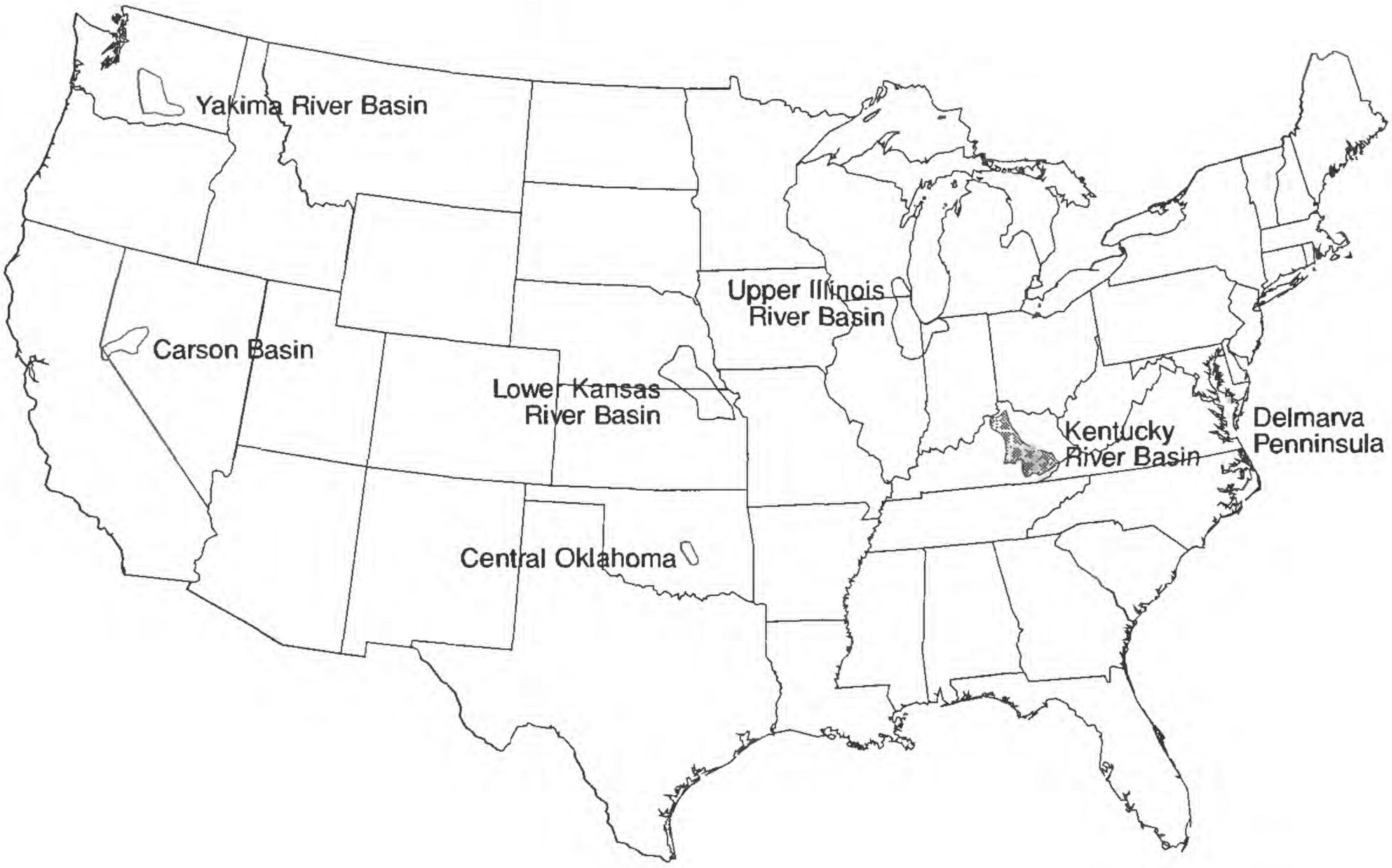
# WATER-QUALITY ASSESSMENT OF THE KENTUCKY RIVER BASIN, KENTUCKY: DISTRIBUTION OF METALS AND OTHER TRACE ELEMENTS IN SEDIMENT AND WATER, 1987-90

By Stephen D. Porter, Kevin D. White, and J.R. Clark

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 94-4134



Louisville, Kentucky
1995

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# PREFACE

In April 1986, the U.S. Geological Survey (USGS) established the National Water-Quality Assessment (NAWQA) Program to (1) provide a nationally consistent description of the status of water quality in a large, representative part of the nation's surface- and ground-water systems, (2) define water-quality trends of recent decades, and (3) relate past and present water-quality to relevant natural features, the history of land and water use, and present land-management and waste-management practices (Hirsch and others, 1988). This information is made available to water managers, policy makers, and the public to provide an improved scientific basis for evaluating the effectiveness of water-quality management programs, and for predicting the likely effects of changes in land-management and water-management practices. The NAWQA Program is organized into study units on the basis of known hydrologic systems (large parts of aquifers or aquifer systems and major river basins). The study units are large, commonly involving areas of several thousand square miles. The Kentucky River Basin was selected as one of four pilot project studies that focused primarily on surface water. Previous USGS publications from the Kentucky River Basin NAWQA program include the project description (White and others, 1987), a summary of biological investigations in the basin (Bradfield and Porter, 1990), effects of oil production on water resources in the basin (Evaldi and Kipp, 1991), and a retrospective assessment of surface water quality in the Kentucky River Basin (Smoot and others, 1991).

This report completes one of the intermediate activities undertaken as part of the Kentucky River Basin pilot project, which was created to evaluate the occurrence and distribution of metals and other trace elements in the basin, to define trends (or lack of trends) in water quality, and to determine relations of observed concentrations or trends in water-quality conditions to natural and human factors. Water-quality issues related to the distribution of concentrations and loads of metals in streams of the Kentucky River Basin include relations with regional geologic, hydrologic, and other natural characteristics, as well as the effects of human activities. Those activities include land disturbance from coal mining and agriculture, municipal and industrial wastewater discharges and landfills, oil-well brine discharges, and urban stormwater runoff. Temporal changes in the concentrations and loads of metals in streams of the Kentucky River Basin may be associated with (1) regulatory changes (with respect to point-source discharges, waste-management practices, and best-management practices to reduce contaminants in stormwater runoff), (2) changes of land use in the basin (for example, increased urbanization or changes in the areal percentage of surface-mining or agricultural activities), (3) changes in the rate of mineral resource recovery that are associated with market demand for coal or oil, and (4) changes associated with the magnitude of precipitation and streamflow in the Kentucky River Basin.

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## ILLUSTRATIONS

## TABLES

## CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

| **Multiply** | **By** | **To obtain** |
|---|---|---|
| inch (in.) | 25.4 | millimeter |
| mile (mi) | 1.609 | kilometer |
| acre | 0.4047 | square hectometer |
| square mile ($mi^2$) | 2.590 | square kilometer |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second |
| ton per year (ton/yr) | 0.9072 | megagram per year |
| ton per square mile per year [$(ton/mi^2)/yr$] | 0.07358 | megagram per square kilometer per year |

Temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$°F = 1.8\ (°C) + 32$$

**Sea level:** In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

**Abbreviated water-quality units used in this report:** Chemical concentrations, sample volumes, and sediment-particle sizes are given in metric units.

Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. Chemical concentration in sediment is given in micrograms of constituent per gram of sediment (μg/g) [or milligrams of constituent per kilogram of sediment (mg/kg)].

Sample volumes of water samples are given in liters (L) or milliliters (mL). Sediment-particle sizes are given in millimeters (mm) or micrometers (μm).

Water year: The 12-month period from October 1 through September 30. The water year is designated by the calender year in which it ends.

Other abbreviations used in this report:

| | |
|---|---|
| ANOVA | Analysis of variance |
| BWMP | Basic water-monitoring program (of the Kentucky Division of Water) |
| CV-AAS | Cold vapor-atomic absorption spectrophotometry |
| GD | Geologic Division (of the U.S. Geological Survey) |
| GIS | Geographic information system |
| HG-AAS | Hydride generation-atomic absorption spectrophotometry |
| ICP-AES | Inductively coupled plasma-atomic emission spectrometry |
| ICP-MS | Inductively coupled plasma-mass spectrometry |
| ICP-OES | Inductively coupled plasma-optical emission spectrometry |
| KDOW | Kentucky Division of Water |
| KDWSSC | Kentucky domestic water supply source-criterion |
| LOEL | Lowest observed effect level |
| MPV | Most probable value |
| NAWQA | National Water-Quality Assessment |
| NURE | National Uranium Resources Evaluation |
| NWQL | National Water Quality Laboratory (of the U.S. Geological Survey) |

Standard abbreviations used in station names:

| | | | | | |
|---|---|---|---|---|---|
| Cr | Creek | M | Middle | R | River |
| Fk | Fork | N | North | S | South |
| Ky | Kentucky | nr | near | | |

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## ABSTRACT

The U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program is designed to provide a nationally consistent description of the current status of water quality, to define water-quality trends, and to relate past and present water-quality conditions to natural features, uses of land and water, and other water-quality effects from human activities. The Kentucky River Basin is one of four NAWQA pilot projects that focused primarily on the quality of surface water. Water, sediment, and bedrock samples were collected in the Kentucky River Basin during 1987-90 for the purpose of (1) describing the spatial distribution, transport, and temporal variability of metals and other trace elements in streams of the basin; (2) estimating mean annual loads, yields, and trends of constituent concentrations and identifying potential causes (or sources) of spatial patterns; (3) providing baseline information for concentrations of metals in streambed and suspended sediments; (4) identifying stream reaches in the Kentucky River Basin with chronic water-quality problems; and (5) evaluating the merits of the NAWQA pilot study-approach for the assessment of metals and other trace elements in a river system.

The spatial distribution of metals and other trace elements in streambed sediments of the Kentucky River Basin is associated with regional differences of geology, land use and cover, and the results of human activities. Median concentrations of constituents differed significantly among physiographic regions of the basin because of relations to bedrock geochemistry and land disturbance. Concentrations of potentially toxic metals were large in urban and industrial areas of the basin. Elevated concentrations of certain metals were also found in streambed sediments of the Knobs Region because of the presence of Devonian shale bedrock. Elevated concentrations of lead and zinc found in streambed sediments of the Bluegrass Region are likely associated with urban stormwater runoff, point-source discharges, and waste-management practices. Concentrations of cadmium, chromium, copper, mercury, and silver were elevated in streambed sediments downstream from wastewater-treatment plant discharges. Streambed-sediment concentrations of barium, chromium, and lithium were elevated in streams that receive brine discharges from oil production. Elevated concentrations of antimony, arsenic, molybdenum, selenium, strontium, uranium, and vanadium in streambed sediments of the Kentucky River Basin were generally associated with natural sources.

Concentrations of metals and other trace elements in water samples from fixed stations (stations where water-quality samples were collected for 3.5 years) in the Kentucky River Basin were generally related to stream discharge and the concentration of suspended sediment, whereas constituent concentrations in the suspended-sediment matrix were indicative of natural and human sources. Estimated mean annual loads and yields for most metals and other trace elements were associated with the transport of suspended sediment.

Land disturbance, such as surface mining and agriculture, contribute to increased transport of sediment in streams, thereby increasing concentrations of metals in water samples during periods of intense or prolonged rainfall and increased stream discharge. Concentrations of many metals and trace elements were reduced during low streamflow. Although total-recoverable and dissolved concentrations of certain metals and trace elements were large in streams affected by land disturbance, concentrations of constituents in the suspended-sediment matrix were commonly large in streams in the Knobs and Eastern Coal Field Regions (because of relations with bedrock geochemistry) and in streams that receive wastewater or oil-well-brine discharges. Concentrations and mean annual load estimates for aluminum, chromium, copper, iron, lead, manganese, and mercury were larger than those obtained from data collected by a State agency, probably because of differences in sample-collection methodology, the range of discharge associated with water-quality samples, and laboratory analytical procedures. However, concentrations, loads, and yields of arsenic, barium, and zinc were similar to those determined from the State data.

Significant upward trends in the concentrations of aluminum, iron, magnesium, manganese, and zinc were indicated at one or more fixed stations in the Kentucky River Basin during the past 10 to 15 years. Upward trends for concentrations of aluminum, iron, and manganese were found at sites that receive drainage from coal mines in the upper Kentucky River Basin, whereas upward trends for zinc may be associated with urban sources. Water-quality criteria established by the U.S. Environmental Protection Agency (USEPA) or the State of Kentucky for concentrations of aluminum, beryllium, cadmium, chromium, copper, iron, manganese, nickel, silver, and zinc were exceeded at one or more fixed stations in the Kentucky River Basin. On a qualitative basis, dissolved concentrations of certain metals and trace elements were large during low streamflow at sites where (1) concentrations of these constituents in underlying streambed sediments were large, or (2) dissolved-oxygen concentrations were small. Concentrations of barium, lithium, and strontium were large during low streamflow, which indicates the influence of ground-water baseflows on the quality of surface water during low flow.

The effects of point-source discharges, landfills, and other waste-management practices are somewhat localized in the Kentucky River Basin and are best indicated by the spatial distribution of metals and other trace elements in streambed sediments and in the suspended-sediment fraction of water samples at stream locations near the source. It was not possible to quantify the contribution of point sources to the total transport of metals and other trace elements at fixed stations because data were not available for wastewater effluents. Quantification of baseline concentrations of metals and other trace elements in streambed sediments provides a basis for the detection of water-quality changes that may result from improvements in wastewater treatment or the implementation of best-management practices for controlling contamination from nonpoint sources in the Kentucky River Basin.

## INTRODUCTION

The U.S. Geological Survey (USGS) proposed a National Water-Quality Assessment (NAWQA) Program in 1985 to (1) provide a nationally consistent description of current water-quality conditions for a large part of the

Nation's water resources; (2) define long-term trends (or lack of trends) in water quality; and (3) identify, describe, and explain, to the extent possible, the major natural and human factors that affect observed water-quality conditions and trends. In 1986, a pilot NAWQA program was begun, the purpose of which was to develop, test, and refine methods useful for a full-scale NAWQA program (Hirsch and others, 1988). The Kentucky River Basin was selected as one of the seven pilot studies and focused primarily on surface-water quality issues, including metals and trace elements in water and sediments.

Concern about the contamination of waters by metals and other trace elements has been increasing during the past decade because (1) most elements persist in the aquatic environment for extended periods of time; (2) downstream transport of contaminated sediments may result in degraded water quality at a considerable distance from the source of contamination; (3) elevated concentrations of dissolved metals and suspended metals (metals attached to suspended sediments) can adversely affect beneficial water uses; and (4) many of these elements can be toxic to aquatic organisms, or can result in chronic, sublethal effects, including bioaccumulation and biomagnification in the food chain. Metals and trace elements can enter receiving streams from natural sources as a result of weathering of rocks and soils, as well as from human activities, including wastewater discharges, land disturbance (agriculture, construction, and surface mining), solid-waste disposal, urban stormwater runoff, and atmospheric deposition of particulates originating from automotive exhausts or industrial emissions.

Although dissolved concentrations of metals and trace elements in water are generally small or below limits of detection (Hem, 1989), concentrations of elements adsorbed to suspended sediments or streambed sediments are typically several orders of magnitude larger than the dissolved phase (Horowitz, 1991). Because most metals are strongly associated with particulates under normal water-quality conditions, relative to dissolved oxygen, pH, and oxidation-reduction relations (redox potential), streambed sediments function as a repository, or "sink," where these constituents tend to accumulate. However, metals can also be released from sediments (desorbed) if water quality is degraded as a result of eutrophication, mine drainage, or other processes that result in the reduction of pH and (or) dissolved oxygen. Certain trace elements can also be released from sediments if other metals with greater adsorption affinity are discharged to the water (ion exchange processes) or if certain biologically mediated processes occur; for example, bacterial methylation of certain heavy metals or ingestion of fine-fraction sediments by benthic (bottom-dwelling) aquatic organisms (Elder, 1988).

## Purpose and Scope

The purpose of this report is to (1) describe the spatial distribution and the temporal variability of metals and other trace elements in sediments and water of the Kentucky River Basin; (2) identify potential causes of spatial patterns and constituent loads, yields, and trends; (3) provide baseline information regarding concentrations of metals and trace elements in streambed sediments of the Kentucky River Basin; (4) identify stream reaches in the basin where the accumulation of metals in sediments has created chronic water-quality problems; and (5) evaluate the National Water-Quality Assessment (NAWQA) pilot-study approach for assessing water-quality conditions in the Kentucky River Basin. Analyses of water, sediment, and bedrock samples collected in the basin during 1987-90 are the foundation for this report.

The distribution of metals and other trace elements in the Kentucky River Basin is evaluated by use of several approaches. A synoptic collection of streambed-sediment samples was done during the fall of 1987 at 473 sites. Sampling sites ranged from small, first- and second-order streams to a longitudinal series of locations in the Kentucky River. The purpose of this survey was to describe the spatial distribution of metals and other trace elements in relation to differences in land use, geology, and physiography. Representative bedrock samples were collected during the survey to evaluate natural geochemical contributions of constituents to streambed sediments as a result of weathering processes.

Water and suspended-sediment samples were collected monthly, from April 1987 through March 1990, at seven fixed stations to determine seasonal trends, loads, and yields of metals and other trace elements. Additional samples were collected at the fixed stations during large streamflows; that is, at streamflows equaled or exceeded only 10 percent of the time. These data were collected to improve the precision of annual transport estimates at the fixed stations. Water samples were also collected in conjunction with synoptic surveys made during low flow in August 1987 and August 1988, and dissolved concentrations of metals and other trace elements were determined at 74 stream locations. Water-quality data were also collected by the Kentucky Division of Water (KDOW) at 11 basic water-monitoring program (BWMP) sites in the Kentucky River Basin during 1986-89. Four of the 11 BWMP sites are at the same locations as the NAWQA fixed stations. Data from KDOW were evaluated to develop an improved understanding of the spatial distribution of constituent concentrations, loads, and trends, and to compare differences in sampling and analysis protocols.

## Occurrence and Distribution of Metals and Other Trace Elements in the Hydrologic Environment

Biogeochemical partitioning of metals and trace elements among water, suspended sediments, and bottom sediments is regulated by pH, redox potential, sediment particle size, and the occurrence and nature of clay minerals, organic matter, and hydrous oxides of iron and manganese (Elder, 1988). Most metals and trace elements are associated with sediments in well-oxygenated streams with near-neutral pH. Trace elements within a riverine system are transported primarily on suspended sediments, especially after periods of rainfall or snowmelt that result in increased streamflow. Process mechanisms that result in the accumulation of metals by sediments include (1) adsorption on fine-grained material (Horowitz, 1991), (2) coprecipitation with hydrous iron and manganese oxides (Jenne, 1968), and (3) complexation with organic matter (Davis, 1984). Differences in clay mineralogy and organic matter content can account for several orders of magnitude of difference in cation exchange capacity or for the ability of sediments to concentrate positively charged metal ions (Horowitz, 1991).

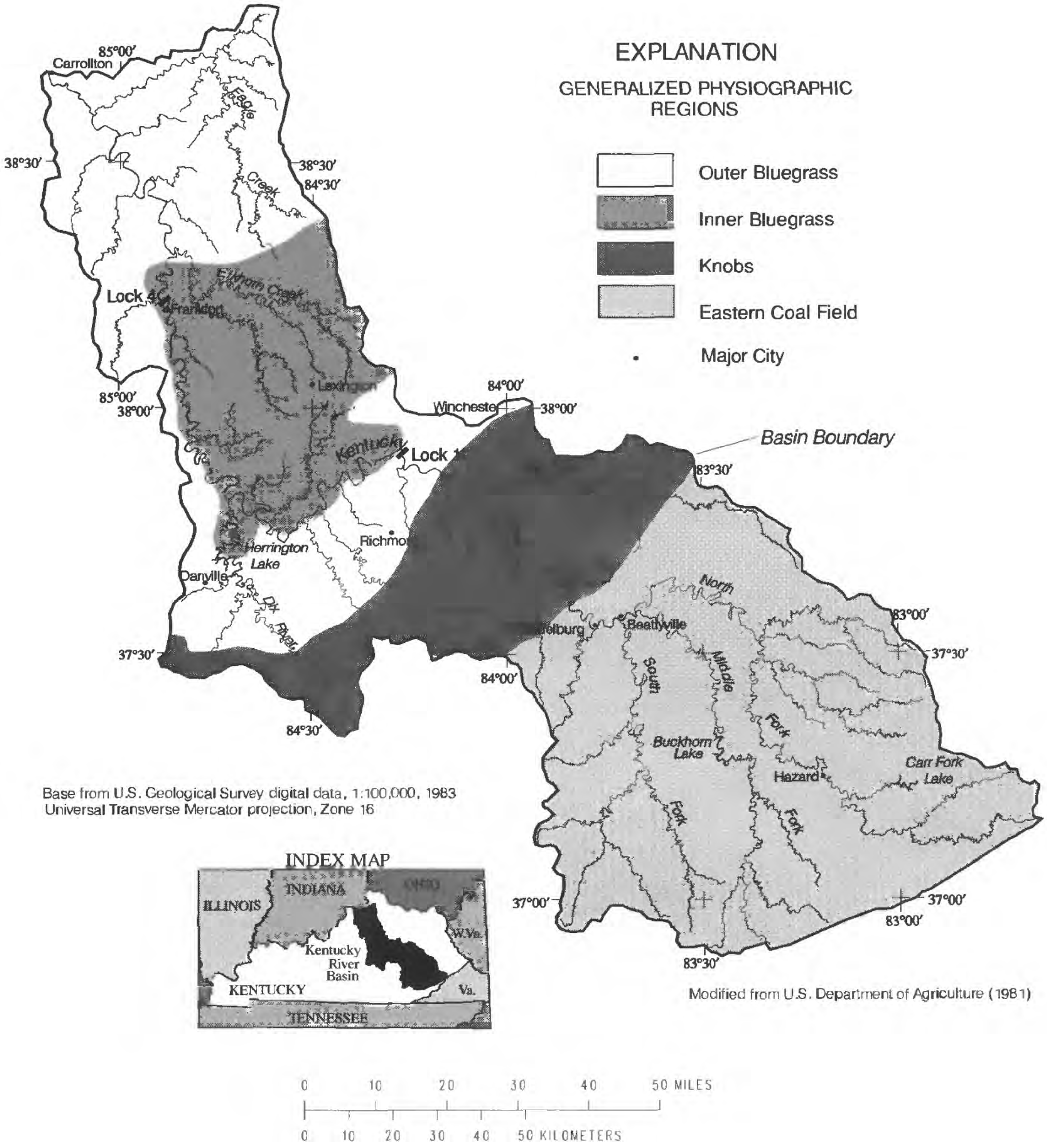
The capacity of streambed sediments to accumulate and retain metals and other trace elements is affected by particle size (Forstner and Wittmann, 1981). The relative surface area available for adsorption of metals increases as particle size decreases; thus, concentrations of elements in stream sediments tend to be greatest among fine-fraction (silt- and clay-size; <63 μm) particles (Horowitz and Elrick, 1987). Therefore, it is generally necessary that chemical analyses of stream sediments refer to a specific size-fraction so that size sorting of streambed material does not bias among-site differences in sediment concentrations of metals that may be attributable to natural (geological) or human causes (de Groot and others, 1982; Stamer and others, 1985). Although the analysis of large size-fractions (sand-size and greater; >63 μm) may be useful in certain spatial studies of metals, because of comparatively less transport of larger particulates (Wilber and Hunter, 1979; Tessier and others, 1982), fine-fraction sediments generally contain higher concentrations of metals and trace elements (Horowitz, 1991). Moreover, fine-fraction sediments are in the size range that can be ingested by benthic macroinvertebrates (Tessier and others, 1982; Luoma, 1989), potentially resulting in adverse, acute or chronic effects on aquatic life.

## DESCRIPTION OF THE KENTUCKY RIVER BASIN

The Kentucky River Basin is in east-central Kentucky and encompasses approximately 3,500 mi of streams within a drainage area of about 7,000 mi$^2$ (White and others, 1987). The Kentucky River drains all or parts of 39 of Kentucky's 120 counties and serves as a water source for over 95 percent of the basin's population. Surface elevation in the basin ranges from about 420 ft above sea level at the mouth of the Kentucky River to more than 3,200 ft in the southeastern part of the basin.

Originating in the Eastern Coal Field Region of southeastern Kentucky, the main stem of the Kentucky River flows approximately 405 mi northwesterly to its confluence with the Ohio River at Carrollton, in north-central Kentucky (fig. 1). The North, Middle, and South Fork Subbasins of the Upper Kentucky River Basin constitute three hydrologic units that drain the Eastern Coal Field Region. Principal municipalities of the upper Kentucky River Basin include Whitesburg, Hazard, Jackson, Booneville, and Beattyville.

From the junction of the three forks of the Kentucky River near Beattyville, the river is characterized by a series of 14 navigational pools that historically were important for the transportation of coal, timber, and other resources. More recently, the pools have been extensively used for municipal and industrial water supply, recreation, and wastewater-discharge assimilation. From Lock and Dam 14 at Heidelberg, the Kentucky River flows to the northwest through a hydrologic unit in the middle part of the basin, which receives drainage from the Knobs Region. Major tributaries of the Middle Kentucky River include Sturgeon Creek, Station Camp Creek, and Red River. Principal municipalities of the Middle Kentucky River Basin include Irvine and Clay City.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Modified from U.S. Department of Agriculture (1981)

**Figure 1.** Physiographic regions of the Kentucky River Basin.

From Lock and Dam 10 near Boonesboro, the Kentucky River initially flows to the southeast, in the direction of the Kentucky River Fault, and then to the north through the Lower Kentucky River Basin, which constitutes a hydrologic unit that drains the Bluegrass Region. Major tributaries of the Lower Kentucky River include Dix River, Elkhorn Creek, and Eagle Creek. Principal municipalities of the Lower Kentucky River Basin include Richmond, Danville, Lexington, Georgetown, Versailles, Frankfort, and Carrollton.

## Precipitation and Hydrologic Patterns

The climate of the Kentucky River Basin is classified as "moist continental" (Strahler and Strahler, 1979). The average annual precipitation ranges from more than 50 in. in the upper part of the basin to about 40 in. in the lower part (Elam and others, 1972). The monthly distribution of precipitation is fairly uniform; October usually has the smallest amount, and March has the largest amount (Conner, 1982). Precipitation records from Lexington indicate an upward trend during water years 1961-75 and a downward trend since 1976.

Seasonal Kendall trend tests indicate a strong upward trend in stream discharge in the Kentucky River Basin during the early 1960's to the mid-1970's and a strong downward trend during 1976-86 (Smoot and others, 1991). Hydrologic patterns have varied, however, because of periods of prolonged drought, followed by periods of average or above-average precipitation. Hydrologic conditions in the Kentucky River Basin varied considerably during the intensive phase of data collection for the NAWQA pilot-project (1987-90). An extended period of drought occurred in the basin during 1986-88. Streambed-sediment samples collected during fall 1987 and water samples collected through late 1988 are representative of low flow in the basin. In contrast, precipitation in the basin was above average during the latter stage of the NAWQA study. Major flooding occurred in the Kentucky River Basin in early 1989, and streamflow was significantly above average during 1989-90.

## Physiography, Geology, and Land Use

The Kentucky River Basin is characterized by four physiographic regions: the Eastern Coal Field, the Knobs, and the Inner and Outer Bluegrass Regions. Each region is topographically distinct, and variations in surface-water features, water-quality characteristics, land use, and population density correspond with physiographic and geologic differences within the basin.

The Kentucky River Basin is underlain by sedimentary rocks of Paleozoic age. Age of exposed bedrock ranges from Middle Ordovician in the lower part of the basin to Pennsylvanian in the upper part of the basin (McFarlan, 1943). The variation in the geochemical properties of rocks and other geologic materials (as well as those of soils derived from these materials) affects regional concentrations of metals and other trace elements in sediments and water from streams within the different physiographic regions.

## Eastern Coal Field Region

The Eastern Coal Field Region is characterized by sandstone, siltstone, and shale (fig. 2) of Pennsylvanian age interbedded with numerous coal seams (McFarlan, 1943). Approximately 98,000 acres of land have been affected by coal-mining activities in the upper Kentucky River Basin, notably in the North and Middle Fork Kentucky River hydrologic units (White and others, 1987) (fig. 3a). Elevated loads and yields of aluminum, iron, manganese, and other trace elements in streams of the Eastern Coal Field Region were related to land disturbance from coal-mining activities (Smoot and others, 1991). Major stream tributaries in the Eastern Coal Field Region include Frozen Creek, Quicksand Creek, Carr Fork, and Rockhouse Creek in the North Fork Kentucky River hydrologic unit; Cutshin Creek and Greasy Creek in the Middle Fork Kentucky River hydrologic unit; and Red Bird River, Goose Creek, and Sexton Creek in the South Fork Kentucky River hydrologic unit.

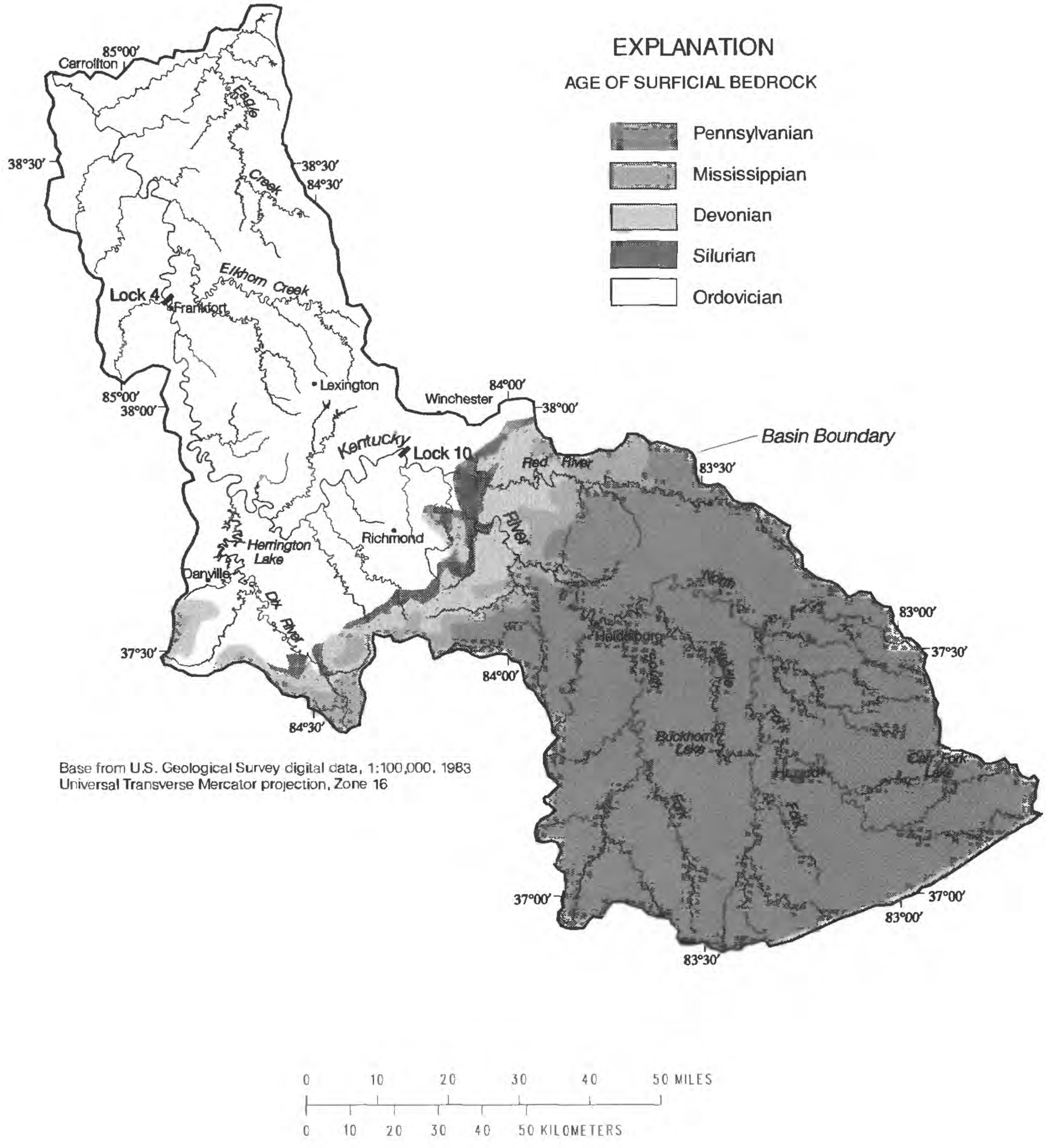
Although coal production in the Eastern Coal Field Region remained relatively constant during 1980-89, coal production significantly increased in the headwaters of the North Fork Kentucky River (Letcher County) and decreased in the headwaters of the South Fork Kentucky River (Clay County) (B. Davidson, Kentucky Geological Survey, written commun., 1991). Greater than 75 percent of the coal produced in the Kentucky River Basin during 1980-89 was mined in the North Fork Kentucky River hydrologic unit.

## Knobs Region

The Knobs Region in the Middle Kentucky River Basin is characterized by hilly to mountainous topography and relatively low population density (fig. 1). The Knobs Region is underlain by dolomitic limestone with interbedded shale of Silurian age, oil shales of Devonian age, and limestone and shale (interbedded with siltstones and sandstones) of Mississippian age (fig. 2). The Knobs Region is a topographic transition zone between the Bluegrass and Eastern Coal Field Regions. Iron ore was produced in the Knobs during the 1800's. The production of oil and gas in the region has resulted in elevated concentrations of barium, iron, manganese, nickel, sodium, and other constituents in water and sediments (Logan and others, 1989; Smoot and others, 1991; Walker and others, 1991). Concentrations of many metals and trace elements are large in bedrock, soils, and ground water in the Knobs Region (McFarlan, 1943; Smoot and others, 1991). Major tributaries of the Kentucky River in the Knobs Region include Red River, Station Camp Creek, and the Big Sinking Creek/Millers Creek system.

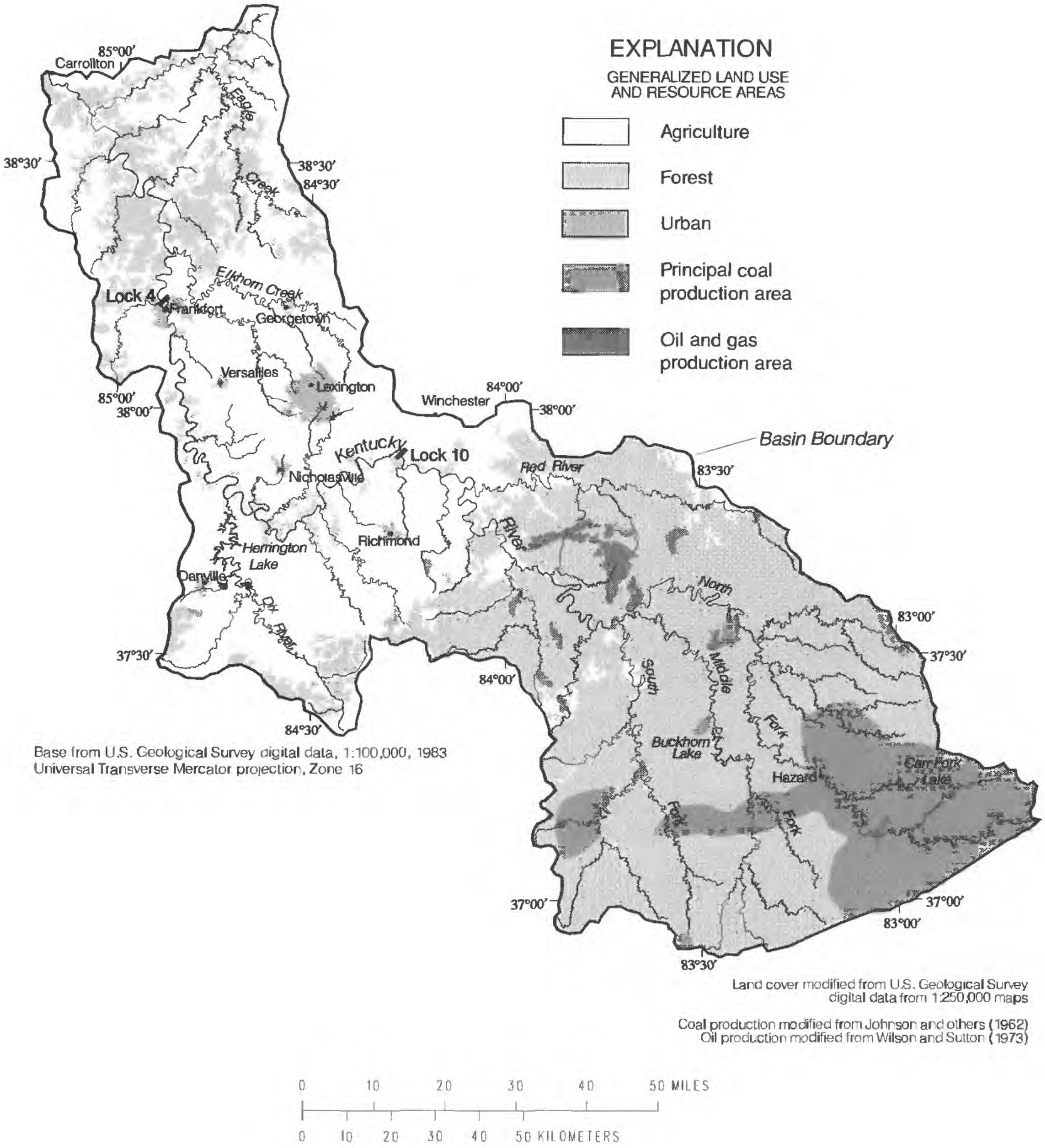
## Bluegrass Regions

The Bluegrass Regions in the Lower Kentucky River Basin are characterized by gently rolling topography. Differences between the Inner and Outer Bluegrass Regions are related to hydrology, land uses, and population density. The limestone of the Inner Bluegrass Region has weathered by solution, resulting in an extensive area of karst topography. Soils in the Inner Bluegrass Region are developed from phosphate-rich limestone of Ordovician age. Rock phosphate was mined in some places in the Inner Bluegrass Region



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

**Figure 2.** Generalized bedrock geology of the Kentucky River Basin.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Land cover modified from U.S. Geological Survey digital data from 1:250,000 maps

Coal production modified from Johnson and others (1962)
Oil production modified from Wilson and Sutton (1973)

**Figure 3a.** Generalized land cover and major mineral-resource areas in the Kentucky River Basin.

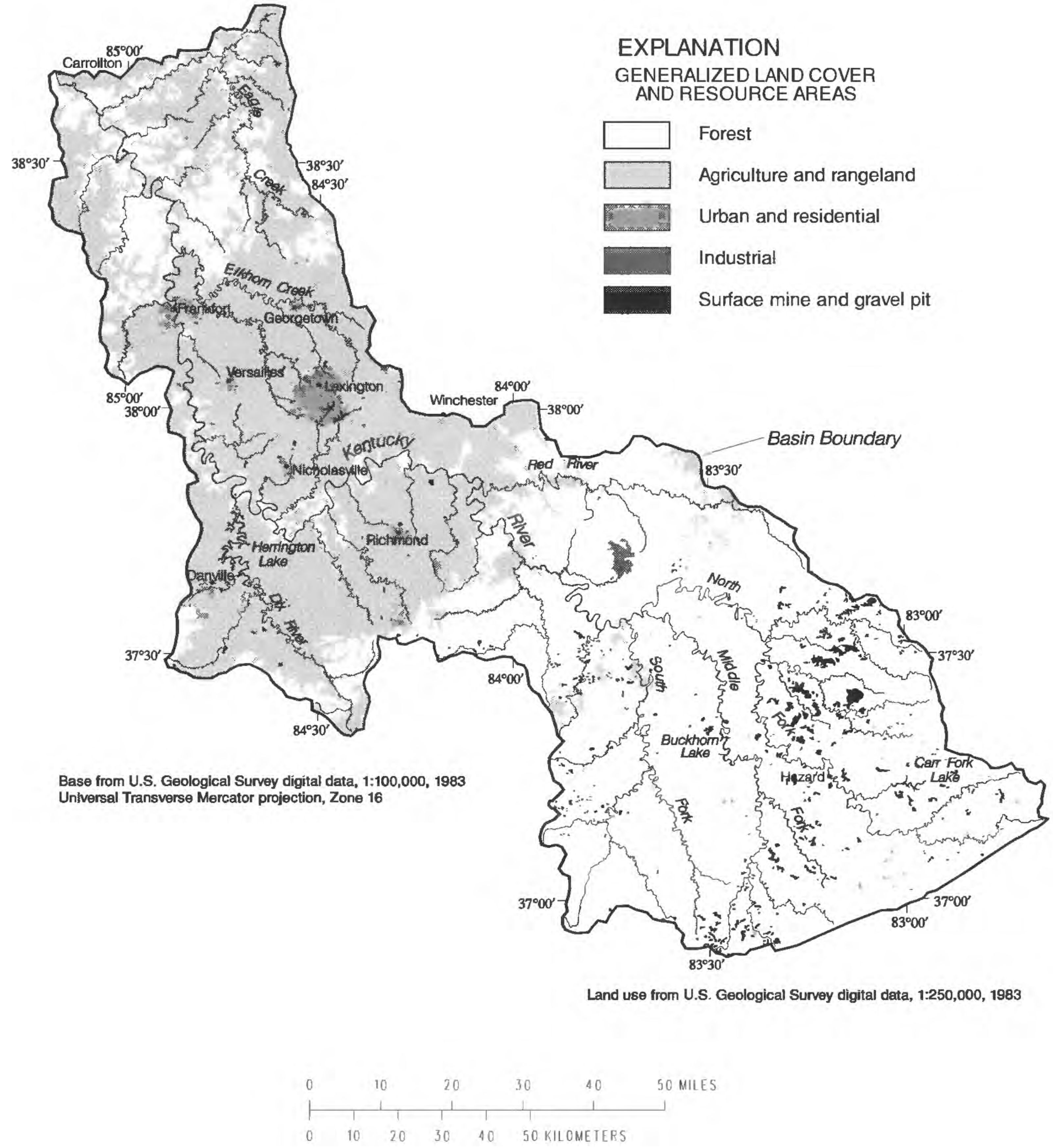
during the 1920's (McFarlan, 1943). Nearly half of the population of the Kentucky River Basin resides in the Inner Bluegrass urban centers of Lexington, Frankfort, Georgetown, Nicholasville, and Versailles (fig. 3b), all of which rely on the Kentucky River as a primary source of water. Major Inner Bluegrass tributaries to the Kentucky River include the North and South Forks of Elkhorn Creek, Hickman Creek, Jessamine Creek, and Clear Creek.

The Outer Bluegrass Region (fig. 1) is characterized by fossiliferous limestone, dolomite, and shale of Ordovician age (fig. 2). In contrast with the Inner Bluegrass karst, most of the drainage in the Outer Bluegrass Region is at the land surface. Soils of the Outer Bluegrass Region are derived from bedrock that contains considerable quantities of magnesium and potassium, compared with phosphate-rich soils of the Inner Bluegrass Region. Soils in the northern part of the region are also affected by loess deposits that overlie rocks of Ordovician age (White and others, 1987). Localized veins of lead and zinc were mined in the northern part of the Outer Bluegrass Region (Henry and Franklin counties) during the early 1900's (McFarlan, 1943).

Although agriculture is the predominant land use throughout the Outer Bluegrass Region (figs. 3a and 3b), the southern part is more urbanized and includes the cities of Richmond, Danville, and numerous residential and commercial areas adjacent to the greater Lexington metropolitan area. Major tributaries to the Kentucky River in the Outer Bluegrass Region include Eagle Creek, Drennon Creek, and Benson Creek in the northern part and Dix River, Silver Creek, Otter Creek and Paint Lick Creek in the southern part of the area. Streams in the southern part of the Outer Bluegrass Region originate from the Knobs Region (fig. 1).

## Sources of Metals and Other Trace Elements

Metals and other trace elements detected in streams of the Kentucky River Basin are from natural and human sources. Streambed-sediment concentrations of metals and other trace elements within hydrologic systems differ with regional geology within hydrologic systems because of differences in the geochemistry of rocks and soils (Berry and Mason, 1959; Conner, 1981; Forstner and Wittman, 1981). Human nonpoint sources of metals are thought to result in larger transport of contaminants in the Kentucky River Basin than point-source discharges (Gianessi, 1986; Smoot and others, 1991). Land disturbances such as surface mining of coal or other minerals can result in increased concentrations and loads of metals in affected streams (Moore, 1981; Dyer 1982, 1983; Tessier and others, 1982). Agricultural practices also can affect the concentrations and transport of metals in streams and rivers (Elder, 1988; Hoffman and others, 1990). Human activities in or near urban centers can indirectly affect the occurrence and distribution of metals and other trace elements in streams as a result of stormwater runoff from highways (Van Hassel and others, 1980; Harrison and Wilson, 1985a-c) and atmospheric deposition of cadmium, lead, mercury, and zinc (Elder, 1988). Historical water-quality data for metals in the Kentucky River Basin, as well as streambed sediment metals data from the U.S. Department of Energy, National Uranium Resource Evaluation (NURE) Program (Sargent and others, 1982) were discussed in the Kentucky River Basin NAWQA retrospective report (Smoot and others, 1991).



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Land use from U.S. Geological Survey digital data, 1:250,000, 1983

**Figure 3b.** Generalized land uses in the Kentucky River Basin.

Some municipal and industrial wastewater discharges in the Kentucky River Basin (fig. 4; table 1) are known to contribute large loads of metals to receiving streams. Elevated concentrations of heavy metals in water and sediments have been associated with point-source discharges in Elkhorn Creek (Logan and others, 1983b), Silver Creek (Logan and others, 1984), and Bailey Run (Logan and others, 1988). Unpublished water-quality and sediment data collected by the KDOW also indicate point-source discharge contributions of metals to Jessamine Creek (Town Branch), Clarks Run, and Hickman Creek (KDOW facility files). Municipal and industrial landfills in the Kentucky River Basin (fig. 5) also may contribute metals and other trace elements to streams; however, the source and magnitude of metals contamination from waste-disposal activities can be difficult to determine if wastewater-treatment plants and landfills are in the same general area.

Elevated concentrations of metals in water and sediments have also been associated with oil and gas production in Ross Creek (Logan and others, 1983a), Millers Creek (Logan and others, 1989) and South Fork Red River (Logan and others, 1990). Evaldi and Kipp (1991) reported large concentrations and loads of metals and other trace elements in streams affected by oil production (Furnace Fork and Big Sinking Creek), compared with those measured in an unaffected stream in the same region (Cat Creek).

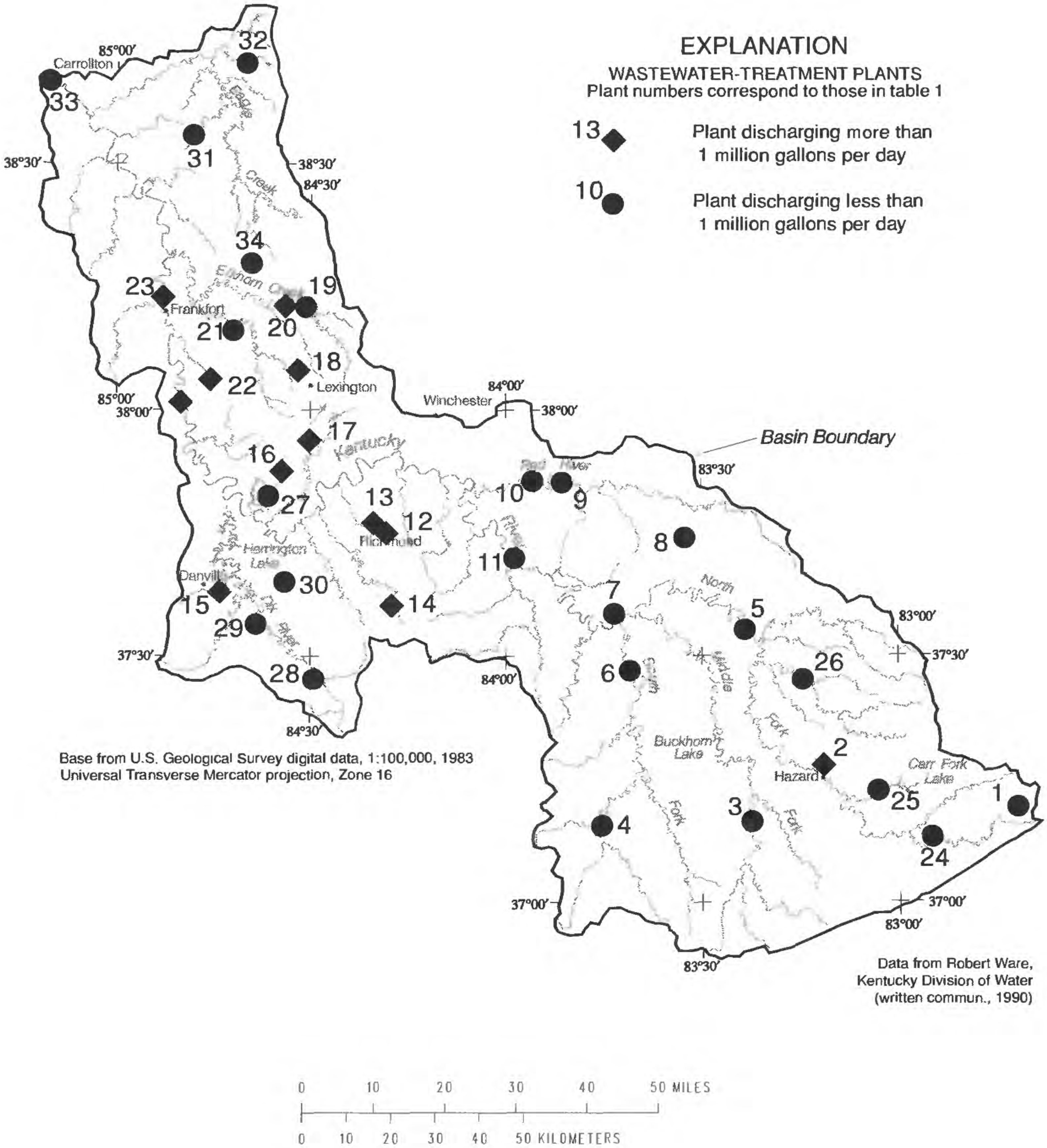
Other sources of metals and trace elements to streams include stormwater runoff and ground-water inflows from open dumps, unprotected raw-material storage sites, automobile-salvage and scrap-metal yards, underground storage tanks, vehicle-maintenance facilities and transportation terminals, and construction sites. Relative contributions of metals and other trace elements from small domestic or commercial discharges are unknown but could be locally important. Inflow of metals and other trace elements to streams from diffuse, local or regional sources may result in site-specific enrichment of constituents in streambed sediments that does not correspond to known sources of contamination.

## APPROACH AND METHODS

### Streambed Sediments

#### Site Selection

The selection of sites for evaluating the spatial distribution of metals and other trace elements in streambed sediments was based on two approaches: (1) random selection of small streams that drain catchments of 6 $mi^2$ or less, and (2) systematic selection of sites on the Kentucky River main stem, major tributaries, and other sites representative of specific land and water uses in the basin. A total of 372 small (first- and second-order) stream sites were randomly selected throughout the basin. An additional 105 large (greater than third-order) stream sites were selected to incorporate (1) sites spaced at 20- to 30-mi intervals on the Kentucky River main stem, (2) water-quality monitoring sites (NAWQA and KDOW fixed stations), (3) stream sites with the potential for constituent accumulation resulting from human activities, and (4) streams sites representative of natural conditions. Locations of streambed-sediment sites, and their classification by county, physiographic region, and predominant land-cover characteristics are listed in table 21.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

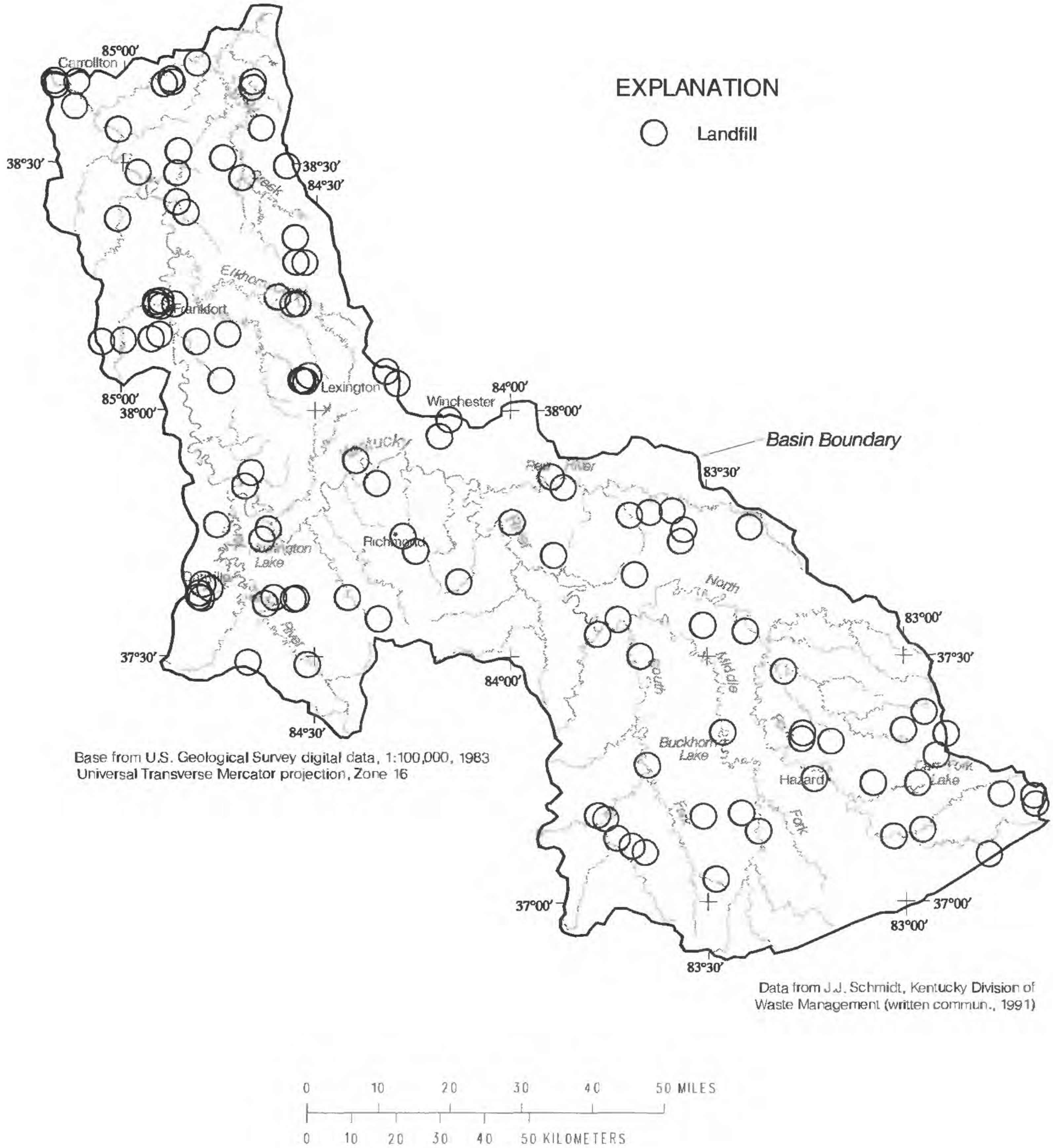
Data from Robert Ware,
Kentucky Division of Water
(written commun., 1990)

**Figure 4.** Locations of selected municipal and industrial wastewater-treatment plants in the Kentucky River Basin.

Table 1. Locations of selected municipal wastewater-treatment-plant discharges in the Kentucky River Basin

[ID, identification number for wastewater-treatment plant as shown on figure 4; *, locations where concentrations of metals and other trace elements were measured in wastewater effluent samples; UT, unidentified tributary stream]

| ID | Wastewater-treatment facility | Receiving stream |
|---|---|---|
| 1 | Fleming-Neon | North Fork Kentucky River |
| 2 | Hazard | North Fork Kentucky River |
| 3 | Hyden | Middle Fork Kentucky River |
| 4 | Manchester | Goose Creek |
| *5 | Jackson | North Fork Kentucky River |
| *6 | Booneville | South Fork Kentucky River |
| *7 | Beattyville | Kentucky River |
| 8 | Campton | Swift Camp Creek |
| 9 | Stanton | Red River |
| 10 | Clay City | Red River |
| 11 | Irvine | Kentucky River |
| 12 | Richmond | Dreaming Creek |
| *13 | Richmond | Tate Creek |
| *14 | Berea | Silver Creek |
| *15 | Danville | Clarks Run |
| 16 | Nicholasville | Town Branch Jessamine Creek |
| *17 | Lexington | West Hickman Creek |
| *18 | Lexington | Town Branch South Elkhorn Creek |
| *19 | Georgetown | Lanes Run North Elkhorn Creek |
| *20 | Georgetown | North Elkhorn Creek |
| 21 | Midway | South Elkhorn Creek |
| *22 | Versailles | Glenns Creek |
| *23 | Frankfort | Kentucky River |
| 24 | Whitesburg | North Fork Kentucky River |
| 25 | Vicco | Carr Fork |
| 26 | Hindman | Troublesome Creek |
| 27 | Wilmore | UT of Jessamine Creek |
| 28 | Brodhead | Dix River |
| 29 | Stanford | Logan Creek |
| 30 | Lancaster | White Oak Creek |
| 31 | Owenton | Stevens Creek |
| 32 | Williamstown | Streammill Branch Eagle Creek |
| 33 | Carrollton | Kentucky River |
| 34 | Stamping Ground | Locust Fork North Elkhorn Creek |



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Data from J.J. Schmidt, Kentucky Division of Waste Management (written commun., 1991)

**Figure 5.** Locations of municipal and industrial landfills in the Kentucky River Basin.

## Description of a Nested Analysis of Variance Study Design

Several subdesigns were included in the streambed-sediment study approach to evaluate sources of variance relative to analytical variability, intersite and intrasite variability, differences between sieving methods, and site-specific relations with streambed-sediment data reported by KDOW. A nested analysis of variance (ANOVA) design for small (low-order) streams was used to determine the relative contribution to overall variance resulting from sampling design and laboratory analytical procedures. A description of ANOVA and its application to environmental analyses is given in Green (1979). Computer programs used for ANOVA in this study are described in Grundy and Miesch (1987).

The ANOVA design incorporated 30 samples at each of 4 levels, 3 of which were built into the sampling design as follows: (1) a square grid pattern was placed over topographic maps of the Kentucky River Basin to define a large number of 10 km by 10 km ANOVA cells that were further divided into 4 quadrants each; (2) 30 ANOVA cells within the basin were chosen by a random-number generator; (3) 1 quadrant from each of the 30 cells was randomly selected, and an appropriate stream site was chosen for sample collection; (4) an additional quadrant from each of the 30 ANOVA cells was randomly selected, and a stream site was chosen to evaluate "within-cell" or intersite variability; and (5) 1 stream per cell was resampled 100 m upstream from the original collection site to evaluate "onsite" or intra-site variability. One sample from each ANOVA cell was analyzed in duplicate (split sample) to determine analytical variance.

## Methods of Sample Collection

Streambed sediment samples were collected from small and large stream sites during fall 1987. Field samples were collected by compositing numerous surficial-sediment samples. The fine-fraction (<63 μm) sediments submitted for chemical analyses, however, were obtained by dry-sieving techniques at small stream sites and by wet-sieving techniques at large stream sites. Representative bedrock samples also were collected to evaluate the relation between geochemistry and streambed-sediment chemistry among distinct physiographic regions in the basin.

Streambed-sediment and bedrock samples were collected at the small stream sites by personnel from the USGS Geologic Division (GD), Branch of Geochemistry. Five to seven representative subsamples of the surficial bottom material (top 1-2 cm) were collected at each site with a scoop, placed on a 2-mm screen, and processed into a pan. All implements were made of stainless steel. The less-than-2-mm fraction was transferred to an aerobic sample bag, air dried, and submitted to the GD laboratory in Denver, Colo. Bedrock samples were collected from the stream channel and submitted to the GD laboratory. The sediment and bedrock samples were further processed at the laboratory where a jaw crusher was used to break up large aggregates of material and a ceramic-plate pulverizer was used to reduce the samples to approximately 150 μm-size particles. The streambed sediments were dry sieved through a 63-μm stainless-steel sieve (Arbogast, 1990) in the GD laboratory.

Streambed-sediment samples were collected at the large stream sites by personnel from the USGS Water Resources Division, Kentucky District. Where possible, equal volumes of surficial streambed sediments were collected at five to seven points along a cross section of each stream site with a plastic scoop or spoon (wadeable streams) or with a dredge or core sampler (unwadeable streams). It was not always possible to obtain representative samples of the stream cross section; fine material was absent from the middle of the channel at some sites, whereas the bottom of the channel was predominantly bedrock at other sites. In such cases, sediment was collected from depositional areas such as pools, sheltered places behind rocks, macrophyte beds, and other areas of reduced stream velocity. Sediment samples were wet sieved in the field with native water through a 2-mm stainless-steel sieve to remove large particles and then flushed through a 63-$\mu$m stainless-steel sieve. The fine-fraction sediments were placed in plastic containers, dried, and submitted to the GD laboratory for further processing and analysis (Arbogast, 1990; p. 26-28).

## Methods of Analytical Determination

Streambed-sediment samples were analyzed for 46 metals and other trace elements, and bedrock samples were analyzed for 28 metals and trace elements, in accordance with methods described by Arbogast (1990). All samples were analyzed by the GD, Branch of Geochemistry analytical laboratory in Denver, Colo. Constituents in bedrock samples were determined by direct current-arc emission spectrographic methods, which resulted in different detection limits (generally larger) than those reported for streambed sediments. Most of the constituents in sediments were determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES). Concentrations of antimony, arsenic, and selenium were determined by hydride generation-atomic absorption spectrophotometry (HG-AAS), and mercury concentrations were determined by cold vapor-atomic absorption spectrophotometry (CV-AAS). Methods of sample extraction were designed to assay total concentrations of most metals and other trace elements. Streambed-sediment samples were digested by means of a combination of hydrochloric, nitric, perchloric, and hydrofluoric acids for the ICP-AES analyses; a combination of hydrofluoric, nitric, and perchloric acids for the HG-AAS analyses; and a combination of nitric acid and sodium dichromate solution for CV-AAS analyses (Arbogast, 1990). Boron, extracted from samples by use of hot water, was analyzed by ICP-AES. Concentrations of total carbon and total sulfur were determined by combustion and titration in an automated carbon analyzer and sulfur analyzer. Analysis of carbonate carbon was by coulometric titration after samples were treated with perchloric acid. Organic carbon concentration was assumed to be equal to the difference between total and carbonate carbon concentrations. Uranium was determined by ultraviolet fluorescence after samples were treated with nitric acid (Arbogast, 1990). Data from the streambed-sediment survey are presented in a separate report by Ryder and others (1993).

## Quality Assurance

Quality assurance and quality control (QA/QC) procedures for the NAWQA pilot program are presented in Mattraw and others (1989). In addition, documented QA/QC procedures were followed by the GD Branch of Geochemistry analytical laboratory (Arbogast, 1990). Supplemental QA/QC protocols for streambed-sediment analyses for the NAWQA program included sample splits and analysis of standard reference materials randomly placed within each batch of 40 samples analyzed (Sanzolone and Ryder, 1989). Additional analysis of split samples was provided by the ANOVA design as described previously. Further details concerning the analytical quality assurance program and results for the NAWQA surface-water pilot studies are given in Sanzolone and Ryder (1989).

## Methods of Data Analysis

The spatial distribution of metals and other trace elements in streambed sediments of the Kentucky River Basin was assessed by ANOVA (or Kruskal-Wallis tests) among groups of sites that were classified by physiographic region, land use, and tributary subbasins; analysis of downstream spatial trends in the Kentucky River main stem; identification of stream sites characterized by elevated concentrations of specific constituents; and multivariate classification of tributary subbasins of the Kentucky River. Sediment-chemistry data were log transformed, and land-use percentage data were arc sine transformed when necessary to meet assumptions of normality for statistical procedures (Zar, 1984). Censored data (those below analytical limits of detection) were set to the indicated detection limit, set to a value of 0.7 times the detection limit, or fit to a log-normal distribution depending on the type of analysis to be done (Helsel, 1991). In each case, a method was adopted that maximized information without sacrificing statistical integrity.

Statistical analyses were done by use of SYSTAT (Wilkinson, 1989) or PC-SAS (SAS Institute, Inc., 1985). The use of the term "significant" in this report indicates that the probability of Type I statistical error is less than 5 percent ($p < 0.05$). Statistical correlations are discussed only if the absolute value of the correlation coefficient is greater than 0.85 ($|r| > 0.85$).

Baseline concentrations of constituents in streambed sediments were determined for small streams within forested catchments in each of the four physiographic regions of the Kentucky River Basin. The relation between bedrock geochemistry and baseline streambed-sediment concentrations of metals and trace elements within a physiographic region was evaluated by ANOVA comparison of constituent concentrations among different rock types (limestone, sandstone, shale, and coal). Downstream spatial trends for streambed sediments were assessed by use of regression analysis with distance from mouth (stream mile) as the independent variable. The concentration of a constituent in a streambed-sediment sample is defined as "elevated" if the concentration is greater than the value indicated at the 95th percentile of the combined small- and large-stream data set (number of observations equals 441 [n = 441]) for that constituent.

Data for the ANOVA subdesign were processed by use of the ANOV-1.EXE program of the STATPAC statistical package (Grundy and Miesch, 1987). Constituent concentrations that were below the detection limit (censored) at 50 percent or more of the ANOVA sites (silver, gold, bismuth, cadmium, europium, holmium, molybdenum, tin, and tantalum) were excluded from the analysis. Censored values for the other constituents were set to 0.7 times the detection limit. The percentages of variance explained among levels of the ANOVA design (variance components) were deemed significant if the estimated Q-value (Grundy and Miesch, 1987) was less than 0.05 ($Q < 0.05$). Level 1 (between-cell variance) and level 2 (within-cell variance) indicate intersite differences, or variability among different streams in a region or area. Level 3 (intrasite variance) indicates variability within the same stream site, and level 4 (analytical variance) indicates differences attributable to laboratory procedures.

Potential differences in the median concentrations of metals and other trace elements in streambed sediments resulting from differences in sample-collection methods were evaluated by comparison of paired streambed-sediment samples collected at 23 large stream sites; in each pair, one sample was wet sieved and the other was dry sieved. Concentrations of selected constituents in fine-fraction streambed sediments (from this investigation) and bulk-sediment data collected by KDOW (Dave Leist, Kentucky Division of Water, written commun., 1991) during the same time period at 10 stream sites in the Kentucky River Basin were compared to evaluate differences due to sample-processing and laboratory analytical methodologies. Data were compared by use of Mann-Whitney U-tests (Zar, 1984).

### Use of boxplots

Boxplots (Tukey, 1977) were constructed to provide graphical displays of the median, interquartile range, quartile skew, and extreme data values for metals and other trace elements in streambed sediments in relation to physiographic region. Boxplots were also constructed to display and compare concentrations of constituents in bedrock samples with respect to lithology. Boxplots were not constructed for data sets consisting of less than 10 observations.

Boxplots consist of a box drawn from the 25th percentile to the 75th percentile, which indicates the interquartile range. A horizontal line is drawn across the box at the median, and the two parts of the box represent the quartile skew. Vertical lines (whiskers) are drawn from the quartiles to the largest data value less than or equal to the upper quartile plus 1.5 times the interquartile range (upper adjacent value) and the smallest data value greater than or equal to the lower quartile minus 1.5 times the interquartile range (lower adjacent value). Values more extreme in either direction of these values are plotted individually; those from 1.5 to 3.0 times the interquartile range are plotted with an asterisk (outside values) and those greater than 3.0 times the interquartile range are plotted with a circle (far-outside values). Censored data (those less than the analytical detection limit) were fit to a log-normal distribution (Smoot and others, 1991); any part of the boxplot below the detection limit is indicated by dashed lines.

## Methods for Classifying Streambed-Sediment Sites and Subbasins

Streambed-sediment sites were classified relative to physiographic region and predominant land and water uses in the catchment area upstream from the site. Information on physiographic region and general land cover was obtained from USGS digital data at 1:250,000 scale. Percentages of each land-cover classification upstream from each large stream site were determined by use of geographic information system (GIS) technology (fig. 3b). The predominant land use upstream from each small stream site was estimated from USGS topographic maps (1:24,000) as one of the following classifications: (1) forest, (2) agriculture, (3) oil production, (4) coal production, and (5) urban. Locations of point-source discharges from selected municipal and industrial wastewater-treatment plants (WWTP) are shown in figure 4. The locations of municipal and industrial landfills are shown in figure 5. Classification of tributary subbasins in the Kentucky River Basin was limited to those catchments with five or more streambed sediment sites.

Subbasins of the Kentucky River Basin were classified by multivariate cluster analysis (Gauch, 1982; Pielou, 1984). Cluster analysis is a statistical procedure that illustrates hierarchal similarities (or dissimilarities) among subbasin units according to interrelations of the concentrations of metals and other trace elements in streambed sediments. Hierarchal clusters are those that completely contain other clusters of subbasins (those that may be further subdivided into clusters within clusters). Results of cluster analysis can be represented as a "tree" or dendrogram. The linkage of each subbasin or group of subbasins is indicated as a joining of branches of the tree (or clusters) in the dendrogram. Those subbasins that are joined at the lowest order of clustering (toward the left side of the cluster dendrogram) are most similar with respect to relative concentrations of constituents in streambed sediments from a subbasin. This can be considered the "trace-element signature" representing the collective concentrations of metals and other trace elements in streambed sediments. Subbasins that have similar trace-element signatures appear in the same cluster. In contrast, clusters that are joined at the highest order of clustering (toward the right side of the cluster dendrogram) are least similar.

Factor analyses and Kruskall-Wallis tests were used to distinguish groups of constituents in streambed sediments in which concentrations of metals and other trace elements significantly differed among (1) the 31 subbasins within the Kentucky River Basin, and (2) the specific subbasins within the upper, middle, or lower parts of the basin. Concentrations of selected metals and other trace elements identified in the described groups of constituents were normalized with respect to concentrations of iron (Tessier and others, 1982; Elder, 1988), and median concentrations of these normalized constituents for each subbasin were used to generate a correlation matrix. The correlation matrix was used as a measure of dissimilarity among subbasins for classification with cluster analysis because correlations measure the similarity in patterns across environmental gradients, regardless of differences in the magnitude of constituent concentrations.

## Water and Suspended Sediment

### Site Selection

Surface-water samples were collected monthly, as well as during periods of above-average streamflow, from April 1987 through March 1990, at seven fixed stations in the Kentucky River Basin. The purpose of the fixed-station network was to determine ambient water-quality conditions, constituent loads and yields, and seasonal and long-term trends of metals and other trace elements. The criteria for the selection of each fixed-station location and the list of all constituents determined is presented in Griffin and others (1994). To supplement information concerning the spatial distribution of metals and other trace elements, USGS personnel collected additional water samples during synoptic investigations done in August 1987 and August 1988. Water samples were collected at 74 sites to describe water-quality conditions during low streamflow in the Kentucky River Basin.

### Methods of Sample Collection

Water samples were collected by cross-sectional integrated sampling methods described by Guy and Norman (1970), Edwards and Glysson (1988), and Ward and Harr (1990) to provide an isokinetic, discharge-weighted composite sample. Water samples were composited in a 14-L polypropylene churn splitter and agitated to maintain a homogeneous sample mixture. Water-chemistry samples were taken from the churn splitter, preserved with concentrated nitric acid to lower the pH of the sample to less than 2.0 standard units, and sent to a USGS lab for analysis of total-recoverable concentrations of 15 metals. Additional water samples from the churn splitter were passed through a 143-mm diameter, 0.45-$\mu$m polycarbonate filter by use of a peristaltic pump, and the filtrate was similarly preserved for laboratory analyses for 23 dissolved metals. All samples were analyzed by the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo.

