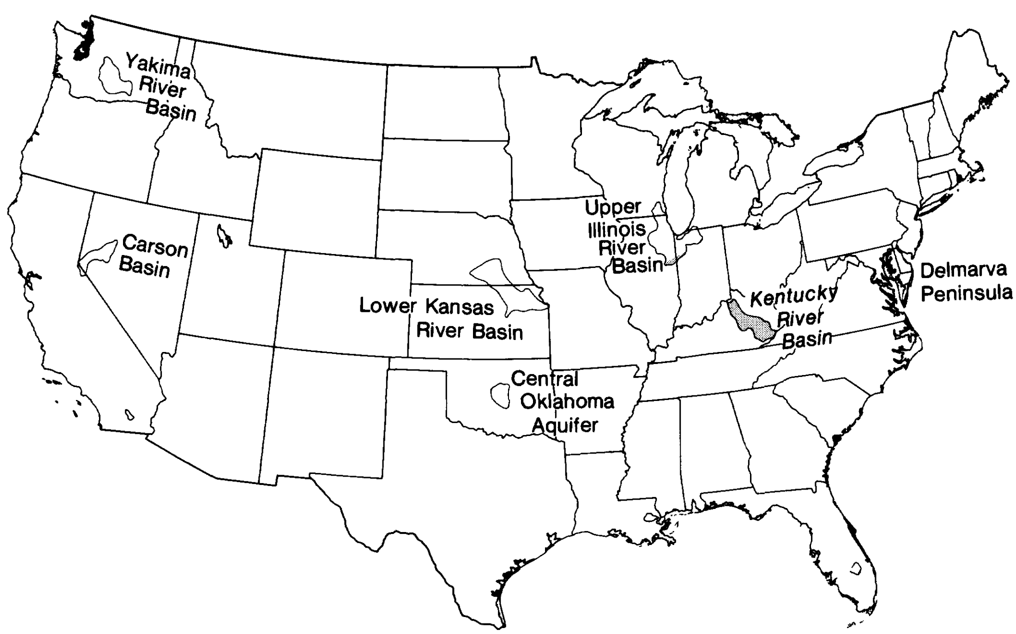
SURFACE WATER-QUALITY ASSESSMENT OF THE KENTUCKY RIVER BASIN, KENTUCKY: ANALYSIS OF AVAILABLE WATER-QUALITY DATA THROUGH 1986

By J.L. Smoot, T.D. Liebermann, R.D. Evaldi, and K.D. White

With a section on BIOLOGICAL INDICATORS OF WATER QUALITY *by* A.D. Bradfield



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FOREWORD

One of the great challenges faced by water-resources scientists is providing reliable water-quality information to guide the management and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resources agencies and by academic institutions. Many of these organizations are collecting water-quality data for a host of purposes, including compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research to advance our understanding of water-quality processes. In fact, during the past two decades, tens of billions of dollars have been spent on water-quality data-collection programs. Unfortunately, the utility of these data for present and future regional and national assessments is limited by such factors as the areal extent of the sampling network, the frequency of sample collection, the varied collection and analytical procedures, and the types of water-quality characteristics determined.

To address this deficiency, the Congress appropriated funds for the U.S. Geological Survey, beginning in 1986, to test and refine concepts for a National Water-Quality Assessment (NAWQA) Program that, if fully implemented, would:

1. Provide a nationally consistent description of 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, as possible, the major factors that affect observed water-quality conditions and trends.

As presently envisioned, a full-scale NAWQA Program would be accomplished through investigations of a large set of major river basins and aquifer systems that are distributed throughout the Nation and that account for a large percentage of the Nation's population and freshwater use. Each investigation would be conducted by a small team that is familiar with the river basin or aquifer system. Thus, the investigations would take full advantage of the region-specific knowledge of persons in the areas under study.

Four surface-water projects and three ground-water projects are being conducted as part of the pilot program to test and refine the assessment methods and to help determine the need for and the feasibility of a full-scale program. An initial activity of each pilot project is to compile, screen, and interpret available data to provide an initial description of water-quality conditions and trends in the study area. The results of this analysis of available data are presented in individual reports for each project.

The pilot studies depend heavily on cooperation and information from many Federal, State, interstate, and local agencies. The assistance and suggestions of all are gratefully acknowledged.

Philip Cohen
Chief Hydrologist

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SURFACE WATER-QUALITY ASSESSMENT OF THE KENTUCKY RIVER BASIN, KENTUCKY: ANALYSIS OF AVAILABLE WATER-QUALITY DATA THROUGH 1986

By James L. Smoot, Timothy D. Liebermann, Ronald D. Evaldi, and Kevin D. White

EXECUTIVE SUMMARY

Beginning in 1986, the Congress appropriated funds for the U.S. Geological Survey to test and refine concepts for a National Water-Quality Assessment (NAWQA) program. The long-term goals for a full-scale program are to provide a nationally consistent description of current water-quality conditions for a large part of the Nation's surface- and ground-water resources, to define long-term trends (or lack of trends) in water quality, and to identify, describe, and explain, as possible, the major factors that affect observed conditions and trends in water quality. This information, obtained on a continuing basis, would be 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 contemplated changes in land- and water-management practices. At present (1990), the assessment program is in a pilot phase in seven project areas that represent diverse hydrologic environments and water-quality conditions.

This report completes one of the first activities undertaken as part of the Kentucky River basin pilot project, which was to compile, screen, and interpret available water-quality data for the study unit through 1986. The report includes information on the sources and types of water-quality data available, the utility of available water-quality data for assessment purposes, and a description of current (1976-86) water-quality conditions and trends and their relation to natural and human factors. Water-quality data from a broader historical period (1951-86) were also used for comparison to current-period conditions.

The Kentucky River Basin

The Kentucky River flows through east-central Kentucky and drains an area of about 7,000 square miles. As shown in figure ES-1, the river originates in the uplands of southeast Kentucky and flows northwestward through the central part of the State to its junction with the Ohio River. The main stem of the Kentucky River is defined to include the North Fork. The upper Kentucky River basin lies in the Eastern Coal Field physiographic region and supports primarily silviculture, coal mining, and oil and gas production. The middle part of the basin lies in the Knobs physiographic region and supports silviculture, oil and gas production, and small amounts of agriculture and urbanization. The lower part of the basin lies in the Inner and Outer Bluegrass regions and supports primarily agricultural and urban development. The major population centers in the basin, Lexington and Frankfort, are in this region. Because land uses are generally controlled by geology and physiography, water-quality conditions and their causative factors in the different parts of the basin (upper, middle, and lower) are generally distinctive from each other.

The main stem of the Kentucky River is characterized by a series of 14 locks and dams from a point just downstream of the confluence of the North, Middle, and South Forks of the Kentucky River to the mouth. These locks and dams were originally constructed to provide a minimum water depth of 6 feet for navigation. The pooled conditions behind each dam have a substantial effect on water-quality conditions, especially during low-flow periods.

The Kentucky River and its tributaries are used extensively for municipal and industrial water supply, recreation, and wastewater discharge and assimilation. Water from the river, its tributaries, and reservoirs provides more than 95 percent of the public supply in the basin. The Kentucky River basin is the most densely populated river basin in the State and is projected to be the area of most growth in the future. Annual surface-water use in the basin (1985) exceeded the flow of the river about 4 percent of the time, based on flow duration near the river mouth. Because of Kentucky's dependence on surface-water supplies, the quality of water in the Kentucky River is of great interest and concern.

