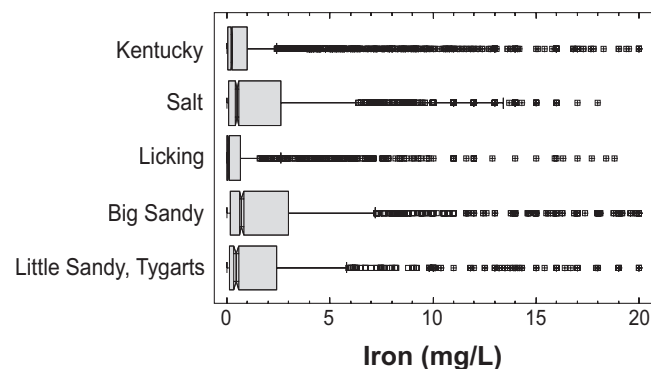


Figure 93. Summary of iron values grouped by major watershed. Higher values were excluded for clarity.

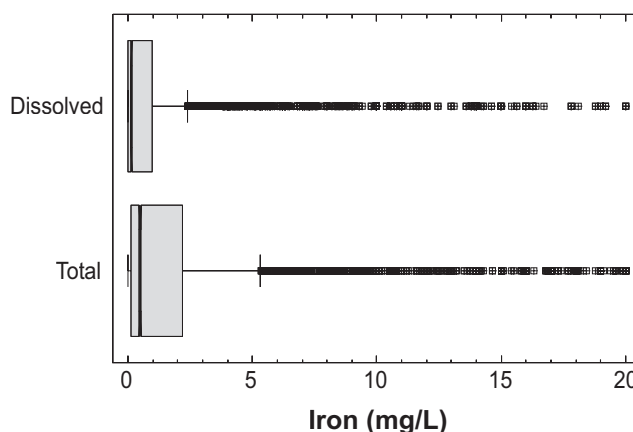


Figure 94. Comparison of total and dissolved iron values. Higher values were excluded for clarity.

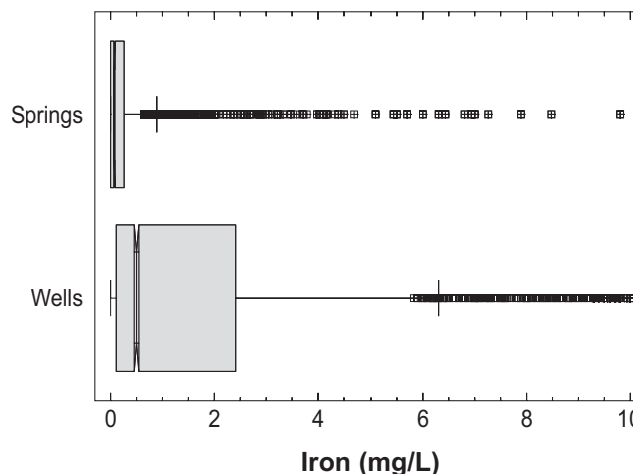


Figure 95. Comparison of iron values from wells and springs. Higher values were excluded for clarity.

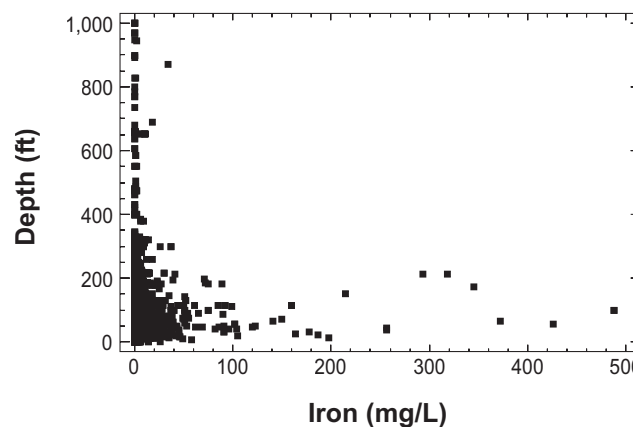


Figure 96. Plot of iron values versus well depth. Higher values were excluded for clarity.

Manganese. Manganese (Mn) is a naturally occurring cation that is widely present in groundwater supplies. Manganese and iron behave similarly geochemically, so high manganese concentrations can be expected from wells and springs that produce water with high iron concentrations.

There is no EPA primary drinking-water standard for manganese in water supplies because there are no identified serious health threats posed by it. There is, however, a secondary standard of 0.05 mg/L for manganese, because higher concentrations produce objectionable odor, taste, color, corrosion, and staining.

The data repository contained 9,079 manganese concentrations from 6,005 sites in basin management units 1, 2, and 5 (Table 17). Like iron concentrations, manganese concentrations are high enough to require

Table 17. Summary of manganese values (mg/L). SMCL: 0.05 mg/L.

	BMU 1	BMU 2	BMU 5
Values	3,788	2,561	2,730
Maximum	20.1	540	83
75th percentile	0.20	0.29	0.50
Median	0.06	0.04	0.11
25th percentile	0.01	0.01	0.03
Minimum	0.00	0.00	0.00
Interquartile range	0.19	0.28	0.47
Sites	2,458	1,816	1,731
Sites > 0.05 mg/L	840	663	642

treatment before groundwater is suitable for domestic use. More than one-third of all sites produce water having more than 0.05 mg/L of manganese.

The distribution of manganese concentrations is generally similar in the three basin management units (Figs. 97-99), although BMU 1 has fewer very high values than BMU 2 or BMU 5.

Site distribution is very dense in the southern part of the Eastern Kentucky Coal Field and the west-

ern part of the Outer Bluegrass Region (Fig. 100) because the National Uranium Resource Evaluation program sampled these areas. Values that exceed the SMCL are found throughout the project area.

Although manganese concentrations that exceed the SMCL are found in every physiographic region and major watershed, they are most common in the Eastern Kentucky Coal Field (Kentucky

River, Big Sandy River, Little Sandy River, and Tygarts Creek watersheds) and the Outer Bluegrass Region (Salt River watershed) (Figs. 101-102).

Dissolved manganese concentrations have a higher median value and larger interquartile range than total manganese concentrations (Fig. 103), suggesting that suspended particulate material does not

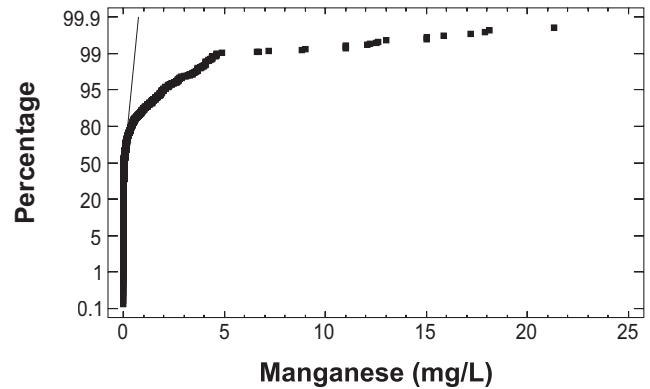


Figure 98. Cumulative plot of manganese values from BMU 2. Higher values were excluded for clarity.

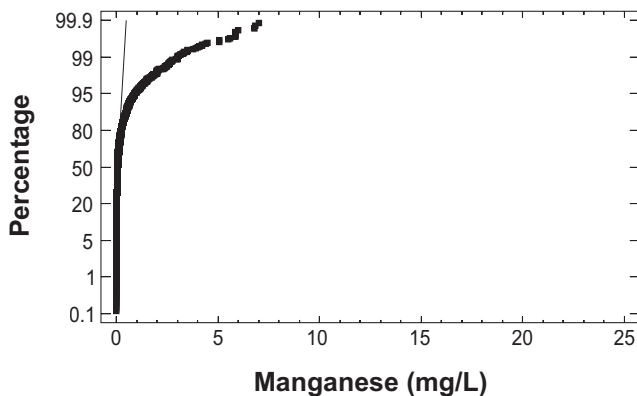


Figure 97. Cumulative plot of manganese values from BMU 1. Higher values were excluded for clarity.

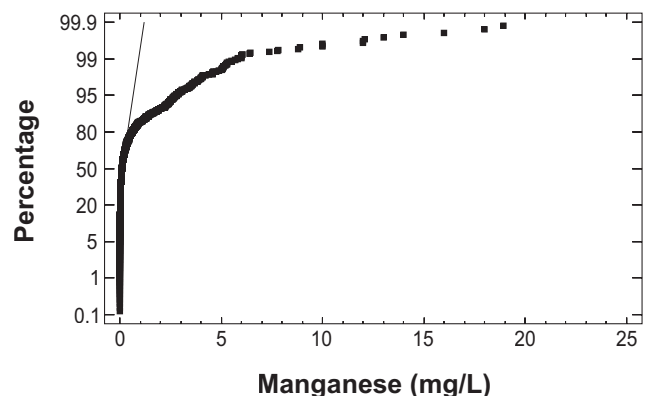


Figure 99. Cumulative plot of manganese values from BMU 5. Higher values were excluded for clarity.

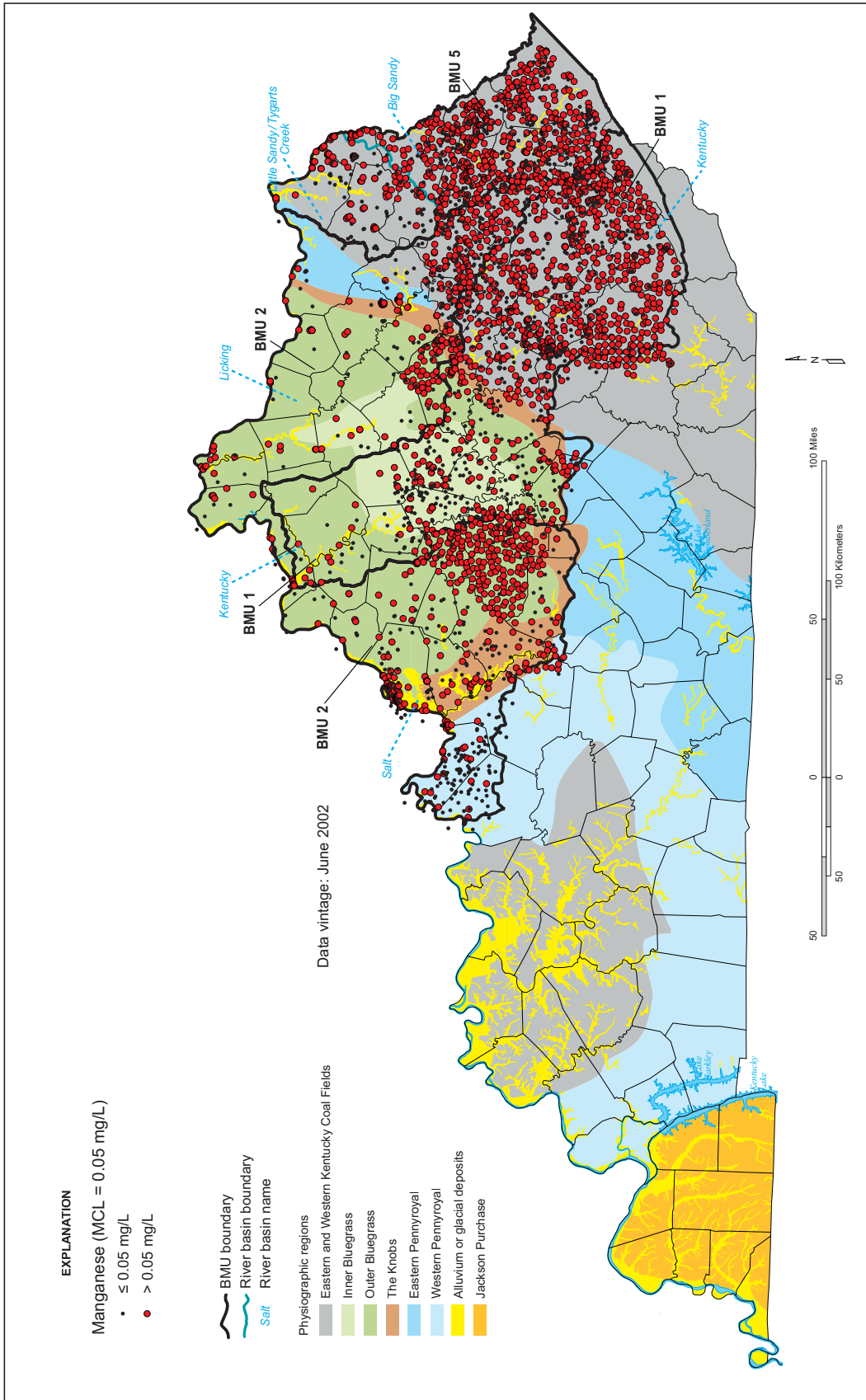


Figure 100. Locations of sampled sites and ranges of manganese values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

contribute significant amounts of manganese to the analysis.

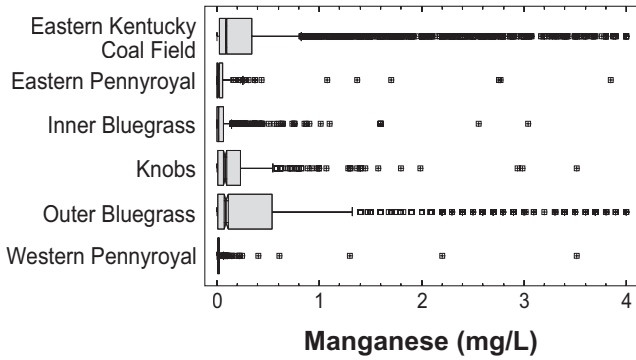


Figure 101. Summary of manganese values grouped by physiographic region. Higher values were excluded for clarity.

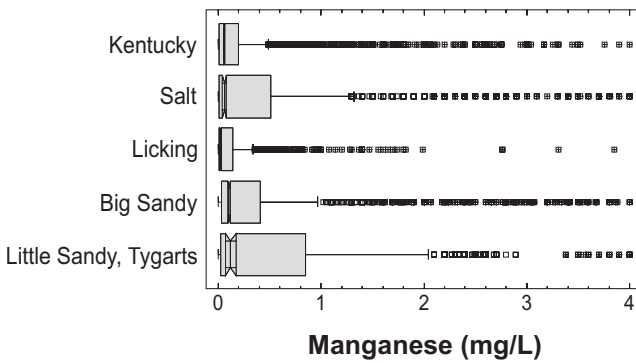


Figure 102. Summary of manganese values grouped by major watershed. Higher values were excluded for clarity.

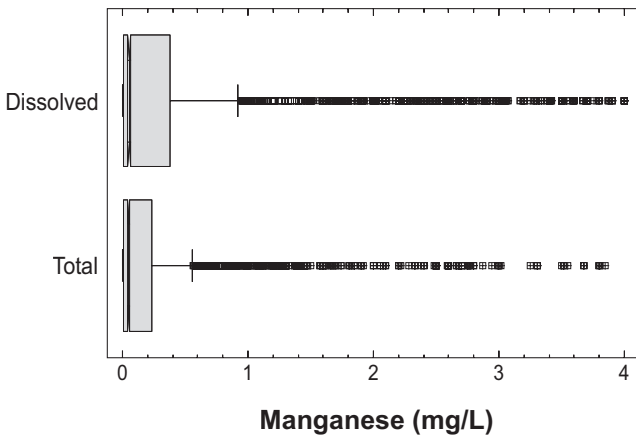


Figure 103. Comparison of total and dissolved manganese values. Higher values were excluded for clarity.

Groundwater from wells is generally higher in manganese than groundwater from springs (Fig. 104).

The highest manganese concentrations are typically found in wells less than 100 ft deep, rather than in deeper wells (Fig. 105).

In summary, the geochemical similarity between manganese and iron is demonstrated in the similarity of their concentrations in groundwater. Both commonly occur at concentrations that affect taste and can stain containers and clothing. The highest manganese concentrations are found in groundwater from the Eastern Kentucky Coal Field and the western part of the Outer Bluegrass Region, and in shallow wells rather than deep wells or springs. All features of the distribution of manganese concentrations appear primarily related to bedrock type. There is no evidence to suggest that nonpoint-source contamination significantly contributes to manganese concentrations in the project area.

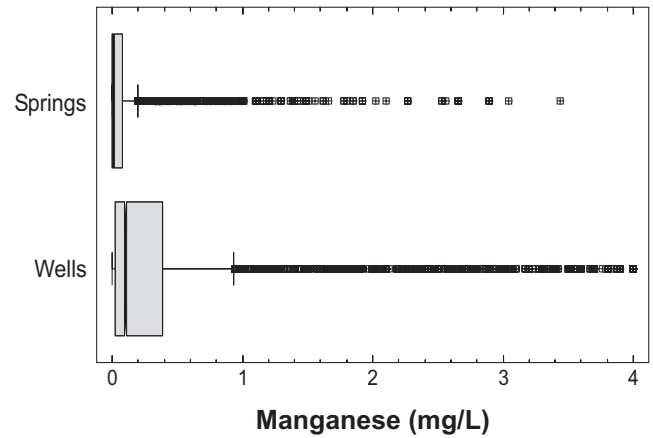


Figure 104. Comparison of manganese values from wells and springs. Higher values were excluded for clarity.

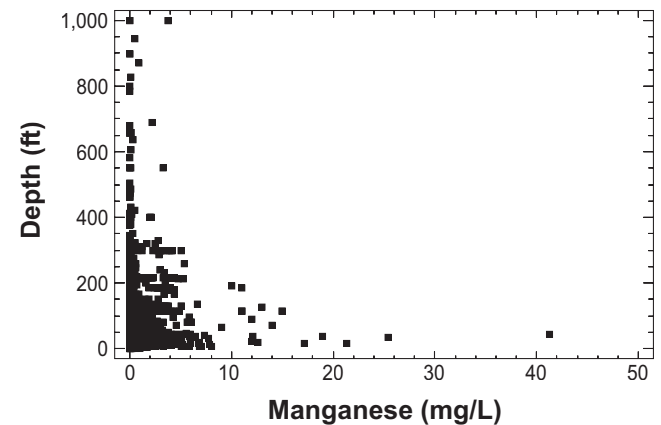


Figure 105. Plot of manganese values versus well depth.

Nutrients

The nutrients nitrogen and phosphorus occur naturally and also may be introduced to groundwater systems from urban and agricultural fertilizer applications, livestock or human wastes, and fossil-fuel combustion. High nutrient levels in groundwater generally indicate contamination from fertilizer, sewage systems, or confined feedlot operations. Excessive nutrients can lead to algal blooms and eutrophication in surface-water systems, and excessive nitrate or nitrite in drinking water can pose health hazards.

Nitrogen Species. Nitrogen in water occurs predominantly as either the anion nitrate (NO_3^-) under oxidizing conditions or the cation ammonium (NH_4^+) under reducing conditions. Nitrite (NO_2^-) and ammonia (NH_3) are thermodynamically less stable forms of aqueous nitrogen that may be present under reducing conditions. Because it is positively charged, ammonium is readily adsorbed on soil and mineral particles, thus limiting its mobility, whereas the negatively charged nitrate and nitrite anions are highly mobile. Nitrite, ammonium, and ammonia are unstable in oxidizing environments (Hem, 1985). For this reason, high concentrations of these species in shallow, aerated groundwater are indicators of likely contamination by sewage or other forms of organic waste. Nitrite, ammonium, and ammonia may also occur in deep, old, reducing groundwater systems.

Runoff from fertilizer use, leachate from septic tanks, and sewage are major sources of nitrogen species. Nitrate is commonly used as fertilizer; high nitrate concentrations generally indicate contamination by fertilizer or by human or animal waste. Caves in karst terrain that are home to large bat colonies may accumulate large amounts of guano that contribute nitrogen to local groundwater. Nitrite concentrations in groundwater are generally low because nitrite oxidizes quickly to nitrate in oxidizing environments and to nitrogen gas in reducing environments (Fetter, 1993).