Suspended-sediment samples also were collected for the determination of concentrations of metals and other trace elements in the suspended-sediment matrix (as micrograms of constituent per gram of sediment). Approximately 20 L of water was collected as described previously. Suspended sediment in the water sample was dewatered by a combination of gravity settling and centrifugation (Horowitz, 1986; Ward and Harr, 1990). Duplicate water samples were collected from the churn splitter for the determination of total suspended-sediment (mass) concentrations (in units of milligrams per liter) so that the concentration of metals in the suspended-sediment fraction of water could be calculated (as micrograms per liter). Total suspended-sediment concentrations were determined by the USGS Kentucky District Sediment Laboratory in accordance with procedures outlined by Guy (1969).

### Methods of Analytical Determination

Total-recoverable and dissolved concentrations of metals and other trace elements were determined from water samples as described by Fishman and Friedman (1989). Water samples were digested by heating with 6 M hydrochloric acid, resulting in total-recoverable determinations for metals and other trace elements. The total suspended-sediment concentration (in units of milligrams per liter) in water samples was determined by use of the evaporation method (Fishman and Friedman, 1989), and the percentage of sand and fines in water samples was determined by wet sieving the total suspended-sediment samples with a 63-$\mu$m sieve. Results of water-quality determinations are stored in computerized data-management systems maintained by the USGS (WATSTORE) and the U.S. Environmental Protection Agency (STORET). The water-chemistry data have been published in the USGS Water Resources Data Reports (Toms and others, 1988; Garcia and others, 1989, 1990; McClain and others, 1991).

The dewatered suspended-sediment samples were submitted to the USGS Sediment Partitioning Research Laboratory in Doraville, Ga. The samples were processed for the determination of total surface area according to methods described by Horowitz (1991). The suspended-sediment samples were then forwarded to the USGS GD, Branch of Geochemistry analytical laboratory in Menlo Park, Calif., where the samples were digested with hydrochloric, nitric, hydrofluoric, and perchloric acids and subsequently allowed to dry. The dried samples were then forwarded to the Branch of Geochemistry's analytical laboratory in Denver, Colo., where concentrations of metals and other trace elements were determined according to methods described by Arbogast (1990). Therefore, the same laboratory (and analytical methods) was used for determinations of constituent concentrations in suspended-sediment and streambed-sediment samples.

Concentrations of aluminum, calcium, iron, potassium, magnesium, sodium, phosphorus, titanium, beryllium, cobalt, chromium, copper, manganese, nickel, vanadium, and zinc were determined by inductively coupled plasma-optical emission spectrometry (ICP-OES). Concentrations of silver, arsenic, cadmium, molybdenum, lead, antimony, and thallium were determined by inductively coupled plasma-mass spectrometry (ICP-MS) (Ryder and others, 1993).

## Quality Assurance

General QA/QC procedures for the NAWQA program are presented by Mattraw and others (1989). Specific QA/QC practices of the analytical laboratory are discussed by Friedman and Erdmann (1982), and information regarding laboratory precision and accuracy for specific water-quality constituents are presented by Fishman and Friedman (1989). Quality assurance and control procedures for the determination of metals and other trace elements in suspended sediment are discussed by Arbogast (1990), and QA/QC procedures for determination of total suspended sediments are presented by Guy (1969).

## Methods of Data Analysis

Various methods of analysis were used to describe spatial and temporal patterns in the distribution of metals and other trace elements in the Kentucky River Basin. Descriptive statistics for constituent concentrations, loads, and yields are presented in tabular format. Statistical relations among groups of constituents and fixed stations were determined by correlation, linear regression, and analysis of variance. Estimates of mean annual constituent loads at fixed stations were determined by multiple-regression analysis. Constituent yields were determined by dividing the load estimate by the area of the drainage basin upstream from the fixed station. Temporal trends for constituent concentrations at fixed stations were determined by seasonal Kendall trend analysis.

### Descriptive statistics

Descriptive statistical information for water-chemistry data collected at the seven NAWQA fixed stations from April 1987 through March 1990 are presented in summary tables (tables 17-20). Similar descriptive statistical summary tables are presented for data collected by the KDOW at 11 fixed stations in the basin (tables 17 and 18). Four fixed stations are common to the NAWQA and State-agency data sets. Statisical summaries of concentrations, loads, and trends for the two data sets are presented separately because methods of sample collection and analysis substantially differed between the USGS and the State. The differences of sample-collection techniques are described in Martin and others (1992). Descriptive statistics are used to report the range of constituent concentrations at fixed stations in the Kentucky River Basin and to compare or contrast median concentrations of metals and other trace elements among fixed stations.

Because of limitations of laboratory analytical procedures, concentrations of constituents determined below the detection limit may not be accurate. In such cases, the concentration is said to be less than the analytical detection limit, or "censored." The treatment of censored data in this report differs, depending on the type of statistical analysis. For the purpose of descriptive statistical summary tables, censored data were fit to a log-normal distribution before the computation of quantiles (Helsel, 1991). The log-normal fitting procedure was used to estimate a "most probable" distribution of data. The resultant values indicated in the statistical summary tables were computed from these distributions, and the number of censored values and the analytical detection limits are indicated in the summary tables.

### Calculation of constituent loads and yields

Although the instantaneous load of a constituent is simply the concentration of the constituent multiplied by the discharge of the stream at the time the sample was collected, the load of a constituent as a function of time is more difficult to estimate. Average annual constituent loads calculation by multiplying average constituent concentrations and average annual discharge are likely to be low because systematic (monthly) monitoring of water quality may not include periods of runoff during which a large percentage of the total load of metals and other trace elements is transported.

Mean annual loads calculated from historical (monthly) water-quality data during the Kentucky River Basin NAWQA retrospective analysis indicated large error estimates (standard error of the regression) for metals and other trace elements (Smoot and others, 1991). An objective of the NAWQA pilot project was to improve transport estimates by sampling periods of runoff. Improvements in transport estimates would be indicated by a smaller standard error in regression relations than in the retrospective results.

Mean annual loads were calculated for the period April 1987 through March 1990 according to the procedure described by Smoot and others (1991), except that monthly water-quality data were supplemented by data from samples collected during periods of runoff at the fixed stations. Censored values were set equal to one-half of the detection limit. A multiple-regression model was developed to predict the mean annual load for each constituent based on discharge and two seasonality factors as independent variables in the relation (Cohn and others, 1989; Smoot and others, 1991). Daily constituent loads for the period of record were summed and averaged, and mean annual load was calculated for each constituent. Constituent yields were calculated by dividing the mean annual load by the total drainage area upstream from the fixed station.

Several statistics used as indicators of uncertainty are listed in the tables for constituent loads and yields. The standard error of the regression (in percent) is a measure of the goodness of fit of the regression relation. The flow duration (in percent) of the highest sampled discharge provides an estimate of the adequacy of the sampling regime at high flow, when the largest loads of most metals and other trace elements are expected. The proportion of load estimated beyond the range of sampled discharge is a measure of the load that results from extrapolation beyond the range of data used to derive the regression relation.

### Trend analysis

The seasonal Kendall test, a nonparametric test for trend detection applicable to data sets characterized by seasonal variability (Hirsch and others, 1982; Crawford and others, 1983), was applied to metals and other trace-element data for the seven fixed stations, as well as five BWMP sites maintained by KDOW. With this test, the effect of seasonal variation is reduced by comparing observations from the same season of each year. Continuous (monthly) data are generally available from 1980 through 1990 (depending on the constituent and fixed stations) and represent from 70 to 134 determinations of each constituent at each site. Continuous data are available for 1975-90 for the Kentucky River at Lock 2.

The seasonal Kendall trend test is monotonic and is designed to provide a single summary statistic for the entire period of record. A significance probability (p-value) of the trend is computed that indicates the probability of erroneously rejecting the null hypothesis that no trend in the data exists (that the constituent values are random, independent, and identically distributed). The seasonal Kendall slope estimator is an estimate of the magnitude of the slope of the trend line. Slopes were determined with values that are multiples of 12 months apart. The median of these slopes is defined as the change per year resulting from the trend. Trend-line slopes that were not significant at a p-value of less than or equal to 0.20 were not reported, nor were the results of trend analyses based on less than 10 seasonal comparisons. For data sets containing censored data, the seasonal Kendall test was applied after "less-than" values were set to zero, and then again with "less than" values set to the detection limit. Results of the two trend tests were compared. If results were similar, it was assumed that the censored data did not affect the trend results, and the smaller slope estimator and the larger p-value were reported. If results were not similar, it was assumed that the censored data affected the trend results, and the trend was only reported as upward or downward.

### Flow-adjusted trend analysis

Many water-quality characteristics, such as the concentration of suspended sediments, are correlated with stream discharge. Because metals and many other trace elements are typically adsorbed to and transported by suspended sediment, changes in the concentration of metals and other trace elements with time may correspond more to trends of stream discharge (and suspended-sediment loads) than to changes in processes or the sources of metals. Water-quality trends were normalized with respect to discharge by use of regression analyses to determine a best-fit relation between constituent concentrations and discharge and by application of the seasonal Kendall trend test procedure to the residuals (the difference between observed and predicted values). Data sets containing censored values were not used because of the uncertainty of deriving residuals from "less-than" values. Flow-adjusted trends were not generally indicated when the nonadjusted trends were not significant. Further discussion of specific assumptions and procedures used to estimate water-quality trends in this report can be found in Smoot and others (1991).

# DISTRIBUTION OF METALS AND OTHER TRACE ELEMENTS IN STREAMBED SEDIMENTS AND BEDROCK SAMPLES IN THE KENTUCKY RIVER BASIN

## Spatial Distribution of Metals and Other Trace Elements in Streambed Sediments

Concentrations of metals and other trace elements in streambed sediments differ significantly among physiographic regions in the Kentucky River Basin. The predominant source of variance is attributable to the differences in the geochemistry of bedrock that characterize each physiographic region. Soils derived from limestones of Ordovician age, sandstones of Pennsylvanian age, and shales of Devonian age contain different concentrations of constituents, and the presence or relative abundance of metals and trace elements (the trace-element signature) in soil and streambed sediments naturally corresponds to the trace-element signature of local bedrock. However, the trace-element signature of sediment that has been transported to the stream from disturbed lands such as coal mines, construction areas, and farms can be substantially different from the trace-element signature found in streams that drain undisturbed forested catchments. Urban stormwater runoff from the greater Lexington metropolitan area may be associated with large concentrations of lead, zinc, and other metals in the sediments of the Elkhorn Creek Subbasin and other streams in the Inner Bluegrass Region. Brine discharges associated with oil and gas production in the Knobs Region can result in the accumulation of lithium, strontium, and other elements in the sediments of affected streams.

Concentrations of cadmium, chromium, copper, lead, mercury, and silver in streambed sediments tend to be large downstream from point-source discharges and landfills. However, the effects of these human sources of metals generally do not extend to the Kentucky River or major tributaries downstream from the source. The natural occurrence of many metals and trace elements in Devonian shale can result in sediment concentrations in streams of the Knobs Region that exceed those detected downstream from point-source discharges. Thus, the effects of human activities on concentrations of constituents in streambed sediments must be interpreted with respect to natural or baseline concentrations derived for each physiographic region of the Kentucky River Basin.

### Occurrence of Metals and Other Trace Elements in Streambed Sediments

Detectable concentrations of 29 metals and trace elements (table 2) were found in all streambed-sediment samples collected from 441 stream sites in the Kentucky River Basin (pl. 1). Concentrations of beryllium, boron, mercury, and sulfur were detected in greater than 90 percent of the samples. Concentrations of bismuth, europium, gold, holmium, and tin were not detected in any of the streambed-sediment samples collected in the Kentucky River Basin. Cadmium and silver were detected in only 2.3 percent and 1 percent of the streambed-sediment samples, generally from streams affected by industrial or municipal point-source discharges. Had the USGS analytical detection limits for cadmium been lower than they were, an analysis of nonpoint sources of cadmium, such as urban stormwater runoff and atmospheric deposition (Forstner and Wittmann, 1981), might have been possible. The detection limit for cadmium in this investigation (2 $\mu$g/g) was as much as an order of magnitude greater than the detection limit reported by KDOW. The State agency reported considerable variability in the concentration of cadmium in streambed sediments, ranging from 0.1 to 1.0 $\mu$g/g (Logan and others, 1983a, 1983b, 1984, 1987, 1988, and 1990).

### Occurrence of Metals and Other Trace Elements in Bedrock Samples

The percentage of bedrock samples that contained detectible concentrations of 45 metals and trace elements ranged from 0 percent for 3 constituents to greater than 90 percent for 8 constituents (table 3). In general, the lower frequency of detection of constituents in bedrock samples, when compared with streambed sediment-samples, corresponded to differences in analytical methods. For example, detectible concentrations of antimony were found in 9 percent of the bedrock samples when the analytical detection limit was 200 $\mu$g/g, whereas antimony was detected in 100 percent of streambed-sediment samples when the analytical detection limit was 0.1 $\mu$g/g.

Mean concentrations of aluminum, barium, cerium, chromium, iron, manganese, potassium, and titanium in bedrock samples (table 3) were smaller than those calculated for streambed-sediment samples. Although human sources

Table 2. Summary of metals and other trace elements in streambed sediments of the Kentucky River Basin, 1987-88

[Concentrations in micrograms per gram; number of samples = 441; ICP-AES, inductively coupled plasma-atomic emission spectrometry; HG-AAS, hydride generation-atomic absorption spectrophotometry; CV-AAS, cold vapor-atomic absorption spectrophotometry; <, less than; *, calculated by difference of total carbon and inorganic carbon]

| Element | Analytical method | Detection limit | Percent detection | Minimum | Maximum | Geometric mean |
|---|---|---|---|---|---|---|
| Aluminum | ICP-AES | 500 | 100 | 27,000 | 110,000 | 62,700 |
| Antimony | HG-AAS | .1 | 100 | .2 | 6.1 | .5 |
| Arsenic | HG-AAS | .1 | 36.4 | 2.5 | 110 | 7.5 |
| Barium | ICP-AES | 1 | 100 | 81 | 830 | 470 |
| Beryllium | ICP-AES | 1 | 99.2 | <1 | 4 | 2 |
| Bismuth | ICP-AES | 10 | 0 | <10 | <10 | <10 |
| Boron | ICP-AES | .4 | 91.4 | .2 | 20 | 1.0 |
| Cadmium | ICP-AES | 2 | 2.3 | <2 | 31 | <2 |
| Calcium | ICP-AES | 500 | 100 | 700 | 170,000 | 11,000 |
| Cerium | ICP-AES | 4 | 100 | 48 | 130 | 88 |
| Chromium | ICP-AES | 1 | 100 | 8 | 410 | 64 |
| Cobalt | ICP-AES | 1 | 100 | 6 | 84 | 20 |
| Copper | ICP-AES | 1 | 100 | 8 | 410 | 22 |
| Europium | ICP-AES | 2 | 0 | <2 | <2 | <2 |
| Gallium | ICP-AES | 4 | 100 | 4 | 32 | 17 |
| Gold | ICP-AES | 8 | 0 | <8 | <8 | <8 |
| Holmium | ICP-AES | 4 | 0 | <4 | <4 | <4 |
| Iron | ICP-AES | 500 | 100 | 12,000 | 96,000 | 35,000 |
| Lanthanum | ICP-AES | 2 | 100 | 26 | 63 | 45 |
| Lead | ICP-AES | 4 | 100 | 13 | 930 | 30 |
| Lithium | ICP-AES | 2 | 100 | 16 | 110 | 44 |
| Magnesium | ICP-AES | 50 | 100 | 2,300 | 49,000 | 6,400 |
| Manganese | ICP-AES | 4 | 100 | 160 | 29,000 | 1,400 |
| Mercury | CV-AAS | .02 | 90.7 | <.02 | 1.82 | <.04 |
| Molybdenum | ICP-AES | 2 | 8.4 | <2 | 120 | <2 |
| Neodymium | ICP-AES | 4 | 100 | 25 | 61 | 41 |
| Nickel | ICP-AES | 2 | 100 | 9 | 460 | 32 |
| Niobium | ICP-AES | 4 | 77.4 | 4 | 19 | 7 |
| Phosphorus | ICP-AES | 50 | 100 | 200 | 12,000 | 1,100 |
| Potassium | ICP-AES | 500 | 100 | 9,000 | 39,000 | 20,700 |
| Scandium | ICP-AES | 2 | 100 | 4 | 18 | 10 |
| Selenium | HG-AAS | .1 | <.1 | <.1 | 4.5 | .6 |
| Silver | ICP-AES | 2 | 1.0 | <2 | 28 | <2 |
| Sodium | ICP-AES | 50 | 100 | 1,100 | 10,000 | 3,400 |
| Strontium | ICP-AES | 2 | 100 | 47 | 330 | 100 |
| Sulfur | Titration | 100 | 99.2 | <100 | 11,300 | 510 |
| Thorium | ICP-AES | 4 | 100 | <5 | 23 | 12 |
| Tin | ICP-AES | 10 | 0 | <10 | <10 | <10 |
| Titanium | ICP-AES | 50 | 100 | 800 | 5,800 | 3,200 |
| Uranium | Fluorometry | .05 | 100 | .3 | 31 | 1.1 |
| Vanadium | ICP-AES | 2 | 100 | 29 | 330 | 81 |
| Ytterbium | ICP-AES | 1 | 100 | 1 | 4 | 3 |
| Yttrium | ICP-AES | 2 | 100 | 13 | 47 | 24 |
| Zinc | ICP-AES | 4 | 100 | 33 | 650 | 99 |
| Inorganic carbon | Titration | 100 | 99.8 | <100 | 56,500 | 1,750 |
| Organic carbon | * | 100 | 99.8 | <100 | 120,000 | 19,000 |
| Total carbon | Infrared | 100 | 100 | 3,400 | 120,000 | 24,000 |

Table 3. Summary of metals and other trace elements in bedrock samples from the Kentucky River Basin, 1987-88

[Concentrations in micrograms per gram; number of samples = 208; ICP-OES, inductively coupled plasma-optical emission spectrometry; ICP-MS, inductively coupled plasma-mass spectrometry; ICP-AES, inductively coupled-atomic emission spectrometry; DC-AES, direct current-atomic emission spectrometry; <, less than]

| Element | Analytical method | Detection limit | Percent detection | Minimum | Maximum | Geometric mean |
|---|---|---|---|---|---|---|
| Aluminum | ICP-OES | 500 | 100 | 500 | 130,000 | 12,500 |
| Antimony | ICP-MS | 200 | 9 | <200 | <200 | <200 |
| Arsenic | ICP-MS | 200 | 9 | <200 | <200 | <200 |
| Barium | ICP-AES | 20 | 86 | <20 | 1,500 | 130 |
| Beryllium | ICP-OES | 1 | 55 | <1 | 20 | 2 |
| Bismuth | ICP-AES | 10 | 0 | <10 | <10 | <10 |
| Boron | ICP-OES | 10 | 63 | <10 | 300 | 38 |
| Cadmium | ICP-MS | 20 | 0 | <20 | <20 | <20 |
| Calcium | ICP-OES | 500 | 90 | <500 | 200,000 | 15,000 |
| Cerium | ICP-AES | 4 | 90 | <4 | 150 | 26 |
| Chromium | ICP-OES | 10 | 57 | <10 | 200 | 24 |
| Cobalt | ICP-OES | 6 | 45 | <6 | 150 | 14 |
| Copper | ICP-OES | 5 | 85 | <5 | 500 | 17 |
| Europium | ICP-AES | 4 | 7 | <4 | <4 | <4 |
| Gallium | ICP-AES | 5 | 51 | <5 | 70 | 10 |
| Germanium | DC-AES | 10 | 16 | <10 | 100 | 12 |
| Gold | ICP-AES | 8 | 0 | <8 | <8 | <8 |
| Holmium | ICP-AES | 4 | 9 | <4 | 93 | 5 |
| Iron | ICP-OES | 500 | 100 | 500 | 200,000 | 16,000 |
| Lanthanum | ICP-OES | 35 | 43 | <35 | 150 | 56 |
| Lead | ICP-MS | 10 | 74 | <10 | 150 | 18 |
| Lithium | ICP-AES | 2 | 82 | <2 | 250 | 13 |
| Magnesium | ICP-OES | 200 | 97 | <200 | 100,000 | 11,000 |
| Manganese | ICP-OES | 4 | 100 | 10 | 5,000 | 420 |
| Molybdenum | ICP-MS | 2 | 20 | <2 | 300 | 7 |
| Neodymium | ICP-AES | 2 | 85 | <2 | 69 | 13 |
| Nickel | ICP-OES | 5 | 62 | <5 | 500 | 15 |
| Niobium | ICP-OES | 20 | 14 | <20 | 20 | <20 |
| Phosphorus | ICP-OES | 2,000 | 26 | <2,000 | 40,000 | 3,000 |
| Potassium | ICP-OES | 300 | 97 | <300 | 39,000 | 5,000 |
| Scandium | ICP-OES | 10 | 63 | <10 | 30 | <10 |
| Silver | ICP-MS | 2 | 7 | <2 | <2 | <2 |
| Sodium | ICP-OES | 2,000 | 84 | <2,000 | 24,000 | 5,000 |
| Strontium | ICP-OES | 100 | 75 | <100 | 3,000 | 300 |
| Tantalum | ICP-OES | 40 | 9 | <40 | <40 | <40 |
| Thorium | ICP-MS | 100 | 9 | <100 | <100 | <100 |
| Tin | ICP-AES | 10 | 12 | <10 | 87 | 12 |
| Titanium | ICP-OES | 20 | 100 | 20 | 10,000 | 1,100 |
| Tungsten | DC-AES | 20 | 9 | <20 | 39 | <20 |
| Uranium | Fluorometry | 100 | 9 | <100 | <100 | <100 |
| Vanadium | ICP-OES | 10 | 87 | <10 | 700 | 50 |
| Ytterbium | ICP-AES | 1 | 60 | <1 | 17 | 2 |
| Yttrium | ICP-OES | 10 | 97 | <10 | 520 | 36 |
| Zinc | ICP-OES | 200 | 1 | <200 | 700 | <200 |
| Zirconium | DC-AES | 4 | 100 | 4 | 1,000 | 70 |

may have contributed to the occurrence of higher concentrations of these elements in sediment samples from certain streams, dense elements (those with large specific gravity) tend to accumulate in the bedload of a stream, whereas lighter elements can be washed out with the suspended load. Mean concentrations of boron, calcium, magnesium, phosphorus, sodium, and strontium were larger in bedrock samples than in streambed-sediment samples. Smaller concentrations of those elements in streambed sediments may have resulted because these elements can form soluble salts with major anions in the water, they have a lower adsorption affinity to sediments, and they are used in some biological processes.

## Relation of Bedrock Geochemistry to Streambed-Sediment Concentrations of Metals and Other Trace Elements

Bedrock samples that represent differences with respect to geologic age and composition are expected to have specific chemical characteristics that differ among rock types and physiographic regions (Goldschmidt, 1958). Kruskal-Wallis and Tukey multiple range tests (Tukey, 1977; Zar, 1984; Wilkinson, 1989) were used to determine whether median concentrations of constituents were significantly different among samples of different bedrock types in the Kentucky River Basin. Statistically significant differences were indicated for concentrations of aluminum, barium, cerium, chromium, cobalt, copper, iron, lead, nickel, potassium, titanium, and vanadium. For example, concentrations of aluminum, iron, and titanium were significantly larger in sandstone samples than in limestone, shale, and coal samples. Concentrations of calcium, phosphorus, strontium, and yttrium were larger in Ordovician limestone samples from the Inner Bluegrass Region than in other rock samples from the Kentucky River Basin.

Shale samples from the Kentucky River Basin contain larger median concentrations of a variety of trace elements, including chromium, copper, lead, nickel, and vanadium (figs. 6 and 7), than do samples of other rock types. Bedrock samples of shale from the Kentucky River Basin were identified as either "New Albany Shale" of Devonian age, or "black shale" of Ordovician or Pennsylvanian age. Although concentrations of many constituents in Devonian shale samples were similar or larger than concentrations in Ordovician or Pennsylvanian shale samples, median concentrations of potassium were significantly smaller in samples of Devonian shale.

Concentrations of metals and other trace elements were also elevated in bedrock samples identified as mudstone, siltstone, or fire clay. Concentrations of beryllium, cerium, gallium, lanthanum, and neodymium were larger in fire clay and mudstone samples than in limestone, sandstone, or shale samples (table 4). However, concentrations of chromium, cobalt, copper, iron, lead, lithium, nickel, and vanadium in mudstone and fire clay samples were similar to those indicated for shale samples from the basin.

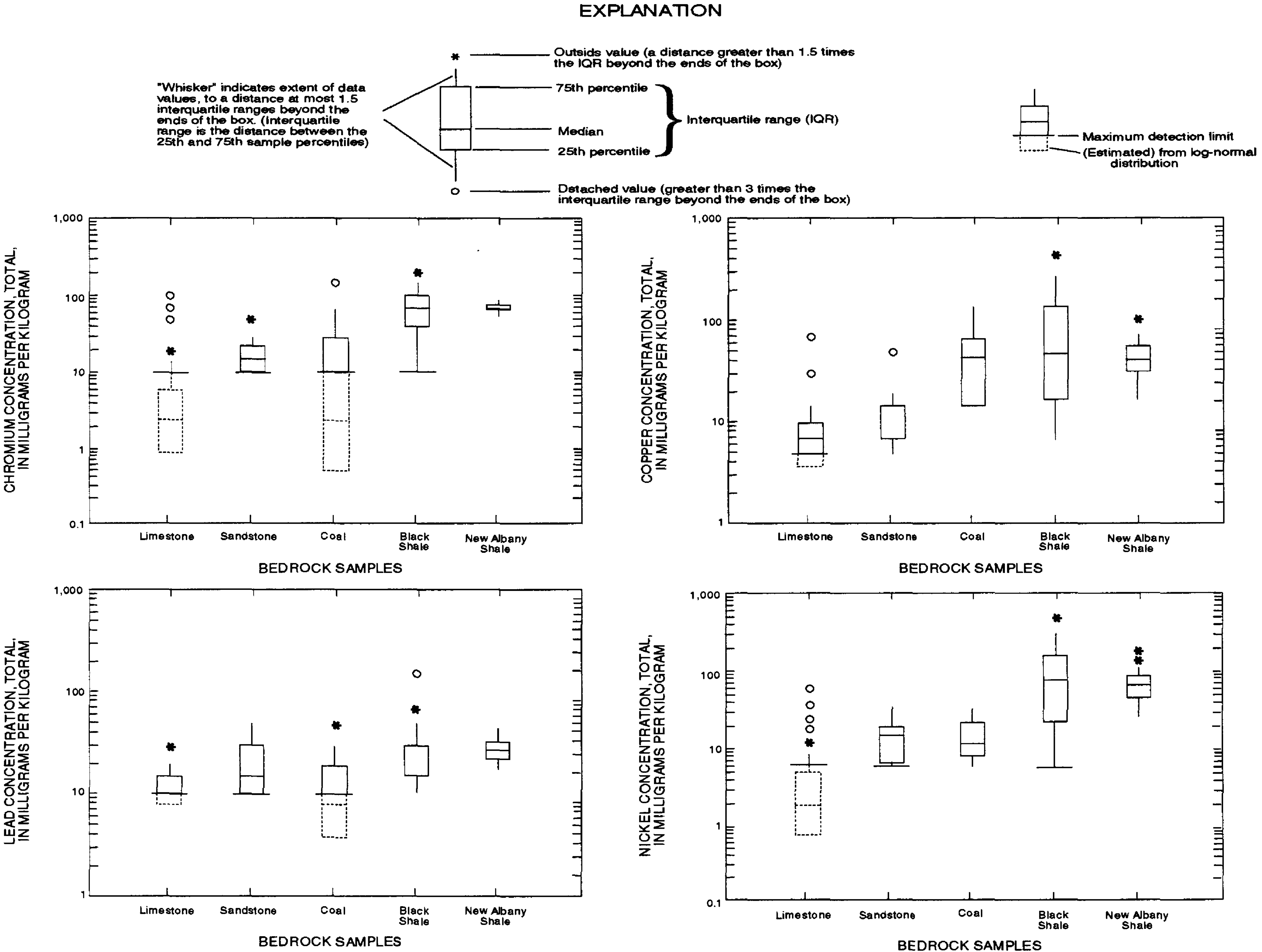


**Figure 6.** Concentrations of selected metals in bedrock samples collected from streams in the Kentucky River Basin.

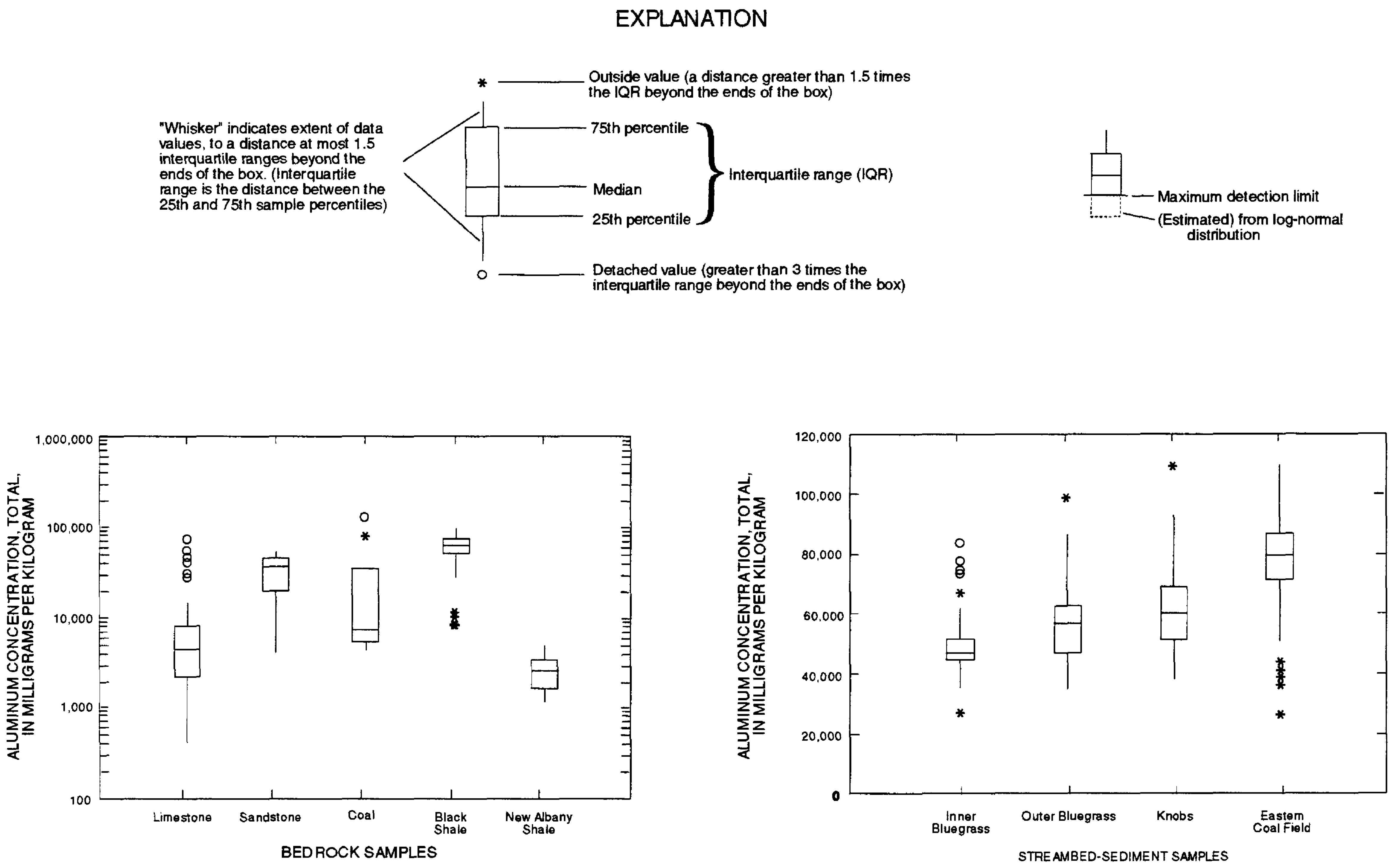


**Figure 7.** Concentrations of selected metals in bedrock and streambed-sediment samples from streams in the Kentucky River Basin.

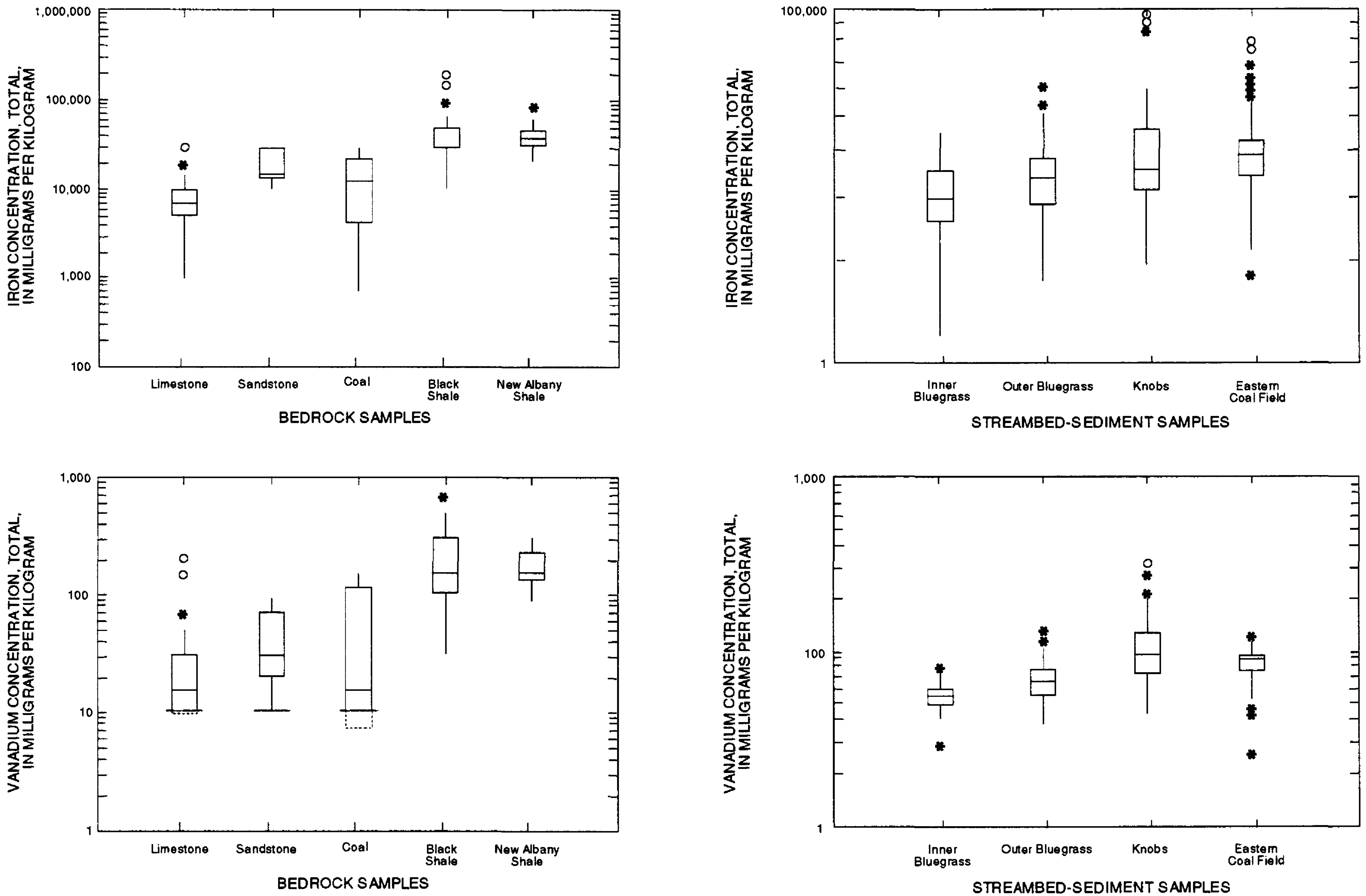


**Figure 7.** Concentrations of selected metals in bedrock and streambed-sediment samples from streams in the Kentucky River Basin--Continued.

Table 4. Concentrations (geometric mean) of metals and other trace elements in bedrock samples from the Kentucky River Basin

[Concentrations in micrograms per gram; --, no data]

| Constituent | Bedrock samples | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Limestone | Fossiliferous limestone | Mudstone | Siltstone | Sandstone | Coal | Fire clay | Black shale | Dolomite | New Albany Shale | Quartz arenite |
| Aluminum | 5,000 | 4,000 | 63,000 | 40,000 | 32,000 | 13,000 | 63,000 | 50,000 | 10,000 | 2,500 | 10,000 |
| Barium | 50 | 32 | 500 | 250 | 200 | 130 | 400 | 400 | 50 | 400 | 160 |
| Beryllium | 1 | 1 | 4 | 4 | 2 | 8 | 5 | 4 | 1 | 2 | -- |
| Boron | 16 | 10 | 100 | 50 | 60 | 80 | 100 | 100 | 20 | -- | 60 |
| Calcium | 130,000 | 200,000 | 5,000 | 5,000 | 1,000 | 1,000 | 1,000 | 4,000 | 100,000 | 6,000 | 600 |
| Cerium | 10 | 13 | 79 | 63 | 40 | 16 | 100 | 63 | 25 | -- | 16 |
| Chromium | 13 | 10 | 100 | 20 | 20 | 20 | 100 | 60 | 10 | 60 | 20 |
| Cobalt | 10 | 10 | 20 | 10 | 10 | 10 | 20 | 20 | 10 | 20 | 20 |
| Copper | 8 | 8 | 50 | 30 | 10 | 40 | 30 | 50 | 10 | 40 | 6 |
| Gallium | 6 | 5 | 20 | 20 | 10 | 10 | 30 | 20 | 6 | -- | 5 |
| Germanium | 10 | 10 | 10 | 10 | 10 | 20 | 10 | 10 | 10 | 40 | 10 |
| Iron | 6,300 | 6,300 | 50,000 | 25,000 | 16,000 | 7,900 | 40,000 | 32,000 | 20,000 | 40,000 | 3,200 |
| Lanthanum | 50 | 50 | 80 | 60 | 50 | 50 | 100 | 60 | 50 | 40 | -- |
| Lead | 10 | 10 | 50 | 20 | 20 | 10 | 30 | 20 | 20 | 20 | 10 |
| Lithium | 6 | 4 | 40 | 25 | 13 | 16 | 63 | 40 | 8 | 40 | 8 |
| Magnesium | 20,000 | 10,000 | 20,000 | 8,000 | 4,000 | 600 | 16,000 | 20,000 | 63,000 | 6,000 | 800 |
| Manganese | 400 | 790 | 320 | 400 | 500 | 25 | 160 | 400 | 630 | 630 | 200 |
| Molybdenum | 5 | 5 | 13 | 5 | 5 | 5 | 5 | 16 | 6 | 13 | 5 |
| Neodymium | 8 | 10 | 40 | 30 | 20 | 8 | 50 | 32 | 16 | 2 | 8 |
| Nickel | 6 | 5 | 50 | 10 | 10 | 10 | 30 | 50 | 8 | 60 | 10 |
| Potassium | 2,500 | 2,500 | 25,000 | 7,900 | 7,900 | 2,000 | 20,000 | 20,000 | 5,000 | 630 | 3,200 |
| Sodium | 3,200 | 3,200 | 6,300 | 6,300 | 6,300 | 2,500 | 5,000 | 7,900 | 3,200 | 20,000 | 2,000 |
| Strontium | 800 | 2,000 | 300 | 200 | 100 | 100 | 200 | 200 | 100 | 100 | 100 |
| Titanium | 300 | 200 | 5,000 | 6,000 | 3,000 | 600 | 4,000 | 4,000 | 300 | 3,000 | 1,000 |
| Vanadium | 20 | 20 | 200 | 50 | 30 | 20 | 200 | 200 | 20 | 200 | 20 |
| Ytterbium | 1 | 1 | 2 | 2 | 1 | 2 | 3 | 3 | 1 | 20 | -- |
| Yttrium | 20 | 20 | 50 | 60 | 40 | 50 | 50 | 50 | 20 | 200 | 20 |
| Zirconium | 40 | 20 | 300 | 500 | 400 | 50 | 200 | 200 | 30 | 5 | 200 |
| Number of samples | 30 | 47 | 4 | 6 | 22 | 10 | 8 | 45 | 13 | 19 | 4 |

## Relations of Metal and Trace-Element Concentrations in Streambed Sediments to Physiographic Region

Because of the spatial variation in geochemical characteristics of bedrock samples, it is expected that the spatial variations in chemistry of soils and stream sediments would correspond to physiographic gradients in the Kentucky River Basin. Kruskal-Wallis and Tukey multiple range tests (Tukey, 1977; Zar, 1984; Wilkinson, 1989) were used to determine whether median concentrations of constituents in streambed sediments were significantly different among physiographic regions in the basin. Statistically significant differences indicated for certain metals and other trace elements correspond to regional differences of geology in the basin. For example, median concentrations of aluminum in sandstone samples and samples of black shale were larger than those in limestone samples (fig. 7). Correspondingly, median concentrations of aluminum in streambed-sediment samples were significantly larger in the Eastern Coal Field Region, which is characterized by sandstone, shale, and coal, than in any other region. Similarly, vanadium concentrations in shale samples were significantly larger than those in limestone or sandstone samples. Median streambed-sediment concentrations of vanadium were largest in the Knobs Region, followed by the Eastern Coal Field and the Outer and Inner Bluegrass Regions. Similar relations between regional geology and physiography were indicated for streambed-sediment concentrations of calcium, nickel, phosphorus, strontium, titanium, and yttrium.

In contrast, the range of iron concentrations in streambed-sediment samples was similar for all physiographic regions, even though the median concentration of iron in limestone was significantly smaller than in other bedrock samples (fig. 7). A similar relation with respect to manganese indicates that sediment concentrations of these constituents are affected more by geochemical processes (for example, precipitation of iron oxide and manganese oxide coatings on particles) than by regional geochemistry. The lack of correlation between iron and manganese concentrations in streambed-sediment samples (Spearman's rho = 0.018) may indicate that the processes contributing to sediment accumulation of iron and manganese are independent. The conditions under which ferric hydroxides are precipitated differ from those that produce precipitates of hydrous manganese oxides; iron and manganese precipitates in streambed sediments may be derived from different components of rocks in the region.

Relations between bedrock geochemistry and regional differences in streambed-sediment chemistry are less understood for other trace elements because (1) the percentage of constituent detection was low for bedrock samples and for sediment samples, (2) the percentage of detection was high for sediment samples and low for bedrock samples because of differences in analytical methodology, (3) sediment concentrations of certain elements may be associated more with human activities than with differences in regional geology, or (4) certain constituent-specific differences may be associated with chemical-weathering processes. As a result, significant relations for these elements among physiographic regions of the Kentucky River Basin cannot be established.

Although concentrations of certain trace elements were larger in shale and sandstone than in limestone, streambed-sediment concentrations of nickel, lead, and zinc were relatively large in the Inner Bluegrass Region, probably because of effects of point-source discharges and urban nonpoint sources. Two natural geochemical factors may contribute to accumulation of these metals in streambed sediments. First, much of the manganese in streambed sediments of the region is likely to be present as manganese-oxide coatings, which are efficient adsorptive traps for metals. Second, naturally occurring lead in the carbonate rocks of the region may be concentrated in the insoluble residuum. Nevertheless, concentrations of trace elements in streambed sediments that exceeded those indicated for bedrock samples (tables 3 and 4) or exceeded baseline sediment-conditions within a physiographic region (to be discussed) are most likely attributable to human sources.

Stormwater runoff from disturbed lands, such as coal mines and farms, as well as discharges from other human activities, may contribute larger concentrations of certain metals and trace elements downstream from the source than are contributed by streams that drain forested subbasins. Median streambed-sediment concentrations of aluminum, cerium, gallium, lanthanum, neodymium, and niobium were significantly larger in streams affected by coal mining activities than in streams outside the Eastern Coal Field Region. Although concentrations of these elements tended to be large in fire clays and other geologic materials of the Eastern Coal Field Region (table 4), surface mining can expose these materials to weathering, potentially resulting in larger than expected concentrations in streambed sediments. In contrast, urban streambed sediments of the Inner Bluegrass Region contained significantly larger concentrations of mercury, phosphorus, and sulfur than were contained in sediments from the other regions. Although natural and human sources both likely contribute to the accumulation of phosphorus in streambed sediments of the region, the accumulation of mercury and sulfur is probably attributable to human sources; for example, as a result of atmospheric contamination. Sediment concentrations of lithium were significantly larger in streams that receive brine discharges from oil wells than in other streams in the basin, a finding that corresponds to water-quality data presented by Evaldi and Kipp (1991) and by Walker and others (1991).

## Elevated Concentrations of Metals and Other Trace Elements in Streambed Sediments in the Kentucky River Basin

The spatial distribution of stream locations where elevated streambed-sediment concentrations of metals and other trace elements are found is predominately associated with the geology of the Kentucky River Basin. Land disturbance and other nonpoint-source effects can affect streambed-sediment chemistry regionally, but the effects of wastewater discharges and other waste-management practices appear to be limited to stream reaches that are close to the discharge location. Elevated concentrations are defined as those constituent concentrations in streambed sediments that equal or exceed the concentration indicated at the 95th percentile of the total sample population (n = 441).

Although many of the elevated concentrations found during the study were within the range expected for geologic materials in the Kentucky River Basin (Goldschmidt, 1958; Conner, 1981), concentrations of arsenic, chromium, nickel, lead, and zinc (table 5) were in the "heavily polluted" range according to U.S. Environmental Protection Agency (USEPA) guidelines for sediment classification (U.S. Environmental Protection Agency, 1977; Logan and others, 1987). Concentrations for copper in table 5 were in USEPA's "moderately polluted" range, whereas guidelines are not established for cadmium or mercury for the concentrations indicated in table 5. Streambed-sediment concentrations of barium, iron, manganese, and phosphorus in table 5 exceeded the lower limits of USEPA's "heavily polluted" classification by an order of magnitude; however, the four-acid extraction process applied to sediment samples before chemical determinations would be expected to yield larger concentrations of these elements than the "total-recoverable" extraction process used by the USEPA. Concentrations of these elements were similar to those reported for geologic materials in the Kentucky River Basin (Conner, 1981; Sargent and others, 1982). Elevated concentrations of constituents in sediments from small streams (6-$mi^2$ drainage area or less) generally corresponded with geology or site-specific human activities.

Elevated streambed-sediment concentrations of aluminum, arsenic, molybdenum, potassium, phosphorus, strontium, titanium, uranium, vanadium, and yttrium were found in specific physiographic regions of the Kentucky River Basin. For example, elevated streambed-sediment concentrations of potassium were found in small (less than third order) streams of the Outer Bluegrass Region (fig. 8), and they likely correspond to large concentrations of potassium in shales of Ordovician age from the region. Further, the particular variety of clay in the shaley units of limestone bedrock from the region is structurally similar to muscovite, which contains large amounts of potassium. Agricultural activities in the Lower Kentucky River Basin also may contribute to the accumulation of potassium in the sediments of small streams.

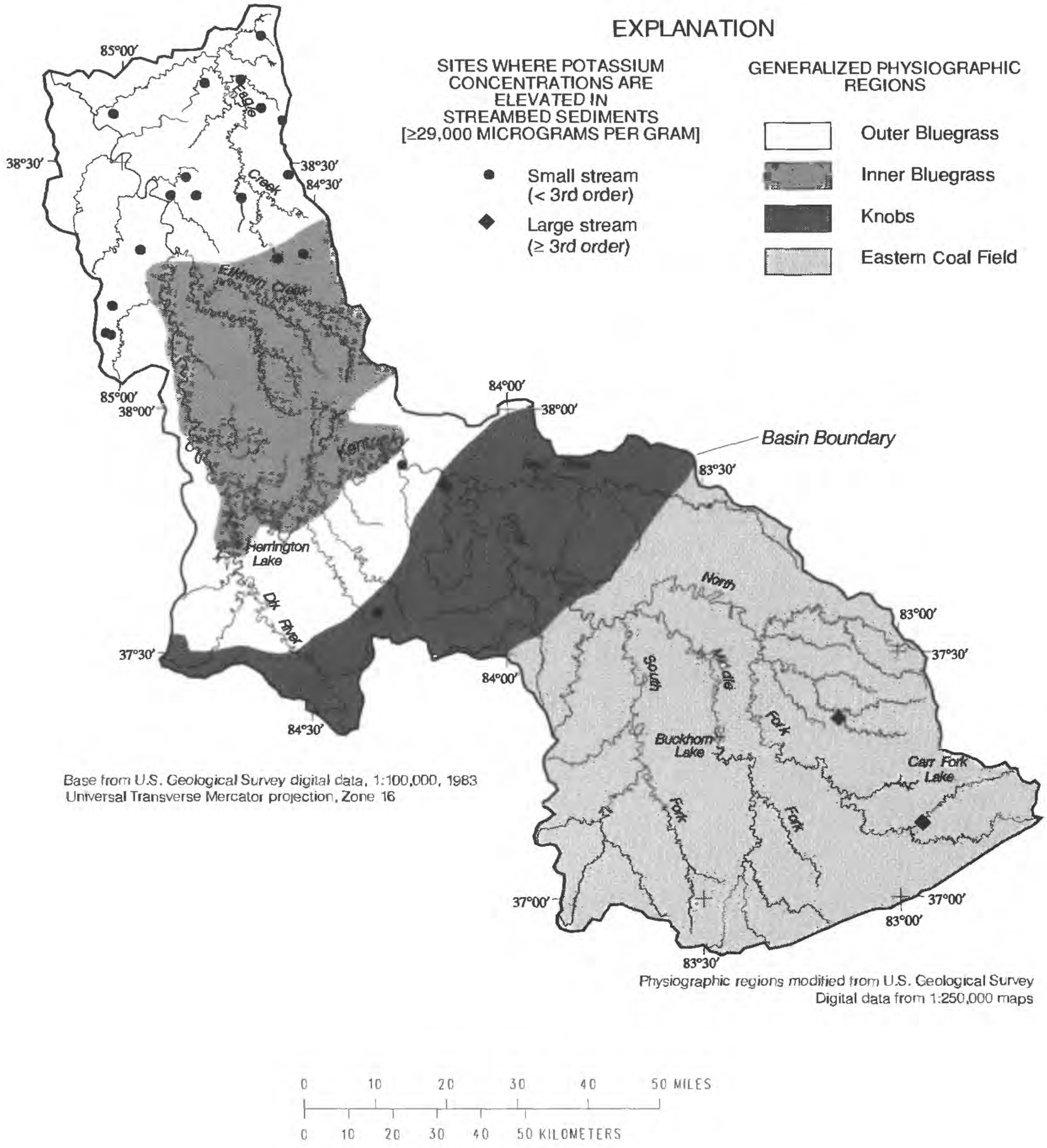
Streambed-sediment concentrations of phosphorus were largest in the Inner Bluegrass Region (fig. 9). Phosphatic limestone and soils are a natural source of phosphorus in the region (McFarlan, 1943). Much of the phosphate in limestones is present in the mineral apatite (calcium phosphate). Streambed-sediment sites where concentrations of yttrium (fig. 10) and strontium were elevated also are associated with the geology of the Inner Bluegrass Region, because yttrium and strontium can substitute for calcium in apatite. Apatite is considerably more resistant to weathering processes than are other components of Ordovician limestones, so these elements become concentrated in the insoluble residuum. Although the source of yttrium and strontium in the Inner Bluegrass is considered to be natural, human activities likely contribute appreciable quantities of phosphorus to streambed sediments as a result of wastewater discharges and landfill leachate in greater Lexington, as well as from agricultural activities in the Elkhorn Creek Subbasin.

Elevated concentrations of arsenic, molybdenum, uranium, and vanadium in streambed sediments were generally restricted to the Knobs Region. The primary source of these elements in the Kentucky River Basin is likely the weathering of pyritic shale bedrock; however, large concentrations of arsenic (fig. 11) were also found at a few stream sites that are affected by coal mining or agriculture. Larger than expected concentrations of arsenic in

Table 5. Elevated concentrations of metals and other trace elements in streambed sediments of the Kentucky River Basin, 1987-88

[Concentrations in micrograms per gram; value reported is the concentration indicated at the 95th percentile of 441 samples]

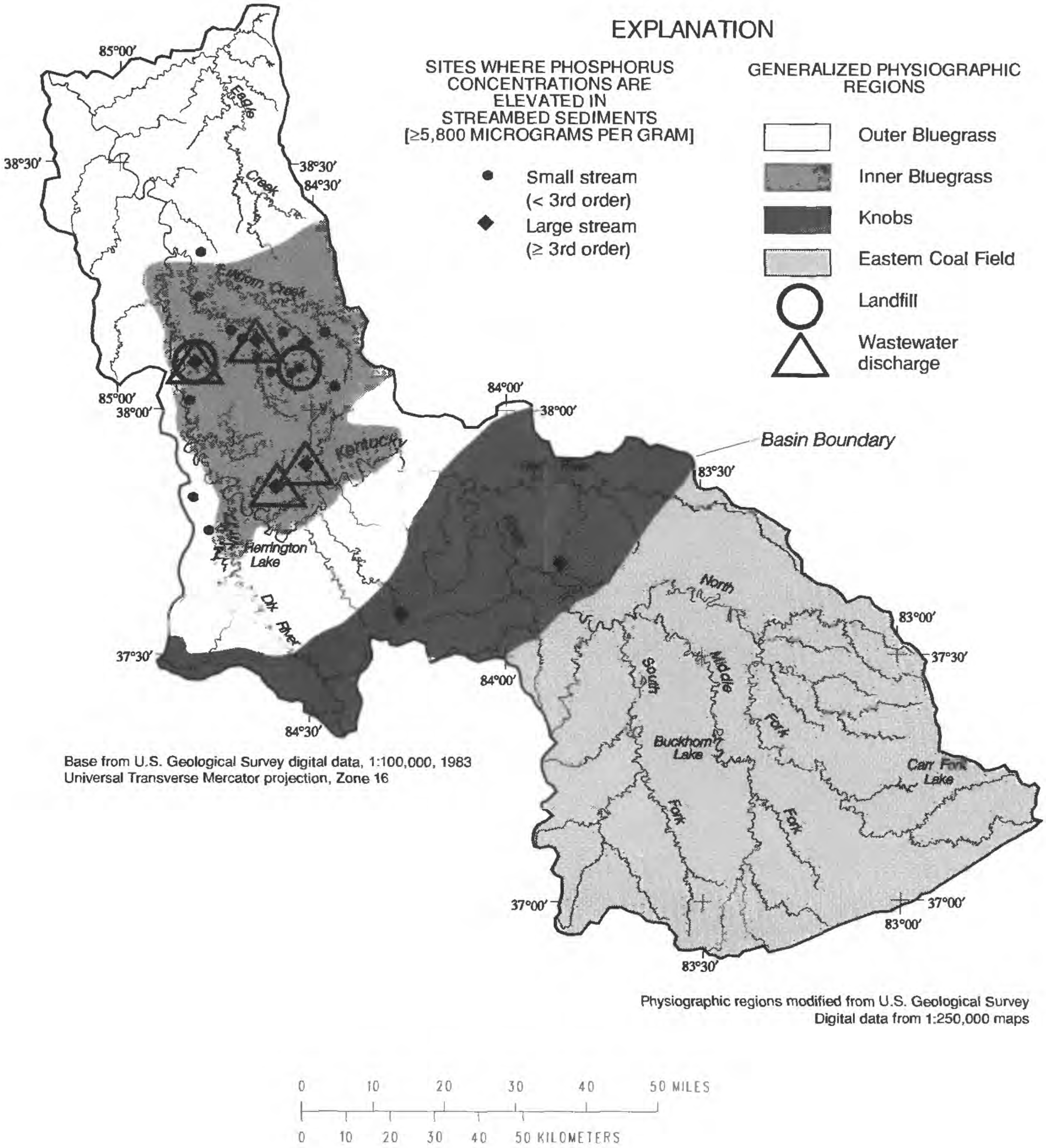
| Constituent | Concentration | Constituent | Concentration | Constituent | Concentration |
|---|---|---|---|---|---|
| Aluminum | 92,000 | Lanthanum | 58 | Silver | 2 |
| Antimony | 1.4 | Lead | 61 | Sodium | 6,500 |
| Arsenic | 18 | Lithium | 76 | Strontium | 170 |
| Barium | 640 | Magnesium | 11,000 | Sulfur | 1,800 |
| Boron | 3.4 | Manganese | 4,400 | Thorium | 16 |
| Cadmium | 2 | Mercury | .14 | Titanium | 4,500 |
| Calcium | 85,000 | Molybdenum | 4 | Uranium | 2.9 |
| Cerium | 120 | Neodymium | 55 | Vanadium | 140 |
| Chromium | 99 | Nickel | 67 | Yttrium | 33 |
| Cobalt | 38 | Niobium | 13 | Zinc | 200 |
| Copper | 44 | Phosphorus | 5,800 | Inorganic carbon | 25,000 |
| Gallium | 25 | Potassium | 29,000 | Organic carbon | 37,000 |
| Iron | 53,000 | Scandium | 16 | Total carbon | 55,000 |
|  |  | Selenium | 1.1 |  |  |



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Physiographic regions modified from U.S. Geological Survey
Digital data from 1:250,000 maps

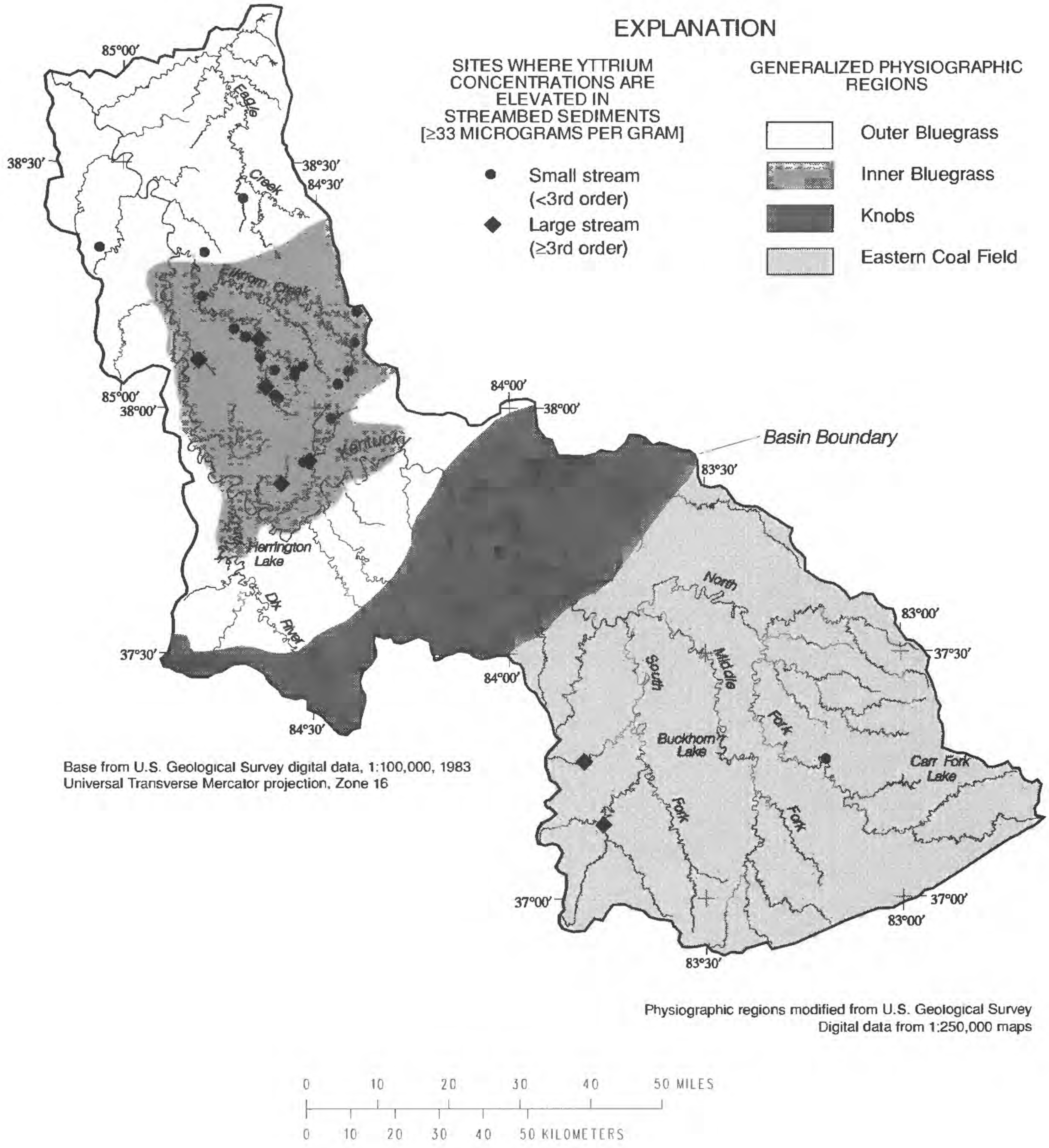
**Figure 8.** Streambed-sediment sites in the Kentucky River Basin characterized by elevated concentrations of potassium.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Physiographic regions modified from U.S. Geological Survey
Digital data from 1:250,000 maps

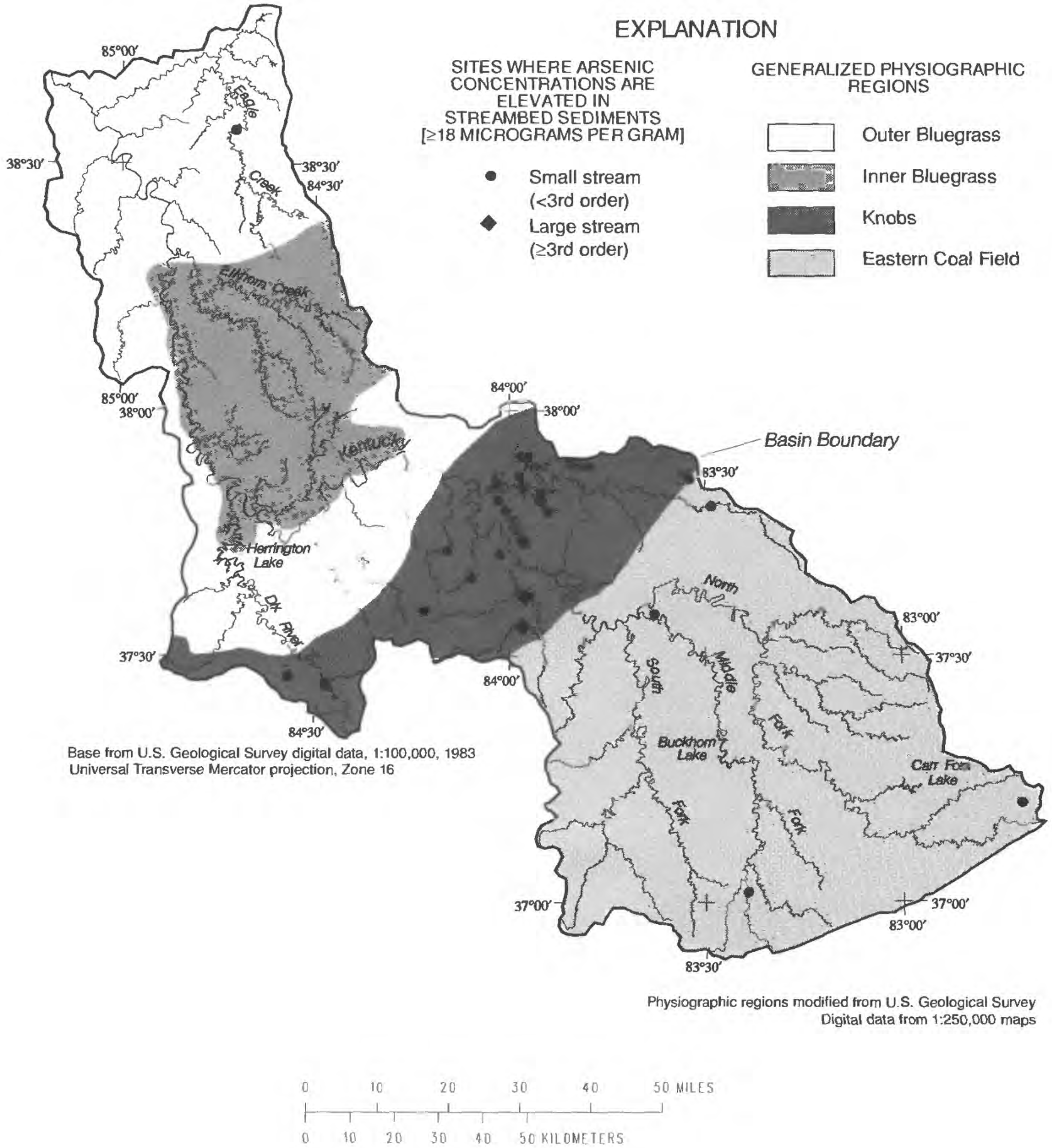
**Figure 9.** Streambed-sediment sites in the Kentucky River Basin characterized by elevated concentrations of phosphorus.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Physiographic regions modified from U.S. Geological Survey
Digital data from 1:250,000 maps

**Figure 10.** Streambed-sediment sites in the Kentucky River Basin characterized by elevated concentrations of yttrium.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Physiographic regions modified from U.S. Geological Survey
Digital data from 1:250,000 maps

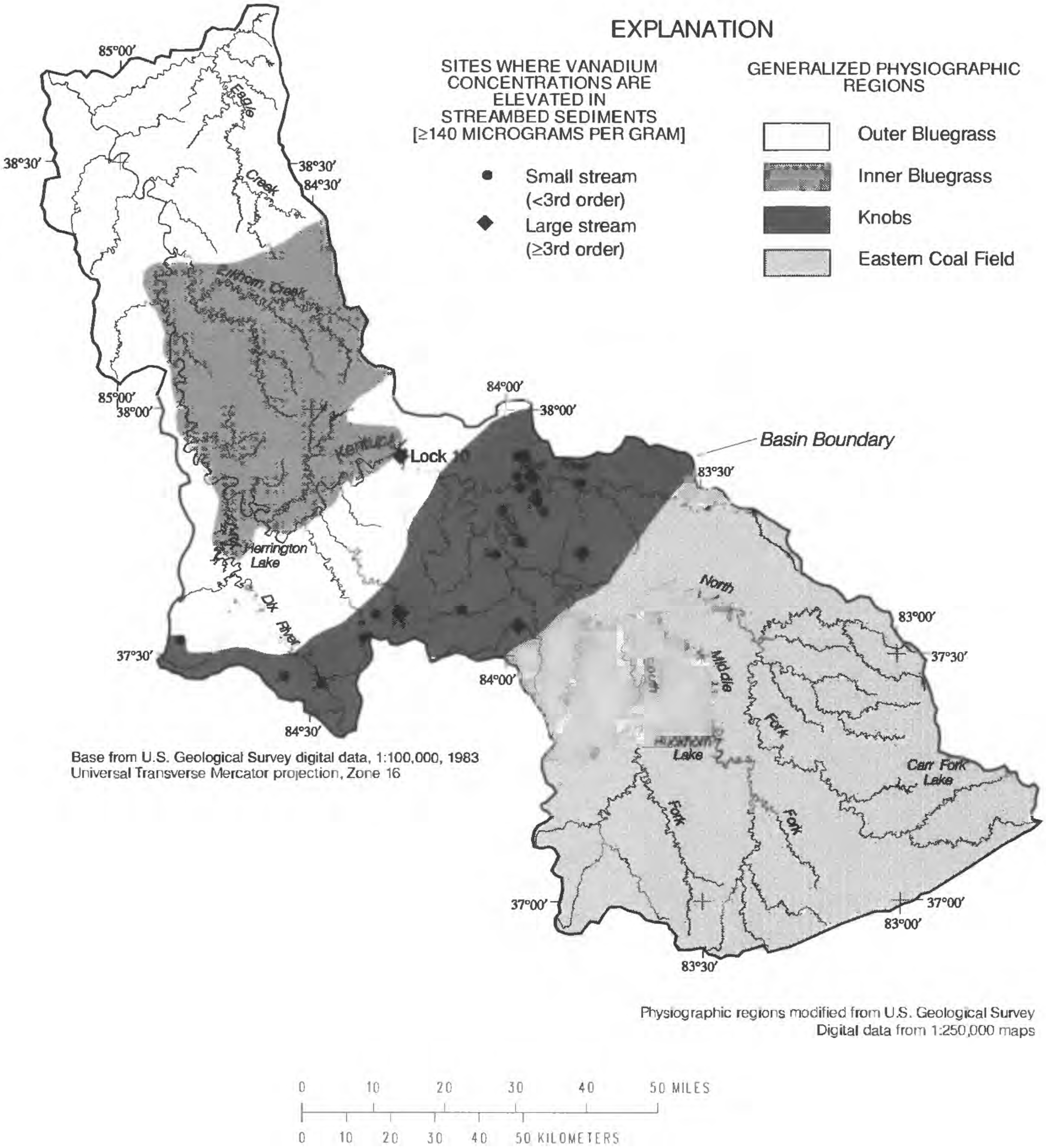
**Figure 11.** Streambed-sediment sites in the Kentucky River Basin characterized by elevated concentrations of arsenic.

streambed sediments can also be related to above-average amounts of ferric hydroxide precipitates in sediments, because these precipitates can be a highly adsorptive trap for arsenates. The largest concentrations of molybdenum, uranium, and vanadium in streambed sediment collected during the NURE program in the Kentucky River Basin were found in areas where Devonian black shale crops out (Sargent and others, 1982). Concentrations of vanadium in streambed sediments were elevated in the Kentucky River downstream from tributaries that receive drainage from the Knobs Region (fig. 12), but the effect of these tributaries did not extend downstream from Lock 10.

Concentrations of iron in streambed sediments were largest in small streams in the lowermost half of the Eastern Coal Field Region and in the Knobs Region (fig. 13). Much of the iron in streambed sediments is present in magnetite, ilmenite, and other heavy minerals. Because total concentrations of iron were determined during the analysis of streambed-sediment samples, a considerable amount of the iron detected in samples likely was present as heavy minerals, rather than as ferric hydroxide precipitates. Ferric hydroxide, however, is commonly precipitated as acidic waters are neutralized downstream from the source; therefore, elevated iron concentrations would be expected and were found at stream locations affected by coal mining and other land disturbance. The yield of total iron in water at the North Fork Kentucky River at Jackson during 1983-85 was attributed to increased sediment transport resulting from coal mining (Smoot and others, 1991). Elevated sediment transport was also reported for subbasins where the predominant land use is agriculture, such as the Eagle Creek Subbasin (Flint, 1983).

In general, concentrations of aluminum in streambed sediments were largest in large streams of the Eastern Coal Field Region (fig. 14). The distribution of titanium concentrations was similar to that for aluminum. Concentrations of these constituents were large in bedrock samples from the Eastern Coal Field Region; streambed-sediment concentrations were typically largest in large stream channels, where velocity has slowed sufficiently to allow clays to settle to the bottom. Accumulation of these constituents in the Eastern Coal Field Region may indicate cumulative effects from coal mining and other land disturbance in the region, although the geochemistry of streambed sediments may simply correspond to bedrock geochemistry of the region. However, sediment concentrations of aluminum and titanium also were elevated in large streams that receive drainage from agricultural lands, such as Eagle Creek in the Outer Bluegrass Region. Similar observations were reported by Smoot and others (1991). Large concentrations of total aluminum have been common in water samples from the North Fork Kentucky River at Jackson and Eagle Creek at Glencoe.