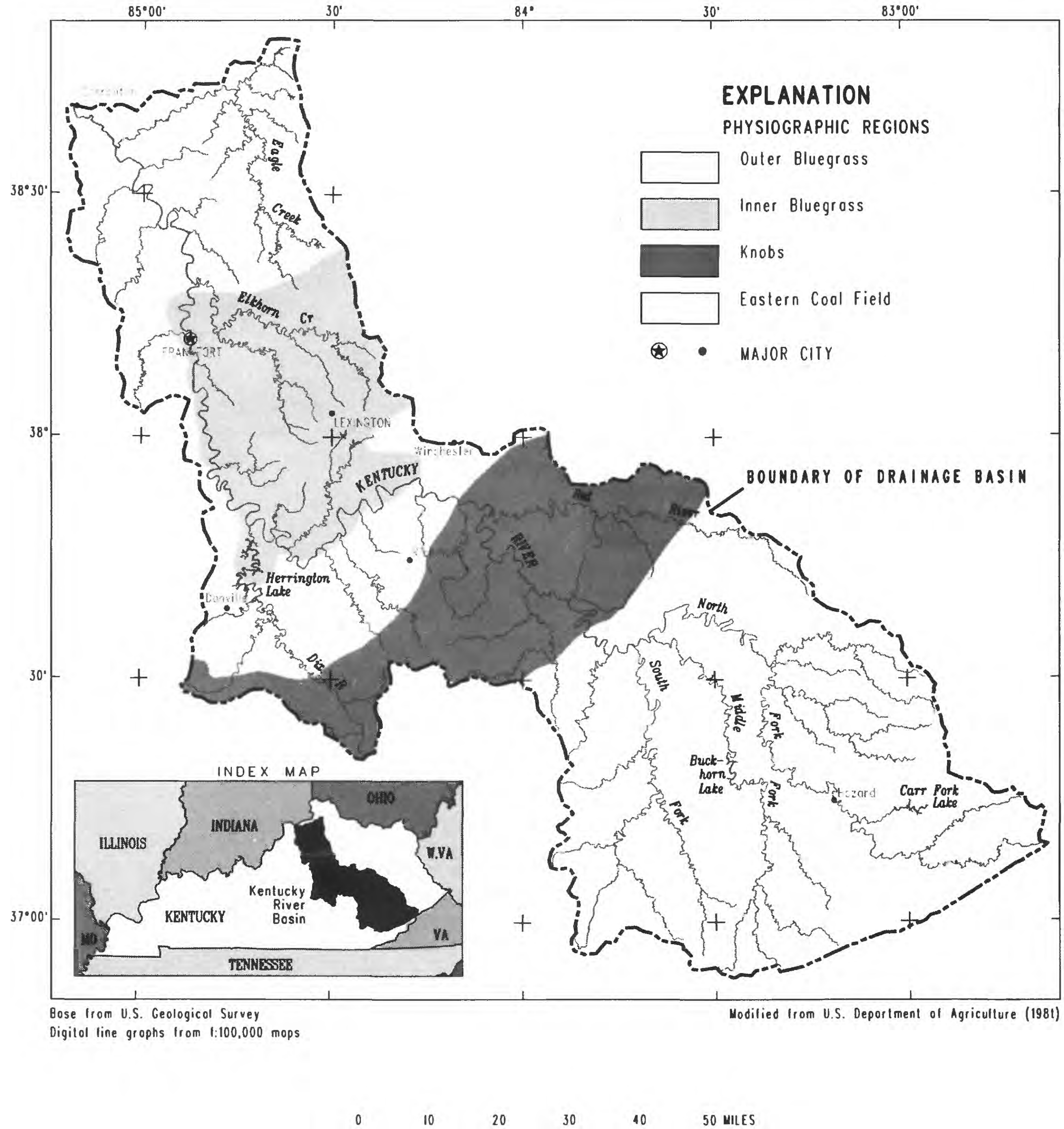

Figure ES-1.--The Kentucky River basin, Kentucky.

Sources and Characteristics of Available Surface Water-Quality Data

Retrievals of surface water-quality data from the U.S. Environmental Protection Agency's computer file (STORET) and the U.S. Geological Survey's Water Data Storage and Retrieval system (WATSTORE) identified six agencies as having collected most of the water-quality data in the Kentucky River basin. These agencies are: Kentucky Division of Water; Kentucky Department for Surface Mining Reclamation and Enforcement; U.S. Army Corps of Engineers; U.S. Environmental Protection Agency; U.S. Geological Survey; and U.S. Office of Surface Mining Reclamation and Enforcement. These retrievals included data from 1951 through 1986 for about 8,000 samples collected from more than 500 sites.

To ensure that the available data were suitable for analysis, it was necessary to evaluate (or screen) the data with respect to sampling purpose, methods, and the number of observations. Only 30 sites in the basin had 10 or more values for one or more constituents obtained during water years 1976-86. The data base from these 30 sites consisted of about 2,300 samples, containing 34,000 individual determinations for 93 different constituents or properties.

The water-quality monitoring program of the Kentucky Division of Water accounts for most of the data available for individual site statistical analyses for the 1976-86 period. The other major sources of data obtained during this period were from the National Stream Quality Accounting Network program and from miscellaneous measurements, both components of U.S. Geological Survey operations. Although the available data are generally well distributed with respect to season and flow condition, relatively few high-flow periods were sampled at most sites.

Existing water-quality information for the basin is adequate for making a generalized assessment of common water-quality properties and constituents of interest, such as pH, alkalinity, major ions, nutrients, and selected major metals and trace elements. With the exception of synthetic organic compounds and several trace elements, the occurrence of a specific constituent in the surface water of the Kentucky River basin can be determined by using existing information. However, the existing data are not adequate to address questions concerning the distribution and transport of many constituents or to associate water-quality conditions with causative factors. Trend detection for concentrations of trace elements, synthetic organic compounds, and radionuclides was hampered due to short, if any, period of record and the occurrence of concentrations less than laboratory detection levels.

Current Water-Quality Conditions and Long-Term Trends

The quality of most surface water in the Kentucky River basin is generally suitable to support designated uses on the basis of applicable Federal and State water-quality criteria. However, because of point and nonpoint sources of contamination, water in some stream reaches in the basin do not meet applicable Federal and State quality criteria and do not support designated uses.

In the upper Kentucky River basin, which is characterized by rugged topography and steep stream slopes, land-disturbance activities associated with both surface and underground mining substantially affect water-quality conditions. The annual sediment yield for the North Fork Kentucky River basin is about 15 times the yield of the entire Kentucky River basin as a whole. Sediment deposition also occurs in this region, particularly in the pool behind lock and dam 14 downstream of the confluence of the North, Middle, and South Forks. The chemical quality of streams can also be affected by land disturbance activities, including mining. This is particularly true for concentrations of iron, sulfate, and other dissolved constituents. More than 60 percent of the dissolved sulfate load in the Kentucky River basin originates in the upper basin. In addition, about 55 percent of the dissolved chloride load for the entire basin is attributed to brine discharges from oil and gas production areas in the upper basin. Because of the changes in water quality, and the resulting loss of habitat due to sedimentation, only a few, more tolerant, biological organisms are able to survive in the most affected stream reaches of this region.

The middle Kentucky River basin corresponds roughly to the Knobs physiographic region and is characterized by pristine water-quality conditions as well as by conditions that reflect the effects of oil and gas production activities. In largely undeveloped areas, water in some reaches of the Red River in this region is classified as Outstanding Resource Water, the State's highest classification, and supports a large, diversified biological community. However, an area of intensive oil and gas production substantially affects the quality of water in several streams nearby. Dissolved solids, barium, sodium, chloride, bromide, and other dissolved constituent concentrations are particularly increased as a result of brine discharges that originate from oil production activities. Some stream reaches draining active oil and gas fields

Table ES-1.—*Summary of median concentrations and mean annual yields for selected water-quality constituents in the Kentucky River basin*

[mg/L, milligrams per liter; tons/mi², tons per square mile]

Station	Dissolved solids		Nitrogen, total as N		Phosphorus, total as P		Suspended sediment		Iron, total	
	Median concen-tration (mg/L)	Mean annual yield (tons/mi²)	Median concen-tration (mg/L)	Mean annual yield (tons/mi²)	Median concen-tration (mg/L)	Mean annual yield (tons/mi²)	Median concen-tration (mg/L)	Mean annual yield (tons/mi²)	Median concen-tration (mg/L)	Mean annual yield (tons/mi²)
UPPER BASIN										
North Fork Kentucky River at Jackson	295	234	0.76	1.59	0.03	0.203	27	1,480	1,200	17.7
Middle Fork Kentucky River at Tallega	124	140	.46	.67	.02	.094	22	133	930	3.12
South Fork Kentucky River at Booneville	145	144	.52	.89	.02	.062	12	172	550	2.86
LOWER BASIN										
Kentucky River below Frankfort	180	211	1.4	1.84	.08	.183	18	108	400	2.48
Elkhorn Creek near Midway	358	432	9.3	9.06	.98	1.59	10	18.7	350	.613
Kentucky River at Lock 2, at Lockport	177	227	1.3	2.18	.10	.265	37	105	1,100	2.53

support only a few, highly tolerant, aquatic organisms as a result of the high concentrations of dissolved constituents. Approximately 35 percent of the chloride load in the entire basin originates from the middle basin.