Nitrate, nitrite, ammonia, and ammonium concentrations are reported differently for different pur-

poses. Analyses for geochemical investigations traditionally report concentrations as weight per volume of the measured ions (mg/L of NO_3^- , NO_2^- , NH_3 , or NH_4^+). Analyses for environmental purposes generally report the concentrations as equivalent amounts of nitrogen (nitrate-nitrogen, nitrite-nitrogen, ammonia-nitrogen, or ammonium-nitrogen), however. Consequently, nitrogen data must be examined closely to determine how they were recorded, and concentration units must be standardized before data summaries and evaluations can be made.

The EPA has established a drinking-water MCL of 10 mg/L for nitrate-nitrogen (equivalent to 44.3 mg/L nitrate) and 1.0 mg/L for nitrite-nitrogen (equivalent to 3.2 mg/L nitrite) because higher concentrations can lead to methemoglobinemia (blue baby syndrome) in infants, where the oxygen-carrying ability of the child's blood is severely reduced. Lifetime exposure to nitrite-nitrogen concentrations greater than 1 mg/L also can produce diuresis, increased starchy deposits, and hemorrhaging of the spleen. No human health-based concentration limits have been established for ammonia or ammonium. Ammonia concentrations of 1 to 10 mg/L can be toxic to aquatic life, however.

Nitrate-Nitrogen. The data repository contained 2,547 nitrate-nitrogen measurements at 741 sites. Nitrate-nitrogen concentrations exceeded the MCL of 10 mg/L at 45 sites (Table 18).

Cumulative data plots are similar for BMU 1 and BMU 2 (Figs. 106–107), with many values greater than 10 mg/L, whereas only four values greater than 10 mg/L were reported from BMU 5 (Fig. 108).

The map of sampled sites and ranges of nitrate-nitrogen concentrations (Fig. 109) show a sparse site distribution in the Outer Bluegrass, Knobs, and Eastern and Western Pennyroyal Regions, and a dense site distribution in the Inner Bluegrass and Eastern Kentucky Coal Field Regions in BMU 2 and BMU 5. Most sites where nitrate-nitrogen concentrations exceed 10 mg/L are found in the Inner and Outer Bluegrass Regions of BMU 1 and BMU 2.

Table 18. Summary of nitrate-nitrogen values (mg/L). MCL: 10 mg/L.

	BMU 1	BMU 2	BMU 5
Values	935	1,069	543
Maximum	84.8	108	16.0
75th percentile	2.897	3.29	0.5
Median	0.79	0.65	0.07
25th percentile	0.1	0.09	0.02
Minimum	0.0	0.0	0.0
Interquartile range	2.77	3.2	0.48
Sites	176	294	271
Sites > 10.0 mg/L	20	22	3

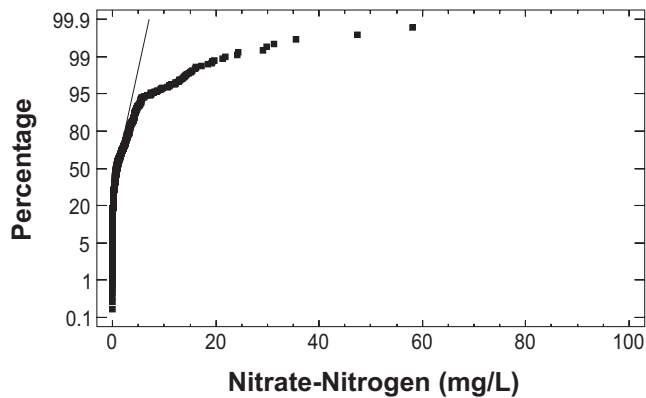


Figure 106. Cumulative plot of nitrate-nitrogen values from BMU 1.

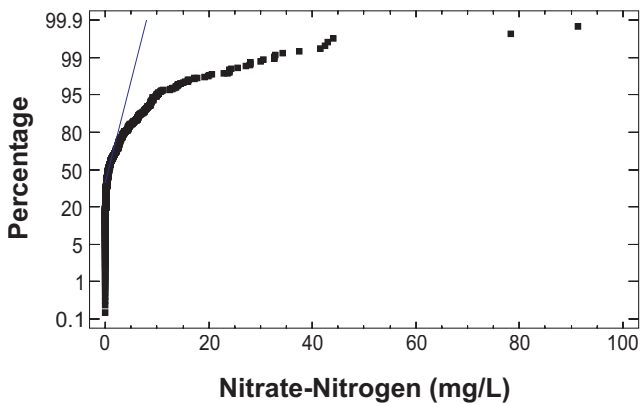


Figure 107. Cumulative plot of nitrate-nitrogen values from BMU 2.

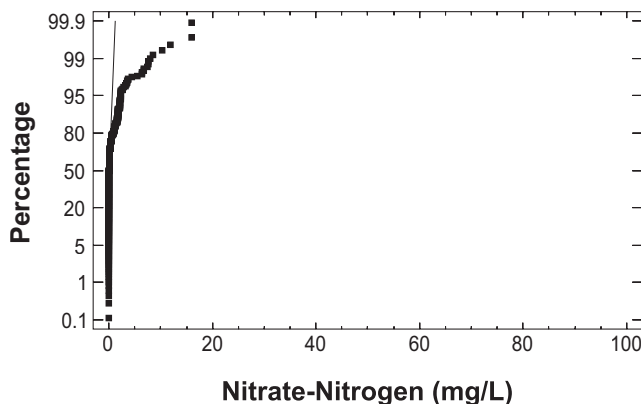


Figure 108. Cumulative plot of nitrate-nitrogen values from BMU 5.

Groundwater having nitrate-nitrogen concentrations greater than 10 mg/L is most common in the Inner and Outer Bluegrass Regions of the Kentucky, Salt, and Licking River watersheds (Figs. 109–110), and relatively rare in watersheds of the Big Sandy and Little Sandy Rivers and Tygarts Creek (Fig. 111).

Groundwater from wells and springs has about the same range of nitrate-nitrogen concentrations (Fig. 112), whereas total (unfiltered samples) nitrate-nitrogen concentrations are generally higher than dissolved (filtered samples) concentrations (Fig. 113).

The highest nitrate-nitrogen concentrations are found in shallow wells; concentrations greater than 5 mg/L are rare in groundwater from wells deeper than about 150 ft (Fig. 114).

In summary, more than 99 percent of all nitrate-nitrogen measurements in BMU 5 and more than 95 percent of all measurements in BMU 1 and BMU 2 are less than the MCL of 10 mg/L. Values as high as 108 mg/L have been recorded, however, and sites where nitrate-nitrogen concentrations exceed the recommended health-based limit occur in all basin management units. High nitrate-nitrogen concentrations are most likely in the carbonate Inner and Outer Bluegrass Regions in water from both springs and shallow wells. These results suggest that nonpoint-source nutrients are contributing nitrate to the groundwater system. A statewide summary of nitrate data (Conrad and others, 1999b) can be viewed on the KGS Web site (kgsweb.uky.edu/olops/pub/kgs/ic60_11.pdf).

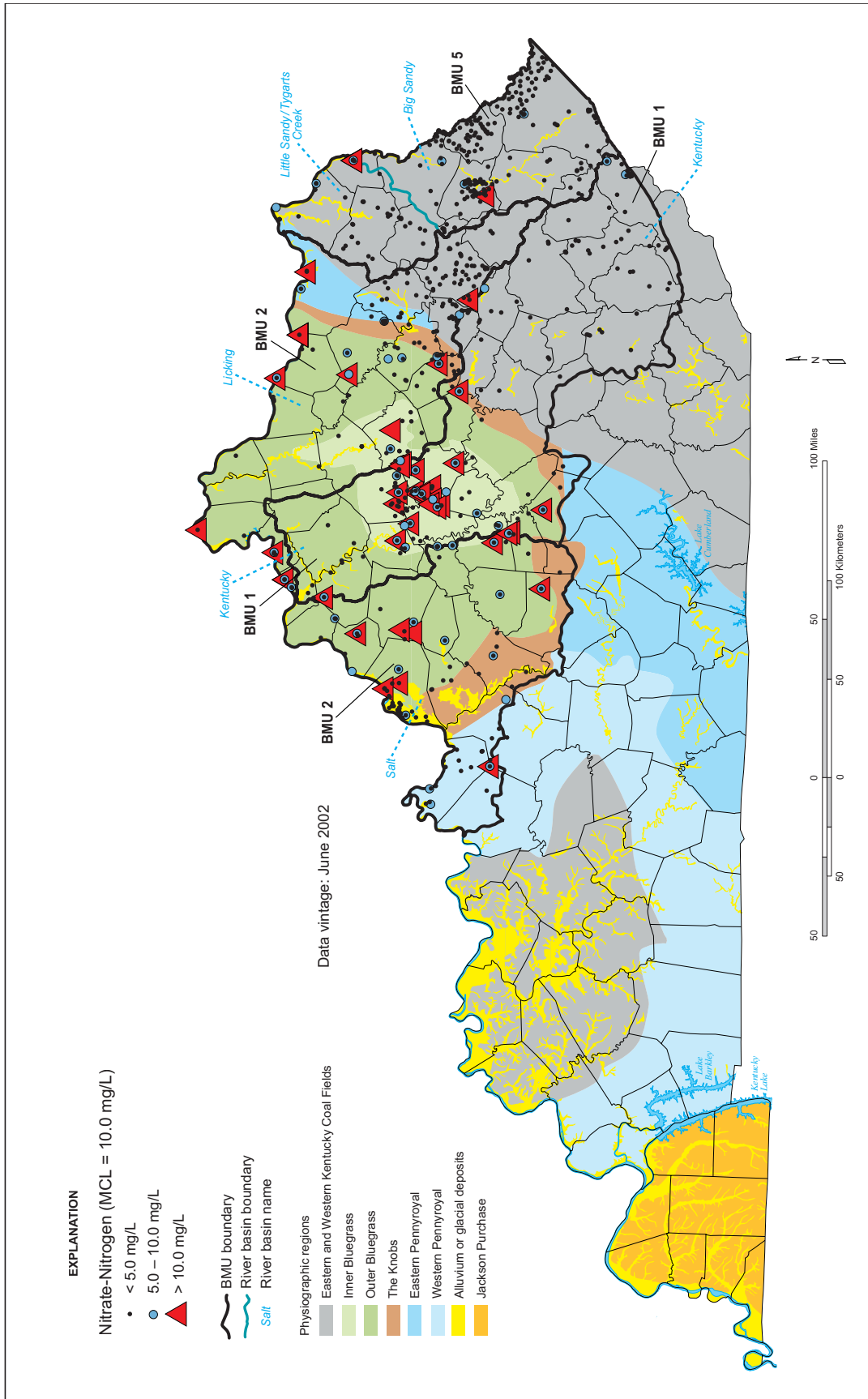


Figure 109. Locations of sampled sites and ranges of nitrate-nitrogen values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

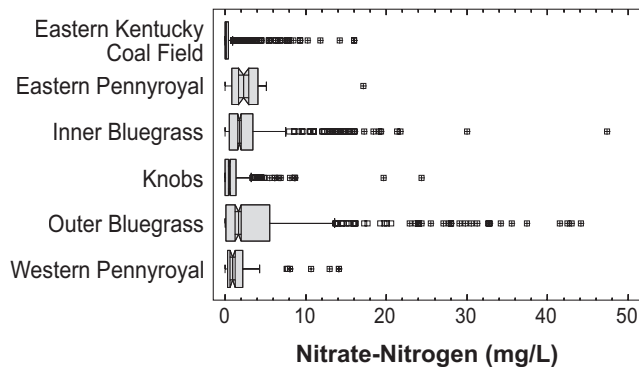


Figure 110. Summary of nitrate-nitrogen values grouped by physiographic region. Higher values were excluded for clarity.

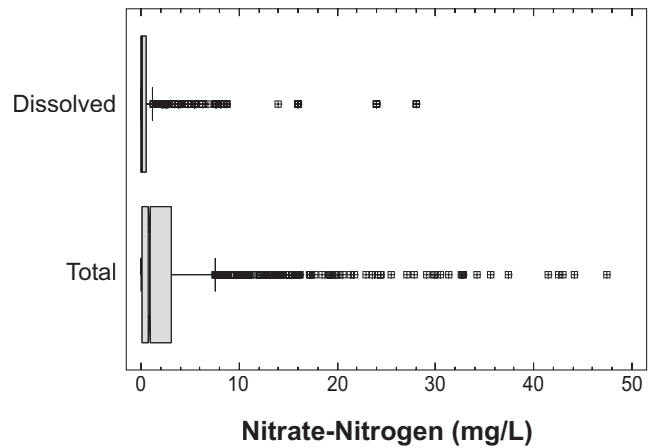


Figure 113. Comparison of total and dissolved nitrate-nitrogen values. Higher values were excluded for clarity.

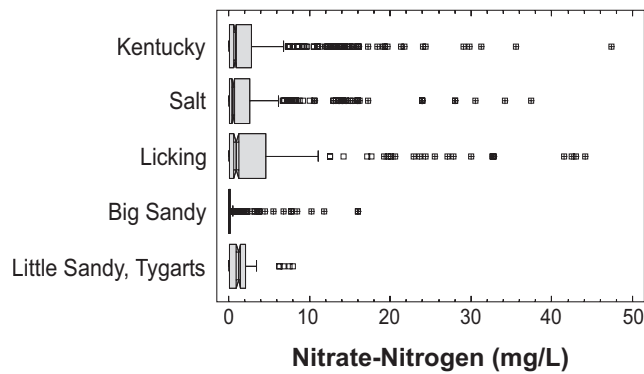


Figure 111. Summary of nitrate-nitrogen values grouped by major watershed. Higher values were excluded for clarity.

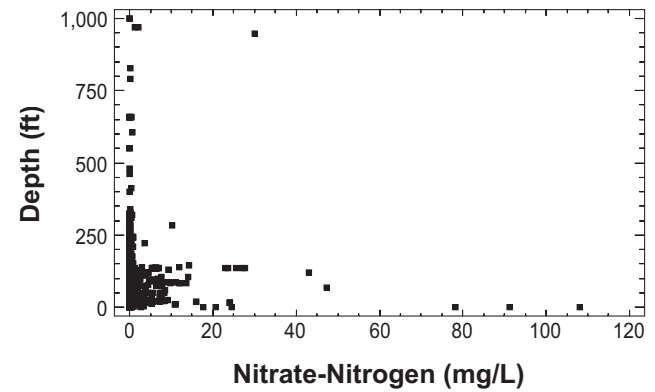


Figure 114. Plot of nitrate-nitrogen values versus well depth.

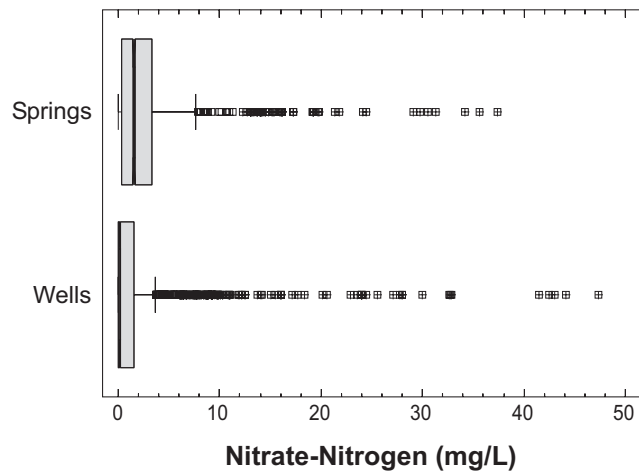


Figure 112. Comparison of nitrate-nitrogen values from wells and springs. Higher values were excluded for clarity.

Nitrite-Nitrogen. The data repository contained 1,965 measurements of nitrite-nitrogen from 339 sites. The median value in each BMU is well below the EPA MCL of 1.0 mg/L; however, nitrite-nitrogen concentrations exceed 1.0 mg/L at four sites in the project area (Table 19).

The distribution of measured values is similar in each basin management unit, with more than 99 percent of the values being well below 1.0 mg/L (Figs. 115-117).

The distribution of sampled sites is not uniform throughout the project area (Fig. 118); the densest sampling is along the eastern border of BMU 5 and along the Ohio River in the Salt River watershed of BMU

2. Sites where nitrite-nitrogen exceeds the MCL of 1.0 mg/L occur in the Eastern Kentucky Coal Field of BMU 1 and the Western Pennyroyal and Outer Bluegrass Regions of BMU 2 (Figs. 118-120).

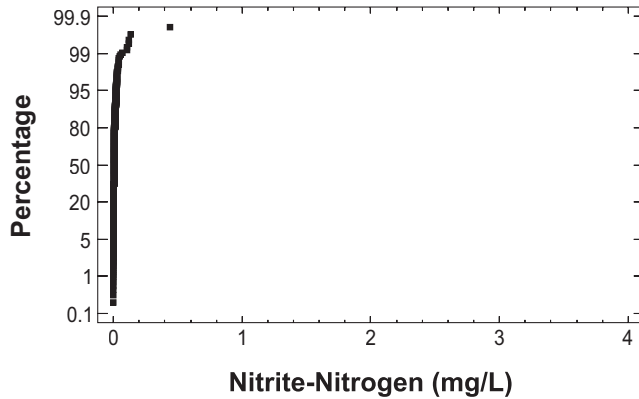


Figure 115. Cumulative plot of nitrite-nitrogen values from BMU 1.

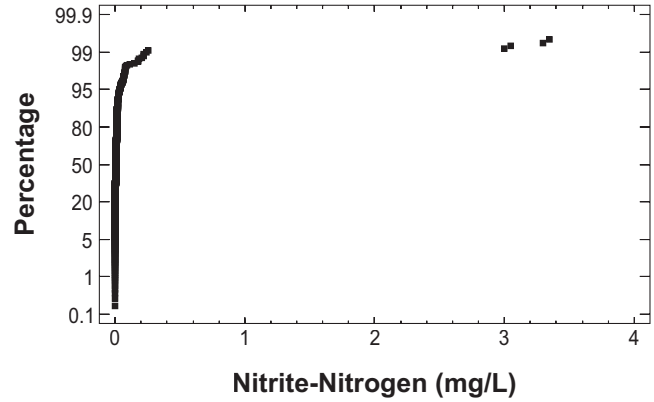


Figure 116. Cumulative plot of nitrite-nitrogen values from BMU 2.

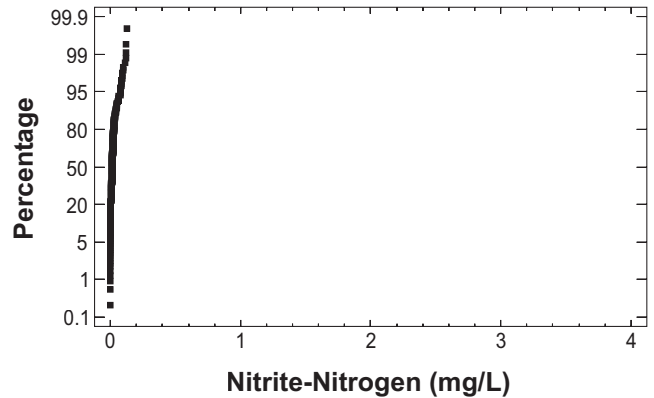


Figure 117. Cumulative plot of nitrite-nitrogen values from BMU 5.

Table 19. Summary of nitrite-nitrogen values (mg/L). MCL: 1.0 mg/L.