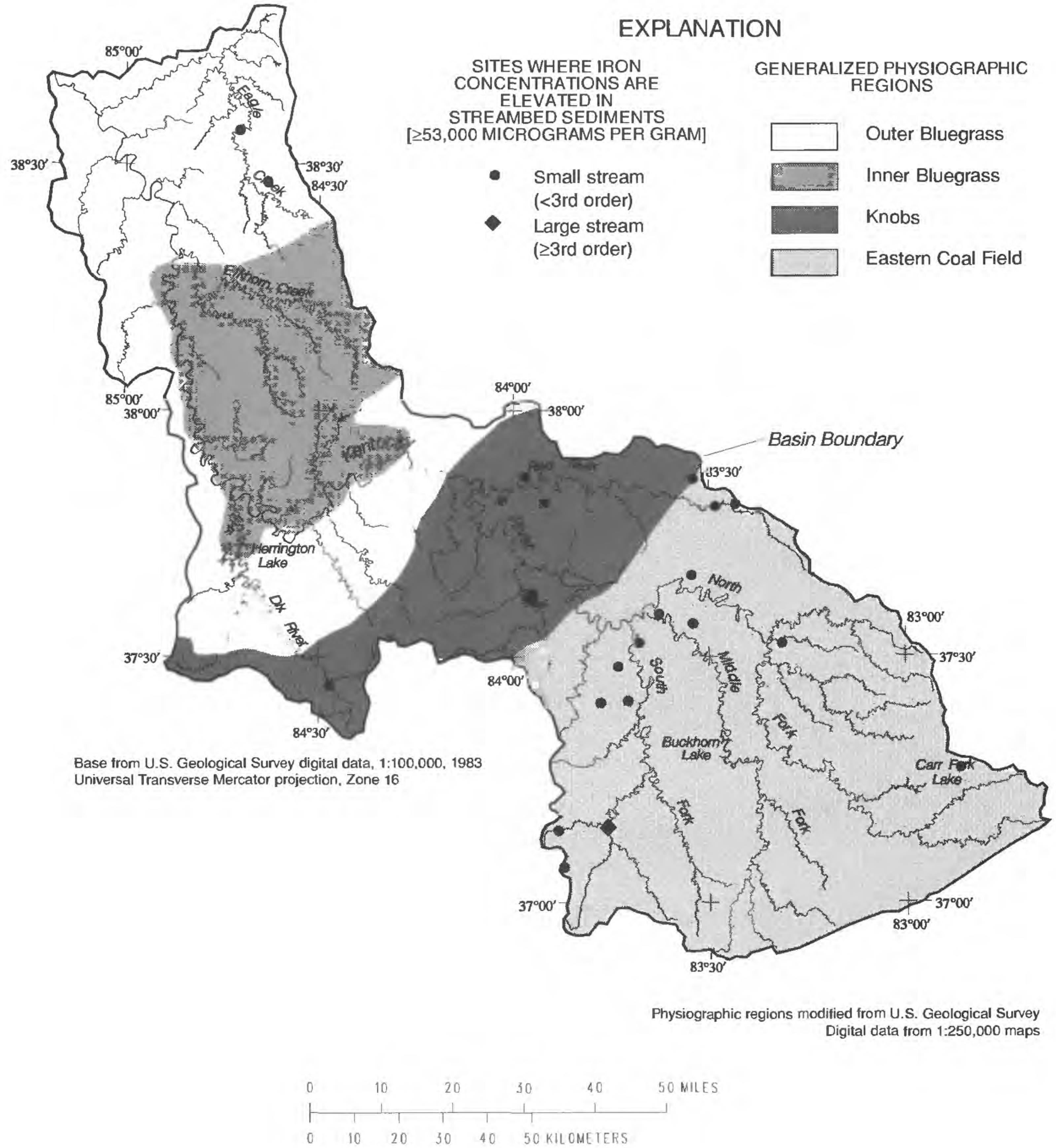
Elevated concentrations of lanthanum and several other rare-earth elements were present in streambed sediments in the Eastern Coal Field Region (fig. 15), particularly in the North Fork Kentucky River hydrologic unit. Large concentrations of cerium, gallium, lanthanum, neodymium, and niobium are probably associated with heavy minerals or clays of the region, but they are typically found in the sediments of streams that receive drainage from coal-mining areas. Concentrations of cerium, gallium, lanthanum, and neodymium were larger in fire clay, mudstone, and siltstone samples from the Eastern Coal Field Region than in bedrock samples from other regions. However, large



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Physiographic regions modified from U.S. Geological Survey
Digital data from 1:250,000 maps

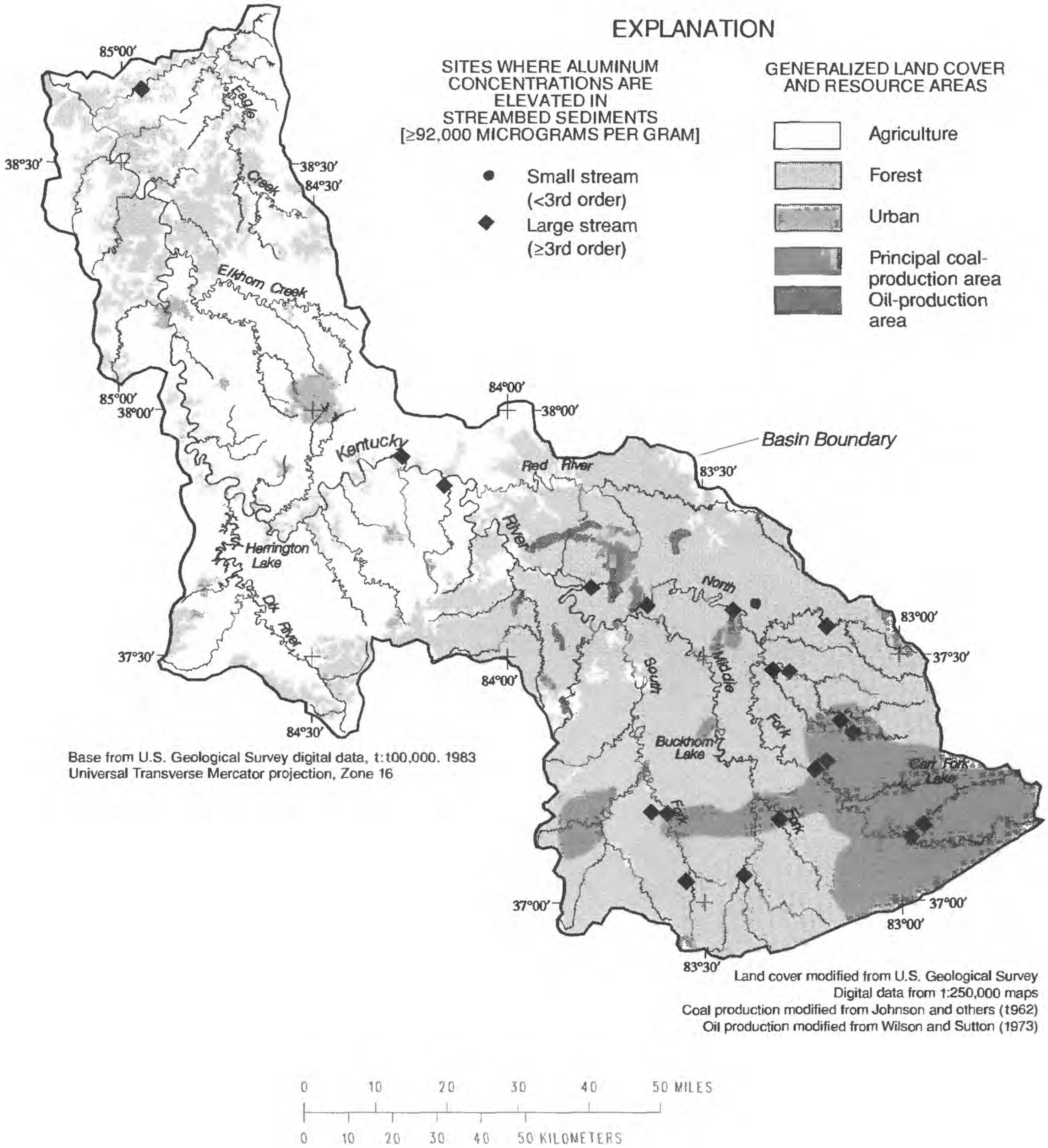
**Figure 12.** Streambed-sediment sites in the Kentucky River Basin characterized by elevated concentrations of vanadium.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Physiographic regions modified from U.S. Geological Survey
Digital data from 1:250,000 maps

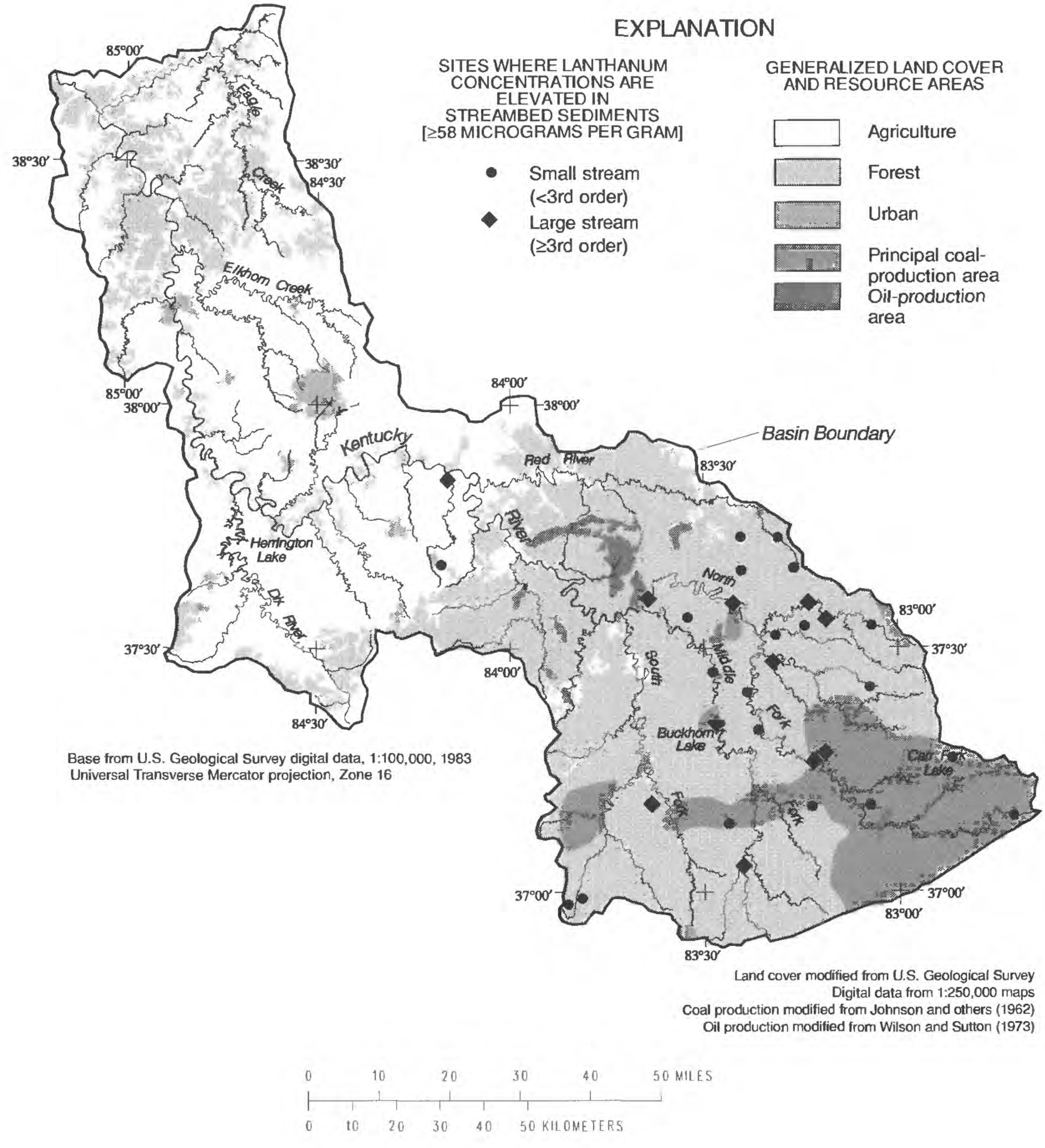
**Figure 13.** Streambed-sediment sites in the Kentucky River Basin characterized by elevated concentrations of iron.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Land cover modified from U.S. Geological Survey
Digital data from 1:250,000 maps
Coal production modified from Johnson and others (1962)
Oil production modified from Wilson and Sutton (1973)

**Figure 14.** Streambed-sediment sites in the Kentucky River Basin characterized by elevated concentrations of aluminum.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Land cover modified from U.S. Geological Survey
Digital data from 1:250,000 maps
Coal production modified from Johnson and others (1962)
Oil production modified from Wilson and Sutton (1973)

**Figure 15.** Streambed-sediment sites in the Kentucky River Basin characterized by elevated concentrations of lanthanum.

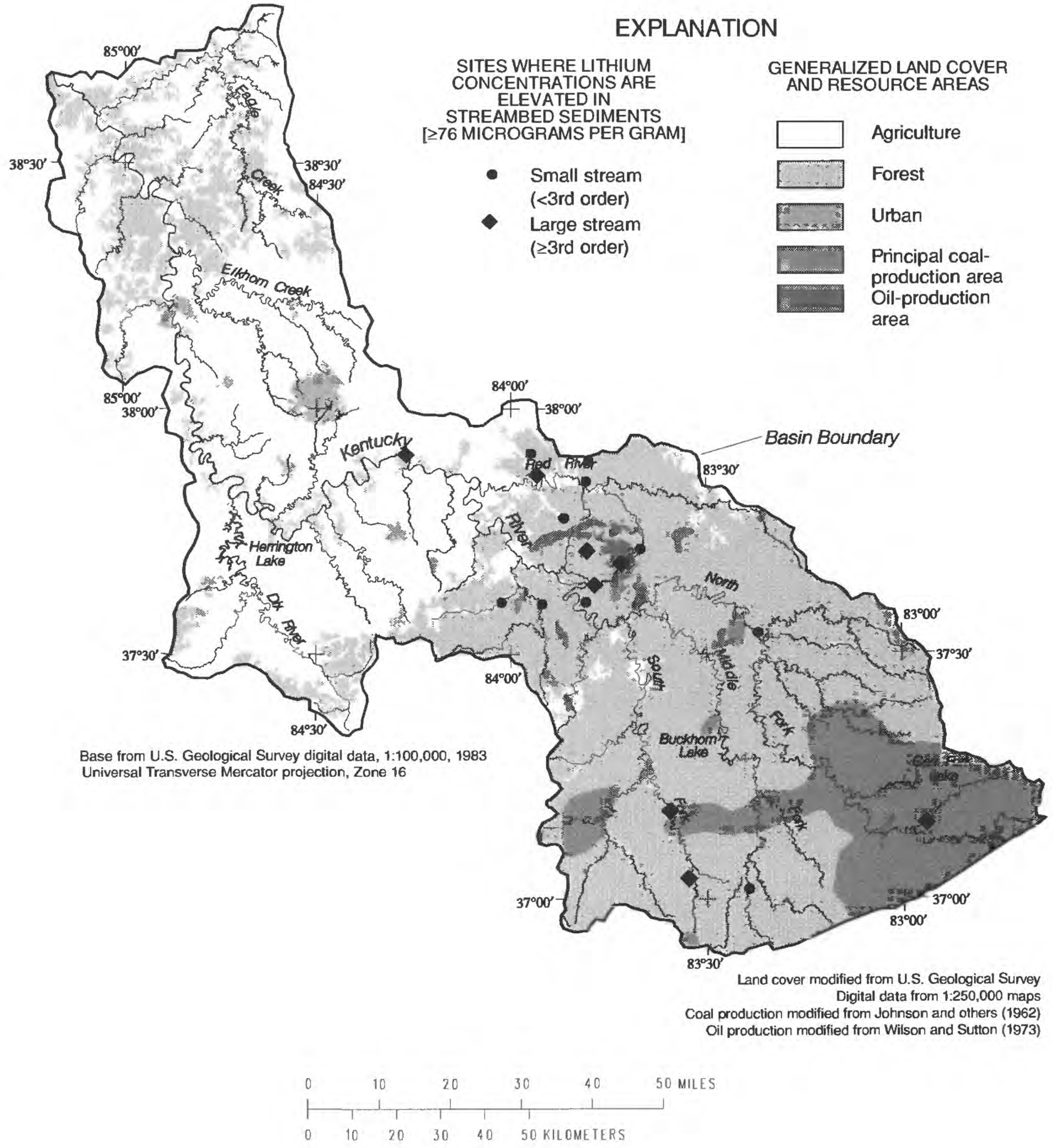
concentrations of rare-earth elements in streambed sediments may correspond to land disturbance (exposure of coal and associated fire clays to weathering) rather than just to natural geochemical processes.

The results of human activities can affect concentrations of metals and other trace elements in streambed sediments on a local to regional scale. For example, concentrations of barium and lithium were elevated in the sediment of streams affected by oil-well brine discharges. Elevated concentrations of lithium in streambed sediments (fig. 16) associated with oil production or coal mining may extend downstream to Lock 10 (fig. 16). However, large lithium concentrations at certain small-stream locations may be associated with regional geochemical features (for example, acidic bedrock or soils). The distribution of stream locations characterized by elevated concentrations of barium is similar to the distribution of lithium (fig. 16) and may be associated with the discharge of oil-well brines (Sidhu and Mitsch, 1987; Smoot and others, 1991) and the use of barite (barium sulfate) as an additive to well-drilling fluids (Aller and others, 1989). In addition, sporadic, natural occurrences of barite in the basin may explain elevated sediment concentrations of barium in small streams that are not affected by oil production.

Concentrations of potentially toxic metals (Elder, 1988; Kentucky Natural Resources and Environmental Protection Cabinet, 1990) in streambed sediments were generally elevated in or near urban areas. However, elevated concentrations of certain metals were also found at certain stream sites in the Knobs Region. These occurrences are thought to be related to the chemical properties of Devonian shale bedrock. Point-source discharges or landfill leachates can result in the accumulation of metals in streambed sediments close to the source; however, sediment concentrations of metals commonly decrease downstream from the discharge or landfill location. If the source of potentially toxic metals in streambed sediments is regional and associated with geological or nonpoint sources, then concentrations downstream from the source remain elevated. The following sections (Copper through Selenium) are discussions relative to these potentially toxic metals.

### Copper

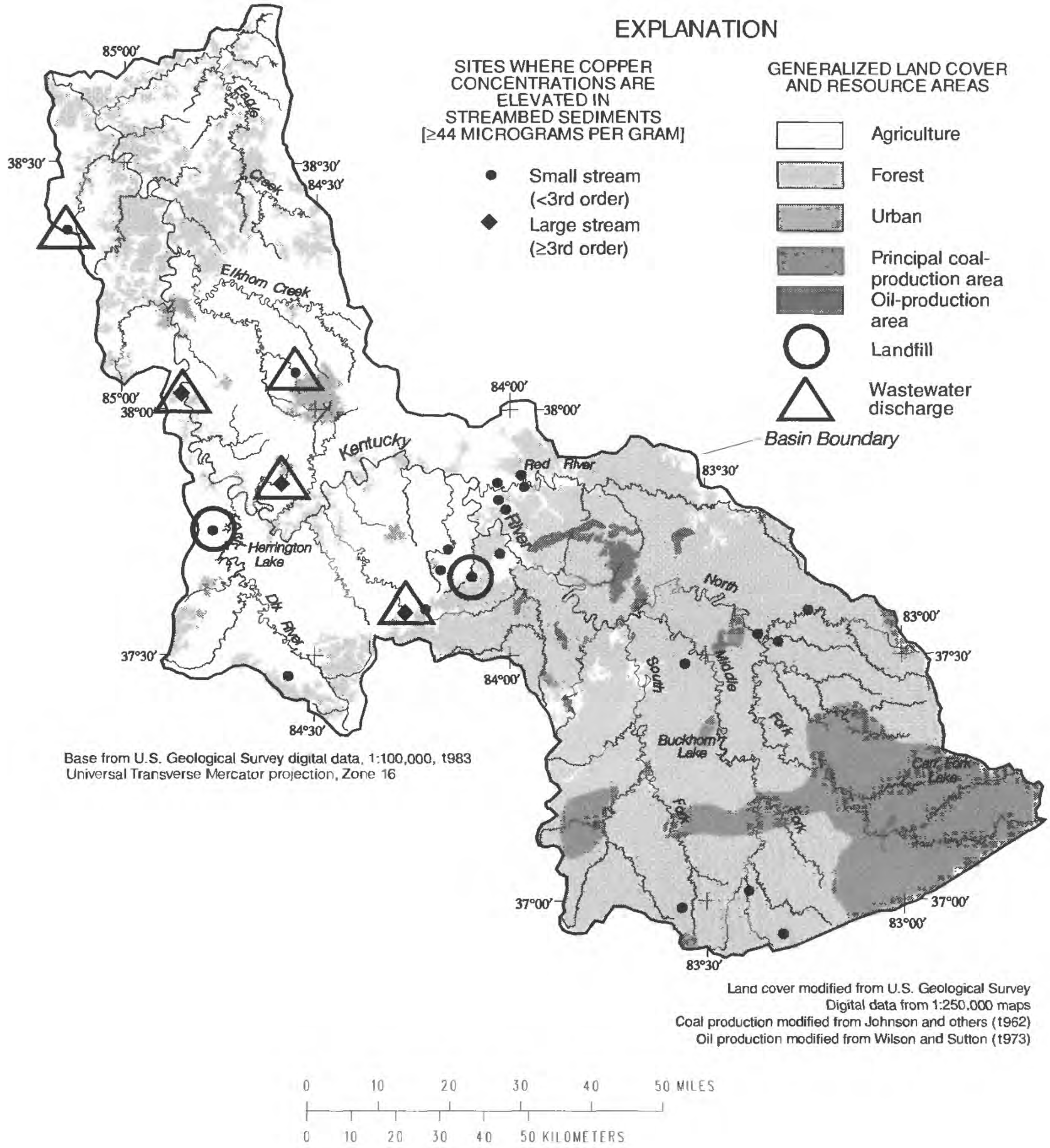
Concentrations of copper in streambed sediments were large downstream from certain point-source discharges and landfills in the Bluegrass Regions of the basin, as well as at various stream locations in the Knobs and Eastern Coal Field Regions (fig. 17). Concentrations of copper were significantly larger in shale and coal samples than in limestone and sandstone samples (fig. 6), a fact that may account for elevated concentrations of copper in streambed sediments in the Knobs and Eastern Coal Field Regions. Although limestone bedrock is not naturally rich in copper, the alkaline waters of the Bluegrass Regions favor the precipitation of copper ions from solution, thus potentially resulting in accumulation of copper in streambed sediments downstream of point-source discharges. Elevated concentrations of copper in water and streambed sediments downstream from point-source discharges were also reported by Stamer and others (1985), Logan and others (1988), and Freeman and others (1989).



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Land cover modified from U.S. Geological Survey
Digital data from 1:250,000 maps
Coal production modified from Johnson and others (1962)
Oil production modified from Wilson and Sutton (1973)

**Figure 16.** Streambed-sediment sites in the Kentucky River Basin characterized by elevated concentrations of lithium.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Land cover modified from U.S. Geological Survey
Digital data from 1:250,000 maps
Coal production modified from Johnson and others (1962)
Oil production modified from Wilson and Sutton (1973)

**Figure 17.** Streambed-sediment sites in the Kentucky River Basin characterized by elevated concentrations of copper.

### Chromium

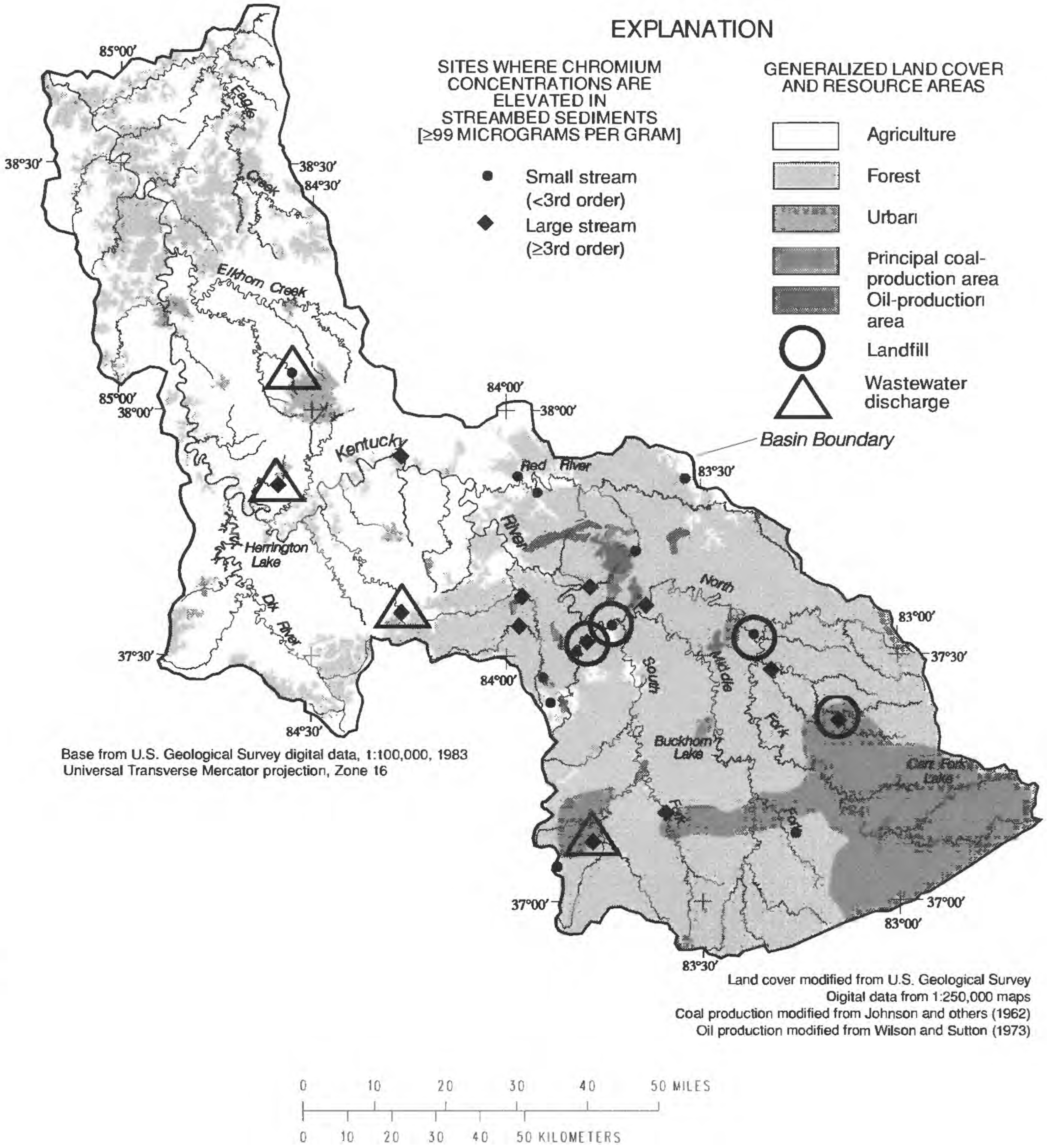
Concentrations of chromium in streambed sediments were elevated downstream from point-source discharges and landfills, but large concentrations of chromium were also present at sites in or near areas of oil production and coal mining (fig. 18). However, chromium-rich heavy minerals likely provide a natural source of this metal in streambed sediments at some low-energy stream locations, particularly in the Knobs Region. Although chromium concentrations were significantly larger in shale than in other types of rock samples (fig. 6) and shale strata are the source of oil in the Kentucky River Basin, the clustering of elevated chromium concentrations at sites near oil-production areas may not be related to this activity. Logan and others (1989) reported small concentrations of chromium in water and sediments near oil-production areas in the basin. Further, chromium has not been a constituent of concern in oil-well-brine discharges (Robert Ware, Kentucky Division of Water, oral commun., 1991).

Concentrations of chromium in shales, particularly mudstone and fire clay samples, were larger than those in other geologic materials, and elevated concentrations of chromium in streambed sediments of the Knobs and Eastern Coal Field Regions could be a result of land disturbance and accelerated weathering of these materials. Stamer and others (1985) attributed elevated concentrations of chromium in the sediments of the Schuylkill River to industrial discharges, but suggested that larger concentrations reported by Rickert and others (1977) in the Willamette River Basin, Oreg. were reflective of (basalt) geology and soils of the basin. However, no physiographic patterns were observed for chromium in sediment samples collected in the Kentucky River Basin during the NURE program (Smoot and others, 1991).

### Lead and zinc

Concentrations of lead and zinc in streambed sediments of the Bluegrass Regions were elevated downstream from point-source discharges and landfills. However, the widespread distribution of stream sites where concentrations of lead and zinc were elevated (figs. 19 and 20) may indicate regional geochemical differences; for example, the presence of New Albany Shale bedrock in the Knobs Region of the basin. Accumulation of these metals in sediment could also result from nonpoint-sources, such as atmospheric deposition and stormwater runoff from urban areas. Larger than expected concentrations of lead in other regions of the basin may result from local point-source discharges, landfill leachates, or other human influences; for example, disposal of batteries and scattering of lead pellets from shotgun shells. Data collected by the NURE program also indicated that maximum lead concentrations in streambed sediments were found in the Inner Bluegrass Region (Smoot and others, 1991, p. 178).

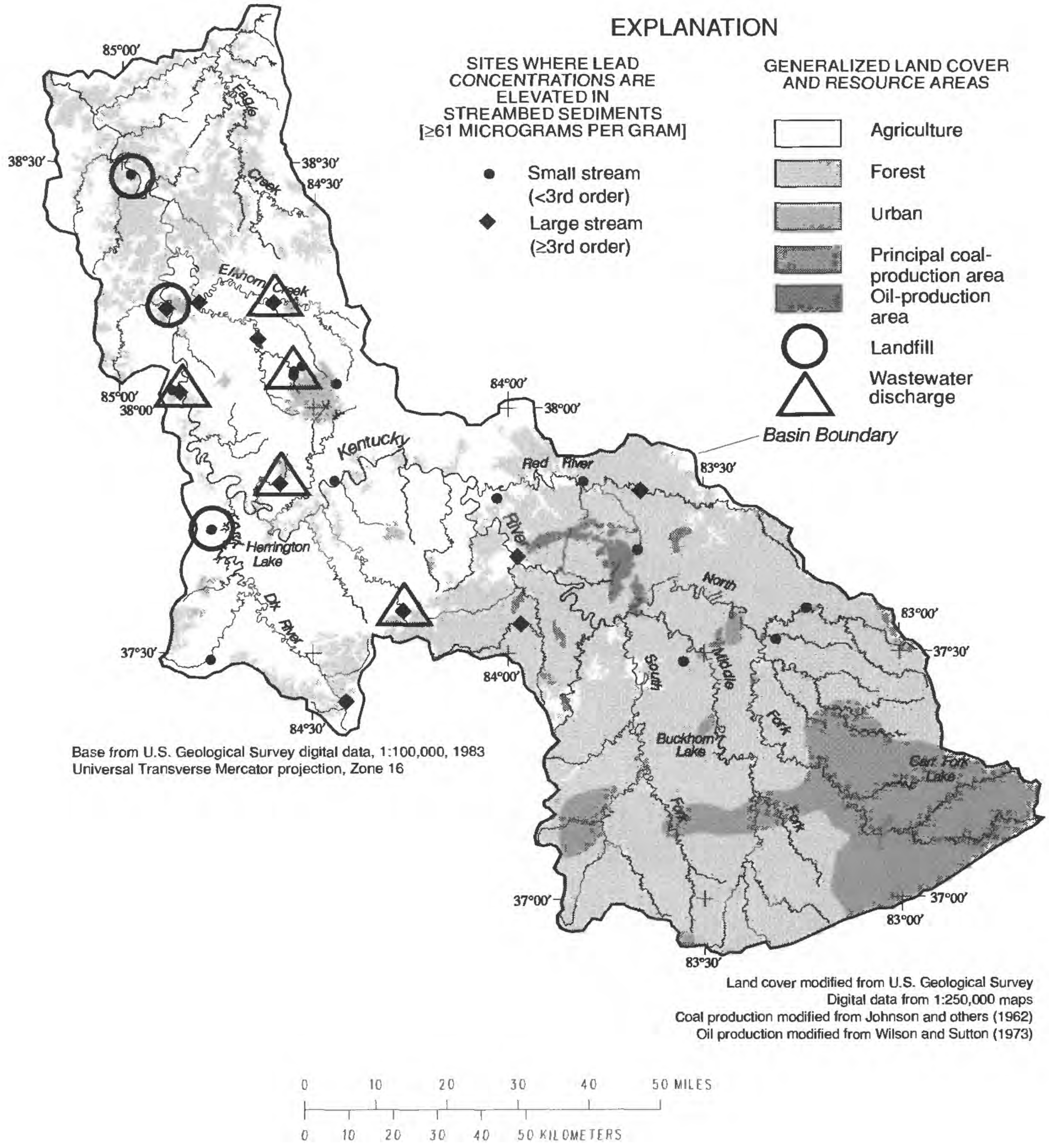
Although natural sources of lead and zinc are present in the Knobs Region, elevated concentrations of these constituents in streambed sediments in the urbanized Inner Bluegrass Region likely result from human sources. Martin and Smoot (1986) found that urban stormwater runoff in central Florida contained substantial concentrations of lead and zinc. Van Hassel and others (1980) found that sediment concentrations of lead and zinc were elevated in



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Land cover modified from U.S. Geological Survey
Digital data from 1:250,000 maps
Coal production modified from Johnson and others (1962)
Oil production modified from Wilson and Sutton (1973)

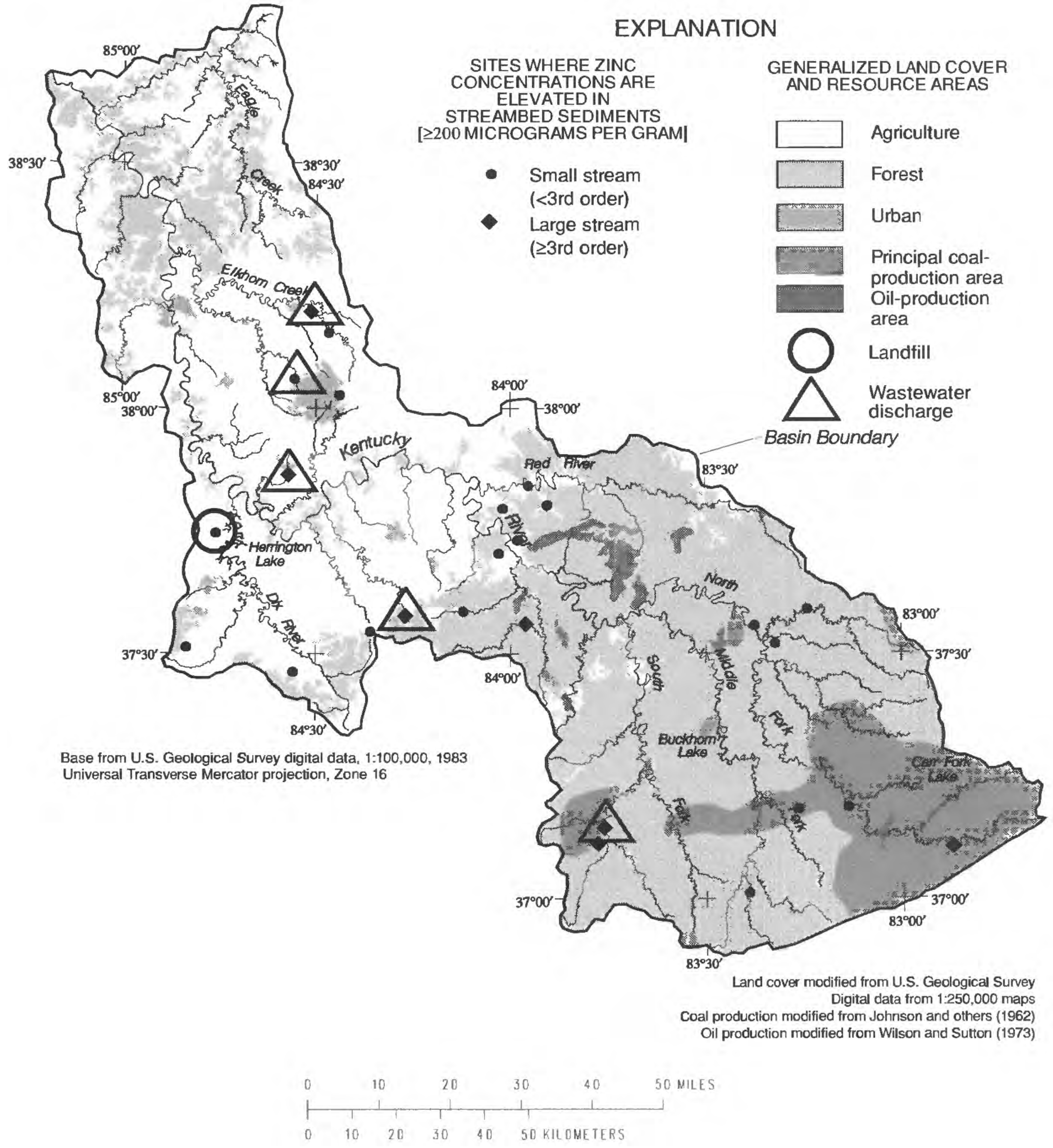
**Figure 18.** Streambed-sediment sites in the Kentucky River Basin characterized by elevated concentrations of chromium.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Land cover modified from U.S. Geological Survey
Digital data from 1:250,000 maps
Coal production modified from Johnson and others (1962)
Oil production modified from Wilson and Sutton (1973)

**Figure 19.** Streambed-sediment sites in the Kentucky River Basin characterized by elevated concentrations of lead.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Land cover modified from U.S. Geological Survey
Digital data from 1:250,000 maps
Coal production modified from Johnson and others (1962)
Oil production modified from Wilson and Sutton (1973)

**Figure 20.** Streambed-sediment sites in the Kentucky River Basin characterized by elevated concentrations of zinc.

streams adjacent to highways and that concentrations were highly correlated with the density of traffic. Concentrations of lead and zinc in streambed sediments are elevated throughout the heavily populated Elkhorn Creek Subbasin.

### Mercury

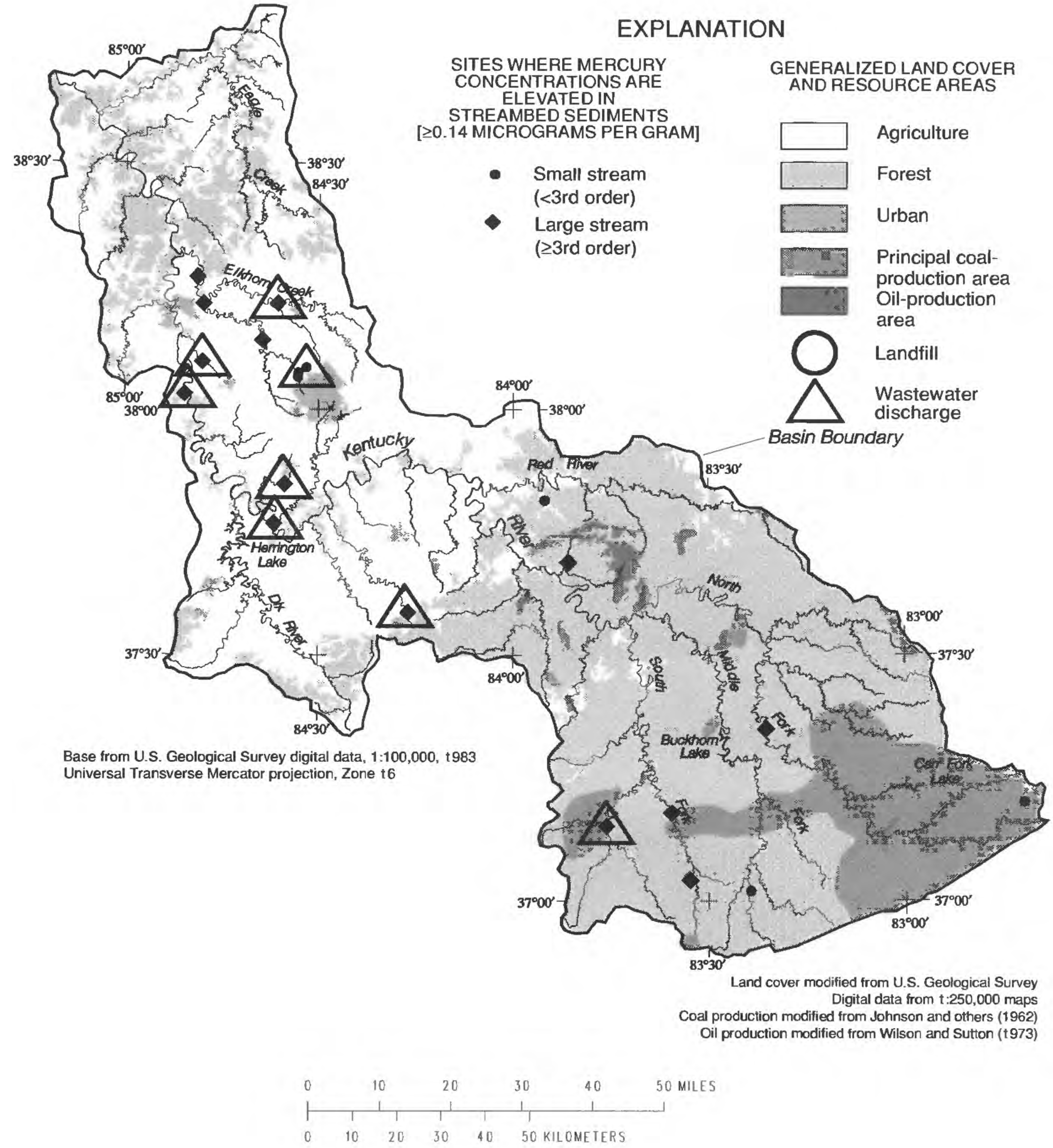
Elevated concentrations of mercury in streambed sediments were found in streams that receive point-source discharges or landfill leachates, as well as in certain streams of the Eastern Coal Field Region (fig. 21). Sediment concentrations of mercury in Town Branch of South Elkhorn Creek and Silver Creek, downstream from the Lexington and Berea wastewater discharges, exceed the USEPA "heavily polluted" guideline of greater than 1.0 $\mu$g/g (U.S. Environmental Protection Agency, 1977). Large concentrations of mercury were reported by KDOW in streams of the greater Lexington area (Logan and others, 1983a, 1983b) and downstream from industrial discharges (Logan and others, 1988). Elevated concentrations of mercury can also result from urban nonpoint sources; for example, atmospheric deposition (Elder, 1988). Elevated streambed-sediment concentrations of mercury in the Kentucky River Basin were greater than extreme values reported from the Schuylkill River near Philadelphia (Stamer and others, 1985) but less than those reported from first- and second-order streams in the Chicago area (Colman and Sanzolone, 1991).

### Antimony

Concentrations of antimony in streambed sediments were largest in small streams of the Knobs Region; however, concentrations were also elevated downstream from point-source discharges. Mean concentrations of antimony were less than those reported in streams of the Chicago area (J.A. Colman and R.F. Sanzolone, U.S. Geological Survey, written commun., 1990), illustrating the potential effect of urban development on sediment chemistry.

### Cadmium and silver

Detectable concentrations of cadmium and silver in streambed sediments of the Kentucky River Basin were generally limited to streams that receive discharges of industrial wastewater. Sediment concentrations of cadmium in these streams were similar to those reported by KDOW (Logan and others, 1983a, 1983b, 1988). Cadmium concentrations in streambed sediments from Town Branch of South Elkhorn Creek and Bailey Run exceeded the USEPA "heavily polluted" guideline of 6 $\mu$g/g (U.S. Environmental Protection Agency, 1977). Cadmium concentrations were also elevated in streambed-sediment samples from three small streams in the Knobs Region, possibly indicating a relation with the geochemistry of New Albany Shale. Other potential sources of cadmium include wastes from mining (Smoot and others, 1991); however, concentrations of cadmium in sediments from the Eastern Coal Field Region are less than the detection limit of 2 $\mu$g/g.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Land cover modified from U.S. Geological Survey
Digital data from 1:250,000 maps
Coal production modified from Johnson and others (1962)
Oil production modified from Wilson and Sutton (1973)

**Figure 21.** Streambed-sediment sites in the Kentucky River Basin characterized by elevated concentrations of mercury.

Detectable concentrations of silver in streambed sediments were found in South Elkhorn Creek and Silver Creek, downstream from point-source discharges. Silver concentrations in streambed sediments collected during the NURE program were all less than the detection limit of 2 $\mu g/g$ (Smoot and others, 1991).

### Selenium

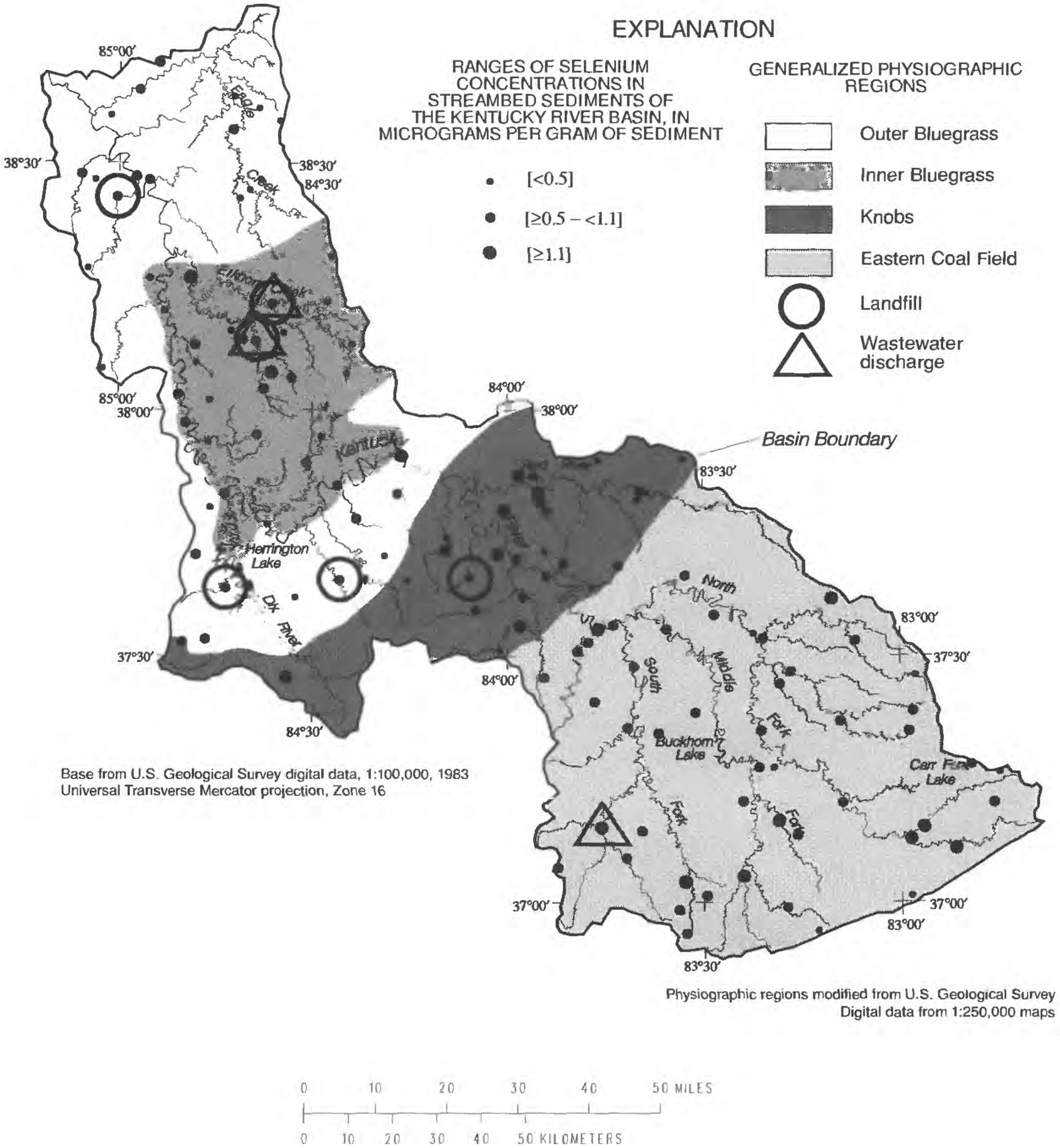
Concentrations of selenium in streambed sediments were generally larger in the Knobs and Eastern Coal Field Regions than in the Inner and Outer Bluegrass Regions (fig. 22). The source of elevated concentrations of selenium appears to be related primarily to the Devonian shales in the Knobs Region; however, the presence of large concentrations of selenium in the sediments of certain streams affected by coal mining may indicate a relation with land disturbance.

## Distribution of Metals and Other Trace Elements in Streambed Sediments in the Kentucky River Main Stem

Concentrations of barium, boron, gallium, lithium, nickel, scandium, thorium, and zinc in streambed sediments in the Kentucky River decreased significantly from the headwaters to the mouth of the Kentucky River; however, considerable unexplained variance exists in these regression relations with river mile ($r^2 = 0.25$ to $0.50$; $n = 19$). Concentrations of antimony, calcium, magnesium, and phosphorus in streambed sediments generally increased from headwaters to mouth, whereas concentrations of iron, lead, manganese, molybdenum, niobium, strontium, and titanium were similar throughout the length of the river. Concentrations of barium, chromium, copper, lithium, nickel, uranium, and vanadium in Kentucky River bed sediments were largest upstream from Lock 10, a finding that indicates the regional effect of tributary streams that receive drainage from the Knobs Region (Devonian shales). Human activities such as oil production and agriculture contribute to the spatial distribution and transport of these constituents. Concentrations of antimony, calcium, lead, phosphorus, and strontium were larger upstream from Lock 4, a pattern that corresponds with geology (Ordovician limestones) and major urban areas in this region. Concentrations of mercury in sediments were elevated in the Kentucky River at a site downstream from Hickman Creek, which receives urban stormwater runoff and point-source discharges from Lexington.

## Measurement of Baseline Concentrations of Metals and Other Trace Elements in Streambed Sediments

Streams that receive drainage from forested catchments were identified in order to define baseline concentrations of metals and other trace elements in streambed sediments in the Kentucky River Basin. Stream locations that are directly affected by agriculture, coal mining, oil production, or urban activities were excluded from this determination; however, the classification of a site as "forested" does not necessarily indicate "pristine" or "unaffected by human activity." Baseline concentrations of metals and other trace elements differed among physiographic regions of the basin (table 6)



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

Physiographic regions modified from U.S. Geological Survey
Digital data from 1:250,000 maps

**Figure 22.** Ranges of concentrations of selenium at streambed-sediment sites in the Kentucky River Basin.

Table 6. Baseline concentrations (geometric mean) of constituents in streambed sediments, by physiographic region in the Kentucky River Basin, and in soils of the eastern United States

[Concentrations in micrograms per gram; --, data not given; <, less than]

| Constituent | Physiographic region[1] | | | | Soils of the eastern United States |
|---|---|---|---|---|---|
| | Inner Bluegrass | Outer Bluegrass | Knobs | Eastern Coal Field | |
| Aluminum | 49,000 | 60,000 | 62,000 | 76,000 | 33,000 |
| Antimony | .5 | .4 | .8 | .5 | .5 |
| Arsenic | 5.7 | 5.9 | 13.4 | 7.6 | 4.8 |
| Barium | 410 | 440 | 450 | 510 | 300 |
| Boron | 1.2 | 1.1 | .8 | .9 | 32 |
| Calcium | 37,000 | 27,000 | 5,100 | 3,700 | 3,400 |
| Cerium | 75 | 82 | 84 | 100 | 78 |
| Chromium | 49 | 58 | 76 | 73 | 36 |
| Cobalt | 15 | 21 | 22 | 21 | 7 |
| Copper | 18 | 20 | 21 | 24 | 14 |
| Gallium | 13 | 16 | 16 | 20 | 10 |
| Iron | 28,000 | 35,000 | 40,000 | 39,000 | 14,000 |
| Lanthanum | 39 | 41 | 42 | 52 | 33 |
| Lead | 34 | 24 | 33 | 29 | 14 |
| Lithium | 34 | 40 | 54 | 52 | -- |
| Magnesium | 6,200 | 7,800 | 5,700 | 6,000 | 2,300 |
| Manganese | 1,600 | 1,600 | 900 | 1,100 | 285 |
| Mercury | .05 | .04 | .04 | .04 | .08 |
| Molybdenum | 2 | 2 | 4 | 2 | -- |
| Neodymium | 36 | 38 | 39 | 48 | 44 |
| Nickel | 24 | 28 | 43 | 35 | 11 |
| Niohium | 5 | 6 | 7 | 9 | 13 |
| Phosphorus | 3,100 | 1,700 | 530 | 650 | 180 |
| Potassium | 17,000 | 26,000 | 20,000 | 22,000 | 7,400 |
| Scandium | 8 | 10 | 11 | 12 | 7 |
| Selenium | .4 | .4 | .7 | .6 | .3 |
| Silver | <2 | <2 | <2 | <2 | -- |
| Sodium | 2,700 | 3,700 | 3,300 | 3,900 | 2,600 |
| Strontium | 130 | 110 | 69 | 97 | 51 |
| Sulfur | 658 | 578 | 382 | 349 | -- |
| Thorium | 10 | 11 | 12 | 14 | -- |
| Titanium | 2,400 | 3,400 | 3,400 | 3,700 | 3,000 |
| Uranium | .9 | .7 | 1.6 | 1.3 | -- |
| Vanadium | 60 | 74 | 110 | 89 | 46 |
| Yttrium | 26 | 26 | 20 | 22 | 23 |
| Zinc | 77 | 77 | 110 | 110 | 40 |
| Inorganic carhon | 7,940 | 5,900 | 723 | 497 | -- |
| Organic carhon | 23,200 | 17,500 | 15,400 | 17,700 | 15,000 |
| Total carbon | 36,100 | 26,100 | 17,600 | 19,600 | -- |
| Number of samples | 18 | 41 | 38 | 104 | 371 |

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[1] McFarlan (1943).

because of differences in regional geochemistry. With the exception of boron, cadmium, mercury, selenium, and silver, median baseline concentrations of metals and other trace elements differed significantly among the physiographic regions (Kruskal-Wallis and Tukey multiple range tests; $p < 0.05$). Baseline concentrations of most metals in streambed sediments generally exceeded concentrations reported in soils from the eastern United States (Shacklette and others, 1984). However, baseline concentrations for many of the rare earth elements, as well as for antimony, arsenic, mercury, sodium, and titanium, were similar to those reported for soils.

## Sources of Variance in Concentrations of Metals and Other Trace Elements in Streambed Sediments

The percentage of variance in constituent concentrations explained by the distance between streambed-sediment locations and by error inherent in laboratory analytical procedures generally indicates that (1) variance is largest among streams that are distant from one another in the Kentucky River Basin (table 7; level 1), (2) variance is somewhat smaller among streams that are within the same general region of the basin (table 7; level 2), but larger than between locations (100 m apart) in the same stream (table 7; level 3), and (3) variance attributable to laboratory procedures (table 7; level 4) is generally smaller than the variance observed among different streams. In most cases, the variance tends to decrease from level 1 to level 4. Results of a one-way hierarchal ANOVA, evaluated at a significance level of 0.05, are presented for each constituent (table 7) as the percentage of variance attributable to each level and the total variance component for the constituent. The variance associated with the geometric mean for each level can be calculated by multiplying the variance percentage by the total variance component.

The variance percentage is significantly larger at level 1 ("between-cell," basin-scale variability) for aluminum, arsenic, cerium, chromium, cobalt, copper, gallium, lanthanum, lithium, nickel, scandium, sodium, titanium, and vanadium. This pattern likely indicates that differences in the concentrations of these metals and trace elements are associated with relatively large spatial differences among physiographic regions in the Kentucky River Basin, which have unique geologic and land-use characteristics. In contrast, variance percentage is significantly larger at level 2 ("within-cell," regional-scale variability) for beryllium, calcium, lead, magnesium, potassium, strontium, ytterbium, and zinc. This pattern may indicate that concentrations of those constituents in bedrock and soils differ substantially within relatively small (10 km by 10 km) parts of the Kentucky River Basin.

Although the variance percentage attributable to variability within a particular stream (level 3) is generally less than that observed among different streams in the Kentucky River Basin, within-stream variance significantly exceeds intersite variance (level 1 or 2) for iron, manganese, phosphorus, and sulfur, as well as for certain ancillary constituents such as total carbon and organic carbon. Small-scale variability of these constituents probably reflects biogeochemical processes that occur in association with stream sediments (Elder, 1988). The rates of these processes

Table 7. Percentage of variance explained for concentrations of constituents in streambed sediments of small streams, relative to intersite, intrasite, and analytical variability

[Level 1, basin-scale intersite variability; level 2, regional-scale intersite variability; level 3, within-stream variability; level 4, analytical laboratory variability]

| Constituent | Level 1 | Level 2 | Level 3 | Level 4 | Total variance component |
|---|---|---|---|---|---|
| Aluminum | 58.3 | 22.8 | 18.5 | 0.4 | 0.01229 |
| Antimony | 58.6 | 2.8 | 31.8 | 6.9 | .08755 |
| Arsenic | 69.5 | 16.5 | 11.0 | 3.1 | .09204 |
| Barium | 41.8 | 27.2 | 0 | 30.9 | .01303 |
| Beryllium | 33.0 | 46.8 | 12.2 | 8.1 | .01913 |
| Boron | 0 | 48.5 | 0 | 51.5 | .13379 |
| Calcium | 34.5 | 60.8 | 4.4 | .3 | .34022 |
| Cerium | 50.3 | 39.8 | 4.1 | 5.9 | .01114 |
| Chromium | 44.4 | 37.9 | 12.2 | 5.6 | .01556 |
| Cobalt | 50.3 | 34.1 | 13.8 | 1.9 | .02768 |
| Copper | 57.1 | 33.3 | 7.2 | 2.5 | .04744 |
| Gallium | 53.3 | 19.4 | 16.0 | 11.3 | .01166 |
| Iron | 29.8 | 31.8 | 36.2 | 2.2 | .01815 |
| Lanthanum | 60.6 | 28.8 | 3.6 | 7.1 | .00855 |
| Lead | 20.9 | 72.9 | 3.9 | 2.3 | .09578 |
| Lithium | 58.3 | 22.7 | 17.3 | 1.7 | .01417 |
| Magnesium | 22.0 | 67.1 | 10.4 | .5 | .04735 |
| Manganese | 35.4 | 24.0 | 39.8 | .8 | .06089 |
| Mercury | 34.9 | 13.5 | 8.5 | 43.1 | .07748 |
| Neodymium | 59.0 | 23.3 | 6.4 | 11.4 | .00883 |
| Nickel | 66.5 | 25.1 | 7.5 | 1.0 | .05456 |
| Niobium | 47.4 | 6.4 | 18.2 | 28.1 | .06594 |
| Phosphorus | 64.0 | 14.8 | 20.0 | 1.2 | .08843 |
| Potassium | 31.7 | 34.0 | 23.0 | 11.4 | .00701 |
| Scandium | 51.9 | 26.5 | 20.5 | 1.1 | .01228 |
| Sodium | 74.2 | 18.1 | 7.5 | .4 | .05395 |
| Strontium | 21.3 | 69.3 | 8.1 | 1.3 | .01768 |
| Sulfur | 0 | 64.2 | 20.0 | 15.8 | .11496 |
| Thallium | 54.4 | 12.3 | 14.2 | 19.1 | .01491 |
| Titanium | 62.4 | 19.2 | 9.0 | 9.5 | .01357 |
| Uranium | 60.8 | 30.3 | 2.3 | 6.8 | .12128 |
| Vanadium | 57.2 | 33.1 | 9.0 | .8 | .02684 |
| Yttrium | 6.3 | 76.9 | 14.9 | 2.0 | .00901 |
| Ytterbium | 13.4 | 73.2 | 0 | 13.4 | .00773 |
| Zinc | 40.4 | 46.4 | 12.5 | .8 | .04317 |
| Total carbon | .9 | 75.2 | 22.6 | 1.3 | .05755 |
| Organic carbon | 0 | 65.4 | 22.4 | 12.1 | .05207 |
| Carbonate carbon | 17.6 | 56.0 | 15.6 | 10.8 | .59905 |

are likely to differ to a greater extent in small streams than in large streams because of heterogeneity (or patchiness) of microhabitats, groundwater influences, and other biogeochemical factors that contribute to sorption processes.

The variance associated with laboratory analytical differences (level 4) is generally less than 10 percent. Laboratory variance for most metals ranges from 0.4 percent for aluminum to 5.6 percent for chromium. Laboratory variance for elements such as barium, mercury, niobium, and thorium is large, ranging from 19 percent to 43 percent, probably because most of the analytical results are near the laboratory detection limit. The relatively large (51.5 percent) laboratory variance for boron (table 7), however, is not associated with analytical detection limits, and the variance percentage for boron is not significantly different among all levels; these sources of error variance confound the environmental interpretation of boron data in the Kentucky River Basin. Laboratory variance (level 4) is not significantly different from within-stream variance (level 3) for antimony, lanthanum, neodymium, uranium, and ytterbium; however, intersite (level 1 and level 2) variance is significantly larger for those trace elements.

## Factor Analysis of Metals and Other Trace-Element Concentrations in Bed Sediments of Small Streams

Factor analysis is a multivariate statistical technique that can be used to explain relations among groups of constituents with respect to environmental gradients within a hydrologic system. Factors (eigenvectors) produced from the analysis indicate (1) the relative importance or weighting of each constituent with respect to other constituents and (2) statistical groups of constituents that are likely to correspond with sources. Further discussions of factor analysis and other multivariate ordination techniques are given by Gauch (1982) and Pielou (1984).

Results from factor analysis of concentrations of metals and other trace elements in streambed sediment samples from first- and second-order streams indicate close relations to the geology of the Kentucky River Basin. The varimax rotation was applied to maximize the differences among the various factors; that is, to produce distinct trace-element signatures that could be used to distinguish differences in natural sources of metals and other trace elements in the basin. A five-factor model, having a minimum eigenvalue of 2.01, was used to generate factor weightings for each geochemical variable (table 8). These weightings represent the correlations between the varimax factor scores and the constituent concentrations.

Elements that are typically associated with clastic sedimentary rocks have the largest loading in factor 1. Aluminosilicate minerals, such as clay minerals, seem to be the predominant influence on this factor, as is demonstrated by the large factor loadings for aluminum, gallium, and other trace elements that tend to be concentrated in clays (Wedepohl, 1978). The influence of heavy-mineral oxides is also indicated by the moderately large loadings for chromium, niobium, titanium, and iron. Streams with positive factor 1 scores are in the Eastern Coal Field Region in the upper Kentucky

Table 8. Five-factor varimax model indicating relative weighting of sediment-constituent concentrations in first- and second-order streams of the Kentucky River Basin, October 1987

| Factor 1 | | Factor 2 | | Factor 3 | | Factor 4 | | Factor 5 | |
|---|---|---|---|---|---|---|---|---|---|
| Aluminum | 0.92 | Arsenic | 0.89 | Manganese | 0.84 | Magnesium | 0.80 | Organic carbon | 0.71 |
| Gallium | .87 | Uranium | .76 | Yttrium | .84 | Carbonate carbon | .68 | Total carbon | .61 |
| Neodymium | .86 | Vanadium | .76 | Phosphorus | .64 | Calcium | .65 | Mercury | .54 |
| Scandium | .86 | Nickel | .76 | Ytterbium | .57 | Strontium | .51 | Strontium | .47 |
| Lanthanum | .84 | Antimony | .75 | Cobalt | .43 | Potassium | .49 | Total sulfur | .43 |
| Cerium | .83 | Zinc | .65 | Barium | .36 | Total carbon | .49 | Lead | .40 |
| Thallium | .80 | Copper | .59 | Lead | .34 | Total sulfur | .49 | Phosphorus | .32 |
| Beryllium | .79 | Iron | .56 | Calcium | .22 | Copper | .25 | Antimony | .29 |
| Lithium | .72 | Chromium | .54 | Cerium | .21 | Cobalt | .19 | Copper | .25 |
| Barium | .70 | Cobalt | .50 | Iron | .19 | Phosphorus | .19 | Uranium | .25 |
| Chromium | .69 | Scandium | .35 | Organic carbon | .19 | Gallium | .15 | Boron | .23 |
| Niobium | .69 | Beryllium | .34 | Strontium | .18 | Manganese | .12 | Zinc | .22 |
| Titanium | .63 | Lithium | .33 | Carbonate carbon | .16 | Scandium | .10 | Yttrium | .20 |
| Potassium | .58 | Lead | .31 | Total carbon | .12 | Iron | .10 | Barium | .20 |
| Sodium | .58 | Mercury | .30 | Neodymium | .08 | Titanium | .07 | Calcium | .14 |
| Iron | .57 | Aluminum | .23 | Lanthanum | .08 | Aluminum | .06 | Lanthanum | .12 |
| Zinc | .49 | Gallium | .22 | Mercury | .08 | Nickel | .05 | Neodymium | .11 |
| Vanadium | .48 | Titanium | .19 | Arsenic | .07 | Zinc | .03 | Carbonate carbon | .09 |
| Nickel | .42 | Niobium | .19 | Beryllium | .07 | Yttrium | .03 | Niobium | .05 |
| Copper | .41 | Total sulfur | .16 | Total sulfur | .04 | Lithium | .02 | Arsenic | .00 |
| Cobalt | .36 | Thallium | .16 | Nickel | .03 | Sodium | .01 | Cerium | -.01 |
| Ytterbium | .31 | Organic carbon | .13 | Gallium | .02 | Boron | .01 | Thallium | -.02 |
| Mercury | .14 | Potassium | .12 | Thallium | .01 | Vanadium | .01 | Beryllium | -.02 |
| Strontium | .09 | Magnesium | .08 | Uranium | -.03 | Antimony | .00 | Sodium | -.04 |
| Arsenic | .09 | Barium | .08 | Zinc | -.05 | Lead | .00 | Manganese | -.09 |
| Uranium | .07 | Neodymium | .03 | Chromium | -.07 | Beryllium | -.01 | Ytterbium | -.11 |
| Lead | .04 | Ytterbium | .02 | Copper | -.07 | Organic carbon | -.03 | Gallium | -.12 |
| Magnesium | .04 | Yttrium | -.01 | Potassium | -.08 | Niobium | -.07 | Aluminum | -.12 |
| Boron | .00 | Total carbon | -.01 | Niobium | -.09 | Arsenic | -.07 | Vanadium | -.18 |
| Yttrium | -.07 | Cerium | -.02 | Boron | -.09 | Chromium | -.09 | Iron | -.18 |
| Organic carbon | -.07 | Lanthanum | -.03 | Magnesium | -.11 | Mercury | -.14 | Scandium | -.19 |
| Manganese | -.12 | Boron | -.04 | Antimony | -.12 | Barium | -.15 | Magnesium | -.19 |
| Antimony | -.13 | Manganese | -.10 | Scandium | -.13 | Ytterbium | -.20 | Chromium | -.21 |
| Total sulfur | -.27 | Carbonate carbon | -.20 | Aluminum | -.17 | Uranium | -.26 | Lithium | -.24 |
| Total carbon | -.42 | Phosphorus | -.26 | Vanadium | -.21 | Neodymium | -.27 | Nickel | -.24 |
| Phosphorus | -.42 | Sodium | -.26 | Titanium | -.22 | Thallium | -.30 | Cobalt | -.33 |
| Carbonate carbon | -.51 | Calcium | -.29 | Sodium | -.22 | Lanthanum | -.30 | Potassium | -.36 |
| Calcium | -.58 | Strontium | -.37 | Lithium | -.24 | Cerium | -.31 | Titanium | -.38 |

River Basin. The geochemistry of streambed-sediment samples collected in the upper Kentucky River Basin is most representative of the chemical associations found in shales of the region.

Factor 2 is indicative of the New Albany Shale, a Devonian black shale that is rich in certain metals and other trace elements. The association of antimony, arsenic, chromium, cobalt, copper, iron, uranium, vanadium, and zinc is concentrated in the anaerobic, sedimentary environment of typical black shales, such as the Kupferschiefer Shale, Chattanooga Shale, and the New Albany Shale (Krauskopf, 1955; Goldschmidt, 1958; Wedepohl, 1978). Constituents with large factor scores for factor 2 are typically associated with stream sites either on or just downstream from outcrops of New Albany Shale. The New Albany Shale is the single largest source of natural trace-element accumulation in stream sediments of the Kentucky River Basin.

Factor 3 characterizes the cherty residuum from rocks of the Inner Bluegrass Region. Weathering of the carbonate bedrock of Lower Ordovician age in the Inner Bluegrass Region has produced karst topography and a surficial cover of nearly insoluble material. This insoluble residuum, which is composed mostly of granular chert with some apatite, dominates the stream sediments of the region. Much of the siliceous material in streambed sediments is coated with manganese oxide. Manganese and trace elements that are associated with manganese oxide coatings, such as barium and cobalt have large to moderate loadings in factor 3, as do elements that are commonly associated with apatite; for example, phosphorus, yttrium, and ytterbium. Although calcium is a principal constituent of apatite and cerium is generally concentrated in that mineral, loadings for these constituents in factor 3 are small; these elements are strongly associated with factor 4 and factor 1.

Factor 4 is characterized by large loadings for calcium, magnesium, strontium, and carbonate carbon, representing dolomitic-carbonate sedimentary bedrock of Upper Ordovician age in the Outer Bluegrass Region. The large loading for potassium in factor 4 may be associated with agricultural activities (for example, application and runoff of agricultural fertilizers) in the Outer Bluegrass Region. Alternatively, the high potassium loading may be related to the particular type of clay found in the shale layers of the Outer Bluegrass limestone. However, the Upper Ordovician rocks in Kentucky are not known to be rich in potassium.

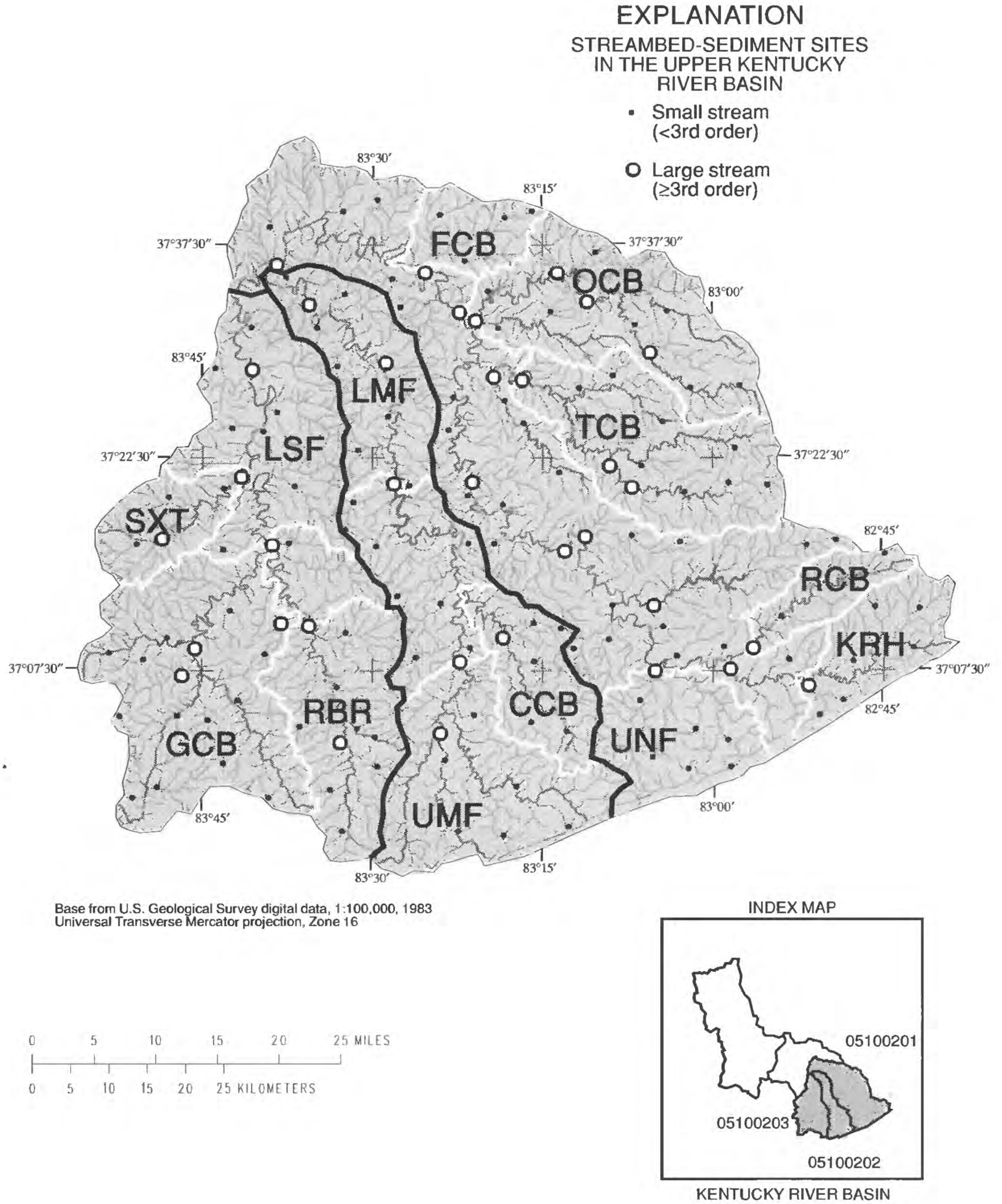
Elements that tend to concentrate in organic-rich sediments, such as lead, mercury, strontium, and sulfur, have large to moderate loadings in factor 5. Organic enriched sediments are generally characteristic of "low-energy" (low stream gradient), anaerobic, sedimentary environments. Because no consistent relation was found between the geology of the Kentucky River Basin and the location of sites with high scores for factor 5, stream locations with large scores for this factor are assumed to be affected by local conditions. For example, stream gradients at those stream sites may be unusually low. Alternatively, stream locations with large scores for factor 5 may have been affected by the discharge of organic wastes or sediment from agricultural activities.