Agriculture and urbanization substantially affect water quality in the lower Kentucky River basin. Characterized by gently rolling terrane and limestone bedrock, this physiographic region is home to most of the basin population and is the center of a large, world-renowned thoroughbred horse industry. Corn, tobacco, and livestock production also contribute to the agricultural land-use in this region. Because of population density and agricultural activities, the largest inputs of nitrogen and phosphorus into streams are estimated to occur in the lower basin, including about 76 percent of the annual load of ammonia and organic nitrogen. Nearly 80 percent of the total ammonia and nitrogen load transported in the lower Kentucky River is estimated to originate from nonpoint sources. Suspended-sediment yields are large in basins draining agricultural land, and in places the yields approach those observed in areas of the upper basin that are affected by mining activities. Biological communities in some stream reaches draining urban areas have been substantially affected due to low dissolved oxygen concentrations and high concentrations of trace metals and other constituents resulting from wastewater inputs and nonpoint source runoff.

A data summary describing the median concentration and mean annual yield for selected constituents is presented in table ES-1. Organized by region (upper and lower basin), differences in water quality that result from different land-use activities can be identified. Water-quality trends and Federal and State criteria exceedances for selected constituents are summarized in tables ES-2 and ES-3 for those sites where at least 10 observations were made. Other significant results, organized by constituent class, are described below.

Precipitation and Streamflow

From the analysis of long-term data, two time-periods exhibited significant trends in the magnitudes of streamflow and precipitation. A strong increasing trend in flow and precipitation occurred from the early 1960's to the mid-1970's, and a strong decreasing flow and precipitation trend is indicated since the mid-1970's. Most water-quality data available were collected during the period of decreasing streamflow and precipitation.

pH and Major Inorganic Constituents

Streams in the Kentucky River basin are generally well buffered and slightly alkaline, as a result of an abundance of carbonate minerals in the soil and bedrock. Median pH values ranged from 7.1 to 7.8. Acid-mine drainage in the upper part of the basin is quickly neutralized by carbonate minerals in soils. Water of the Kentucky River basin generally becomes increasingly alkaline from the Eastern Coal Fields region downstream to the Bluegrass region. In the pooled reaches of the main stem, pH values have occasionally exceeded 9.0 (the maximum criterion for aquatic life). These high values most likely result from algal productivity and associated reduction of carbon-dioxide concentrations.

Table ES-2. —*Summary of water-quality trends for selected constituents and properties*

[Trend-line slope is defined as the median rate of change in the constituent over the sampling period. The magnitude of this slope is divided by the median concentration and reported as percent change per year. Trend-line slopes not significant at 0.2 probability level were not included. mg/L, milligrams per liter; μg/L, micrograms per liter; μS/cm, microsiemens per centimeter; mL, milliliter; —, median trend slope magnitude unknown]

Constituent or property	Number of sites	Trends, unadjusted for flow: Increasing trends: Number of sites	Median trend-line slope	Trends, unadjusted for flow: Decreasing trends: Number of sites	Median trend-line slope	Flow-adjusted trends: Increasing trends: Number of sites	Median trend-line slope	Flow-adjusted trends: Decreasing trends: Number of sites	Median trend-line slope
Major cations and anions									
Calcium, dissolved, in mg/L	11	1	1.6	0		1	1.7	0	
Magnesium, dissolved, in mg/L	11	3	7.6	0		2	10.6	0	
Hardness, in mg/L as $CaCO_3$	11	8	1.45	1	-2.4	8	6.55	0	
Sodium, dissolved, in mg/L	11	2	8.8	0		1	—	1	-12
Potassium, dissolved, in mg/L	11	2	9.8	1	-5.6	2	4.2	0	
Alkalinity, mg/L as $CaCO_3$	11	5	3.9	1	-1.7	3	3.2	0	
Chloride, dissolved, in mg/L	11	6	8.85	0		7	9.9	0	
Sulfate, dissolved, in mg/L	6	2	7.6	0		3	8.8	0	
Nutrients									
Nitrogen, total, in mg/L as N	11	0		0		1	4.6	1	-3.2
Nitrogen, $NO_2 + NO_3$, total, in mg/L as N	11	4	8.15	0		3	9.3	0	
Nitrogen, ammonia, total, in mg/L as N	11	1	26	6	—	0		0	
Nitrogen, TKN, total, mg/L as N	11	1	3.1	4	-8.3	1	3.9	2	-5.0
Phosphorus, total, in mg/L as P	11	0		3	-17	1	4.8	1	-13
Phosphorus, dissolved, in mg/L as P	5	0		0		0		0	
Organic carbon and oxygen demand									
Organic carbon, total, in mg/L	11	1	23	3	-25	0		0	-32
Biochemical oxygen demand, in mg/L	10	0		4	-7.95	0		0	
Chemical oxygen demand, in mg/L	10	0		3	-50	0		0	
Major metals and trace elements									
Aluminum, total, in μg/L	10	0		0		0		0	
Arsenic, total, in μg/L	11	0		4	—	0		0	
Barium, total, in μg/L	11	1	—	5	-9.8	0		0	
Cadmium, total, in μg/L	11	2	—	5	—	0		0	
Chromium, total, in μg/L	11	1	—	5	-61	0		0	
Copper, total, in μg/L	11	0		10	-15.5	0		0	
Iron, total, in μg/L	11	0		5	-16	0		3	-9.8
Lead, total, in μg/L	11	0		9	-33	0		0	
Manganese, total, in μg/L	11	0		1	-8.3	2	6.1	1	-3.5
Mercury, total, in μg/L	11	0		6	-30.5	0		0	
Nickel, total, in μg/L	6	0		2	-62	0		0	
Selenium, total, in μg/L	11	0		0		0		0	
Silver, total, in μg/L	11	0		0		0		0	
Zinc, total, in μg/L	11	0		3	-32	0		1	-53
Miscellaneous water quality measures									
Specific conductance, in μS/cm	29	19	3.7	1	-2.2	9	3.8	0	
Dissolved solids, in mg/L	11	7	6.7	0		8	5.7	0	
Suspended sediment, in mg/L	11	0		7	-17	0		1	-13
Acidity, in mg/L as $CaCO_3$	10	0		2	-12.2	0		1	-7.0
Dissolved oxygen, in mg/L	2	0		0		0		0	
pH, in standard units	11	1	—	4	—	0		1	—
Coliform, fecal, in colonies/100 mL	10	0		3	-39	0		3	-51

Table ES-3.—*Summary of water-quality criteria exceedances at sites for selected constituents and properties*

[Censored values greater than the water-quality criteria were not included in the percentage computations. mg/L, milligrams per liter; μg/L, micrograms per liter; mL, milliliter; –, constituent criteria exist, but not exceeded]

U.S. ENVIRONMENTAL PROTECTION AGENCY

MCL = maximum contaminant level
MCLG = MCL goal
PMCLG = proposed MCLG
SMCL = secondary MCL
ALA = aquatic life (acute)
ALC = aquatic life (chronic)

KENTUCKY

KYDWS = domestic water supply
KYAH = warmwater aquatic habitat
KYR = recreational waters

Constituent or property	Number of sites	Number of sites with data not meeting criteria	Median percentage of observations not meeting criteria at each site								
			MCL	MCLG	PMCLG	SMCL	ALA	ALC	KYDWS	KYAH	KYR
Major cations and anions											
Magnesium, total, in mg/L	15	15				94.3			94.3		
Chloride, dissolved, in mg/L	11	0	–	–	–						
Sulfate, total, in mg/L	10	0	–	–	–						
Fluoride, dissolved, in mg/L	11	1			–				32.4		
Major metals and trace elements											
Arsenic, total, in μg/L	11	2	1.15	–	1.15	–				1.15	
Barium, total, in μg/L	11	0		–		–					
Cadmium, total, in μg/L	11	10	6.3		4.4		7.8	21.6		4.1	
Chromium, total, in μg/L	11	1	1.3	–		–					
Copper, total, in μg/L	11	10	–	–			4.9	9.4			
Iron, total, in μg/L	15	15	–	–	–	83.7	–	35		35	
Lead, total, in μg/L	11	11	12.1	–	100	–	8.5	66.2	12.1		
Manganese, total, in μg/L	11	0	–	–	–						
Mercury, total, in μg/L	11	11	7.1	–	4.7	–	6.9	100		53.7	
Selenium, total, in μg/L	11	0		–		–					
Silver, total, in μg/L	11	10						100			
Zinc, total, in μg/L	11	11	–	–	–		1.5	13.8		13.8	
Miscellaneous water-quality measures											
Dissolved solids, in mg/L	15	4	–	–	–	1.4					
Alkalinity, mg/L as $CaCO_3$	16	7					–	12.3			
Dissolved oxygen, in mg/L	5	1					17.6	58.8			
pH, in standard units (below)	11	9	–	–	–	4.5	–	4.5		2.3	2.3
pH, in standard units (above)	11	6	–	–	–	1.25	–	1.5		1.5	1.5
Coliform, fecal, in colonies/100mL	11	11							6.5		

Three major source areas of dissolved solids in streams in the Kentucky River basin are: the North Fork Kentucky River basin, which receives drainage from coal mining and oil and gas production areas; the middle part of the basin, which receives drainage from oil and gas production areas; and the Elkhorn Creek Basin, which receives effluent discharges and urban stormwater runoff. Only about 3 percent of the more than 1,600 observations of dissolved-solids concentrations measured in samples from 30 sites in the basin exceeded the Federal secondary maximum contaminant level (SMCL) criterion of 500 mg/L. Concentrations of dissolved solids in the main stem of the Kentucky River generally decrease with distance downstream as a result of dilution. Long-term positive trends in dissolved-solids concentrations, ranging from about 3 to 10 percent per year, were detected for 7 of 11 long-term sites in the study area. Increased production of coal, oil, and gas during 1976-86 is thought to be a causative factor for these trends.