	BMU 1	BMU 2	BMU 5
Values	777	908	280
Maximum	1.5	13.4	0.13
75th percentile	0.008	0.01	0.023
Median	0.005	< 0.006	0.01
25th percentile	0.002	0.002	0.004
Minimum	0.0	0.0	0.0
Interquartile range	0.006	0.008	0.019
Sites	85	145	109
Sites > 1.0 mg/L	1	3	0

< means analytical result reported as less than the stated analytical detection limit

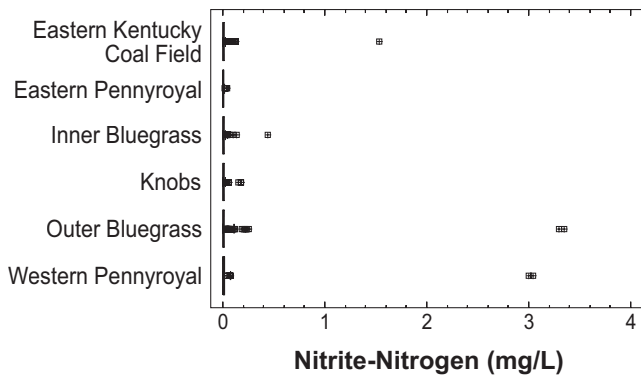


Figure 119. Summary of nitrite-nitrogen values grouped by physiographic region. Higher values were excluded for clarity.

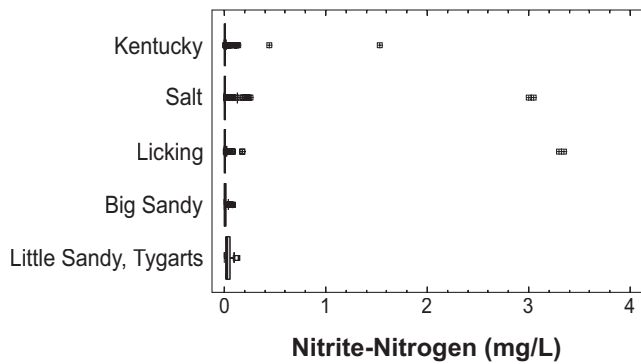


Figure 120. Summary of nitrite-nitrogen values grouped by major watershed. Higher values were excluded for clarity.

Nitrite-nitrogen concentrations that exceeded the MCL of 1.0 mg/L were reported from wells rather than from springs (Fig. 121).

Both dissolved (filtered samples) and total (unfiltered samples) groundwater can contain nitrite-nitrogen concentrations greater than the MCL of 1.0 mg/L (Fig. 122).

Nitrite-nitrogen concentrations high enough to present health concerns are found in wells less than 100 ft deep (Fig. 123).

In summary, nitrite-nitrogen concentrations that exceed the health-based limit of 1.0 mg/L are rare in the project area. Four sites produced such groundwater; three of those were in karst limestone terrain. These occurrences probably mark sites where nonpoint-source nitrate has been partially reduced in the groundwater environment.

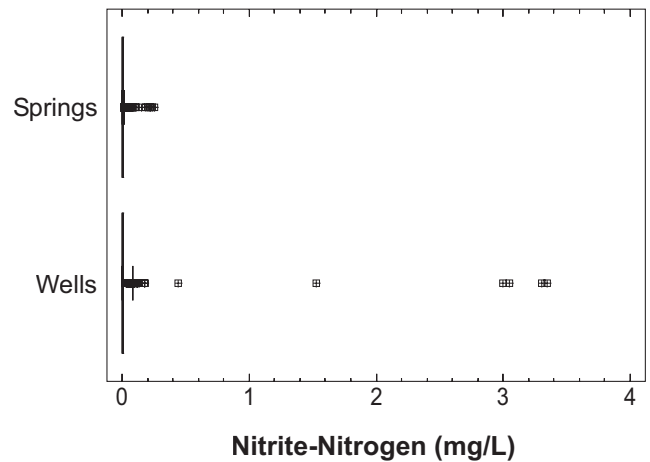


Figure 121. Comparison of nitrite-nitrogen values from wells and springs. Higher values were excluded for clarity.

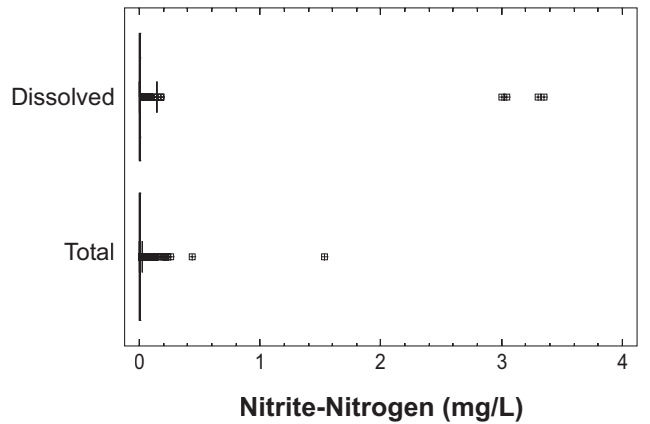


Figure 122. Comparison of total and dissolved nitrite-nitrogen values. Higher values were excluded for clarity.

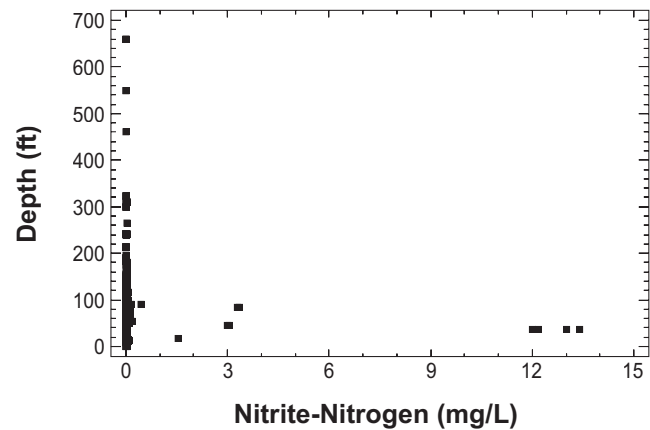


Figure 123. Plot of nitrite-nitrogen values versus well depth.

Ammonia-Nitrogen. The data repository contained 1,675 ammonia-nitrogen measurements from 213 sites in the project area (Table 20). The median concentration in each BMU was below analytical detection. Although there are no EPA health-based standards for ammonia-nitrogen, the Kentucky Division of Water has recommended a risk-based upper limit of 0.110 mg/L. Values greater than 0.11 mg/L are uncommon in the project area, but were observed at 81 of the 213 sites (Table 20).

Cumulative data plots show differences between the basin management units. In BMU 1, approximately 95 percent of the reported values are less than 0.11 mg/L (Fig. 124), whereas that number falls to about 90 percent in BMU 2 (Fig. 125) and to about 65 percent in BMU 5 (Fig. 126).

The map of sampled sites and ranges of concentrations (Fig. 127) shows denser sampling in the Eastern Kentucky Coal Field and more sites that exceed 0.11 mg/L ammonia-nitrogen in the Eastern Kentucky Coal Field than in other regions. Site density is lowest in the Outer Bluegrass Region.

The median and 75th percentile ammonia-nitrogen concentrations are below 0.11 mg/L in all physiographic regions (Fig. 128). Most concentrations higher than 0.11 mg/L are found in the Eastern Kentucky Coal Field and the Outer Bluegrass Region.

Groundwater from the Big Sandy River watershed has the highest median and 75th percentile ammonia-nitrogen concentrations, as well as the largest interquartile range (Fig. 129). The interquartile range

Table 20. Summary of ammonia-nitrogen values (mg/L). DOW recommendation: 0.11 mg/L.

	BMU 1	BMU 2	BMU 5
Values	849	659	167
Maximum	22.5	20.55	13.15
75th percentile	< 0.05	< 0.05	0.387
Median	< 0.02	< 0.02	< 0.05
25th percentile	< 0.02	< 0.02	< 0.02
Minimum	0.0	0.0	0.016
Sites	76	89	48
Sites > 0.11 mg/L	26	19	36

< means analytical result reported as less than the stated analytical detection limit

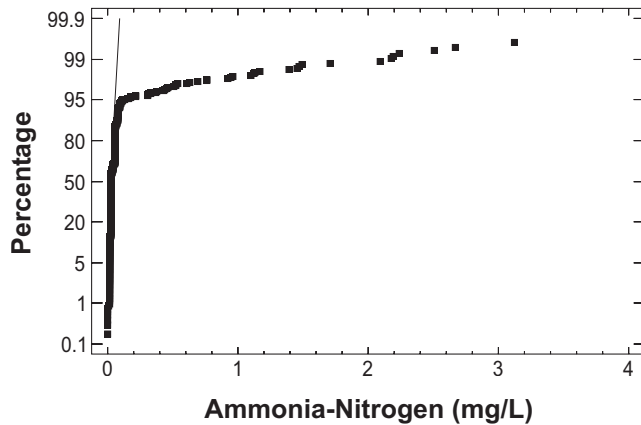


Figure 124. Cumulative plot of ammonia-nitrogen values from BMU 1. Extreme values were omitted to better show the majority of the data.

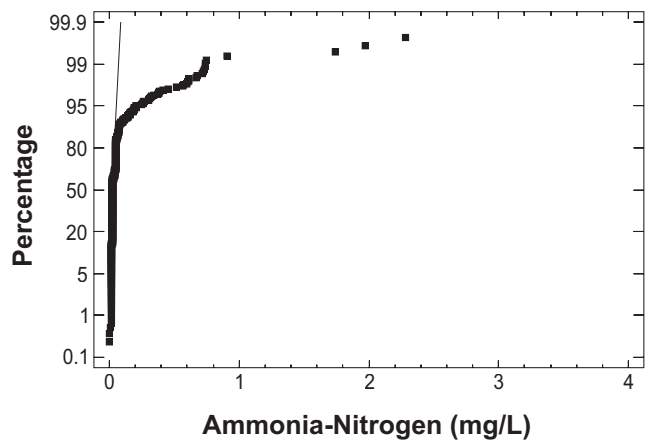


Figure 125. Cumulative plot of ammonia-nitrogen values from BMU 2. Extreme values were omitted to better show the majority of the data.

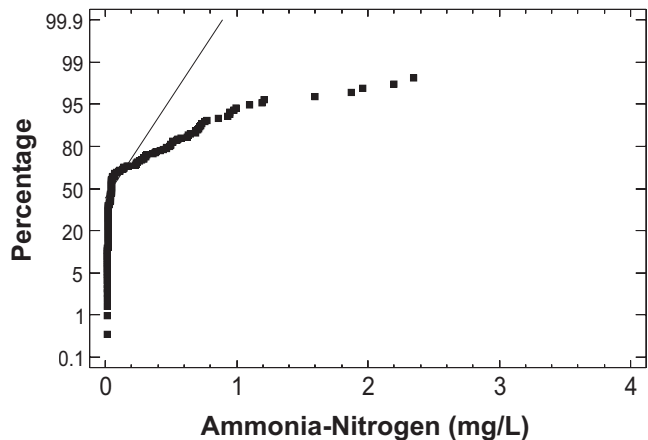


Figure 126. Cumulative plot of ammonia-nitrogen values from BMU 5. Extreme values were omitted to better show the majority of the data.

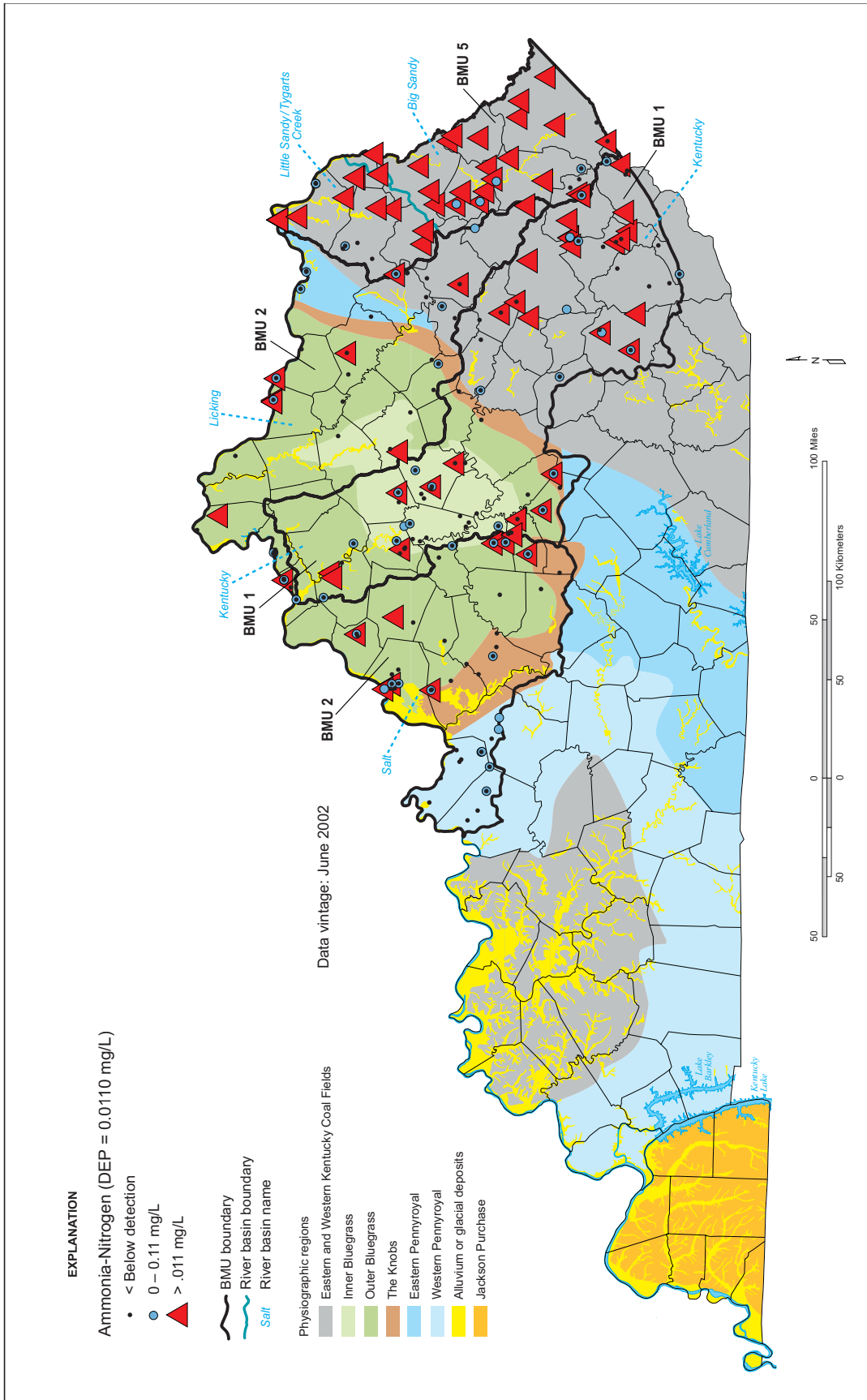


Figure 127. Locations of sampled sites and ranges of ammonia-nitrogen values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

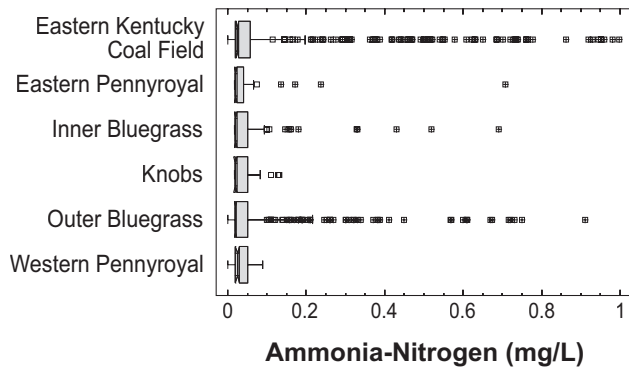


Figure 128. Summary of ammonia-nitrogen values grouped by physiographic region. Higher values were excluded for clarity.

of values is similar for samples from all other watersheds.

The median and 75th percentile concentration values for dissolved ammonia-nitrogen are significantly greater than that of total ammonia-nitrogen (Fig. 130), although the highest concentrations are found in total (unfiltered) samples.

High ammonia-nitrogen concentrations are more likely to be found in groundwater from wells than from springs (Fig. 131), and more likely to be found in shallow wells than in wells deeper than about 100 ft (Fig. 132).

In summary, ammonia-nitrogen concentrations in groundwater are generally below the criteria set by DOW (0.11 mg/L) throughout the project area. The highest concentrations occur in the Eastern Kentucky Coal Field and Outer Bluegrass Region, and particularly in the Big Sandy River watershed of the Eastern Kentucky Coal Field. The most likely sources of ammonia-nitrogen there are naturally occurring nitrogen in both coal and leaf litter. The available data do not indicate that nonpoint-source ammonia-nitrogen contributes significantly to groundwater supplies.

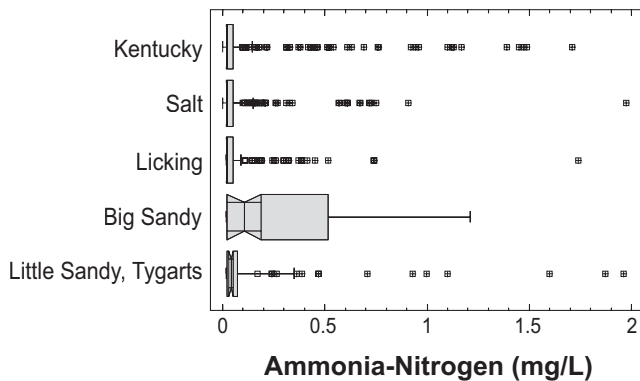


Figure 129. Summary of ammonia-nitrogen values grouped by major watershed. Higher values were excluded for clarity.

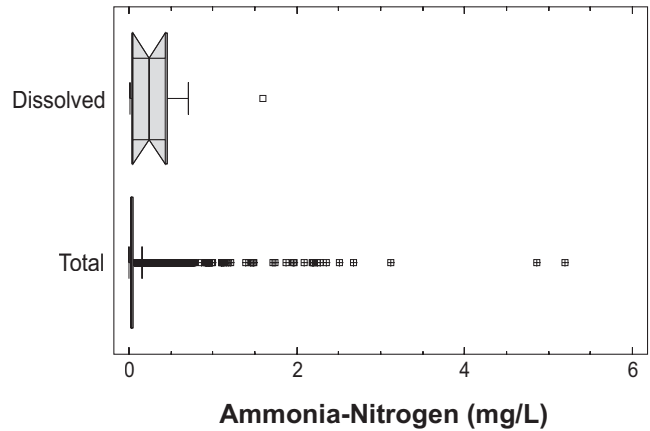


Figure 130. Comparison of total and dissolved ammonia-nitrogen values. Higher values were excluded for clarity.

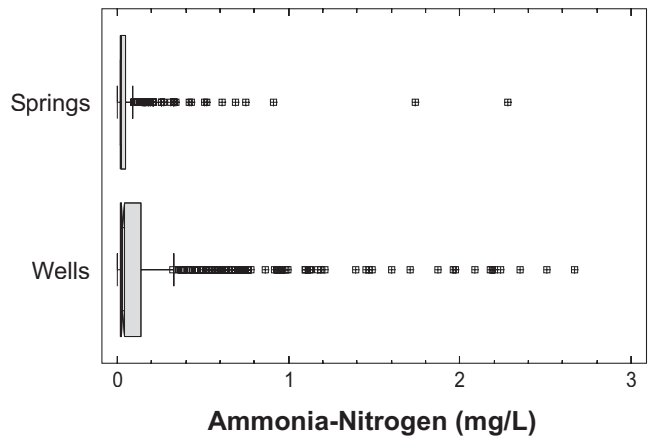


Figure 131. Comparison of ammonia-nitrogen values from wells and springs. Higher values were excluded for clarity.