## Classification of Subbasins in the Kentucky River Basin

Streambed-sediment data for each of 31 tributary stream subbasins of the Kentucky River were analyzed to (1) obtain a better understanding of natural and human sources of metals and other trace elements in the basin, (2) distinguish small spatial differences in the relative concentrations of constituents within physiographic regions of the basin, and (3) identify stream reaches (or groups of streams) that function as the source of constituents in sediment and water of the Kentucky River main stem and its major tributaries. Multivariate cluster analysis of subbasins reveals a hierarchal classification that corresponds with differences in the trace-element signatures of streambed sediments among subbasin locations. Differences in the trace-element signatures among subbasins within the entire Kentucky River Basin are indicated by relative differences in the concentrations of major metals and other trace elements. Results from cluster analysis indicate that subbasins are grouped by physiographic region and the human activities in these regions.

In contrast, differences in the trace-element signatures within regions of the Kentucky River Basin are distinguished by differences in concentrations of calcium and rare-earth elements (Upper Kentucky River Basin (figs. 23 and 24; table 9)); differences in concentrations of arsenic, nickel, strontium, and vanadium (Middle Kentucky River Basin (figs. 25 and 26; table 10)); or differences in concentrations of aluminum, arsenic, barium, cobalt, lead, and yttrium (Lower Kentucky River Basin (figs. 27 and 28; table 11)). Results from cluster analysis indicate that subbasins in the Upper Kentucky River Basin are grouped in relation to a land-disturbance gradient, from virtually undisturbed forests to extensive surface-mining disturbance. Regional effects of oil production and waste-management practices contribute to these differences. Subbasins in the Middle Kentucky River Basin are separated by physiographic differences, specifically the Knobs and Eastern Coal Field regions, as well as regional influences from oil-well brine discharges. Subbasins in the Lower Kentucky River Basin are clustered in relation to urban and rural land uses, as well as geologic differences.

The Upper Kentucky River consists of three hydrologic units: the North Fork Kentucky River (05100201), the Middle Fork Kentucky River (05100202), and the South Fork Kentucky River (05100203) (fig. 23). These units lie exclusively in the Eastern Coal Field Region; the predominant land use is coal mining, but some land is affected by oil production. Cluster analysis of subbasins in the Upper Kentucky River hydrologic units (fig. 24) reveals three clusters that are separated primarily on the basis of differences in concentrations of calcium, cerium, lanthanum, neodymium, phosphorus, and strontium. Cluster A contains the headwaters of the Middle Fork (UMF) and North Fork (KRH) of the Kentucky River, as well as the Rockhouse Creek (RCB) and Troublesome Creek (TCB) Subbasins. These areas are characterized by large concentrations of calcium, cerium, and strontium, and smaller concentrations of phosphorus in streambed sediments.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

**Figure 23.** Subbasins and streambed-sediment sites in the Upper Kentucky River Basin. (Three-letter subbasin codes and eight-digit hydrologic unit codes are identified in table 9.)

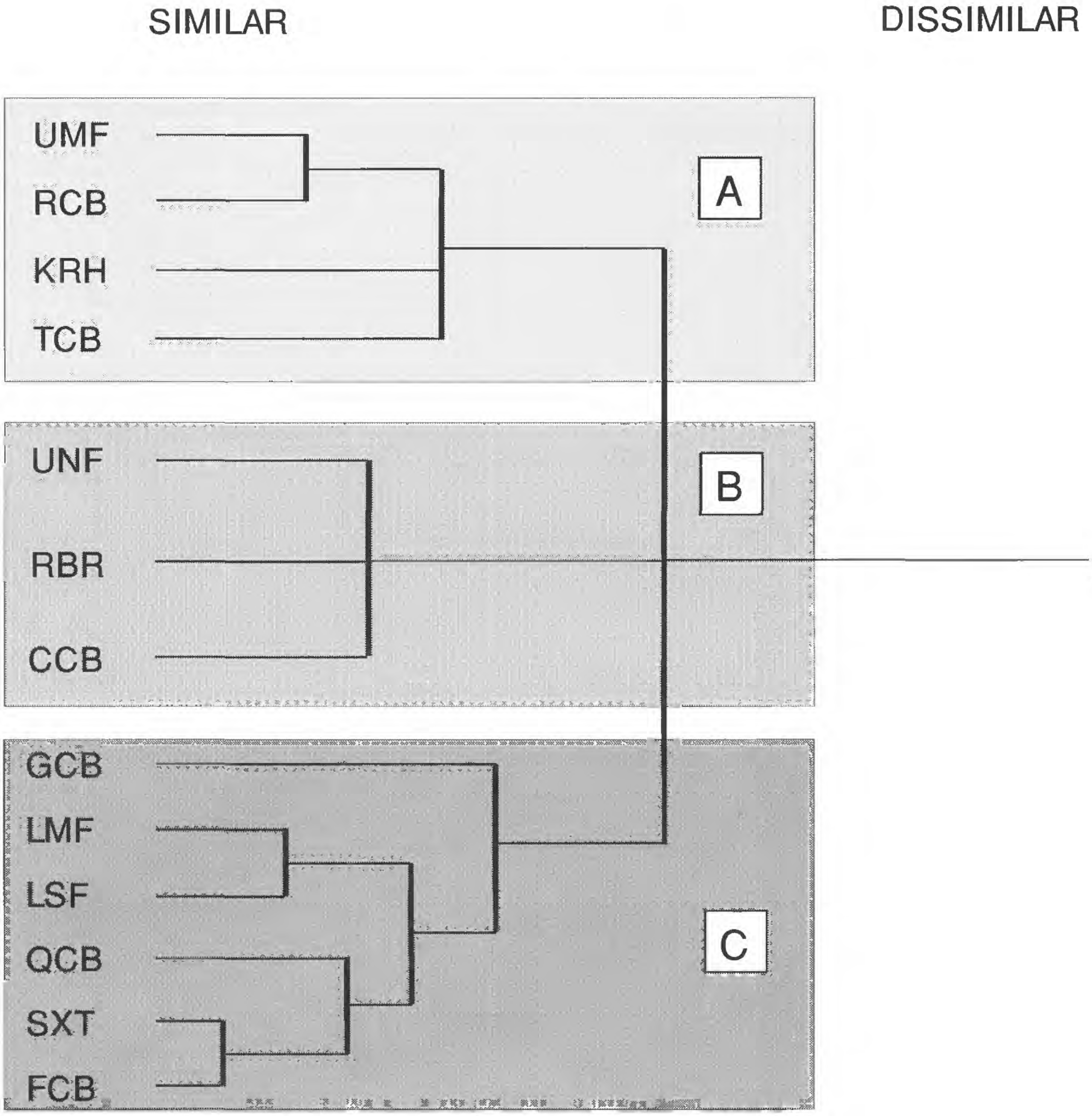


**Figure 24.** Cluster-analysis dendrogram for subbasins in the Upper Kentucky River Basin. (Three-letter subbasin codes are identified in table 9.)

Table 9. Identification of hydrologic units and subbasins in the Upper Kentucky River Basin shown in figures 23 and 24

| Hydrologic unit | Subbasin | Description |
|---|---|---|
| North Fork Kentucky River hydrologic unit (05100201) | FCB | Frozen Creek Subbasin |
| | KRH | Headwaters of the Kentucky River |
| | QCB | Quicksand Creek Subbasin |
| | RCB | Rockhouse Creek Subbasin |
| | TCB | Troublesome Creek Subbasin |
| | UNF | Headwater tributaries of North Fork Kentucky River |
| Middle Fork Kentucky River hydrologic unit (05100202) | CCB | Cutshin Creek Subbasin |
| | LMF | Downstream tributaries of Middle Fork Kentucky River |
| | UMF | Headwaters of Middle Fork Kentucky River |
| South Fork Kentucky River hydrologic unit (05100203) | GCB | Goose Creek Subbasin |
| | LSF | Downstream tributaries of South Fork Kentucky River |
| | RBR | Red Bird River Subbasin |
| | SXT | Sexton Creek Subbasin |

Table 10. Identification of subbasins in the Middle Kentucky River Basin (hydrologic unit 05100204) shown in figures 25 and 26

| Subbasin | Description |
|---|---|
| BSC | Big Sinking Creek Subbasin |
| LRR | Lower Red River Subbasin |
| SCC | Station Camp Creek Subbasin |
| STC | Sturgeon Creek Subbasin |
| URR | Upper Red River Subbasin |

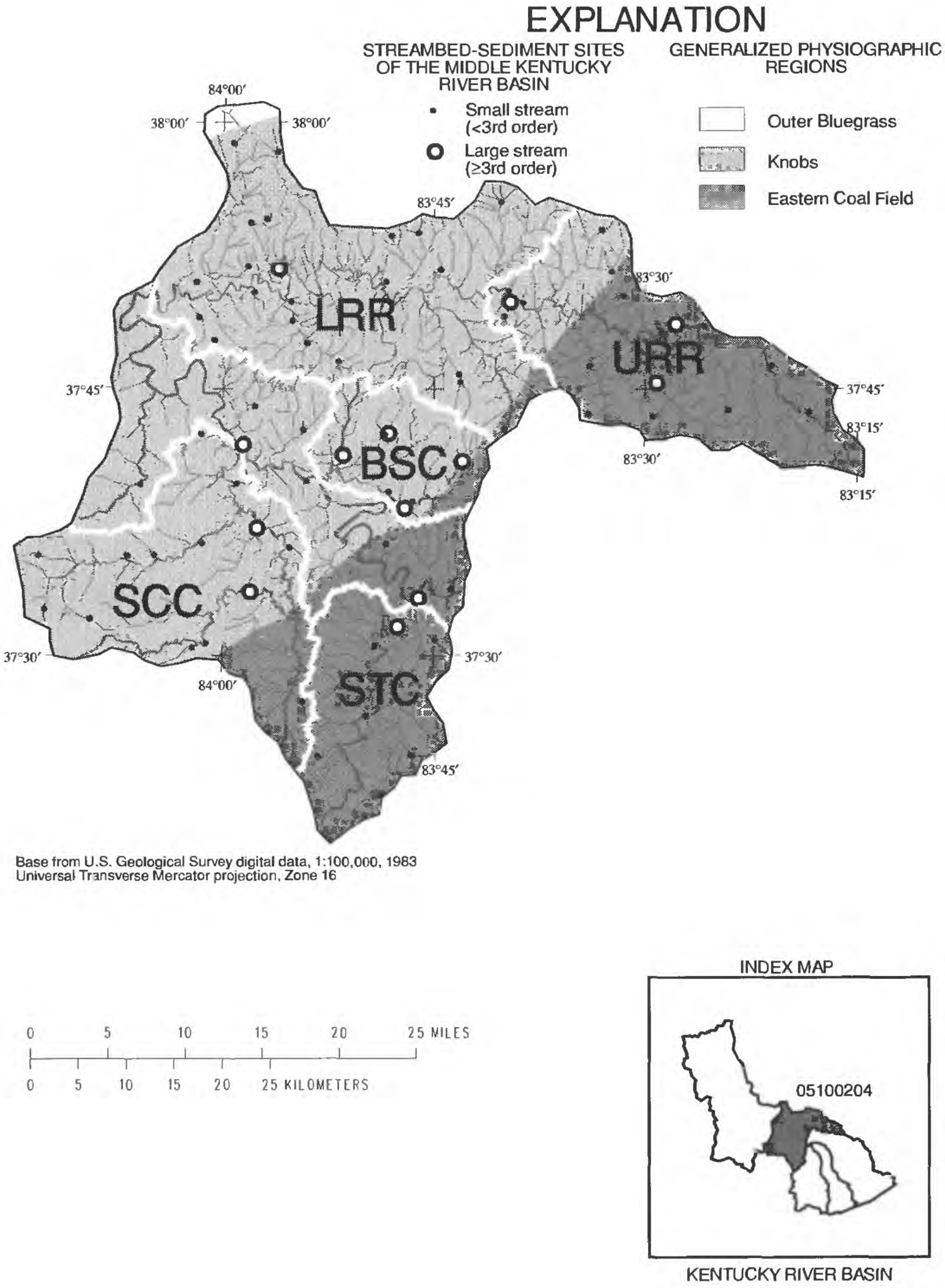


**Figure 25.** Subbasins and streambed-sediment sites in the Middle Kentucky River Basin. *(Three-letter subbasin codes are identified in table 10.)*

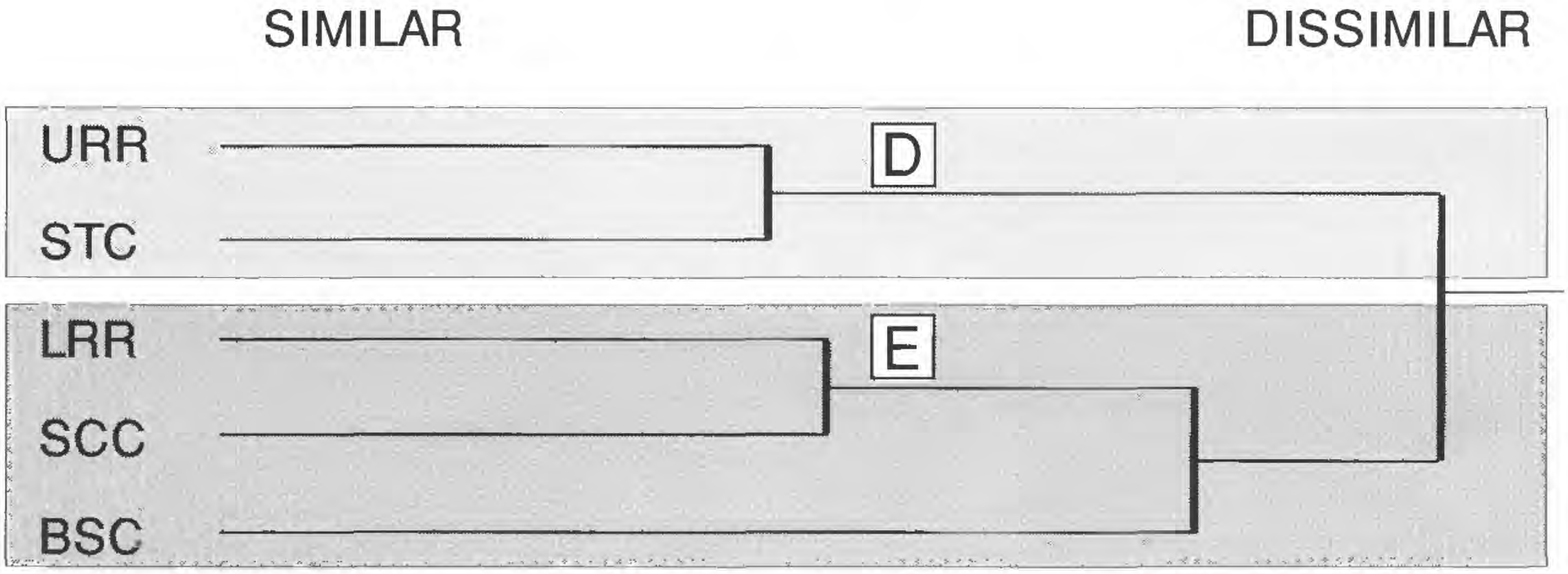
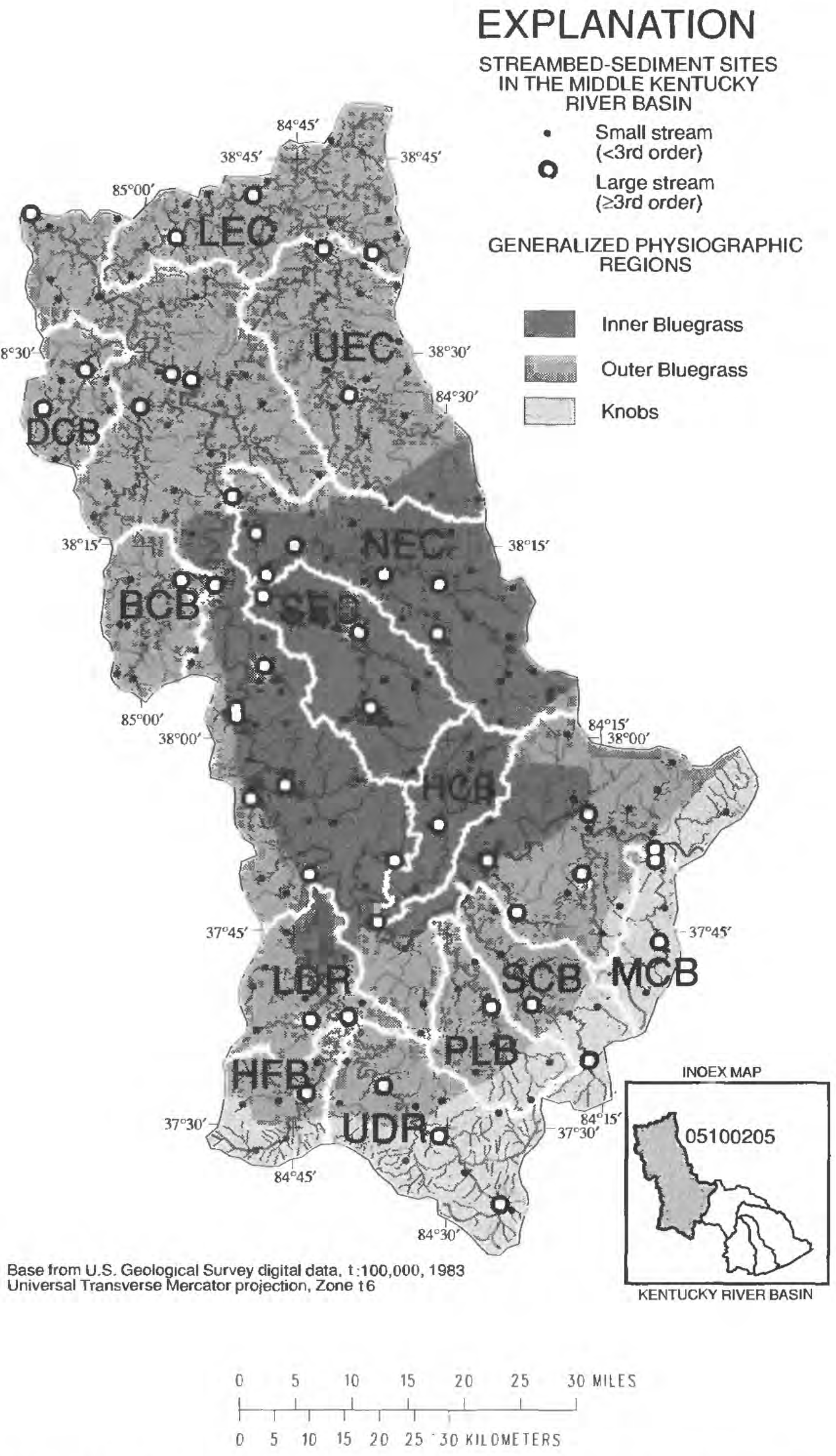


**Figure 26.** Cluster-analysis dendrogram for subbasins in the Middle Kentucky River Basin. (Three-letter subbasin codes are identified in table 10.)



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

**Figure 27.** Subbasins and streambed-sediment sites in the Lower Kentucky River Basin. (Three-letter subbasin codes are identified in table 11.)

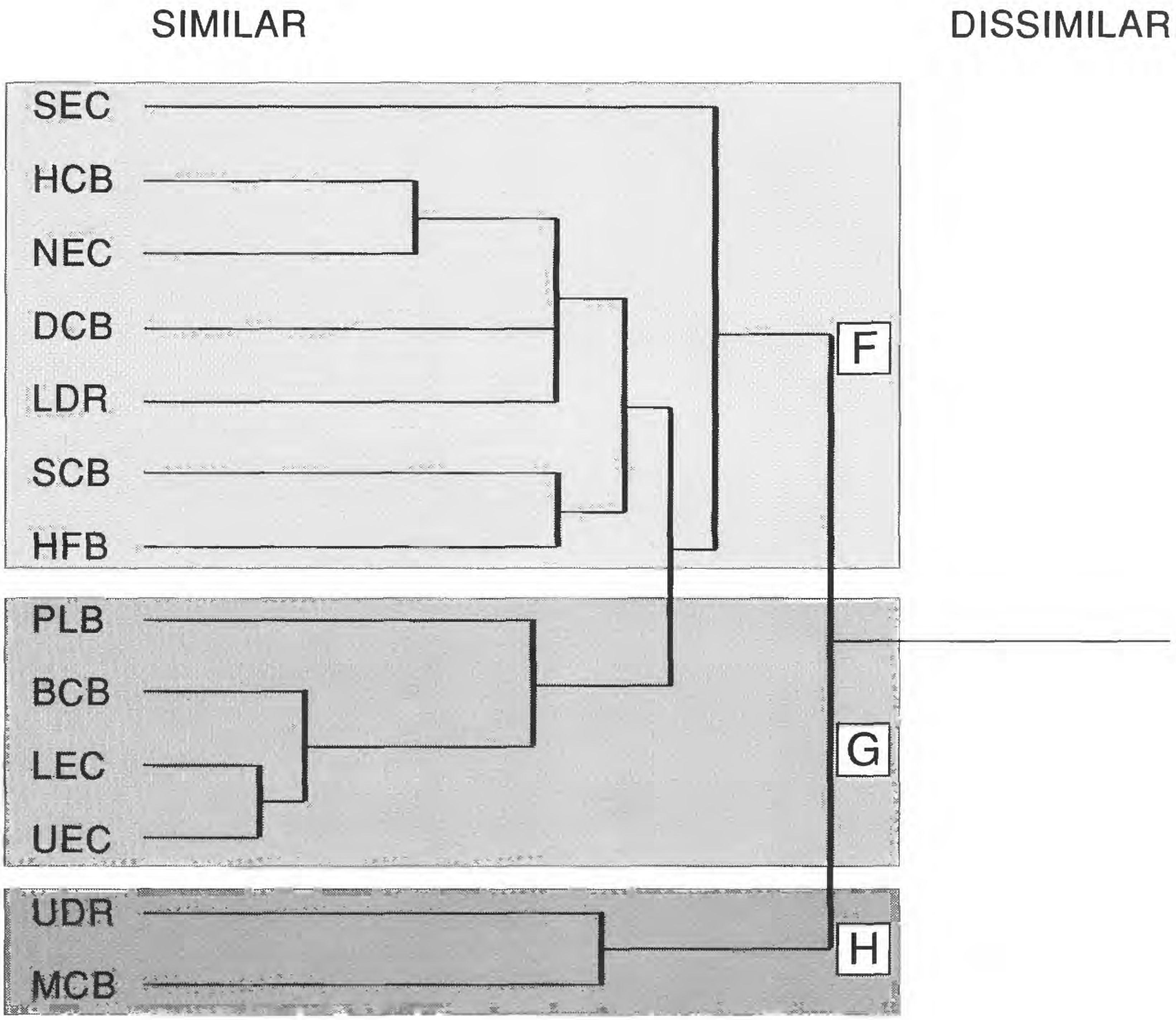


**Figure 28.** Cluster-analysis dendrogram for subbasins in the Lower Kentucky River Basin. (Three-letter subbasin codes are identified in table 11.)

Table 11. Identification of subbasins in the Lower Kentucky River Basin (hydrologic unit 05100205) shown in figures 27 and 28

| Subbasin | Description |
|---|---|
| BCB | Benson Creek Subasin |
| DCB | Drennon Creek Subbasin |
| HCB | Hickman Creek Subbasin |
| HFB | Hanging Fork Subbasin |
| LDR | Lower Dix River Subbasin |
| LEC | Lower Eagle Creek Subbasin |
| MCB | Muddy Creek Subbasin |
| NEC | North Elkhorn Creek Subbasin |
| PLB | Paint Lick Creek Subbasin |
| SCB | Silver Creek Subassin |
| SEC | South Elkhorn Creek Subbasin |
| UDR | Upper Dix River Subbasin |
| UEC | Upper Eagle Creek Subbasin |

Cluster B contains the Redbird River (RBR) and Cutshin Creek (CCB) Subbasins, as well as streams in the southwestern part of the North Fork Kentucky River hydrologic unit (fig. 23; subbasin UNF), where surface mining is less extensive and streambed sediments contained smaller concentrations of cerium, neodymium, and strontium than subbasins in cluster A. Subbasins in cluster C are characterized by streams that contained larger concentrations of lanthanum and phosphorus and smaller concentrations of calcium and strontium. Those subbasins are in the northwestern part of the Eastern Coal Field Region. Streams in those subbasins are affected by a variety of human activities, including extensive coal mining, agriculture, point-source discharges, waste-management practices, and oil-production (figs. 3a and 3b). Streambed-sediment concentrations of barium and lithium were larger in those subbasins.

The Middle Kentucky River hydrologic unit (05100204) includes parts of the Outer Bluegrass, Knobs, and Eastern Coal Field Regions (fig. 25). The predominant human activities are agriculture and oil production. Cluster analysis of subbasins in the Middle Kentucky River hydrologic unit (fig. 26) reveals two clusters that are distinguished by physiographic region, primarily because of differences in median concentrations of arsenic, calcium, nickel, strontium, uranium, and vanadium in streambed sediments. Cluster D contains two subbasins that lie within the Eastern Coal Field Region (fig. 25): Upper Red River (URR) and Sturgeon Creek (STC). Cluster E contains three subbasins that are in the Knobs Region, one of which is affected by oil-well-brine discharges (Big Sinking Creek (BSC)). The occurrence of Devonian shales likely accounts for the larger concentrations of arsenic, nickel, uranium, and vanadium in streambed sediments of the subbasins in cluster E, whereas elevated concentrations of barium, lithium, and chromium distinguish the Big Sinking Creek Subbasin from the Station Camp Creek (SCC) and Lower Red River (LRR) Subbasins.

Results of cluster analysis indicate that the subbasins of the Middle Kentucky River hydrologic unit are less similar to one another (subbasins are joined further to the right in the dendrogram) (fig. 26) than are the subbasins of the Upper Kentucky River hydrologic unit described previously. The geology of the Middle Kentucky River hydrologic unit is more complex, ranging in rock composition from dolomitic limestones of Silurian age to Devonian-age and Mississippian-age shales, to sandstones, siltstones, and shales of Pennsylvanian age. The diversity of geology in the Middle Kentucky River hydrologic unit likely accounts for the dissimilarity among subbasins, as indicated by concentrations of metals and other trace elements in streambed sediments.

The Lower Kentucky River hydrologic unit (05100205) contains the Inner and Outer Bluegrass Regions and part of the Knobs Region (fig. 27). Land uses are predominantly agricultural and urban. Cluster analysis of subbasins in the Lower Kentucky River hydrologic unit (fig. 28) reveals three clusters that are distinguished by physiographic region and land uses, primarily because of differences in concentrations of aluminum, arsenic, barium, cobalt, sodium, phosphorus, lead, titanium, and yttrium in streambed sediments.

Cluster F contains subbasins that are in the Inner and Outer Bluegrass Regions and are affected by urban land uses. For example, North Elkhorn Creek (NEC), South Elkhorn Creek (SEC) and Hickman Creek (HCB) (fig. 27) are affected by point-source discharges, urban stormwater runoff, and landfills in the greater Lexington metropolitan area. Subbasins in cluster F contained elevated concentrations of barium, phosphorus, lead, and yttrium, compared with other subbasins in the Lower Kentucky River hydrologic unit. The inclusion of the mostly rural Drennon Creek Subbasin (DCB) in this cluster is due to elevated concentrations of barium in streambed sediments, which may indicate a local occurrence of barite in the subbasin. Cluster G contains rural subbasins in the Outer Bluegrass Region, which are mostly affected by agriculture. Subbasins in cluster G include Eagle Creek (UEC and LEC), Benson Creek (BCB), and Paint Lick Creek (PLB). Those subbasins contained elevated concentrations of aluminum, cobalt, sodium, and titanium in streambed sediments, compared with other streams in the Lower Kentucky River hydrologic unit. Cluster H contains two subbasins, the Upper Dix River (UDR) and Muddy Creek (MCB), which are in the Knobs Region. These subbasins are underlain by shale of Devonian age; streambed sediments are characterized by elevated concentrations of arsenic and cobalt and smaller concentrations of barium and phosphorus.

Cluster analysis of all 31 subbasins in the Kentucky River Basin (fig. 29; table 12) reveals three major clusters that are distinguished by differences in concentrations of major metals, as well as other elements such as calcium, magnesium, phosphorus, and potassium. Each major cluster is subdivided into two additional clusters that indicate regional differences in geology and human activities. Cluster 1 (fig. 29) represents subbasins that are characterized by elevated streambed-sediment concentrations of calcium, lead, phosphorus, strontium, and yttrium. Cluster 1a contains streams that are affected primarily by urban land uses, whereas Cluster 1b includes rural streams that are affected by other human activities; for example, waste-management practices or coal mining. Cluster 2 contains subbasins that are characterized by large sediment concentrations of calcium, cerium, magnesium,

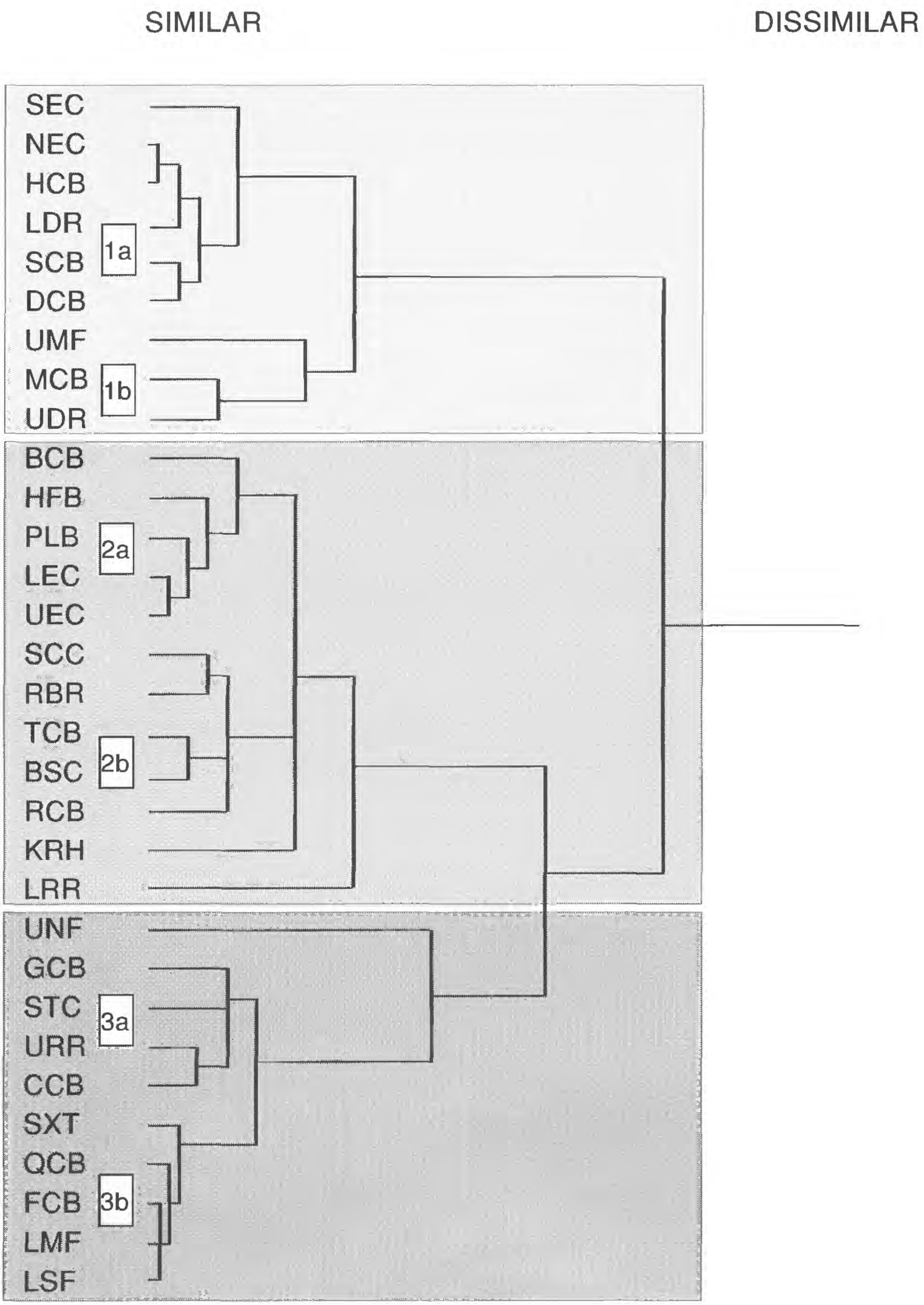


**Figure 29.** Cluster-analysis dendrogram for subbasins in the Kentucky River Basin. (Three-letter subbasin codes are identified in table 12.)

Table 12. Identification of subbasins in the Kentucky River Basin shown in figure 29

| Subbasin | Description |
|---|---|
| BCB | Benson Creek Subbasin |
| BSC | Big Sinking Creek Subbasin |
| CCB | Cutshin Creek Subbasin |
| DCB | Drennon Creek Subbasin |
| FCB | Frozen Creek Subbasin |
| GCB | Goose Creek Subbasin |
| HCB | Hickman Creek Subbasin |
| HFB | Hanging Fork Subbasin |
| KRH | Headwaters of the Kentucky River |
| LDR | Lower Dix River Subbasin |
| LEC | Lower Eagle Creek Subbasin |
| LMF | Downstream tributaries of Middle Fork Kentucky River |
| LRR | Lower Red River Subbasin |
| LSF | Downstream tributaries of South Fork Kentucky River |
| MCB | Muddy Creek Subbasin |
| NEC | North Elkhorn Creek Subbasin |
| PLB | Paint Lick Creek Subbasin |
| QCB | Quicksand Creek Subbasin |
| RBR | Red Bird River Subbasin |
| RCB | Rockhouse Creek Subbasin |
| SCB | Silver Creek Subbasin |
| SCC | Station Camp Creek Subbasin |
| SEC | South Elkhorn Creek Subbasin |
| STC | Sturgeon Creek Subbasin |
| SXT | Sexton Creek Subbasin |
| TCB | Troublesome Creek Subbasin |
| UDR | Upper Dix River Subbasin |
| UEC | Upper Eagle Creek Subbasin |
| UMF | Headwaters of Middle Fork Kentucky River |
| UNF | Headwater tributaries of North Fork Kentucky River |
| URR | Upper Red River Subbasin |

and potassium but smaller concentrations of phosphorus and strontium. Those subbasins are also affected by land disturbance, which may have contributed to regionally elevated concentrations of aluminum and titanium. Cluster 2a includes streams that drain agricultural catchments, whereas cluster 2b contains subbasins that are affected by coal mining or oil production.

Cluster 3 (fig. 29) includes subbasins in the Eastern Coal Field Region. Streambed sediments are characterized by elevated concentrations of aluminum, titanium, and a variety of rare-earth elements. Subbasins in cluster 3a contain larger percentages of forested lands than do subbasins in cluster 3b. Subbasins in cluster 3b are characterized by widespread land disturbance, primarily from coal mining. Subbasins in cluster 3b contained larger concentrations of cerium, lanthanum, and neodymium and smaller concentrations of calcium than subbasins in cluster 3a.

## Assessment of Study Approach

### Evaluation of Sample-Processing Methods

Analysis of sample-processing methods, specifically wet sieving compared with dry sieving of paired streambed-sediment samples ($n = 23$) does not indicate a significant difference in the median concentrations of most metals and other constituents (table 13). However, concentrations of gallium, lithium, niobium, titanium, and vanadium were significantly larger in samples processed by wet-sieving methods (Mann-Whitney U-tests; $p < 0.05$). Comparison of sample-processing methods in the Upper Illinois River Basin (J.A. Colman and R.F. Sanzolone, written commun., 1990) and Yakima River Basin (G.J. Fuhrer, U.S. Geological Survey, written commun., 1990) indicated significant differences between wet- and dry-sieving methods for greater than 40 percent of the constituents determined. Although those differences may have resulted from within-stream variability or from streambed-sediment replicates that did not represent "paired samples," sediment processing methods should be standardized in future NAWQA streambed-sediment investigations. Because the percentage difference between constituent concentrations determined from paired, dry- and wet-sieved samples did not generally exceed the variance percentage reported for laboratory or within-stream variability, streambed sediment data for small streams (dry-sieved) and large streams (wet-sieved) were combined for assessments of geologic and human sources of metals and other trace elements in the Kentucky River Basin.

### Evaluation of Bulk-Sediment and Fine-Fraction Streambed-Sediment Samples

Median streambed-sediment concentrations of metals at nine stream locations in the Kentucky River Basin were significantly larger in fine-fraction (<63 μm) streambed-sediment samples than in bulk-sediment samples reported by KDOW during the same time period (Dave Leist, Kentucky Division of Water, written commun., 1991). Although the sediment samples were collected by different agencies on different dates, larger concentrations of metals in fine-fraction samples than in bulk-sediment samples from the same locations (fig. 30) may be attributable in part to differences in grain-size trace-element relations (Horowitz and Elrick, 1987). Concentrations of trace metals in streambed sediments generally increase as the average grain size in a sample decreases (Horowitz, 1991). Bulk-sediment samples collected by the State agency may have contained a large percentage of coarse, sand-size

Table 13. Median concentrations of constituents in streambed sediments, by sample-processing method, and significance of Mann-Whitney U-tests

[Concentrations in micrograms per gram; <, less than; number of paired samples = 23]

| Constituent | Sample-processing method | | Mann-Whitney U-test (p-value) |
|---|---|---|---|
| | Wet sieving | Dry sieving | |
| Aluminum | 68,000 | 62,000 | 0.159 |
| Arsenic | <10 | <10 | .442 |
| Barium | 480 | 500 | .921 |
| Beryllium | <2 | <2 | .130 |
| Calcium | 10,000 | 13,000 | .629 |
| Cerium | 91 | 92 | .775 |
| Chromium | 78 | 68 | .187 |
| Cobalt | 22 | 20 | .474 |
| Copper | 25 | 22 | .306 |
| Gallium | 19 | 17 | .049 |
| Iron | 37,000 | 35,000 | .290 |
| Lanthanum | 47 | 45 | .257 |
| Lead | 31 | 31 | .489 |
| Lithium | 58 | 45 | .013 |
| Magnesium | 7,200 | 6,300 | .153 |
| Manganese | 1,500 | 1,300 | .716 |
| Mercury | .08 | .04 | .103 |
| Molybdenum | <2 | <2 | .590 |
| Neodymium | 43 | 43 | .956 |
| Nickel | 37 | 36 | .461 |
| Niobium | 10 | 6 | .020 |
| Phosphorus | 900 | 800 | .903 |
| Potassium | 21,000 | 21,000 | .342 |
| Scandium | 12 | 11 | .121 |
| Sodium | 3,300 | 3,800 | .235 |
| Strontium | 99 | 110 | .636 |
| Sulfur | 630 | 600 | .667 |
| Thorium | 12 | 13 | .632 |
| Titanium | 3,900 | 3,200 | <.001 |
| Uranium | 1.10 | .85 | .494 |
| Vanadium | 100 | 79 | .019 |
| Yttrium | 25 | 25 | .301 |
| Zinc | 120 | 100 | .194 |
| Carbonate carbon | 2,300 | 2,900 | .676 |
| Organic carbon | 22,000 | 22,000 | .441 |
| Total carbon | 24,000 | 26,000 | .956 |

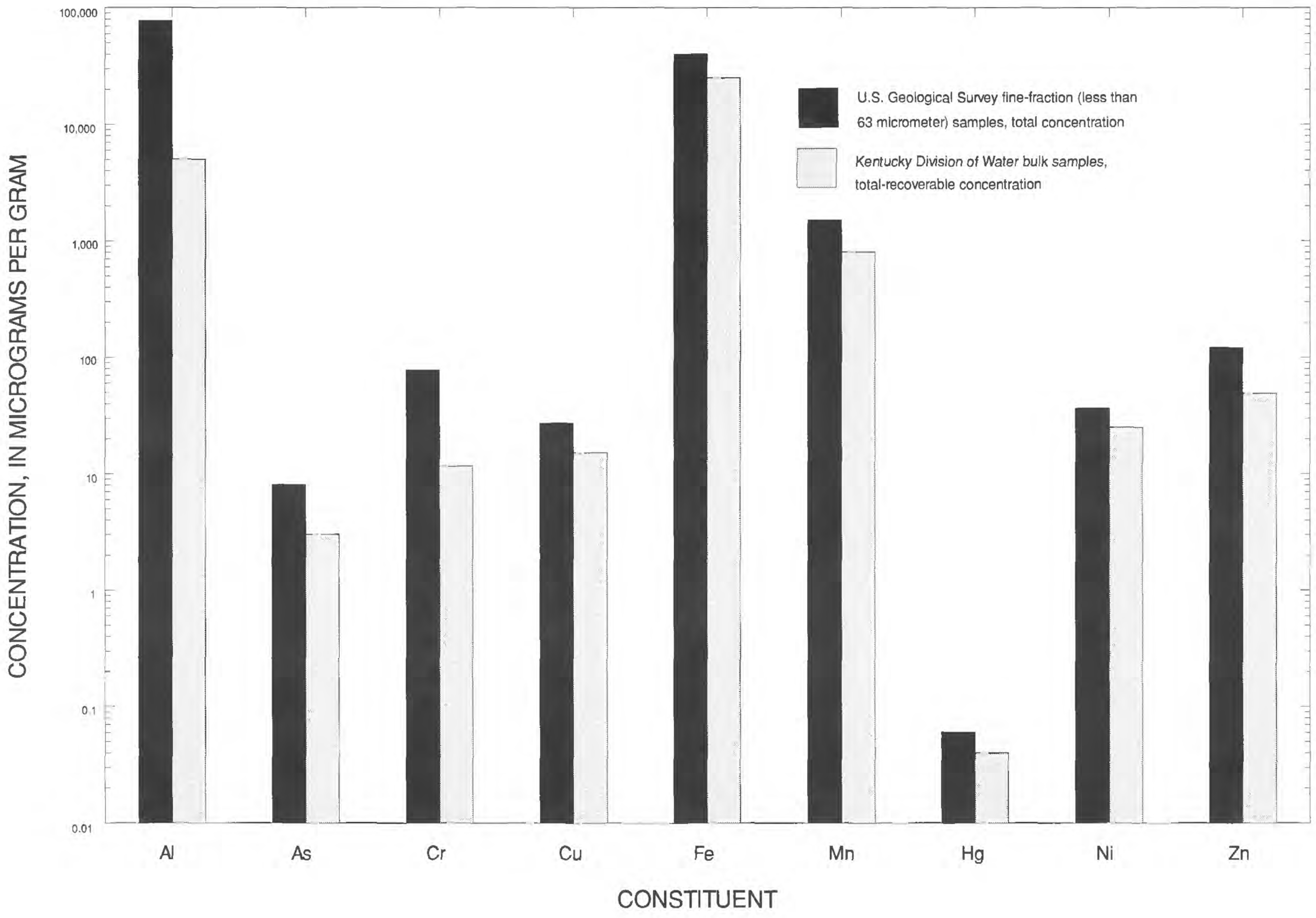


**Figure 30.** Comparison of median concentrations of metals in streambed-sediment samples from nine paired stream-sites in the Kentucky River Basin.

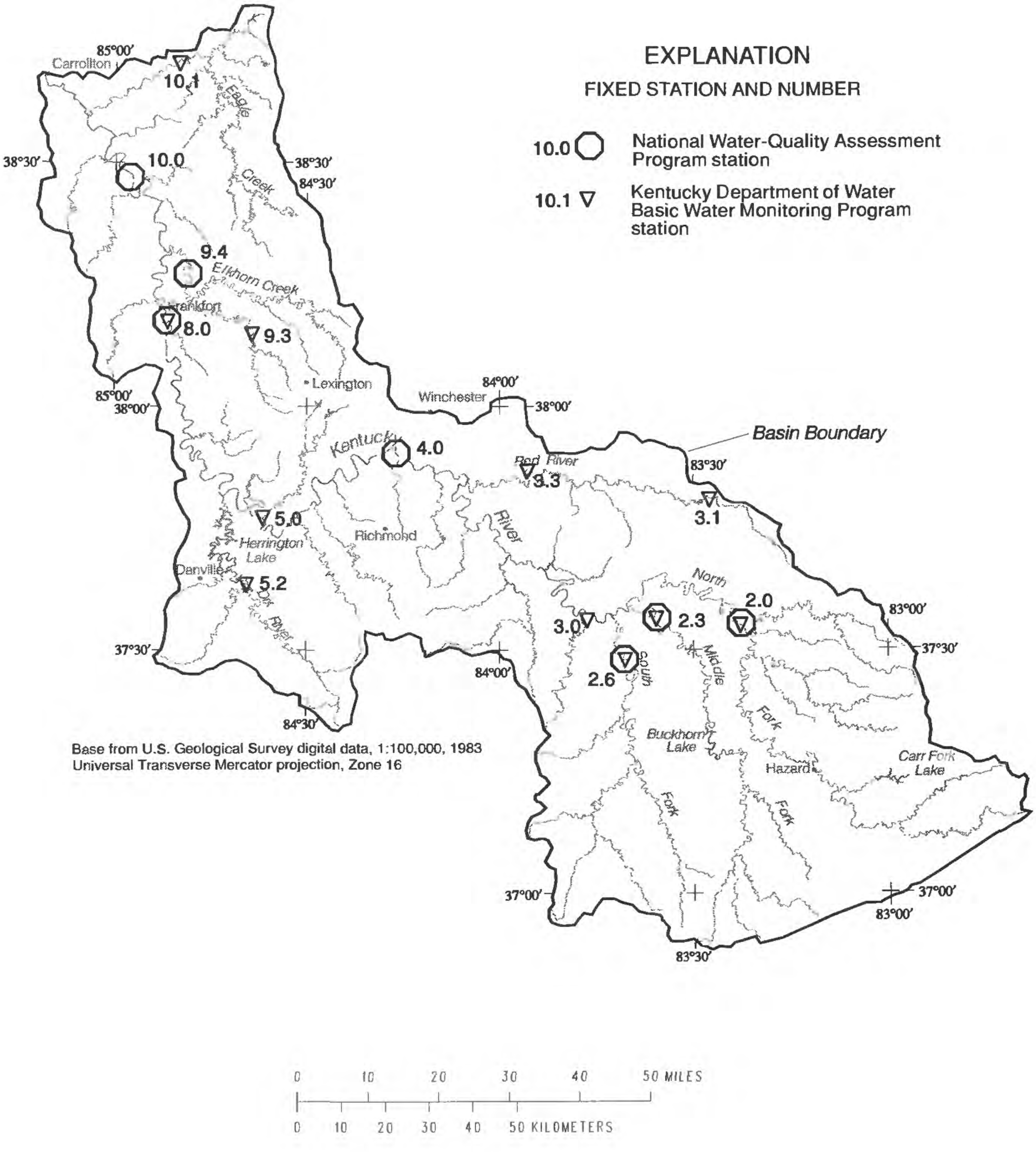
particles, which have been shown to accumulate fewer metal ions relative to total sediment mass because of surface-area-to-volume relations (Forstner and Wittmann, 1981).

However, differences in the concentrations of metals and other trace elements between fine-fraction and bulk-sediment samples are likely to be affected by differences of laboratory methods of sample preparation and extraction. Methods for the "total" extraction of metals from fine-fraction sediment samples (which require use of hydrochloric, nitric, perchloric, and hydrofluoric acids before chemical determinations) probably resulted in more complete recovery of certain elements than "total recoverable" sample-preparation methods (which require only hydrochloric (or nitric) acid as an extractant). Total-extraction methods effectively dissolve the mass of all elements present in the sediment matrix, whereas total-recoverable methods solubilize only those elements that are adsorbed to the surface of sediment particles. Larger concentrations of aluminum, calcium, chromium, iron, potassium, and trace elements that characterize the inner matrix of sediment particles would be expected when total sample-extraction methods are employed. Similar differences are noted in the "total extraction" concentration of certain metals and other trace elements in the suspended-sediment fraction of water samples compared to "total-recoverable" concentrations of metals in the same water-quality samples.

## DISTRIBUTION OF METALS AND OTHER TRACE ELEMENTS IN WATER AND SUSPENDED SEDIMENT IN STREAMS IN THE KENTUCKY RIVER BASIN

The range of concentrations and annual loads of metals and other trace elements in the Kentucky River and its major tributaries is affected by regional geology, seasonal hydrology, and human activities. The primary source of most metals and trace elements in water samples is the suspended sediment in the sample. Concentrations of aluminum, iron, manganese, and several other trace elements in water samples from the seven NAWQA fixed stations were significantly correlated with the concentration of suspended sediment. Although concentrations of other trace elements were not statistically correlated with suspended-sediment concentrations in water samples, maximum concentrations and mean annual loads of many metals and other trace elements were associated with high sediment transport at specific sites in the Kentucky River Basin. Land disturbance, such as surface mining and agriculture, contributes to increased transport of suspended sediment in streams, thereby increasing total concentrations of metals and other trace elements in water during periods of intense or long-duration rainfall and increased stream discharge. These conditions occur during winter and early spring, as well as after intense thunderstorms during the summer.

A total of 14 fixed water-quality monitoring stations were available for study in the Kentucky River Basin (fig. 31); 11 KDOW fixed stations with monthly sampling conducted since the early 1980's, and 3 additional fixed stations maintained by the NAWQA pilot project from April 1987 through August 1991 (Griffin and others, 1994). The fixed station on the Kentucky River at Lock 2 is a USGS NASQAN station; monthly or quarterly water-quality sampling has been done since 1975. Four of the fixed stations (fig. 31) were monitored by the USGS and KDOW during the NAWQA intensive-sampling period.



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 16

**Figure 31.** Locations of fixed-stations in the Kentucky River Basin.

Fixed-station descriptions, streamflow, and basin characteristics are given in table 14, and a list of metals and other trace elements determined in water samples collected at NAWQA fixed stations is given in table 15.

## Concentrations of Metals and Other Trace Elements in the Suspended-Sediment Fraction

Although total-recoverable concentrations of certain metals and other trace elements in water samples, reported in units of micrograms per liter, is a function of the mass of suspended sediment present in the sample, the concentration of metals in the suspended-sediment matrix, reported in units of micrograms per gram, may indicate differences in the sources of constituents. This is consistent with interpretations derived from concentrations of metals and other trace elements in streambed sediments. For example, median and maximum concentrations of total vanadium in water samples are larger in the North Fork Kentucky River at Jackson (fig. 31; site 2.0) than at other fixed stations, primarily because total concentrations of suspended sediment also are larger at this location. In contrast, median and maximum concentrations of vanadium in the suspended-sediment matrix are large in the Kentucky River at Lock 10 (fig. 31; site 4.0), probably because (1) concentrations of vanadium are large in Devonian shales of the Knobs Region, (2) concentrations of vanadium in streambed sediments are correspondingly large in the Knobs Region when compared with other physiographic regions in the basin, and (3) the Kentucky River at Lock 10 is downstream from tributaries that drain the Knobs Region.

Maximum concentrations of total molybdenum in water samples are larger in the North Fork Kentucky River than at other fixed stations, corresponding to elevated suspended-sediment transport, whereas maximum concentrations of molybdenum in the suspended-sediment matrix are larger in water samples from Elkhorn Creek at Frankfort (fig. 31; site 9.4) than at other fixed stations. Although sediment concentrations of molybdenum are elevated in the Knobs Region because of natural sources (Devonian shale bedrock), the larger median concentration of molybdenum in Elkhorn Creek (Inner Bluegrass Region) may be associated with wastewater discharges in the Lexington-Georgetown metropolitan area.

The concentration of a particular metal or trace element in a water sample represents the sum of the mass of the constituent present in the dissolved fraction and the suspended-sediment fraction. The concentration of the constituent present in the suspended-sediment fraction (in micrograms per liter) can be calculated by multiplying the concentration of the constituent in the suspended-sediment matrix (micrograms per gram) by the concentration of suspended-sediment mass in the sample (milligrams per liter), and dividing by 1,000. Comparisons of load estimates for total-recoverable concentrations of constituents with load estimates for the suspended-sediment fraction indicate that (1) load estimates for aluminum, chromium, and iron for the suspended-sediment-fraction are larger than estimates for total-recoverable concentrations, (2) load estimates for arsenic, lead, manganese, nickel, and zinc are similar for total and suspended-sediment fraction concentrations, and (3) load estimates for total-recoverable concentrations of copper are larger

Table 14. Streamflow and basin characteristics for fixed stations in the Kentucky River Basin shown in figure 31

[mi$^2$, square miles, ft$^3$/s, cubic feet per second, KDOW, Kentucky Division of Water; NAWQA, National Water-Quality Assessment Program; --, no data]

| Site number | Agency or program | Station name | Drainage area (mi$^2$) | Average discharge (ft$^3$/s) | 7-day 10-year low flow (ft$^3$/s) | Land use or cover, in percent[1] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Urban | Agri-culture | Forest | Lakes and reservoirs | Mining |
| 2.0 | KDOW/NAWQA | North Fork Kentucky River at Jackson | 1,101 | 1,349 | 3.1 | 0.3 | 0.2 | 95.2 | 0.1 | 4.2 |
| 2.3 | KDOW/NAWQA | Middle Fork Kentucky River at Tallega | 537 | 725 | 0 | .1 | 1.2 | 96.0 | .1 | 2.6 |
| 2.6 | KDOW/NAWQA | South Fork Kentucky River at Booneville | 722 | 1,045 | 1.0 | .2 | 5.9 | 92.8 | 0 | 1.0 |
| 3.0 | KDOW | Kentucky River at Lock 14, at Heidelberg | 2,657 | 3,626 | 12.0 | .3 | 3.0 | 94.0 | .1 | 2.6 |
| 3.1 | KDOW | Red River near Hazel Green | 65.8 | 87.7 | 0 | .2 | 12.0 | 87.8 | 0 | .1 |
| 3.3 | KDOW | Red River at Clay City | 362 | 484 | 3.8 | 1.1 | 14.6 | 84.2 | 0 | .1 |
| 4.0 | NAWQA | Kentucky River at Lock 10, near Winchester | 3,955 | 5,253 | 35 | 1.3 | 12.3 | 84.5 | .1 | 1.9 |
| 5.0 | KDOW | Kentucky River at Camp Nelson | 4,425 | -- | 44 | 1.5 | 19.6 | 77.1 | .1 | 1.7 |
| 5.2 | KDOW | Dix River near Danville | 318 | 464 | 0 | 3.4 | 68.4 | 27.9 | 0 | .4 |
| 8.0 | KDOW/NAWQA | Kentucky River at Lock 4, at Frankfort | 5,411 | 7,041 | 172 | 2.4 | 29.0 | 66.9 | .1 | 1.5 |
| 9.3 | KDOW | South Elkhorn Creek near Midway | 105 | 152 | -- | 23.1 | 75.4 | .1 | 0 | .8 |
| 9.4 | NAWQA | Elkhorn Creek at Frankfort | 473 | 617 | 6.8 | 13.4 | 84.4 | 1.8 | 0 | 0 |
| 10.0 | NAWQA | Kentucky River at Lock 2, at Lockport | 6,180 | 8,227 | 202 | 3.4 | 34.4 | 60.7 | .1 | 0 |
| 10.1 | KDOW | Eagle Creek at Glencoe | 437 | 562 | 0 | 4.7 | 57.3 | 37.8 | .1 | 0 |

[1] Rows may not total to 100 percent because of rounding error.

**Table 15.** Laboratory analyses for metals and other trace elements in water-quality samples collected at National Water-Quality Assessment fixed stations

[mg/L, milligrams per liter; µg/L, micrograms per liter; µg/g, micrograms per gram; percent, parts per hundred or $10^4$ µg/g; --, not applicable]

| Constituent | WATSTORE code[1] | Reporting level[2] |
|---|---|---|
| Aluminum, total recoverable (µg/L as Al) | 01105 | 10 |
| Aluminum, sediment, suspended (percent as Al) | 30221 | .01 |
| Aluminum, dissolved (µg/L as Al) | 01106 | 10 |
| Antimony, sediment, suspended (µg/g as Sb) | 29816 | .1 |
| Antimony, dissolved (µg/g as Sb) | 01095 | 1 |
| Arsenic, sediment, suspended (µg/g as As) | 29818 | .1 |
| Arsenic, dissolved (µg/L as As) | 01000 | 1 |
| Barium, total recoverable (µg/L as Ba) | 01007 | 100 |
| Barium, dissolved (µg/L as Ba) | 01005 | 2 |
| Beryllium, total recoverable (µg/L as Be) | 01012 | 10 |
| Beryllium, sediment, suspended (µg/g as Be) | 29822 | 2 |
| Beryllium, dissolved (µg/L as Be) | 01010 | .5 |
| Boron, total recoverable (µg/L as B) | 01022 | 10 |
| Boron, dissolved (µg/L as B) | 01020 | 10 |
| Cadmium, total recoverable (µg/L as Cd) | 01027 | 1 |
| Cadmium, sediment, suspended (µg/g as Cd) | 29826 | .1 |
| Cadmium, dissolved (µg/L as Cd) | 01025 | .1 |
| Chromium, total recoverable (µg/L as Cr) | 01034 | 1 |
| Chromium, sediment, suspended (µg/g as Cr) | 29829 | 2 |
| Chromium, dissolved (µg/L as Cr) | 01030 | .5 |
| Cobalt, sediment, suspended (µg/g as Co) | 35031 | 2 |
| Cobalt, dissolved (µg/L as Co) | 01035 | 3 |
| Copper, total recoverable (µg/L as Cu) | 01042 | 10 |
| Copper, sediment, snspended (µg/g as Cu) | 29832 | 2 |
| Copper, dissolved (µg/L as Cu) | 01040 | .5 |
| Iron, total recoverable (µg/L as Fe) | 01045 | 10 |
| Iron, sediment, snspended (percent as Fe) | 30269 | .01 |
| Iron, dissolved (µg/L as Fe) | 01046 | 3 |
| Lead, total recoverable (µg/L as Pb) | 01051 | 5 |
| Lead, sediment, suspended (µg/g as Pb) | 29836 | .1 |
| Lead, dissolved (µg/L as Pb) | 01049 | .5 |
| Magnesium, sediment, suspended (percent as Mg) | 30277 | .01 |
| Magnesium, dissolved (mg/L as Mg) | 00925 | .01 |
| Manganese, total recoverable (µg/L as Mn) | 01055 | 10 |
| Manganese, sediment, snspended (µg/g as Mn) | 29839 | 8 |
| Manganese, dissolved (µg/L as Mn) | 01056 | 1 |
| Mercury, total recoverable (µg/L as Hg) | 71900 | .1 |
| Mercury, dissolved (µg/L as Hg) | 71890 | .1 |
| Molybdenum, total recoverable (µg/g as Mo) | 01062 | 1 |
| Molybdenum, sediment, suspended (µg/g as Mo) | 29843 | .1 |
| Molybdenum, dissolved (µg/g as Mo) | 01060 | 10 |
| Nickel, total recoverable (µg/L as Ni) | 01067 | 1 |
| Nickel, sediment, suspended (µg/g as Ni) | 29845 | 4 |
| Nickel, dissolved (µg/L as Ni) | 01065 | 10 |
| Selenium, dissolved (µg/L as Se) | 01145 | 1 |
| Silver, total recoverable (µg/L as Ag) | 01077 | 1 |
| Silver, sediment, suspended (µg/g as Ag) | 29850 | .1 |
| Silver, dissolved (µg/L as Ag) | 01075 | 1 |
| Strontium, dissolved (µg/L as Sr) | 01080 | 5 |
| Thallium, sediment, suspended (µg/g) | -- | .1 |
| Titanium, sediment, snspended (percent as Ti) | 30317 | .01 |
| Vanadium, sediment, snspended (µg/g) | 29853 | 4 |
| Vanadium, dissolved (µg/L as V) | 01085 | 6 |
| Zinc, total recoverable (µg/L as Zn) | 01092 | 10 |
| Zinc, sediment, suspended (µg/g as Zn) | 29855 | 4 |
| Zinc, dissolved (µg/L) | 01090 | 3 |

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[1] National WATer data STOrage and REtrieval system, number identifies parameter in computer data base.

[2] Smallest unit results reported for given constituent.

than those for the suspended-sediment fraction. These differences are most probably attributable to differences in laboratory sample-preparation and analytical techniques.

## Sources of Metals, Other Trace Elements, and Suspended Sediment in Streams in the Kentucky River Basin

The source of metals and other trace elements in water samples from a specific stream site in the Kentucky River Basin is associated with the transport of streambed sediments and soils from the drainage basin. Concentrations of metals and other trace elements in streambed sediments have been demonstrated to differ significantly among physiographic regions of the Kentucky River Basin because of regional geochemical differences. Streambed sediments can also accumulate constituents from wastewater discharges, runoff and seepage from landfills, brine discharges from oil and gas production, and numerous other land-use activities. These constituents likely accumulate in sediments during periods of low to moderate streamflow, because water-quality conditions (for example, dissolved oxygen concentration and pH) in the Kentucky River Basin generally favor adsorption processes.

Seasonal resuspension and washout of streambed sediments during periods of high streamflow help cause concentrations of aluminum, beryllium, cadmium, chromium, copper, iron, manganese, mercury, nickel, silver, and zinc in the main stem and certain tributaries of the Kentucky River to exceed Kentucky water-quality criteria (Kentucky Natural Resources and Environmental Protection Cabinet, 1990). With the exception of cadmium, mercury, and silver, total-recoverable concentrations of these constituents in water samples are positively correlated with the concentration of suspended sediment and streamflow at one or more fixed stations in the Kentucky River Basin. In contrast, total-recoverable concentrations of barium, lithium, and strontium are largest during low flow, such as the period of extended drought that occurred in the Kentucky River Basin during 1987-88. Concentrations of boron, calcium, magnesium, potassium, and sodium are negatively correlated with discharge. Increases in the concentrations of these constituents may indicate water-quality effects from ground water sources during low flow or dilution effects from precipitation runoff during seasonal high flows.

Water-quality data collected from wastewater-treatment plant discharges in the Kentucky River Basin during the NAWQA pilot project indicate that point-source discharges can contribute appreciable concentrations of boron, cadmium, chromium, lead, mercury, molybdenum, nickel, silver, and zinc to streams in the basin (table 16). Concentrations of these and other metals and trace elements are elevated in streambed-sediment samples from sites immediately downstream from wastewater discharges. However, fixed stations in the basin are generally far from major point-source discharges, and direct water-quality effects of these discharges with respect to metals and other trace elements are not readily apparent.

Table 16. Summary of metal and other trace-element concentrations in selected wastewater-treatment-plant effluents in the Kentucky River Basin, September 1990

[Total-recoverable concentrations in micrograms per liter; <, less than; number of samples = 12)

| Element | Minimum | Median | Maximum |
|---|---|---|---|
| Aluminum | 20 | 90 | 520 |
| Barium | <100 | <100 | <100 |
| Beryllium | <10 | <10 | <10 |
| Boron | 80 | 210 | 490 |
| Cadmium | <1 | <1 | 2 |
| Chromium | <1 | 1 | 15 |
| Copper | 10 | 25 | 50 |
| Iron | 90 | 200 | 7,800 |
| Lead | 1 | 3 | 17 |
| Manganese | <10 | 40 | 440 |
| Mercury | <.1 | .2 | 1.4 |
| Molybdenum | 1 | 9 | 390 |
| Nickel | 3 | 7 | 88 |
| Silver | <1 | <1 | 7 |
| Zinc | <10 | 70 | 180 |

For example, the South and North Forks of Elkhorn Creek receive municipal and industrial wastewater discharges from the Lexington-Georgetown metropolitan area; however, concentrations, loads, and yields of most metals in Elkhorn Creek at Frankfort (approximately 25 to 40 mi downstream from the metropolitan areas; fig. 31) are smaller than indicated at other fixed stations. Median concentrations of arsenic, beryllium, chromium, cobalt, nickel, silver, and thallium in the suspended-sediment matrix are significantly smaller in Elkhorn Creek than other fixed stations, although median concentrations of boron, cadmium, copper, lead, and zinc in the suspended-sediment matrix do not significantly differ among fixed stations. However, median concentrations of molybdenum in the suspended-sediment matrix are significantly larger in Elkhorn Creek than at other fixed stations.

## Transport of Metals and Other Trace Elements in Streams

Estimates of mean annual loads of antimony, arsenic, boron, cadmium, chromium, lead, lithium, magnesium, silver, strontium, titanium, vanadium, and zinc are largest in the Kentucky River at Lock 2 (fig. 31, site 10.0), probably because (1) water-quality data from the most downstream fixed station reflects land- and water-uses within approximately 90 percent of the drainage basin and (2) mean annual discharge and suspended-sediment loads are largest at this site. However, with the exception of antimony and cadmium, the mean annual yield of these constituents, defined as the mean annual load per square mile of drainage area, is largest in the North Fork Kentucky River at Jackson (fig. 31, site 2.0). The North Fork Kentucky River also yields the largest loads of aluminum, beryllium, cobalt, copper, iron, nickel, and thallium. This pattern of yields corresponds with a similarly large yield of suspended sediment at this location (Smoot and others, 1991). However, large concentrations of metals and other trace elements in bedrock and soils of the Eastern Coal Field Region likely contribute to the large yields of these constituents.

Mean annual loads of manganese and nickel are largest in the Kentucky River at Lock 10, downstream from tributaries that drain the Knobs Region. Median concentrations of arsenic, chromium, copper, iron, molybdenum, nickel, and vanadium in the suspended-sediment matrix are larger in the Kentucky River at Lock 10 than at the other fixed stations. This pattern corresponds with elevated concentrations of these metals in shales of Devonian age and streambed sediments of the Knobs Region. Brine discharges from oil-production facilities in the Knobs Region may also affect the quality of water in the Kentucky River at Lock 10. For example, the median concentration of barium at Lock 10 is larger than indicated for other fixed stations during low-flow conditions of 1987-88. Walker and others (1991) reported significantly larger concentrations and loads of barium, chromium, iron, manganese, nickel, and vanadium in streams that receive oil-well-brine discharges than in unaffected streams in the Knobs Region of the Kentucky River Basin.

## Seasonal Trends for Concentrations of Metals and Other Trace Elements at Fixed Stations

Results of Seasonal Kendall trend analyses of metals and other trace elements indicate significant upward trends for concentrations of aluminum, iron, magnesium, manganese, and zinc at one or more fixed stations in the Kentucky River Basin. Trends for aluminum, iron, and manganese were found at fixed stations that receive drainage from coal mines in the upper part of the basin, whereas concentrations of zinc were increasing near urban centers in the middle to lower part of the basin, specifically in the Kentucky River at Camp Nelson and Lock 4 (fig. 31, sites 4.0 and 8.0). Downward trends in the concentrations of barium and boron at fixed stations are not significant when concentrations are normalized with respect to discharge.

Despite the correlation of aluminum, iron, and manganese concentrations with concentrations of suspended sediment, significant trends are not indicated for concentrations of suspended sediment at sites where trends were found for these metals. Although concentrations of suspended sediment were decreasing in Elkhorn Creek at Frankfort and the Kentucky River at Lock 2; significant trends in the concentrations of metals were not found at these sites even though concentrations of these metals are correlated with suspended-sediment concentrations. Trends for concentrations of suspended sediment appear to be independent of trends for concentrations of metals and other trace elements at fixed stations in the Kentucky River Basin.

## Water-Quality Conditions and Trends

The concentrations, loads, and trends for metals and other trace elements at fixed stations in the Kentucky River Basin may be interpreted in relation to differences or changes in hydrologic characteristics, natural factors, and the effects of human activities. In addition, constituent concentrations at fixed stations in the basin can be compared with variety of benchmark values to estimate the potential effects of metals and other trace elements on humans and aquatic organisms.

Water-quality criteria have been established for total-recoverable concentrations of a variety of metals and other trace elements in water. These criteria are based upon potential adverse effects to (1) human health, with respect to the suitability of the resource for domestic water supply or for the consumption of fish tissue, and (2) aquatic life, in relation to acute or chronic toxicity. The Commonwealth of Kentucky has established water-quality criteria for such metals and trace elements (Kentucky Natural Resources and Environmental Protection Cabinet, 1990) which have been termed "priority pollutants" by the USEPA. In general, Kentucky water-quality criteria are numerically equivalent to criteria established by the USEPA (U.S. Environmental Protection Agency, 1986); however, the Federal water-quality criteria for certain constituents may differ from Kentucky criteria.

For finished public drinking water, the USEPA has established Maximum Contaminant Levels (MCL's) for certain metals and trace elements (U.S. Environmental Protection Agency, 1990a). An MCL is an enforceable, health-based regulation. The USEPA has also established Secondary Maximum Contaminant Levels (SMCL's) for constituents that affect the aesthetic quality of drinking water (U.S. Environmental Protection Agency, 1990b). At high concentrations, health implications as well as aesthetic degradation may also exist. SMCL's are not Federally enforceable but are intended as guidelines for the states.

### Aluminum

Aluminum is one of the most abundant elements in the earth's crust, but it is not generally present in natural water at concentrations greater than a few tenths of a milligram per liter (Hem, 1989). Aluminum can be toxic to fish (Hutchinson and others, 1989), and it can bioaccumulate in aquatic organisms. The toxicity of aluminum salts varies with water hardness, turbidity, and pH (National Academy of Sciences-National Academy of Engineering, 1972). Elevated concentrations of aluminum have been observed in acidic water from mine drainage and in runoff and lake waters of regions affected by acidic precipitation (Driscoll, 1985).

Although Kentucky has not established a water-quality criterion for aluminum, the USEPA has established acute and chronic aquatic-life criteria for acid-soluble aluminum of 750 $\mu$g/L and 87 $\mu$g/L, respectively (U.S. Environmental Protection Agency, 1988). The USEPA has established a secondary maximum contaminant level (SMCL) for aluminum in finished drinking water of 50 to 200 $\mu$g/L (U.S. Environmental Protection Agency, 1991). Concentrations of total-recoverable aluminum at fixed stations in the Kentucky

River Basin frequently exceeded the 200 μg/L criterion throughout the NAWQA pilot study, and significant upward trends for total-recoverable aluminum were apparent at several locations in the basin.

Concentrations of total-recoverable aluminum at fixed stations in the Kentucky River Basin ranged from less than the analytical detection limit of 1 to 24,000 μg/L; KDOW reports a maximum concentration of 12,000 μg/L) (table 17). Smoot and others (1991) reported a maximum total-recoverable aluminum concentration of 160,000 μg/L in the Kentucky River Basin. Total-recoverable aluminum concentrations were positively correlated with concentrations of suspended sediment, iron, manganese, nickel, and zinc, as well as with stream discharge. Dissolved-aluminum concentrations ranged from less than the detection limit of 10 to 900 μg/L (table 17). Median concentrations of total-recoverable and dissolved aluminum were significantly larger at all fixed stations during a period of above-average precipitation (1989-90) than during the extended drought period of 1987-88.

Median concentrations of total-recoverable aluminum determined from data obtained during the NAWQA study were larger than concentrations reported by KDOW (table 17) because (1) a greater proportion of water samples collected during the study were during periods of elevated discharge, (2) field and laboratory methods differ between the two agencies, (3) fewer samples ($n = 13$ to 17) were analyzed for total-recoverable aluminum, compared with the number of KDOW samples ($n = 38$ to 46), and (or) (4) some samples could have been contaminated during collection or analysis.