Concentrations and loads of dissolved sodium and chloride increase in the central part of the basin downstream from tributaries draining oil-producing areas. Elevated dissolved sodium and chloride concentrations related to wastewater discharges and possibly road salting are present in South Elkhorn Creek, which receives wastewater and stormwater from the Lexington urban area. Road salt might account for as much as 11 percent of the estimated annual chloride transported from the Kentucky River basin. From 1980 to 1986, the increase in salt application in the Kentucky River basin averaged about 12 percent per year. About 2 percent of the annual load of dissolved sodium and chloride is estimated to originate from atmospheric deposition.

Increasing trends in dissolved chloride concentrations were identified at all sites on the main stem downstream from Jackson, Kentucky. At Lock 14 on the Kentucky River, flow-adjusted chloride concentrations were determined to be increasing at a rate of about 3 mg/L per year (or about 30 percent per year). The increasing trends are attributed to increases in oil brine discharges in the North Fork Kentucky River basin, particularly from areas downstream of Jackson, Kentucky.

The largest dissolved sulfate concentrations in the basin are in streams draining the upper part of the basin, particularly the North Fork Kentucky River basin, which is intensively mined for coal. More than one-third of the dissolved sulfate load in the Kentucky River originates in this part of the basin. Atmospheric deposition contributes about 11 percent of the total sulfate load leaving the basin. Increasing trends in total sulfate concentrations were significant at the 0.1 probability level on all main stem sites. The greatest increases in sulfate concentrations over time were associated with stream sites in the upper basin, where mining activities are prevalent.

Suspended Sediment

Suspended-sediment concentrations in the Kentucky River basin generally decrease downstream from areas draining the Eastern Coal Field region, but then increase in the most downstream part of the basin as a result of drainage from agricultural areas. The estimated annual sediment yield for the North Fork Kentucky River basin, which has about 4 percent of it's area disturbed by mining, is about 1,500 tons per square mile. In contrast, the estimated annual sediment yield of the headwater area of the Red River basin, which has less than 0.1 percent of it's area disturbed by mining, is about 150 tons per square mile. The estimated annual sediment yield from the Eagle Creek basin, in which more than 50 percent of the land is used for mixed row-crop and pasture, is about 1,000 tons per square mile.

Transport estimates indicate that nearly 75 percent of the 1.8 million tons of suspended sediment annually transported from the upper Kentucky River basin (North, Middle, and South Forks) is deposited behind Lock and Dam 14 in the uppermost navigational pool on the Kentucky River. The annual transport of sediment from the entire Kentucky River basin is about 650,000 tons, which is only about one-half the dissolved-solids load transported out of the basin each year. Although decreasing trends in suspended-sediment concentrations were detected at 7 of 11 sites during the 1976-86 period, most of these decreases were related to decreases in streamflow during the same period.

Nutrients

Concentrations of total nitrogen and total phosphorus gradually increase from the headwater reaches to the mouth of the Kentucky River as a result of downstream increases in population density and agricultural activities. Largest nutrient concentrations and yields typically occur in South Elkhorn Creek, which receives sewage and industrial effluent discharges from the most urban part of the basin. More than 20 percent of the samples collected at South Elkhorn Creek at Midway, Kentucky exceeded the warmwater aquatic habitat criterion of 0.05 milligrams of un-ionized ammonia per liter adopted by the State of Kentucky. Greater than 95 percent of the annual load of ammonia and organic nitrogen is estimated to originate in the lower part of the basin. About 80 percent of this load originates from nonpoint sources such as agricultural and urban runoff. The balance is due principally to point sources such as municipal and industrial effluents.

Major Metals and Trace Elements

Most major metals and trace elements present in the surface water of the Kentucky River basin originate from nonpoint sources and generally are a reflection of the geology. Concentrations and yields of several constituents, including iron, manganese, copper, chromium, and aluminum, seem to be closely related to land-disturbance activities such as coal mining and agricultural cultivation.

Basinwide, 70 percent of water samples analyzed for total iron had concentrations that exceeded the Federal SMCL value of 300 μg/L established for public water supplies. The median concentration of total iron in water at many stream sites in the Eastern Coal Field region exceeded the Kentucky water-quality criterion of 1,000 μg/L. These high concentrations typically decrease downstream, but on many occasions remained above established criterion. Largest total iron yields originated from the North Fork Kentucky River basin and were more than 4 times greater than yields for any other stream site. Virtually all (99 percent) of the total iron transported from the Kentucky River basin originates from nonpoint sources. Both flow-adjusted and nonflow-adjusted concentrations of dissolved and total iron decreased at many sites in the basin. This may be due to the implementation of mining regulations and to the application of improved mining and reclamation techniques.

Similar to iron, more than 70 percent of all analyses for total manganese exceeded the State and Federal criterion of 50 μg/L and many sites in the Eastern Coal Field region have, on occasion, exceeded a total manganese concentration of 1,000 μg/L. Although derived from natural geologic sources, many of these large concentrations are attributed to land-disturbance activities such as mining. Transport estimates for selected sites in the basin indicated that the largest yield of total manganese was for the North Fork Kentucky River upstream of Jackson, Kentucky, an area intensively mined for coal. However, the largest yield determined for dissolved manganese was that for the upper Red River basin. Land disturbance activities in the upper Red River basin that might cause the observed manganese yields include agriculture, silviculture, and some coal mining.

About 5 percent of all total recoverable cadmium concentrations (606 observations) exceeded Federal drinking water criteria. Cadmium concentrations also exceeded Federal aquatic life (chronic) criteria on occasion (1 percent of all observations). More than 150 observations (15 percent) exceeded Federal aquatic life criteria for total recoverable copper. The source of these elements probably is from weathered rocks. Land-disturbance activities such as mining seem to affect copper transport especially. Total copper concentrations decreased during the period 1976-86, but the decrease might reflect decreasing flow conditions during this same period.

Trend analyses indicated that lead and mercury concentrations in streams decreased during the 1976-86 period. The relations among lead and mercury concentrations and streamflow could not be determined. Total recoverable lead concentrations exceeded Federal drinking water criteria in 60 observations (9 percent of all observations) and exceeded Federal aquatic life (acute) criteria in 47 observations (7 percent). Lead concentrations generally were larger in the more urban parts of the basin. Total recoverable mercury concentrations exceeded both Federal drinking water criteria and Federal aquatic life (acute) criteria for about 6 percent of all observations (623 observations). Widespread in occurrence, the source of mercury in the basin could not be associated with any particular land use and, thus, seems to be derived from natural geologic sources.

Concentrations of total zinc exceeded Kentucky's warmwater aquatic habitat criterion of 47 μg/L for about 16 percent of the samples collected between 1976 and 1986. Transport estimates for total and dissolved zinc indicate that zinc is contributed from a number of different land uses. This indicates that zinc might be derived from natural sources, such as the weathering of geologic materials or atmospheric deposition.

Pesticides and Other Synthetic Organic Compounds

Historical data on organic compounds in the Kentucky River basin are limited. Almost no data exists for polychlorinated biphenyls (PCBs), phenols, phthalate esters, and polycyclic aromatic hydrocarbons in streams. The presence of several organochlorine insecticides was detected in a small number of fish tissue and streambed sediment samples. Of the highly persistent organochlorine compounds detected, only chlordane, commonly used for the control of termites, continues to be used on a wide spread basis. Four organochlorine pesticides were detected in at least 50 percent of samples analyzed—chlordane and lindane in streambed sediment, and DDT and DDE in fish tissue.