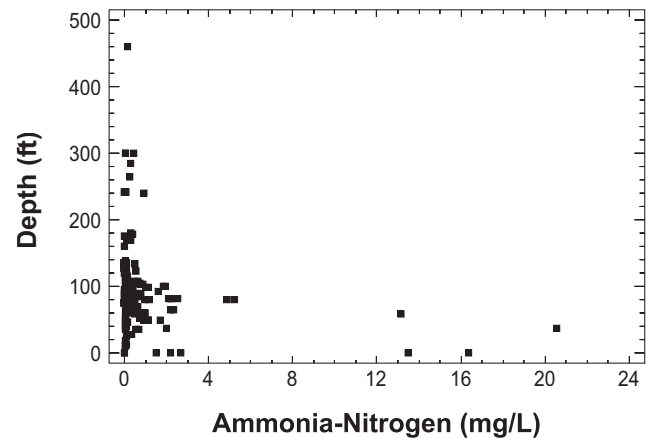


Figure 132. Plot of ammonia-nitrogen values versus well depth.

Phosphorus Species. Phosphorus is a common element in the earth's crust, and also is an important constituent of the carbonate rocks that make up Kentucky's karst regions. Most inorganic phosphorus compounds and minerals have low solubility, which limits phosphorus concentrations in natural waters. Phosphorus species are readily adsorbed onto soil particles and organic material, which limits their mobility in nature.

Phosphorus is an important nutrient and commonly is the limiting nutrient in aquatic ecosystems. The most important man-made sources of phosphorus are phosphate fertilizers, sewage, and animal waste. Prior to the 1960's, phosphate was added to detergents, but this practice was ended because of the eutrophication that resulted when sewage disposal facilities released the water to streams and lakes.

Orthophosphate (complexes containing PO_4 as $\text{H}_2\text{PO}_4^{-1}$ or HPO_4^{-2}) is the most common form of phosphorus in most natural waters (Hem, 1985). The specific form of orthophosphate is pH-dependent, but normal sample collection and analysis procedures report all phosphate determined on a filtered sample as total orthophosphate. Phosphorus can also occur as organic particulate material. Reports of total or total extractable phosphorus that result from analysis of unfiltered water samples generally include both dissolved orthophosphate and particulate phosphorus. In groundwater samples, the difference between phosphorus re-

ported as total orthophosphate and total phosphorus is usually because of particulate organic phosphorus.

There are no health-based water-quality standards for phosphorus species in water. The Kentucky Division of Water recommends that orthophosphate concentrations be less than 0.04 mg/L $\text{PO}_4\text{-P}$ based on the Texas surface-water standard, and that total phosphorus be less than 0.1 mg/L, based on results from the U.S. Geological Survey's National Water-Quality Assessment program.

Orthophosphate. The data repository contained 1,722 orthophosphate measurements from 186 sites in the project area (Table 21). The maximum concentration in each basin management unit is well in excess of the 0.04 mg/L criterion. Furthermore, the 75th percentile values for each basin management unit and the median value for BMU 1 all exceed 0.04 mg/L. More than 75 percent of the sites in BMU 1 and BMU 2 have produced values greater than 0.04 mg/L.

Cumulative data plots are different for each basin management unit (Figs. 133-135). In BMU 1 (Fig. 133), more than 80 percent of the reported concentrations are less than 10 mg/L, but there are many values that are more than 500 mg/L.

The data distribution in BMU 2 (Fig. 134) shows that more than 80 percent of the reported values are less than 10 mg/L, but there are fewer extremely high values than in BMU 1.

Table 21. Summary of orthophosphate-P values (mg/L as P). DOW recommendation: 0.04 mg/L.

	BMU 1	BMU 2	BMU 5
Values	867	699	156
Maximum	1,950	368	254
75th percentile	0.31	0.20	0.03
Median	0.14	0.04	0.02
25th percentile	0.01	0.01	0.01
Minimum	0.0	0.0	0.0
Interquartile range	0.30	0.19	0.02
Sites	68	78	40
Sites > 0.04 mg/L	53	66	10

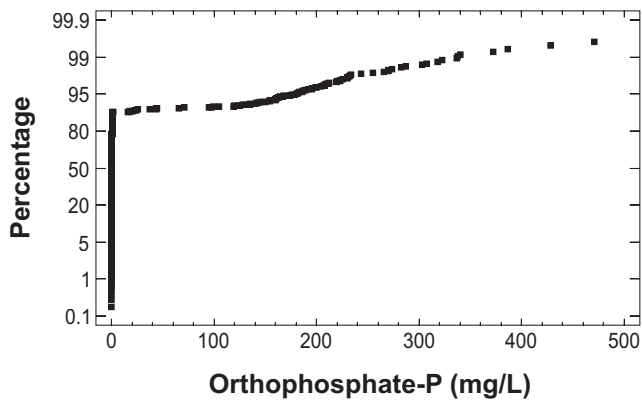


Figure 133. Cumulative plot of orthophosphate values from BMU 1. Extreme values were omitted to better show the majority of the data.

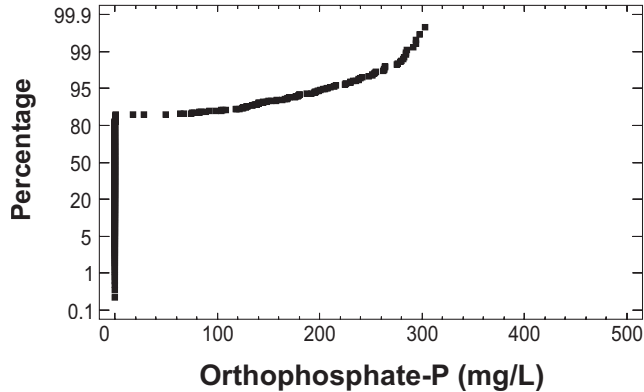


Figure 134. Cumulative plot of orthophosphate values from BMU 2. Extreme values were omitted to better show the majority of the data.

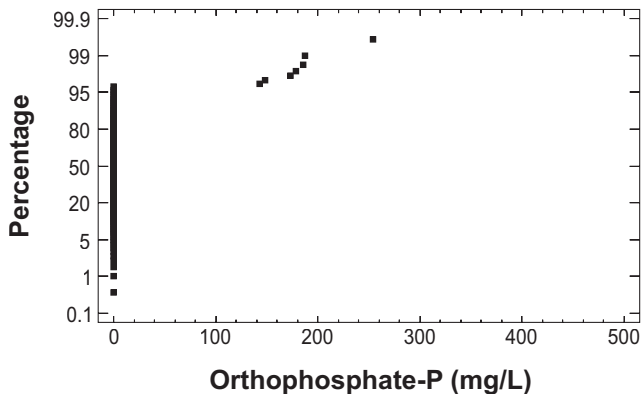


Figure 135. Cumulative plot of orthophosphate values from BMU 5. Extreme values were omitted to better show the majority of the data.

The data distribution in BMU 5 (Fig. 135) shows that more than 95 percent of the reported values are less than 10 mg/L, and there are few extremely high values.

Sampled sites are sparsely distributed throughout the project area (Fig. 136). More than half of the sites in the Inner and Outer Bluegrass and Western Pennyroyal Regions of the Kentucky, Salt, and Licking River watersheds exceed 0.4 mg/L (Figs. 137–138). Most sites in the Eastern Kentucky Coal Field in watersheds of the Big Sandy River, Little Sandy River, and Tygarts Creek produce groundwater that has orthophosphate concentrations below the recommended limit.

Springs and wells show the same range of orthophosphate concentrations (Fig. 139), and values much greater than the recommended limit are found at all well depths (Fig. 140).

In summary, orthophosphate concentrations exceeded the recommended limit of 0.04 mg/L by several orders of magnitude in the project area. Such sites are concentrated in the Inner and Outer Bluegrass and Western Pennyroyal Regions, where limestone strata are known to be enriched in phosphorus. The high orthophosphate concentrations are therefore considered to reflect the composition of bedrock rather than any significant nonpoint-source contamination.

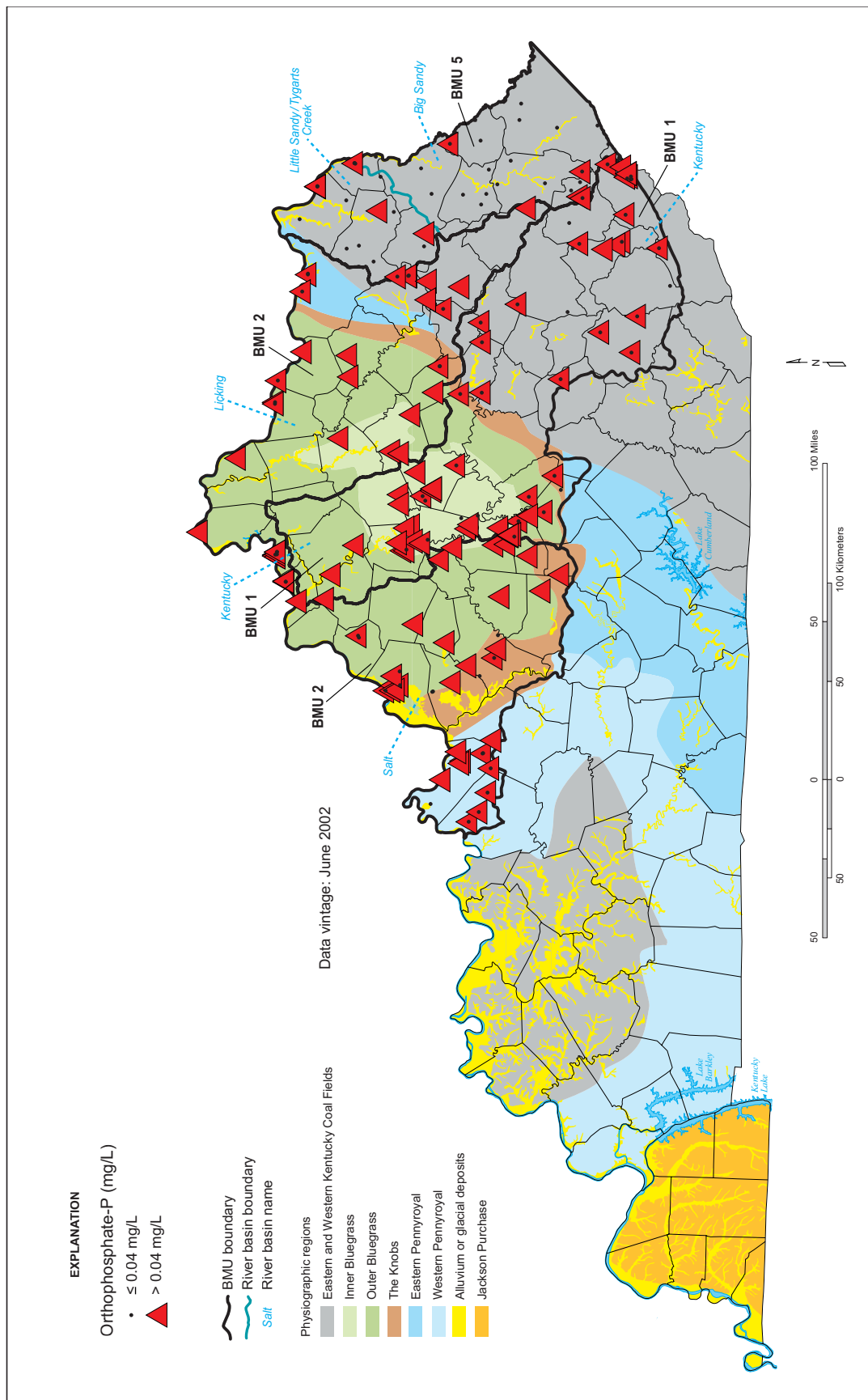


Figure 136. Locations of sampled sites and ranges of orthophosphate values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

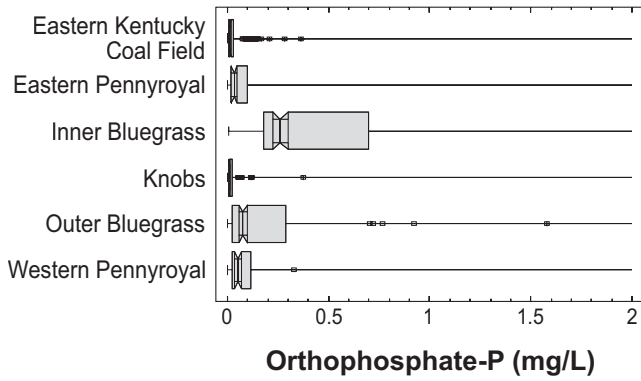


Figure 137. Summary of orthophosphate values grouped by physiographic region. Higher values were excluded for clarity.

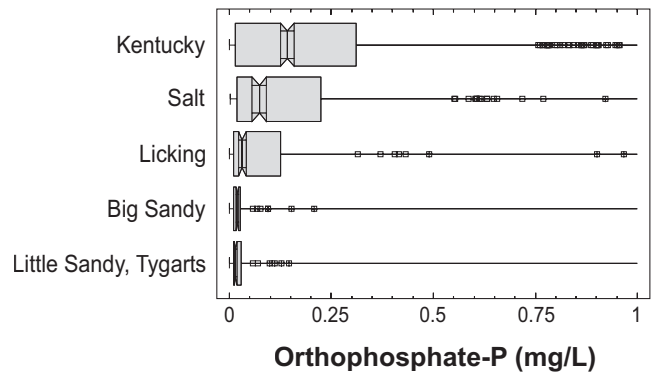


Figure 138. Summary of orthophosphate values grouped by major watershed. Higher values were excluded for clarity.

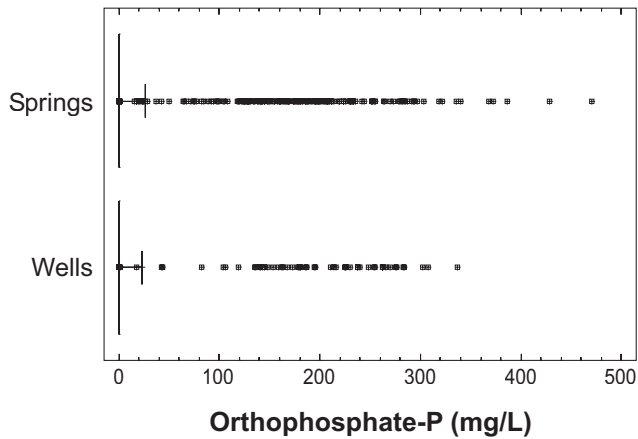


Figure 139. Comparison of orthophosphate values from wells and springs. Higher values were excluded for clarity.

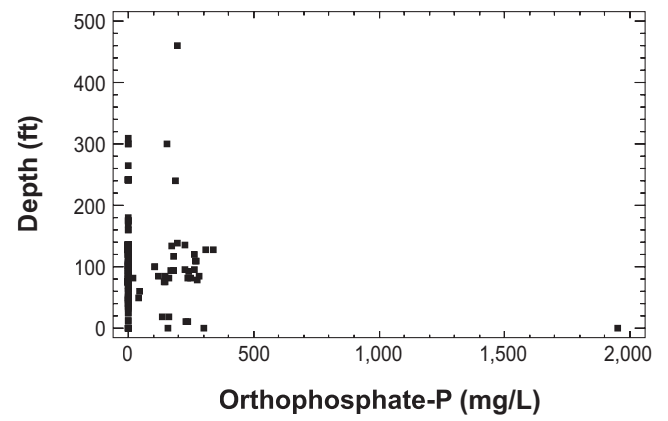


Figure 140. Plot of orthophosphate values versus well depth.

Total Phosphorus. The database contained 1,356 reports of total phosphorus at 301 sites (Table 22). The median concentration in BMU 1 (Kentucky River watershed) exceeded the recommended value of 0.1 mg/L, and 130 of the 301 sites have produced groundwater that exceeds the recommended concentration of total phosphorus.

The distribution of reported values from BMU 1 (Fig. 141) differs slightly from the data distribution in BMU 2 (Fig. 142) and BMU 5 (Fig. 143). Only about 50 percent of the concentrations reported from sites in BMU 1 are less than 0.1 mg/L, whereas that percentage in BMU 2 and BMU 5 is 75 percent to 80 percent. Samples from BMU 5 (Fig. 143) have the fewest values greater than 0.1 mg/L.

Site distribution is uneven throughout the project area (Fig. 144); many sites are along the Ohio River in BMU 2 and the eastern part of BMU 5. Sites where total phosphorus exceeds the recommended value occur more commonly in the Inner and Outer Bluegrass Regions (Figs. 144–146).

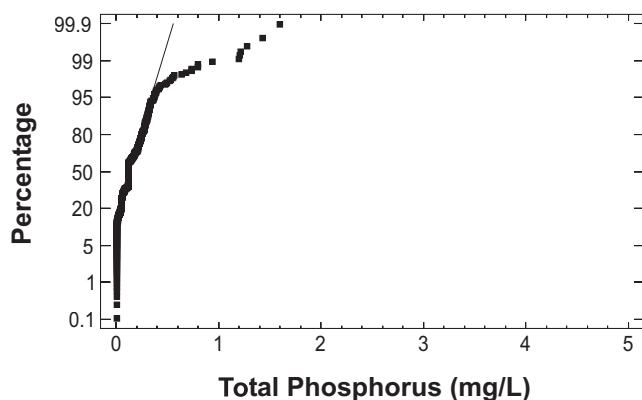


Figure 141. Cumulative plot of total phosphorus values from BMU 1. Extreme values were omitted to better show the majority of the data.

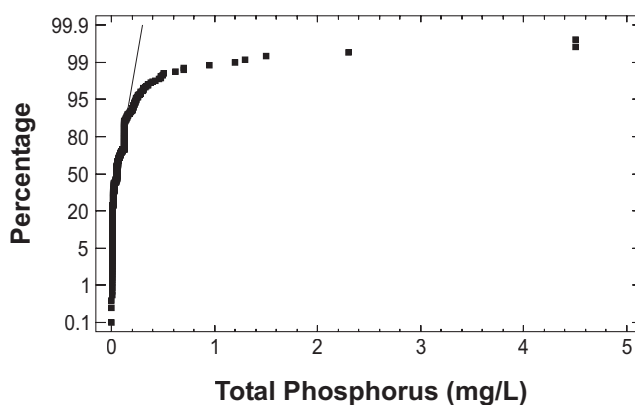


Figure 142. Cumulative plot of total phosphorus values from BMU 2. Extreme values were omitted to better show the majority of the data.

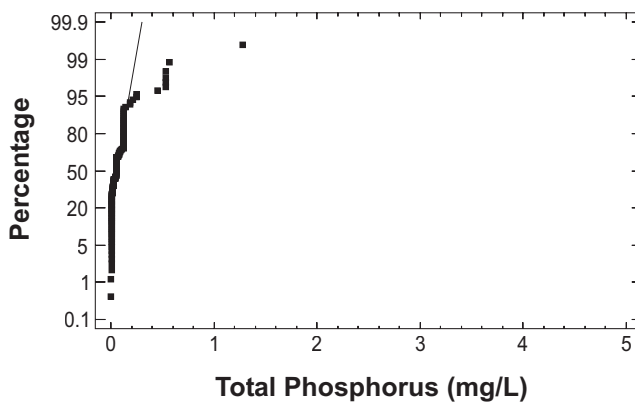


Figure 143. Cumulative plot of total phosphorus values from BMU 5. Extreme values were omitted to better show the majority of the data.

Table 22. Summary of total phosphorus values (mg/L of P). DOW recommendation: 0.1 mg/L.