Concentrations of aluminum in the suspended-sediment matrix ranged from 15,300 to 127,000 μg/g (table 18) and were comparable to the range of aluminum concentrations in streambed sediments of 27,000 to 110,000 μg/g (table 1). The concentrations of aluminum shown in table 18 were significantly smaller in Elkhorn Creek than at other fixed stations, probably because the bedrock, soils, and streambed sediments of the Inner Bluegrass Region contain smaller concentrations of aluminum than other physiographic regions in the Kentucky River Basin. Although concentrations of aluminum in streambed sediments were significantly larger in the Eastern Coal Field Region, median concentrations of aluminum in the suspended-sediment matrix did not significantly differ among other fixed stations in the basin.

Concentrations of aluminum in the suspended-sediment fraction of water samples ranged from 50 to 190,000 μg/L (table 17). The median aluminum concentration was largest (7,700 μg/L) in the North Fork Kentucky River, probably because (1) aluminum concentrations were larger in bedrock and streambed-sediment samples from the Eastern Coal Field Region, (2) concentrations of aluminum in water correlated with suspended-sediment concentrations, and (3) the estimated annual yield of suspended sediment from the North Fork Kentucky River Basin at Jackson (948 ton/mi$^2$) was nearly four times larger than any of the other fixed stations. The estimated mean annual load of sediment in the North Fork Kentucky River at Jackson exceeded sediment loads in other tributaries of the Kentucky River by an order of magnitude (Smoot and others, 1991). The predominant source of sedimentation in the North Fork Basin is land disturbance resulting from surface mining.

With the exception of the North Fork Kentucky River at Jackson, estimated mean annual loads and yields for aluminum at the fixed stations during 1987-90 (table 19) generally exceeded those reported by Smoot and others (1991). Mean annual loads and yields for aluminum in the Middle Fork Kentucky River at Tallega, South Elkhorn Creek near Midway, and Red River near Hazel Green were nearly an order of magnitude larger than indicated before 1987. Although aluminum loads for the North Fork Kentucky River were somewhat less than previously reported, the mean annual yield of aluminum remained larger in the North Fork Kentucky River at Jackson than at the other fixed stations (table 19). Yields of total-recoverable and dissolved aluminum were also elevated in the Kentucky River at Lock 10.

The primary source of aluminum in streams of the Kentucky River Basin is most likely the weathering of geologic materials in the Eastern Coal Field and Knobs Regions. Concentrations, loads, and yields of aluminum were largest in areas affected by land disturbance such as surface mining and agriculture. Contributions of total-recoverable aluminum in WWTP effluents in the basin ranged from 20 to 520 μg/L (table 16). Point-source discharges represented a minor contribution to the total aluminum loads in the Kentucky River at Lock 2.

Significant upward trends for concentrations of aluminum were apparent in the North, Middle, and South Forks of the Kentucky River, as well as in South Elkhorn Creek and the Dix River (table 20). Because concentrations of total-recoverable aluminum were strongly correlated with total suspended-sediment concentrations, upward trends for aluminum in the basin would be expected to correspond with similar trends in sediment mass transport. However, trends were not indicated for concentrations of suspended sediment at these fixed stations.

### Antimony

Antimony is a USEPA priority pollutant that can be toxic to plants and animals. The concentrations of antimony in natural waters are very low; however, relatively few determinations of antimony have been reported (Hem, 1989). In addition to the natural occurrence of antimony in bedrock and streambed sediments in the Knobs Region of the Kentucky River Basin, antimony salts are used in the fireworks, rubber, textile, ceramic, glass, and paint industries (National Academy of Sciences-National Academy of Engineering, 1972). The proposed maximum contaminant level (MCL) in finished drinking water for antimony ranges from 5 to 10 μg/L, and the Kentucky domestic water supply source-criterion (KDWSSC) for antimony is 146 μg/L. Kentucky acute and chronic aquatic life criteria for antimony are 9,000 μg/L and 1,600 μg/L, respectively. Concentrations of antimony in streams of the Kentucky River Basin were generally 1 μg/L or less and were similar at all fixed stations. No significant trends were detected for concentrations of antimony at any of the fixed stations.

Concentrations of dissolved antimony were at or below the analytical detection limit of 1 μg/L at all fixed stations (table 17). Concentrations of antimony in the suspended-sediment fraction of water ranged from less than 0.01 to 2.4 μg/L, the largest concentrations being found in the Kentucky River at Lock 4. Concentrations of antimony in the suspended-sediment matrix ranged from 0.2 to 90 μg/g (table 18). Matrix concentrations of antimony in the Kentucky River at Lock 4 and Lock 2 during winter 1988 and 1989 exceeded the maximum concentration determined from streambed-sediment samples (6.1 μg/g; table 2). However, median concentrations of antimony in the suspended-sediment matrix did not significantly differ among fixed stations in the Kentucky River Basin. Estimated annual loads of antimony were largest in the Kentucky River main stem and increased downstream from Lock 10 to Lock 2 (table 19).

### Arsenic

Arsenic is listed as a USEPA priority pollutant and is recognized as a potential carcinogen. The MCL for arsenic is 50 μg/L, and the Kentucky acute and chronic aquatic-life criteria for trivalent arsenic are 360 μg/L and 190 μg/L, respectively. Concentrations determined at fixed stations in the Kentucky River Basin during 1987-90 were less than 50 μg/L. No significant long-term trends were indicated for arsenic at fixed stations in the Kentucky River Basin.

Concentrations of total-recoverable arsenic ranged from less than the detection limit of 2 to 21 μg/L at fixed stations maintained by KDOW, and concentrations of arsenic in the suspended-sediment fraction of water ranged from 0.01 to 14 μg/L (table 17). Concentrations of dissolved arsenic ranged from less than the detection limit of 1 to 6 μg/L.

Concentrations of arsenic in the suspended-sediment matrix ranged from 3.0 to 28.1 μg/g (table 18). Median concentrations were largest (13 μg/g) in the Kentucky River at Lock 10, which corresponds with geologic sources (Devonian shale bedrock) in the Knobs Region. The baseline concentration of arsenic in streambed sediments of the Knobs Region is 13.4 μg/g (table 6). The median concentration of arsenic in the suspended-sediment matrix was smallest in Elkhorn Creek (table 18); however, this concentration exceeded the baseline concentration of arsenic in streambed sediments from the Bluegrass Regions by one-third, possibly indicating accumulation due to point-source discharges or other human activities.

Mean annual arsenic loads for the period 1987-90 were largest in the Kentucky River main stem, ranging from 13 ton/yr at Lock 10 to approximately 20 ton/yr at Lock 2 and Lock 4 (table 19). Estimated loads and yields of arsenic in the Kentucky River were approximately twice those reported by Smoot and others (1991).

Although Gianessi (1986) estimated that about two-thirds of the arsenic transported from the Kentucky River Basin originates from municipal and industrial wastewater effluents, yields of arsenic in Elkhorn Creek, which receives drainage from the Lexington metropolitan area, were among the lowest for fixed stations in the Kentucky River Basin. The mean annual yield of arsenic was largest in the North Fork Kentucky River at Jackson (table 19); this large yield probably corresponds with suspended-sediment transport associated with coal mining rather than arsenic accumulation due to other point and nonpoint sources in the region.

## Barium

Barium is an alkaline-earth metal that is present in most surface water and ground water, as well as in treated drinking water (Hem, 1989). The predominant source of barium in the Kentucky River Basin is carbonate sedimentary rocks, and average baseline concentrations of barium in streambed sediments did not significantly differ among physiographic regions in the basin. The MCL and KDWSSC criteria for total barium in domestic water supplies is 1,000 μg/L. Concentrations in the Kentucky River Basin were generally less than the criteria; however, brine discharges from oil-field operations have frequently resulted in concentrations that substantially exceed 1,000 μg/L in affected streams (Evaldi and Kipp, 1991; Sidhu and Mitsch, 1987). Although Smoot and others (1991) reported downward trends for barium in the Upper Kentucky River Basin for the 1976-86 period, no significant long-term trends are detected for barium at fixed stations in the Kentucky River Basin when the 1987-90 data are added to the retrospective data base and concentrations are normalized with respect to discharge.

Total-recoverable barium concentrations reported by KDOW ranged from less than the detection limit of 1 to 360 μg/L, whereas concentrations of barium determined at NAWQA fixed stations ranged from less than the detection limit of 100 to 200 μg/L (table 17). Dissolved barium concentrations ranged from 13 to 130 μg/L and were negatively correlated with discharge and concentrations of suspended sediment. Median concentrations of dissolved barium were significantly larger at all fixed stations during a period of extended drought (1987-88) than during a period of above-average precipitation (1989-90). This relation may indicate contributions of barium from ground-water sources during low streamflow.

Mean annual loads for barium were largest in the Kentucky River main stem, ranging from 260 ton/yr at Lock 14 to 526 ton/yr at Camp Nelson, Ky. (KDOW data; table 19). The estimated loads for barium were similar to or lower than those reported by Smoot and others (1991). Dissolved barium loads ranged from 183 ton/yr at Lock 10 to 221 ton/yr at Lock 2. The dissolved barium load at Lock 2 was less than half the value reported at this location before 1987.

The KDOW data indicate a downstream increase of barium loads in the Kentucky River that may reflect oil-well-brine discharges that occur in the Middle Kentucky River Basin (Evaldi and Kipp, 1991; Smoot and others, 1991). Water-quality effects are most apparent during seasonal periods of low discharge. The median concentration of dissolved barium during low-flow conditions (1987-88) in the Kentucky River at Lock 10, downstream from oil-production areas in the basin, was significantly larger than at other fixed stations. During above-average flow conditions (1989-90), median barium concentrations were similar at all fixed stations.

The mean annual yield of barium was largest in Elkhorn Creek (0.259 tons/mi$^2$) (table 19). Although Elkhorn Creek is affected by point-source discharges from the cities of Lexington, Georgetown, and Midway, concentrations of total-recoverable barium in selected WWTP effluents in the basin were less than 100 μg/L (table 16). The source of barium enrichment in Elkhorn Creek may be related to the karst hydrology of the subbasin.

Concentrations of barium were strongly correlated with concentrations of calcium, magnesium, and strontium, which were significantly larger in streambed sediments of the Inner Bluegrass Region than at other fixed stations.

## Beryllium

Beryllium is an uncommon alkaline-earth element that is recognized as a USEPA priority pollutant and potential carcinogen. The USEPA has proposed a MCL of 1 μg/L for beryllium (U.S. Environmental Protection Agency, 1990a), and Kentucky has adopted the USEPA lowest-observed effect levels (LOEL) for protection of aquatic life, which are 130 μg/L and 5.3 μg/L for acute and chronic toxicity, respectively. In addition, Kentucky water-quality criteria establish a beryllium criterion of 0.117 μg/L for the protection of human health from the consumption of fish tissue. The criterion is based upon an acceptable risk level of no more than one additional cancer case in a population of 1 million people.

The chronic aquatic-life LOEL criterion for beryllium was exceeded in about 10 percent of the suspended-sediment fraction samples from the North Fork Kentucky River during 1987-90. Beryllium concentrations were significantly correlated directly with discharge, and the LOEL criterion was exceeded only during periods of high streamflow. Long-term trends for concentrations of beryllium could not be established for the fixed stations in the basin because most dissolved and total-recoverable concentrations of beryllium were less than the analytical detection limit.

Concentrations of total-recoverable beryllium were at or below the analytical detection limit of 10 μg/L, and concentrations of dissolved beryllium ranged from less than the detection limit of 0.5 to 1.3 μg/L (table 17). Concentrations of the suspended-sediment fraction of beryllium ranged from less than 0.01 to 7.1 μg/L. Median suspended-sediment fraction concentrations of beryllium were significantly larger during a period of above-average precipitation (1989-90) than during the period of extended drought (1987-88) in the North Fork Kentucky River at Jackson and the Kentucky River at Lock 10.

Concentrations of beryllium in the suspended-sediment matrix ranged from less than the detection limit of 1 to 6 μg/g (table 18). The median matrix concentration of beryllium in Elkhorn Creek was smaller than at the other fixed stations. This may indicate that beryllium accumulation in streams of the Kentucky River Basin is not particularly associated with point-source discharges. When the concentration of beryllium in the suspended-sediment matrix is converted to the effective concentration in water as the suspended-sediment fraction, the median concentration of beryllium exceeds the KWQC criterion of 0.117 μg/L at all fixed stations except Elkhorn Creek and the South Fork Kentucky River at Booneville.

Mean annual loads of beryllium ranged from 0.4 to 5.7 ton/yr and are largest in the Kentucky River main stem, as well as in the North Fork Kentucky River at Jackson (table 19). The mean annual yield was largest in the North Fork Kentucky River, probably because of geology and land disturbances from coal mining in this region. Concentrations of beryllium are larger in coal, shale, fire clay, and other bedrock samples in the Eastern Coal Field Region than in bedrock samples from other physiographic regions in the Kentucky River Basin. Concentrations of beryllium in selected WWTP effluents in the basin were less than 10 μg/L (table 16).

## Boron

Boron is an essential trace element for the growth of plants; however, boron is toxic to a number of sensitive plants at concentrations exceeding 1,000 μg/L. An upper limit of 5,000 μg/L was recommended by the National Academy of Sciences-National Academy of Engineering (1972) for livestock waters. Although water from thermal springs contains large concentrations of boron, most surface water contains only a few hundred micrograms per liter (Hem, 1989). Concentrations of boron in streams of the Kentucky River Basin were generally less than 300 μg/L; however, boron concentrations may be as large as 490 μg/L in point-source discharges in the basin (table 16).

Total-recoverable boron concentrations ranged from less than the analytical detection limit of 10 to 300 μg/L, and dissolved boron concentrations ranged from the detection limit of 10 to 160 μg/L (table 17). Dissolved boron concentrations were negatively correlated with discharge at the Elkhorn Creek fixed station. Median concentrations of total and dissolved boron did not significantly differ among the fixed stations. Concentrations of boron in the suspended-sediment matrix range from less than the detection limit of 0.2 to 6.8 μg/g (table 18). Median matrix concentrations of boron were not significantly different among fixed stations.

Mean annual loads for total-recoverable boron ranged from 27 to 452 ton/yr and dissolved-boron loads ranged from 8 to 159 ton/yr (table 19). Estimated boron loads were largest in the Kentucky River main stem, and mean annual loads of boron increased from Lock 10 downstream to Lock 2. Large yields of total-recoverable boron in the North Fork Kentucky River at Jackson and the Kentucky River at Lock 2 may be related to the transport of suspended sediment; however, the large yield of total-recoverable boron in the Kentucky River at Lock 2 may be additionally associated with urban land use. The dissolved-boron yield was largest in Elkhorn Creek at Frankfort, possibly indicating effects of point-source discharges in the greater Lexington metropolitan area. Boron yields in the Kentucky River increased downstream from Elkhorn Creek.

A slight downward trend for the 1987-90 period was detected for dissolved boron at several sites in the Kentucky River Basin (table 20). However, the trend was not apparent when boron concentrations were normalized to discharge.

## Cadmium

Detectible concentrations of cadmium in surface or ground water unaffected by human activity are rare. Cadmium is a USEPA priority pollutant, and the MCL is 5 μg/L (U.S. Environmental Protection Agency, 1991). Cadmium is also known to bioaccumulate in plants and animals. Kentucky acute and chronic aquatic-life criteria have been established at 3.9 µg/L and 1.1 µg/L, respectively. The aquatic-life criteria were exceeded in about 10 percent of samples collected during 1987-90 from the Kentucky River at Lock 10, 8 percent at Lock 2, 4 percent at Lock 4 and Elkhorn Creek, and 2 percent in the South Fork Kentucky River. Maximum concentrations of cadmium in water samples from the Kentucky River at Lock 2 and Elkhorn Creek at Frankfort equaled or exceeded the MCL. Long-term trends for cadmium cannot be established at any of the fixed stations because most of the total-recoverable and dissolved cadmium concentrations were less than the analytical detection limit.

Concentrations of total-recoverable cadmium ranged from less than the analytical detection limit of 1 to 4 µg/L; however, KDOW reported a maximum of 5 µg/L in the Kentucky River at Lock 4. Dissolved-cadmium concentrations ranged from less than the detection limit of 0.1 to 7.9 µg/L (table 17). Concentrations of cadmium in the suspended-sediment fraction of water range from less than 0.01 to 1.7 µg/L.

Concentrations of cadmium in the suspended-sediment matrix ranged from less than the detection limit of 0.1 to 11 µg/g (table 18), and median concentrations did not significantly differ among fixed stations. Concentrations of cadmium were not correlated with discharge or the concentration of the suspended sediment.

Mean annual load estimates for dissolved cadmium ranged from 0.2 to 2.7 ton/yr, were largest in the Kentucky River main stem, and increased downstream from Lock 10 to Lock 2 (table 19). Loads for the suspended-sediment fraction of cadmium ranged from 0.04 to 1.2 ton/yr. Comparisons of transport estimates (table 19) indicate that cadmium loads in the Kentucky River were larger downstream from the Knobs Region and the greater Lexington metropolitan area, and that a large percentage of cadmium in the Kentucky River is transported in the dissolved fraction. Loads and yields for cadmium concentrations at fixed stations in the Kentucky River Basin were less than reported by Smoot and others (1991) for cadmium data collected before 1987. Historical cadmium concentrations reported by water-quality agencies may be biased because of contamination problems associated with the collection or analysis of samples.

Specific sources of cadmium in the Kentucky River Basin are poorly understood. Although Gianessi (1986) estimated that at least 85 percent of the cadmium exiting the basin originates from nonpoint sources, detectible concentrations of cadmium in streambed sediments were only found downstream from point-source discharges. Concentrations of cadmium in selected WWTP effluents in the Kentucky River Basin ranged from less than 1 to 2 µg/L (table 10), although higher concentrations have been reported downstream from certain industrial discharges in the basin (Logan and others, 1988). Cadmium can also enter the atmosphere from industrial processes or from the combustion of fossil fuel (Hem, 1989), and it can enter streams by way of wet or dry deposition. Cadmium in streams can also originate from agricultural sources, because concentrations of cadmium have been detected in phosphate fertilizers and certain pesticides (National Academy of Sciences-National Academy of Engineering, 1972).

## Chromium

Chromium is a transition metal that may be present in surface water as trivalent cations or hexavalent anions (Hem, 1989). Hexavalent chromium is listed as a USEPA priority pollutant, and the MCL has been established at 100 µg/L (U.S. Environmental Protection Agency, 1991). The toxicity of chromium to aquatic life varies with the valance state and form of chromium, oxidation-reduction and pH relations, and synergistic or antagonistic effects of other constituents. The Kentucky acute and chronic aquatic-life criteria for hexavalent chromium are 16 µg/L and 11 µg/L, whereas the criteria for trivalent chromium are 1,700 µg/L and 210 µg/L, based on a total hardness concentration of 100 mg/L as $CaCO_3$.

Concentrations of total-recoverable chromium in the Kentucky River Basin were less than the MCL; however, concentrations at fixed stations occasionally exceeded the Kentucky acute or chronic aquatic-life criterion for hexavalent chromium. However, relations between the concentrations of total-recoverable and hexavalent chromium in the Kentucky River Basin are unknown. Although Smoot and others (1991) reported that total-recoverable concentrations of chromium were decreasing from the late 1970's to the mid-1980's at 5 of 11 fixed stations in the Kentucky River Basin, no significant trend is detected for chromium at any of the fixed stations when the 1987-90 data are added to the data base.

Concentrations of total-recoverable chromium ranged from less than the analytical detection limit of 1 to 31 µg/L, and dissolved-chromium concentrations varied from less than 1 to 2.5 µg/L (table 17). In contrast, concentrations in the suspended-sediment fraction of chromium in water ranged from 0.02 to 220 µg/L, indicating that aquatic-life criteria may have been exceeded in about 27 percent of the samples. The primary source of chromium in streams of the Kentucky River Basin seems to be geologic sources. Concentrations of chromium in streambed sediments were largest in the Knobs and Eastern Coal Field Regions, and elevated concentrations of chromium were observed in these regions during periods of high streamflows. Chromium concentrations were correlated with concentrations of aluminum, iron, manganese, and suspended sediment in water samples, as well as with stream discharge, at several of the fixed stations. Concentrations of chromium in the suspended-sediment matrix ranged from 5 to 190 µg/g (table 18), which is within the range determined for streambed sediments (8 to 410 µg/g) in the Kentucky River Basin.

Mean annual load estimates for total-recoverable concentrations of chromium ranged from 5.6 to 78 ton/yr and were largest in the Kentucky River at Lock 2 (table 19). Loads calculated from KDOW total-recoverable chromium data were smaller, ranging from 0.3 to 37 ton/yr. Load estimates for the suspended-sediment fraction of chromium (15 to 161 ton/yr) were considerably larger than either of the total-recoverable loads, which likely indicates that a substantial percentage of chromium is associated with clay mineralogy or as chromite in the suspended-sediment matrix. Although increases in chromium loads along the main stem Kentucky River may indicate cumulative effects, chromium yields were generally similar among fixed stations. Differences or increases in chromium loads probably are a result of increases of discharge rather than differences in sources. Estimated loads and yields for chromium at fixed stations in the Kentucky River Basin were generally similar to those reported by Smoot and others (1991).

Gianessi (1986) estimated that about 6 percent of the total chromium transport by the Kentucky River at Lock 2 originates from point sources. Although concentrations of chromium in streambed sediments were elevated downstream from point-source discharges in the Lexington area, the median concentration of chromium in the suspended-sediment matrix at the Elkhorn Creek fixed station (table 18) was significantly smaller than median concentrations at other fixed stations, and chromium yields at fixed stations in the Elkhorn Creek drainage were not significantly different from yields at other fixed stations in the Kentucky River Basin. Total-recoverable concentrations of chromium in wastewater treatment plants ranged from less than 1 to 15 μg/L (table 16).

## Cobalt

Cobalt is a transition metal that is a micronutrient for the growth of plants and animals. Concentrations of cobalt in natural water are generally less than a few micrograms per liter (Hem, 1989). Dissolved concentrations of cobalt in the Kentucky River Basin were all less than the analytical detection limit of 3 μg/L (table 17). Long-term trends were not detected for concentrations of cobalt at any of the fixed stations in the Kentucky River Basin.

Concentrations of cobalt in the suspended-sediment fraction of water in the Kentucky River Basin ranged from 0.01 to 41 μg/L (table 17). The largest concentrations corresponded to periods of high streamflows in the North Fork Kentucky River. Concentrations of cobalt in the suspended-sediment matrix from 4 to 55 μg/g, the largest concentrations being reported in the Upper Kentucky River Basin (table 18). Cobalt is only a minor constituent in carbonate rocks (Hem, 1989), and the median concentration of cobalt in the suspended-sediment matrix (table 18) in Elkhorn Creek (Inner Bluegrass karst drainage area) was significantly smaller than at other fixed stations.

Transport estimates for cobalt reveal elevated yields from coal mining areas drained by the North Fork Kentucky River at Jackson. Mean annual loads of cobalt were largest in the Kentucky River main stem; however, load estimates were of the same magnitude in the North Fork (table 19). The primary source of cobalt in the Kentucky River appears to be land disturbance in the North Fork Kentucky River Subbasin. Concentrations of cobalt are larger in samples of fire clay, mudstone, and black shale than in other geologic materials in the Kentucky River Basin (table 4).

## Copper

Copper is a USEPA priority pollutant that is a micronutrient for the growth of plants and animals, but even small concentrations of copper in surface water can be toxic to aquatic life. Copper sulfate is frequently used to control nuisance growths of algae in water-supply reservoirs. The toxicity of copper is a function of the total hardness of the water, because copper ions are complexed by anions that contribute to water hardness. Assuming a hardness of 100 mg/L, the Kentucky acute and chronic aquatic-life criteria for copper are 18 μg/L and 12 μg/L, respectively. Although detectible concentrations of copper in water are not known to have an adverse effect on humans, the SMCL for copper has been established at 1,000 μg/L, which corresponds with the taste-threshold concentration for this element (National Academy of Sciences-National Academy of Engineering, 1972).

Concentrations of copper in the Kentucky River Basin did not exceed the SMCL but did exceed aquatic-life criteria at all fixed stations during periods of above average stream discharge and sediment transport. Although Smoot and others (1991) reported that total-recoverable concentrations of copper were decreasing from the late 1970's to the mid-1980's, at 10 of 11 fixed stations, no significant trend was detected for copper at any of the fixed stations when the 1987-90 data were added to this data base.

Data collected during the study indicate that concentrations of total-recoverable copper at fixed stations ranged from less than the detection limit of 10 to 100 μg/L. Data collected by the KDOW during the same time period show that total-recoverable copper concentrations ranged from less than the detection limit of 1 to 26 μg/L (table 17). Dissolved-copper concentrations ranged from less than the detection limit of 0.5 to 29 μg/L. The concentration of copper in the suspended-sediment fraction of water ranged from 0.02 to 74 μg/L. Chronic aquatic-life criteria (for total-recoverable copper) were exceeded in greater than 25 percent of samples collected during 1987-90 (table 17).

Concentrations of copper in the suspended-sediment matrix ranged from 7 to 1,000 μg/g (table 18). Median matrix concentrations of copper did not significantly differ among fixed stations. However, concentrations of copper in the suspended-sediment matrix from the South Fork Kentucky River and Kentucky River at Lock 10 during early fall 1989 exceeded the maximum concentrations observed in all streambed-sediment and bedrock samples from the basin (500 μg/g; tables 2 and 3). The elevated concentrations of copper occurred during normal discharge conditions rather than during a period of high flow. Potential sources of copper (other than natural geologic sources) upstream from these fixed stations are unknown.

Mean annual load estimates for total-recoverable copper at the NAWQA fixed stations ranged from 5.2 to 135 ton/yr (table 19). The range of mean annual load estimates for total-recoverable copper at the KDOW fixed stations was approximately an order of magnitude smaller (0.4 to 44.2 tons/yr) (table 19). Differences between NAWQA and KDOW loads for copper may be attributable to differences of sampling methodology or to problems with determining small concentrations of copper in water samples. Suspended-sediment fraction loads of copper were intermediate, ranging from 4 to 60.2 ton/yr. Copper loads were largest in the Kentucky River main stem, and the mean annual load and yield for the suspended-sediment fraction were larger for the North Fork Kentucky River at Jackson than for either the Middle or South Forks (table 19). Estimated loads and yields for copper were generally similar to or smaller than those reported at fixed stations in the Kentucky

River Basin by Smoot and others (1991). Mean annual copper load in the Kentucky River at Lock 2 (120 ton/yr) during 1987-90 is less than half the value indicated before 1987 (283 ton/yr).

Mean annual dissolved-copper loads were largest in the Kentucky River main stem; however, yields of dissolved copper were similar for all fixed stations (table 19). The estimated dissolved-copper load for Elkhorn Creek was similar to that at the North Fork Kentucky River; however, approximately 26 percent of the copper load in Elkhorn Creek appears to have been transported in the dissolved fraction, whereas only 4 percent of the load in the North Fork Kentucky River was transported as dissolved copper. Larger amounts of dissolved copper transported at Elkhorn Creek, than at other fixed stations may be a result of point-source discharges or other human activities.

On the basis of point-source load estimates by Gianessi (1986), less than 1 percent of the copper transported out of the Kentucky River Basin originates from point sources. The maximum concentration of total-recoverable copper in selected WWTP effluents was 50 μg/L (table 16). The primary source of copper in the basin seems to be the weathering of shales and the transport of soils derived from shale bedrock in the Knobs and Eastern Coal Field Regions. However, elevated concentrations of copper in streambed sediments also were found downstream from point-source discharges in the Inner Bluegrass Region.

### Iron

Although iron is the second most abundant element in the Earth's outer crust, concentrations of iron in water are generally small (Hem, 1989). Iron is an objectionable constituent in water supplies because of unpleasant taste or staining of plumbing fixtures and laundry at concentrations greater than the SMCL of 300 μg/L. Although iron is an essential element in the metabolism of plants and animals, elevated concentrations of iron can be acutely or chronically toxic to aquatic organisms. Ferric hydroxide precipitates can interfere with respiratory processes of aquatic fauna or adversely affect bottom-dwelling organisms by degrading aquatic microhabitats. The USEPA chronic aquatic-life criterion for iron has been set at 1,000 μg/L (U.S. Environmental Protection Agency, 1986). Kentucky water-quality standards adopt a chronic criterion of 3,500 μg/L if it is established that there will be no damage to aquatic life; the acute criterion is 4,000 μg/L.

Concentrations of total-recoverable iron in streams of the Kentucky River Basin generally exceeded the SMCL and frequently exceeded Kentucky acute and chronic aquatic-life criteria during periods of above-average stream discharge. Maximum concentrations of dissolved iron in streams of the basin were less than aquatic-life criteria but exceeded the SMCL at four of seven NAWQA fixed stations.

Total-recoverable iron concentrations at the NAWQA fixed stations ranged from less than the analytical detection limit of 10 to 65,000 μg/L. Total-recoverable iron concentrations at the KDOW fixed stations ranged from less than 10 to 29,000 μg/L. Dissolved-iron concentrations ranged from less than the detection limit of 3 to 1,500 μg/L (table 17). Median concentrations of dissolved iron were significantly larger at most fixed stations during a period of above-average precipitation (1989-90) than during a period of extended drought (1987-88). Total-recoverable and dissolved concentrations of iron were positively correlated with concentrations of suspended sediment in water samples, as well as with stream discharge.

Median total-recoverable concentrations of iron in this study were larger than indicated from data collected by the KDOW (table 17) during the same period because (1) a greater proportion of water samples were collected during periods of high flow, (2) field and laboratory methods differ between the USGS and KDOW, (3) fewer samples (n = 13 to 17) were analyzed for total-recoverable iron concentrations, compared to the number of KDOW samples (n = 38 to 46), and (or) (4) contamination during sample collection or analysis may have affected analytical results.

Concentrations of iron in the suspended-sediment matrix ranged from 11,200 to 86,000 μg/g (table 18), which corresponds to the range of iron concentrations in streambed sediments of 12,000 to 96,000 μg/g (table 1). Median matrix concentrations of iron were significantly smaller at the Elkhorn Creek station, and significantly larger at stations on the Middle Fork Kentucky River and Kentucky River at Lock 10, than at other fixed stations in the basin (table 18). Median concentrations of dissolved iron at the fixed stations were distributed in a similar spatial pattern. Large concentrations of iron in the dissolved and suspended-sediment fractions of water in the Middle Fork Kentucky River may be related to the discharge of iron-rich, hypolimnetic water from Buckhorn Lake (P. Neichter, U.S. Army Corps of Engineers, written commun., 1991), located about 35 mi upstream from the fixed stations at Tallega.

Elevated dissolved and suspended-sediment-matrix concentrations of iron in the Kentucky River at Lock 10 may be associated with bedrock geochemistry of the Knobs Region and (or) oil-well brine discharges in streams of the Middle Kentucky River Basin. For example, Logan and others (1989) reported elevated concentrations of iron in the water and bed sediments of streams affected by brine discharges in the Millers Creek Subbasin. Smaller concentrations of dissolved and suspended-sediment matrix concentrations of iron in Elkhorn Creek may be related to the small concentrations of iron in bedrock samples and soils of the Inner Bluegrass Region.

Concentrations of iron in the suspended-sediment fraction of water samples ranged from 41 to 76,000 μg/L (table 17). The median concentration of iron was largest (3,200 μg/L) in the North Fork Kentucky River, and corresponds to elevated mass transport of sediment in the North Fork hydrologic unit. The estimated mean annual yield of suspended sediment from the North Fork Kentucky River Basin at Jackson (948 ton/mi$^2$) was three to four times larger than the yield at other fixed stations , and the estimated mean annual load of sediment in the North Fork Kentucky River at Jackson exceeded sediment-load estimates for other tributaries of the Kentucky River by 5 to 10 times (Smoot and others, 1991). The primary source of accelerated sedimentation in the North Fork Kentucky River Basin is land disturbance, primarily surface mining.

Concentrations, loads, and yields of iron in the main stem of the Kentucky River exceeded those reported by Smoot and others (1991). Concentrations and loads of iron (tables 17 and 19) initially decreased in the Kentucky River downstream from Lock 10, but concentrations were frequently largest at Lock 2 during periods of high streamflow. Increases in iron transport downstream from Lock 4 may be attributable to stormwater runoff from urban and agricultural areas of the Inner Bluegrass Region. Gianessi (1986) estimated that only 40 ton/yr of iron originate from point sources in the Kentucky River Basin. Concentrations of total-recoverable iron in selected WWTP effluents in the Kentucky River Basin ranged from 90 to 7,800 μg/L (table 16). Effluent concentrations of iron may correspond more with concentrations of iron in the water-supply source for a community than to contamination of water before wastewater discharges.

Based on KDOW data for the period of 1979-89, significant upward trends are apparent for total-recoverable iron concentrations at 9 of 11 fixed stations, and these trends remain significant when iron concentrations are adjusted for discharge (table 20). Because concentrations of iron are strongly correlated with concentrations of suspended sediment, upward trends for iron in the basin likely correspond to increases of suspended-sediment transport that result from land disturbance by surface mining, agriculture, and other human activities.

## Lead

Although lead is widely dispersed in the environment, natural sources (sedimentary rocks in particular) release little lead to water because of the low solubility of lead hydroxy carbonates (Hem, 1989). Sources of lead in the Kentucky River Basin include not only shales and other sedimentary rocks but also current and past human activities. Among these activities are the combustion of leaded gasoline and coal. Although regulation of exhaust emissions from motor vehicles has substantially reduced atmospheric concentrations of lead, elevated concentrations of lead in streambed sediments persist in urban areas of the Kentucky River Basin (fig. 19). Streambed-sediment data obtained by the NURE program indicated maximum lead concentrations of 900 μg/g in the Lexington area and other areas in the Inner Bluegrass Region (Smoot and others, 1991).

Lead is recognized as a USEPA priority-pollutant that can be acutely or chronically toxic to humans (particularly children) and aquatic life. Lead pipe was formerly used in water-distribution systems and is still present in many old buildings. The MCL (U.S. Environmental Protection Agency, 1991) and Kentucky's domestic water supply criterion for lead have recently been lowered from 50 to 5 μg/L. The toxicity of lead to aquatic organisms is a function of water hardness. Based upon a total hardness concentration of 100 mg/L, the Kentucky acute and chronic aquatic life criteria are 82 μg/L and 3 μg/L, respectively. Although total-recoverable concentrations of lead at fixed stations in the Kentucky River Basin were frequently (18 to 64 percent of water samples) less than analytical detection limits, lead concentrations that were determined often exceeded the MCL and chronic aquatic life criteria. Smoot and others (1991) reported significant downward trends for lead at many fixed stations during the 1979-86 period of record. However, no significant trend is detected for dissolved or total-recoverable lead concentrations at fixed stations in the Kentucky River Basin when the 1987-90 data are added to the historical data base.

Total-recoverable lead concentrations at NAWQA fixed stations in the Kentucky River Basin ranged from less than the analytical detection limit of 5 to 85 μg/L, and dissolved-lead concentrations ranged from less than the detection limit of 5 to 10 μg/L (table 17). Total-recoverable lead concentrations at KDOW fixed stations ranged from less than 2 to 153 μg/L. Median concentrations of lead exceeded the chronic aquatic-life criterion at all NAWQA fixed stations; however, concentrations of total-recoverable lead were larger than those reported by KDOW at comparative fixed stations. Concentrations of dissolved lead were larger during the low-flow period of 1987-88, whereas total-recoverable lead concentrations were larger during the period of above-average discharge (1989-90).

Concentrations of lead in the suspended-sediment matrix ranged from 8.7 to 500 μg/g (table 18), which corresponds to the range of lead concentrations detected in streambed sediments (12 to 930 μg/g) in the basin. No significant differences of median lead concentrations in the suspended-sediment matrix were indicated among fixed stations. Concentrations of lead in the suspended-sediment fraction ranged from 0.03 to 60 μg/L (table 17), and concentrations were larger during periods of above-average precipitation and stream discharge (1989-90). Although lead concentrations were not correlated with concentrations of suspended sediment in water samples, lead concentrations were largest in the North Fork Kentucky River at Jackson. Concentrations of lead in the suspended-sediment matrix were largest during fall and winter 1988-89, possibly indicating washout of streambed sediments that had accumulated lead during the preceding drought period.

Mean annual loads for total-recoverable lead indicate an upward, longitudinal trend in the Kentucky River from the North Fork at Jackson downstream to Lock 2 (table 19). Load estimates for total-recoverable lead concentrations at fixed stations in the basin were similar to or smaller than those reported by Smoot and others (1991) and ranged from 0.2 ton/yr in the Red River near Hazel Green to 50.2 ton/yr in the Kentucky River at Camp Nelson (KDOW fixed stations), and from 5.7 ton/yr in the Middle Fork Kentucky River at Tallega to 94.5 ton/yr in the Kentucky River at Lock 2 (NAWQA fixed stations) (table 19). Yields for total-recoverable lead were similar among fixed stations; however, yields were large in Elkhorn Creek compared with other NAWQA fixed stations, and in the Kentucky River at Camp Nelson, compared with other KDOW fixed stations. A downstream increase in the mean annual load and yield of lead in the Kentucky River (before 1987) was also reported by Smoot and others (1991). The yield of lead for the suspended-sediment fraction was largest in the North Fork Kentucky River at Jackson at 0.03 (tons/mi$^2$)/yr.

The accelerated transport of lead at Lock 2 may have resulted in part from the contribution of lead-enriched streambed sediments from urban streams in the Inner Bluegrass Region of the basin. Gianessi (1986) estimated that about 3 percent of the load of lead transported by the the Kentucky River at Lock 2 is attributable to point sources in the basin. Concentrations of total-recoverable lead in selected WWTP effluents in the basin ranged from

1 to 17 µg/L (table 16). The yield of total-recoverable lead was largest in Elkhorn Creek, which is affected by urban point and nonpoint sources.

### Lithium

Lithium is an alkali metal that generally is present in surface waters at concentrations of less than 2 µg/L (Hem, 1989). According to Bradford (1963), lithium can be toxic to plants at concentrations of 60 to 100 µg/L. Concentrations of dissolved lithium in streams of the Kentucky River Basin are commonly less than the analytical detection limit. However, streambed-sediment concentrations of lithium are elevated in oil-producing areas of the Kentucky River Basin, and dissolved lithium concentrations in streams affected by oil-well-brine discharges have been known to range from 140 to 650 µg/L (Evaldi and Kipp, 1991). Natural sources of lithium in the basin are probably limited to the weathering of sedimentary rocks, notably shales, mudstones, and siltstones.

Concentrations of dissolved lithium in this study ranged from less than the analytical detection limit of 4 to 23 µg/L (table 17). Median concentrations of dissolved lithium were significantly larger at most fixed stations during a period of extended drought conditions (1987-88) than during the period of above-average precipitation (1989-90). This relation likely indicates the effect of ground-water contributions during periods of low streamflow. Mean annual loads of lithium were largest in the Kentucky River main stem; however, the yield of dissolved lithium was largest in the North Fork Kentucky River at Jackson (table 19). This large yield at Jackson may indicate lithium accumulation resulting from coal mining or other land disturbance in that part of the basin.

Mean annual loads of dissolved lithium in the Kentucky River increased from Lock 10 downstream to Lock 2, possibly indicating effects of oil-well-brine discharges in the Knobs Region. However, in contrast with the distribution of elevated concentrations of lithium in streambed sediments, concentrations of dissolved lithium at fixed stations remained relatively constant throughout the basin. Yields of dissolved lithium were larger at fixed stations on the North Fork Kentucky River and Elkhorn Creek than at other fixed stations (table 19). No significant trends for dissolved-lithium concentrations were detected at fixed stations in the Kentucky River Basin.

### Magnesium

Magnesium is an alkaline-earth metal that is a major element, essential for plant and animal nutrition (Hem, 1989). The natural source of magnesium in the Kentucky River Basin is the weathering of sedimentary rocks, notably dolomitic limestones in the Bluegrass Regions and shales of the Eastern Coal Field and Knobs Regions. Dissolved magnesium concentrations ranged from 3,000 to 47,000 µg/L (table 17). Magnesium concentrations were positively correlated with concentrations of calcium, sodium, and strontium, and negatively correlated with stream discharge. Concentrations of magnesium in the suspended-sediment matrix ranged from 4,400 to 47,900 µg/g (table 18), and median concentrations were not significantly different among fixed stations in the Kentucky River Basin. Concentrations of the suspended-sediment fraction of magnesium in water ranged from 9.0 to 14,000 mg/L (table 17). Magnesium concentrations were largest in the North Fork Kentucky River at Jackson during periods of above-average streamflow.

Mean annual loads for dissolved magnesium ranged from 3,630 ton/yr in Elkhorn Creek to 64,500 ton/yr in the Kentucky River at Lock 2 (table 19) and were similar to loads reported by Smoot and others (1991). Loads of magnesium in the suspended-sediment fraction ranged from 824 ton/yr in Elkhorn Creek to 14,100 ton/yr in the Kentucky River at Lock 2, indicating that a substantial amount of magnesium is transported in the dissolved phase. The yield of dissolved and suspended-sediment fractions of magnesium was largest in the North Fork Kentucky River at Jackson and smallest in Elkhorn Creek.

A significant upward trend was detected for concentrations of dissolved magnesium in the Kentucky River at Lock 2, and the trend persists when concentrations are adjusted discharge (table 20). An upward flow-adjusted trend for concentrations of dissolved magnesium is also indicated in the North Fork Kentucky River at Jackson.

### Manganese

Although manganese is an essential element in plant metabolism, it is an undesirable impurity in water supplies because water that contains appreciable concentrations of manganese can deposit black oxide stains and cause unpleasant tastes and odors. The SMCL and the Kentucky domestic water supply source criterion for manganese have been set at 50 µg/L. Median concentrations of total-recoverable manganese in the Kentucky River Basin exceeded 50 µg/L at all NAWQA fixed stations. The major source of manganese in the basin is probably the weathering of sedimentary rocks. In lakes and reservoirs that develop thermal stratification, bottom sediments may become anoxic and manganese oxide previously deposited may be reduced and dissolved. Hypolimnetic water released from reservoirs can contain substantial concentrations of dissolved manganese (Hem, 1989).

Manganese concentrations at fixed stations in the Kentucky River Basin were correlated with concentrations of iron, aluminum, and suspended sediment, as well as with stream discharge. Trend analyses of total-recoverable concentrations of manganese during 1979-89 indicate significant increases of manganese concentrations at 8 of 10 KDOW fixed stations in the basin, and the trends persist at 7 of these fixed stations when concentrations are adjusted for discharge (table 20).

Total-recoverable concentrations of manganese in the Kentucky River Basin ranged from less than the analytical detection limit of 10 to 2,200 µg/L, and dissolved-manganese concentrations ranged from less than the detection limit of 1 to 490 µg/L (table 17). Median concentrations of manganese were larger at fixed stations in the Eastern Coal Field and Knobs Regions than at sites in the Inner and Outer Bluegrass Regions. Elevated concentrations of total-recoverable manganese were found in the North Fork Kentucky River at Jackson, particularly during periods of above-average streamflow. Median concentrations of total-recoverable manganese were significantly larger at all fixed stations during a period of above-average precipitation and stream discharge (1989-90) than during the period of extended drought (1987-88).

Concentrations of manganese in the suspended-sediment matrix ranged from 110 to 37,100 μg/g (table 18); elevated concentrations were found in the Kentucky River at Lock 10 and Lock 4, after an extended period of low discharge. However, median matrix concentrations of manganese did not significantly differ among fixed stations. Concentrations of manganese in the suspended-sediment fraction of water ranged from 3.0 to 2,200 μg/L and corresponded with the range of total-recoverable concentrations of manganese. Median concentrations of manganese were significantly smaller during a period of extended drought (1987-88) than during the period of above-average precipitation (1989-90).

Mean annual loads were similar for total-recoverable manganese and suspended-sediment-fraction manganese, and they ranged from 168 ton/yr in the Middle Fork Kentucky River at Tallega to approximately 2,900 ton/yr in the Kentucky River at Lock 2 and Lock 4 (table 19). Loads for dissolved manganese ranged from 8 ton/yr in Elkhorn Creek to 450 ton/yr in the Kentucky River at Lock 10. Comparisons of loads and yields of manganese at the fixed stations (table 19) indicate that about 95 percent of manganese was transported in the suspended phase, whereas only 5 percent was transported in the dissolved phase. Yields for total-recoverable manganese were largest in the North Fork Kentucky River at Jackson and in Elkhorn Creek at Frankfort. In contrast, dissolved-manganese yields were largest in the South Fork Kentucky River at Booneville and in the Kentucky River at Lock 10. Estimated loads and yields for manganese at fixed stations in the Kentucky River Basin were similar to those reported by Smoot and others (1991).

### Mercury

Mercury is a USEPA priority pollutant that can be toxic to humans and will bioaccumulate in fish and other aquatic organisms. Although mercury concentrations are very small in most streams, rarely exceeding more than a few tenths of a microgram per liter, the natural tendency of mercury to volatilize results in a wide dispersion of mercury throughout the environment because of atmospheric deposition. Sources of mercury contamination include the burning of fossil fuels (National Academy of Sciences-National Academy of Engineering, 1972), the use of organomercurial compounds or mercuric chlorides as biocides in agricultural and commercial applications (Hem, 1989), and discharges from industrial sources.

Organic complexes such as methyl mercury may be produced by methanogenic bacteria in contact with metallic mercury in stream sediments (Hem, 1989). Methyl mercury can be acutely or chronically toxic to organisms and biomagnified in the aquatic food chain, resulting in mercury concentrations in fish tissue that exceed action levels established by the U.S. Food and Drug Administration. Acute and chronic warmwater aquatic habitat criteria have been set by Kentucky water-quality criteria at 2.4 μg/L and 0.012 μg/L, respectively. The Kentucky water-quality criterion for protection of human health from the consumption of mercury in fish tissue is 0.146 μg/L. The MCL for mercury is 2 μg/L, and Kentucky domestic water supply criterion is 0.144 μg/L. Because the analytical detection limit for mercury is 0.1 μg/L, the potential frequency that concentrations exceed the chronic aquatic habitat criterion cannot be evaluated. The acute aquatic habitat criterion for mercury was not exceeded in any of the water samples collected at fixed stations in the Kentucky River Basin.

The Kentucky domestic water supply criterion for total-recoverable mercury was exceeded in 10 to 25 percent of samples collected at fixed stations in the Kentucky River Basin. However, the MCL was exceeded in less than 1 percent of 327 water samples. Maximum concentrations of total-recoverable mercury at fixed stations ranged from 0.2 to 2.3 μg/L, and maximum concentrations of dissolved mercury ranged from 0.6 to 2.1 μg/L (table 17). Median total-recoverable mercury concentrations were at or below analytical detection limits at all fixed stations. The ranges of mercury concentrations are similar to those published in water-quality reports by the KDOW (Logan and others, 1983a, 1983b, 1984). However, Smoot and others (1991) reported maximum concentrations of total-recoverable and dissolved mercury of 113 and 40 μg/L, respectively, in the Kentucky River Basin before 1987 and indicated that 7 percent of 623 measurements exceeded the MCL of 2 μg/L.

Approximately 1 ton of mercury was transported out of the Kentucky River Basin each year during the NAWQA pilot study. Mean annual loads of mercury were nearly an order of magnitude larger at fixed stations on the Kentucky River than at other fixed stations in the basin (table 19). However, transport estimates were smaller than those reported by Smoot and others (1991) and seemed to remain constant throughout the middle to lower reaches of the Kentucky River. Although significant downward trends for mercury were reported at several fixed stations in the Kentucky River Basin by Smoot and others (1991), no significant trends are indicated for mercury when the 1987-90 data are added to the historical data base.

Because a considerable percentage of the mercury data was below the detection limit and large errors in the estimation of mercury transport are possible, evaluating sources of mercury contamination in the Kentucky River Basin is difficult. Streambed-sediment concentrations of mercury are were largest in streams affected by point-source discharges and other urban influences in central Kentucky; however, several rural streams in the Eastern Coal Field Region also contained elevated concentrations of mercury in streambed sediments. Concentrations of total-recoverable mercury exceeded the MCL in streams that receive point-source discharges (Logan and others, 1983a, 1983b, 1984). Concentrations of total-recoverable mercury in selected WWTP effluents in the Kentucky River Basin ranged from less than 0.1 to 1.4 μg/L (table 16). Mercury concentrations were occasionally elevated in major tributaries of the Eastern Coal Field Region (table 17), possibly indicating a relation with bedrock geochemistry and land disturbances from coal mining.

## Molybdenum

Molybdenum is a transition metal and an essential element in animal and plant nutrition, particularly for legumes (Hem, 1989). Molybdenum is an essential micronutrient for the growth of algae, and certain species may concentrate molybdenum by a factor of as much as 15 (National Academy of Sciences-National Academy of Engineering, 1972). Molybdenum can also bioaccumulate in plants, sometimes in amounts that cause problems for grazing animals. However, the factors that influence the toxicity of molybdenum in plants and water are not well understood, and water-quality criteria have not been established. Average concentrations of molybdenum in rivers and lakes range from less than 10 to about 100 μg/L (Hem, 1989). Concentrations of total-recoverable molybdenum in the Kentucky River Basin ranged from less than the analytical detection limit of 1 to 60 μg/L, and dissolved-molybdenum concentrations ranged from less than the detection limit of 10 to 30 μg/L (table 17). Median concentrations of molybdenum did not substantially differ among fixed stations, and significant trends for molybdenum were not indicated at fixed stations in the Kentucky River Basin.

Concentrations of molybdenum in the suspended-sediment matrix ranged from 0.4 to 74.1 μg/g; the largest concentrations were in Elkhorn Creek at Frankfort (table 18). Median matrix concentrations of molybdenum were significantly smaller in streams of the Eastern Coal Field Region (North, Middle, and South Forks of the Kentucky River) than in other regions. Concentrations of molybdenum in the suspended-sediment fraction of water ranged from 0.01 to 2.28 μg/L (table 17). Median concentrations of molybdenum in the suspended-sediment fraction were significantly larger at most fixed stations during a period of above-average precipitation (1989-90) than during the period of extended drought (1987-88). Concentrations of molybdenum were largest during periods of elevated streamflow in Elkhorn Creek and the North Fork Kentucky River at Jackson (table 17).

Mean annual loads for total-recoverable molybdenum ranged from 2.4 to 19 ton/yr, whereas loads for the suspended-sediment fraction were considerably less, ranging from 0.14 to 2.7 ton/yr (table 19). Loads of molybdenum were largest at fixed stations in the Kentucky River; however, yields of total-recoverable molybdenum were largest in the Middle Fork Kentucky River and Elkhorn Creek. Comparison of total-recoverable molybdenum loads with suspended-sediment fraction loads for molybdenum indicate that a substantial percentage of molybdenum may be transported in the dissolved phase. However, the dissolved molybdenum load cannot be estimated because most of the data from the fixed stations were less than the analytical detection limit of 10 μg/L.

Sources of molybdenum in the Kentucky River Basin include Devonian black shales and mudstones, and elevated concentrations of molybdenum are detected in streambed sediments from the Knobs Region. Concentrations of molybdenum in selected WWTP effluents ranged from 1 to 390 μg/L (table 16); the largest concentrations were found at treatment facilities that receive industrial wastes. Molybdenum is used extensively as an alloy in steel and in welding rods and is also used extensively as a lubricant additive (Hem, 1989). Elevated concentrations of molybdenum in the suspended-sediment matrix in Elkhorn Creek could be a result of industrial activities in Lexington and Georgetown.

## Nickel

Nickel is a USEPA priority pollutant that can adversely affect humans and aquatic organisms. Nickel is an important industrial metal that is used extensively in stainless steel. Substantial amounts of nickel can be contributed to the environment by waste disposal (Hem, 1989) and atmospheric emissions. Nickel ions are toxic, particularly to plant life, and can exhibit synergism when present with other metallic ions (National Academy of Sciences-National Academy of Engineering, 1972). For water with total hardness of 100 mg/L, the Kentucky acute and chronic warmwater aquatic habitat criteria are 1,418 μg/L and 158 μg/L, respectively. The Kentucky domestic water-supply source criterion for nickel has been set at 13.4 μg/L, and the Kentucky criterion for protection of human health from the consumption of fish tissue is 100 μg/L.

Concentrations of nickel at fixed stations in the Kentucky River Basin did not exceed aquatic life criteria. However, total-recoverable nickel concentrations exceeded the Kentucky domestic water-supply criterion in 25 percent (or greater) of water samples from four of seven NAWQA fixed stations in the basin (table 17). No significant long-term trends were indicated for nickel concentrations at any of the fixed stations.

Concentrations of total-recoverable nickel in the Kentucky River Basin ranged from less than the analytical detection limit of 1 to 70 μg/L, and dissolved-nickel concentrations were generally less than the detection limit of 10 μg/L (table 17). Total-recoverable nickel concentrations were correlated with stream discharge and concentrations of aluminum, iron, manganese, vanadium, and suspended sediment in water samples. Median concentrations of total-recoverable nickel were largest in the North Fork Kentucky River at Jackson and in the Kentucky River at Lock 10 (table 17). Concentrations of total-recoverable nickel were significantly larger at four of seven fixed stations during a period of above-average precipitation and discharge (1989-90) than during the period of extended drought (1987-88).

Concentrations of nickel in the suspended-sediment matrix ranged from 14 to 498 μg/g (table 18), and median concentrations of nickel were significantly larger in the South Fork Kentucky River at Booneville and in the Kentucky River at Lock 10 than at other fixed stations. Concentrations of nickel in the suspended-sediment fraction of water ranged from 0.04 to 160 μg/L (table 17), and the largest concentrations occurred during flood conditions in January 1989.

Mean annual loads for total-recoverable nickel at fixed stations ranged from 5.2 to 94.9 ton/yr (table 19). Loads for the suspended-sediment fraction of nickel were similar, ranging from 5.0 to 81.6 ton/yr. The load and yield of total-recoverable nickel were large in the Kentucky River at Lock 10 compared with other fixed stations; however, the yield of nickel was also large in the North Fork Kentucky River at Jackson. Transport estimates for nickel were similar to those reported by Smoot and others (1991), and comparison of total-recoverable nickel loads with loads of nickel in the suspended-sediment fraction indicates that a considerable percentage of nickel in the Kentucky River Basin is transported by suspended sediment. The elevated annual nickel load in the Kentucky River at Lock 10 likely corresponds with the proximity of this fixed station to streams that drain the Knobs Region. Concentrations of nickel in streambed sediments of the Knobs Region were significantly larger than those of other physiographic regions in the basin, probably because of the predominance of Devonian shales in the region.

The primary source of nickel in the Kentucky River Basin is probably the weathering of shales, mudstones, and fire clays. The correlation of nickel concentrations with concentrations of suspended sediment likely explains the elevated concentrations and yields of nickel in the North Fork Kentucky River. Industrial discharges and waste-management practices also contribute nickel to streams in the Kentucky River Basin, but these effects were not readily apparent at any of the fixed stations. Concentrations of total-recoverable nickel in selected WWTP effluents ranged from 3 to 88 μg/L (table 16); the largest concentrations were found at facilities that receive industrial wastes. Concentrations of nickel in streambed sediments were elevated downstream from wastewater-treatment plants in the greater Lexington area, and waste-disposal practices in this part of the basin contribute to loads of nickel in the Kentucky River main stem.

## Selenium

Selenium is a nonmetallic trace element that is listed as a primary pollutant by the USEPA. Selenium is an essential micronutrient for plants and animals but can be toxic in excessive amounts. Kentucky acute and chronic warmwater aquatic habitat criteria for total-recoverable concentrations of selenium are 20 μg/L and 4 μg/L, respectively. The Kentucky domestic water supply source criterion for selenium has been set at 10 μg/L; however the MCL is 50 μg/L (U.S. Environmental Protection Agency, 1991). Selenium is a relatively rare element, and concentrations of selenium in natural waters seldom exceed 1 μg/L (Hem, 1989). Sources of selenium in the Kentucky River Basin include sedimentary rocks and fly ash from coal-fired powerplants that operate in Kentucky.

All determinations of dissolved-selenium concentrations at fixed stations in the Kentucky River Basin were less than MCL and Kentucky aquatic-life criteria. Concentrations of dissolved selenium ranged from less than the analytical detection limit of 1 to 2 μg/L (table 17). Mean annual loads and yields for selenium were not determined because most of the concentrations were less than the detection limit. No significant trends for selenium were detected at any of the fixed stations.

## Silver

Silver is a USEPA priority pollutant that is extensively used for photography and various industrial and commercial purposes. Although average concentrations of silver in natural waters are small (0.3 μg/L), elevated silver concentrations can be acutely or chronically toxic to aquatic organisms, and sublethal amounts can bioaccumulate in fish and invertebrate organisms (Hem, 1989). The Kentucky warmwater aquatic habitat acute-toxicity criterion is 4 μg/L, given a total water hardness of 100 mg/L. Although

Kentucky water-quality standards do not specify a chronic aquatic-life criterion, the USEPA chronic criterion for silver is 0.12 µg/L. The MCL and Kentucky domestic water supply source criteria for silver are 50 µg/L. Maximum concentrations of dissolved silver at four of seven fixed stations exceeded acute aquatic-life criteria. No significant trends for dissolved-silver concentrations were detected at any of the fixed-stations.

Concentrations of dissolved silver ranged from less than the analytical detection limit of 1 to 9 µg/L (table 17). Median concentrations of silver were less than the detection limit at all fixed stations. Concentrations of silver in the suspended-sediment matrix ranged from less than the detection limit of 0.1 to 10 µg/g (table 18), and the median concentration of silver in the suspended-sediment matrix was significantly larger at Elkhorn Creek to other fixed stations. Concentrations of silver in the suspended-sediment fraction of water ranged from less than 0.01 to 3.7 µg/L (table 17); the largest concentrations were found at the South Fork Kentucky River fixed station.

Mean annual loads for the suspended-sediment fraction of silver ranged from 0.03 to 0.63 ton/yr (table 19). Silver transport increased from the North Fork Kentucky River at Jackson downstream to the Kentucky River at Lock 2. However, transport error estimates of the relation are large, probably because ambient concentrations of silver were small and not correlated with discharge. Silver transport in the North Fork Kentucky River was larger than that in the Middle and South Forks of the Kentucky River.

### Strontium

Strontium is an alkaline-earth metal that is fairly common in igneous and sedimentary rocks. Concentrations of strontium are generally larger in ground water than in surface water (Hem, 1989). Strontium concentrations in the Kentucky River Basin were negatively correlated with stream discharge and positively correlated with concentrations of certain major elements such as calcium, magnesium, potassium, and sodium. Concentrations of dissolved strontium ranged from 40 to 1,200 µg/L (table 17); the largest concentrations were found in the North Fork Kentucky River at Jackson and in the Kentucky River at Lock 10. Median concentrations of dissolved strontium at fixed stations were significantly larger during a period of extended drought (1987-88) than during the period of above-average precipitation (1989-90). This relation probably indicates the effects of ground-water contributions to streams in the Kentucky River Basin during periods of low streamflow.

Estimated mean annual transport of strontium ranged from 72.5 to 1,230 ton/yr (table 19) and was largest in the Kentucky River main stem. However, the yield of strontium was largest in the North Fork Kentucky River at Jackson. Estimated strontium loads in the Kentucky River remained relatively constant from Lock 10 to Lock 2. The elevated yield of strontium in the North Fork Kentucky River may be associated with land-disturbance or deep-mining activities associated with the extraction of coal in this part of the basin. Although streambed-sediment concentrations of strontium are largest in the Inner Bluegrass Region, strontium transport in Elkhorn Creek was similar to that for the Middle and South Forks of the Kentucky River (table 19). Significant trends in the concentration of dissolved strontium were not detected at any of the fixed stations in the Kentucky River Basin.

### Thallium

Thallium is a USEPA priority pollutant that can be toxic to humans and aquatic life. Thallium salts are used as poison for rats and other rodents, as well as in dyes, pigments in fireworks, and optical glass (National Academy of Sciences-National Academy of Engineering, 1972). The Kentucky domestic water supply source criterion for thallium is 13 μg/L. Kentucky acute and chronic LOEL aquatic-life criteria for thallium are 1,400 μg/L and 40 μg/L, respectively. The Kentucky water-quality criterion for protection of human health from the consumption of fish tissue for thallium is 48 μg/L. Examination of thallium concentrations in the Kentucky River Basin indicate that none of the above criteria were exceeded at any of the fixed stations.

Concentrations of thallium in the suspended-sediment matrix ranged from less than 0.1 to 4.1 μg/g (table 18). The concentrations of thallium in the suspended-sediment fraction of water ranged from 0.01 to 1.7 μg/L (table 17); the largest concentrations were found at fixed stations in the North and South Forks of Kentucky River during periods of high flow.

Estimated mean annual loads for thallium ranged from 0.11 to 1.6 ton/yr (table 19) and remained relatively constant from the North Fork Kentucky River at Jackson to the Kentucky River at Lock 2. The North Fork Kentucky River Subbasin appears to be the primary source of thallium in the basin.

### Titanium

Titanium is a transition metal that is widely distributed in rocks and soil. The oxide is used as a white pigment in paint, constituting a potentially widespread human source of titanium; however, the natural abundance of titanium in geologic materials would otherwise be available without human contributions (Hem, 1989). Although titanium is an abundant element in crustal rocks, concentrations of titanium in natural water are generally very small.

Concentrations of titanium in the suspended-sediment matrix at fixed stations in the Kentucky River Basin ranged from less than 100 to 6,100 μg/g (table 18); the largest concentrations were found in the Eastern Coal Field and Knobs Regions. The median matrix concentration of titanium was significantly smaller in Elkhorn Creek than at other fixed stations. The concentration of titanium in the suspended-sediment fraction of water ranged from 4 to 9,100 μg/L (table 17). Median concentrations of titanium in the suspended-sediment fraction were significantly larger at five of seven fixed stations during a period of above-average precipitation (1989-90) than during the period of extended drought (1987-88). The largest concentrations of titanium (7,400 to 9,100 μg/L) occurred in the North Fork Kentucky River at Jackson during flood conditions of January 1989.

Mean annual loads for titanium ranged from 620 ton/yr in the Middle Fork Kentucky River at Tallega to 9,240 ton/yr in the Kentucky River at Lock 2 (table 19). Mean annual loads of titanium increased downstream from the North Fork Kentucky River at Jackson to the Kentucky River at Lock 2. Titanium transport was smallest in Elkhorn Creek at Frankfort and the Middle Fork Kentucky River at Tallega. The estimated yield for titanium at the fixed station on North Fork Kentucky River at Jackson was approximately four times larger than at other fixed stations. The source of titanium in the North Fork is attributable to the weathering of rocks; however, land disturbance in the region may contribute to the mobilization of sediment and the transport of titanium-enriched sediment. Streambed-sediment concentrations of titanium were elevated in the North Fork Kentucky River hydrologic unit, probably because concentrations of titanium are largest in rock strata of the Eastern Coal Field Region, and coal mining in the region exposes geologic materials to weathering. The smaller than expected transport of titanium in the Middle Fork Kentucky River at Tallega may be attributable to the location of Buckhorn Lake, approximately 35 mi upstream, where considerable amounts of sediment are deposited upstream from the dam.

## Vanadium

Vanadium is a transition metal that is involved in biochemical processes in plants and animals; however, vanadium can bioaccumulate in the food chain, resulting in chronic toxicity to organisms that feed upon prey that have accumulated excessive amounts of vanadium (National Academy of Sciences-National Academy of Engineering, 1972). Vanadium was concentrated by certain marine organisms during the formation of coal and oil-producing strata millions of years ago (Hem, 1989). Elevated streambed-sediment concentrations of vanadium in the Kentucky River Basin were found in the Knobs Region because of the presence of shales of Devonian age. Concentrations of dissolved vanadium at fixed stations in the Kentucky River Basin were all less than the analytical detection limit of 6 μg/L (table 17); consequently, significant trends for vanadium were not detected at any of the fixed stations. Smoot and others (1991) reported a maximum dissolved-vanadium concentration of 67 μg/L.

Concentrations of vanadium in the suspended-sediment matrix ranged from less than 6 to 175 μg/g (table 18). Median concentrations of vanadium were significantly larger in the Kentucky River at Lock 10 and in the Middle Fork Kentucky River at Tallega than at any of the other fixed stations. The fixed station on the Kentucky River at Lock 10 integrates drainage from oil-producing areas in the Knobs Region. The concentration of vanadium in the suspended-sediment fraction of water ranged from 0.02 to 230 μg/L (table 17). Median concentrations of vanadium in the suspended-sediment fraction were largest in the North Fork Kentucky River at Jackson, where concentrations of suspended sediment were larger than in other tributaries to the Kentucky River.

Estimated mean annual loads for the suspended-sediment fraction of vanadium ranged from 15.4 ton/yr in the Middle Fork Kentucky River at Tallega to 215 ton/yr in the Kentucky River at Lock 2 (table 19). Mean annual loads of vanadium increased from the North Fork Kentucky River downstream to the Kentucky River at Lock 2. However, the yield of vanadium was largest in the North Fork Kentucky River at Jackson (table 19).

### Zinc

Zinc, a USEPA priority pollutant, is an essential micronutrient for plant and animal metabolism that can be acutely or chronically toxic to aquatic organisms. Adverse synergistic effects can occur when zinc is present with cadmium, copper, or other heavy metals, and zinc is known to biomagnify through the aquatic food chain (National Academy of Sciences-National Academy of Engineering, 1972). The toxicity of zinc depends on the total hardness of the water because zinc ions are complexed by anions that contribute to total water hardness. Given a total hardness concentration of 100 mg/L, the Kentucky acute and chronic warmwater aquatic habitat criteria for zinc are 117 μg/L and 106 μg/L, respectively. The SMCL for zinc is 5,000 μg/L. Concentrations of total-recoverable zinc exceeded the chronic aquatic-life criterion in 10 to 15 percent of samples collected during 1986-89 by KDOW at 4 of 11 fixed stations. The maximum zinc concentration indicated by KDOW data during the period was 1,500 μg/L (table 17), more than three times the maximum concentration reported by Smoot and others (1991). Although USGS data show that total-recoverable zinc concentrations exceeded aquatic-life criteria in greater than 25 percent of water samples from the North Fork Kentucky River at Jackson, samples from other fixed stations contained concentrations of total-recoverable and dissolved zinc that were less than aquatic-life criteria. Significant upward trends for concentrations of total-recoverable zinc (table 20) were detected in the Kentucky River at Camp Nelson and at Lock 4, as well as in South Elkhorn Creek near Midway, possibly indicating effects from human activities in the Lexington metropolitan area. Streambed-sediment concentrations of zinc were elevated in this region of the Kentucky River Basin.

Concentrations of total-recoverable zinc at fixed stations in the Kentucky River Basin ranged from less than the analytical detection limit of 1 to 1,500 μg/L (table 17). Dissolved-zinc concentrations ranged from less than the detection limit of 3 to 130 μg/L. Total-recoverable zinc concentrations were correlated with concentrations of suspended sediment, aluminum, iron, and manganese, in addition to stream discharge. Median concentrations of total-recoverable zinc were significantly larger at five of seven NAWQA fixed stations during a period of above-average precipitation and streamflow (1989-90) than during a period of extended drought (1987-88).

Median zinc concentrations at KDOW fixed stations were largest in South Elkhorn Creek near Midway. Water quality at this location is affected by effluents from wastewater-treatment plants in the greater Lexington metropolitan area. Concentrations of total-recoverable zinc in selected wastewater-treatment plant effluents in the Kentucky River Basin ranged from less than 10 to 180 μg/L (table 16). The median zinc concentration was largest in the North Fork Kentucky River at Jackson, which indicates that coal mining also is a significant source of zinc in the Kentucky River Basin.

Concentrations of dissolved zinc were also elevated in the North Fork Kentucky River; however, median concentrations of dissolved zinc did not significantly differ among fixed stations.

Concentrations of zinc in the suspended-sediment matrix ranged from 54 to 1,890 $\mu g/g$ (table 18), and largest concentrations were found in the South Fork Kentucky River at Booneville and in the Kentucky River at Lock 10. However, median zinc concentrations in the suspended-sediment matrix did not significantly differ among fixed stations. The concentrations of zinc in the suspended-sediment fraction of water (table 17) ranged from 0.16 to 260 $\mu g/L$, and elevated concentrations were found in the North Fork Kentucky River at Jackson.

Mean annual loads for total-recoverable zinc ranged from approximately 3 to 815 ton/yr at KDOW fixed stations and from 26.4 to 267 ton/yr at NAWQA fixed stations (table 19). Loads for dissolved zinc ranged from 5 to 59 ton/yr (table 19). Loads for zinc increased from the North Fork Kentucky River downstream to the Kentucky River at Lock 2. The mean annual yield for total-recoverable zinc (KDOW data) was largest in the North Fork Kentucky River at Jackson and in the Kentucky River at Camp Nelson. The magnitude of loads and yields for total-recoverable and suspended-sediment-fraction zinc closely corresponded at all NAWQA fixed stations, indicating that the transport of zinc in the Kentucky River Basin is strongly associated with the transport of suspended sediment. Transport estimates for dissolved and total-recoverable concentrations of zinc were generally twice those reported by Smoot and others (1991). However, the load of zinc in the Kentucky River at Lock 2 was considerably smaller than determined from water-quality data collected before 1987, whereas load estimates from KDOW data in the Kentucky River at Camp Nelson and Frankfort are three to five times larger than reported by Smoot and others (1991).

## Relations Among Concentrations of Metals and Other Trace Elements in Streambed Sediments and in Solution During Low Streamflows

Relations between concentrations of metals and other trace elements in streambed sediments and concentrations of dissolved constituents in the water column are affected by dissolved-oxygen concentrations and other factors. Results from a synoptic field investigation, done during a period of low streamflow in August 1987 at 74 stream sites in the Kentucky River Basin, indicate that dissolved concentrations of certain trace elements are also significantly correlated with concentrations of metals in streambed sediments. Dissolved concentrations of metals and other trace elements are correlated with certain water-quality constituents and properties, including dissolved oxygen (DO) and specific conductance. For example, dissolved concentrations of iron, manganese, molybdenum, and silica were large at stream locations where DO concentration was small. Dissolved-oxygen concentrations ranged from 1.1 to 15.4 mg/L, and concentrations were less than the Kentucky warmwater aquatic-life criterion of 5 mg/L at 20 percent of the stream locations sampled during the synoptic survey. Large concentrations of dissolved cadmium and chromium were correlated with small concentrations of DO in streams of the urbanized Inner Bluegrass Region; the reduction in DO concentration may be the result of wastewater discharges, landfills, and urban runoff. Dissolved beryllium and lead concentrations were large in streams of the Knobs Region that were characterized by small concentrations of DO. No relation is indicated between the concentration of dissolved elements and pH, which ranged from 5.9 to 9.0.

During low flow, site-specific relations would be expected when comparing concentrations of dissolved constituents with their concentrations in underlying streambed sediments. Although total concentrations of aluminum, barium, chromium, copper, iron, lithium, nickel, vanadium, and zinc in streambed sediments are highly intercorrelated in most regions of the Kentucky River Basin, only dissolved concentrations of chromium, copper, and nickel are significantly correlated with their concentrations in underlying streambed sediments. Concentrations of dissolved beryllium, lead, and molybdenum are correlated with concentrations of these trace elements in streambed sediments, but only at stream sites in the Knobs Region. Although concentrations of dissolved barium, boron, and strontium are intercorrelated throughout the basin, concentrations of these trace elements were unrelated to their presence in streambed sediments.

Relations among trace-element constituents in streambed sediments during low streamflows differ with respect to natural and human sources of metals in the basin. For example, streambed-sediment concentrations of chromium, copper, and nickel are highly intercorrelated in streams of the urbanized Inner Bluegrass Region but are unrelated to streambed-sediment concentrations of aluminum, iron, and manganese, as indicated for other regions of the Kentucky River Basin. Silver concentrations are correlated with molybdenum concentrations in urban streambed sediments. These relations in urban streams of the Inner Bluegrass Region may indicate water-quality effects from point-source discharges, landfill operations, or other human activities. Streambed-sediment concentrations of lead are correlated with streambed-sediment concentrations of calcium and strontium, probably indicating relations with bedrock geochemistry of the Inner Bluegrass Region.

In contrast, concentrations of many metals and other trace elements in rural streams of the Kentucky River Basin are correlated with iron and aluminum concentrations. This pattern may indicate that the source of metals is predominantly the weathering of geologic materials and (or) land disturbance due to coal mining or agriculture.