Fecal Indicator Bacteria

Elevated concentrations of fecal coliform bacteria generally were detected in two areas of the Kentucky River basin: the North Fork Kentucky River basin upstream of Jackson and the most populated area of the basin around Lexington and Frankfort. On the basis of observed seasonal pattern of concentration, point sources of fecal coliform predominate in the upper basin, and nonpoint sources account for more of the fecal coliform bacteria in water of the lower basin. Approximately 5 to 10 percent of the fecal coliform measurements obtained throughout the basin exceeded the Kentucky domestic water-supply criterion of 2,000 colonies per 100 milliliters of water. About 40 to 50 percent of all fecal coliform measurements exceeded the Kentucky criterion of 200 colonies per 100 milliliters for primary contact recreational water.

INTRODUCTION

Beginning in 1986, the Congress has annually appropriated funds for the U.S. Geological Survey to test and refine concepts for a National Water-Quality Assessment (NAWQA) Program. The long-term goals for a full-scale program would be to:

1. Provide a nationally consistent description of current water-quality conditions for a large part of the Nation's surface- and ground-water resources,
2. Define long-term trends (or lack of trends) in water quality, and
3. Identify, describe, and explain, as possible, the major factors that affect observed water-quality conditions and trends.

The results of the NAWQA Program will be 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 contemplated changes in land- and water-management practices. Concepts for a full-scale NAWQA Program are described by Hirsch and others (1988).

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.

At present (1990), the assessment program is in a pilot phase in seven project areas throughout the country that represent diverse hydrologic environments and water-quality conditions. Pilot project studies that focus primarily on surface water include the Yakima River basin in Washington; the lower Kansas River basin in Kansas and Nebraska; the Upper Illinois River basin in Illinois, Indiana, and Wisconsin; and the Kentucky River basin in Kentucky. Pilot project studies that focus primarily on ground water are the Carson basin in western Nevada and eastern California; the Central Oklahoma aquifer in Oklahoma; and the Delmarva Peninsula in Delaware, Maryland, and Virginia.

One of the initial activities undertaken in each pilot project is to compile, screen, and interpret the water-quality data available within each study unit. These data have been collected for widely differing purposes by a diverse group of organizations. This preliminary assessment will provide an initial description of water-quality conditions and will assist in the formulation of plans for project field activities. The assessment also will provide the foundation for identification of areas and reaches that have significant water-quality problems and will develop hypotheses about the causative factors that influence water-quality conditions.

Purpose and Scope

This report describes the sources and types of water-quality data that are available for the Kentucky River basin and provides a preliminary assessment of water-quality conditions and trends. The report illustrates the utility of available water-quality data for assessment; defines the types of water-quality data that are lacking; and describes regional water-quality conditions and trends, and their relations to natural and human factors.

Surface water-quality data are available at more than 550 sites in the basin. The quantity and the quality of available data are extremely variable; therefore, several screening techniques are utilized prior to data analysis. The screened data are divided into two data sets primarily based on historic watershed conditions and frequency of data collection at the sites. The "historical record" includes all data obtained during the period 1951 through September 1986, and is used primarily for determination of spatial variability in water-quality conditions. The "current-record" period includes only data collected during water years 1976 through 1986 and is used for determination of temporal variability, such as trends, in water-quality constituents.

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U.S. Army Corps of Engineers; U.S. Office of Surface Mining Reclamation and Enforcement; U.S. Soil Conservation Service; Kentucky Department of Agriculture; Kentucky Department of Environmental Protection; Kentucky Department of Fish and Wildlife Resources; Kentucky Department for Surface Mining, Reclamation, and Enforcement; Kentucky Geological Survey; Kentucky Water Resources Research Institute; Kentucky American Water Company; University of Louisville; Murray State University; Kentucky Resources Council; and the Lexington-Fayette Urban County Government.

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DESCRIPTION OF THE KENTUCKY RIVER BASIN

The Kentucky River flows through east-central Kentucky and drains an area of about 7,000 square miles (fig. 1). The river originates in the uplands of southeast Kentucky and flows northwestward through the central part of the State to its junction with the Ohio River at Carrollton in north-central Kentucky. The main stem of the Kentucky River, including the North Fork, is about 405 miles long. Other major tributaries of the Kentucky River include the Middle and South Forks Kentucky River, Red River, Dix River, Elkhorn Creek, and Eagle Creek.

A navigation system on the Kentucky River consists of 14 locks and dams that provide a minimum water depth of 6 feet from a point just downstream of the confluence of the North, Middle, and South Forks of the river to the mouth at Carrollton (pl. 1). Currently (1990), these locks and dams are operated on a seasonal basis for commercial and recreational traffic.

Principal municipalities, in downstream order, are: Hazard, Richmond, Danville, Lexington, Georgetown, Frankfort, and Carrollton. The Kentucky River drains all or parts of 39 of the State's 120 counties (fig. 1).

Physiography and Topography

The Kentucky River basin is in four physiographic regions: the Inner and Outer Bluegrass, the Knobs, and the Eastern Coal Field (fig. 2). Each of these regions is topographically distinct and reflects the underlying geology. The variation in soil type, land use, population distribution, surface-water features, and the prevailing water-quality characteristics and issues are largely attributable to the physiographic and geologic features.

The Kentucky River basin is underlain by sedimentary rocks of the Paleozoic age. As shown in figure 3, exposed rocks range in stratigraphic sequence from the Middle Ordovician to the Pennsylvanian Systems (McFarlan, 1943). Numerous faults cross the Kentucky River and its tributaries. The principal fault, known as the Kentucky River Fault, is responsible for the southwest-northeast directional character of the river in the middle part of the basin. Except for the Bluegrass Regions, only a thin layer of unconsolidated material overlies the bedrock in the basin.

Inner Bluegrass Region

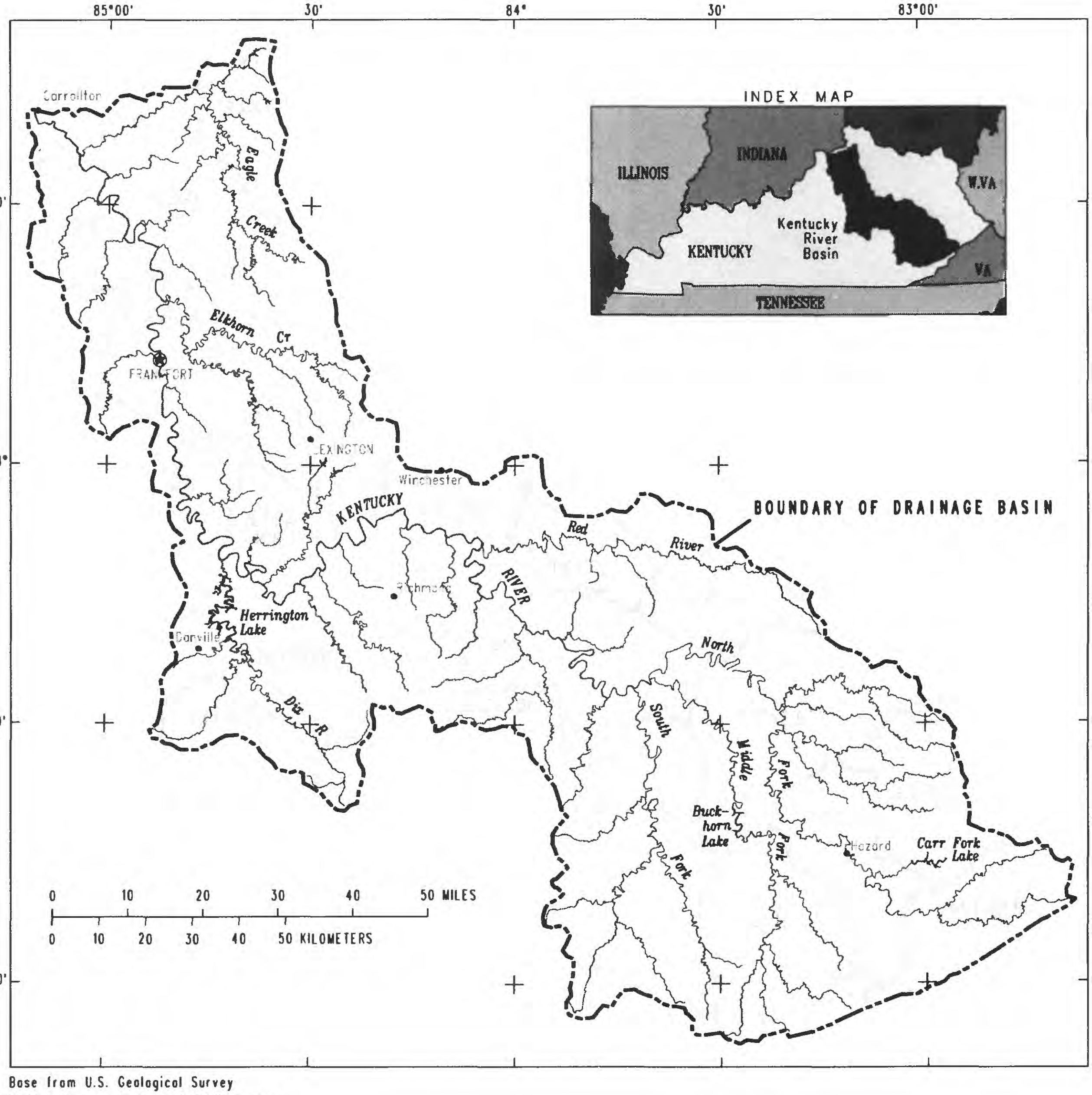
The north-central part of the basin lies within the Inner Bluegrass region. This region is a gently rolling upland underlain by thick-bedded phosphatic limestone of Ordovician age. The limestone of the Inner Bluegrass has been subjected to considerable weathering by solution, both on and beneath the surface, to produce an extensive area of karst topography. As a result, a substantial part of the drainage occurs through the subsurface. The karst topography is dotted with sinkholes, some as large as 60 feet deep and one square mile in area.