	BMU 1	BMU 2	BMU 5
Values	596	624	136
Maximum	1.6	14.0	1.28
75th percentile	0.24	0.12	0.12
Median	0.12	0.05	0.05
25th percentile	0.05	0.01	0.01
Minimum	0.0	0.0	0.0
Interquartile range	0.19	0.11	0.11
Sites	83	13	83
Sites > 0.1 mg/L	58	55	16

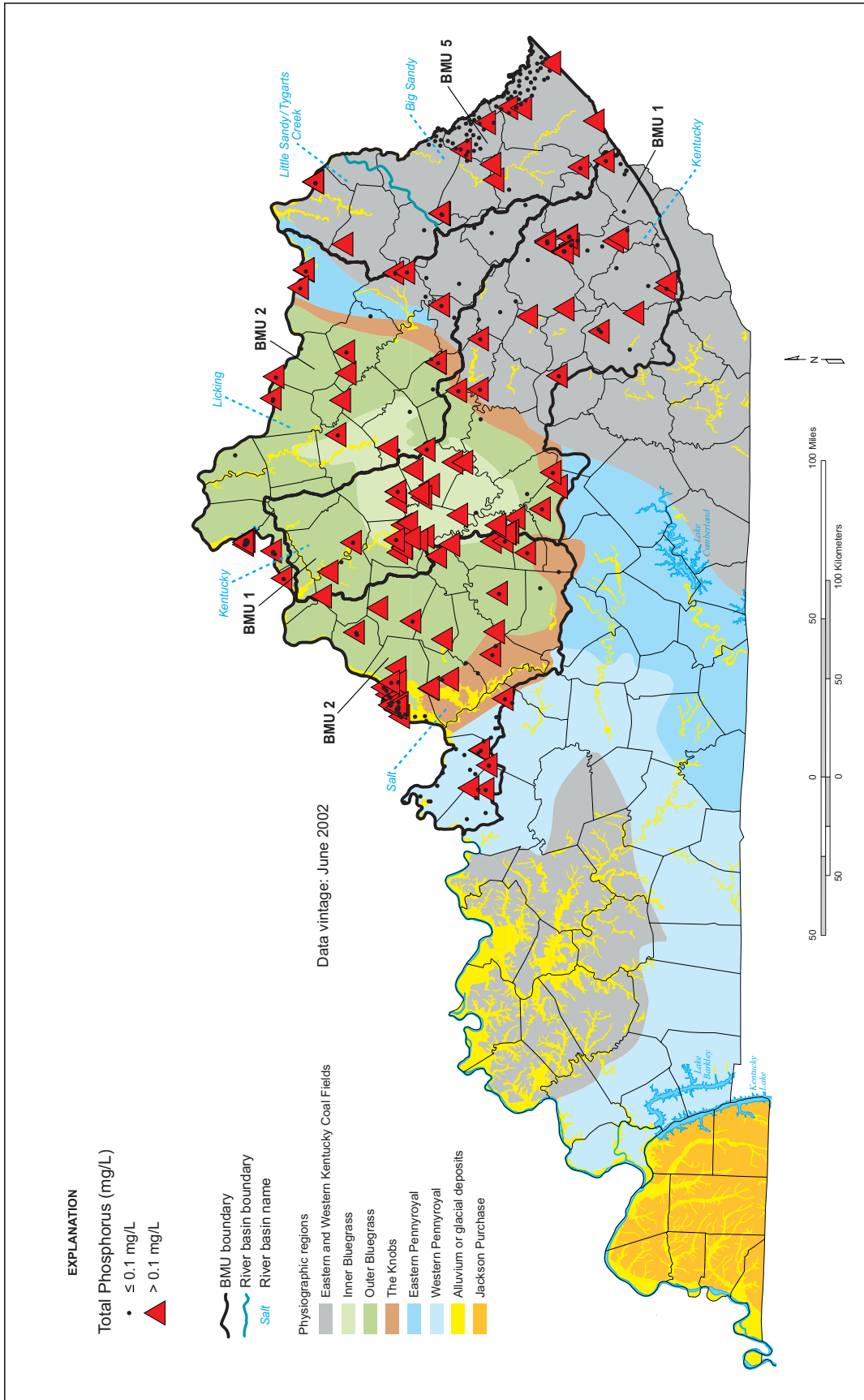


Figure 144. Locations of sampled sites and ranges of total phosphorus values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

Groundwater from springs has a higher median value and larger interquartile range of values than groundwater from wells, although the total range of values is similar (Fig. 147).

Phosphorus concentrations in filtered samples (dissolved phosphorus) are generally lower than concentrations from unfiltered (total) groundwater (Fig. 148).

As was the case for orthophosphate, total phosphorus concentrations well in excess of the recommended concentrations are found in wells as deep as 300 ft. Between land surface and a depth of 300 ft, there is no significant trend in total phosphorus concentrations (Fig. 149).

In summary, like orthophosphate concentrations, total phosphorus commonly exceeds the recommended limit of 0.1 mg/L in all regions and watersheds of the project area. Also as with orthophosphate, such sites are most common in the Inner and Outer Blue-

grass Regions, where limestone bedrock is known to be enriched in phosphorus. The high phosphorus concentrations are therefore considered to reflect the composition of bedrock rather than any significant nonpoint-source contribution.

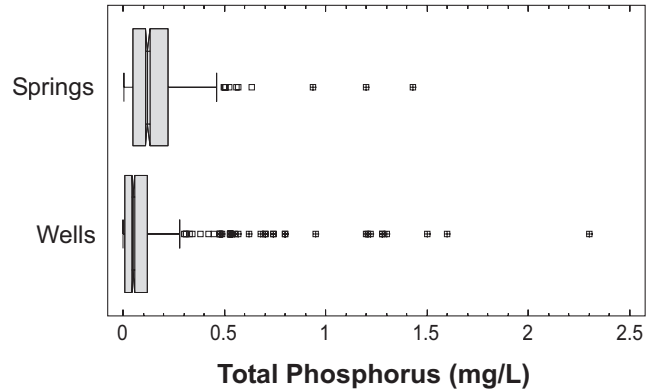


Figure 147. Comparison of total phosphorus values from wells and springs. Higher values were excluded for clarity.

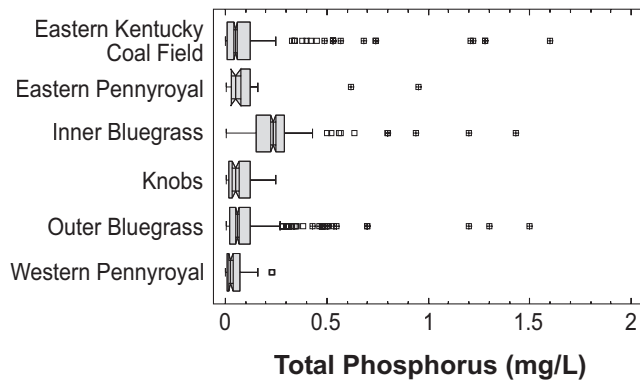


Figure 145. Summary of total phosphorus values grouped by physiographic region. Higher values were excluded for clarity.

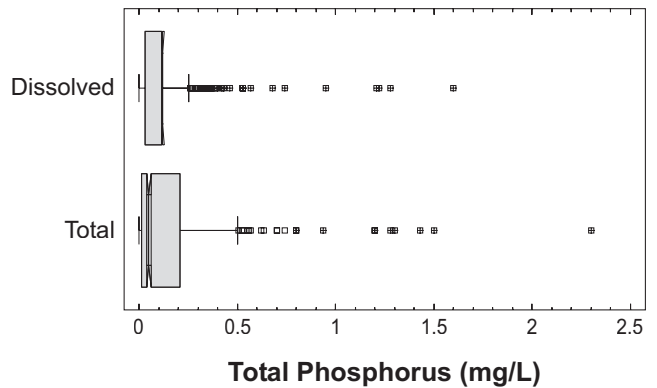


Figure 148. Comparison of total and dissolved phosphorus values. Higher values were excluded for clarity.

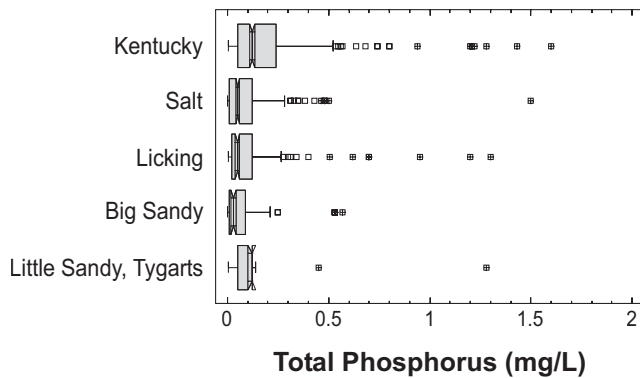


Figure 146. Summary of total phosphorus values grouped by major watershed. Higher values were excluded for clarity.

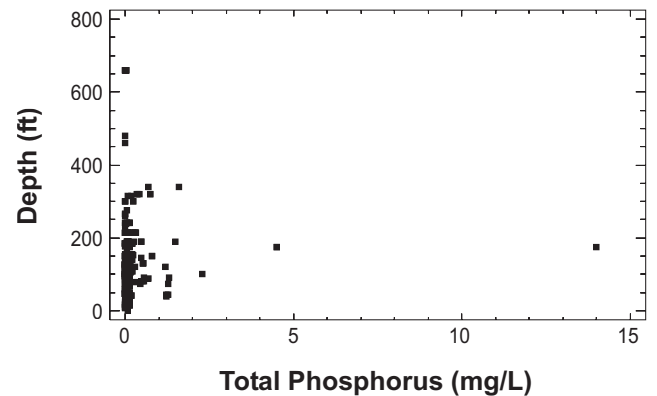


Figure 149. Plot of total phosphorus values versus well depth.

Pesticides

A large number of synthetic organic pesticides (including insecticides, herbicides, and growth regulators) have been developed and applied in agricultural and urban settings. Some, such as the organochlorine insecticide DDT, were banned decades ago, but still persist in soils and sediments and could still be released to groundwater systems. Most recently developed pesticides that have been approved for use are less persistent in natural environments; however, they may still have undesirable impacts on human health and groundwater suitability for various uses.

The environmental significance of pesticides in groundwater is difficult to determine precisely for several reasons (U.S. Geological Survey, 1999): (1) standards and guidelines are available for only a small number of individual pesticide chemicals and are generally not available for the equally important degradation products, (2) new pesticides are being developed continually, (3) environmental testing does not account for pesticide mixtures or breakdown products, which may be more potent than the original active ingredients, (4) only a limited suite of health and ecological effects have been tested, (5) concentrations much higher than those used in testing may be introduced to groundwater systems when pesticides are applied or after rains, and (6) some detrimental effects such as endocrine disruption and other subtle health effects have not been fully assessed. For these reasons, and because once contaminated, groundwater typically is slow to respond to changes in pesticide type and application methods, quantifying the existence of any detectable pesticides in Kentucky groundwater is important.

According to the 2000 agriculture sales data, atrazine, glyphosate, metolachlor, simazine, and 2,4-D are the top five pesticides sold in Kentucky. Alachlor and cyanazine have also been used extensively in the past. Glyphosate has not been measured in groundwater samples and so will not be discussed in this report. Toxicological information for pesticides was obtained

from the Extension Toxicology Network (extoxnet.orst.edu) and the Environmental Protection Agency Integrated Risk Information System (www.epa.gov/iris).

2,4-D. The pesticide 2,4-D belongs to the chemical class of phenoxy compounds. Predominant uses are as a systemic herbicide to control broadleaf weeds in cultivated agriculture, pasture and range land, forest management, home and garden settings, and to control aquatic vegetation. It has a low persistence in soils, with a half-life of less than 7 days, and is readily degraded by microorganisms in aquatic environments. The EPA has established an MCL of 0.07 mg/L for 2,4-D because the nervous system can be damaged from exposure at higher levels.

The data repository contained 1,054 2,4-D analyses from 232 sites in the project area (Table 23). No value exceeded the MCL of 0.07 mg/L. The maximum reported concentration was 0.0276 mg/L, found in a spring in the Outer Bluegrass Region of BMU 2. The second highest value was 0.0011 mg/L, and more than 99 percent of all reported concentrations were 0.001 mg/L or less. Only 21 percent of all measured 2,4-D concentrations exceeded analytical detection limits; 29 percent of all sites had detectable 2,4-D concentrations. Detectable concentrations of 2,4-D were found in 40 percent of the sampled wells and 22 percent of the sampled springs. There was no significant variation in 2,4-D concentrations with well depth.

Sample-site density was greatest in the Western Pennyroyal Region and lowest in the Knobs and Outer Bluegrass Regions (Fig. 150). Sites where 2,4-D exceeded analytical detection were predominantly in the limestone terrain of the Western Pennyroyal and Inner Bluegrass Regions.

Because of the narrow range of values and the small number of sites where concentrations exceeded analytical detection limits, no further analysis was performed.

In summary, concentrations of 2,4-D do not exceed the MCL in the project area, and are typically less than 0.001 mg/L. Detectable amounts of 2,4-D are found most commonly in wells and springs in the limestone terrain of the Western Pennyroyal and Inner Bluegrass Regions. The presence of 2,4-D at some sites in the project area indicates that some pesticides are entering the groundwater system.

Table 23. Summary of 2,4-D values (mg/L). MCL: 0.07 mg/L.

	BMU 1	BMU 2	BMU 5
Values	493	447	114
Maximum	0.0011	0.0276	< 0.0009
75th percentile	< 0.0001	< 0.0009	< 0.0001
Median	< 0.0001	< 0.0001	< 0.0001
25th percentile	< 0.0001	< 0.0001	< 0.0001
Minimum	0.00	< 0.0001	< 0.0001
Sites	67	118	47
Sites > 0.07 mg/L	0	0	0
Sites where detected	7	51	11

< means analytical result reported as less than the stated analytical detection limit

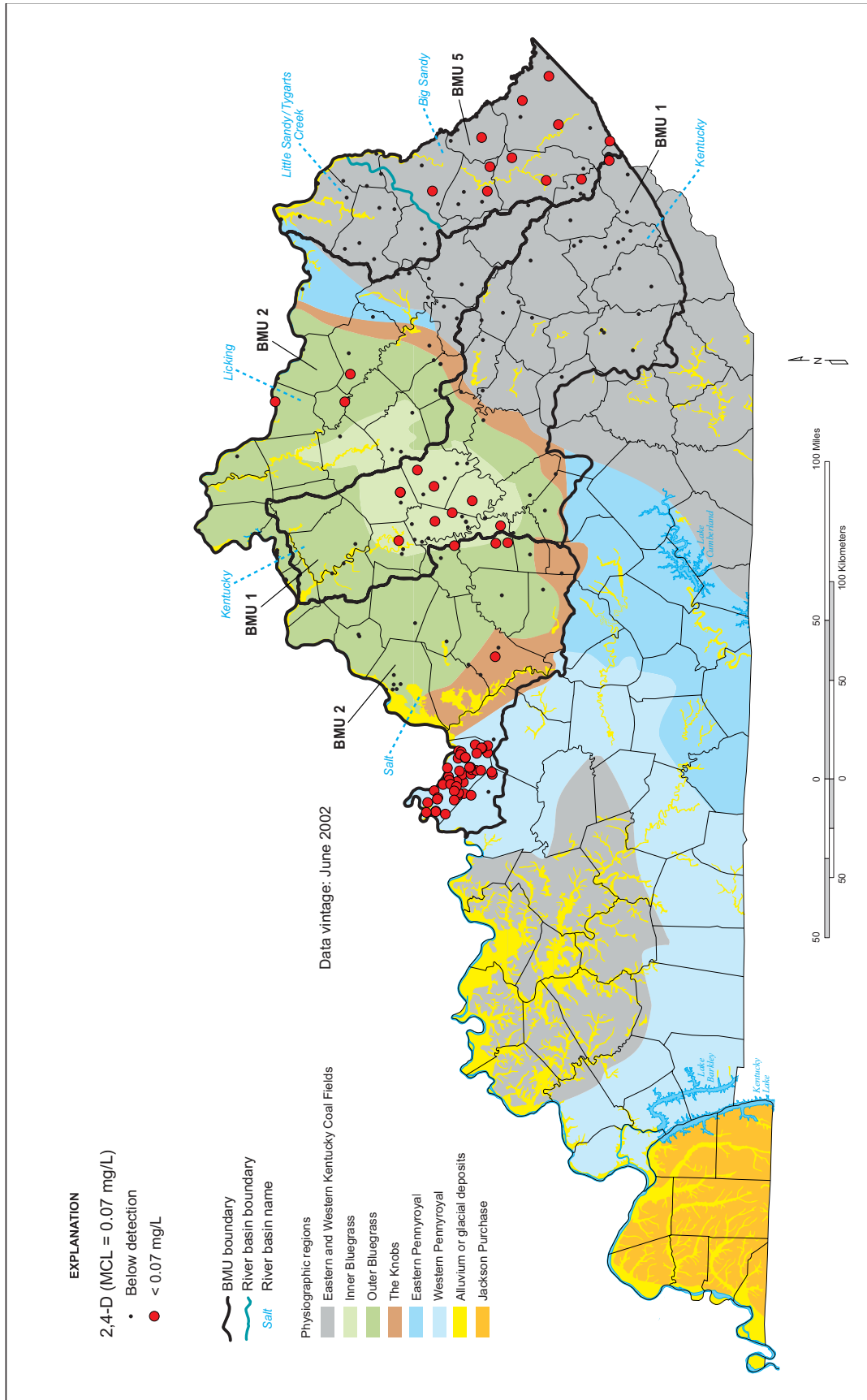


Figure 150. Locations of sampled sites and ranges of 2,4-D values. No values exceeded the MCL. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

Alachlor. Alachlor belongs to the chemical class of anilines. Predominant use is the control of annual grasses and broadleaf weeds in field corn, soybeans, and peanuts. It has a low persistence in soils and half-life of about 8 days. It is moderately mobile in sandy and silty soils and breaks down rapidly in natural water because of microbial activity. The breakdown is significantly slower under reducing conditions. The EPA has found alachlor to pose a risk for skin and eye irritation on short-term exposure, and to potentially cause damage to the liver, kidney, spleen, and the lining of the nose and eyelids, and possibly cause cancer on long-term exposure. For these reasons, the EPA has set an MCL of 0.002 mg/L for alachlor.

The data repository contained 1,130 measurements of alachlor from 196 sites in the project area (Table 24). No values exceeded the MCL. Fifteen analyses exceeded detection limits; 10 sites produced water that had detectable alachlor.

Sample density was greatest in the Eastern Kentucky Coal Field and Inner Bluegrass Regions, and lowest in the Outer Bluegrass and Western Pennyroyal Regions (Fig. 151).

Of the reported concentrations that exceeded analytical detection, 12 were samples from springs and three were samples from wells. No further analysis was performed because of the small number of detected alachlor concentrations.

In summary, alachlor was detected at only 5 percent of the sampled sites, and none of the measured concentrations exceeded the EPA MCL of 0.002 mg/L. Alachlor use is probably very limited in the project area because corn, soybeans, and peanuts are not produced in this part of Kentucky. The presence of alachlor at some sites in the project area indicates that some pesticides are entering the groundwater system.

Table 24. Summary of alachlor values (mg/L). MCL: 0.002 mg/L.