## Assessment of Study Approach

### Limitations in the Interpretation of Dissolved-Trace-Element Data

The quality of dissolved-trace-element data has recently been challenged in the scientific literature. Among the cited problems are potential contamination of samples in the field, differences in sample-collection and sample-processing techniques among water-quality laboratories nationwide, and other factors (Shiller and Boyle, 1987; Flegal and Coale, 1989; Windom and others, 1991). The issue of data quality relates to detections of dissolved trace elements at the parts-per-billion level. Data-quality problems are not necessarily indicated for large total-recoverable or suspended-sediment concentrations of metals and other trace elements. The USGS has completed sufficient evaluation to conclude that at least some dissolved trace-element data are questionable and should probably be viewed as qualitative. Although further evaluation of the issue is continuing, the USGS has provisionally categorized dissolved trace-element data as follows (D.A. Rickert, U.S. Geological Survey, written commun., 1991):

1. Noncontaminated or minimally contaminated--barium, calcium, cobalt, lithium, magnesium, molybdenum, nickel, sodium, silicon, strontium, uranium, and vanadium.

2. Significantly contaminated--arsenic, boron, beryllium, cadmium, chromium, copper, lead, mercury, and zinc.

3. Differences result from filtration artifacts rather than contamination--aluminum, iron, and manganese.

4. As yet undetermined--selenium and silver.

Nearly all water-quality agencies and other organizations employed methods similar to the methods used by the USGS for collecting, processing, and analyzing samples for dissolved trace-elements before 1985. As a result, it may be assumed that most dissolved trace-element data obtained from streams before 1985 represent overestimations of the actual constituent concentrations.

### Comparison of U.S. Geological Survey and Kentucky Division of Water Metal Concentrations and Loads at Paired Fixed Stations

Total-recoverable concentrations and loads for aluminum, chromium, copper, iron, lead, manganese, and zinc at four NAWQA fixed stations (fig. 31) are larger than those reported by KDOW for the same stream sites (tables 17 and 19). Because the method of determining loads is identical for both data sets, the differences of constituent loads are attributable to differences in the concentrations of metals determined in water samples, as well as to the distribution of samples with respect to the range of discharge at fixed stations. These differences may have resulted from a combination of the following factors: (1) differences of sample-collection methodology, particularly with respect to the relative amounts of suspended sediment obtained by each method, (2) differences in the range of discharge associated with water-quality samples (relative to flow-duration curves for the fixed stations), and (3) differences of laboratory analytical procedures.

Martin and others (1992) reported that water samples collected by vertically integrated, isokinetic sampling methods can contain significantly larger concentrations of total-recoverable metals than those obtained from mid channel, near-surface grab samples, the methodology used by the Kentucky Division of Water. Concentrations of dissolved trace elements did not significantly differ between sampling methods. Grab samples are likely to underestimate total-recoverable concentrations of metals and other trace elements in streams because (1) a substantial percentage of total-recoverable metals is associated with suspended sediment, and (2) total suspended-sediment concentrations are likely to increase from the stream surface to the bottom (Guy, 1970).

The NAWQA sample-collection strategy for the determination of total-recoverable concentrations of metals was designed to calculate constituent loads by incorporating the collection of samples during periods of elevated discharge, defined as the upper 10 percent of the flow-duration curve. Median concentrations of total-recoverable metals indicated in table 17 do not represent (or provide an integration of) water-quality conditions at fixed stations over time. Calculating loads at fixed stations by multiplying the average constituent concentration by the average discharge would underestimate transport, because periods of elevated discharge would not have been represented in calculations. Therefore, loads for metals and other trace elements calculated in this way from NAWQA data are likely to exceed those calculated from KDOW data because a considerable percentage of constituent transport occurs during periods of elevated discharge.

Total-recoverable concentrations of metals reported by the USGS were determined by the inductively-coupled plasma procedure (ICP), after extraction from water samples with hydrochloric acid (Fishman and Friedman, 1989). In contrast, total-recoverable metal concentrations reported by KDOW were determined by atomic absorption spectrometry (AAS) after extraction with concentrated nitric acid (G. Wheatley, Kentucky Division of Environmental Services, written commun., 1991; U.S. Environmental Protection Agency, 1983). Although the results of both analytical procedures are reported as "total-recoverable" concentrations, it is possible that differences in sample extraction and laboratory analysis procedures result in disparate concentrations of constituents from the same sample. For example, Friedman and Fishman (1989) report that the precision of ICP and AAS determinations for several trace elements differed significantly between the methods. They reported that concentrations of chromium, iron, and manganese determined by AAS were significantly larger than those determined by ICP.

Results of total-recoverable determinations for metals and other trace elements from reference samples reported by the USGS National Water Quality Laboratory (NWQL) and the Kentucky Natural Resources and Environmental Protection Cabinet's laboratory generally indicate that (1) determinations of total-recoverable concentrations of aluminum, arsenic, barium, copper, iron, lead, mercury, and zinc by the NWQL are larger than those reported by the State, and (2) determinations of total-recoverable concentrations of chromium and manganese by the NWQL are smaller than those reported by the State (H.K. Long, USGS Branch of Quality Assurance, written commun., 1991). Between-laboratory comparisons of the median deviation from the most probable value (MPV) for total-recoverable analyses indicate that concentrations of aluminum, barium, copper, iron, lead, and zinc were underestimated by the State, whereas concentrations of arsenic and mercury were overestimated by NWQL. Concentrations of manganese were overestimated by the State, whereas chromium concentrations were underestimated by NWQL. Although the number of reference-sample comparisons between analytical laboratories was small (n = 4 to 6), the differences indicated in the reported concentrations of metals and other trace elements in relation to the MPV may partly explain similar differences of load estimates for constituents at fixed stations in the

Kentucky River Basin. However, the findings reported by Martin and others (1992) clearly indicate that sampling methods can also contribute to differences in the total-recoverable concentrations of trace elements in water samples, which in turn can result in differences in annual loads and yields calculated for these constituents.

## Evaluation of Load Estimates for Metals and Other Trace Elements

The deficiency of historical (pre-1986) water-quality data for developing annual loads and yields for the Kentucky River Basin was described by Smoot and others (1991). Because of this data deficiency, targeted water-quality sampling was done during periods of low and high streamflow to improve the precision of transport estimates for metals and other trace elements in the Kentucky River Basin. Mean annual loads during 1987-90 (table 19) for aluminum, arsenic, iron, and zinc were generally larger than previously reported loads. Loads for all other metals and trace elements were similar to or smaller than loads computed from data obtained before 1986.

The uncertainty associated with the relation between discharge and the concentration of total-recoverable and dissolved metals and other trace elements (standard error of regression; table 19) was smaller for dissolved concentrations of aluminum and barium than for loads reported by Smoot and others (1991). The same was true for total-recoverable concentrations of iron, lead, manganese, mercury, and zinc. This reduction in uncertainty indicates that metal and other trace element determinations from a small number of water samples may be used to calculate loads with increased accuracy and precision if the data base includes determinations from periods of low and high discharge. The standard error of regression associated with the calculation of dissolved-strontium loads was generally less than 40 percent, which is among the lowest indicated for trace elements in the Kentucky River Basin.

In contrast, the standard errors of regression were similar to those reported by Smoot and others (1991) for dissolved-iron concentrations and for total-recoverable concentrations of aluminum, cadmium, chromium, copper, and nickel. This indicates that collecting water samples to represent varying discharge conditions (in relation to a flow-duration curve) rather than collecting water-quality samples with a random or systematic study design may not improve estimates of loads for these constituents. Moreover, the standard error of regression associated with loads for total-recoverable concentrations of arsenic and magnesium was larger than that reported by Smoot and others (1991); this result may indicate that additional error is introduced for certain constituents when data from high and low discharge periods are included in the regression relation.

Mean annual loads calculated from total-recoverable concentrations of many metals and trace elements differed from those calculated from the suspended-sediment-fraction data (table 19). Further, the standard error of regression for suspended-sediment fraction loads of metals and other trace elements was generally larger than error estimates associated with total-recoverable or dissolved loads. However, loads for the suspended-sediment fraction of arsenic, lead, manganese, nickel, and zinc were similar to those estimated from total-recoverable concentrations. In contrast, loads for the suspended-sediment fraction of aluminum, chromium, and iron exceeded loads calculated from total-recoverable concentrations by 1 to 2 orders of magnitude. However, statistical correlations between total-recoverable and suspended-sediment-fraction concentrations of aluminum and iron were highly significant ($p < 0.001$) and explained greater than 90 percent of variance. Although the regression relation between total-recoverable and suspended-sediment-fraction concentrations of chromium was highly significant, from 20 to 40 percent of the variance remains unexplained by the regression relation.

The multiacid extraction procedure used before the determination of metals in the suspended-sediment matrix may account for increased suspended-sediment-fraction loads of aluminum and iron, because these elements form the inner matrix of sediment particles and are not totally extracted by sample-preparation procedures described for total-recoverable determinations. In contrast, estimated loads for total-recoverable concentrations of copper exceeded those indicated for the suspended-sediment fraction. This may have resulted from analytical differences between the NWQL laboratory, which did the total-recoverable determinations, and the USGS GD laboratory, which did the suspended-sediment-matrix determinations.

## Evaluation of Sample Replicates and Field Blanks

On the basis of 11 pairs of water-quality samples representing consecutive, duplicate samples of water from streams in the Kentucky River Basin, the median percentage difference between dissolved concentrations of metals and other trace elements ranged from less than 10 percent to 47 percent. The median percentage differences between dissolved concentrations of iron (47 percent), zinc (37 percent), and aluminum (22 percent) were greater than differences for other constituents. The median percentage differences between dissolved concentrations of cadmium, copper, and manganese were less than 20 percent. Median differences between dissolved concentrations of other metals and trace elements were either less than 10 percent or were undefined because the concentrations were consistently below the analytical detection limits. The percentage difference between dissolved concentrations of constituents increased with stream discharge and the concentration of suspended sediment. Differences between concentrations of aluminum, barium, iron, manganese, mercury, and zinc exceeded 100 percent during periods of above-average suspended-sediment transport.

Information concerning potential field contamination of water-quality samples is limited to one field blank sample of deionized water. Total concentrations of most metals and other trace elements in the field blank were less than analytical detection limits, with the exception of the total-recoverable concentration of lead, which was at the detection limit of 1 μg/L. Dissolved concentrations of metals and other trace elements were generally below analytical detection limits. However, the dissolved concentration of boron (20 μg/L) was twice the analytical detection limit. Concentrations at or near the analytical detection limit for dissolved iron, magnesium, mercury, silica, silver, and strontium are also indicated in the field blank sample. Although detectible concentrations of these constituents may have been present in the deionized source water or introduced during shipping and laboratory preparation procedures, the presence of boron, lead, mercury, and silver in the field blank sample confounds the interpretation of certain water-quality relations.

## SUMMARY AND CONCLUSIONS

The spatial distribution of metals and other trace elements in streambed sediments from the Kentucky River Basin is the result of regional differences of geology, land use and cover, and the results of human activities. Significant differences are indicated among bedrock samples of different mineralogy, with respect to (1) median concentrations of metals and other trace elements, and (2) the trace-element signature, or relative abundance of constituents in geologic materials. For example, sandstones and shales of Pennsylvanian age of the Eastern Coal Field Region contain large concentrations of aluminum, iron, and titanium; shales of Devonian age of the Knobs Region contain large concentrations of chromium, copper, lead, nickel, and vanadium; and limestones of Ordovician age of the Inner and Outer Bluegrass Regions contain large concentrations of calcium, phosphorus, strontium, and yttrium. Soils and streambed sediments derived from these geologic materials contain trace-element signatures that are similar to those indicated for the bedrock types within a physiographic region. Land disturbance, such as coal mining and agriculture, expose geologic materials to weathering, resulting in accelerated transport of sediment by streams in the region and increases in streambed-sediment concentrations of trace elements such as cerium, gallium, lanthanum, and neodymium. Concentrations of these trace elements are larger in geologic samples (identified as fire clay, mudstone, and siltstone) from the Eastern Coal Field Region than they are elsewhere in the Kentucky River Basin.

Potentially toxic concentrations of metals in streambed sediments are large in urban and industrial areas of the basin; however, concentrations of certain metals are also elevated in streambed sediments of the Knobs Region because of the presence of shales of Devonian age. Elevated concentrations of arsenic, barium, chromium, iron, lead, manganese, nickel, and zinc in streambed sediments of the Kentucky River Basin equaled or exceeded the USEPA's "heavily-polluted" classification. Concentrations of lead and zinc are elevated in streambed sediments of the urbanized Inner Bluegrass Region and are likely a result of urban stormwater runoff, point-source discharges, and waste-management practices. Concentrations of cadmium, chromium, copper, mercury, and silver are elevated in sediments of streams that receive WWTP discharges. Streambed-sediment concentrations of barium, chromium, and lithium are elevated in streams that receive brine discharges from oil production. Elevated concentrations of antimony, arsenic, molybdenum, selenium, strontium, uranium, and vanadium in streambed sediments of the Kentucky River Basin are generally associated with natural geologic sources, rather than human sources.

The range of concentrations and mean annual loads of metals and other trace elements in the Kentucky River and its major tributaries is affected by regional geology, seasonal hydrology, and human activities. The primary source of metals and other trace elements in water samples is generally suspended sediment. Concentrations, loads, and yields of many metals and other trace elements at fixed stations are associated with the transport of suspended sediment. Land disturbance, such as surface mining and agriculture, contribute to accelerated transport of sediment in streams, thereby increasing constituent concentrations in water samples during periods of intense or long-duration rainfall and increased stream discharge. These conditions occur during winter and early spring, as well as after intense thunderstorms during the summer. Increased transport of sediment results in large annual loads and yields of metals and other trace elements in streams affected by land disturbance.

Concentrations of dissolved metals and other trace elements at fixed stations in the Kentucky River Basin are generally a function of discharge and site-specific physiochemical conditions; for example, concentrations of constituents in streambed sediment and the concentration of dissolved oxygen in water. Total-recoverable and suspended-sediment-fraction concentrations of metals and other trace elements in water are related to discharge, the concentration of suspended sediment in the sample, and the concentration of metals and other trace elements in the suspended-sediment matrix. Constituent concentrations in the suspended-sediment matrix can indicate natural and human sources. Although total-recoverable and dissolved concentrations of certain metals and other trace elements are large in streams affected by land disturbance, concentrations of constituents in the suspended-sediment matrix are commonly larger in streams that receive drainage from the Knobs Region (shale bedrock of Devonian age) or in streams that receive wastewater or oil-well-brine discharges. Total-recoverable and suspended-sediment-fraction concentrations of many metals and trace elements are smaller during low-flow conditions, such as the extended drought of 1987-88, than at medium or high flows.

On a qualitative basis, dissolved concentrations of certain metals and trace elements are large during low-flow conditions at locations where (1) concentrations of these constituents in underlying streambed sediments are large or (2) dissolved-oxygen concentrations are small. However, dissolved concentrations of barium, lithium, and strontium are generally large during low streamflow, particularly during the extended drought of 1987-88; this pattern likely indicates the effect of ground water on the quality of surface water during low-flow conditions. Alternatively, relatively small concentrations of these constituents during normal to above-average flow conditions may result from the effects of dilution from rainwater or snowmelt.

Total-recoverable concentrations of aluminum, beryllium, cadmium, chromium, copper, iron, manganese, nickel, silver, and zinc exceeded water-quality criteria established by the USEPA or the State of Kentucky at one or more fixed stations in the Kentucky River Basin during 1987-90. Concentrations of aluminum, iron, and manganese frequently exceeded established criteria during periods of high flow at most fixed stations. Concentrations of copper, lead, and silver occasionally exceeded acute or chronic aquatic-life criteria at many fixed stations. Concentrations of nickel exceeded the Kentucky domestic water-supply source criterion in 25 percent of samples from the Kentucky River. Acute or chronic aquatic-life criteria for total-recoverable concentrations of beryllium, cadmium, chromium, and zinc were exceeded in 2 to 15 percent of water-quality samples from the

North Fork Kentucky River at Jackson and the Kentucky River at Lock 10. Water-quality criteria for antimony, arsenic, barium, boron, cobalt, lithium, mercury, selenium, or thallium were not exceeded in water samples collected from NAWQA fixed stations during 1987-90.

Mean annual loads for many metals and other trace elements were largest in the Kentucky River at Lock 2, because water-quality characteristics at this location reflect a combination of land and water uses within approximately 90 percent of the basin, and because mean annual discharge and suspended-sediment transport were largest at this location. Estimated yields of many metals and other trace elements were largest in the North Fork Kentucky River at Jackson, because yields of suspended sediment resulting from land disturbance were greatest there. In contrast, mean annual loads of manganese and nickel were largest in the Kentucky River at Lock 10, probably because of the large concentrations of these metals in bedrock and soils in the Knobs Region.

Significant upward trends in the total-recoverable concentrations of aluminum, iron, magnesium, manganese, and zinc were indicated at one or more fixed stations in the Kentucky River Basin since the mid-1970's or early 1980's. Upward trends for concentrations of aluminum, iron, and manganese were significant at sites that receive drainage from coal mines in the Upper Kentucky River Basin. Although the tonnage of coal mined in the basin has remained relatively constant since 1980, the total acreage disturbed by surface-mining operations is presumed to increase with time and the effects of sedimentation processes are cumulative. Concentrations of zinc in streambed sediments increased in the Kentucky River main stem downstream from the Lexington metropolitan area. Downward trends in the concentration of barium and boron are possibly related to similar trends for discharge at fixed stations in the Kentucky River Basin.

Total-recoverable concentrations and mean annual loads of aluminum, chromium, copper, iron, lead, manganese, and mercury at four NAWQA fixed stations were larger than indicated from water-quality data collected by the KDOW at the same fixed stations. These differences probably resulted from a combination of the following factors: (1) differences of sample-collection methodology, particularly with respect to the relative amounts of suspended sediment obtained by each method; (2) differences in the range and distribution of discharge represented by water-quality samples; (3) differences of laboratory analytical procedures; and (4) potential sample-contamination problems. Comparisons of NAWQA concentrations (and loads) of metals and other trace elements with KDOW data data at common fixed stations indicate that the two water-quality data sets for the period represent statistically distinct populations that should not be combined for further statistical analyses. However, mean annual loads (as well as total-recoverable concentrations) of arsenic, barium, and zinc were similar to those determined from KDOW data.

Median concentrations of aluminum, arsenic, chromium, copper, iron, mercury, nickel, and zinc in streambed sediments, based on nine paired stream sites, were significantly larger than those reported by the State for bulk-sediment samples. In this case, differences probably resulted because (1) fine-fraction (less than 63-μm) sediment samples are known to contain relatively larger concentrations of trace elements than bulk-sediment samples, and (2) multiple-acid extraction methods are known to recover larger concentrations of elements than single-acid ("total-recoverable") methods of sample extraction. Total-recoverable methods of extraction are operational definitions of sample preparation, and the efficiency of constituent recovery varies within and among water-quality laboratories. Multiple-acid extraction methods completely dissolve elements and minerals in water or sediment matrices, resulting in the total recovery of metals and other trace elements. However, water-quality criteria established by regulatory agencies normally refer to total-recoverable concentrations of constituents, and the relation between "total" and "total-recoverable" concentrations of constituents in water-quality samples is poorly understood for most metals and other trace elements.

The approach used for the NAWQA pilot study was adequate for evaluating the occurrence and spatial distribution of metals and other trace elements in relation to natural sources and regional-scale water-quality effects from human activities. Examples of human activities in the Kentucky River Basin that affect the occurrence and distribution of metals and other trace elements on a regional scale include (1) land disturbance from surface mining or agriculture, (2) oil-well-brine discharges, and (3) urban stormwater runoff. The effects of WWTP discharges and other waste-management practices on the concentration of metals and other trace elements in sediment and water are indicated by elevated concentrations of these constituents at sites immediately downstream from the source. However, it is not possible to determine the relative contribution of point sources to the total transport of metals and other trace elements at the fixed stations because sufficient quantifiable data are not available to characterize wastewater-effluent quality nor the volume of effluents being discharged. Current regulations at the State and Federal levels do not require the collection of such data at a frequency and accuracy for such evaluations. Further, the biogeochemistry and transport processes of metals and other trace elements are complex and function at considerably different scales of spatial and temporal resolution than addressed in the overall NAWQA pilot-project study approach.

The effects of point-source discharges, landfills, and other waste-management practices are somewhat localized in the Kentucky River Basin. These effects are best indicated by the spatial distribution of the concentrations of metals and other trace elements in streambed sediments and in the suspended-sediment fraction of water samples from stream locations near the source. The quantification of baseline concentrations of metals and other trace elements in streambed sediments, as well as baseline concentrations and transport estimates for metals and other trace elements that are associated with the suspended-sediment matrix, provide a basis for detecting water-quality changes that may result from improvements in wastewater treatment or the implementation of best-management practices for controlling contamination from nonpoint sources.

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Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | MIN | Concentration at indicated percentile, in micrograms per liter (or as indicated) | | | | | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 10 | 25 | 50 (median) | 75 | 90 | |
| Aluminum, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 44 | 7 | 10 | <10 | *8.2 | 12 | 20 | 50 | 85 | 90 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 44 | 13 | 10 | <10 | *4.6 | *8.3 | 15 | 38 | 60 | 100 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 43 | 15 | 10 | <10 | *3.4 | *6.7 | 10 | 30 | 96 | 120 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 43 | 10 | 10 | <10 | *5.5 | 10 | 20 | 50 | 120 | 360 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 42 | 9 | 10 | <10 | *7.0 | 10 | 20 | 40 | 70 | 90 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 41 | 10 | 10 | <10 | *4.1 | *7.6 | 20 | 20 | 96 | 280 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 46 | 9 | 10 | <10 | *5.5 | 10 | 20 | 50 | 80 | 900 |
| Aluminum, suspended-sediment fraction | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | .1 | 200 | 550 | 1,100 | 7,700 | 47,000 | 144,000 | 190,000 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | .1 | 300 | 560 | 1,100 | 4,700 | 16,000 | 25,000 | 36,000 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | .1 | 100 | 410 | 740 | 2,500 | 12,000 | 39,000 | 72,000 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | .1 | 300 | 740 | 1,300 | 4,600 | 19,000 | 54,000 | 98,000 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | .1 | 220 | 480 | 1,100 | 3,600 | 23,000 | 42,000 | 90,000 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | .1 | 50 | 110 | 330 | 690 | 5,000 | 18,000 | 49,000 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | .1 | 260 | 730 | 1,400 | 4,200 | 22,000 | 33,000 | 75,000 |
| Aluminum, total-recoverable | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 17 | 0 | 10 | 40 | -- | 640 | 3,400 | 12,000 | -- | 24,000 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 17 | 0 | 10 | 30 | -- | 160 | 1,400 | 3,100 | -- | 5,800 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 16 | 0 | 10 | 80 | -- | 270 | 780 | 3,500 | -- | 13,000 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 16 | 1 | 10 | <10 | -- | 430 | 2,400 | 5,200 | -- | 11,000 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 16 | 1 | 10 | <10 | -- | 350 | 2,500 | 6,100 | -- | 11,000 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 13 | 0 | 10 | 30 | -- | 190 | 400 | 5,000 | -- | 12,000 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 16 | 0 | 10 | 100 | -- | 270 | 3,050 | 6,600 | -- | 12,000 |
| Aluminum, total-recoverable (KDOW) | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1986-89 | 44 | 0 | 1 | 2 | 69 | 130 | 250 | 740 | 2,000 | 5,300 |
| 2.3 | M Fk Ky R at Tallega | 1986-89 | 44 | 0 | 1 | 3 | 40 | 80 | 190 | 590 | 1,400 | 2,900 |
| 2.6 | S Fk Ky R at Booneville | 1986-89 | 44 | 0 | 1 | 3 | 31 | 63 | 110 | 260 | 700 | 2,400 |
| 3.0 | Ky R at Lock 14, Heidelberg | 1986-89 | 45 | 1 | 1 | <1 | 35 | 59 | 170 | 500 | 1,400 | 6,400 |
| 3.1 | Red R near Hazel Green | 1986-89 | 44 | 1 | 1 | <1 | 30 | 63 | 130 | 540 | 1,500 | 12,000 |
| 3.3 | Red R at Clay City | 1986-89 | 43 | 0 | 1 | 2 | 63 | 95 | 240 | 670 | 1,600 | 3,100 |
| 5.0 | Ky R at Camp Nelson | 1986-89 | 45 | 1 | 1 | <1 | 42 | 72 | 220 | 1,000 | 4,400 | 8,400 |
| 5.2 | Dix R near Danville | 1986-89 | 45 | 0 | 1 | 3 | 45 | 70 | 160 | 430 | 1,400 | 6,300 |
| 8.0 | Ky R at Lock 4, Frankfort | 1986-89 | 46 | 1 | 1 | <1 | 30 | 84 | 180 | 770 | 3,300 | 6,000 |
| 9.3 | S Elkhorn Cr Near Midway | 1986-89 | 45 | 0 | 1 | 10 | 48 | 95 | 230 | 350 | 1,200 | 3,400 |
| 10.1 | Eagle Cr at Glencoe | 1986-89 | 38 | 0 | 1 | 5 | 58 | 260 | 470 | 1,100 | 3,200 | 11,000 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Besin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | Concentration at indicated percentile, in micrograms per liter (or as indiceted)<br>MIN | 10 | 25 | 50 (median) | 75 | 90 | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Antimony, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 22 | 21 | 1 | <1 | -- | <1 | <1 | <1 | -- | 1 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 22 | 22 | 1 | <1 | -- | <1 | <1 | <1 | -- | <1 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 21 | 20 | 1 | <1 | -- | <1 | <1 | <1 | -- | 1 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 24 | 23 | 1 | <1 | -- | <1 | <1 | <1 | -- | 1 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 24 | 23 | 1 | <1 | -- | <1 | <1 | <1 | -- | 1 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 22 | 20 | 1 | <1 | -- | <1 | <1 | <1 | -- | 1 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 25 | 24 | 1 | <1 | -- | <1 | <1 | <1 | -- | 1 |
| Antimony, suspended-sediment fraction | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 34 | 0 | .01 | <.01 | <0.01 | .01 | .10 | .32 | 0.81 | 1.5 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 37 | 0 | .01 | <.01 | <.01 | .01 | .03 | .10 | .15 | .70 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 32 | 0 | .01 | <.01 | <.01 | .01 | .02 | .09 | .35 | 1.1 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 39 | 0 | .01 | .01 | .01 | .02 | .04 | .18 | .42 | .59 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 36 | 0 | .01 | .01 | .01 | .01 | .04 | .19 | .48 | 2.4 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 0 | .01 | <.01 | <.01 | .01 | .01 | .06 | .09 | .32 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 35 | 0 | .01 | .01 | .01 | .02 | .05 | .23 | .34 | .47 |
| Arsenic, dissolved | | | | | | | | | | | | |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 46 | 45 | 1 | <1 | <1 | <1 | <1 | <1 | <1 | 1 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 45 | 42 | 1 | <1 | <1 | <1 | <1 | <1 | <1 | 1 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 46 | 40 | 1 | <1 | <1 | <1 | <1 | <1 | 1 | 2 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 46 | 31 | 1 | <1 | <1 | <1 | <1 | 1 | 1 | 6 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | 19 | 1 | <1 | <1 | <1 | 1 | 2 | 2 | 5 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 47 | 30 | 1 | <1 | <1 | <1 | <1 | 1 | 1 | 5 |
| Arsenic, suspended-sediment fraction | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 34 | 0 | .01 | .02 | .06 | .13 | 1.1 | 4.3 | 12 | 14 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 38 | 0 | .01 | .05 | .07 | .14 | .52 | 1.3 | 2.5 | 3.2 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 32 | 0 | .01 | .01 | .05 | .10 | .27 | 1.5 | 4.1 | 6.8 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 39 | 0 | .01 | .08 | .14 | .26 | .53 | 2.3 | 6.7 | 9.9 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 36 | 0 | .01 | .05 | .08 | .18 | .50 | 2.9 | 5.6 | 9.9 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 0 | .01 | .01 | .02 | .04 | .08 | .86 | 2.3 | 6.5 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 36 | 0 | .01 | .05 | .10 | .20 | .55 | 2.8 | 5.0 | 7.9 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | MIN | Concentration at indicated percentile, in micrograms per liter (or as indicated) 10 | 25 | 50 (median) | 75 | 90 | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arsenic, total-recoverable (KDOW) | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1986-89 | 44 | 21 | 2 | <2 | -- | *1 | *1 | 2 | 5 | 13 |
| 2.3 | M Fk Ky R at Tallega | 1986-89 | 44 | 30 | 2 | <2 | -- | *1 | *1 | 2 | 6 | 9 |
| 2.6 | S Fk Ky R at Booneville | 1986-89 | 44 | 27 | 2 | <2 | -- | *1 | *1 | 2 | 4 | 21 |
| 3.0 | Ky R at Lock 14, Heidelberg | 1986-89 | 45 | 24 | 2 | <2 | -- | *1 | *1 | 2 | 4 | 14 |
| 3.1 | Red R near Hazel Green | 1986-89 | 44 | 28 | 2 | <2 | -- | *1 | *2 | 2 | 4 | 14 |
| 3.3 | Red R at Clay City | 1986-89 | 43 | 16 | 2 | <2 | -- | *1 | *1 | 4 | 6 | 13 |
| 5.0 | Ky R at Camp Nelson | 1986-89 | 44 | 19 | 2 | <2 | -- | *1 | *1 | 3 | 6 | 12 |
| 5.2 | Dix R near Danville | 1986-89 | 44 | 19 | 2 | <2 | -- | *1 | *1 | 3 | 8 | 18 |
| 8.0 | Ky R at Lock 4, Frankfort | 1986-89 | 45 | 17 | 2 | <2 | -- | *1 | *1 | 2 | 7 | 15 |
| 9.3 | S Elkhorn Cr Near Midway | 1986-89 | 44 | 20 | 2 | <2 | -- | *1 | *1 | 3 | 5 | 9 |
| 10.1 | Eagle Cr at Glencoe | 1986-89 | 38 | 16 | 2 | <2 | -- | *1 | *1 | 3 | 6 | 7 |
| Barium, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 47 | 0 | 2 | 21 | 23 | 30 | 39 | 51 | 64 | 74 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 47 | 0 | 2 | 16 | 19 | 23 | 32 | 40 | 45 | 50 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 46 | 0 | 2 | 15 | 16 | 21 | 36 | 50 | 77 | 110 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 48 | 0 | 2 | 16 | 22 | 26 | 39 | 65 | 78 | 130 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 47 | 0 | 2 | 16 | 21 | 23 | 37 | 46 | 59 | 73 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | 0 | 2 | 13 | 16 | 20 | 23 | 25 | 28 | 33 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 48 | 0 | 2 | 15 | 21 | 22 | 33 | 44 | 50 | 62 |
| Barium, total-recoverable | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 16 | 5 | 100 | <100 | -- | *86 | 100 | 100 | -- | 200 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 16 | 13 | 100 | <100 | -- | *29 | *49 | *85 | -- | 200 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 15 | 8 | 100 | <100 | -- | *76 | *91 | 100 | -- | 200 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 17 | 11 | 100 | <100 | -- | *59 | *81 | 100 | -- | 200 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 16 | 8 | 100 | <100 | -- | *78 | *93 | 100 | -- | 200 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 13 | 7 | 100 | <100 | -- | *68 | *91 | 100 | -- | 200 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 17 | 11 | 100 | <100 | -- | *54 | *79 | 100 | -- | 200 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less then; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | MIN | Concentration at indicated percentile, in micrograms per liter (or as indicated) 10 | 25 | 50 (median) | 75 | 90 | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Barium, total-recoverable (KDOW) | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1986-89 | 44 | 1 | 1 | <1 | 15 | 25 | 37 | 64 | 84 | 110 |
| 2.3 | M Fk Ky R at Tallega | 1986-89 | 44 | 0 | 1 | 5 | 16 | 22 | 42 | 55 | 66 | 130 |
| 2.6 | S Fk Ky R at Booneville | 1986-89 | 44 | 0 | 1 | 2 | 12 | 20 | 40 | 49 | 88 | 200 |
| 3.0 | Ky R at Lock 14, Heidelberg | 1986-89 | 45 | 1 | 1 | <1 | 11 | 25 | 39 | 62 | 120 | 360 |
| 3.1 | Red R near Hazel Green | 1986-89 | 44 | 0 | 1 | 1 | 8 | 14 | 22 | 32 | 57 | 240 |
| 3.3 | Red R at Clay City | 1986-89 | 42 | 0 | 1 | 14 | 20 | 33 | 64 | 96 | 130 | 230 |
| 5.0 | Ky R at Camp Nelson | 1986-89 | 45 | 1 | 1 | <1 | 13 | 30 | 47 | 76 | 100 | 220 |
| 5.2 | Dix R near Danville | 1986-89 | 45 | 1 | 1 | <1 | 8 | 14 | 27 | 44 | 58 | 250 |
| 8.0 | Ky R at Lock 4, Frankfort | 1986-89 | 46 | 1 | 1 | <1 | 19 | 29 | 43 | 64 | 96 | 160 |
| 9.3 | S Elkhorn Cr Near Midway | 1986-89 | 45 | 1 | 1 | <1 | 7 | 12 | 22 | 39 | 61 | 87 |
| 10.1 | Eagle Cr at Glencoe | 1986-89 | 38 | 2 | 1 | <1 | 8 | 11 | 22 | 36 | 48 | 110 |
| Beryllium, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 47 | 46 | .5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | .7 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 47 | 46 | .5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | .7 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 46 | 45 | .5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | .7 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 48 | 47 | .5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | .7 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 47 | 44 | .5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | .9 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | 41 | .5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | 1.3 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 48 | 48 | .5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 |
| Beryllium, suspended-sediment fraction | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 34 | 0 | .01 | .01 | .02 | .05 | .55 | 2.3 | 5.6 | 7.1 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 38 | 1 | .02 | <.02 | *.03 | .04 | .16 | .57 | 1.0 | 1.2 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 32 | 2 | .01 | <.01 | *.01 | *.03 | .10 | .66 | 1.5 | 2.3 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 39 | 1 | .01 | <.01 | .03 | .04 | .18 | .73 | 2.0 | 3.1 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 37 | 3 | .01 | <.01 | *.02 | *.05 | .15 | .81 | 1.6 | 3.1 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 11 | .01 | <.01 | *.01 | *.01 | *.03 | .23 | .53 | 1.6 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 36 | 1 | .01 | <.01 | *.03 | .05 | .20 | .87 | 1.2 | 2.4 |
| Beryllium, total-recoverable | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 16 | 16 | 10 | <10 | -- | <10 | <10 | <10 | -- | <10 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 16 | 16 | 10 | <10 | -- | <10 | <10 | <10 | -- | <10 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 15 | 15 | 10 | <10 | -- | <10 | <10 | <10 | -- | <10 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 17 | 16 | 10 | <10 | -- | <10 | <10 | <10 | -- | 10 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 16 | 16 | 10 | <10 | -- | <10 | <10 | <10 | -- | <10 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 13 | 12 | 10 | <10 | -- | <10 | <10 | <10 | -- | 10 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 17 | 16 | 10 | <10 | -- | <10 | <10 | <10 | -- | 10 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | MIN | Concentration at indicated percentile, in micrograms per liter (or as indicated) 10 | 25 | 50 (median) | 75 | 90 | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boron, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 44 | 3 | 10 | <10 | 10 | 20 | 20 | 30 | 40 | 50 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 44 | 16 | 10 | <10 | *5 | *8 | 10 | 20 | 30 | 40 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 43 | 15 | 10 | <10 | *5 | *8 | 10 | 20 | 40 | 50 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 43 | 7 | 10 | <10 | *8 | 10 | 20 | 30 | 40 | 50 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 42 | 2 | 10 | <10 | 10 | 10 | 20 | 30 | 50 | 60 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 41 | 1 | 10 | <10 | 20 | 20 | 40 | 90 | 130 | 160 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 42 | 3 | 10 | <10 | 10 | 20 | 20 | 30 | 60 | 70 |
| Boron, total-recoverable | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 16 | 3 | 10 | <10 | -- | 10 | 20 | 50 | -- | 70 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 15 | 6 | 10 | <10 | -- | *5 | 20 | 50 | -- | 300 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 14 | 2 | 10 | <10 | -- | 20 | 30 | 40 | -- | 60 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 16 | 3 | 10 | <10 | -- | 10 | 30 | 50 | -- | 90 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 15 | 0 | 10 | 20 | -- | 30 | 40 | 70 | -- | 80 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 12 | 0 | 10 | 10 | -- | 30 | 40 | 80 | -- | 200 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 16 | 0 | 10 | 10 | -- | 20 | 40 | 60 | -- | 90 |
| Cadmium, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 47 | 13 | .1 | <.1 | *.1 | *.1 | *.2 | *.3 | .5 | 1.1 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 45 | 16 | .1 | <.1 | *.1 | *.1 | .2 | .2 | .4 | .9 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 46 | 15 | .1 | <.1 | *.1 | *.1 | *.1 | *.2 | .4 | 3.7 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 48 | 7 | .1 | <.1 | *.1 | *.2 | *.3 | *.6 | 1.3 | 2.9 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 47 | 12 | .1 | <.1 | *.1 | *.1 | *.2 | *.5 | .9 | 2.8 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 45 | 8 | .1 | <.1 | *.1 | *.2 | *.3 | *.6 | 1.0 | 5.5 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 48 | 6 | .1 | <.1 | *.1 | *.1 | *.3 | *.6 | 1.1 | 7.9 |
| Cadmium, suspended-sediment fraction | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 34 | 0 | .01 | .01 | .01 | .01 | .09 | .16 | .51 | 1.0 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 38 | 0 | .01 | .01 | .01 | .01 | .02 | .05 | .11 | .17 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 32 | 1 | .01 | <.01 | *<.01 | *.01 | *.02 | .04 | .15 | .91 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 39 | 0 | .01 | .01 | .01 | .02 | .04 | .11 | .41 | 1.7 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 36 | 1 | .01 | <.01 | *.01 | *.03 | *.06 | .13 | .34 | .45 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 1 | .01 | <.01 | <.01 | .01 | .02 | .07 | .29 | .76 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 36 | 0 | .01 | .01 | .01 | .02 | .05 | .14 | .26 | 1.2 |
| Cadmium, total-recoverable | | | | | | | | | | | | |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 17 | 10 | 1.0 | <1.0 | -- | *.7 | *.8 | 1.0 | -- | 2.0 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 16 | 15 | 1.0 | <1.0 | -- | <1.0 | <1.0 | <1.0 | -- | 1.0 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 13 | 8 | 1.0 | <1.0 | -- | <1.0 | <1.0 | 1.0 | -- | 4.0 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | MIN | Concentration at indicated percentile, in micrograms per liter (or as indicated) 10 | 25 | 50 (median) | 75 | 90 | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cadmium, total-recoverable (KDOW) | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1986-89 | 44 | 42 | 1 | <1 | <1 | <1 | <1 | <1 | <1 | 1 |
| 2.3 | M Fk Ky R at Tallega | 1986-89 | 44 | 42 | 1 | <1 | <1 | <1 | <1 | <1 | <1 | 1 |
| 2.6 | S Fk Ky R at Booneville | 1986-89 | 44 | 40 | 1 | <1 | <1 | <1 | <1 | <1 | <1 | 1 |
| 3.0 | Ky R at Lock 14, Heidelberg | 1986-89 | 45 | 41 | 1 | <1 | <1 | <1 | <1 | <1 | <1 | 1 |
| 3.1 | Red R near Hazel Green | 1986-89 | 44 | 40 | 1 | <1 | <1 | <1 | <1 | <1 | <1 | 1 |
| 3.3 | Red R at Clay City | 1986-89 | 43 | 41 | 1 | <1 | <1 | <1 | <1 | <1 | <1 | 1 |
| 5.0 | Ky R at Camp Nelson | 1986-89 | 45 | 42 | 1 | <1 | <1 | <1 | <1 | <1 | <1 | 1 |
| 5.2 | Dix R near Danville | 1986-89 | 45 | 44 | 1 | <1 | <1 | <1 | <1 | <1 | <1 | 1 |
| 8.0 | Ky R at Lock 4, Frankfort | 1986-89 | 46 | 43 | 1 | <1 | <1 | <1 | <1 | <1 | <1 | 5 |
| 10.1 | Eagle Cr at Glencoe | 1986-89 | 38 | 38 | 1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Chromium, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 47 | 43 | .5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | 1.7 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 47 | 43 | .5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | .9 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 46 | 44 | .5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.6 | 1.1 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 45 | 37 | .5 | <.5 | <.5 | *.1 | *.2 | *.4 | 1.0 | 2.5 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 47 | 45 | .5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | 2.1 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 42 | 31 | .5 | <.5 | *.1 | *.2 | *.3 | *.5 | .9 | 2.4 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 46 | 41 | .5 | <.5 | -- | -- | *.1 | *.2 | .6 | 1.7 |
| Chromium, suspended-sediment fraction | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 34 | 0 | .01 | .18 | .49 | 1.3 | 12 | 44 | 170 | 220 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 38 | 0 | .01 | .31 | .51 | 1.5 | 4.6 | 14 | 32 | 48 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 32 | 0 | .01 | .11 | .41 | .81 | 2.6 | 17 | 39 | 67 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 39 | 0 | .01 | .29 | .73 | 1.5 | 4.9 | 22 | 62 | 88 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 37 | 0 | .01 | .22 | .49 | 1.4 | 4.7 | 22 | 46 | 91 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 0 | .01 | .02 | .12 | .37 | 1.0 | 8.2 | 19 | 50 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 36 | 0 | .01 | .34 | .77 | 1.5 | 5.5 | 22 | 40 | 87 |
| Chromium, total-recoverable | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 16 | 2 | 1.0 | <1.0 | -- | 2.8 | 6.5 | 20 | -- | 31 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 16 | 4 | 1.0 | <1.0 | -- | *1.2 | 3.5 | 5.5 | -- | 10 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 15 | 3 | 1.0 | <1.0 | -- | 1.0 | 5.0 | 7.0 | -- | 19 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 17 | 6 | 1.0 | <1.0 | -- | *1.0 | 5.0 | 8.5 | -- | 15 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 16 | 3 | 1.0 | <1.0 | -- | 3.0 | 4.5 | 8.8 | -- | 15 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 13 | 3 | 1.0 | <1.0 | -- | *1.6 | 7.0 | 9.0 | -- | 17 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 17 | 3 | 1.0 | <1.0 | -- | 3.5 | 8.0 | 10 | -- | 15 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | MIN | Concentration at indicated percentile, in micrograms per liter (or as indicated) 10 | 25 | 50 (median) | 75 | 90 | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chromium, total-recoverable (KDOW) | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1986-89 | 44 | 9 | 1 | <1 | *1 | 1 | 2 | 3 | 8 | 8 |
| 2.3 | M Fk Ky R at Tallega | 1986-89 | 44 | 6 | 1 | <1 | *1 | 1 | 2 | 3 | 6 | 7 |
| 2.6 | S Fk Ky R at Booneville | 1986-89 | 44 | 5 | 1 | <1 | *1 | 1 | 2 | 4 | 5 | 8 |
| 3.0 | Ky R at Lock 14, Heidelberg | 1986-89 | 45 | 6 | 1 | <1 | *1 | 1 | 2 | 4 | 6 | 12 |
| 3.1 | Red R near Hazel Green | 1986-89 | 44 | 7 | 1 | <1 | *1 | 1 | 2 | 4 | 4 | 19 |
| 3.3 | Red R at Clay City | 1986-89 | 43 | 6 | 1 | <1 | *1 | 1 | 2 | 4 | 6 | 9 |
| 5.0 | Ky R at Camp Nelson | 1986-89 | 45 | 8 | 1 | <1 | *1 | 1 | 2 | 4 | 8 | 12 |
| 5.2 | Dix R near Danville | 1986-89 | 45 | 5 | 1 | <1 | *1 | 1 | 2 | 4 | 8 | 10 |
| 8.0 | Ky R at Lock 4, Frankfort | 1986-89 | 46 | 4 | 1 | <1 | *1 | 2 | 3 | 4 | 7 | 9 |
| 9.3 | S Elkhorn Cr Near Midway | 1986-89 | 45 | 0 | 1 | 1 | 2 | 2 | 3 | 4 | 6 | 9 |
| 10.1 | Eagle Cr at Glencoe | 1986-89 | 38 | 7 | 1 | <1 | *1 | 1 | 2 | 3 | 8 | 18 |
| Cobalt, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 47 | 47 | 3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 47 | 47 | 3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 46 | 46 | 3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 4.D | Ky R at Lock 10, Winchester | 1987-90 | 48 | 48 | 3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 47 | 47 | 3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | 44 | 3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 48 | 48 | 3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| Cobalt, suspended-sediment fraction | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 34 | 0 | .01 | .16 | .19 | .38 | 3.1 | 12 | 30 | 41 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 38 | 0 | .01 | .10 | .16 | .25 | .94 | 3.3 | 5.1 | 6.6 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 32 | 0 | .01 | .04 | .17 | .24 | .63 | 4.1 | 11 | 18 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 39 | 0 | .01 | .09 | .25 | .42 | 1.1 | 4.8 | 14 | 23 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 37 | 0 | .01 | .07 | .14 | .31 | .94 | 5.5 | 11 | 23 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 0 | .01 | .01 | .03 | .09 | .19 | 1.6 | 4.0 | 12 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 36 | 0 | .01 | .08 | .21 | .40 | 1.1 | 5.9 | 8.7 | 17 |
| Copper, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 46 | 9 | .5 | <.5 | *.5 | *.7 | 1.1 | 1.3 | 1.8 | 2.4 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 45 | 6 | .5 | <.5 | *.4 | .7 | .8 | 1.3 | 2.3 | 7.2 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 45 | 8 | .5 | <.5 | *.4 | .6 | .9 | 1.2 | 1.6 | 2.6 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 47 | 3 | .5 | <.5 | .7 | 1.2 | 2.0 | 2.9 | 3.5 | 10 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 46 | 4 | .5 | <.5 | *.7 | *1.0 | *1.5 | *2.1 | 2.8 | 4.7 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 45 | 4 | .5 | <.5 | *.8 | *1.1 | *1.9 | *3.1 | 4.8 | 29 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 47 | 1 | .5 | <.5 | .9 | 1.0 | 1.4 | 2.2 | 3.2 | 6.9 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | MIN | Concentration at indicated percentile, in micrograms per liter (or as indicated) 10 | 25 | 50 (median) | 75 | 90 | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Copper, suspended-sediment fraction | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 34 | 0 | NA | 0.13 | 0.24 | 0.54 | 5.0 | 21 | 43 | 57 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 38 | 0 | NA | .13 | .23 | .58 | 1.6 | 5.4 | 8.0 | 10 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 32 | 0 | NA | .05 | .21 | .32 | 1.0 | 7.9 | 15 | 24 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 39 | 0 | NA | .27 | .46 | 1.1 | 2.0 | 8.0 | 21 | 28 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 37 | 0 | NA | .15 | .25 | .63 | 1.9 | 7.8 | 21 | 74 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 0 | NA | .02 | .09 | .18 | .40 | 2.7 | 8.5 | 18 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 36 | 0 | NA | .20 | .29 | .61 | 1.9 | 9.7 | 13 | 21 |
| Copper, total-recoverable | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 16 | 4 | 10 | <10 | -- | *8.6 | 10 | 38 | -- | 60 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 16 | 9 | 10 | <10 | -- | *6.8 | *8.9 | 10 | -- | 20 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 15 | 6 | 10 | <10 | -- | *5.6 | 10 | 20 | -- | 100 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 17 | 3 | 10 | <10 | -- | 10 | 20 | 20 | -- | 30 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 16 | 6 | 10 | <10 | -- | *7.1 | 15 | 20 | -- | 100 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 13 | 5 | 10 | <10 | -- | *7.6 | 10 | 20 | -- | 30 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 17 | 4 | 10 | <10 | -- | *9.6 | 10 | 20 | -- | 30 |
| Copper, total-recoverable (KDOW) | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1986-89 | 44 | 4 | 1 | <1 | *1 | 2 | 3 | 6 | 10 | 22 |
| 2.3 | M Fk Ky R at Tallega | 1986-89 | 43 | 8 | 1 | <1 | *1 | 1 | 3 | 5 | 8 | 19 |
| 2.6 | S Fk Ky R at Booneville | 1986-89 | 44 | 7 | 1 | <1 | *1 | 1 | 2 | 5 | 12 | 21 |
| 3.0 | Ky R at Lock 14, Heidelberg | 1986-89 | 45 | 9 | 1 | <1 | *1 | 1 | 3 | 4 | 11 | 15 |
| 3.1 | Red R near Hazel Green | 1986-89 | 44 | 6 | 1 | <1 | *1 | 1 | 3 | 5 | 10 | 24 |
| 3.3 | Red R at Clay City | 1986-89 | 43 | 6 | 1 | <1 | *1 | 1 | 2 | 5 | 10 | 23 |
| 5.0 | Ky R at Camp Nelson | 1986-89 | 45 | 3 | 1 | <1 | 1 | 1 | 3 | 5 | 9 | 16 |
| 5.2 | Dix R near Danville | 1986-89 | 45 | 4 | 1 | <1 | *1 | 1 | 2 | 4 | 11 | 21 |
| 8.0 | Ky R at Lock 4, Frankfort | 1986-89 | 46 | 8 | 1 | <1 | *1 | 1 | 2 | 5 | 8 | 13 |
| 9.3 | S Elkhorn Cr Near Midway | 1986-89 | 45 | 5 | 1 | <1 | *1 | 2 | 4 | 6 | 11 | 26 |
| 10.1 | Eagle Cr at Glencoe | 1986-89 | 38 | 1 | 1 | <1 | 1 | 2 | 3 | 6 | 11 | 21 |
| Iron, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 47 | 1 | 3 | <3 | 5 | 7 | 14 | 40 | 100 | 130 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 47 | 0 | 3 | 10 | 23 | 31 | 45 | 79 | 100 | 170 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 46 | 0 | 3 | 4 | 15 | 28 | 38 | 73 | 140 | 850 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 48 | 2 | 3 | <3 | 5 | 14 | 43 | 84 | 140 | 410 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 47 | 4 | 3 | <3 | *3 | 6 | 18 | 46 | 96 | 150 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | 1 | 3 | <3 | 4 | 7 | 10 | 19 | 100 | 360 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 48 | 4 | 3 | <3 | *3 | 5 | 19 | 62 | 100 | 1,500 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | MIN | Concentration at indicated percentile, in micrograms per liter (or as indicated) 10 | 25 | 50 (median) | 75 | 90 | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Iron, suspended-sediment fraction** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | 0.1 | 150 | 260 | 550 | 3,200 | 21,000 | 58,000 | 76,000 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | .1 | 180 | 320 | 650 | 2,200 | 7,100 | 12,000 | 15,000 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | .1 | 59 | 230 | 390 | 1,200 | 5,000 | 20,000 | 35,000 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | .1 | 240 | 430 | 720 | 2,400 | 9,000 | 25,000 | 45,000 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | .1 | 120 | 260 | 620 | 1,800 | 11,000 | 20,000 | 42,000 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 0 | .1 | 41 | 90 | 200 | 460 | 4,100 | 10,000 | 28,000 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | .1 | 180 | 410 | 660 | 1,900 | 10,000 | 18,000 | 35,000 |
| **Iron, total-recoverable** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 16 | 0 | 10 | 260 | -- | 970 | 6,700 | 30,000 | -- | 65,000 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 16 | 0 | 10 | 210 | -- | 520 | 3,100 | 6,800 | -- | 13,000 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 15 | 0 | 10 | 260 | -- | 740 | 2,200 | 8,300 | -- | 32,000 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 17 | 0 | 10 | 350 | -- | 1,300 | 5,500 | 11,000 | -- | 31,000 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 16 | 0 | 10 | 210 | -- | 610 | 4,400 | 11,000 | -- | 31,000 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 13 | 1 | 10 | <10 | -- | 290 | 1,600 | 6,800 | -- | 18,000 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 17 | 0 | 10 | 170 | -- | 480 | 5,100 | 11,000 | -- | 33,000 |
| **Iron, total-recoverable (KDOW)** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1986-89 | 44 | 0 | 10 | 60 | 250 | 370 | 680 | 1,600 | 3,800 | 12,000 |
| 2.3 | M Fk Ky R at Tallega | 1986-89 | 44 | 0 | 10 | 70 | 180 | 270 | 480 | 1,200 | 3,100 | 5,100 |
| 2.6 | S Fk Ky R at Booneville | 1986-89 | 44 | 0 | 10 | 40 | 130 | 220 | 320 | 440 | 1,600 | 5,200 |
| 3.0 | Ky R at Lock 14, Heidelberg | 1986-89 | 45 | 0 | 10 | 60 | 180 | 280 | 460 | 860 | 3,200 | 17,000 |
| 3.1 | Red R near Hazel Green | 1986-89 | 44 | 0 | 10 | 100 | 270 | 400 | 600 | 1,400 | 3,600 | 29,000 |
| 3.3 | Red R at Clay City | 1986-89 | 43 | 0 | 10 | 220 | 420 | 560 | 820 | 1,500 | 3,300 | 7,000 |
| 5.0 | Ky R at Camp Nelson | 1986-89 | 45 | 0 | 10 | 30 | 96 | 180 | 380 | 1,800 | 9,400 | 17,000 |
| 5.2 | Dix R near Danville | 1986-89 | 45 | 1 | 10 | <10 | 56 | 120 | 220 | 410 | 2,200 | 15,000 |
| 8.0 | Ky R at Lock 4, Frankfort | 1986-89 | 46 | 0 | 10 | 70 | 87 | 150 | 260 | 1,500 | 6,100 | 9,800 |
| 9.3 | S Elkhorn Cr Near Midway | 1986-89 | 45 | 0 | 10 | 90 | 200 | 260 | 320 | 480 | 1,400 | 5,400 |
| 10.1 | Eagle Cr at Glencoe | 1986-89 | 38 | 0 | 10 | 90 | 140 | 280 | 540 | 1,300 | 5,000 | 25,000 |
| **Lead, dissolved** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 47 | 37 | .5 | <.5 | -- | *.1 | *.4 | 1.2 | -- | 10 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 45 | 40 | .5 | <.5 | -- | *.0 | *.1 | .6 | -- | 8.0 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 45 | 37 | .5 | <.5 | -- | *.1 | *.3 | 1.0 | -- | 4.0 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 47 | 33 | .5 | <.5 | -- | *.2 | *.7 | 2.3 | -- | 6.5 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 46 | 37 | .5 | <.5 | -- | *.1 | *.4 | 1.2 | -- | 8.0 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | 32 | .5 | <.5 | -- | *.2 | .7 | 3.2 | -- | 10 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 47 | 39 | .5 | <.5 | -- | *.1 | *.3 | .9 | -- | 7.5 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | MIN | Concentration at indicated percentile, in micrograms per liter (or as indicated) 10 | 25 | 50 (median) | 75 | 90 | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lead, suspended-sediment fraction** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 34 | 0 | 0.01 | 0.13 | 0.25 | 0.42 | 5.0 | 18 | 41 | 60 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 38 | 0 | .01 | .12 | .20 | .42 | 1.4 | 5.4 | 8.6 | 23 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 32 | 0 | .01 | .04 | .19 | .34 | .86 | 6.7 | 14 | 40 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 39 | 0 | .01 | .31 | .39 | .64 | 2.3 | 8.3 | 23 | 30 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 36 | 0 | .01 | .23 | .45 | .65 | 3.1 | 8.9 | 24 | 46 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 0 | .01 | .03 | .15 | .31 | 1.4 | 4.3 | 18 | 41 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 35 | 0 | .01 | .24 | .34 | .71 | 3.6 | 11 | 19 | 22 |
| **Lead, total-recoverable** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 16 | 9 | 5 | <5 | -- | *1.4 | *4.2 | 23 | -- | 57 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 16 | 9 | 5 | <5 | -- | *1.6 | *3.7 | 7.8 | -- | 85 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 15 | 8 | 5 | <5 | -- | *2.2 | *3.6 | 6.0 | -- | 22 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 17 | 7 | 5 | <5 | -- | *3.5 | 7.0 | 13 | -- | 25 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 16 | 7 | 5 | <5 | -- | *2.8 | 5.0 | 7.8 | -- | 44 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 13 | 8 | 5 | <5 | -- | *1.2 | *3.4 | 18 | -- | 34 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 17 | 4 | 5 | <5 | -- | *5.6 | *8.8 | 18 | -- | 26 |
| **Lead, total-recoverable (KDOW)** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1986-89 | 44 | 16 | 2 | <2 | *.3 | *.7 | *1.7 | 3.8 | 7.5 | 72 |
| 2.3 | M Fk Ky R at Tallega | 1986-89 | 44 | 17 | 2 | <2 | *.4 | *.7 | *1.5 | 3.0 | 4.5 | 48 |
| 2.6 | S Fk Ky R at Booneville | 1986-89 | 44 | 28 | 2 | <2 | *.4 | *.6 | *1.0 | 2.0 | 2.5 | 4.0 |
| 3.0 | Ky R at Lock 14, Heidelberg | 1986-89 | 45 | 15 | 2 | <2 | *.4 | *.8 | *1.8 | 4.5 | 14 | 27 |
| 3.1 | Red R near Hazel Green | 1986-89 | 44 | 18 | 2 | <2 | *.4 | *.7 | *1.4 | 2.0 | 6.0 | 23 |
| 3.3 | Red R at Clay City | 1986-89 | 43 | 21 | 2 | <2 | *.4 | *.7 | *1.2 | 2.0 | 4.2 | 7.0 |
| 5.0 | Ky R at Camp Nelson | 1986-89 | 45 | 10 | 2 | <2 | *.5 | *1.2 | 2.0 | 5.0 | 12 | 153 |
| 5.2 | Dix R near Danville | 1986-89 | 45 | 19 | 2 | <2 | *.2 | *.6 | *1.5 | 3.0 | 11 | 78 |
| 8.0 | Ky R at Lock 4, Frankfort | 1986-89 | 46 | 16 | 2 | <2 | *.4 | *.8 | *1.9 | 5.2 | 9.0 | 44 |
| 9.3 | S Elkhorn Cr Near Midway | 1986-89 | 45 | 8 | 2 | <2 | *1.4 | *1.8 | 3.0 | 4.5 | 9.4 | 16 |
| 10.1 | Eagle Cr at Glencoe | 1986-89 | 38 | 20 | 2 | <2 | *.3 | *.5 | *1.1 | 2.0 | 4.0 | 27 |
| **Lithium, dissolved** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 47 | 1 | 4 | <4 | 5 | 5 | 9 | 14 | 17 | 23 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 47 | 36 | 4 | <4 | *1 | *1 | *2 | *4 | 7 | 13 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 46 | 27 | 4 | <4 | *1 | *2 | *3 | 5 | 9 | 17 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 48 | 18 | 4 | <4 | *2 | *3 | 5 | 7 | 9 | 14 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 47 | 16 | 4 | <4 | *2 | *3 | 5 | 7 | 9 | 21 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | 7 | 4 | <4 | *4 | 5 | 6 | 7 | 9 | 16 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 48 | 16 | 4 | <4 | *2 | *3 | 5 | 7 | 10 | 14 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | MIN | Concentration at indicated percentile, in micrograms per liter (or as indicated) 10 | 25 | 50 (median) | 75 | 90 | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Magnesium, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 47 | 0 | 10 | 4,800 | 9,700 | 14,000 | 24,000 | 34,000 | 40,000 | 47,000 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 47 | 0 | 10 | 4,300 | 5,300 | 6,600 | 9,000 | 11,000 | 12,000 | 13,000 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 46 | 0 | 10 | 3,000 | 4,600 | 6,400 | 9,100 | 13,000 | 17,000 | 20,000 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 48 | 0 | 10 | 3,900 | 6,500 | 8,400 | 10,000 | 14,000 | 18,000 | 26,000 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 47 | 0 | 10 | 4,800 | 6,900 | 8,000 | 9,800 | 11,000 | 12,000 | 17,000 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | 0 | 10 | 3,000 | 4,400 | 5,300 | 6,900 | 8,600 | 10,000 | 14,000 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 48 | 0 | 10 | 4,500 | 5,500 | 7,400 | 9,400 | 11,000 | 13,000 | 15,000 |
| Magnesium, suspended-sediment fraction | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | .1 | 98 | 130 | 170 | 720 | 3,800 | 10,000 | 14,000 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | .1 | 61 | 70 | 110 | 370 | 1,200 | 2,000 | 2,500 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | .1 | 14 | 70 | 100 | 230 | 890 | 2,900 | 5,300 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | .1 | 33 | 130 | 190 | 430 | 1,600 | 4,800 | 7,700 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | .1 | 33 | 70 | 150 | 410 | 2,300 | 3,700 | 8,200 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | .1 | 9.0 | 40 | 70 | 160 | 540 | 1,800 | 4,500 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | .1 | 45 | 100 | 160 | 350 | 1,800 | 3,400 | 6,100 |
| Manganese, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 47 | 0 | 1 | 7 | 20 | 42 | 54 | 77 | 138 | 280 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 47 | 0 | 1 | 13 | 21 | 35 | 63 | 89 | 130 | 140 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 46 | 0 | 1 | 19 | 36 | 54 | 84 | 140 | 180 | 320 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 48 | 0 | 1 | 4 | 9 | 21 | 40 | 98 | 140 | 390 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 47 | 4 | 1 | <1 | *2 | *4 | 13 | 32 | 110 | 490 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | 0 | 1 | 2 | 4 | 5 | 8 | 11 | 26 | 71 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 48 | 3 | 1 | <1 | 2 | 3 | 7 | 15 | 38 | 300 |
| Manganese, suspended-sediment fraction | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | .01 | 23 | 40 | 60 | 140 | 660 | 1,600 | 2,200 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | .01 | 22 | 40 | 50 | 110 | 230 | 320 | 410 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | .01 | 3.0 | 20 | 50 | 80 | 250 | 720 | 1,000 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | .01 | 8.0 | 40 | 70 | 140 | 320 | 750 | 1,400 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | .01 | 21 | 40 | 60 | 130 | 470 | 690 | 1,600 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | .01 | 3.0 | 10 | 20 | 70 | 240 | 660 | 1,600 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | .01 | 16 | 40 | 50 | 91 | 380 | 670 | 1,100 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | MIN | Concentration at indicated percentile, in micrograms per liter (or as indicated) | | | | | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 10 | 25 | 50 (median) | 75 | 90 | |
| **Manganese, total-recoverable** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 16 | 0 | 10 | 60 | -- | 110 | 300 | 770 | -- | 2,200 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 16 | 0 | 10 | 40 | -- | 100 | 160 | 240 | -- | 420 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 15 | 0 | 10 | 70 | -- | 160 | 230 | 380 | -- | 950 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 17 | 0 | 10 | 80 | -- | 120 | 240 | 520 | -- | 1,400 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 16 | 0 | 10 | 50 | -- | 100 | 280 | 560 | -- | 1,600 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 13 | 1 | 10 | <10 | -- | 50 | 140 | 610 | -- | 1,500 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 17 | 0 | 10 | 40 | -- | 65 | 270 | 590 | -- | 1,000 |
| **Manganese, total-recoverable (KDOW)** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1986-89 | 44 | 0 | 10 | 30 | 75 | 100 | 110 | 180 | 370 | 680 |
| 2.3 | M Fk Ky R at Tallega | 1986-89 | 44 | 0 | 10 | 40 | 60 | 70 | 95 | 130 | 190 | 470 |
| 2.6 | S Fk Ky R at Booneville | 1986-89 | 44 | 0 | 10 | 30 | 60 | 70 | 120 | 160 | 240 | 310 |
| 3.0 | Ky R at Lock 14, Heidelberg | 1986-89 | 45 | 0 | 10 | 80 | 100 | 100 | 170 | 240 | 300 | 730 |
| 3.1 | Red R near Hazel Green | 1986-89 | 44 | 0 | 10 | 20 | 30 | 52 | 100 | 130 | 390 | 920 |
| 3.3 | Red R at Cley City | 1986-89 | 43 | 0 | 10 | 50 | 60 | 70 | 110 | 140 | 190 | 270 |
| 5.0 | Ky R at Camp Nelson | 1986-89 | 45 | 0 | 10 | 20 | 40 | 50 | 80 | 140 | 600 | 790 |
| 5.2 | Dix R near Danville | 1986-89 | 45 | 1 | 10 | <10 | 10 | 20 | 40 | 65 | 120 | 880 |
| 8.0 | Ky R at Lock 4, Frankfort | 1986-89 | 46 | 0 | 10 | 20 | 30 | 50 | 65 | 90 | 450 | 790 |
| 9.3 | S Elkhorn Cr Near Midway | 1986-89 | 45 | 0 | 10 | 30 | 50 | 90 | 120 | 220 | 290 | 530 |
| 10.1 | Eagle Cr at Glencoe | 1986-89 | 38 | 0 | 10 | 10 | 29 | 40 | 80 | 160 | 240 | 890 |
| **Mercury, dissolved** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 43 | 35 | .1 | <.1 | -- | -- | -- | *.1 | .3 | 2.1 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 44 | 34 | .1 | <.1 | -- | -- | -- | *.1 | .3 | 1.0 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 43 | 36 | .1 | <.1 | -- | -- | -- | *.1 | .2 | .7 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 45 | 15 | .1 | <.1 | -- | *.1 | .1 | .2 | .3 | 1.8 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 44 | 24 | .1 | <.1 | -- | -- | *.1 | .1 | .2 | 1.8 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | 18 | .1 | <.1 | -- | *.1 | .1 | .2 | .3 | .6 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 46 | 22 | .1 | <.1 | -- | *.1 | .1 | .2 | .3 | .6 |
| **Mercury, total-recoverable** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 15 | 10 | .1 | <.1 | -- | <.1 | <.1 | .1 | -- | .3 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 15 | 11 | .1 | <.1 | -- | -- | -- | .2 | -- | 2.0 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 14 | 9 | .1 | <.1 | -- | -- | -- | .1 | -- | 2.3 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 17 | 7 | .1 | <.1 | -- | *.1 | .1 | .2 | -- | .4 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 15 | 10 | .1 | <.1 | -- | -- | *.1 | .1 | -- | .2 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 13 | 5 | .1 | <.1 | -- | *.1 | .1 | .2 | -- | .5 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 16 | 10 | .1 | <.1 | -- | -- | *.1 | .2 | -- | .3 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | MIN | Concentration at indicated percentile, in micrograms per liter (or as indicated) 10 | 25 | 50 (median) | 75 | 90 | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mercury, total-recoverable (KDOW) | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1986-89 | 40 | 18 | 0.1 | <0.1 | -- | *0.1 | 0.1 | 0.1 | 0.3 | 0.6 |
| 2.3 | M Fk Ky R at Tallega | 1986-89 | 40 | 24 | .1 | <.1 | -- | -- | *.1 | .1 | .3 | .6 |
| 2.6 | S Fk Ky R at Booneville | 1986-89 | 41 | 23 | .1 | <.1 | -- | -- | *.1 | .1 | .3 | .8 |
| 3.0 | Ky R at Lock 14, Heidelberg | 1986-89 | 41 | 22 | .1 | <.1 | -- | -- | *.1 | .1 | .2 | .9 |
| 3.1 | Red R near Hazel Green | 1986-89 | 40 | 21 | .1 | <.1 | -- | -- | *.1 | .1 | .3 | .5 |
| 3.3 | Red R at Clay City | 1986-89 | 42 | 18 | .1 | <.1 | -- | *.1 | .1 | .1 | .2 | .7 |
| 5.0 | Ky R at Camp Nelson | 1986-89 | 42 | 21 | .1 | <.1 | -- | -- | *.1 | .1 | .2 | 1 |
| 5.2 | Dix R near Danville | 1986-89 | 41 | 19 | .1 | <.1 | -- | *.1 | .1 | .1 | .2 | .3 |
| 8.0 | Ky R at Lock 4, Frankfort | 1986-89 | 42 | 21 | .1 | <.1 | *0.1 | *.1 | *.1 | .1 | .2 | .2 |
| 9.3 | S Elkhorn Cr Near Midwey | 1986-89 | 38 | 10 | .1 | <.1 | -- | *.1 | .1 | .1 | .2 | 2 |
| 10.1 | Eagle Cr at Glencoe | 1986-89 | 34 | 12 | .1 | <.1 | -- | *.1 | .1 | .1 | .2 | .4 |
| Molybdenum, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 47 | 44 | 10 | <10 | <10 | <10 | <10 | <10 | <10 | 20 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 47 | 47 | 10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 46 | 46 | 10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 48 | 48 | 10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 47 | 46 | 10 | <10 | <10 | <10 | <10 | <10 | <10 | 10 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | 29 | 10 | <10 | <10 | <10 | <10 | 10 | 20 | 30 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 48 | 48 | 10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| Molybdenum, suspended-sediment fraction | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 34 | 0 | .01 | <.01 | .01 | .01 | .15 | .49 | 1.3 | 1.60 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 38 | 0 | .01 | <.01 | .01 | .01 | .03 | .15 | .29 | .61 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 32 | 0 | .01 | <.01 | <.01 | .01 | .02 | .13 | .27 | 1.19 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 39 | 0 | .01 | .01 | .03 | .04 | .08 | .36 | .98 | 2.28 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 36 | 0 | .01 | .01 | .02 | .04 | .07 | .41 | .92 | 1.55 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 0 | .01 | <.01 | .01 | .03 | .07 | .16 | .43 | .68 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | .01 | .02 | .02 | .04 | .08 | .31 | .77 | .90 |
| Molybdenum, total-recoverable | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 16 | 6 | 1 | <1 | -- | -- | *1 | *4 | -- | 60 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 16 | 5 | 1 | <1 | -- | *1 | 3 | 3 | -- | 4 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 15 | 7 | 1 | <1 | -- | *1 | *1 | 3 | -- | 4 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 17 | 7 | 1 | <1 | -- | *1 | *1 | 3 | -- | 6 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 16 | 4 | 1 | <1 | -- | *1 | 2 | 4 | -- | 6 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 13 | 0 | 1 | 1 | -- | 2 | 5 | 10 | -- | 18 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 17 | 4 | 1 | <1 | -- | *1 | 3 | 4 | -- | 6 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | MIN | Concentration at indicated percentile, in micrograms per liter (or as indicated) 10 | 25 | 50 (median) | 75 | 90 | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nickel, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 45 | 44 | 10 | <10 | <10 | <10 | <10 | <10 | <10 | 10 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 45 | 44 | 10 | <10 | <10 | <10 | <10 | <10 | <10 | 10 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 44 | 42 | 10 | <10 | <10 | <10 | <10 | <10 | <10 | 10 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 46 | 42 | 10 | <10 | <10 | <10 | <10 | <10 | <10 | 20 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 45 | 44 | 10 | <10 | <10 | <10 | <10 | <10 | <10 | 10 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 41 | 37 | 10 | <10 | <10 | <10 | <10 | <10 | <10 | 20 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 47 | 42 | 10 | <10 | -- | -- | -- | *2 | 4 | 20 |
| Nickel, suspended-sediment fraction | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 34 | 0 | .01 | .29 | .41 | .77 | 5.9 | 22 | 66 | 160 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 38 | 0 | .01 | .18 | .31 | .58 | 2.2 | 6.3 | 11 | 14 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 32 | 0 | .01 | .08 | .38 | .52 | 1.6 | 8.4 | 22 | 33 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 39 | 0 | .01 | .21 | .60 | .97 | 2.7 | 11 | 35 | 130 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 37 | 0 | .01 | .14 | .31 | .79 | 2.3 | 12 | 25 | 43 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 0 | .01 | .04 | .06 | .19 | .42 | 3.2 | 8.3 | 22 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 36 | 0 | .01 | .17 | .47 | .84 | 2.4 | 12 | 19 | 36 |
| Nickel, total-recoverable | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 16 | 0 | 1 | 2 | -- | 6 | 14 | 34 | -- | 70 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 16 | 2 | 1 | <1 | -- | 2 | 4 | 9 | -- | 11 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 15 | 2 | 1 | <1 | -- | 3 | 5 | 13 | -- | 32 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 17 | 2 | 1 | <1 | -- | 7 | 11 | 16 | -- | 38 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 16 | 3 | 1 | <1 | -- | 1 | 5 | 14 | -- | 39 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 13 | 1 | 1 | <1 | -- | 3 | 5 | 10 | -- | 16 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 17 | 2 | 1 | <1 | -- | 2 | 6 | 14 | -- | 34 |
| Selenium, dissolved | | | | | | | | | | | | |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 22 | 21 | 1 | <1 | -- | <1 | <1 | <1 | -- | 1 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 21 | 20 | 1 | <1 | -- | <1 | <1 | <1 | -- | 2 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 24 | 23 | 1 | <1 | -- | <1 | <1 | <1 | -- | 1 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 24 | 23 | 1 | <1 | -- | <1 | <1 | <1 | -- | 1 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 22 | 22 | 1 | <1 | -- | <1 | <1 | <1 | -- | <1 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 30 | 29 | 1 | <1 | <1 | <1 | <1 | <1 | <1 | 1 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | Concentration at indicated percentile, in micrograms per liter (or as indicated) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | MIN | 10 | 25 | 50 (median) | 75 | 90 | MAX |
| **Silver, dissolved** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 45 | 38 | 1 | <1 | -- | -- | -- | *1 | 1 | 9 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 45 | 34 | 1 | <1 | -- | -- | -- | *1 | 2 | 8 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 44 | 36 | 1 | <1 | -- | -- | -- | *1 | 2 | 5 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 46 | 41 | 1 | <1 | -- | -- | -- | -- | 1 | 4 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 45 | 39 | 1 | <1 | <1 | <1 | <1 | <1 | 1 | 3 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 41 | 36 | 1 | <1 | <1 | <1 | <1 | <1 | 1 | 2 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 47 | 40 | 1 | <1 | <1 | <1 | <1 | <1 | 1 | 6 |
| **Silver, suspended-sediment fraction** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 33 | 3 | .01 | <.01 | *<.01 | *.01 | *.02 | .10 | .37 | .54 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 38 | 3 | .01 | <.01 | *<.01 | *<.01 | *.01 | *.02 | .05 | .81 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 32 | 2 | .01 | <.01 | *<.01 | *<.01 | *.01 | .03 | .14 | 3.7 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 38 | 2 | .01 | <.01 | *<.01 | *<.01 | *.01 | *.04 | .12 | .80 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 35 | 0 | .01 | <.01 | <.01 | <.01 | .03 | .06 | .13 | .21 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 1 | .01 | <.01 | .01 | .01 | .03 | .08 | .35 | .83 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 36 | 0 | .01 | <.01 | <.01 | <.01 | .02 | .07 | .15 | .80 |
| **Silver, total-recoverable** | | | | | | | | | | | | |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 16 | 16 | 1 | <1 | -- | <1 | <1 | <1 | -- | <1 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 13 | 10 | 1 | <1 | -- | <1 | <1 | <1 | -- | 2 |
| **Strontium, dissolved** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 47 | 0 | 5 | 120 | 130 | 200 | 390 | 640 | 770 | 870 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 47 | 0 | 5 | 44 | 64 | 88 | 130 | 190 | 220 | 250 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 46 | 0 | 5 | 40 | 61 | 92 | 160 | 240 | 430 | 570 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 48 | 0 | 5 | 72 | 110 | 140 | 210 | 380 | 620 | 1,200 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 47 | 0 | 5 | 71 | 110 | 130 | 210 | 260 | 390 | 660 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | 0 | 5 | 61 | 86 | 110 | 140 | 170 | 240 | 350 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 48 | 0 | 5 | 71 | 95 | 130 | 180 | 260 | 320 | 430 |
| **Thallium, suspended-sediment fraction** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 34 | 0 | .01 | <.01 | .01 | .01 | .15 | .49 | 1.2 | 1.7 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 38 | 0 | .01 | <.01 | <.01 | .01 | .04 | .17 | .25 | .59 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 32 | 0 | .01 | <.01 | <.01 | .01 | .02 | .16 | .36 | 1.2 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 39 | 0 | .01 | .01 | .01 | .01 | .05 | .24 | .59 | .83 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 36 | 0 | .01 | <.01 | <.01 | .01 | .05 | .25 | .53 | .82 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 1 | .01 | <.01 | <.01 | <.01 | .01 | .06 | .20 | .48 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 36 | 0 | .01 | <.01 | .01 | .01 | .04 | .23 | .46 | .65 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | Concentration at indicated percentile, in micrograms per liter (or as indicated): MIN | 10 | 25 | 50 (median) | 75 | 90 | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Titanium, suspended-sediment fraction | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | 0.1 | 9 | 30 | 60 | 360 | 2,500 | 7,400 | 9,100 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | .1 | 15 | 20 | 60 | 222 | 760 | 1,300 | 1,780 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | .1 | 7 | 20 | 40 | 130 | 630 | 2,100 | 3,650 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | .1 | 13 | 40 | 70 | 210 | 1,000 | 3,000 | 4,970 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | .1 | 13 | 20 | 60 | 180 | 1,400 | 2,600 | 4,740 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 0 | .1 | 4 | 10 | 20 | 51 | 380 | 1,000 | 3,600 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | .1 | 13 | 40 | 70 | 200 | 1,100 | 2,300 | 3,930 |
| Vanadium, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 47 | 47 | 6 | <6 | <6 | <6 | <6 | <6 | <6 | <6 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 47 | 47 | 6 | <6 | <6 | <6 | <6 | <6 | <6 | <6 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 46 | 46 | 6 | <6 | <6 | <6 | <6 | <6 | <6 | <6 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 48 | 48 | 6 | <6 | <6 | <6 | <6 | <6 | <6 | <6 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 47 | 47 | 6 | <6 | <6 | <6 | <6 | <6 | <6 | <6 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | 44 | 6 | <6 | <6 | <6 | <6 | <6 | <6 | <6 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 48 | 48 | 6 | <6 | <6 | <6 | <6 | <6 | <6 | <6 |
| Vanadium, suspended-sediment fraction | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 34 | 0 | .01 | .25 | .74 | 1.5 | 16 | 59 | 170 | 230 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 38 | 0 | .01 | .40 | .77 | 1.4 | 6.3 | 21 | 32 | 45 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 32 | 0 | .01 | .14 | .51 | .97 | 3.0 | 22 | 49 | 90 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 39 | 0 | .01 | .41 | 1.2 | 2.1 | 6.8 | 29 | 75 | 130 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 37 | 0 | .01 | .32 | .69 | 1.7 | 5.7 | 30 | 68 | 120 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 0 | .01 | .02 | .13 | .42 | .78 | 8.8 | 23 | 63 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 36 | 0 | .01 | .37 | 1.0 | 2.1 | 6.7 | 31 | 50 | 100 |
| Zinc, dissolved | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 47 | 10 | 3 | <3 | *2 | 3 | 6 | 13 | 27 | 130 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 47 | 10 | 3 | <3 | *2 | 3 | 6 | 14 | 22 | 79 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 46 | 7 | 3 | <3 | *2 | 4 | 6 | 12 | 21 | 46 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 48 | 10 | 3 | <3 | *2 | 3 | 6 | 10 | 13 | 82 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 47 | 9 | 3 | <3 | *2 | 4 | 5 | 9 | 17 | 38 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | 10 | 3 | <3 | *2 | 4 | 7 | 11 | 30 | 83 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 48 | 12 | 3 | <3 | *2 | *3 | 5 | 10 | 16 | 55 |