Soils in the Inner Bluegrass region developed from the phosphatic limestone. These soils have good drainage characteristics and are especially well suited for growing grasses for livestock and tobacco. The principal soil series are Maury soils on the gentler slopes and McAfee soils on the steeper slopes and in the areas of karst topography. These soils are moderately deep (20-80 inches) and consist of a silt loam surface layer and a clayey subsoil (U.S. Department of Agriculture, 1983).

Surface altitudes in the Inner Bluegrass region range from about 800 to 1,000 feet. The Kentucky River and some of its tributaries are entrenched more than 350 feet below the upland. Average slope of the Kentucky River in this region is about 0.7 foot per mile (Miller and others, [no date]). Elkhorn Creek is the only major tributary located entirely within the Inner Bluegrass region.

Outer Bluegrass Region

The northern half of the basin, not included in the Inner Bluegrass region, lies within the Outer Bluegrass region (fig. 2). The Outer Bluegrass region is underlain by thin-bedded limestones of Ordovician



Base from U.S. Geological Survey
Digital line graphs from 1:100,000 maps

Figure 1.--Kentucky River Basin.

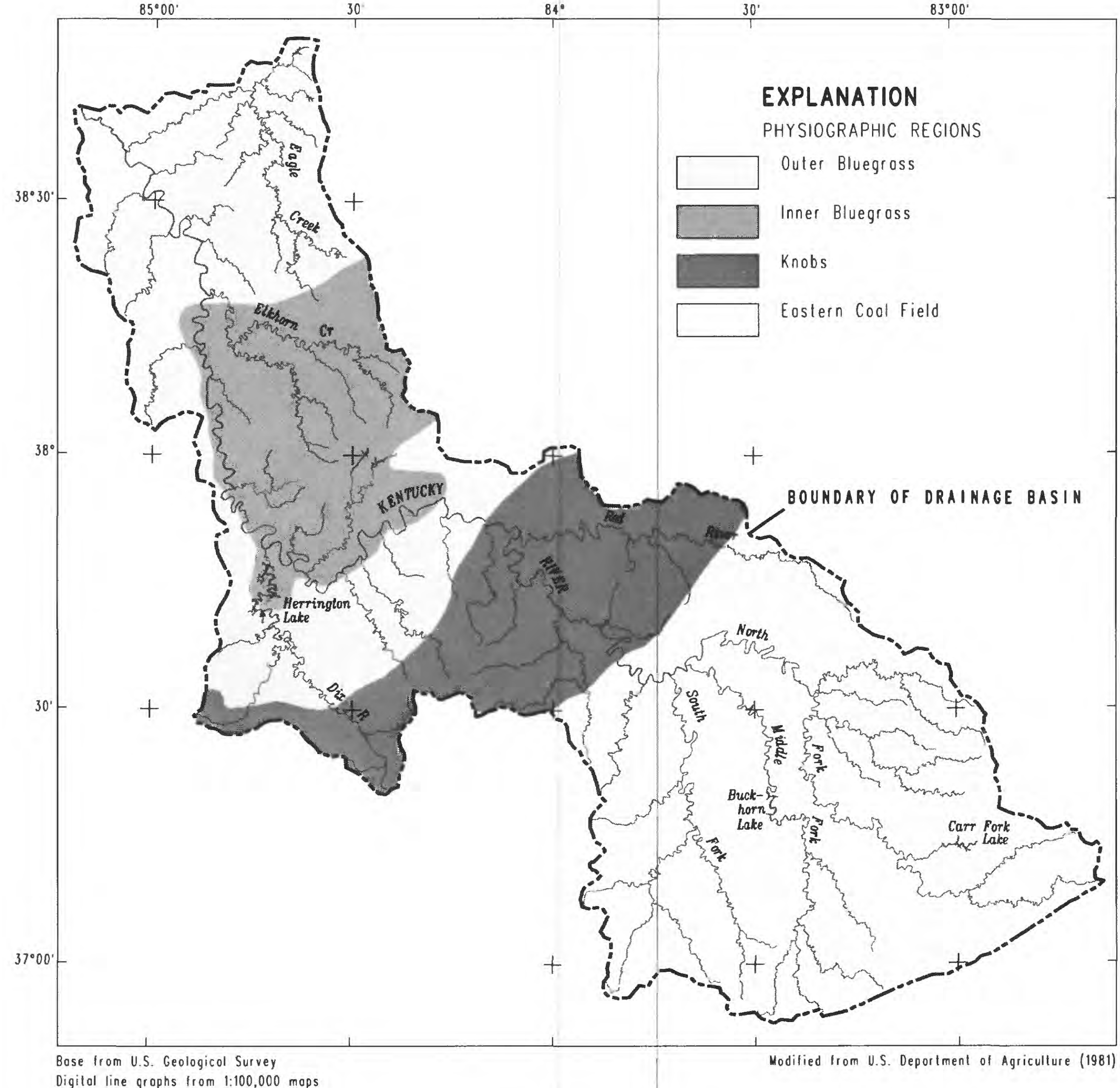


Figure 2.--Physiographic regions of the Kentucky River basin.