	BMU 1	BMU 2	BMU 5
Values	574	420	136
Maximum	0.0004	0.000721	0.00027
75th percentile	< 0.00005	< 0.00005	< 0.00004
Median	< 0.00004	< 0.00004	< 0.00004
25th percentile	< 0.00004	< 0.00004	< 0.00004
Minimum	< 0.00002	< 0.00002	< 0.00002
Sites	70	77	49
Sites > 0.002 mg/L	0	0	0
Sites where detected	2	8	0

< means analytical result reported as less than the stated analytical detection limit

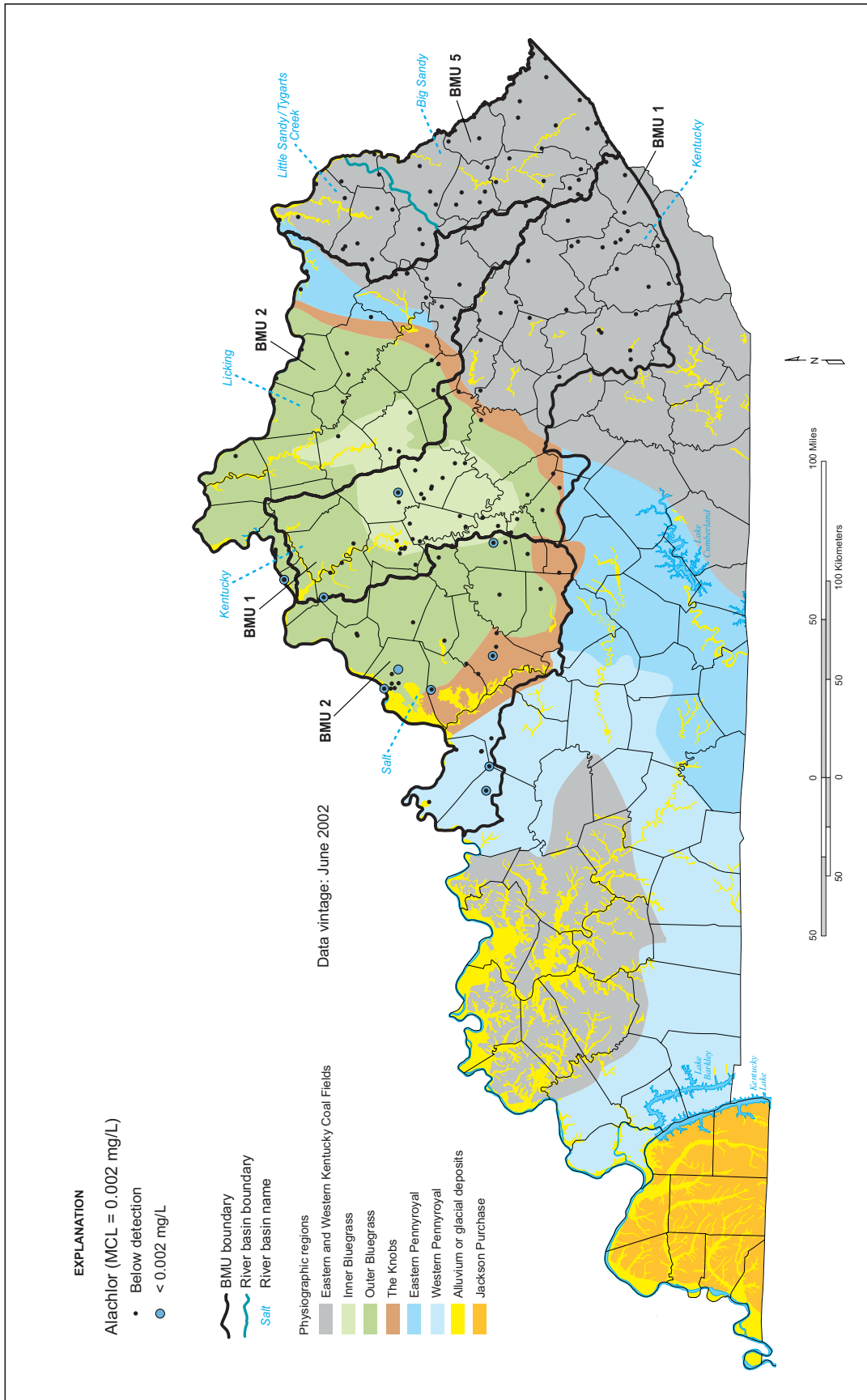


Figure 151. Locations of sampled sites and ranges of alachlor values. No values exceeded the MCL. Superimposed symbols indicate that values exceeded at different sampling times fell into different ranges.

Atrazine. Atrazine belongs to the chemical class of triazines. Predominant use is to control broadleaf and grassy weeds in corn, sorghum, and other crops and in conifer reforestation plantings. It is highly persistent in soils, moderately soluble in water, and not readily sorbed to sediments.

The EPA has set an MCL of 0.003 mg/L for atrazine. Atrazine can cause a variety of acute health effects from exposures at higher levels. These effects include congestion of heart, lungs, and kidneys; hypotension, antidiuresis; muscle spasms; weight loss; and adrenal degeneration. Atrazine also has the potential to cause cardiovascular damage, retinal and some muscle degeneration, and mammary tumors from a lifetime exposure at levels above the MCL.

The data repository contained 804 reports of atrazine concentrations from 137 sites in the project area (Table 25). Only 97 of the 804 measurements exceeded analytical detection limits, and only one site, a spring in the Western Pennyroyal Region of the Salt River watershed, yielded groundwater with an atrazine concen-

tration greater than the MCL. Atrazine was detected at 33 of 137 sites in the project area.

Sample density is greatest in the Inner Bluegrass Region of the Kentucky River watershed (Fig. 152). Twenty-seven springs and five wells produced water with detectable amounts of atrazine. Because of the narrow range of values and the small number of sites where concentrations exceeded analytical detection limits, no further analysis was performed.

In summary, one site produced water that had an atrazine concentration greater than the MCL of 0.003 mg/L. Atrazine was detected at 27 springs and five wells in the project area, most of which were in the limestone terrain of the Inner and Outer Bluegrass and Western Pennyroyal Regions. Atrazine use is probably very limited in the project area because the types of crops atrazine is used on are not grown in this part of the state. The presence of atrazine in the project area indicates that some pesticides are entering the groundwater system.

Table 25. Summary of atrazine values (mg/L). MCL: 0.003 mg/L.

	BMU 1	BMU 2	BMU 5
Values	428	300	76
Maximum	0.001039	0.004753	0.00194
75th percentile	< 0.0003	< 0.0003	< 0.0003
Median	< 0.00006	< 0.00006	< 0.0003
25th percentile	< 0.00005	< 0.00005	< 0.00005
Minimum	0.000005	0.000018	< 0.00004
Sites	60	63	14
Sites > 0.003 mg/L	0	1	0
Sites where detected	12	18	3

< means analytical result reported as less than the stated analytical detection limit

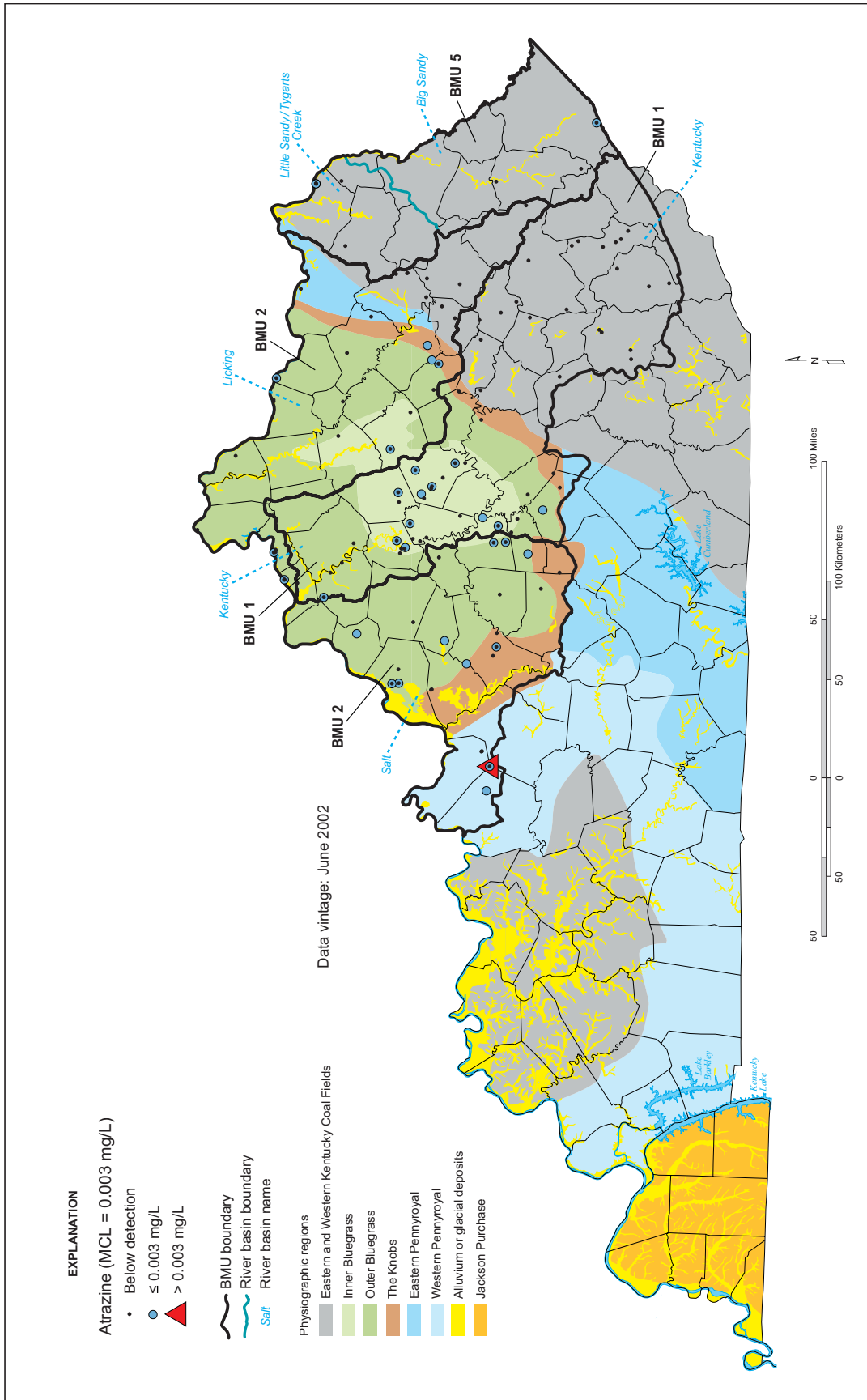


Figure 152. Locations of sampled sites and ranges of atrazine values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

Cyanazine. Cyanazine belongs to the chemical class of triazines. It is used mainly to control annual grasses and broadleaf weeds in corn. It has low to moderate persistence in soils and is rapidly degraded by microbial activity. Cyanazine has a half-life of 2 to 14 weeks, depending on soil type, and is stable in water. There is no EPA MCL for cyanazine; however, DOW has set a health advisory limit (HAL) of 0.001 mg/L.

The data repository contained 776 results of cyanazine analyses from 170 sites in the project area (Table 26). Only one value exceeded analytical detection limits; this site also exceeded the HAL. Because only one cyanazine concentration was greater than analytical detection, no further analyses were performed.

As with the other pesticides, sample-site density was greatest in the Eastern Kentucky Coal Field and Inner Bluegrass Regions, and lowest in the Outer Bluegrass and Western Pennyroyal Regions (Fig. 153).

In summary, only one of 170 sites in the project area produced water that had detectable cyanazine. Cyanazine use is probably very limited in the project area because the types of crops cyanazine is used on are not grown in this part of the state. The presence of cyanazine in the project area indicates that some pesticides are entering the groundwater system.

Table 26. Summary of cyanazine values (mg/L). HAL: 0.001 mg/L.

	BMU 1	BMU 2	BMU 5
Values	492	374	128
Maximum	< 0.001	< 0.001	0.00126
75th percentile	< 0.00005	< 0.00005	< 0.00005
Median	< 0.00005	< 0.00004	< 0.00004
25th percentile	< 0.00004	< 0.00004	< 0.00004
Minimum	< 0.00004	< 0.00004	< 0.00004
Sites	68	74	47
Sites > 0.001 mg/L	0	0	1
Sites where detected	0	0	1

< means analytical result reported as less than the stated analytical detection limit

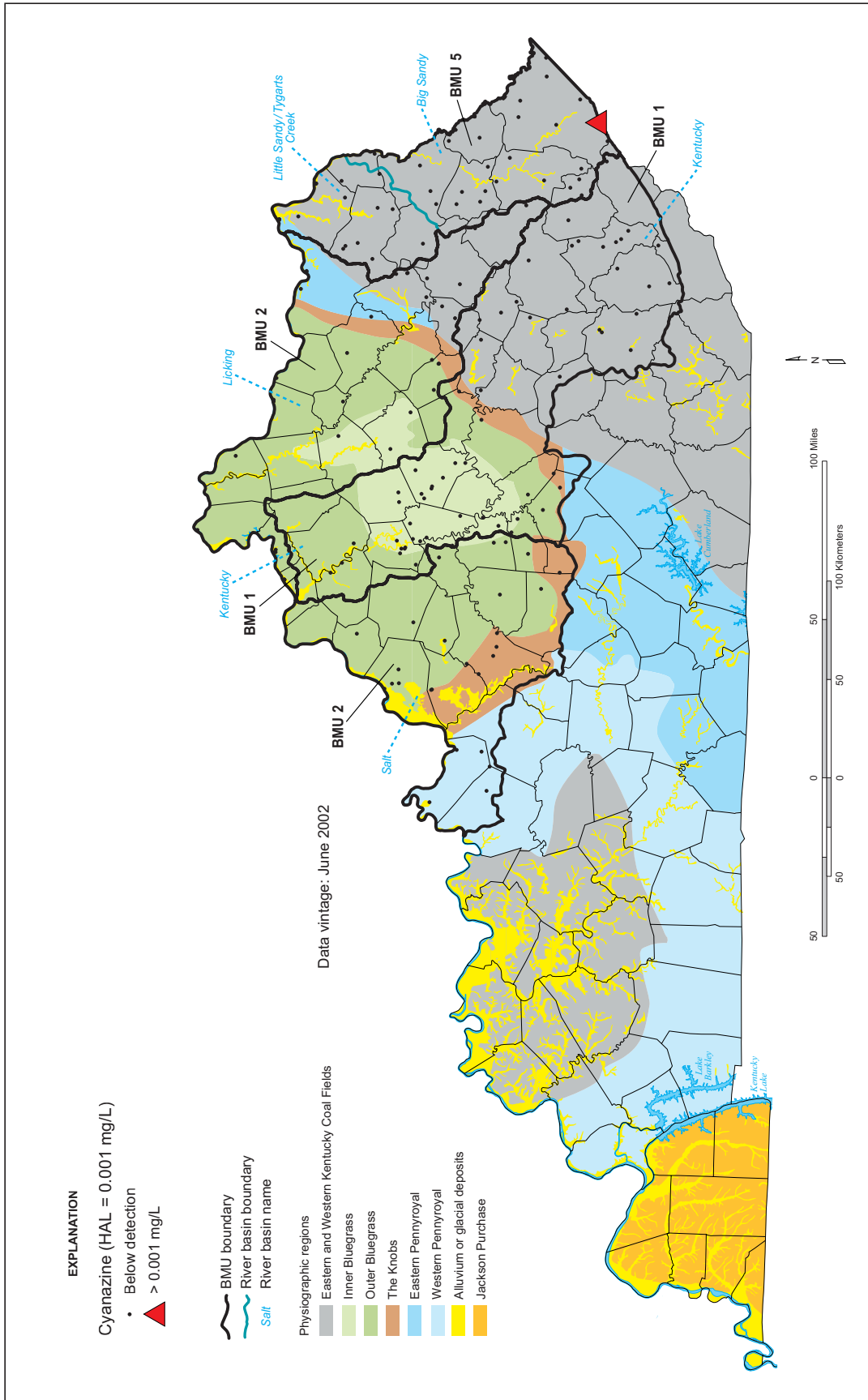


Figure 153. Locations of sampled sites and ranges of cyanazine values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

Metolachlor. Metolachlor belongs to the chemical class of amides. It is predominantly used to control broad-leaf and grassy weeds in field corn, soybeans, peanuts, grain sorghum, potatoes, pod crops, cotton, safflower, stone fruits, nut trees, highway rights-of-way, and woody ornamentals. It is moderately persistent in soils, with a half-life of 15 to 70 days, and is highly persistent in water. There is no MCL for metolachlor; DOW has set a health advisory limit of 0.1 mg/L.

The data repository contained 1,125 metolachlor concentrations from 192 sites in the project area (Table 27). No values exceeded the HAL; 64 measurements from 15 springs and two wells exceeded analytical detection limits.

Sample-site distribution is most dense in the Eastern Kentucky Coal Field and Inner Bluegrass Regions (Fig. 154). Because of the very small number of sites where metolachlor exceeded analytical detection limits, no further analysis was performed.

In summary, metolachlor is probably not used much in the project area. It is rarely detected in groundwater, and is more common in springs than in wells. The presence of metolachlor in the project area indicates that some pesticides are entering the groundwater system.

Table 27. Summary of metolachlor values (mg/L). HAL: 0.1 mg/L.

	BMU 1	BMU 2	BMU 5
Values	572	418	135
Maximum	< 0.004	0.000908	< 0.0002
75th percentile	< 0.00005	< 0.00005	< 0.00005
Median	< 0.00005	< 0.00004	< 0.00004
25th percentile	< 0.00004	< 0.00004	< 0.00004
Minimum	0.000004	0.000008	0.000022
Sites	69	75	48
Sites > 0.1 mg/L	0	0	0
Sites where detected	7	9	1

< means analytical result reported as less than the stated analytical detection limit

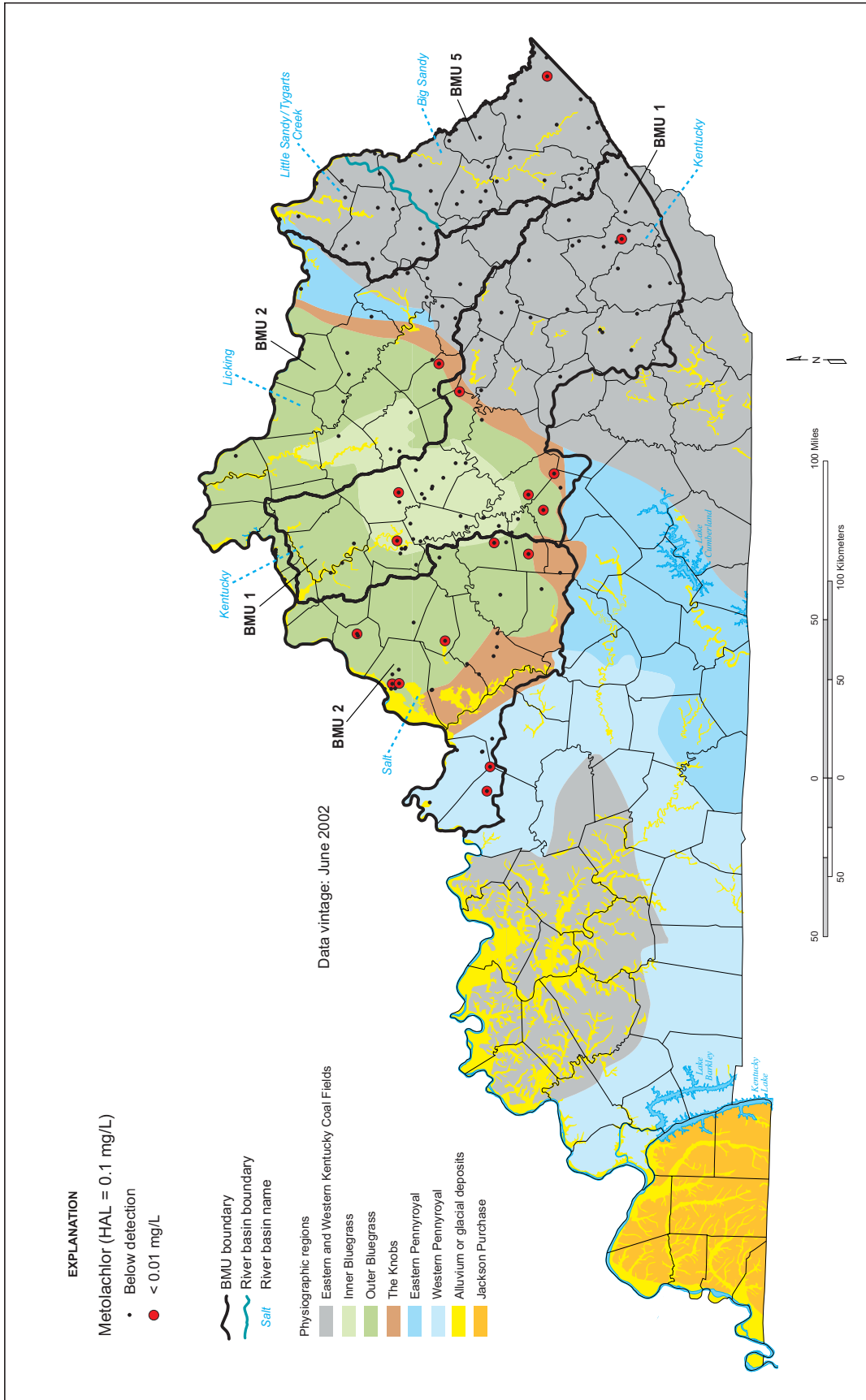


Figure 154. Locations of sampled sites and ranges of metolachlor values. No values exceeded the HAL. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

Simazine. Simazine belongs to the chemical class of triazines. It is predominantly used to control broadleaf weeds and annual grasses in fields where berry fruits, nuts, vegetables, and ornamental crops are grown, and on turfgrass. It is moderately persistent in soils, with a half-life of about 60 days, and is moderately persistent in water, with a half-life that depends on the amount of algae present.