Table 17. Summary of metal and other trace-element concentrations for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program; --, unknown; KDOW, Kentucky Division of Water data obtained from STORET; NA, not applicable. This table includes only those sites with 10 or more observations; the 10- and 90-percentile values are not shown for sites having 30 or fewer observations.]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per liter | MIN | Concentration at indicated percentile, in micrograms per liter (or as indicated) 10 | 25 | 50 (median) | 75 | 90 | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Zinc, suspended-sediment fraction | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 34 | 0 | 0.01 | 0.78 | 1.2 | 2.7 | 23 | 88 | 190 | 260 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 38 | 0 | .01 | .80 | .97 | 2.0 | 7.8 | 21 | 33 | 44 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 32 | 0 | .01 | .21 | 1.1 | 1.4 | 4.5 | 36 | 64 | 110 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 39 | 0 | .01 | .89 | 1.8 | 2.9 | 9.9 | 35 | 90 | 130 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 37 | 0 | .01 | .68 | 1.1 | 2.5 | 9.5 | 35 | 72 | 130 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 33 | 0 | .01 | .16 | .57 | 1.1 | 2.6 | 15 | 45 | 98 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 36 | 0 | .01 | 1.0 | 1.4 | 3.3 | 10 | 35 | 67 | 110 |
| Zinc, total-recoverable | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 16 | 1 | 10 | <10 | -- | 22 | 40 | 130 | -- | 230 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 16 | 5 | 10 | <10 | -- | *9 | 25 | 40 | -- | 130 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 15 | 2 | 10 | <10 | -- | 20 | 30 | 40 | -- | 110 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 17 | 2 | 10 | <10 | -- | 15 | 30 | 70 | -- | 90 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 15 | 5 | 10 | <10 | -- | *10 | 30 | 50 | -- | 100 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 13 | 2 | 10 | <10 | -- | 10 | 20 | 45 | -- | 110 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 17 | 2 | 10 | <10 | -- | 10 | 30 | 50 | -- | 90 |
| Zinc, total-recoverable (KDOW) | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1986-89 | 42 | 1 | 1 | <1 | 7 | 13 | 19 | 61 | 110 | 390 |
| 2.3 | M Fk Ky R at Tallega | 1986-89 | 42 | 0 | 1 | 6 | 8 | 10 | 18 | 24 | 72 | 320 |
| 2.6 | S Fk Ky R at Booneville | 1986-89 | 42 | 0 | 1 | 3 | 5 | 8 | 15 | 33 | 56 | 320 |
| 3.0 | Ky R at Lock 14, Heidelberg | 1986-89 | 43 | 0 | 1 | 4 | 5 | 9 | 13 | 33 | 67 | 370 |
| 3.1 | Red R near Hazel Green | 1986-89 | 43 | 1 | 1 | <1 | 7 | 10 | 17 | 28 | 96 | 340 |
| 3.3 | Red R at Clay City | 1986-89 | 41 | 1 | 1 | <1 | 7 | 12 | 17 | 28 | 58 | 270 |
| 5.0 | Ky R at Camp Nelson | 1986-89 | 43 | 0 | 1 | 5 | 7 | 14 | 19 | 41 | 320 | 1,500 |
| 5.2 | Dix R near Danville | 1986-89 | 43 | 0 | 1 | 4 | 8 | 11 | 15 | 30 | 190 | 390 |
| 8.0 | Ky R at Lock 4, Frankfort | 1986-89 | 44 | 0 | 1 | 4 | 6 | 11 | 20 | 34 | 190 | 450 |
| 9.3 | S Elkhorn Cr Near Midway | 1986-89 | 43 | 0 | 1 | 7 | 14 | 20 | 28 | 46 | 73 | 290 |
| 10.1 | Eagle Cr at Glencoe | 1986-89 | 38 | 1 | 1 | <1 | 8 | 10 | 16 | 26 | 72 | 270 |

(page 151 follows)

Table 18. Summary of suspended-sediment-matrix concentrations of metals and other trace elements for selected fixed stations in the Kentucky River Basin

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per gram | MIN | Concentration at indicated percentile, in micrograms per gram | | | | | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 10 | 25 | 50 (median) | 75 | 90 | |
| Aluminum total | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | 100 | 34,200 | 76,400 | 87,900 | 95,600 | 103,000 | 112,000 | 126,000 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | 100 | 74,800 | 86,900 | 93,600 | 103,000 | 112,000 | 121,000 | 125,000 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | 100 | 20,300 | 59,000 | 86,500 | 93,200 | 103,000 | 118,000 | 122,000 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | 100 | 57,100 | 74,200 | 84,400 | 96,900 | 109,000 | 118,000 | 127,000 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | 100 | 33,200 | 61,800 | 74,200 | 84,900 | 103,000 | 106,000 | 127,000 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | 100 | 15,300 | 30,900 | 49,400 | 56,800 | 67,900 | 72,000 | 93,300 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | 100 | 57,400 | 69,800 | 77,300 | 85,300 | 100,000 | 107,000 | 120,000 |
| Antimony, total | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | .1 | .30 | .40 | .50 | .68 | .70 | .95 | 3.3 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | .1 | .40 | .40 | .50 | .70 | .80 | 1.2 | 10 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | .1 | .40 | .40 | .50 | .60 | 1.1 | 2.3 | 6.0 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | .1 | .40 | .50 | .60 | .80 | 1.2 | 2.1 | 5.9 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 39 | 0 | .1 | .40 | .50 | .60 | .76 | 1.4 | 3.4 | 90 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | .1 | .20 | .35 | .47 | .65 | .81 | 2.7 | 5.0 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | .1 | .40 | .50 | .60 | .70 | 1.1 | 2.6 | 42 |
| Arsenic, total | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | .1 | 4.10 | 6.97 | 7.70 | 8.95 | 10.2 | 10.8 | 13.1 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | .1 | 7.60 | 8.40 | 9.10 | 10.7 | 11.9 | 14.4 | 18.3 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | .1 | 4.90 | 6.45 | 9.15 | 10.6 | 12.3 | 16.1 | 21.1 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | .1 | 8.60 | 9.53 | 10.4 | 12.8 | 15.4 | 21.1 | 27.7 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 39 | 0 | .1 | .10 | 9.30 | 10.2 | 11.9 | 15.4 | 18.0 | 28.1 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | .1 | 3.00 | 3.80 | 5.77 | 7.65 | 8.97 | 11.6 | 14.8 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | .1 | 7.80 | 9.31 | 9.82 | 11.1 | 12.3 | 15.0 | 17.3 |
| Beryllium, total | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 1 | 2 | <2 | 3 | 3 | 4 | 4 | 4 | 4 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 38 | 0 | 2 | 3 | 3 | 3 | 4 | 4 | 4 | 5 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 2 | 2 | <2 | *2 | 3 | 3 | 4 | 4 | 4 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 1 | 2 | <2 | 3 | 3 | 4 | 4 | 4 | 5 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 3 | 2 | <2 | *2 | *3 | *3 | 4 | 4 | 5 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 31 | 9 | 2 | <2 | *2 | *2 | 2 | 2 | 3 | 6 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 1 | 2 | <2 | *2 | 3 | 3 | 4 | 4 | 4 |

Table 18. Summary of suspended-sediment-matrix concentrations of metals and other trace elements for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per gram | MIN | Concentration at indicated percentile, in micrograms per gram | | | | | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 10 | 25 | 50 (median) | 75 | 90 | |
| **Cadmium, total** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | 0.1 | 0.20 | 0.20 | 0.40 | 0.70 | 1.1 | 1.7 | 3.9 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | .1 | .10 | .30 | .30 | .50 | .7 | 1.2 | 3.3 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 1 | .1 | <.10 | .20 | .37 | .55 | 1.2 | 2.0 | 4.1 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 1 | .1 | <.10 | .40 | .50 | .80 | 1.6 | 2.5 | 5.4 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 39 | 0 | .1 | .30 | .40 | .50 | 1.0 | 2.3 | 4.7 | 11 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | .1 | .10 | .50 | .95 | 1.3 | 1.6 | 2.7 | 4.7 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 1 | .1 | <.10 | .31 | .50 | .70 | 1.1 | 2.1 | 4.2 |
| **Chromium total** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | 2 | 30 | 70 | 75 | 87 | 100 | 140 | 150 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | 2 | 73 | 79 | 85 | 93 | 110 | 140 | 160 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | 2 | 27 | 57 | 83 | 94 | 130 | 150 | 190 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | 2 | 51 | 75 | 86 | 97 | 115 | 140 | 180 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | 2 | 34 | 64 | 73 | 90 | 110 | 140 | 150 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | 2 | 5.0 | 39 | 60 | 67 | 79 | 97 | 110 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | 2 | 61 | 72 | 75 | 90 | 100 | 130 | 150 |
| **Cobalt, total** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | 2 | 18 | 21 | 22 | 24 | 27 | 33 | 37 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | 2 | 18 | 19 | 21 | 22 | 24 | 26 | 30 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | 2 | 10 | 22 | 23 | 26 | 29 | 34 | 43 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | 2 | 14 | 20 | 22 | 25 | 28 | 30 | 55 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | 2 | 7.0 | 15 | 21 | 23 | 24 | 26 | 33 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | 2 | 4.0 | 8.0 | 13 | 15 | 16 | 20 | 23 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | 2 | 17 | 18 | 20 | 22 | 24 | 25 | 28 |
| **Copper, total** | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | 2 | 22 | 29 | 32 | 35 | 38 | 49 | 220 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | 2 | 25 | 28 | 31 | 34 | 39 | 51 | 110 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | 2 | 25 | 28 | 30 | 33 | 40 | 98 | 1,000 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | 2 | 19 | 27 | 32 | 45 | 66 | 96 | 670 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | 2 | 21 | 25 | 30 | 38 | 51 | 110 | 190 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | 2 | 7.0 | 21 | 25 | 28 | 32 | 39 | 52 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | 2 | 22 | 25 | 29 | 33 | 38 | 56 | 110 |

Table 18. Summary of suspended-sediment-matrix concentrations of metals and other trace elements for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per gram | Concentration at indicated percentile, in micrograms per gram | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | MIN | 10 | 25 | 50 (median) | 75 | 90 | MAX |
| Iron, total | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | 100 | 24,700 | 37,800 | 39,100 | 42,000 | 43,900 | 46,300 | 48,300 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | 100 | 40,700 | 43,700 | 46,500 | 50,400 | 54,900 | 61,700 | 86,000 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | 100 | 11,700 | 33,400 | 43,000 | 45,700 | 50,100 | 51,700 | 63,900 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | 100 | 30,600 | 41,600 | 43,900 | 47,700 | 52,100 | 56,900 | 81,000 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | 100 | 18,200 | 34,400 | 39,400 | 45,100 | 48,300 | 50,900 | 56,000 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | 100 | 11,200 | 18,100 | 29,300 | 34,800 | 40,100 | 43,800 | 51,100 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | 100 | 32,400 | 38,000 | 41,900 | 44,100 | 47,500 | 50,500 | 59,700 |
| Lead, total | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | .1 | 21.5 | 24.1 | 27.1 | 30.5 | 36.8 | 46.8 | 134 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | .1 | 20.4 | 23.5 | 26.7 | 32.3 | 39.5 | 53.6 | 334 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | .1 | 18.9 | 20.3 | 24.6 | 29.6 | 40.6 | 128 | 305 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | .1 | 14.5 | 23.4 | 28.0 | 37.6 | 48.5 | 108 | 326 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 39 | 0 | .1 | 18.8 | 24.9 | 31.4 | 43.0 | 71.6 | 159 | 500 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | .1 | 8.70 | 29.7 | 38.8 | 43.3 | 61.4 | 122 | 353 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | .1 | 20.9 | 25.1 | 30.3 | 40.1 | 53.7 | 134 | 243 |
| Magnesium, total | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | 100 | 7,000 | 7,300 | 7,800 | 9,500 | 16,200 | 21,100 | 47,900 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | 100 | 6,500 | 7,600 | 7,900 | 9,200 | 10,800 | 13,200 | 19,900 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | 100 | 5,700 | 6,700 | 7,100 | 8,800 | 10,300 | 13,700 | 17,900 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | 100 | 4,400 | 7,600 | 8,500 | 9,600 | 11,400 | 14,800 | 20,800 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | 100 | 6,200 | 7,600 | 8,100 | 9,200 | 10,600 | 16,900 | 28,000 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | 100 | 5,500 | 6,000 | 6,800 | 7,700 | 10,100 | 15,300 | 24,600 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | 100 | 7,300 | 7,600 | 8,000 | 9,200 | 10,100 | 11,900 | 15,100 |
| Manganese, total | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | 8 | 722 | 1,070 | 1,380 | 2,360 | 3,830 | 5,860 | 12,800 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | 8 | 1,060 | 1,140 | 1,450 | 2,150 | 4,860 | 6,610 | 12,200 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | 8 | 1,160 | 1,420 | 1,670 | 2,540 | 3,730 | 8,150 | 9,690 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | 8 | 1,200 | 1,310 | 1,470 | 2,040 | 4,320 | 6,570 | 19,500 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | 8 | 1,230 | 1,490 | 1,640 | 2,070 | 3,700 | 12,200 | 37,100 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | 8 | 110 | 1,170 | 2,040 | 2,540 | 2,960 | 4,700 | 8,450 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | 8 | 1,270 | 1,420 | 1,600 | 1,890 | 3,340 | 5,330 | 7,640 |

Table 18. Summary of suspended-sediment-matrix concentrations of metals and other trace elements for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per gram | MIN | Concentration at indicated percentile, in micrograms per gram | | | | | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 10 | 25 | 50 (median) | 75 | 90 | |
| Molybdenum, total | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | 0.1 | 0.60 | 0.67 | 0.70 | 0.85 | 1.07 | 1.33 | 3.90 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | .1 | .50 | .60 | .70 | .90 | 1.20 | 1.50 | 4.60 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | .1 | .40 | .60 | .60 | .80 | 1.10 | 2.90 | 11.1 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | .1 | .80 | 1.00 | 1.27 | 2.05 | 2.92 | 3.84 | 8.80 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 39 | 0 | .1 | .50 | 1.00 | 1.30 | 1.90 | 2.90 | 4.30 | 22.8 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | .1 | .70 | .90 | 1.00 | 1.95 | 7.57 | 16.4 | 74.1 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | .1 | 1.00 | 1.01 | 1.20 | 1.65 | 2.47 | 3.19 | 9.30 |
| Nickel, total | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | 4 | 38 | 40 | 43 | 50 | 59 | 73 | 164 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | 4 | 37 | 39 | 41 | 47 | 51 | 55 | 76 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | 4 | 24 | 43 | 50 | 57 | 70 | 97 | 303 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | 4 | 31 | 45 | 51 | 62 | 67 | 76 | 498 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | 4 | 27 | 36 | 44 | 50 | 59 | 66 | 136 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | 4 | 14 | 19 | 28 | 33 | 35 | 48 | 60 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | 4 | 34 | 37 | 40 | 46 | 54 | 58 | 87 |
| Silver, total | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 3 | .1 | <.10 | *.07 | .12 | .30 | .40 | 1.6 | 3.1 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 3 | .1 | <.10 | .10 | .10 | .20 | .30 | .40 | 3.8 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 2 | .1 | <.10 | .10 | .20 | .20 | .42 | .60 | 8.8 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 2 | .1 | <.10 | .10 | .20 | .20 | .30 | .60 | 4.6 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 39 | 0 | .1 | .10 | .10 | .20 | .20 | .40 | 1.2 | 4.6 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 1 | .1 | <.10 | .25 | .67 | 1.1 | 1.6 | 4.0 | 5.7 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | .1 | .10 | .10 | .20 | .20 | .30 | .59 | 10 |
| Thallium, total | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | .1 | .20 | .60 | .70 | .80 | 1.0 | 1.2 | 3.8 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | .1 | .40 | .60 | .80 | .90 | 1.0 | 1.1 | 3.8 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | .1 | .20 | .55 | .60 | .80 | .90 | 1.3 | 2.8 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | .1 | .50 | .70 | .70 | .90 | 1.0 | 1.3 | 3.7 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 39 | 0 | .1 | .50 | .50 | .80 | .80 | 1.0 | 1.2 | 4.1 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 1 | .1 | <.10 | .30 | .50 | .60 | .70 | .85 | 1.7 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | .1 | .50 | .50 | .70 | .80 | .90 | 1.1 | 3.8 |

Table 18. Summary of suspended-sediment-matrix concentrations of metals and other trece elements for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; <, less than; *, value estimated from log-normal-fit program]

| Site number | Station name | Period of record (water years) | N | N less than DL | Minimum DL, in micrograms per gram | MIN | Concentration at indicated percentile, in micrograms per gram: 10 | 25 | 50 (median) | 75 | 90 | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Titanium, total | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | 100 | 1,500 | 3,800 | 4,200 | 4,800 | 5,200 | 5,500 | 5,800 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | 100 | 3,700 | 4,100 | 4,700 | 5,000 | 5,300 | 5,700 | 6,100 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | 100 | 1,500 | 3,200 | 4,400 | 4,800 | 5,000 | 5,400 | 5,800 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | 100 | 3,400 | 3,900 | 4,700 | 5,100 | 5,300 | 5,500 | 6,000 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | 100 | 1,600 | 3,600 | 4,300 | 4,900 | 5,200 | 5,500 | 5,700 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 1 | 100 | <100 | 1,700 | 3,200 | 3,600 | 4,300 | 5,000 | 5,300 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | 100 | 3,700 | 4,100 | 4,700 | 4,900 | 5,200 | 5,400 | 5,600 |
| Vanadium, total | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | 4 | 41 | 98 | 107 | 118 | 126 | 136 | 152 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | 4 | 99 | 107 | 118 | 131 | 141 | 153 | 164 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | 4 | 36 | 71 | 108 | 119 | 134 | 157 | 164 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | 4 | 72 | 110 | 125 | 135 | 153 | 156 | 171 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | 4 | 40 | 85 | 105 | 121 | 138 | 149 | 175 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | 4 | 6 | 38 | 63 | 75 | 85 | 96 | 166 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | 4 | 78 | 99 | 106 | 120 | 135 | 144 | 156 |
| Zinc, total | | | | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 36 | 0 | 4 | 116 | 130 | 147 | 167 | 188 | 263 | 494 |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 39 | 0 | 4 | 116 | 134 | 142 | 155 | 178 | 244 | 300 |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 34 | 0 | 4 | 107 | 139 | 147 | 159 | 200 | 270 | 1,890 |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 42 | 0 | 4 | 85 | 128 | 148 | 194 | 214 | 270 | 1,810 |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 40 | 0 | 4 | 97 | 122 | 145 | 169 | 199 | 265 | 359 |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 34 | 0 | 4 | 54 | 117 | 145 | 173 | 217 | 269 | 316 |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | 40 | 0 | 4 | 103 | 125 | 132 | 148 | 200 | 257 | 335 |

(page 157 follows)

**Table 19.** Mean annual loads and yields of metals and other trace elements for selected fixed stations in the Kentucky River Basin, April 1987 through March 1990

[Transport estimates for Elkhorn Creek at Frankfort are based only on discharge records for April 1988 through March 1990; N, number of concentration observations; <, less than; KDOW, Kentucky Division of Water data for January 1986 through December 1989 obtained from STORET. This table includes only those stations having 10 or more observations.]

| | | | | Transport estimates | | Uncertainty factors, in percent | | |
|---|---|---|---|---|---|---|---|---|
| Site number | Station name | Number of observations | Number of censored observations | Mean annual load, in tons per year | Mean annual yield, in tons per square mile per year | Standard error of regression | Flow duration of greatest sampled discharge | Portion of load estimated beyond range of sampled discharge |
| Aluminum, dissolved | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 44 | 7 | 60.9 | 0.055 | 67.3 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 44 | 13 | 26.4 | .049 | 88.0 | 99.8 | 2.17 |
| 2.6 | S Fk Ky R at Booneville | 43 | 15 | 42.0 | .058 | 68.1 | 99.7 | 18.4 |
| 4.0 | Ky R at Lock 10, Winchester | 43 | 10 | 349 | .088 | 121 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 42 | 9 | 273 | .050 | 63.7 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 41 | 10 | 34.6 | .073 | 82.8 | 99.7 | 20.1 |
| 10.0 | Ky R at Lock 2, Lockport | 46 | 9 | 462 | .075 | 85.0 | 100 | 0 |
| Aluminum, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | 117,000 | 106 | 112 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | 12,400 | 23.1 | 73.3 | 99.8 | 2.67 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | 26,400 | 36.6 | 160 | 99.7 | 34.3 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | 117,000 | 29.7 | 71.5 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 40 | 0 | 129,000 | 23.8 | 79.6 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 0 | 16,200 | 34.3 | 120 | 99.7 | 52.2 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 0 | 161,000 | 26.0 | 71.2 | 100 | 0 |
| Aluminum, total recoverable | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 17 | 0 | 9,300 | 8.45 | 97.7 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 17 | 0 | 2,620 | 4.94 | 74.3 | 99.8 | 2.12 |
| 2.6 | S Fk Ky R at Booneville | 16 | 0 | 3,420 | 4.74 | 87.0 | 99.7 | 29.8 |
| 4.0 | Ky R at Lock 10, Winchester | 16 | 1 | 33,400 | 8.44 | 205 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 16 | 1 | 40,500 | 7.49 | 186 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 13 | 0 | 3,730 | 7.88 | 112 | 99.7 | 34.8 |
| 10.0 | Ky R at Lock 2, Lockport | 16 | 0 | 28,000 | 4.52 | 58.2 | 100 | 0 |
| Aluminum, total recoverable (KDOW) | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 44 | 0 | 5,330 | 4.84 | 134 | 97.4 | 73.6 |
| 2.3 | M Fk Ky R at Tallega | 44 | 0 | 1,650 | 3.08 | 144 | 93.9 | 52.9 |
| 2.6 | S Fk Ky R at Booneville | 44 | 0 | 839 | 1.16 | 100 | 98.3 | 51.8 |
| 3.0 | Ky R at Lock 14, Heidelberg | 45 | 1 | 11,900 | 4.48 | 215 | 96.8 | 55.9 |
| 3.1 | Red R near Hazel Green | 44 | 1 | 887 | 1.35 | 260 | 99.6 | 10.2 |
| 3.3 | Red R at Clay City | 43 | 0 | 1,150 | 3.19 | 115 | 100 | 0 |
| 5.0 | Ky R at Camp Nelson | 45 | 1 | 38,800 | 8.77 | 195 | 99.7 | 8.88 |
| 5.2 | Dix R near Danville | 45 | 0 | 371 | 1.17 | 194 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 46 | 1 | 35,000 | 6.47 | 206 | 99.8 | 8.00 |
| 9.3 | S Elkhorn Cr near Midway | 45 | 0 | 176 | 1.67 | 86.6 | 100 | 18.0 |
| 10.1 | Eagle Cr at Glencoe | 38 | 0 | 965 | 2.21 | 317 | 99.2 | 33.1 |

**Table 19.** Mean annual loads and yields of metals and other trace elements for selected fixed stations in the Kentucky River Basin, April 1987 through March 1990—Continued

[Transport estimates for Elkhorn Creek at Frankfort are based only on discharge records for April 1988 through March 1990; N, number of concentration observations; <, less than; KDOW, Kentucky Division of Water data for January 1986 through December 1989 obtained from STORET. This table includes only those stations having 10 or more observations.]

|  |  |  |  | Transport estimates |  | Uncertainty factors, in percent |  |  |
|---|---|---|---|---|---|---|---|---|
| Site number | Station name | Number of observations | Number of censored observations | Mean annual load, in tons per year | Mean annual yield, in tons per square mile per year | Standard error of regression | Flow duration of greatest sampled discharge | Portion of load estimated beyond range of sampled discharge |
| Antimony, suspended-sediment fraction |  |  |  |  |  |  |  |  |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | 0.58 | <0.001 | 83.6 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 38 | 0 | .07 | <.001 | 73.7 | 99.8 | 3.04 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | .18 | <.001 | 138 | 99.7 | 33.8 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | .94 | <.001 | 64.2 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 38 | 0 | 1.2 | <.001 | 95.6 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 0 | .05 | <.001 | 104 | 99.7 | 29.16 |
| 10.0 | Ky R at Lock 2, Lockport | 37 | 0 | 1.3 | <.001 | 79.7 | 100 | 0 |
| Arsenic, dissolved |  |  |  |  |  |  |  |  |
| 4.0 | Ky R at Lock 10, Winchester | 46 | 0 | 5.9 | .001 | 10.1 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 46 | 0 | 7.7 | .001 | 29.9 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 44 | 19 | .5 | .001 | 53.2 | 99.7 | 5.63 |
| 10.0 | Ky R at Lock 2, Lockport | 47 | 0 | 8.8 | .001 | 27.4 | 100 | 0 |
| Arsenic, suspended-sediment fraction |  |  |  |  |  |  |  |  |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | 8.8 | .008 | 106 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | 1.1 | .002 | 71.4 | 99.8 | 2.42 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | 2.7 | .004 | 153 | 99.7 | 31.6 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | 13 | .003 | 60.2 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 39 | 1 | 20 | .004 | 132 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 0 | 1.6 | .003 | 99.2 | 99.7 | 49.2 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 0 | 19 | .003 | 58.7 | 100 | 0 |
| Arsenic, total recoverable (KDOW) |  |  |  |  |  |  |  |  |
| 2.0 | N Fk Ky R at Jackson | 44 | 21 | 2.8 | .003 | 111 | 97.4 | 28.3 |
| 2.3 | M Fk Ky R at Tallega | 44 | 0 | 1.8 | .003 | 74.2 | 93.9 | 32.2 |
| 2.6 | S Fk Ky R at Booneville | 44 | 0 | 3.0 | .004 | 70.6 | 98.3 | 24.6 |
| 3.0 | Ky R at Lock 14, Heidelberg | 45 | 0 | 10.9 | .004 | 67.5 | 96.8 | 26.3 |
| 3.1 | Red R near Hazel Green | 44 | 0 | .2 | .003 | 64.4 | 99.6 | 9.04 |
| 3.3 | Red R at Clay City | 43 | 16 | 1.3 | .004 | 116 | 100 | 0 |
| 5.0 | Ky R at Camp Nelson | 44 | 19 | 17 | .004 | 110 | 99.7 | 4.09 |
| 5.2 | Dix R near Danville | 44 | 19 | 1.6 | .005 | 133 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 45 | 17 | 18 | .003 | 124 | 99.8 | 2.00 |
| 9.3 | S Elkhorn Cr near Midway | 44 | 20 | .4 | .003 | 108 | 99.8 | 2.47 |
| 10.1 | Eagle Cr at Glencoe | 38 | 16 | .8 | .002 | 116 | 99.2 | 23.4 |
| Barium, dissolved |  |  |  |  |  |  |  |  |
| 2.0 | N Fk Ky R at Jackson | 47 | 0 | 43.4 | .039 | 13.9 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 47 | 0 | 18.3 | .034 | 14.6 | 99.8 | 1.12 |
| 2.6 | S Fk Ky R at Booneville | 46 | 0 | 24.8 | .034 | 20.1 | 99.7 | 3.47 |
| 4.0 | Ky R at Lock 10, Winchester | 48 | 0 | 183 | .046 | 24.3 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 47 | 0 | 205 | .038 | 20.7 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 44 | 0 | 14.3 | .030 | 15.0 | 99.7 | 7.14 |
| 10.0 | Ky R at Lock 2, Lockport | 48 | 0 | 221 | .036 | 18.1 | 100 | 0 |

**Table 19.** Mean annual loads and yields of metals and other trace elements for selected fixed stations in the Kentucky River Basin, April 1987 through March 1990—Continued

[Transport estimates for Elkhorn Creek at Frankfort are based only on discharge records for April 1988 through March 1990; N, number of concentration observations; <, less than; KDOW, Kentucky Division of Water data for January 1986 through December 1989 obtained from STORET. This table includes only those stations having 10 or more observations.]

| | | | | Transport estimates | | Uncertainty factors, in percent | | |
|---|---|---|---|---|---|---|---|---|
| Site number | Station name | Number of observations | Number of censored observations | Mean annual load, in tons per year | Mean annual yield, in tons per square mile per year | Standard error of regression | Flow duration of greatest sampled discharge | Portion of load estimated beyond range of sampled discharge |
| Barium, total recoverable | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 16 | 0 | 144 | 0.130 | 17.0 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 16 | 0 | 84.6 | .157 | 24.8 | 99.8 | 1.40 |
| 2.6 | S Fk Ky R at Booneville | 15 | 0 | 105 | .145 | 17.6 | 99.7 | 5.65 |
| 4.0 | Ky R at Lock 10, Winchester | 17 | 0 | 649 | .164 | 24.1 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 16 | 0 | 770 | .142 | 17.5 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 16 | 5 | 123 | .259 | 42.1 | 100 | 0 |
| 10.0 | Ky R at Lock 2, Lockport | 17 | 0 | 757 | .122 | 23.9 | 100 | 0 |
| Barium, total recoverable (KDOW) | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 44 | 1 | 82.7 | .075 | 115 | 97.4 | 25.3 |
| 2.3 | M Fk Ky R at Tallega | 44 | 0 | 42.6 | .079 | 70.2 | 93.9 | 33.4 |
| 2.6 | S Fk Ky R at Booneville | 44 | 0 | 53.0 | .073 | 90.3 | 98.3 | 27.1 |
| 3.0 | Ky R at Lock 14, Heidelberg | 45 | 1 | 260 | .098 | 140 | 96.8 | 21.1 |
| 3.1 | Red R near Hazel Green | 44 | 0 | 2.95 | .045 | 122 | 99.6 | 8.97 |
| 3.3 | Red R at Clay City | 42 | 0 | 32.2 | .089 | 76.4 | 100 | 0 |
| 5.0 | Ky R at Camp Nelson | 45 | 1 | 526 | .119 | 154 | 99.7 | 3.86 |
| 5.2 | Dix R near Danville | 45 | 1 | 21.1 | .066 | 143 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 46 | 1 | 450 | .085 | 112 | 99.8 | 2.75 |
| 9.3 | S Elkhorn Cr near Midway | 45 | 1 | 5.61 | .053 | 115 | 99.9 | 5.24 |
| 10.1 | Eagle Cr at Glencoe | 38 | 2 | 10.6 | .024 | 151 | 99.2 | 23.2 |
| Beryllium, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 1 | 4.5 | .004 | 109 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 1 | .44 | .001 | 69.0 | 99.8 | 2.67 |
| 2.6 | S Fk Ky R at Booneville | 34 | 2 | .91 | .001 | 154 | 99.7 | 33.8 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 1 | 4.3 | .001 | 71.6 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 40 | 3 | 4.6 | .001 | 77.8 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 10 | .40 | .001 | 114 | 99.7 | 48.5 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 1 | 5.7 | .001 | 74.8 | 100 | 0 |
| Boron, dissolved | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 44 | 3 | 24.4 | .022 | 44.2 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 44 | 16 | 8.1 | .015 | 55.4 | 99.8 | .88 |
| 2.6 | S Fk Ky R at Booneville | 43 | 15 | 10.9 | .015 | 60.1 | 99.7 | 5.17 |
| 4.0 | Ky R at Lock 10, Winchester | 43 | 7 | 92.6 | .023 | 50.0 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 42 | 2 | 130 | .024 | 35.7 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 41 | 1 | 17.0 | .036 | 32.9 | 99.7 | 3.02 |
| 10.0 | Ky R at Lock 2, Lockport | 42 | 3 | 159 | .026 | 43.7 | 100 | 0 |

**Table 19.** Mean annual loads and yields of metals and other trace elements for selected fixed stations in the Kentucky River Basin, April 1987 through March 1990—Continued

[Transport estimates for Elkhorn Creek at Frankfort are based only on discharge records for April 1988 through March 1990; N, number of concentration observations; <, less than; KDOW, Kentucky Division of Water data for January 1986 through December 1989 obtained from STORET. This table includes only those stations having 10 or more observations.]

| | | | | Transport estimates | | Uncertainty factors, in percent | | |
|---|---|---|---|---|---|---|---|---|
| Site number | Station name | Number of observations | Number of censored observations | Mean annual load, in tons per year | Mean annual yield, in tons per square mile per year | Standard error of regression | Flow duration of greatest sampled discharge | Portion of load estimated beyond range of sampled discharge |
| Boron, total recoverable | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 16 | 3 | 77.8 | 0.071 | 111 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 15 | 6 | 30.8 | .057 | 248 | 99.8 | 1.08 |
| 2.6 | S Fk Ky R at Booneville | 14 | 2 | 39.2 | .054 | 77.6 | 99.7 | 2.55 |
| 4.0 | Ky R at Lock 10, Winchester | 16 | 3 | 193 | .049 | 113 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 15 | 0 | 312 | .058 | 38.0 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 12 | 0 | 27.4 | .058 | 53.4 | 99.7 | 4.58 |
| 10.0 | Ky R at Lock 2, Lockport | 16 | 0 | 452 | .073 | 68.8 | 100 | 0 |
| Cadmium, dissolved | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 47 | 13 | .3 | <.001 | 104 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 47 | 18 | .2 | <.001 | 106 | 99.8 | 1.47 |
| 2.6 | S Fk Ky R at Booneville | 46 | 15 | .2 | <.001 | 102 | 99.7 | 6.53 |
| 4.0 | Ky R at Lock 10, Winchester | 48 | 7 | 2.1 | <.001 | 107 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 47 | 12 | 2.1 | <.001 | 120 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 45 | 8 | .2 | <.001 | 112 | 99.7 | 4.93 |
| 10.0 | Ky R at Lock 2, Lockport | 48 | 6 | 2.7 | <.001 | 125 | 100 | 0 |
| Cadmium, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | .31 | <.001 | 91.0 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | .04 | <.001 | 76.5 | 99.8 | 2.5 |
| 2.6 | S Fk Ky R at Booneville | 34 | 1 | .09 | <.001 | 121 | 99.7 | 23.3 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | .85 | <.001 | 98.2 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 39 | 1 | 1.1 | <.001 | 109 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 0 | .13 | <.001 | 89.9 | 99.7 | 37.4 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 1 | 1.2 | <.001 | 75.8 | 100 | 0 |
| Chromium, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | 116 | .106 | 117 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | 12.4 | .023 | 76.1 | 99.8 | 2.5 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | 26.0 | .036 | 159 | 99.7 | 33.2 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | 121 | .031 | 70.2 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 40 | 0 | 132 | .024 | 81.4 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 0 | 14.9 | .031 | 108 | 99.7 | 49.5 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 0 | 161 | .026 | 71.1 | 100 | 0 |
| Chromium, total recoverable | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 16 | 2 | 17.2 | .016 | 164 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 16 | 4 | 5.6 | .010 | 116 | 99.8 | .8 |
| 2.6 | S Fk Ky R at Booneville | 15 | 3 | 6.3 | .009 | 141 | 99.7 | 10.6 |
| 4.0 | Ky R at Lock 10, Winchester | 17 | 6 | 33.7 | .008 | 109 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 16 | 3 | 74.7 | .014 | 87.0 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 13 | 3 | 6.6 | .014 | 229 | 99.7 | 10.8 |
| 10.0 | Ky R at Lock 2, Lockport | 17 | 3 | 78.2 | .013 | 140 | 100 | 0 |

**Table 19.** Mean annual loads and yields of metals and other trace elements for selected fixed stations in the Kentucky River Basin, April 1987 through March 1990—Continued

[Transport estimates for Elkhorn Creek at Frankfort are based only on discharge records for April 1988 through March 1990; N, number of concentration observations; <, less than; KDOW, Kentucky Division of Water data for January 1986 through December 1989 obtained from STORET. This table includes only those stations having 10 or more observations.]

| | | | | Transport estimates | | Uncertainty factors, in percent | | |
|---|---|---|---|---|---|---|---|---|
| Site number | Station name | Number of observations | Number of censored observations | Mean annual load, in tons per year | Mean annual yield, in tons per square mile per year | Standard error of regression | Flow duration of greatest sampled discharge | Portion of load estimated beyond range of sampled discharge |
| Chromium, total recoverable (KDOW) | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 44 | 9 | 7.4 | 0.007 | 76.8 | 97.4 | 44.8 |
| 2.3 | M Fk Ky R at Tallega | 44 | 6 | 2.7 | .005 | 80.2 | 93.9 | 36.8 |
| 2.6 | S Fk Ky R at Booneville | 44 | 5 | 3.7 | .005 | 74.4 | 98.3 | 31.4 |
| 3.0 | Ky R at Lock 14, Heidelberg | 45 | 6 | 19 | .007 | 88.5 | 96.8 | 33.2 |
| 3.1 | Red R near Hazel Green | 44 | 7 | .3 | .004 | 104 | 99.6 | 9.09 |
| 3.3 | Red R at Clay City | 43 | 6 | 2.9 | .008 | 76.7 | 100 | 0 |
| 5.0 | Ky R at Camp Nelson | 45 | 8 | 37 | .008 | 83.8 | 99.7 | 6.08 |
| 5.2 | Dix R near Danville | 45 | 5 | 1.9 | .006 | 91.0 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 46 | 4 | 37 | .007 | 79.6 | 99.8 | 3.78 |
| 9.3 | S Elkhorn Cr near Midway | 45 | 0 | .6 | .006 | 57.9 | 99.8 | 5.30 |
| 10.1 | Eagle Cr at Glencoe | 38 | 7 | 1.7 | .004 | 110 | 99.2 | 31.2 |
| Cobalt, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | 20 | .018 | 87.3 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | 2.4 | .004 | 59.7 | 99.8 | 2.76 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | 5.8 | .008 | 125 | 99.7 | 31.4 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | 27 | .007 | 70.6 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 40 | 0 | 29 | .006 | 76.3 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 0 | 2.8 | .006 | 95.8 | 99.7 | 48.0 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 0 | 37 | .006 | 66.5 | 100 | 0 |
| Copper, dissolved | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 47 | 10 | 1.5 | .001 | 79.1 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 47 | 8 | .9 | .002 | 86.0 | 99.8 | 1.39 |
| 2.6 | S Fk Ky R at Booneville | 46 | 9 | 1.0 | .001 | 76.6 | 99.7 | 6.15 |
| 4.0 | Ky R at Lock 10, Winchester | 48 | 4 | 11.1 | .003 | 81.2 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 47 | 5 | 12.3 | .002 | 70.7 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 45 | 4 | 1.5 | .003 | 89.0 | 99.7 | 6.21 |
| 10.0 | Ky R at Lock 2, Lockport | 48 | 2 | 13.8 | .002 | 67.2 | 100 | 0 |
| Copper, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | 35.0 | .032 | 113 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | 4.0 | .007 | 77.0 | 99.8 | 2.44 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | 9.5 | .013 | 186 | 99.7 | 33.4 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | 45.0 | .011 | 75.78 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 40 | 0 | 60.2 | .011 | 110 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 0 | 4.2 | .009 | 91.8 | 99.7 | 43.2 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 0 | 58.2 | .009 | 69.4 | 100 | 0 |

**Table 19.** Mean annual loads and yields of metals and other trace elements for selected fixed stations in the Kentucky River Basin, April 1987 through March 1990—Continued

[Transport estimates for Elkhorn Creek at Frankfort are based only on discharge records for April 1988 through March 1990; N, number of concentration observations; <, less than; KDOW, Kentucky Division of Water data for January 1986 through December 1989 obtained from STORET. This table includes only those stations having 10 or more observations.]

| | | | | Transport estimates | | Uncertainty factors, in percent | | |
|---|---|---|---|---|---|---|---|---|
| **Site number** | **Station name** | **Number of observations** | **Number of censored observations** | **Mean annual load, in tons per year** | **Mean annual yield, in tons per square mile per year** | **Standard error of regression** | **Flow duration of greatest sampled discharge** | **Portion of load estimated beyond range of sampled discharge** |
| Copper, total recoverable | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 16 | 4 | 28.9 | 0.026 | 72.7 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 16 | 0 | 8.2 | .015 | 22.7 | 99.8 | 1.32 |
| 2.6 | S Fk Ky R at Booneville | 15 | 6 | 19.9 | .028 | 50.0 | 99.7 | 6.92 |
| 4.0 | Ky R at Lock 10, Winchester | 17 | 3 | 88.0 | .022 | 49.9 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 16 | 6 | 135 | .025 | 101.1 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 13 | 5 | 5.2 | .011 | 59.2 | 99.7 | 16.9 |
| 10.0 | Ky R at Lock 2, Lockport | 17 | 4 | 120 | .019 | 46.5 | 100 | 0 |
| Copper, total recoverable (KDOW) | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 44 | 4 | 7.8 | .007 | 119 | 97.4 | 31.2 |
| 2.3 | M Fk Ky R at Tallega | 43 | 8 | 3.4 | .006 | 128 | 93.9 | 34.0 |
| 2.6 | S Fk Ky R at Booneville | 44 | 7 | 3.7 | .005 | 141 | 98.3 | 21.3 |
| 3.0 | Ky R at Lock 14, Heidelberg | 45 | 9 | 27.8 | .010 | 119 | 96.8 | 34.9 |
| 3.1 | Red R near Hazel Green | 44 | 6 | .4 | .006 | 144 | 99.6 | 8.29 |
| 3.3 | Red R at Clay City | 43 | 6 | 2.8 | .008 | 122 | 100 | 0 |
| 5.0 | Ky R at Camp Nelson | 45 | 3 | 44.2 | .010 | 112 | 99.7 | 4.02 |
| 5.2 | Dix R near Danville | 45 | 4 | 2.1 | .006 | 127 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 46 | 8 | 36.7 | .007 | 108 | 99.8 | 3.43 |
| 9.3 | S Elkhorn Cr near Midway | 45 | 5 | 1.3 | .012 | 124 | 99.8 | 5.03 |
| 10.1 | Eagle Cr at Glencoe | 38 | 1 | 1.8 | .004 | 100 | 99.2 | 25.0 |
| Iron, dissolved | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 47 | 1 | 64.4 | .058 | 74.7 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 47 | 0 | 50.5 | .094 | 60.7 | 99.8 | 1.67 |
| 2.6 | S Fk Ky R at Booneville | 46 | 0 | 86.7 | .120 | 88.2 | 99.7 | 12.5 |
| 4.0 | Ky R at Lock 10, Winchester | 48 | 2 | 635 | .161 | 115 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 47 | 4 | 373 | .069 | 81.3 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 44 | 1 | 36.1 | .076 | 112 | 99.7 | 20.2 |
| 10.0 | Ky R at Lock 2, Lockport | 48 | 4 | 685 | .111 | 119 | 100 | 0 |
| Iron, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | 43,600 | 39.6 | 101 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | 5,390 | 10.0 | 70.4 | 99.8 | 3.02 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | 11,800 | 16.4 | 146 | 99.7 | 33.3 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | 53,400 | 13.5 | 66.4 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 40 | 0 | 62,000 | 11.4 | 74.9 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 33 | 0 | 7,280 | 15.4 | 94.4 | 99.7 | 49.9 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 0 | 77,300 | 12.5 | 64.0 | 100 | 0 |

**Table 19.** Mean annual loads and yields of metals and other trace elements for selected fixed stations in the Kentucky River Basin, April 1987 through March 1990—Continued

[Transport estimates for Elkhorn Creek at Frankfort are based only on discharge records for April 1988 through March 1990; N, number of concentration observations; <, less than; KDOW, Kentucky Division of Water data for January 1986 through December 1989 obtained from STORET. This table includes only those stations having 10 or more observations.]

| | | | | Transport estimates | | Uncertainty factors, in percent | | |
|---|---|---|---|---|---|---|---|---|
| Site number | Station name | Number of observations | Number of censored observations | Mean annual load, in tons per year | Mean annual yield, in tons per square mile per year | Standard error of regression | Flow duration of greatest sampled discharge | Portion of load estimated beyond range of sampled discharge |
| Iron, total recoverable | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 16 | 0 | 22,779 | 20.7 | 59.2 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 16 | 0 | 5,130 | 9.55 | 51.1 | 99.8 | 1.89 |
| 2.6 | S Fk Ky R at Booneville | 15 | 0 | 7,210 | 9.99 | 89.2 | 99.7 | 26.2 |
| 4.0 | Ky R at Lock 10, Winchester | 17 | 0 | 40,800 | 10.3 | 43.2 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 16 | 0 | 44,400 | 8.20 | 50.0 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 13 | 1 | 8,330 | 17.6 | 304 | 99.7 | 35.8 |
| 10.0 | Ky R at Lock 2, Lockport | 17 | 0 | 50,800 | 8.23 | 61.8 | 100 | 0 |
| Iron, total recoverable (KDOW) | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 44 | 0 | 6,170 | 5.60 | 93.1 | 97.4 | 61.0 |
| 2.3 | M Fk Ky R at Tallega | 44 | 0 | 1,950 | 3.64 | 49.4 | 93.9 | 45.7 |
| 2.6 | S Fk Ky R at Booneville | 44 | 0 | 1,670 | 2.31 | 51.6 | 98.3 | 49.0 |
| 3.0 | Ky R at Lock 14, Heidelberg | 45 | 0 | 16,700 | 6.28 | 73.6 | 96.8 | 46.0 |
| 3.1 | Red R near Hazel Green | 44 | 0 | 174 | 2.64 | 97.1 | 99.6 | 12.6 |
| 3.3 | Red R at Clay City | 43 | 0 | 1,700 | 4.69 | 51.3 | 100 | 0 |
| 5.0 | Ky R at Camp Nelson | 45 | 0 | 36,400 | 8.22 | 80.8 | 99.7 | 11.0 |
| 5.2 | Dix R near Danville | 45 | 1 | 655 | 2.06 | 200 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 46 | 0 | 28,500 | 5.27 | 81.3 | 99.8 | 8.81 |
| 9.3 | S Elkhorn Cr near Midway | 45 | 0 | 159 | 1.52 | 64.4 | 99.8 | 12.4 |
| 10.1 | Eagle Cr at Glencoe | 38 | 0 | 1,180 | 2.70 | 155 | 99.2 | 36.1 |
| Lead, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | 33.2 | .030 | 103 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | 4.4 | .008 | 95.2 | 99.8 | 3.09 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | 9.8 | .014 | 140 | 99.7 | 36.2 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | 41.7 | .011 | 56.7 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 39 | 0 | 72.0 | .013 | 117 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 0 | 7.4 | .016 | 121 | 99.7 | 38.2 |
| 10.0 | Ky R at Lock 2, Lockport | 37 | 0 | 74.7 | .012 | 77.4 | 100 | 0 |
| Lead, total recoverable | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 16 | 0 | 15.9 | .014 | 44.8 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 16 | 0 | 5.7 | .010 | 75.0 | 99.8 | 1.01 |
| 2.6 | S Fk Ky R at Booneville | 15 | 0 | 6.9 | .009 | 48.4 | 99.7 | 8.58 |
| 4.0 | Ky R at Lock 10, Winchester | 17 | 7 | 42.4 | .011 | 55.5 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 16 | 7 | 55.9 | .010 | 86.7 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 13 | 0 | 8.9 | .018 | 86.4 | 99.7 | 11.36 |
| 10.0 | Ky R at Lock 2, Lockport | 17 | 4 | 94.5 | .015 | 66.5 | 100 | 0 |

**Table 19.** Mean annual loads and yields of metals and other trace elements for selected fixed stations in the Kentucky River Basin, April 1987 through March 1990—Continued

[Transport estimates for Elkhorn Creek at Frankfort are based only on discharge records for April 1988 through March 1990; N, number of concentration observations; <, less than; KDOW, Kentucky Division of Water data for January 1986 through December 1989 obtained from STORET. This table includes only those stations having 10 or more observations.]

| | | | | Transport estimates | | Uncertainty factors, in percent | | |
|---|---|---|---|---|---|---|---|---|
| Site number | Station name | Number of observations | Number of censored observations | Mean annual load, in tons per year | Mean annual yield, in tons per square mile per year | Standard error of regression | Flow duration of greatest sampled discharge | Portion of load estimated beyond range of sampled discharge |
| Lead, total recoverable (KDOW) | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 44 | 16 | 6.6 | 0.006 | 149 | 97.4 | 42.3 |
| 2.3 | M Fk Ky R at Tallega | 44 | 17 | 2.5 | .005 | 114 | 93.9 | 35.5 |
| 2.6 | S Fk Ky R at Booneville | 44 | 0 | 2.0 | .002 | 37.1 | 98.3 | 23.9 |
| 3.0 | Ky R at Lock 14, Heidelberg | 45 | 15 | 16.6 | .006 | 135 | 96.8 | 31.2 |
| 3.1 | Red R near Hazel Green | 44 | 18 | .2 | .004 | 105 | 99.6 | 8.99 |
| 3.3 | Red R at Clay City | 43 | 21 | 1.2 | .003 | 81.5 | 100 | 0 |
| 5.0 | Ky R at Camp Nelson | 45 | 10 | 50.2 | .011 | 159 | 99.7 | 4.92 |
| 5.2 | Dix R near Danville | 45 | 19 | 2.1 | .007 | 185 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 46 | 16 | 35.2 | .007 | 173 | 99.8 | 2.97 |
| 9.3 | S Elkhorn Cr near Midway | 45 | 8 | .7 | .007 | 108 | 99.6 | 6.30 |
| 10.1 | Eagle Cr at Glencoe | 38 | 0 | 1.3 | .002 | 70.3 | 99.2 | 27.2 |
| Lithium, dissolved | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 47 | 1 | 10.6 | .010 | 37.9 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 47 | 0 | 3.6 | .006 | 31.2 | 99.8 | 1.45 |
| 2.6 | S Fk Ky R at Booneville | 46 | 0 | 5.0 | .006 | 37.6 | 99.7 | 5.69 |
| 4.0 | Ky R at Lock 10, Winchester | 48 | 18 | 24.0 | .006 | 62.2 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 47 | 16 | 32.1 | .006 | 66.7 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 44 | 7 | 4.0 | .008 | 52.8 | 99.7 | 8.86 |
| 10.0 | Ky R at Lock 2, Lockport | 48 | 16 | 36.3 | .006 | 64.6 | 100 | 0 |
| Magnesium, dissolved | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 47 | 0 | 23,500 | 21.3 | 30.8 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 47 | 0 | 5,340 | 9.93 | 18.1 | 99.8 | 1.14 |
| 2.6 | S Fk Ky R at Booneville | 46 | 0 | 6,540 | 9.06 | 15.8 | 99.7 | 3.56 |
| 4.0 | Ky R at Lock 10, Winchester | 48 | 0 | 51,800 | 13.1 | 25.7 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 47 | 0 | 62,100 | 11.5 | 20.8 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 44 | 0 | 3,630 | 7.67 | 12.2 | 99.7 | 5.23 |
| 10.0 | Ky R at Lock 2, Lockport | 49 | 0 | 64,500 | 10.4 | 19.5 | 100 | 0 |
| Magnesium, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | 6,480 | 5.88 | 86.2 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | 914 | 1.70 | 62.1 | 99.8 | 2.46 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | 1,540 | 2.14 | 117 | 99.7 | 27.8 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | 9,930 | 2.51 | 69.4 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 40 | 0 | 12,100 | 2.23 | 83.1 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 0 | 824 | 1.74 | 107 | 99.7 | 33.4 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 0 | 14,100 | 2.27 | 59.5 | 100 | 0 |

**Table 19.** Mean annual loads and yields of metals and other trace elements for selected fixed stations in the Kentucky River Basin, April 1987 through March 1990—Continued

[Transport estimates for Elkhorn Creek at Frankfort are based only on discharge records for April 1988 through March 1990; N, number of concentration observations; <, less than; KDOW, Kentucky Division of Water data for January 1986 through December 1989 obtained from STORET. This table includes only those stations having 10 or more observations.]

| | | | | Transport estimates | | Uncertainty factors, in percent | | |
|---|---|---|---|---|---|---|---|---|
| Site number | Station name | Number of observations | Number of censored observations | Mean annual load, in tons per year | Mean annual yield, in tons per square mile per year | Standard error of regression | Flow duration of greatest sampled discharge | Portion of load estimated beyond range of sampled discharge |
| Manganese, dissolved | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 47 | 0 | 94.4 | 0.086 | 68.3 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 47 | 0 | 36.0 | .067 | 48.7 | 99.8 | 1.04 |
| 2.6 | S Fk Ky R at Booneville | 46 | 0 | 86.0 | .119 | 62.6 | 99.7 | 4.47 |
| 4.0 | Ky R at Lock 10, Winchester | 48 | 0 | 450 | .114 | 141 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 47 | 4 | 196 | .036 | 301 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 44 | 0 | 8.0 | .017 | 85.9 | 99.7 | 11.6 |
| 10.0 | Ky R at Lock 2, Lockport | 48 | 3 | 165 | .027 | 173 | 100 | 0 |
| Manganese, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | 999 | .907 | 69.0 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | 168 | .313 | 48.0 | 99.8 | 1.99 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | 374 | .519 | 120 | 99.7 | 24.4 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | 1,950 | .494 | 80.3 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 40 | 0 | 2,640 | .488 | 91.5 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 0 | 414 | .875 | 125 | 99.7 | 44.9 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 0 | 2,750 | .445 | 59.0 | 100 | 0 |
| Manganese, total recoverable | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 16 | 0 | 897 | .814 | 39.1 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 16 | 0 | 189 | .352 | 46.1 | 99.8 | 1.45 |
| 2.6 | S Fk Ky R at Booneville | 15 | 0 | 419 | .581 | 58.0 | 99.7 | 11.6 |
| 4.0 | Ky R at Lock 10, Winchester | 17 | 0 | 2,020 | .511 | 47.1 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 16 | 0 | 2,870 | .530 | 46.2 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 13 | 1 | 458 | .968 | 146 | 99.7 | 27.7 |
| 10.0 | Ky R at Lock 2, Lockport | 17 | 0 | 2,866 | .464 | 43.9 | 100 | 0 |
| Manganese, total recoverable (KDOW) | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 44 | 0 | 386 | .350 | 56.8 | 97.4 | 41.9 |
| 2.3 | M Fk Ky R at Tallega | 44 | 0 | 128 | .239 | 41.7 | 93.9 | 37.6 |
| 2.6 | S Fk Ky R at Booneville | 44 | 0 | 154 | .214 | 57.5 | 98.3 | 23.9 |
| 3.0 | Ky R at Lock 14, Heidelberg | 45 | 0 | 728 | .274 | 55.2 | 96.8 | 24.1 |
| 3.1 | Red R near Hazel Green | 44 | 0 | 9.1 | .138 | 89.3 | 99.6 | 9.03 |
| 3.3 | Red R at Clay City | 43 | 0 | 75.7 | .209 | 43.2 | 100 | 0 |
| 5.0 | Ky R at Camp Nelson | 45 | 0 | 1,880 | .424 | 66.3 | 99.7 | 6.43 |
| 5.2 | Dix R near Danville | 45 | 1 | 38.5 | .121 | 124 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 46 | 0 | 1,690 | .320 | 62.1 | 99.8 | 5.07 |
| 9.3 | S Elkhorn Cr near Midway | 45 | 0 | 20.5 | .195 | 55.2 | 99.9 | 5.08 |
| 10.1 | Eagle Cr at Glencoe | 38 | 0 | 37.9 | .087 | 102 | 99.2 | 29.5 |

**Table 19.** Mean annual loads and yields of metals and other trace elements for selected fixed stations in the Kentucky River Basin, April 1987 through March 1990—Continued

[Transport estimates for Elkhorn Creek at Frankfort are based only on discharge records for April 1988 through March 1990; N, number of concentration observations; <, less than; KDOW, Kentucky Division of Water data for January 1986 through December 1989 obtained from STORET. This table includes only those stations having 10 or more observations.]

| | | | | Transport estimates | | Uncertainty factors, in percent | | |
|---|---|---|---|---|---|---|---|---|
| Site number | Station name | Number of observations | Number of censored observations | Mean annual load, in tons per year | Mean annual yield, in tons per square mile per year | Standard error of regression | Flow duration of greatest sampled discharge | Portion of load estimated beyond range of sampled discharge |
| Mercury, dissolved | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 43 | 0 | 0.2 | <0.001 | 71.4 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 44 | 0 | .1 | <.001 | 66.8 | 99.8 | 1.47 |
| 2.6 | S Fk Ky R at Booneville | 43 | 0 | .1 | <.001 | 39.4 | 99.7 | 7.19 |
| 4.0 | Ky R at Lock 10, Winchester | 45 | 15 | 1.1 | <.001 | 112 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 44 | 0 | 1.0 | <.001 | 56.8 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 44 | 18 | .1 | <.001 | 75.6 | 99.7 | 9.86 |
| 10.0 | Ky R at Lock 2, Lockport | 46 | 22 | 1.0 | <.001 | 85.5 | 100 | 0 |
| Mercury, total recoverable | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 15 | 0 | .2 | <.001 | 31.7 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 15 | 0 | .2 | <.001 | 53.4 | 99.8 | 1.23 |
| 2.6 | S Fk Ky R at Booneville | 14 | 0 | .2 | <.001 | 95.4 | 99.7 | 4.10 |
| 4.0 | Ky R at Lock 10, Winchester | 17 | 7 | 1.1 | <.001 | 50.7 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 15 | 0 | .8 | <.001 | 24.5 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 13 | 5 | .1 | <.001 | 91.4 | 99.7 | 10.8 |
| 10.0 | Ky R at Lock 2, Lockport | 16 | 0 | 1.0 | <.001 | 28.4 | 100 | 0 |
| Mercury, total recoverable (KDOW) | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 40 | 18 | .1 | <.001 | 75.3 | 96.6 | 29.7 |
| 2.3 | M Fk Ky R at Tallega | 40 | 0 | .1 | <.001 | 47.3 | 93.5 | 31.3 |
| 2.6 | S Fk Ky R at Booneville | 41 | 0 | .1 | <.001 | 50.8 | 98.3 | 19.3 |
| 3.0 | Ky R at Lock 14, Heidelberg | 41 | 0 | .5 | <.001 | 49.2 | 96.8 | 23.1 |
| 3.1 | Red R near Hazel Green | 40 | 0 | <.1 | <.001 | 49.8 | 99.4 | 11.8 |
| 3.3 | Red R at Clay City | 42 | 18 | .1 | <.001 | 71.5 | 100 | 0 |
| 5.0 | Ky R at Camp Nelson | 42 | 0 | .1 | <.001 | 49.4 | 97.4 | 20.2 |
| 5.2 | Dix R near Danville | 41 | 19 | <.1 | <.001 | 64.0 | 99.2 | 18.2 |
| 8.0 | Ky R at Lock 4, Frankfort | 42 | 0 | .1 | <.001 | 22.7 | 98.2 | 15.0 |
| 9.3 | S Elkhorn Cr near Midway | 38 | 10 | <.1 | <.001 | 75.8 | 99.4 | 14.2 |
| 10.1 | Eagle Cr at Glencoe | 34 | 12 | <.1 | <.001 | 57.1 | 98.1 | 36.5 |
| Molybdenum, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | .93 | .001 | 102 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | .12 | <.001 | 84.7 | 99.8 | 2.43 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | .19 | <.001 | 150 | 99.7 | 28.6 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | 2.0 | <.001 | 56.1 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 39 | 0 | 2.7 | <.001 | 95.1 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 0 | .14 | <.001 | 184 | 99.7 | 14.5 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 0 | 2.5 | <.001 | 62.3 | 100 | 0 |

**Table 19.** Mean annual loads and yields of metals and other trace elements for selected fixed stations in the Kentucky River Basin, April 1987 through March 1990—Continued

[Transport estimates for Elkhorn Creek at Frankfort are based only on discharge records for April 1988 through March 1990; N, number of concentration observations; <, less than; KDOW, Kentucky Division of Water data for January 1986 through December 1989 obtained from STORET. This table includes only those stations having 10 or more observations.]

| | | | | Transport estimates | | Uncertainty factors, in percent | | |
|---|---|---|---|---|---|---|---|---|
| Site number | Station name | Number of observations | Number of censored observations | Mean annual load, in tons per year | Mean annual yield, in tons per square mile per year | Standard error of regression | Flow duration of greatest sampled discharge | Portion of load estimated beyond range of sampled discharge |
| Molybdenum, total recoverable | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 16 | 6 | 5.2 | 0.005 | 192 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 16 | 5 | 6.8 | .013 | 61.1 | 99.8 | .40 |
| 2.6 | S Fk Ky R at Booneville | 15 | 7 | 2.4 | .003 | 78.0 | 99.7 | 2.75 |
| 4.0 | Ky R at Lock 10, Winchester | 17 | 7 | 11.3 | .003 | 99.9 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 16 | 4 | 19.0 | .004 | 76.5 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 13 | 0 | 3.4 | .007 | 78.3 | 99.7 | 4.12 |
| 10.0 | Ky R at Lock 2, Lockport | 17 | 4 | 18.1 | .003 | 72.0 | 100 | 0 |
| Nickel, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | 46.6 | .042 | 101 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | 5.0 | .009 | 64.6 | 99.8 | 2.58 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | 13.2 | .018 | 134 | 99.7 | 33.4 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | 74.5 | .019 | 81.6 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 40 | 0 | 66.9 | .012 | 78.2 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 0 | 5.2 | .011 | 95.6 | 99.7 | 45.6 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 0 | 81.6 | .013 | 63.6 | 100 | 0 |
| Nickel, total recoverable | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 16 | 0 | 31.1 | .028 | 66.6 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 16 | 2 | 5.2 | .010 | 79.2 | 99.8 | 2.4 |
| 2.6 | S Fk Ky R at Booneville | 15 | 2 | 10.8 | .015 | 80.6 | 99.7 | 14.5 |
| 4.0 | Ky R at Lock 10, Winchester | 17 | 2 | 94.9 | .024 | 98.7 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 16 | 3 | 80.7 | .015 | 163 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 13 | 1 | 5.4 | .012 | 73.6 | 99.7 | 13.5 |
| 10.0 | Ky R at Lock 2, Lockport | 17 | 2 | 58.0 | .009 | 76.4 | 100 | 0 |
| Silver, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 35 | 3 | .16 | <.001 | 149 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 4 | .03 | <.001 | 142 | 99.8 | 2.89 |
| 2.6 | S Fk Ky R at Booneville | 34 | 2 | .08 | <.001 | 288 | 99.7 | 13.6 |
| 4.0 | Ky R at Lock 10, Winchester | 41 | 2 | .28 | <.001 | 93.2 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 38 | 0 | .46 | <.001 | 124 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 33 | 1 | .12 | <.001 | 122 | 99.7 | 36.8 |
| 10.0 | Ky R at Lock 2, Lockport | 37 | 0 | .63 | <.001 | 103 | 100 | 0 |
| Strontium, dissolved | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 47 | 0 | 601 | .546 | 141 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 47 | 0 | 72.5 | .135 | 25.5 | 99.8 | .97 |
| 2.6 | S Fk Ky R at Booneville | 46 | 0 | 99.4 | .138 | 23.7 | 99.7 | 2.75 |
| 4.0 | Ky R at Lock 10, Winchester | 48 | 0 | 1,100 | .278 | 42.5 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 47 | 0 | 1,230 | .228 | 35.8 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 44 | 0 | 75.6 | .160 | 14.1 | 99.7 | 5.13 |
| 10.0 | Ky R at Lock 2, Lockport | 48 | 0 | 1,220 | .197 | 27.0 | 100 | 0 |

**Table 19.** Mean annual loads and yields of metals and other trace elements for selected fixed stations in the Kentucky River Basin, April 1987 through March 1990—Continued

[Transport estimates for Elkhorn Creek at Frankfort are based only on discharge records for April 1988 through March 1990; N, number of concentration observations; <, less than; KDOW, Kentucky Division of Water data for January 1986 through December 1989 obtained from STORET. This table includes only those stations having 10 or more observations.]

| | | | | Transport estimates | | Uncertainty factors, in percent | | |
|---|---|---|---|---|---|---|---|---|
| Site number | Station name | Number of observations | Number of censored observations | Mean annual load, in tons per year | Mean annual yield, in tons per square mile per year | Standard error of regression | Flow duration of greatest sampled discharge | Portion of load estimated beyond range of sampled discharge |
| Thallium, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | 1.1 | 0.001 | 116 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | .14 | <.001 | 90.6 | 99.8 | 2.64 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | .25 | <.001 | 160 | 99.7 | 38.1 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | 1.1 | <.001 | 59.7 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 39 | 0 | 1.5 | <.001 | 104 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 1 | .11 | <.001 | 198 | 99.7 | 33.4 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 0 | 1.6 | <.001 | 67.7 | 100 | 0 |
| Titanium, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | 5,930 | 5.38 | 113 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | 620 | 1.16 | 74.5 | 99.8 | 2.70 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | 1,340 | 1.85 | 147 | 99.7 | 34.1 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | 6,280 | 1.59 | 72.8 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 40 | 0 | 7,240 | 1.34 | 74.5 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 33 | 0 | 796 | 1.68 | 99.8 | 99.7 | 49.9 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 0 | 9,240 | 1.49 | 66.2 | 100 | 0 |
| Vanadium, snspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | 142 | .129 | 111 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | 15.4 | .029 | 72.8 | 99.8 | 2.63 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | 32.5 | .045 | 158 | 99.7 | 33.5 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | 157 | .040 | 66.6 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 40 | 0 | 176 | .032 | 79.7 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 1 | 20.1 | .042 | 116 | 99.7 | 52.3 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 0 | 215 | .035 | 69.2 | 100 | 0 |
| Zinc, dissolved | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 47 | 10 | 15.3 | .014 | 154 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 47 | 10 | 6.5 | .012 | 128 | 99.8 | 1.02 |
| 2.6 | S Fk Ky R at Booneville | 46 | 7 | 9.3 | .013 | 109 | 99.7 | 5.91 |
| 4.0 | Ky R at Lock 10, Winchester | 48 | 10 | 45.6 | .012 | 110 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 47 | 9 | 47.8 | .009 | 99.5 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 44 | 10 | 5.1 | .011 | 114 | 99.7 | 4.33 |
| 10.0 | Ky R at Lock 2, Lockport | 48 | 12 | 59.1 | .010 | 120 | 100 | 0 |
| Zinc, suspended-sediment fraction | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 36 | 0 | 149 | .135 | 99.2 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 39 | 0 | 17.2 | .032 | 69.9 | 99.8 | 2.48 |
| 2.6 | S Fk Ky R at Booneville | 34 | 0 | 43.1 | .060 | 146 | 99.7 | 35.1 |
| 4.0 | Ky R at Lock 10, Winchester | 42 | 0 | 193 | .049 | 66.5 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 40 | 0 | 216 | .040 | 78.1 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 34 | 0 | 21.3 | .045 | 86.9 | 99.7 | 40.7 |
| 10.0 | Ky R at Lock 2, Lockport | 38 | 0 | 259 | .042 | 66.2 | 100 | 0 |