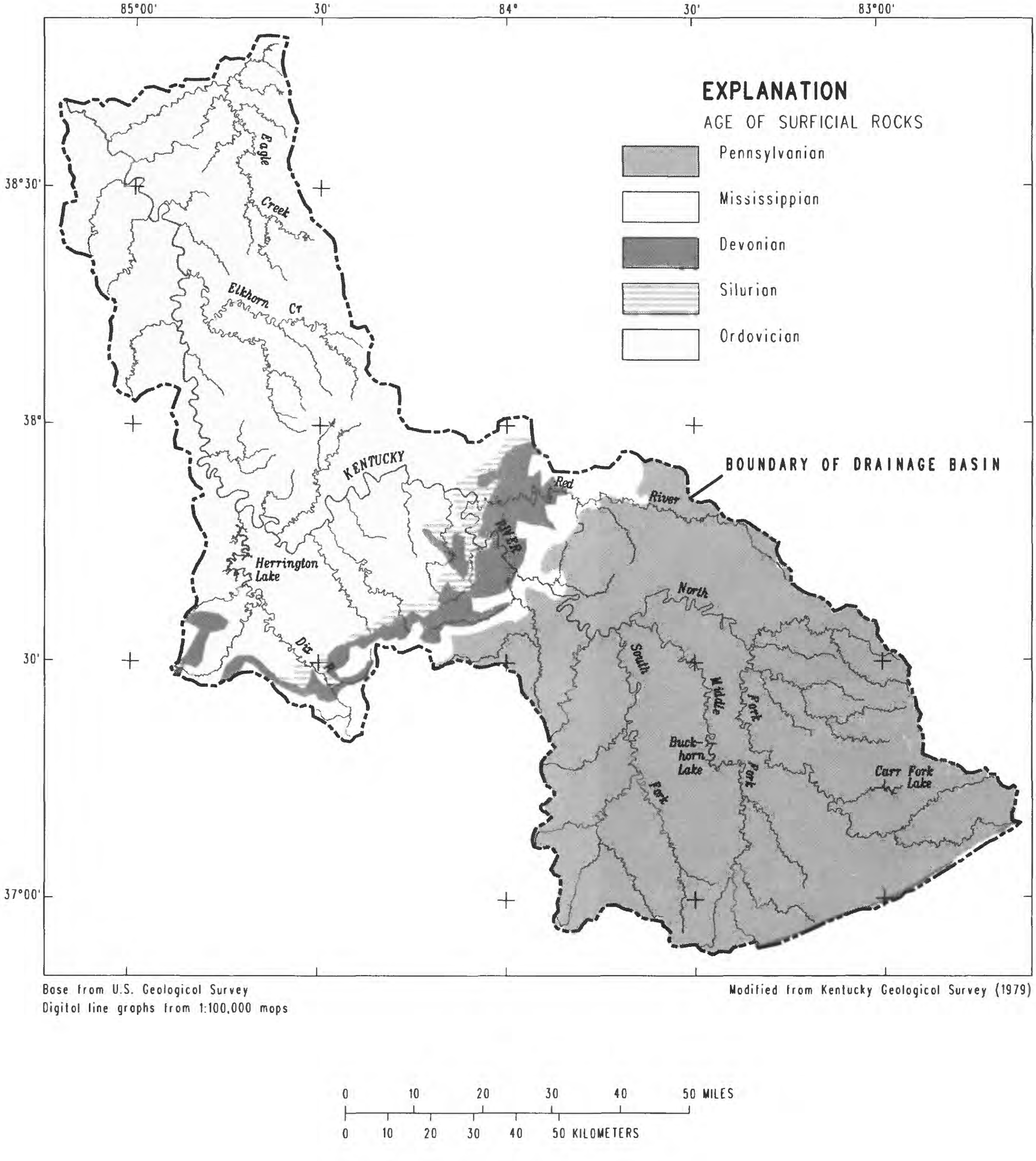


Figure 3.--Generalized geology of the Kentucky River basin.

age that include considerable interbedded shale (McFarlan, 1943, p. 172). Topography in this region resembles that of the Inner Bluegrass except near streams, where it is dissected and rugged. Some surface and subsurface solution has occurred and small sinkholes are fairly common, but most of the drainage is on the surface.

Soils in the Outer Bluegrass region developed from the limestone and interbedded shale and, in places, from overlying loess. These soils are moderately deep (20-50 inches) and are moderately drained. The principal soil series are Eden, Nicholson, Faywood, and McAfee (U.S. Department of Agriculture, 1981). All the soils in the region are generally suited to farming.

Surface altitudes in the Outer Bluegrass typically range from 800 to 1,000 feet. The Kentucky River is deeply entrenched through this region; normal river altitudes range from about 420 feet at Carrollton to about 580 feet near Richmond. The average slope on the main stem in the Outer Bluegrass region is 0.7 foot per mile (Miller and others, [no date]). The steepest slopes of most tributaries in the Outer Bluegrass region occur where the streams drop down to the Kentucky River from the upland areas. Eagle Creek and the Dix River are major tributaries draining the Outer Bluegrass region.

Knobs Region

The Knobs region forms a crescent separating the Bluegrass regions from the Eastern Coal Field region and is named for its characteristic conical and flat-topped hills. These characteristic hills, which are erosional remnants, are comprised of sandy limestone and sandstone caprock of Mississippian age over shales of Devonian age. Broad valleys underlain by shale separate the hills.

Soils on hillsides in the Knobs region developed from the limestone, shale, and sandstone. The Rockcastle and Colyer series, shallow (15-20 inches), clayey soils that have developed on shale residuum on steep slopes, predominate. Soils in the valleys of the Knobs region are poorly drained because of the presence of a dense, subsurface layer of compacted silt overlying shale (U.S. Department of Agriculture, 1981).

Surface altitudes in the Knobs region range from about 600 feet to more than 1,600 feet. Average slope of the Kentucky River in this region is about 0.7 foot per mile, the same as the deeply entrenched downstream reaches. The major tributaries are the Red River draining the northern part and Station Camp Creek draining the southern part of the Knobs region.

Eastern Coal Field Region

The Eastern Coal Field region, in the southern part of the basin, is a very rugged, dissected peneplain consisting of narrow valleys and narrow, steep-sided ridges. Rocks of the region are of Pennsylvanian age and are mainly sandstone, siltstone, and shale with numerous interbedded coal beds.

Soils in the Eastern Coal Field are formed from siltstones, sandstones, and shales. The most prevalent soil series are Shelocta, Jefferson, and Latham, which are moderately deep (20-50 inches), well-drained soils located toward the base of the mountain sides and on benches adjacent to the larger streams (U.S. Department of Agriculture, 1981).

Mountain-top altitudes in the Eastern Coal Field region range from about 1,000 feet to more than 3,000 feet. Average slope of the Kentucky River in this region is about 0.9 foot per mile (Miller and others, [no date]). Major streams draining this region include the North, South, and Middle Fork Kentucky River.

Land Use and Population

The Kentucky River basin has three major land covers: forest, agriculture, and urban. Within each land cover area are scattered or concentrated areas of commercial or industrial use and other activities. The distribution of these land covers is shown in figure 4.

Forests

Forests comprise about 50 percent of the basin land area, and the largest are in the more rugged parts of the Eastern Coal Field region. The Kentucky River basin is in or near the prime range of many of the most prominent hardwood timber species. Hardwoods constitute more than 90 percent of the timber volume. An assortment of pines and eastern red cedar comprise the nonhardwood species. Hickory and poplar are the most prevalent forest tree species, each comprising about 13 percent of the growing stock (U.S. Department of Agriculture, 1981).

Agriculture

Nearly 40 percent of the basin is used for agricultural purposes (U.S. Department of Agriculture, 1981). Farming is concentrated on the rolling uplands of the Inner and Outer Bluegrass regions, but some farming takes place on the level upland ridge tops and benches in the larger stream valleys of the Eastern Coal Field region of the basin. Tobacco, livestock (including horse farms), and corn are the dominant enterprises. Of the three, tobacco occupies the least land area, but it is generally the crop with the highest value. Soy beans and wheat also are grown in parts of the basin, but usually in small quantities.

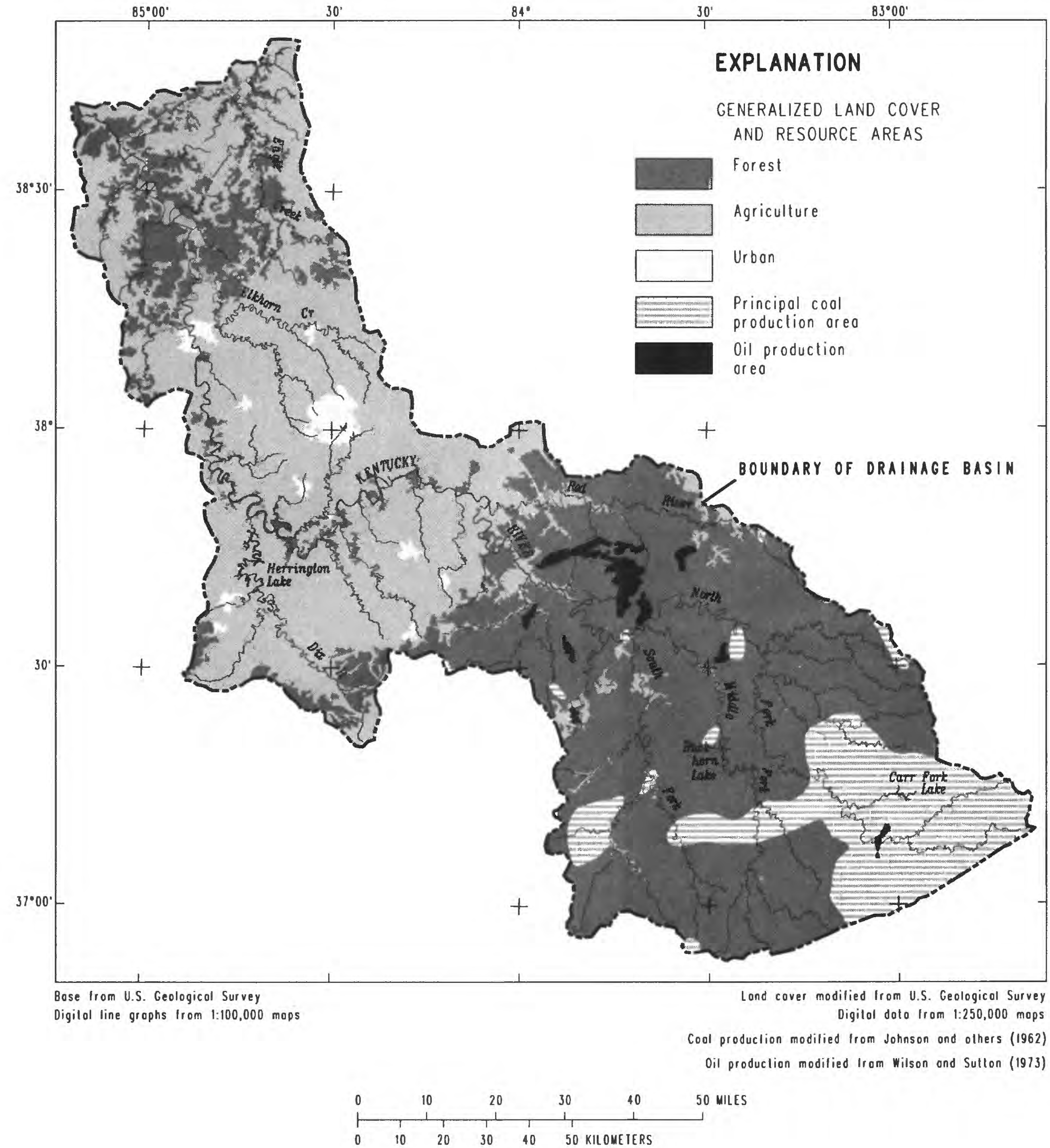


Figure 4.--Generalized land cover and major mineral resource areas in the Kentucky River basin.