The EPA MCL for simazine is 0.004 mg/L. At levels above 0.004 mg/L, long-term exposure to simazine can cause tremors; damage to testes, kidneys, liver, and thyroid; and gene mutations. There is some evidence that simazine may have the potential to cause cancer from a lifetime exposure at levels above the MCL.

The data repository contained 1,193 simazine measurements from 191 sites in the project area

(Table 28). No measurement exceeded the MCL of 0.004 mg/L. Groundwater from 15 springs and one well had simazine concentrations that exceeded analytical detection limits.

Sample-site distribution is most dense in the Eastern Kentucky Coal Field and Inner Bluegrass Regions (Fig. 155). Because of the very small number of sites where simazine exceeded analytical detection limits, no further analysis was performed.

In summary, simazine is probably not used much in the project area. It is rarely detected in groundwater. When found, it is more common in springs than in wells. The presence of simazine in the project area indicates that some pesticides are entering the groundwater system.

Table 28. Summary of simazine values (mg/L). MCL: 0.004 mg/L.

	BMU 1	BMU 2	BMU 5
Values	602	440	151
Maximum	0.000119	0.002528	0.000689
75th percentile	< 0.0003	< 0.0003	< 0.0003
Median	< 0.00005	< 0.00004	< 0.00004
25th percentile	< 0.00004	< 0.00004	< 0.00004
Minimum	0.00001	0.000017	0.00003
Sites	69	74	48
Sites > 0.004 mg/L	0	0	0
Sites where detected	7	7	2

< means analytical result reported as less than the stated analytical detection limit

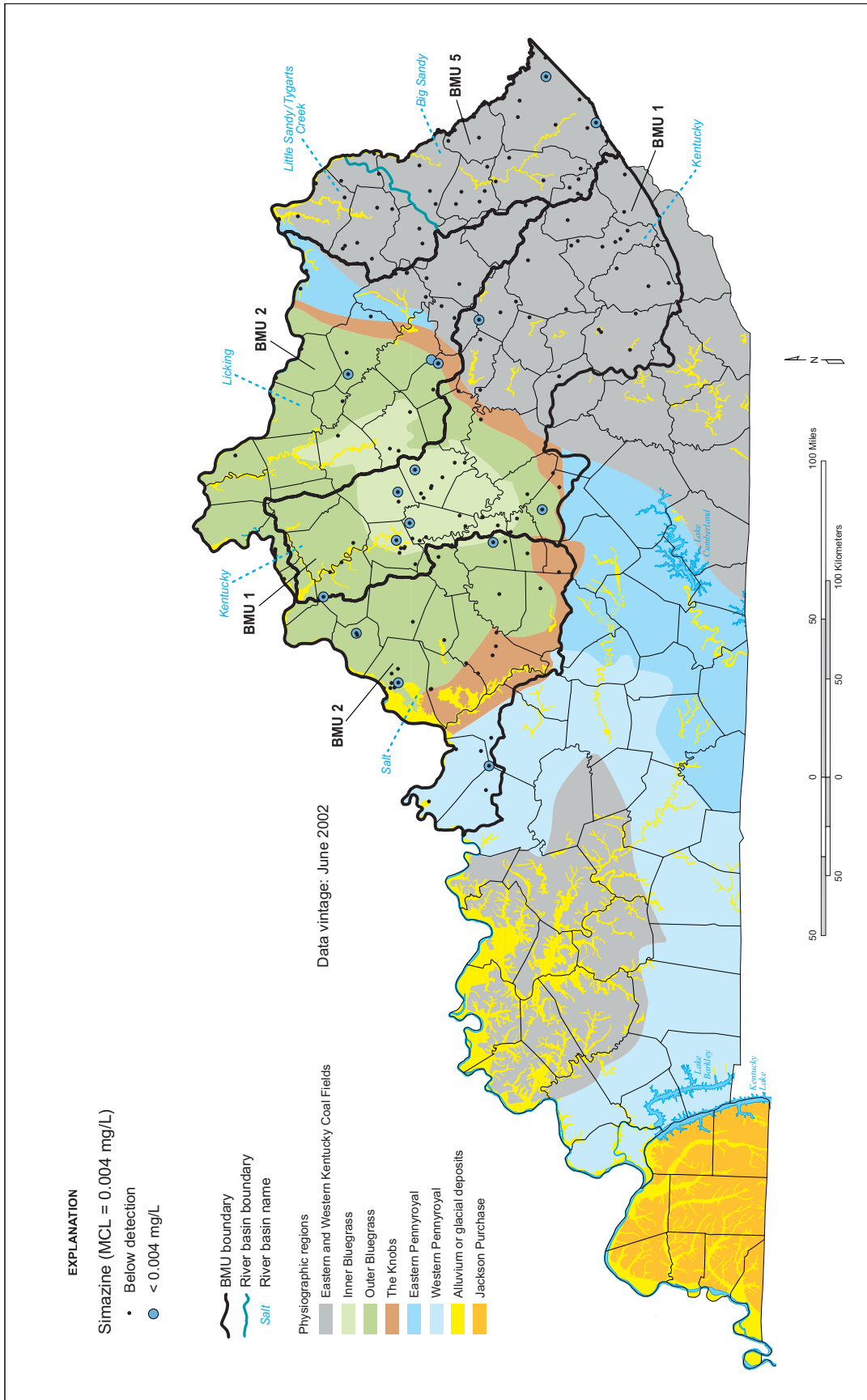


Figure 155. Locations of sampled sites and ranges of simazine values. No values exceeded the MCL. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

Volatile Organic Compounds

The volatile organic compounds benzene, ethylbenzene, toluene, and total xylenes are a group of chemicals characterized by a pale to colorless appearance, sweet odor, and high volatilization. They are used as solvents and in the production of plastics, rubber, and resins. They are also components of gasoline and are most commonly introduced to the environment through spills from leaking gas storage tanks, fumes and exhaust from gas-powered engines, and runoff from gas- or oil-contaminated surfaces such as highways and parking lots. Local groundwater contamination from these compounds can also result from improper disposal of used oil. MTBE (methyl tertiary-butyl ether) is an oxygenate additive used to promote fuel combustion and reduce carbon monoxide and ozone emissions from vehicles. Releases to the environment are most commonly the result of leaking underground storage tanks and pipelines, other spills, and to a lesser extent from air deposition around refineries or urban areas.

Natural sources of these chemicals such as crude oil seeps are rare in the project area. Therefore, any detected amount of these refined volatile organic chemicals indicates groundwater contamination from human activities. Because they are synthetic chemicals, VOC occurrences are not primarily controlled by bedrock geology, physiography, or major river watershed.

Volatile organic compounds may be present in groundwater at very low concentrations, and measurement techniques have improved over time. As a result, some older measurements in the data repository are reported only as less than a detection limit, where the detection limit is larger than some more recently measured values. In such cases, the maximum value reported in the following tables is the maximum value actually measured, not the value of the detection limit. For example, if two VOC analyses are reported as "< 0.02 mg/L" and "0.01 mg/L," the maximum value reported would be 0.01 mg/L.

In addition to excluding groundwater-quality data from any sampling associated with investigations of underground storage tanks, all records from monitoring wells (identified by an AKGWA¹ number that begins with "8"; e.g., 80001234) were excluded from this report to ensure that locally contaminated sites are not skewing regional ground-

water-quality data trends. The following summaries of potential sources and health effects of selected VOC's were taken from the EPA Web sites "Current Drinking Water Standards" (www.epa.gov/safewater/contaminants) and "Integrated Risk Information System" (www.epa.gov/iris).

Benzene. The most common sources of benzene in groundwater are leaks from underground gasoline storage tanks and landfills, and from improper disposal of oil and gasoline from household sources. Potential health effects include anemia, decrease in blood platelets, and increased risk of cancer. For these reasons, the EPA has established an MCL of 0.005 mg/L for benzene.

The data repository contained 619 benzene measurements at 238 sites in the project area (Table 29). Twelve sites produced groundwater with detectable benzene.

Few sites in the Outer Bluegrass Region were sampled for benzene compared to the other regions (Fig. 156). Three of the four sites where benzene exceeds the MCL are in the Outer Bluegrass Region, and eight of the 12 sites where benzene was detected are in the limestone terrain of the Bluegrass and Pennyroyal Regions.

Because of the very small number of sites where benzene was detected, no further data analysis was performed.

In summary, occurrences of benzene in groundwater are rare and isolated in the project area. Four sites produced groundwater with benzene concentrations above the MCL, and 12 sites had detectable amounts of benzene. No widespread pattern of benzene in groundwater was found. The presence of benzene at sites that were not considered locations of point-source releases indicates that the groundwater system is being affected by this volatile organic chemical, however.

Table 29. Summary of benzene values (mg/L). MCL: 0.005 mg/L.

	BMU 1	BMU 2	BMU 5
Values	254	238	127
Maximum	0.0103	3.2	0.003
75th percentile	< 0.0005	< 0.0005	< 0.0005
Median	< 0.0005	< 0.0005	< 0.0005
25th percentile	< 0.0005	< 0.0005	< 0.0005
Minimum	< 0.0005	0.0003	< 0.0005
Sites	78	88	72
Sites > 0.005 mg/L	1	3	0
Sites where detected	3	7	2

< means analytical result reported as less than the stated analytical detection limit

¹Assembled Kentucky Ground Water Database

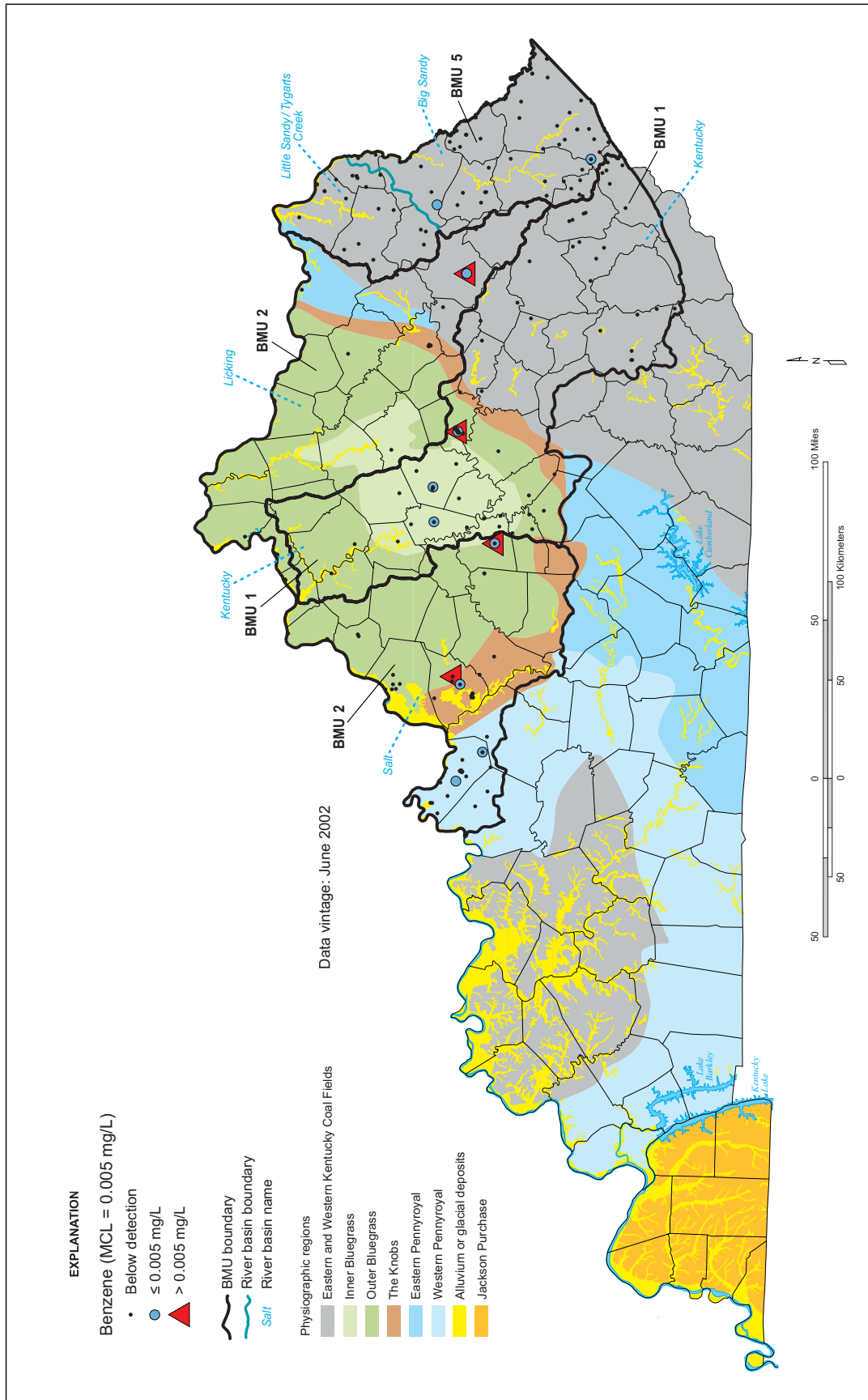


Figure 156. Locations of sampled sites and ranges of benzene values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

Ethylbenzene. Common sources of ethylbenzene are discharge from petroleum refineries and leaking underground gasoline storage tanks. Because ethylbenzene can have health effects such as liver or kidney damage, the EPA has set an MCL for ethylbenzene of 0.7 mg/L.

The data repository contained 596 ethylbenzene measurements at 235 sites in the project area (Table 30). Six sites produced detectable ethylbenzene; no samples exceeded the MCL.

Sample-site distribution is most dense in the Eastern Kentucky Coal Field of BMU 5, the Inner Bluegrass Region of BMU 1, and the Western Pennyroyal Region of BMU 2 (Fig. 157). Four of the six sites where

ethylbenzene was detected are in the limestone terrain of the Inner and Outer Bluegrass Regions.

Because of the very small number of sites where ethylbenzene was detected, no further data analysis was performed.

In summary, detectable levels of ethylbenzene in groundwater are isolated and rare in the project area. No widespread pattern of ethylbenzene occurrence in groundwater was found. The presence of detectable ethylbenzene at sites that were not considered locations of point-source releases indicates that the groundwater system is being affected by this volatile organic chemical, however.

Table 30. Summary of ethylbenzene values (mg/L). MCL: 0.7 mg/L.

	BMU 1	BMU 2	BMU 5
Values	245	224	127
Maximum	0.006	0.062	0.0045
75th percentile	< 0.0005	< 0.0005	< 0.0005
Median	< 0.0005	< 0.0005	< 0.0005
25th percentile	< 0.0005	< 0.0005	< 0.0005
Minimum	< 0.0005	< 0.0005	< 0.0005
Sites	78	85	72
Sites > 0.7 mg/L	0	0	0
Sites where detected	2	2	2

< means analytical result reported as less than the stated analytical detection limit

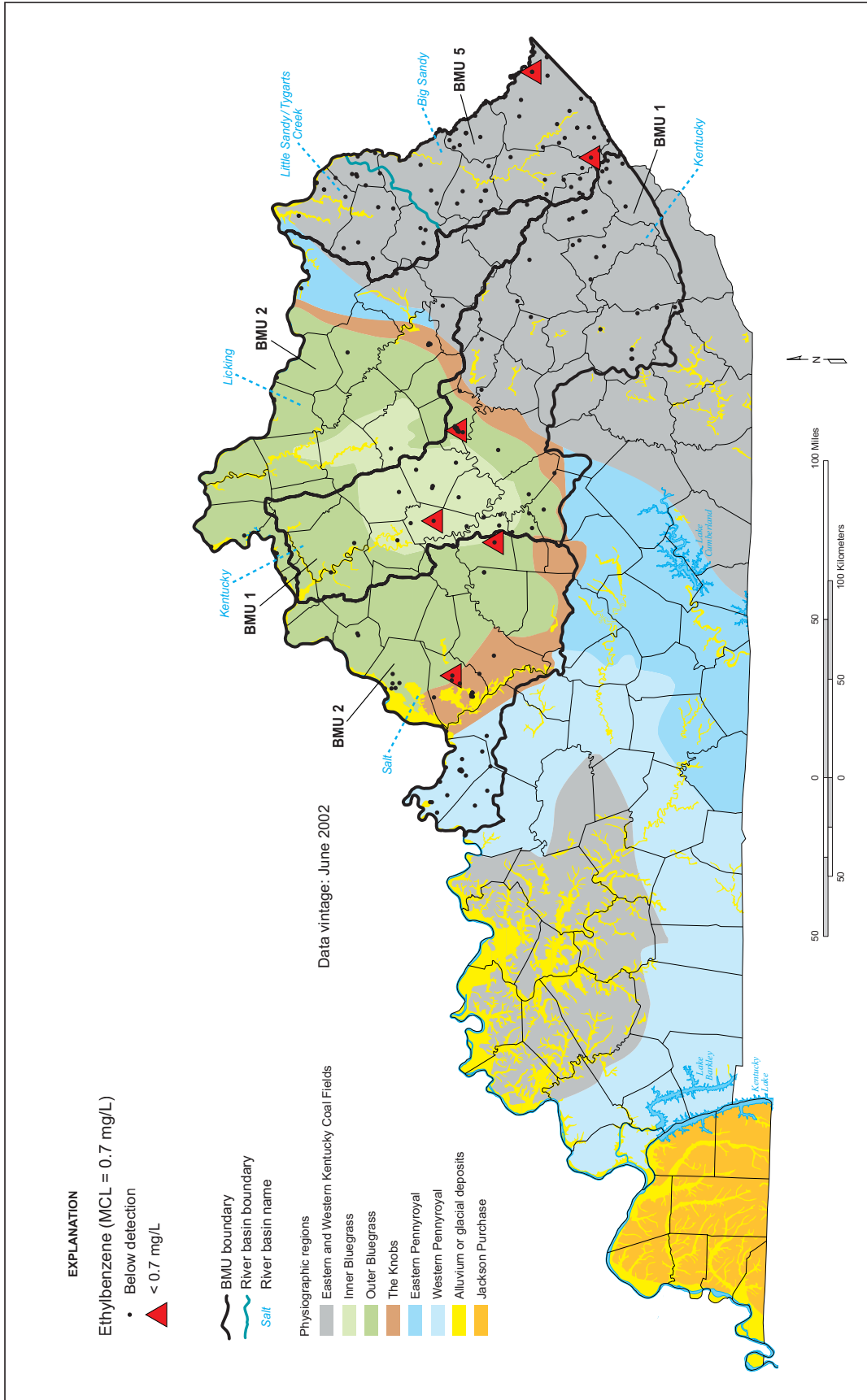


Figure 157. Locations of sampled sites and ranges of ethylbenzene values. No values exceeded the MCL. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

Toluene. Common sources of toluene in groundwater are discharge from petroleum refineries and leaking underground gasoline storage tanks. The potential health effects are damage to the nervous system, kidneys, or liver. The EPA MCL for toluene is 1.0 mg/L.