**Table 19.** Mean annual loads and yields of metals and other trace elements for selected fixed stations in the Kentucky River Basin, April 1987 through March 1990—Continued

[Transport estimates for Elkhorn Creek at Frankfort are based only on discharge records for April 1988 through March 1990; N, number of concentration observations; <, less than; KDOW, Kentucky Division of Water data for January 1986 through December 1989 obtained from STORET. This table includes only those stations having 10 or more observations.]

| | | | | Transport estimates | | Uncertainty factors, in percent | | |
|---|---|---|---|---|---|---|---|---|
| Site number | Station name | Number of observations | Number of censored observations | Mean annual load, in tons per year | Mean annual yield, in tons per square mile per year | Standard error of regression | Flow duration of greatest sampled discharge | Portion of load estimated beyond range of sampled discharge |
| Zinc, total recoverable | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 16 | 1 | 141 | 0.128 | 77.7 | 100 | 0 |
| 2.3 | M Fk Ky R at Tallega | 16 | 5 | 29.4 | .055 | 104 | 99.8 | 2.29 |
| 2.6 | S Fk Ky R at Booneville | 15 | 2 | 40.8 | .057 | 70.0 | 99.7 | 10.36 |
| 4.0 | Ky R at Lock 10, Winchester | 17 | 2 | 226 | .057 | 46.8 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 15 | 5 | 212 | .039 | 33.0 | 100 | 0 |
| 9.4 | Elkhorn Cr at Frankfort | 13 | 2 | 26.4 | .056 | 91.5 | 99.7 | 15.21 |
| 10.0 | Ky R at Lock 2, Lockport | 17 | 2 | 267 | .043 | 34.5 | 100 | 0 |
| Zinc, total recoverable (KDOW) | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 42 | 1 | 189 | .172 | 147 | 97.4 | 57.9 |
| 2.3 | M Fk Ky R at Tallega | 42 | 0 | 24.3 | .045 | 107 | 93.9 | 32.6 |
| 2.6 | S Fk Ky R at Booneville | 42 | 0 | 42.2 | .058 | 134 | 98.3 | 28.0 |
| 3.0 | Ky R at Lock 14, Heidelberg | 43 | 0 | 175 | .066 | 93.4 | 96.8 | 34.4 |
| 3.1 | Red R near Hazel Green | 43 | 1 | 3.23 | .049 | 156 | 99.6 | 9.01 |
| 3.3 | Red R at Clay City | 41 | 1 | 20.3 | .056 | 124 | 100 | 0 |
| 5.0 | Ky R at Camp Nelson | 43 | 0 | 815 | .180 | 162 | 99.7 | 5.15 |
| 5.2 | Dix R near Danville | 43 | 0 | 27.0 | .085 | 138 | 100 | 0 |
| 8.0 | Ky R at Lock 4, Frankfort | 44 | 0 | 559 | .106 | 129 | 99.8 | 4.60 |
| 9.3 | S Elkhorn Cr near Midway | 43 | 0 | 7.98 | .076 | 76.4 | 99.9 | 3.27 |
| 10.1 | Eagle Cr at Glencoe | 38 | 1 | 15.7 | .036 | 150 | 99.2 | 28.4 |

(page 171 follows)

Table 20. Trends for concentrations of metals and other trace elements for selected fixed stations in the Kentucky River Basin

[N, number of observations; P, probability; NA, not applicable; **, censored values affect trend analysis; *, censored values used in analysis; KDOW, Kentucky Division of Water data obtained from STORET; <, less than; down, downward trend. Trend-line slopes not significant at 0.2 probability level are not reported, and those significant at the 0.1 probability level are underlined. Trend-line slopes affected by censored data are reported only as upward or downward.]

| | | | | Results of seasonal Kendall tests for time trend[1] | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Trends, unadjusted for flow | | | Flow-adjusted trends[2] | | |
| | | | | | Trend-line slope | | | Trend-line slope | |
| Site number | Station name | Period of record (water yaars) | N | P level | Micrograms per liter per year | Percent of median concentration, micrograms per liter per year | P level | Micrograms per liter per year | Parcent of median concentration, micrograms per liter per year |
| Aluminum, total recoverable | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1984-89 | 43 | NA | NA | NA | 0.268 | NA | NA |
| 2.3 | M Fk Ky R at Tallega | 1984-89 | **43 | 0.097 | 35.7 | 155 | NA | NA | NA |
| 2.6 | S Fk Ky R at Booneville | 1984-89 | **41 | .012 | 11.7 | 61.6 | NA | NA | NA |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | *16 | .743 | NA | NA | NA | NA | NA |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-89 | **16 | .166 | 210 | 46.7 | NA | NA | NA |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | 13 | NA | NA | NA | .427 | NA | NA |
| 10.0 | Ky R at Lock 2, Lockport | 1987-89 | 16 | NA | NA | NA | .248 | NA | NA |
| Aluminum, total recoverable (KDOW) | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1984-89 | 64 | .022 | 90.8 | 47.4 | .082 | 98.4 | 11.5 |
| 3.3 | Red R at Clay City | 1986-89 | 43 | .628 | NA | NA | .628 | NA | NA |
| 5.2 | Dix R near Danville | 1986-89 | 45 | .164 | 76.0 | 50.0 | .295 | NA | NA |
| 9.3 | S Elkhorn Cr Near Midway | 1984-89 | 65 | .009 | 83.7 | 53.5 | .031 | 65.3 | 36.0 |
| 10.1 | Eagle Cr at Glencoe | 1986-89 | 38 | 1.000 | NA | NA | .613 | NA | NA |
| Barium, dissolved | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | 47 | .230 | NA | NA | .267 | NA | NA |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | 47 | .149 | <.01 | -11 | .387 | NA | NA |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | 46 | .164 | -.02 | -38 | .411 | NA | NA |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 48 | .108 | -.01 | -33 | .794 | NA | NA |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 47 | .086 | -.01 | -25 | .450 | NA | NA |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | 1.00 | NA | NA | .540 | NA | NA |
| 10.0 | Ky R at Lock 2, Lockport | 1977-90 | *83 | .975 | NA | NA | NA | NA | NA |
| Boron, dissolved | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1987-90 | **44 | .130 | NA | NA | NA | NA | NA |
| 2.3 | M Fk Ky R at Tallega | 1987-90 | **44 | .113 | <.00 | -42 | NA | NA | NA |
| 2.6 | S Fk Ky R at Booneville | 1987-90 | **43 | .062 | down | down | NA | NA | NA |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | **43 | .146 | <.00 | -20 | NA | NA | NA |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | **42 | .076 | -.01 | -40 | NA | NA | NA |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | *41 | .235 | NA | NA | NA | NA | NA |
| 10.0 | Ky R at Lock 2, Lockport | 1987-90 | **42 | .066 | -.01 | -40 | NA | NA | NA |

Table 20. Trends for concentrations of metals and other trace elements for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; P, probability; NA, not applicable; **, censored values affect trend analysis; *, censored values used in analysis; KDOW, Kentucky Division of Water data obtained from STORET; <, less than; down, downward trend. Trend-line slopes not significant at 0.2 probability level are not reported, and those significant at the 0.1 probability level are underlined. Trend-line slopes affected by censored data are reported only as upward or downward.]

| | | | | Results of seasonal Kendall tests for time trend[1] | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Trends, unadjusted for flow | | | Flow-adjusted trends[2] | | |
| | | | | | Trend-line slope | | | Trend-line slope | |
| Site number | Station name | Period of record (water years) | N | P level | Micrograms per liter per year | Percent of median concentration, micrograms per liter per year | P level | Micrograms per liter per year | Percent of median concentration, micrograms per liter per year |
| Copper, dissolved | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1982-90 | **60 | 0.094 | <0.00 | NA | NA | NA | NA |
| 2.3 | M Fk Ky R at Tallega | 1982-90 | **60 | .094 | <.00 | NA | NA | NA | NA |
| 2.6 | S Fk Ky R at Booneville | 1982-90 | **57 | .127 | <.00 | NA | NA | NA | NA |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | *48 | 1.00 | NA | NA | NA | NA | NA |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | *47 | 1.00 | NA | NA | NA | NA | NA |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | *46 | 1.00 | NA | NA | NA | NA | NA |
| 10.0 | Ky R at Lock 2, Lockport | 1975-90 | **90 | .102 | <.00 | NA | NA | NA | NA |
| Iron, dissolved | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1979-90 | **80 | .144 | <10 | 3.7 | NA | NA | NA |
| 2.3 | M Fk Ky R at Tallega | 1979-90 | *78 | .616 | NA | NA | NA | NA | NA |
| 2.6 | S Fk Ky R at Booneville | 1979-90 | **74 | .076 | <10 | 8.0 | NA | NA | NA |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | *48 | .230 | NA | NA | NA | NA | NA |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | **47 | .119 | 10 | 83 | NA | NA | NA |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | *44 | .540 | NA | NA | NA | NA | NA |
| 10.0 | Ky R at Lock 2, Lockport | 1975-90 | *92 | .771 | NA | NA | NA | NA | NA |
| Iron, total recoverable (KDOW) | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1979-89 | 91 | .069 | 75 | 23 | 0.004 | 120 | 30 |
| 2.3 | M Fk Ky R at Tallega | 1979-89 | 89 | .071 | 47 | 17 | .009 | 69 | 81 |
| 2.6 | S Fk Ky R at Booneville | 1979-89 | 85 | .031 | 40 | 25 | .006 | 37 | 26 |
| 3.0 | Ky R at Lock 14, Heidelberg | 1980-89 | 105 | .026 | 52 | 34 | .012 | 96 | 170 |
| 3.1 | Red R near Hazel Green | 1979-89 | 118 | .029 | 52 | 36 | .015 | 93 | 86 |
| 3.3 | Red R at Clay City | 1986-89 | 43 | 1.000 | NA | NA | 1.000 | NA | NA |
| 5.0 | Ky R at Camp Nelson | 1980-89 | 103 | .009 | 48 | 33 | .028 | 97 | 55 |
| 5.2 | Dix R near Danville | 1980-89 | *45 | .153 | 80 | 38 | NA | NA | NA |
| 8.0 | Ky R at Lock 4, at Frankfort | 1980-89 | 105 | .013 | 35 | 30 | .041 | 74 | 170 |
| 9.3 | S Elkhorn Cr Near Midway | 1982-89 | 79 | .045 | 68 | 31 | .060 | 54 | 330 |
| 10.1 | Eagle Cr et Glencoe | 1986-89 | 38 | .810 | NA | NA | .477 | NA | NA |
| Magnesium, dissolved | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1980-90 | 69 | .520 | NA | NA | .062 | 1,300 | 36 |
| 2.3 | M Fk Ky R at Tallega | 1980-90 | 65 | .568 | NA | NA | .265 | NA | NA |
| 2.6 | S Fk Ky R at Booneville | 1980-90 | 67 | .581 | NA | NA | .247 | NA | NA |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | 48 | .321 | NA | NA | .358 | NA | NA |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-90 | 47 | .221 | NA | NA | .810 | NA | NA |
| 9.4 | Elkhorn Cr at Frankfort | 1987-90 | 44 | .451 | NA | NA | .617 | NA | NA |
| 10.0 | Ky R at Lock 2, Lockport | 1975-90 | 150 | .001 | 240 | 10 | .002 | 220 | 31 |

Table 20. Trends for concentrations of metals and other trace elements for selected fixed stations in the Kentucky River Basin--Continued

[N, number of observations; P, probability; NA, not applicable; **, censored values affect trend analysis; *, censored values used in analysis; KDOW, Kentucky Division of Water data obtained from STORET; <, less than; down, downward trend. Trend-line slopes not significant at 0.2 probability level are not reported, and those significant at the 0.1 probability level are underlined. Trend-line slopes affected by censored data are reported only as upward or downward.]

| | | | | Results of seasonal Kendall tests for time trend[1] | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Trends, unadjusted for flow | | | Flow-adjusted trends[2] | | |
| | | | | | Trend-line slope | | | Trend-line slope | |
| Site number | Station name | Period of record (water years) | N | P level | Micrograms per liter per year | Percent of median concentration, micrograms per liter per year | P level | Micrograms per liter per year | Percent of median concentration, micrograms per liter per year |
| Manganese, total recoverable (KDOW) | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1979-89 | 91 | 0.043 | 13 | 60 | 0.005 | 14 | 25 |
| 2.3 | M Fk Ky R at Tallega | 1979-89 | 88 | .017 | 11 | 52 | .014 | 11 | 28 |
| 2.6 | S Fk Ky R at Booneville | 1979-89 | 85 | .004 | 10 | 60 | .010 | 10 | 19 |
| 3.0 | Ky R at Lock 14, Heidelberg | 1980-89 | 103 | .016 | 18 | 87 | NA | NA | NA |
| 3.1 | Red R near Hazel Green | 1979-89 | 117 | .014 | 4.6 | 21 | .021 | 5.5 | 13 |
| 3.3 | Red R at Clay City | 1986-89 | 43 | .613 | NA | NA | .350 | NA | NA |
| 5.0 | Ky R at Camp Nelson | 1980-89 | 101 | .017 | 10 | 74 | .047 | 11 | 93 |
| 8.0 | Ky R at Lock 4, at Frankfort | 1980-89 | 104 | .026 | 8.3 | 57 | .056 | 9.0 | 170 |
| 9.3 | S Elkhorn Cr Near Midway | 1982-89 | 80 | .112 | 17 | 33 | .091 | 15 | 22 |
| 10.1 | Eagle Cr at Glencoe | 1986-89 | 38 | .725 | NA | NA | .371 | NA | NA |
| Zinc, total recoverable | | | | | | | | | |
| 2.0 | N Fk Ky R at Jackson | 1980-89 | *50 | .713 | NA | NA | NA | NA | NA |
| 2.3 | M Fk Ky R at Tallega | 1980-89 | *49 | 1.00 | NA | NA | NA | NA | NA |
| 2.6 | S Fk Ky R at Booneville | 1980-89 | *48 | .792 | NA | NA | NA | NA | NA |
| 4.0 | Ky R at Lock 10, Winchester | 1987-90 | *17 | .271 | NA | NA | NA | NA | NA |
| 8.0 | Ky R at Lock 4, Frankfort | 1987-89 | **15 | .077 | 2 | 63 | NA | NA | NA |
| 9.4 | Elkhorn Cr at Frankfort | 1987-89 | *13 | .427 | NA | NA | NA | NA | NA |
| 10.0 | Ky R at Lock 2, Lockport | 1975-89 | *44 | .430 | NA | NA | NA | NA | NA |
| Zinc, total recoverable (KDOW) | | | | | | | | | |
| 5.0 | Ky R at Camp Nelson | 1980-89 | 101 | .033 | 2.5 | 80 | .030 | 4.2 | 22 |
| 5.2 | Dix R near Danville | 1986-89 | 43 | .589 | NA | NA | .681 | NA | NA |
| 8.0 | Ky R at Lock 4, at Frankfort | 1980-89 | 103 | .020 | 2.2 | 54 | .046 | 3.8 | 52 |
| 9.3 | S Elkhorn Cr Near Midway | 1982-89 | 78 | .062 | 6.7 | 39 | NA | NA | NA |

[1] The null hypothesis for the seasonal Kendall test is that no trend in the data exists (the probability distribution of a selected water-quality property or constituent for each of the seasons is unchanged over the period of record tested). The possible outcomes of the test were (a) the null hypothesis was rejected with some degree of confidence (probability (p) level = 0.2) and it was declared that a trend existed in the data or (b) the null hypothesis was not rejected and it was declared that a trend could not be discerned.

[2] Flow-adjusted trends were not computed when (a) the relation between the water-quality property or constituent and discharge was not statistically significant (p level greater than 0.2) or (b) discharge data were unavailable.

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Table 21. Locations of streambed-sediment sites in the Kentucky River Basin, 1987, and principal land uses corresponding to each site

[Degree, minute, and second symbols omitted from latitude and longitude; --, unnumbered; UT, unidentified tributary stream]

| Site number | Stream name | Latitude | Longitude | Station number | County | Land use | Physiographic region[1] |
|---|---|---|---|---|---|---|---|
| 1-5 | Ten Mile Creek | 384533 | 843834 | -- | Grant | Forested | Outer Bluegrass |
| 1-6 | UT to Ten Mile Creek | 384627 | 844138 | -- | Gallatin | Forested | Outer Bluegrass |
| 1-7 | UT to Eagle Creek | 384316 | 844756 | -- | Gallatin | Forested | Outer Bluegrass |
| 1-18 | UT to Kentucky River | 383943 | 850927 | -- | Carroll | Agriculture | Outer Bluegrass |
| 1-19 | UT to Whites Run | 384022 | 850241 | -- | Carroll | Agriculture | Outer Bluegrass |
| 1-20 | Lick Creek | 384128 | 845554 | -- | Carroll | Forested | Outer Bluegrass |
| 1-21 | Lost Branch | 384218 | 845353 | -- | Gallatin | Forested | Outer Bluegrass |
| 1-22 | Slab Lick Branch | 383940 | 844715 | -- | Owen | Forested | Outer Bluegrass |
| 1-23 | UT to Clarks Creek | 384008 | 844138 | -- | Grant | Forested | Outer Bluegrass |
| 1-24 | Clay Lick Creek | 384023 | 843553 | -- | Grant | Forested | Outer Bluegrass |
| 1-25 | Williams Branch | 383857 | 843506 | -- | Grant | Agriculture | Outer Bluegrass |
| 1-26 | Grassy Run | 383514 | 843506 | -- | Grant | Forested | Outer Bluegrass |
| 1-27 | UT to Rattlesnake Creek | 383646 | 843823 | -- | Grant | Agriculture | Outer Bluegrass |
| 1-28 | UT to Rattlesnake Creek | 383813 | 844217 | -- | Grant | Forested | Outer Bluegrass |
| 1-30 | UT to Big Twin Creek | 383549 | 845359 | -- | Owen | Agriculture | Outer Bluegrass |
| 1-31 | UT to Eagle Creek | 383819 | 845954 | -- | Carroll | Forested | Outer Bluegrass |
| 1-32 | Buck Run | 383553 | 850122 | -- | Owen | Forested | Outer Bluegrass |
| 1-33 | Gigal Branch | 383537 | 850919 | -- | Carroll | Forested | Outer Bluegrass |
| 1-40 | Long Branch | 383406 | 850829 | -- | Henry | Agriculture | Outer Bluegrass |
| 1-41 | UT to Kentucky River | 383418 | 850433 | -- | Henry | Agriculture | Outer Bluegrass |
| 1-42 | UT to Big Twin Creek | 383340 | 845818 | -- | Owen | Forested | Outer Bluegrass |
| 1-43 | UT to Big Twin Creek | 383420 | 845459 | -- | Owen | Forested | Outer Bluegrass |
| 1-45 | UT to Eagle Creek | 383409 | 844221 | -- | Owen | Forested | Outer Bluegrass |
| 1-46 | UT to Grassy Run | 383437 | 843843 | -- | Grant | Agriculture | Outer Bluegrass |
| 1-47 | UT to Three Forks Creek | 383053 | 843452 | -- | Grant | Agriculture | Outer Bluegrass |
| 1-48 | North Rays Fork | 382834 | 843404 | -- | Scott | Agriculture | Outer Bluegrass |
| 1-49 | Paynes Run | 382757 | 843804 | -- | Owen | Agriculture | Outer Bluegrass |
| 1-50 | Rush Run | 382837 | 844205 | -- | Owen | Forested | Outer Bluegrass |
| 1-51 | UT to Greenup Creek | 382813 | 845004 | -- | Owen | Forested | Outer Bluegrass |
| 1-52 | UT to Severn Creek | 382745 | 845139 | -- | Owen | Forested | Outer Bluegrass |
| 1-53 | UT to Kentucky River | 382828 | 845836 | -- | Henry | Forested | Outer Bluegrass |
| 1-54 | UT to Five Mile Creek | 382756 | 850344 | -- | Henry | Agriculture | Outer Bluegrass |
| 1-55 | UT to Town Creek | 382743 | 850810 | -- | Henry | Agriculture | Outer Bluegrass |
| 1-61 | UT to Town Creek | 382530 | 851015 | -- | Henry | Agriculture | Outer Bluegrass |
| 1-62 | Rush Creek | 382531 | 850322 | -- | Henry | Agriculture | Outer Bluegrass |
| 1-63 | Pot Ripple Creek | 382419 | 845739 | -- | Henry | Agriculture | Outer Bluegrass |
| 1-64 | UT to Cedar Creek | 382601 | 845225 | -- | Owen | Forested | Outer Bluegrass |
| 1-65 | Sawdridge Creek | 382601 | 844821 | -- | Owen | Forested | Outer Bluegrass |
| 1-66 | UT to Caney Creek | 382543 | 844119 | -- | Owen | Agriculture | Outer Bluegrass |
| 1-67 | Little Indian Branch | 382339 | 843808 | -- | Scott | Agriculture | Outer Bluegrass |
| 1-68 | Mile Run | 382507 | 843416 | -- | Scott | Agriculture | Outer Bluegrass |
| 1-70 | UT to East Fork Eagle Creek | 381842 | 842705 | -- | Scott | Forested | Outer Bluegrass |
| 1-71 | Rogers Gap Creek | 381900 | 843138 | -- | Scott | Forested | Outer Bluegrass |
| 1-72 | UT to Lytles Fork | 381947 | 843756 | -- | Scott | Agriculture | Outer Bluegrass |
| 1-73 | UT to Minors Creek | 382035 | 844243 | -- | Scott | Forested | Outer Bluegrass |
| 1-74 | Cedar Creek | 381905 | 844715 | -- | Owen | Agriculture | Outer Bluegrass |
| 1-75 | UT to Kentucky River | 382209 | 845324 | -- | Henry | Forested | Outer Bluegrass |

Table 21. Locations of streambed-sediment sites in the Kentucky River Basin, 1987, and principal land uses corresponding to each site--Continued

[Degree, minute, and second symbols omitted from latitude and longitude; --, unnumbered; UT, unidentified tributary stream]

| Site number | Stream name | Latitude | Longitude | Station number | County | Land use | Physiographic region[1] |
|---|---|---|---|---|---|---|---|
| 1-76 | Willow Branch | 381918 | 845658 | -- | Franklin | Agriculture | Outer Bluegrass |
| 1-77 | Sweet Home Branch | 381939 | 850330 | -- | Shelby | Agriculture | Outer Bluegrass |
| 1-78 | UT to Drennon Creek | 382140 | 850840 | -- | Henry | Agriculture | Outer Bluegrass |
| 1-80 | Six Mile Creek | 381714 | 850451 | -- | Shelby | Agriculture | Outer Bluegrass |
| 1-81 | Goose Creek | 381721 | 845746 | -- | Franklin | Agriculture | Outer Bluegrass |
| 1-82 | Davis Branch | 381601 | 845512 | -- | Franklin | Agriculture | Outer Bluegrass |
| 1-83 | UT to Elkhorn Creek | 381648 | 844953 | -- | Franklin | Forested | Inner Bluegrass |
| 1-84 | UT to Cedar Creek | 381737 | 844324 | -- | Scott | Agriculture | Inner Bluegrass |
| 1-85 | UT to McConnell Run | 381648 | 843922 | -- | Scott | Agriculture | Inner Bluegrass |
| 1-86 | Lytles Fork | 381822 | 843539 | -- | Scott | Agricultura | Outer Bluegrass |
| 1-87 | UT to Miller Run | 381611 | 842933 | -- | Scott | Agriculture | Inner Bluegrass |
| 1-89 | UT to Goose Creek | 381150 | 842335 | -- | Fayette | Agriculture | Inner Bluegrass |
| 1-90 | UT to Boyd Run | 381312 | 842748 | -- | Scott | Agriculture | Inner Bluegrass |
| 1-92 | UT to North Elkhorn Creek | 381223 | 843819 | -- | Scott | Agriculture | Inner Bluegrass |
| 1-93 | UT to Elkhorn Creek | 381403 | 844158 | -- | Scott | Forested | Inner Bluegrass |
| 1-94 | UT to North Elkhorn Creek | 381341 | 844734 | -- | Franklin | Forested | Inner Bluegrass |
| 1-96 | Dutch Fork | 381225 | 850112 | -- | Shelby | Agriculture | Outar Bluegrass |
| 1-98 | Benson Creek | 380858 | 850212 | -- | Shelby | Agriculture | Outer Bluegrass |
| 1-99 | Benson Creek | 380850 | 850128 | -- | Shelby | Agriculture | Outar Bluegrass |
| 1-100 | South Benson Creek | 380656 | 845446 | -- | Franklin | Agriculture | Outer Bluegrass |
| 1-101 | Glenns Creek | 380758 | 844811 | -- | Woodford | Agriculture | Inner Bluegrass |
| 1-102 | UT to South Elkhorn Creek | 380940 | 844234 | -- | Woodford | Agriculture | Inner Bluegrass |
| 1-103 | UT to Lee Branch | 380840 | 844045 | -- | Woodford | Agriculture | Inner Bluegrass |
| 1-104 | UT to Cane Run | 380929 | 843427 | -- | Scott | Agriculture | Inner Bluegrass |
| 1-105 | UT to North Elkhorn Creek | 380929 | 842805 | -- | Fayette | Agriculture | Inner Bluegrass |
| 1-106 | UT to Elkhorn Creek | 380802 | 842356 | -- | Fayette | Agriculture | Inner Bluegrass |
| 1-107 | UT to North Elkhorn Creek | 380345 | 841959 | -- | Fayette | Agriculture | Inner Bluegrass |
| 1-108 | UT to Elkhorn Creek | 380506 | 842403 | -- | Fayette | Agriculture | Inner Bluegrass |
| 1-109 | UT to North Elkhorn Creek | 380258 | 842627 | -- | Fayette | Urban | Inner Bluegrass |
| 1-110 | Cane Run | 380508 | 843155 | -- | Fayette | Urban | Inner Bluegrass |
| 1-111 | Steeles Run | 380609 | 843827 | -- | Woodford | Agriculture | Inner Bluegrass |
| 1-112 | Glenns Creek | 380343 | 844621 | -- | Woodford | Agricultura | Inner Bluegrass |
| 1-113 | UT to Kentucky River | 380428 | 844831 | -- | Woodford | Agricultura | Inner Bluegrass |
| 1-114 | Little Benson Creek | 380558 | 845509 | -- | Franklin | Agriculture | Outer Bluegrass |
| 1-115 | Benson Creek | 380439 | 850051 | -- | Anderson | Agriculture | Outer Bluegrass |
| 1-116 | Benson Creek | 380503 | 850229 | -- | Anderson | Agriculture | Outer Bluegrass |
| 1-118 | Cedar Brook | 380205 | 845151 | -- | Anderson | Forested | Inner Bluegrass |
| 1-119 | UT to Griers Creek | 380108 | 844852 | -- | Woodford | Forested | Inner Bluegrass |
| 1-120 | Griers Creek | 380117 | 844552 | -- | Woodford | Forested | Inner Bluegrass |
| 1-121 | Shannon Run | 380131 | 844003 | -- | Woodford | Agriculture | Inner Bluegrass |
| 1-122 | UT to Cave Creek | 380138 | 843611 | -- | Fayette | Agriculture | Inner Bluegrass |
| 1-123 | UT to East Hickman Creek | 375848 | 842730 | -- | Fayette | Urban | Inner Bluegrass |
| 1-124 | UT to North Elkhorn Creek | 380122 | 842448 | -- | Fayette | Urban | Inner Bluegrass |
| 1-125 | UT to Baughman Fork | 380026 | 841819 | -- | Clark | Agriculture | Inner Bluegrass |
| 1-127 | UT to Four Mile Creek | 375814 | 840801 | -- | Clark | Agriculture | Outer Bluegrass |
| 1-129 | North Branch Lulbegrud Creek | 375850 | 835914 | -- | Montgomery | Agriculture | Knobs |
| 1-130 | Lulbegrud Creek | 375821 | 835607 | -- | Montgomery | Agriculture | Knobs |

Table 21. Locations of streambed-sediment sites in the Kentucky River Basin, 1987, and principal land uses corresponding to each site--Continued

[Degree, minute, and second symbols omitted from latitude and longitude; --, unnumbered; UT, unidentified tributary stream]

| Site number | Stream name | Latitude | Longitude | Station number | County | Land use | Physiographic region[1] |
|---|---|---|---|---|---|---|---|
| 1-131 | Little Blackwater Creek | 375355 | 833056 | -- | Menifee | Forested | Knobs |
| 1-132 | Landsaw Branch | 375359 | 833305 | -- | Menifee | Forested | Knobs |
| 1-133 | Indian Creek | 375534 | 834015 | -- | Menifee | Forested | Knobs |
| 1-134 | Middle Fork Cane Creek | 375349 | 834606 | -- | Powell | Forested | Knobs |
| 1-135 | Lower Cane Creek | 375339 | 834801 | -- | Powell | Forested | Knobs |
| 1-136 | Brush Creek | 375436 | 835653 | -- | Powell | Forested | Knobs |
| 1-137 | Brush Creek | 375424 | 835802 | -- | Powell | Agriculture | Knobs |
| 1-138 | UT to Upper Howard Creek | 375428 | 840247 | -- | Clark | Agriculture | Knobs |
| 1-139 | Four Mile Creek | 375609 | 840924 | -- | Clark | Urban | Outer Bluegrass |
| 1-140 | Harris Branch | 375438 | 841214 | -- | Clark | Agriculture | Outer Bluegrass |
| 1-141 | Jouett Creek | 375531 | 841742 | -- | Clark | Forested | Outer Bluegrass |
| 1-142 | Shelby Branch | 375542 | 842556 | -- | Fayette | Agriculture | Inner Bluegrass |
| 1-143 | UT to East Hickman Creek | 375644 | 842833 | -- | Fayette | Forested | Inner Bluegrass |
| 1-144 | South Elkhorn Creek | 375737 | 843323 | -- | Jessamine | Urban | Inner Bluegrass |
| 1-145 | East Fork Clear Creek | 375658 | 843836 | -- | Jessamine | Agriculture | Inner Bluegrass |
| 1-146 | UT to Clear Creek | 375605 | 844605 | -- | Woodford | Forested | Inner Bluegrass |
| 1-147 | Gilbert Creek | 375825 | 844930 | -- | Anderson | Forested | Inner Bluegrass |
| 1-150 | UT to Clear Creek | 375348 | 844335 | -- | Woodford | Forested | Inner Bluegrass |
| 1-151 | UT to East Fork Clear Creek | 375336 | 844108 | -- | Jessamine | Agriculture | Inner Bluegrass |
| 1-152 | UT to Hickman Creek | 375328 | 843148 | -- | Jessamine | Agriculture | Inner Bluegrass |
| 1-153 | UT to Kentucky River | 375111 | 842647 | -- | Jessamine | Forested | Outer Bluegrass |
| 1-154 | Marble Creek | 375345 | 842552 | -- | Fayette | Agriculture | Inner Bluegrass |
| 1-155 | UT to Kentucky River | 375312 | 841615 | -- | Madison | Forested | Outer Bluegrass |
| 1-156 | UT to Kentucky River | 375309 | 841348 | -- | Clark | Forested | Outer Bluegrass |
| 1-157 | Muddy Creek | 375252 | 840954 | -- | Clark | Forested | Outer Bluegrass |
| 1-158 | UT to Red River | 375103 | 840153 | -- | Estill | Agriculture | Knobs |
| 1-159 | Snow Creek | 375157 | 835813 | -- | Powell | Forested | Knobs |
| 1-160 | UT to Red River | 374957 | 835511 | -- | Powell | Forested | Knobs |
| 1-161 | UT to Red River | 375106 | 834825 | -- | Powell | Forested | Knobs |
| 1-162 | Dunwoody Branch | 375144 | 834431 | -- | Powell | Forested | Knobs |
| 1-163 | Edward Branch | 375034 | 833943 | -- | Menifee | Forested | Knobs |
| 1-164 | Cane Branch | 375138 | 833222 | -- | Menifee | Forested | Knobs |
| 1-165 | Pine Branch | 375017 | 833132 | -- | Menifee | Agriculture | Knobs |
| 1-166 | Wilson Branch | 374621 | 832104 | -- | Wolfe | Oil and gas | Eastern Coal Field |
| 1-167 | UT to Red River | 374835 | 832550 | -- | Wolfe | Agriculture | Knobs |
| 1-168 | Big Branch | 374819 | 832857 | -- | Wolfe | Forested | Knobs |
| 1-169 | Bearpen Branch | 374620 | 833357 | -- | Wolfe | Forested | Knobs |
| 1-170 | Grays Branch | 374908 | 834003 | -- | Powell | Forested | Knobs |
| 1-171 | Sand Lick Fork | 374552 | 834313 | -- | Powell | Oil and gas | Knobs |
| 1-172 | UT to Hardwick Creek | 374634 | 835147 | -- | Powell | Forested | Knobs |
| 1-173 | Ballard Branch | 374738 | 835359 | -- | Powell | Forested | Knobs |
| 1-174 | UT to Twin Creek | 374746 | 840034 | -- | Estill | Agriculture | Knobs |
| 1-175 | UT to Wodward Creek | 374904 | 840142 | -- | Estill | Forested | Knobs |
| 1-176 | UT to Muddy Creek | 374703 | 840847 | -- | Madison | Agriculture | Knobs |
| 1-177 | UT to Otter Creek | 374711 | 841309 | -- | Madison | Agriculture | Knobs |
| 1-178 | UT to Hicks Branch | 374813 | 841814 | -- | Madison | Agriculture | Outer Bluegrass |
| 1-179 | Jackson Branch | 374650 | 842520 | -- | Madison | Agriculture | Outer Bluegrass |

Teble 21. Locations of streambed-sediment sites in the Kentucky River Basin, 1987, end principal land uses corresponding to each site--Continued

[Degree, minute, and second symbols omitted from latitude and longitude; --, unnumbered; UT, unidentified tributary stream]

| Site number | Stream name | Latitude | Longitude | Station number | County | Land use | Physiographic region[1] |
|---|---|---|---|---|---|---|---|
| 1-180 | UT to Kentucky River | 374902 | 842802 | -- | Madison | Forested | Outer Bluegrass |
| 1-181 | UT to Hickman Creek | 374829 | 843301 | -- | Jessamine | Forested | Inner Bluegrass |
| 1-182 | UT to Kentucky River | 374848 | 843759 | -- | Jessamine | Forested | Inner Bluegrass |
| 1-183 | Shaker Creek | 374811 | 844542 | -- | Mercer | Forested | Outer Bluegrass |
| 1-184 | Shawnee Run | 374918 | 844807 | -- | Mercer | Agriculture | Outer Bluegrass |
| 1-185 | Mocks Branch | 374224 | 844747 | -- | Boyle | Agriculture | Outer Bluegrass |
| 1-186 | UT to Herrington Lake | 374509 | 844542 | -- | Mercer | Agriculture | Outer Bluegrass |
| 1-187 | Tanyard Brench | 374315 | 844006 | -- | Garrard | Agriculture | Outer Bluegrass |
| 1-188 | UT to Kentucky River | 374354 | 843409 | -- | Jessamine | Forested | Outer Bluegrass |
| 1-189 | Dry Branch | 374252 | 842719 | -- | Madison | Agriculture | Outer Bluegrass |
| 1-190 | Brown Branch | 374326 | 842447 | -- | Madison | Agriculture | Outer Bluegrass |
| 1-191 | UT to Taylor Fork | 374218 | 841851 | -- | Madison | Agriculture | Outer Bluegrass |
| 1-192 | Otter Creek | 374502 | 841456 | -- | Madison | Urban | Knobs |
| 1-193 | UT to Muddy Creek | 374256 | 840931 | -- | Madison | Agriculture | Knobs |
| 1-194 | UT to Clear Creek | 374226 | 840131 | -- | Estill | Forested | Knobs |
| 1-195 | UT to White Oak Creek | 374401 | 835743 | -- | Estill | Forested | Knobs |
| 1-196 | UT to Cow Creek | 374241 | 835417 | -- | Estill | Forested | Knobs |
| 1-197 | Wodward Creek | 374227 | 834830 | -- | Estill | Oil and gas | Knobs |
| 1-198 | Barker Branch | 374526 | 834307 | -- | Powell | Oil and ges | Knobs |
| 1-199 | UT to Middle Fork Red River | 374246 | 834002 | -- | Wolfe | Oil and gas | Knobs |
| 1-200 | UT to Swift Camp Creek | 374336 | 833403 | -- | Wolfe | Agriculture | Knobs |
| 1-201 | Swango Fork | 374325 | 832927 | -- | Wolfe | Coal mining | Knobs |
| 1-202 | Lecy Creek | 374347 | 832408 | -- | Wolfe | Forested | Eastern Coal Field |
| 1-203 | Will Lindon Brench | 374339 | 831824 | -- | Wolfe | Forested | Eastern Coal Field |
| 1-205 | UT to Frozen Creek | 373954 | 831555 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-206 | Rock Lick Branch | 373927 | 831820 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-207 | Boone Fork | 373938 | 832405 | -- | Breathitt | Forested | Eestern Coal Field |
| 1-208 | Hunting Fork | 374041 | 832935 | -- | Wolfe | Forested | Eastern Coal Field |
| 1-209 | Right Fork Upper Devil Creek | 373952 | 833240 | -- | Wolfe | Forested | Eastern Coal Field |
| 1-210 | Walker Creek | 373846 | 833908 | -- | Lee | Forested | Knobs |
| 1-211 | UT to Big Sinking Creek | 373842 | 834631 | -- | Lee | Oil and gas | Knobs |
| 1-212 | UT to Big Sinking Creek | 373914 | 834813 | -- | Lee | Forested | Knobs |
| 1-213 | UT to Kentucky River | 373949 | 835403 | -- | Estill | Forested | Knobs |
| 1-214 | UT to Station Camp Creek | 373942 | 835859 | -- | Estill | Agriculture | Knobs |
| 1-215 | UT to Drowning Creek | 373937 | 840550 | -- | Estill | Forested | Knobs |
| 1-216 | Viny Fork | 374026 | 841034 | -- | Madison | Agriculture | Outer Bluegrass |
| 1-217 | Hays Fork | 373918 | 841520 | -- | Madison | Agriculture | Outer Bluegrass |
| 1-218 | Old Town Branch | 374124 | 841852 | -- | Madison | Forested | Outer Bluegrass |
| 1-219 | UT to Paint Lick Creek | 374007 | 842602 | -- | Madison | Agriculture | Outer Bluegrass |
| 1-220 | UT to Back Creek | 374043 | 842854 | -- | Madison | Forested | Outer Bluegrass |
| 1-221 | UT to Sugar Creek | 373933 | 843218 | -- | Garrerd | Agriculture | Outer Bluegrass |
| 1-222 | UT to Boone Creek | 373937 | 843816 | -- | Garrard | Agriculture | Outer Bluegrass |
| 1-223 | UT to Dix River | 373958 | 844351 | -- | Boyle | Agriculture | Outer Bluegrass |
| 1-224 | Mocks Branch | 374055 | 844856 | -- | Boyle | Agriculture | Outer Bluegrass |
| 1-225 | Clarks Run | 373730 | 844836 | -- | Boyle | Agriculture | Outer Bluegrass |
| 1-226 | UT to Henging Fork Creek | 373457 | 844240 | -- | Boyle | Agriculture | Outer Bluegrass |
| 1-227 | Hawkins Brench | 373504 | 843944 | -- | Lincoln | Agriculture | Outer Bluegrass |

Table 21. Locations of streambed-sediment sites in the Kentucky River Basin, 1987, and principal land uses corresponding to each site--Continued

[Degree, minute, and second symbols omitted from latitude and longitude; --, unnumbered; UT, unidentified tributary stream]

| Site number | Stream name | Latitude | Longitude | Station number | County | Land use | Physiographic region[1] |
|---|---|---|---|---|---|---|---|
| 1-228 | UT to Sugar Creek | 373716 | 843236 | -- | Garrard | Agriculture | Outer Bluegrass |
| 1-229 | White Lick Creek | 373418 | 842710 | -- | Garrard | Agriculture | Knobs |
| 1-230 | Henderson Branch | 373628 | 842533 | -- | Madison | Agriculture | Outer Bluegrass |
| 1-231 | Walnut Meadow Branch | 373503 | 841958 | -- | Madison | Agriculture | Knobs |
| 1-232 | Joe Lick Fork | 373538 | 841300 | -- | Madison | Forested | Knobs |
| 1-233 | Copperas Branch | 373538 | 840643 | -- | Madison | Agriculture | Knobs |
| 1-234 | Campbell Branch | 373541 | 840450 | -- | Estill | Agriculture | Knobs |
| 1-235 | UT to Red Lick Creek | 373620 | 840126 | -- | Estill | Forested | Knobs |
| 1-236 | Searcy Branch | 373606 | 835513 | -- | Estill | Forested | Eastern Coal Field |
| 1-237 | Willow Branch | 373619 | 834824 | -- | Lee | Forested | Eastern Coal Field |
| 1-238 | Mikes Branch | 373347 | 834348 | -- | Lee | Forested | Eastern Coal Field |
| 1-239 | UT to Double Cabin Creek | 373509 | 833741 | -- | Lee | Forested | Eastern Coal Field |
| 1-240 | Bean Fork | 373358 | 833229 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-241 | Road Fork | 373504 | 832816 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-242 | Cockrill Fork | 373622 | 832152 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-243 | Carpenter Branch | 373411 | 831950 | -- | Breathitt | Coal mining | Eastern Coal Field |
| 1-244 | UT to Quicksand Creek | 373528 | 831413 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-245 | Allan Patton Branch | 373659 | 831018 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-248 | Hughes Creek | 373248 | 830359 | -- | Breathitt | Coal mining | Eastern Coal Field |
| 1-249 | Sugar Camp Branch | 373152 | 830647 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-250 | Press Howard Fork | 373245 | 831417 | -- | Breathitt | Coal mining | Eastern Coal Field |
| 1-251 | Smith Branch | 373137 | 831854 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-252 | UT to North Fork Kentucky River | 373236 | 832159 | -- | Breathitt | Coal mining | Eastern Coal Field |
| 1-253 | Hurricane Branch | 373305 | 832733 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-254 | Mill Creek | 373137 | 833455 | -- | Lee | Forested | Eastern Coal Field |
| 1-255 | UT to Lower Buffalo Creek | 373139 | 834044 | -- | Lee | Forested | Eastern Coal Field |
| 1-256 | Elk Lick | 373052 | 834457 | -- | Lee | Agriculture | Eastern Coal Field |
| 1-257 | UT to Sturgeon Creek | 373033 | 834912 | -- | Lee | Coal mining | Eastern Coal Field |
| 1-259 | UT to South Fork Station Camp Creek | 373041 | 840111 | -- | Jackson | Forested | Eastern Coal Field |
| 1-260 | Dry Fork | 373027 | 840207 | -- | Jackson | Forested | Eastern Coal Field |
| 1-261 | UT to Owsley Fork | 373204 | 840922 | -- | Jackson | Forested | Knobs |
| 1-262 | Cowbell Creek | 373237 | 841235 | -- | Madison | Forested | Knobs |
| 1-263 | UT to Mason Fork | 373209 | 842149 | -- | Garrard | Agriculture | Knobs |
| 1-264 | UT to Fall Lick | 373107 | 842457 | -- | Garrard | Agriculture | Knobs |
| 1-265 | UT to Drake Creek | 373205 | 843028 | -- | Garrard | Agriculture | Knobs |
| 1-266 | UT to Dix River | 373138 | 843302 | -- | Lincoln | Agriculture | Knobs |
| 1-267 | Saint Asaph Creek | 373151 | 844026 | -- | Lincoln | Urban | Outer Bluegrass |
| 1-268 | UT to Knoblick Creek | 373206 | 844623 | -- | Lincoln | Forested | Knobs |
| 1-269 | Harris Creek | 373145 | 844954 | -- | Lincoln | Agriculture | Knobs |
| 1-271 | UT to Hanging Fork Creek | 372813 | 844840 | -- | Lincoln | Agriculture | Knobs |
| 1-272 | UT to Hanging Fork Creek | 372911 | 844540 | -- | Lincoln | Agriculture | Knobs |
| 1-274 | UT to Cedar Creek | 372727 | 843358 | -- | Lincoln | Agriculture | Knobs |
| 1-275 | UT to Dix River | 372633 | 842813 | -- | Rockcastle | Agriculture | Knobs |
| 1-276 | Grassy Branch | 372336 | 842341 | -- | Rockcastle | Forested | Knobs |
| 1-281 | Hughes Fork | 372723 | 835418 | -- | Jackson | Forested | Eastern Coal Field |
| 1-282 | UT to Sturgeon Creek | 372637 | 834948 | -- | Owsley | Forested | Eastern Coal Field |
| 1-283 | Buck Creek | 372848 | 834354 | -- | Owsley | Coal mining | Eastern Coal Field |

Table 21. Locations of streambed-sediment sites in the Kentucky River Basin, 1987, and principal land uses corresponding to each site--Continued

[Degree, minute, and second symbols omitted from latitude and longitude; --, unnumbered; UT, unidentified tributary stream]

| Site number | Stream name | Latitude | Longitude | Station number | County | Land use | Physiographic region[1] |
|---|---|---|---|---|---|---|---|
| 1-284 | UT to Indian Creek | 372543 | 833826 | -- | Owsley | Forested | Eastern Coal Field |
| 1-285 | McIntosh Fork | 372857 | 833306 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-286 | Hollsnd Branch | 372700 | 832832 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-287 | UT to North Fork Kentucky River | 372646 | 832251 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-288 | Lsne Branch | 372633 | 831820 | -- | Breathitt | Coal mining | Eastern Coal Field |
| 1-289 | Besr Branch | 372725 | 831145 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-290 | Little Millseat Branch | 372818 | 830846 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-291 | Deephole Branch | 372726 | 830156 | -- | Knott | Forested | Eastern Coal Field |
| 1-292 | Fitch Branch | 372736 | 825736 | -- | Knott | Forested | Eastern Coal Field |
| 1-295 | Terry Branch | 372313 | 825802 | -- | Knott | Forested | Eastern Coal Field |
| 1-296 | Buckhorn Creek | 372505 | 830424 | -- | Knott | Forested | Eastern Coal Field |
| 1-299 | Fugste Fork | 372457 | 831638 | -- | Gsrrsrd | Forested | Eastern Coal Field |
| 1-300 | Georges Branch | 372429 | 832317 | -- | Breathitt | Coal mining | Eastern Coal Field |
| 1-301 | Elsome Creek | 372526 | 832837 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-302 | Ingol Fork | 372304 | 833117 | -- | Breathitt | Forested | Eastern Coal Field |
| 1-303 | Lower Wolf Creek | 372422 | 833937 | -- | Owsley | Forested | Eastern Coal Field |
| 1-304 | White Oak Creek | 372436 | 834224 | -- | Owsley | Forested | Eastern Coal Field |
| 1-305 | Brewer Fork | 372424 | 834635 | -- | Owsley | Agriculture | Eastern Coal Field |
| 1-306 | Grassy Creek | 372418 | 835311 | -- | Jackson | Forested | Eastern Coal Field |
| 1-309 | Buncomb Creek | 371944 | 834758 | -- | Clsy | Forested | Eastern Coal Field |
| 1-310 | Burger Branch | 372020 | 834306 | -- | Owsley | Coal mining | Eastern Coal Field |
| 1-311 | Bunches Branch | 372031 | 833649 | -- | Owsley | Forested | Eastern Coal Field |
| 1-312 | Enoch Fork | 371923 | 833141 | -- | Perry | Forested | Eastern Coal Field |
| 1-313 | Anderson Branch | 372034 | 832646 | -- | Perry | Coal mining | Eastern Coal Field |
| 1-314 | Oldhouse Branch | 371952 | 832136 | -- | Perry | Coal mining | Eastern Coal Field |
| 1-315 | Napier Branch | 371913 | 831831 | -- | Perry | Coal mining | Eastern Coal Field |
| 1-316 | Brushy Branch | 372131 | 831330 | -- | Perry | Coal mining | Eastern Coal Field |
| 1-317 | Roaring Branch | 372158 | 830615 | -- | Knott | Forested | Eastern Coal Field |
| 1-318 | Lick Branch | 372007 | 830230 | -- | Knott | Forested | Eastern Coal Field |
| 1-319 | Owens Branch | 372045 | 825836 | -- | Knott | Forested | Eastern Coal Field |
| 1-320 | Wstts Fork | 372034 | 825508 | -- | Knott | Forested | Eastern Coal Field |
| 1-322 | Mill Creek | 371541 | 824451 | -- | Letcher | Forested | Eastern Coal Field |
| 1-323 | Carr Fork | 371642 | 824911 | -- | Knott | Coal mining | Eastern Coal Field |
| 1-324 | Collins Branch | 371619 | 825144 | -- | Knott | Coal mining | Eastern Coal Field |
| 1-326 | Elklick Fork | 371634 | 830253 | -- | Knott | Coal mining | Eastern Coal Field |
| 1-327 | Clear Fork | 371702 | 830708 | -- | Knott | Agriculture | Eastern Coal Field |
| 1-328 | Hominy Mill Branch | 371702 | 831136 | -- | Perry | Coal mining | Eastern Coal Field |
| 1-329 | Forked Mouth Creek | 371625 | 831916 | -- | Perry | Forested | Eastern Coal Field |
| 1-330 | Left Fork Trace Branch | 371626 | 832134 | -- | Leslie | Coal mining | Eastern Coal Field |
| 1-331 | UT to Leatherwood Creek | 371617 | 832940 | -- | Perry | Forested | Eastern Coal Field |
| 1-332 | Long Fork | 371726 | 833225 | -- | Perry | Forested | Eastern Coal Field |
| 1-333 | Little Bullskin Creek | 371627 | 833722 | -- | Clay | Forested | Eastern Coal Field |
| 1-334 | Sester Branch | 371559 | 834308 | -- | Clay | Forested | Eastern Coal Field |
| 1-335 | UT to Robinson Creek | 371622 | 835046 | -- | Clsy | Forested | Eastern Coal Field |
| 1-338 | UT to Little Goose Creek | 370949 | 834805 | -- | Clsy | Coal mining | Eastern Coal Field |
| 1-339 | Little Beech Creek | 371145 | 834233 | -- | Clsy | Forested | Eastern Coal Field |
| 1-340 | Big Branch | 371106 | 833755 | -- | Clsy | Forested | Eastern Coal Field |

Table 21. Locations of streambed-sediment sites in the Kentucky River Basin, 1987, and principal land uses corresponding to each site--Continued

[Degree, minute, and second symbols omitted from latitude and longitude; --, unnumbered; UT, unidentified tributary stream]

| Site number | Stream name | Latitude | Longitude | Station number | County | Land use | Physiographic region[1] |
|---|---|---|---|---|---|---|---|
| 1-341 | Ulysses Creek | 371012 | 833221 | -- | Leslie | Coal mining | Eastern Coal Field |
| 1-342 | Hell for Certain Creek | 371244 | 832747 | -- | Leslie | Coal mining | Eastern Coal Field |
| 1-343 | Sizemore Branch | 371215 | 832359 | -- | Leslie | Forested | Eastern Coal Field |
| 1-344 | Cane Branch | 371052 | 831547 | -- | Leslie | Coal mining | Eastern Coal Field |
| 1-345 | Wooton Creek | 371030 | 831322 | -- | Leslie | Coal mining | Eastern Coal Field |
| 1-346 | UT to North Fork Kentucky River | 371208 | 830851 | -- | Perry | Coal mining | Eastern Coal Field |
| 1-347 | Hurt Fork | 371037 | 830423 | -- | Perry | Coal mining | Eastern Coal Field |
| 1-349 | Stampers Branch | 371119 | 825357 | -- | Letcher | Coal mining | Eastern Coal Field |
| 1-350 | Left Fork Millstone Creek | 371159 | 824544 | -- | Letcher | Coal mining | Eastern Coal Field |
| 1-351 | Bottom Fork | 371152 | 824148 | -- | Letcher | Coal mining | Eastern Coal Field |
| 1-354 | Webb Branch | 370907 | 824221 | -- | Letcher | Coal mining | Eastern Coal Field |
| 1-355 | Blair Branch | 370811 | 824740 | -- | Letcher | Coal mining | Eastern Coal Field |
| 1-356 | Beetree Branch | 370818 | 825318 | -- | Letcher | Coal mining | Eastern Coal Field |
| 1-357 | Elk Creek | 370913 | 825902 | -- | Letcher | Coal mining | Eastern Coal Field |
| 1-358 | Bull Creek | 370835 | 830311 | -- | Perry | Coal mining | Eastern Coal Field |
| 1-359 | Poundmill Branch | 370946 | 830909 | -- | Perry | Forested | Eastern Coal Field |
| 1-360 | Wells Fork | 370905 | 831214 | -- | Perry | Coal mining | Eastern Coal Field |
| 1-361 | UT to Polls Creek | 370812 | 831543 | -- | Leslie | Coal mining | Eastern Coal Field |
| 1-362 | Roundhole Branch | 370908 | 832124 | -- | Leslie | Coal mining | Eastern Coal Field |
| 1-363 | Wet Roundstone Branch | 370827 | 832612 | -- | Leslie | Coal mining | Eastern Coal Field |
| 1-364 | Poundmill Branch | 370622 | 833307 | -- | Clay | Forested | Eastern Coal Field |
| 1-365 | Hays Fork | 370843 | 833927 | -- | Clay | Forested | Eastern Coal Field |
| 1-366 | Rocky Branch | 370525 | 834149 | -- | Clay | Coal mining | Eastern Coal Field |
| 1-367 | Hooker Branch | 370816 | 835008 | -- | Clay | Coal mining | Eastern Coal Field |
| 1-368 | UT to Little Goose Creek | 370844 | 835311 | -- | Clay | Forested | Eastern Coal Field |
| 1-369 | Tuttle Branch | 370417 | 835213 | -- | Clay | Forested | Eastern Coal Field |
| 1-370 | Balls Branch | 370419 | 834709 | -- | Clay | Forested | Eastern Coal Field |
| 1-371 | Swefford Branch | 370402 | 834428 | -- | Clay | Coal mining | Eastern Coal Field |
| 1-372 | Laurel Fork | 370336 | 833623 | -- | Clay | Forested | Eastern Coal Field |
| 1-373 | Hurricane Branch | 370328 | 833120 | -- | Leslie | Oil and gas | Eastern Coal Field |
| 1-374 | Laurel Fork | 370251 | 832946 | -- | Leslie | Forested | Eastern Coal Field |
| 1-375 | UT to Lower Bad Creek | 370424 | 832103 | -- | Leslie | Coal mining | Eastern Coal Field |
| 1-376 | Baker Fork | 370354 | 831559 | -- | Leslie | Coal mining | Eastern Coal Field |
| 1-377 | UT to Cutshin Creek | 370316 | 831254 | -- | Leslie | Forested | Eastern Coal Field |
| 1-378 | Puncheoncamp Branch | 370526 | 830625 | -- | Perry | Forested | Eastern Coal Field |
| 1-379 | Turkey Creek | 370326 | 830133 | -- | Letcher | Forested | Eastern Coal Field |
| 1-380 | UT to Line Fork | 370239 | 825841 | -- | Letcher | Forested | Eastern Coal Field |
| 1-381 | Slipfield Branch | 370424 | 825039 | -- | Letcher | Forested | Eastern Coal Field |
| 1-382 | Oven Fork Branch | 370525 | 824835 | -- | Letcher | Coal mining | Eastern Coal Field |
| 1-384 | Holcomb Branch | 370046 | 825826 | -- | Letcher | Forested | Eastern Coal Field |
| 1-385 | Trace Fork | 370037 | 830212 | -- | Letcher | Forested | Eastern Coal Field |
| 1-386 | Ax Handle Branch | 370127 | 830518 | -- | Perry | Forested | Eastern Coal Field |
| 1-388 | Dollar Branch | 365921 | 831718 | -- | Leslie | Forested | Eastern Coal Field |
| 1-389 | Liek Branch | 370113 | 832336 | -- | Leslie | Forested | Eastern Coal Field |
| 1-390 | Oakley Cave Branch | 370047 | 832933 | -- | Leslie | Coal mining | Eastern Coal Field |
| 1-391 | Wilson Branch | 365906 | 833342 | -- | Clay | Forested | Eastern Coal Field |
| 1-392 | Hubbards Fork | 365832 | 833908 | -- | Clay | Forested | Eastern Coal Field |

Table 21. Locations of streambed-sediment sites in the Kentucky River Basin, 1987, and principal land uses corresponding to each site--Continued

[Degree, minute, and second symbols omitted from latitude and longitude; --, unnumbered; UT, unidentified tributary stream]

| Site number | Stream name | Latitude | Longitude | Station number | County | Land use | Physiographic region[1] |
|---|---|---|---|---|---|---|---|
| 1-393 | Right Fork Otter Creek | 370059 | 834306 | -- | Clay | Forested | Eastern Coal Field |
| 1-394 | Bailey Branch | 365915 | 834852 | -- | Knox | Forested | Eastern Coal Field |
| 1-395 | Green Branch | 365831 | 835102 | -- | Knox | Agriculture | Eastern Coal Field |
| 1-398 | Little Creek | 365611 | 833238 | -- | Bell | Forested | Eastern Coal Field |
| 1-400 | Cawood Branch | 365611 | 832225 | -- | Leslie | Forested | Eastern Coal Field |
| 1-401 | Bill Branch | 365554 | 831826 | -- | Harlan | Forested | Eastern Coal Field |
| 1-402 | Gabes Creek | 365629 | 831243 | -- | Harlan | Forested | Eastern Coal Field |
| 2-1 | Eagle Creek | 383900 | 845654 | 03291510 | Carroll | Agriculture | Outer Bluegrass |
| 2-2 | Eagle Creek | 383811 | 844221 | 03291300 | Grant | Agriculture | Outer Bluegrass |
| 2-3 | Clarks Creek | 383754 | 843730 | 03291310 | Grant | Agriculture | Outer Bluegrass |
| 2-4 | Benson Creek | 381229 | 845614 | 03287545 | Franklin | Agriculture | Outer Bluegrass |
| 2-5 | Elkhorn Creek | 381607 | 844853 | 03289500 | Franklin | Agriculture | Inner Bluegrass |
| 2-6 | Glenns Creek | 380548 | 844802 | 03287300 | Woodford | Urban | Inner Bluegrass |
| 2-7 | South Elkhorn Creek | 380827 | 843843 | 03289300 | Scott | Urban | Inner Bluegrass |
| 2-8 | North Elkhorn Creek | 381212 | 843052 | 03288000 | Scott | Agriculture | Inner Bluegrass |
| 2-9 | Town Branch South Elkhorn Creek | 380430 | 843309 | 03289195 | Fayette | Urban | Inner Bluegrass |
| 2-10 | Hickman Creek | 375332 | 843053 | 03284560 | Jessamine | Urban | Inner Bluegrass |
| 2-11 | Town Fork Jessamine Creek | 375049 | 843512 | 03284630 | Jessamine | Urban | Inner Bluegrass |
| 2-12 | Kentucky River | 375423 | 841613 | 03284000 | Madison | Forested | Outer Bluegrass |
| 2-13 | Otter Creek | 374947 | 841652 | -- | Madison | Agriculture | Outer Bluegrass |
| 2-14 | Tete Creek | 374646 | 842312 | 03284210 | Madison | Agriculture | Outer Bluegrass |
| 2-15 | Red River | 375153 | 835601 | 03283500 | Powell | Forested | Knobs |
| 2-16 | Middle Fork Red River | 374233 | 834814 | 03283320 | Powell | Oil and gas | Knobs |
| 2-17 | Red River | 375000 | 833936 | 03283200 | Powell | Forested | Knobs |
| 2-18 | Dix River | 373832 | 843938 | 03285000 | Garrard | Agriculture | Outer Bluegrass |
| 2-19 | Clarks Run | 373820 | 844316 | 03285200 | Boyle | Urban | Outer Bluegrass |
| 2-20 | Dix River | 373318 | 843610 | 03284800 | Lincoln | Agriculture | Knobs |
| 2-21 | Silver Creek | 373933 | 842146 | 03284315 | Madison | Agriculture | Outer Bluegrass |
| 2-22 | Muddy Creek | 374430 | 840921 | 03283820 | Madison | Agriculture | Outer Bluegrass |
| 2-23 | Muddy Creek | 375048 | 840945 | 03283830 | Madison | Agriculture | Knobs |
| 2-24 | Eagle Creek | 382646 | 843948 | -- | Owen | Agriculture | Outer Bluegrass |
| 2-25 | North Fork Kentucky River | 373246 | 832221 | 03280000 | Breathitt | Coal mining | Eastern Coal Field |
| 2-26 | North Fork Kentucky River | 372052 | 832112 | 03277690 | Perry | Coal mining | Eastern Coal Field |
| 2-27 | Middle Fork Kentucky River | 372914 | 832850 | 03280940 | Breathitt | Forested | Eastern Coal Field |
| 2-28 | North Fork Kentucky River | 373534 | 832523 | 03280120 | Breathitt | Coal mining | Eastern Coal Field |
| 2-29 | Furnace Fork | 374120 | 835127 | 03282100 | Estill | Oil and gas | Knobs |
| 2-30 | Cat Creek | 374954 | 833842 | 03283370 | Powell | Forested | Knobs |
| 2-31 | North Fork Kentucky River | 373609 | 833830 | 03280500 | Lee | Forested | Eastern Coal Field |
| 2-32 | Kentucky River | 374155 | 835832 | 03282250 | Estill | Forested | Knobs |
| 2-33 | Kentucky River | 375140 | 840945 | 03283815 | Madison | Forested | Knobs |
| 2-34 | Kentucky River | 375048 | 842607 | 03284225 | Madison | Forested | Outer Bluegrass |
| 2-35 | Kentucky River | 374604 | 843650 | 03284600 | Garrard | Forested | Outer Bluegrass |
| 2-36 | Kentucky River | 374945 | 844326 | 03286500 | Jessamine | Forested | Inner Bluegrass |
| 2-37 | Kentucky River | 380227 | 845047 | 03287248 | Woodford | Forested | Inner Bluegrass |
| 2-38 | Kentucky River | 381206 | 845254 | 03287500 | Franklin | Forested | Inner Bluegrass |
| 2-39 | North Elkhorn Creek | 381256 | 843621 | 03288150 | Scott | Urban | Inner Bluegrass |
| 2-40 | Kentucky River | 384048 | 851117 | 03291600 | Carroll | Forested | Outer Bluegrass |

Table 21. Locations of streambed-sediment sites in the Kentucky River Basin, 1987, and principal land uses corresponding to each site--Continued

[Degree, minute, and second symbols omitted from latitude and longitude; --, unnumbered; UT, unidentified tributary stream]

| Site number | Stream name | Latitude | Longitude | Station number | County | Land use | Physiographic region[1] |
|---|---|---|---|---|---|---|---|
| 2-41 | Quicksand Creek | 373331 | 831104 | 03279400 | Breathitt | Coal mining | Eastern Coal Field |
| 2-42 | Kentucky River | 381857 | 845113 | 03287575 | Franklin | Forested | Inner Bluegrass |
| 2-43 | South Fork Kentucky River | 372845 | 834038 | 03281500 | Owsley | Forested | Eastern Coal Field |
| 2-44 | South Fork Kentucky River | 371623 | 833850 | 03281200 | Clay | Coal mining | Eastern Coal Field |
| 2-45 | Troublesome Creek | 372802 | 831647 | 03279005 | Breathitt | Coal mining | Eastern Coal Field |
| 2-46 | North Fork Kentucky River | 371558 | 831303 | 03277550 | Perry | Coal mining | Eastern Coal Field |
| 2-47 | Troublesome Creek | 372030 | 830707 | 03277835 | Perry | Coal mining | Eastern Coal Field |
| 2-48 | Goose Creek | 370907 | 834537 | 03281100 | Clay | Forested | Eastern Coal Field |
| 2-49 | Red Bird River | 371043 | 833535 | 03281040 | Clay | Forested | Eastern Coal Field |
| 2-50 | Cutshin Creek | 370954 | 831829 | 03280700 | Leslie | Forested | Eastern Coal Field |
| 2-51 | Middle Fork Kentucky River | 370813 | 832217 | 03280600 | Leslie | Forested | Eastern Coal Field |
| 2-52 | Middle Fork Kentucky River | 370310 | 832400 | 03280551 | Leslie | Forested | Eastern Coal Field |
| 2-53 | Carr Fork | 371209 | 830513 | 03277470 | Perry | Coal mining | Eastern Coal Field |
| 2-54 | Leatherwood Creek | 370735 | 830505 | 03277410 | Perry | Coal mining | Eastern Coal Field |
| 2-55 | North Fork Kentucky River | 370630 | 825136 | 03277305 | Letcher | Coal mining | Eastern Coal Field |
| 2-56 | Rockhouse Creek | 370910 | 825628 | 03277360 | Letcher | Coal mining | Eastern Coal Field |
| 2-57 | Quicksand Creek | 373211 | 832055 | 03279700 | Breathitt | Forested | Eastern Coal Field |
| 2-58 | Middle Fork Kentucky River | 373318 | 833538 | 03281000 | Lee | Forested | Eastern Coal Field |
| 2-59 | Kentucky River | 373319 | 834606 | 03282000 | Lee | Forested | Eastern Coal Field |
| 2-60 | Red River | 374844 | 832750 | 03282500 | Wolfe | Forested | Eastern Coal Field |
| 2-61 | Kentucky River | 375532 | 844917 | 03287000 | Woodford | Forested | Inner Bluegrass |
| 2-62 | Kentucky River | 382821 | 845720 | 03290500 | Henry | Forested | Outer Bluegrass |
| 2-63 | Red Bird River | 370231 | 833249 | 03281017 | Clay | Forested | Eastern Coal Field |
| 2-64 | Middle Fork Kentucky River | 372045 | 832807 | 03280900 | Perry | Forested | Eastern Coal Field |
| 2-65 | Sexton Creek | 372113 | 834135 | 03281351 | Owsley | Forested | Eastern Coal Field |
| 2-66 | Big Sinking Creek | 373822 | 834705 | 03282075 | Lee | Oil and gas | Knobs |
| 2-67 | Sturgeon Creek | 373142 | 834736 | 03282048 | Lee | Forested | Eastern Coal Field |
| 2-68 | Station Camp Creek | 373715 | 835734 | 03282170 | Estill | Forested | Knobs |
| 2-69 | Red Lick Creek | 373340 | 835801 | 03282190 | Estill | Forested | Knobs |
| 2-70 | Clear Creek | 375637 | 844553 | 03287130 | Woodford | Agriculture | Inner Bluegrass |
| 2-72 | Silver Creek | 373516 | 841608 | -- | Madison | Urban | Outer Bluegrass |
| 2-73 | Cane Run | 380821 | 843100 | 03288200 | Scott | Agriculture | Inner Bluegrass |
| 2-74 | Slickway Branch | 381113 | 844810 | -- | Franklin | Urban | Inner Bluegrass |
| 2-75 | Negro Creek | 372409 | 842450 | -- | Rockcastle | Agriculture | Knobs |
| 2-76 | Hays Fork | 373848 | 841807 | -- | Madison | Agriculture | Outer Bluegrass |
| 2-77 | Sexton Creek | 371648 | 834832 | -- | Clay | Forested | Eastern Coal Field |
| 2-78 | Lotts Creek | 371700 | 831115 | -- | Perry | Coal mining | Eastern Coal Field |
| 2-79 | Hector Branch | 371053 | 833802 | -- | Clay | Coal mining | Eastern Coal Field |
| 2-80 | Plum Branch | 375030 | 835746 | -- | Powell | Agriculture | Knobs |
| 2-81 | Frames Branch | 374853 | 835504 | -- | Powell | Agriculture | Knobs |
| 2-82 | Dix River | 372926 | 843046 | -- | Lincoln | Agriculture | Knobs |
| 2-83 | Hanging Fork | 373244 | 844341 | -- | Lincoln | Agriculture | Knobs |
| 2-84 | Drennon Creek | 382839 | 850550 | 03290600 | Henry | Agriculture | Outer Bluegrass |
| 2-85 | Town Creek | 382539 | 850955 | -- | Henry | Agriculture | Outer Bluegrass |
| 2-86 | South Elkhorn Creek | 380235 | 843734 | 03289000 | Fayette | Urban | Inner Bluegrass |
| 2-87 | South Elkhorn Creek | 381254 | 844755 | 03289470 | Franklin | Agriculture | Inner Bluegrass |
| 2-88 | North Elkhorn Creek | 381512 | 844508 | -- | Franklin | Agriculture | Inner Bluegrass |

Table 21. Locations of streambed-sediment sites in the Kentucky River Basin, 1987, and principal land uses corresponding to each site--Continued

[Degree, minute, and second symbols omitted from latitude and longitude; --, unnumbered; UT, unidentified tributary stream]

| Site number | Stream name | Latitude | Longitude | Station number | County | Land use | Physiographic region[1] |
|---|---|---|---|---|---|---|---|
| 2-89 | Cave Creek | 380116 | 843538 | 03288500 | Fayette | Agriculture | Inner Bluegrass |
| 2-90 | North Fork Kentucky River | 370742 | 825829 | -- | Letcher | Coal mining | Eastern Coal Field |
| 2-91 | Middle Fork Quicksand Creek | 372957 | 830529 | -- | Knott | Forested | Eastern Coal Field |
| 2-92 | Eagle Creek | 384217 | 844924 | 03291500 | Owen | Agriculture | Outer Bluegrass |
| 2-93 | Troublesome Creek | 372201 | 830905 | -- | Perry | Coal mining | Eastern Coal Field |
| 2-94 | Lost Creek | 372815 | 831919 | -- | Breathitt | Coal mining | Eastern Coal Field |
| 2-95 | Hunting Creek | 373533 | 831341 | -- | Breathitt | Forested | Eastern Coal Field |
| 2-96 | Horse Creek | 370713 | 834646 | -- | Clay | Forested | Eastern Coal Field |
| 2-97 | North Elkhorn Creek | 380520 | 842140 | -- | Fayette | Urban | Inner Bluegrass |
| 2-98 | North Elkhorn Creek | 380433 | 842447 | 03287600 | Fayette | Urban | Inner Bluegrass |
| 2-99 | Stillwater Creek | 374524 | 832912 | 03283000 | Wolfe | Agriculture | Eastern Coal Field |
| 2-101 | Wolf Run | 380400 | 843315 | 03289190 | Fayette | Urban | Inner Bluegrass |
| 2-102 | Big Sinking Creek | 374100 | 834259 | -- | Lee | Oil and gas | Knobs |
| 2-103 | Bailey Run | 380152 | 845044 | -- | Anderson | Forested | Inner Bluegrass |
| 2-104 | Steeles Run | 380437 | 843618 | -- | Fayette | Agriculture | Inner Bluegrass |
| 2-105 | Six Mile Creek | 382550 | 850020 | 03290490 | Henry | Agriculture | Outer Bluegrass |
| 2-106 | Paint Lick Creek | 373922 | 842543 | -- | Madison | Agriculture | Outer Bluegrass |
| 2-107 | Severn Creek | 382756 | 845522 | -- | Owen | Agriculture | Outer Bluegrass |

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[1] Smoot and others (1991).