The data repository contained 417 toluene measurements at 278 sites in the project area (Table 31). One concentration in BMU 2 exceeded the MCL; 16 sites yielded detectable toluene.

The Eastern Kentucky Coal Field of BMU's 2 and 5 has more sampled sites than the rest of the project

area (Fig. 158). Most sites where toluene was detected are in the Eastern Kentucky Coal Field of BMU 5.

Because of the very small number of sites where toluene was detected, no further data analysis was performed.

In summary, like the other volatile organic chemicals, toluene was rarely detected in groundwater in the project area. The presence of toluene at sites that were not considered locations of point-source releases indicates that the groundwater system is being affected by this volatile organic chemical, however.

Table 31. Summary of toluene values (mg/L). MCL: 1.0 mg/L.

	BMU 1	BMU 2	BMU 5
Values	57	229	131
Maximum	0.026	2.6	0.008
75th percentile	< 0.0005	< 0.001	< 0.0005
Median	< 0.0005	< 0.001	< 0.0005
25th percentile	< 0.0005	< 0.0005	< 0.0005
Minimum	< 0.0005	< 0.0005	< 0.0005
Sites	43	158	77
Sites > 1.0 mg/L	0	1	0
Sites where detected	2	5	9

< means analytical result reported as less than the stated analytical detection limit

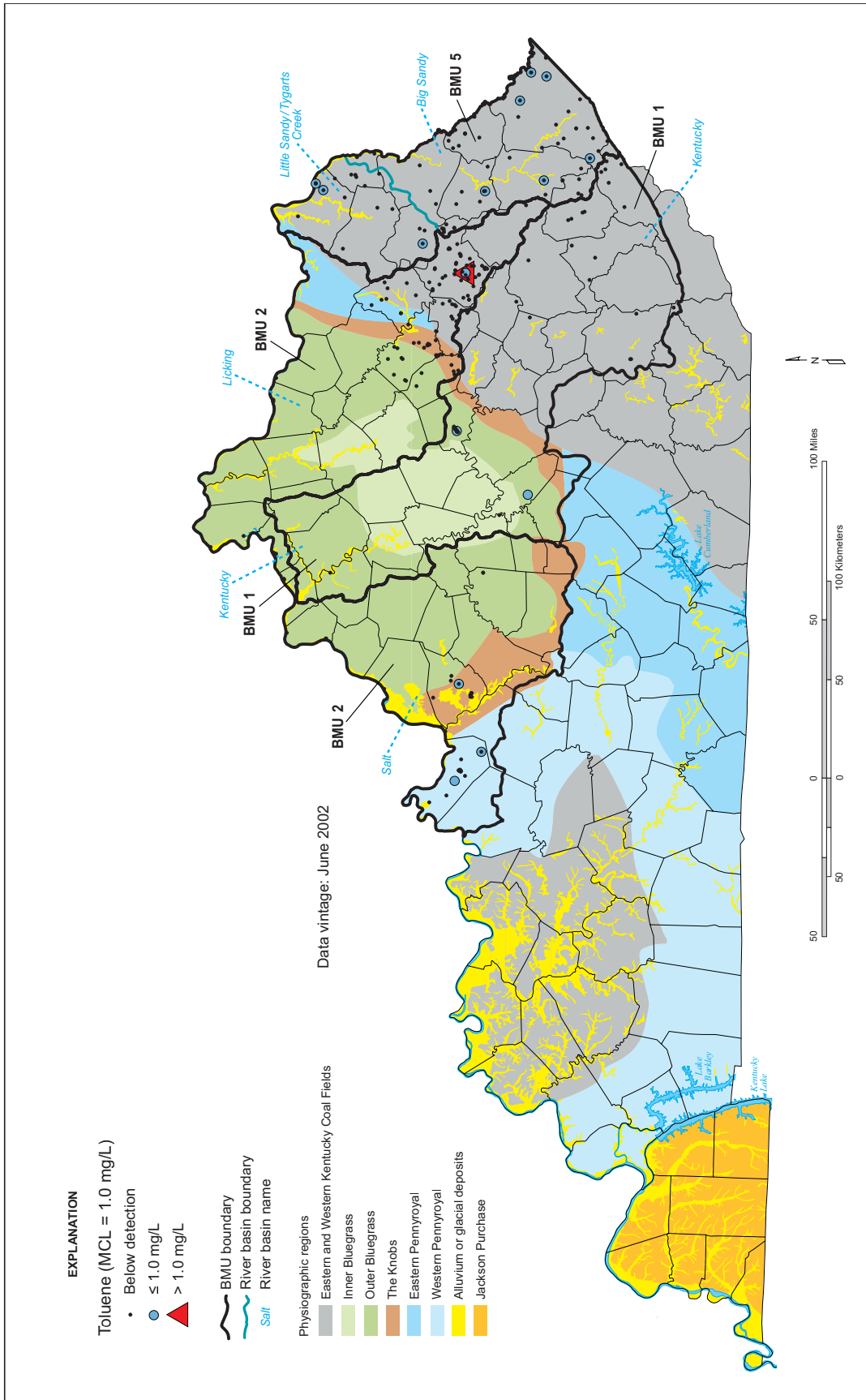


Figure 158. Locations of sampled sites and ranges of toluene values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

Xylenes. Xylenes in groundwater are usually the result of discharge from petroleum refineries or chemical factories, or leaking underground gasoline storage tanks. The primary health effect is damage to the nervous system. The EPA MCL is 10 mg/L for the sum of O-xylene, P-xylene, and M-xylene.

Xylene analyses in the data repository are reported as "1,3-xylene and 1,4-xylene," "1,4-xylene," "M-xylene," "O-xylene," "P-xylene," "total xylene," "xylene," and "xylene mixed isomers."

The data repository contains 735 such measurements at 239 sites in the project area (Table 32). No samples exceeded the MCL of 10 mg/L. Seven of 239 sites produced detectable xylenes.

Because of the very small number of sites where xylenes were detected (Fig. 159), no further data analysis was performed.

In summary, few sampled sites had total xylene concentrations that were above analytical detection limits. Three sites where xylenes were detected are in the Eastern Kentucky Coal Field and four are in the limestone terrain of the Outer Bluegrass and Western Pennyroyal Regions. The presence of xylenes at sites that were not considered locations of point-source releases indicates that the groundwater system is being affected by this volatile organic chemical.

Table 32. Summary of total xylenes values (mg/L). MCL: 10.0 mg/L.

	BMU 1	BMU 2	BMU 5
Values	94	527	114
Maximum	0.0195	1.3	0.0305
75th percentile	< 0.0005	< 0.001	< 0.001
Median	< 0.0005	< 0.001	< 0.0005
25th percentile	< 0.0005	< 0.001	< 0.0005
Minimum	< 0.0005	< 0.0005	< 0.0005
Sites	40	154	45
Sites > 10.0 mg/L	0	0	0
Sites where detected	2	3	2

< means analytical result reported as less than the stated analytical detection limit

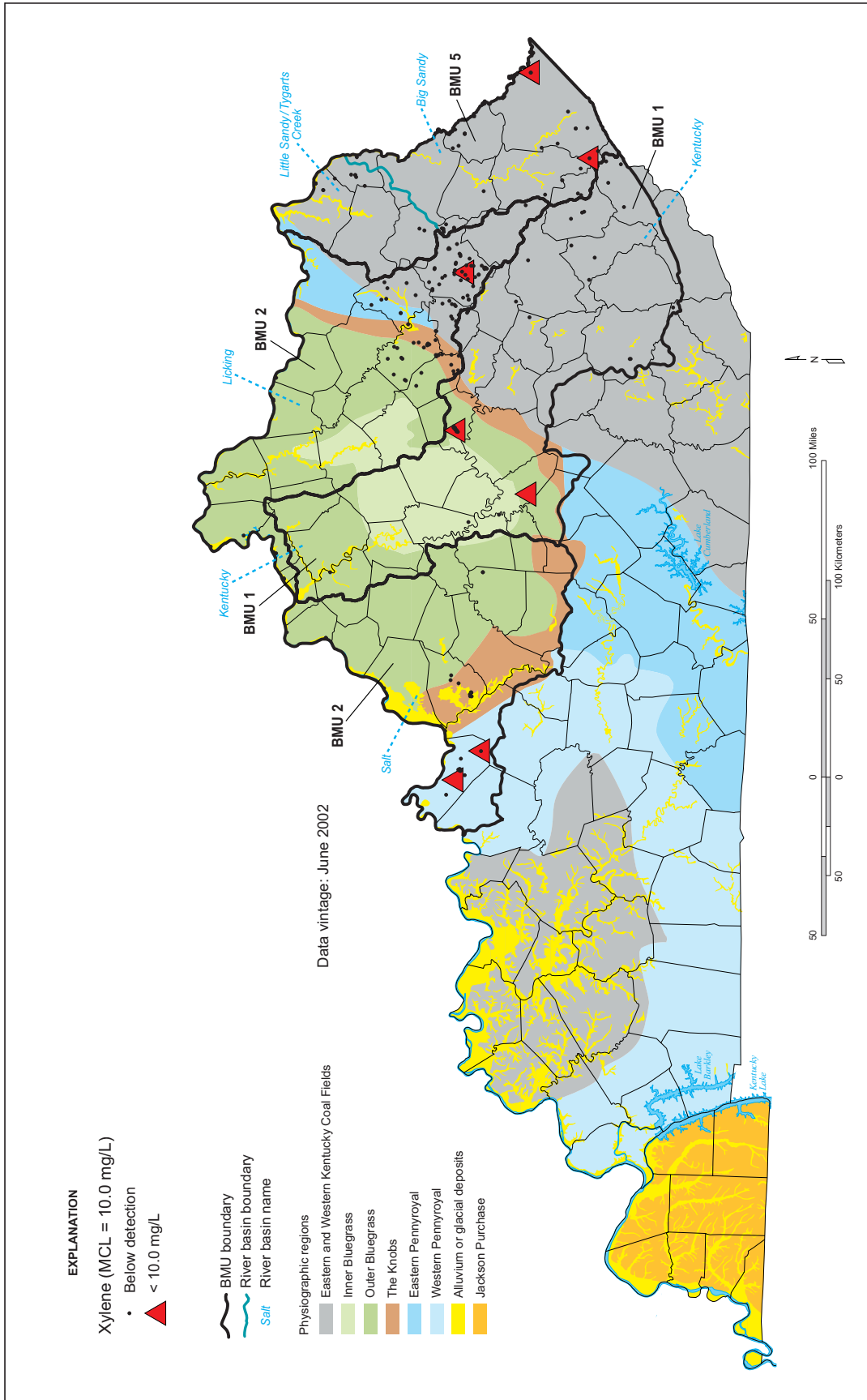


Figure 159. Locations of sampled sites and ranges of total xylenes values. No values exceeded the MCL. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

MTBE. MTBE is a gasoline additive used to promote combustion and reduce emissions. The primary sources of MTBE in groundwater are leaks from gasoline storage tanks or gasoline spills; atmospheric fallout of exhaust gases is also a potential source. Potential health effects have not been established; however, DOW has set a risk-based water-quality standard of 0.050 mg/L.

The data repository contained 574 MTBE measurements at 202 sites in the project area (Table 33). Four sites exceeded 0.05 mg/L, and 19 of 202 sites produced water with detectable MTBE.

Because of the very small number of sites where MTBE was detected (Fig. 160), no further data analysis was performed.

In summary, MTBE generally does not occur at detectable levels in water from wells and springs in the project area. Four of the sites where MTBE was present above analytical detection levels are in the Eastern Kentucky Coal Field; the remainder are in the limestone terrain of the Inner and Outer Bluegrass Regions. The presence of MTBE at sites that were not considered locations of point-source releases indicates that the groundwater system is being affected by this volatile organic chemical.

Table 33. Summary of MTBE values (mg/L). DOW recommendation: 0.05 mg/L.

	BMU 1	BMU 2	BMU 5
Values	268	168	138
Maximum	0.0501	0.18	0.0857
75th percentile	< 0.001	< 0.001	< 0.001
Median	< 0.001	< 0.001	< 0.001
25th percentile	< 0.001	< 0.001	< 0.001
Minimum	< 0.001	< 0.001	< 0.001
Sites	86	55	61
Sites > 0.05 mg/L	1	2	1
Sites where detected	8	8	3

< means analytical result reported as less than the stated analytical detection limit

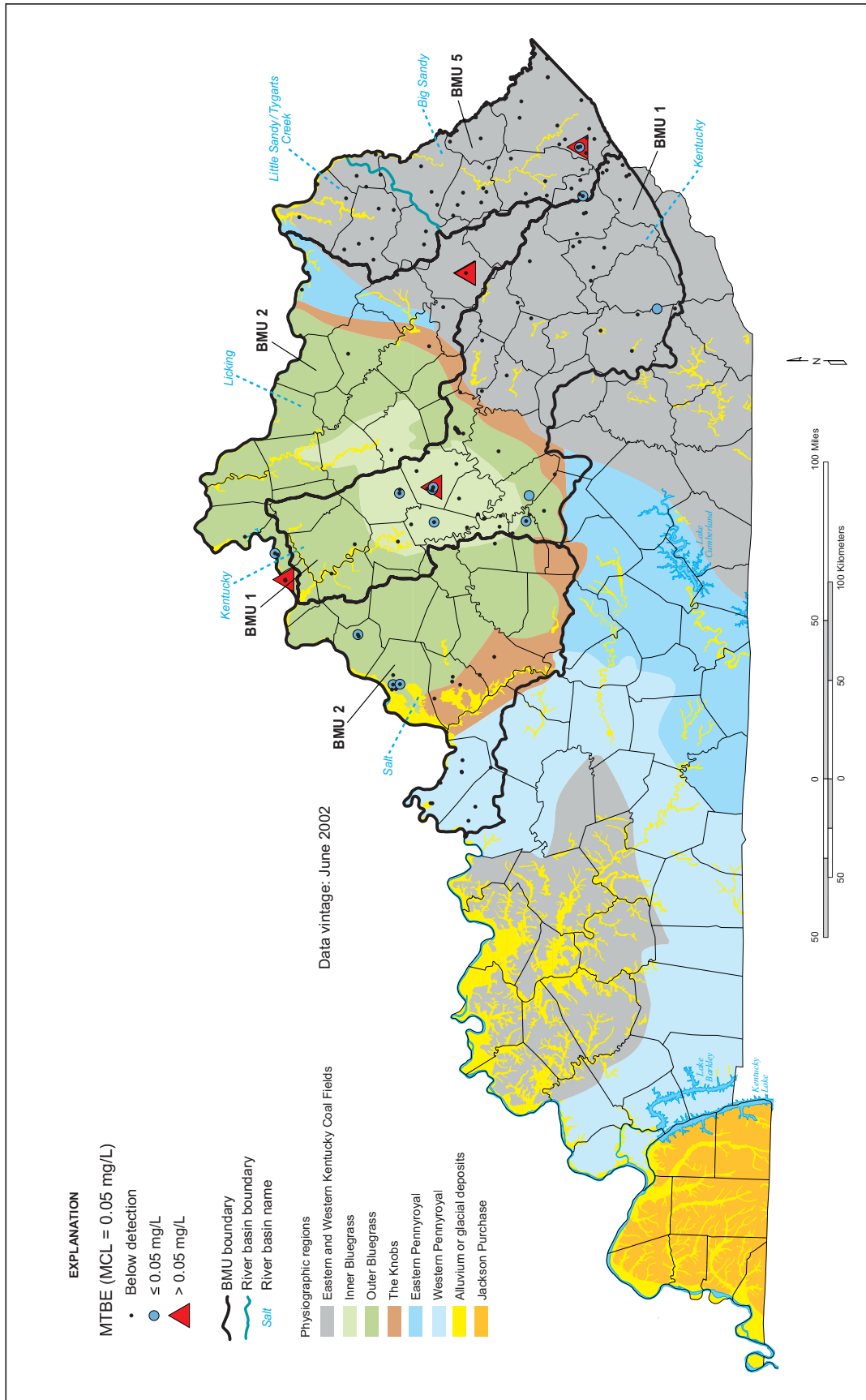


Figure 160. Locations of sampled sites and ranges of MTBE values. Superimposed symbols indicate that values recorded at different sampling times fell into different ranges.

Summary and Conclusions

The goal of this project was to summarize and evaluate groundwater quality from basin management units 1, 2, and 5 (watersheds of the Kentucky River, Salt River, Licking River, Big Sandy River, Little Sandy River, and Tygarts Creek, and adjacent tributaries of the Ohio River). Results of groundwater analyses were obtained from the Kentucky Groundwater Data Repository, which is the largest and most inclusive collection of information on groundwater in Kentucky. The water-quality data were compared to criteria provided by the Kentucky Division of Water; these criteria included maximum contaminant levels, secondary maximum contaminant levels, health advisory limits set by the Environmental Protection Agency, and other criteria established by the Division of Water if there was no MCL, SMCL, or HAL.

Table 34 summarizes the findings. Although there are no widespread areas where groundwater is unusable because of nonpoint-source contamination, many wells and springs have groundwater that exceeds recommended levels for water properties, inorganic anions, metals, nutrients, pesticides, and volatile organic chemicals. In many cases, the sources appear to be natural; in other cases, there is evidence of contamination by nonpoint-source chemicals.

General water properties (pH, total dissolved solids, total suspended solids, electrical conductance, and hardness), inorganic ions (chloride, sulfate, fluoride), and metals (arsenic, barium, mercury, iron, and manganese) are largely controlled by bedrock lithology. Some exceptionally high values of conductance, hardness, chloride, and sulfate may be the effects of deep brines associated with coal fields, oil and gas production, or leaking on-site waste-disposal systems,

Table 34. 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 Minimal 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-phosphorus	X		
	Total phosphorus	X		
Water Properties	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	

and some exceptionally low pH values may show the input of mine drainage. Fluoride, arsenic, and barium exceed recommended health-based standards in some instances, but these cases appear to be the product of natural sources rather than nonpoint-source contributions.

Nutrient concentrations show the effects of both natural and nonpoint-source inputs. Nitrate-nitrogen concentrations that far exceed natural contributions are common, particularly in regions where the land is used for agriculture. Phosphorus concentrations are generally higher in the Inner and Outer Bluegrass Regions, where limestone bedrock is known to be rich in phosphate.

Pesticides are synthetic organic chemicals that do not occur naturally. The presence of any pesticide in groundwater indicates a nonpoint-source contribution from agricultural or urban applications. The relative scarcity of detectable pesticide concentrations found in this study may be misleading, for two reasons. First, shallow wells in rural areas, those most susceptible to pesticide contamination, were not specific targets for sampling in the ambient groundwater-quality investigations that provide many of the data for this summary. Second, pesticide levels in groundwater are known to be highest following applications and after rainfalls. Sampling one time or on a quarterly schedule may miss the presence of pesticides if the sampling does not closely follow field and lawn applications or significant rainfalls. High pesticide concentrations in water from a well or spring are a health hazard when the water is used regularly for domestic purposes, even though the available analyses did not show high pesticide concentrations at the time of sample collection. For these reasons, pesticides may be a greater health threat at some times of the year than these data suggest.

Like pesticides, refined volatile organic chemicals do not occur naturally in groundwater and can have significant health effects at very low concentrations. The occurrence of volatile organic chemicals in groundwater is not natural and can only be the result of human activities. This study excluded analyses of groundwater from wells or springs that were known to be affected by leaking underground storage tanks and other sources of volatile organic chemicals. The detection of volatile organic chemicals in springs and shallow wells that were previously thought to be free of such compounds suggests that volatile organic chemicals are entering regional groundwater systems.

Springs and shallow wells are more likely to have high levels of metals, nutrients, pesticides, and volatile organic chemicals than intermediate or deep wells. The potential contamination of the shallow groundwater system (springs and shallow wells) is cause for concern, as is potential contamination of the intermediate and deeper groundwater system.

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