Coal Mining

Mining of bituminous coal, both at the surface and underground, is a significant land-use activity in the Eastern Coal Field region of the Kentucky River basin. Kentucky is the nation's largest coal producing State and out-produces its nearest State rival by 29 million tons annually (Stanley, 1985). In 1985, 23 percent of the 170 million tons of coal mined in the State was produced in counties within the Kentucky River basin. Of the approximately 40 million tons mined in the basin annually, 55 percent was from underground mines (Stanley, 1985). Ninety-three percent of the coal is mined in Perry, Breathitt, Knott, Leslie, and Letcher Counties. It is estimated that when market demand is high, there are more than 1,200 active mines in these counties, employing about 13,500 people. Approximately 98,000 acres of land in the area have been affected by coal mining activities. Of the acreage affected by mining, about one-half has been reclaimed and revegetated. Geological studies indicate that there are 3.4 billion tons of coal reserves in the area (U.S. Department of Agriculture, 1981). The distribution of these reserves is shown in figure 4. During the period 1976-86, the amount of coal mined in the Kentucky River basin and in other counties in the eastern part of Kentucky was increasing at a rate of about 4 percent per year (Kentucky Department of Mines and Minerals, written commun., 1987).

Oil and Gas Production

Production of oil and gas is a major activity in parts of the Knobs and Eastern Coal Field regions, particularly in Lee, Estill, and Powell Counties (fig. 1). About one million barrels of oil were extracted from the basin in 1980 (Stanley, 1980). Annual oil production in the State of Kentucky approached 6.5 million barrels in 1981 representing 0.2 percent of the Nation's total production (Kentucky Natural Resources and Environmental Protection Cabinet, 1984b). Production of natural gas in Kentucky was about 63 billion cubic feet in 1981, or 0.33 percent of that produced nationally (Kentucky Natural Resources and Environmental Protection Cabinet, 1984b). The spatial distribution of oil reserves in the basin is shown in figure 4.

Population

The Kentucky River basin is the most densely populated river basin in Kentucky and is projected to be the area of most population and industrial growth in the future. As of 1980, about 632,000 people resided in the basin of which about 50 percent are in urban centers having a population of at least 2,500 (U.S. Department of Commerce, 1982). About two-thirds of the urban center residents are in the greater Lexington area.

Urban centers are more numerous in the Inner and Outer Bluegrass regions, and they include Lexington (population 204,165), Frankfort (population 25,973), Richmond (population 21,075), Danville (population 12,942), Georgetown (population 10,972), and Carrollton (population 3,967) (plate 1). The city of Hazard (population 5,429) is the largest urban center located in the sparsely populated Eastern Coal Field region. There are no major cities in the Knobs region.

Climate

The climate of the Kentucky River basin is classified as "moist-continental" by Strahler and Strahler (1979). Mean-annual air temperature is 56 °F (13 °C). The coldest months are January and February, during which daily minimum temperatures average 25 °F (-4 °C); the warmest months are July and August, during which daily-maximum temperatures average 87 °F (31 °C) (U.S. Department of Agriculture, 1981).

The growing season, which is defined as the number of days from the last damaging frost in the spring to the first frost in the fall, averages 184 days. The last frost is usually in April and the first is in October.

Annual precipitation averages about 46 inches and ranges from about 40 inches in the northern part of the basin to greater than 50 inches in the southern part of the basin (Elam and others, 1972). The monthly distribution of precipitation is fairly uniform with October usually having the least amount (averaging 2.34 inches) and March the largest amount (averaging 4.60 inches) (Conner, 1982). Snowfall is highly variable; an average season usually has about 14 days with one or more inches of snowcover on the ground. Thunderstorms occur about 48 days a year, but are more frequent in the spring and summer.

Variations in the water budget occur seasonally and areally throughout the basin. Basinwide, about 63 percent of the 46 inches of annual precipitation returns to the atmosphere through evaporation and transpiration, about 28 percent runs off the surface directly into streams, and about 9 percent enters the ground (Miller and others, [no date]). During the summer months, evapotranspiration tends to be greater in the forested headwater region of the basin than in the agricultural areas of the Bluegrass. Within the basin, there is also a considerable difference in the amount of rainfall runoff and the amount of recharge to the ground-water system. Runoff is greater in the mountains of the Eastern Coal Field than it is in the rolling Inner and Outer Bluegrass regions. In the karst areas of the Bluegrass regions, a substantial amount of rainfall enters the ground-water through numerous sinkholes (Miller and others, [no date]).

Surface-Water Hydrology

The Kentucky River hydrologic system consists of about 3,500 stream miles (U.S. Geological Survey, 1974). The drainage network of the basin is shown on plate 1.

Streamflow varies throughout the basin reflecting seasonal and areal variations in the climate and differences in land use, geology, and topography. Because many streams in the Inner and Outer Bluegrass regions flow through highly permeable karst terrane, surface-water/ground-water interaction is substantial. As a result, many streams commonly have dry and flowing reaches as water moves from one system to the other.

The average annual unit flow of streams in the study area is about 1.4 cubic feet per second per square mile [$(ft^3/s)/mi^2$] and is relatively uniform throughout the basin. However, unit flows during hydrologic extremes differ widely throughout the basin. Peak discharge of streams in Kentucky has been shown to be related to drainage area size, and basin morphologic characteristics, including main channel slope, basin shape, and channel sinuosity (Choquette, 1987). Peak discharge, drainage area, main channel slope, and other characteristics of selected streams in the Kentucky River basin are listed in table 1. Streams with steep main channel slopes have correspondingly higher peak flows per unit area than streams with mild main channel slopes. Unit peak flow having a 100-year recurrence interval in the basin ranged from 344 $(ft^3/s)/mi^2$ at Cutshin Creek at Wooton (site 2.2, channel slope equal to 45 ft/mi) to 18.3 $(ft^3/s)/mi^2$ at Kentucky River at Lock 2, at Lockport (site 10.0, channel slope equal to 1.4 ft/mi).

Low-flow statistics such as the 7-day, 10-year low flow of a stream are often used as measures of the dependable flow during periods of moderate drought and are commonly used in the design of storage and withdrawal facilities and in permitting waste discharges. The 7-day, 10-year low flows for selected streams in the basin are listed in table 1. It should be noted that low-flow is not closely related to drainage area size, but is related to geologic and topographic factors. For example, drainage area and average discharge are similar for the Dix River near Danville (site 5.2) and the Red River at Clay City (site 3.3, table 1). However, because of differences in geology, topography, and land use, low-flow characteristics of the two streams are quite different. For the period of available record, the 7-day, 10-year low-flow discharge was zero for the Dix River (site 5.2) and 3.7 ft^3/s for the Red River (site 3.3). Of the 18 sites with 7-day, 10-year low-flow discharges for the current-record period (1976-86) listed in table 2, nine were equal to or less than the long-term low-flow discharges listed in table 1.

No major natural lakes are present in the Kentucky River basin, but many reservoirs have been constructed for meeting various water-supply needs and for flood protection. Fifteen reservoirs in the basin have a volume greater than 1,000 acre-feet or surface area greater than 100 acres. These reservoirs have a total combined volume of 286,000 acre-feet and a total combined surface area of 6,530 acres (Miller and others, [no date]).

Three lakes—Herrington, Buckhorn, and Carr Fork (pl. 1)—comprise approximately 75 percent of the total reservoir surface area and 90 percent of the total reservoir volume in the basin (Miller and others, [no date]). Buckhorn Lake (21,800 acre-feet) and Carr Fork Lake (6,480 acre-feet) are regulated by the U.S. Army Corps of Engineers to meet flood, recreation, fish and wildlife, and low-flow augmentation objectives (U.S. Army Corps of Engineers, 1981). Buckhorn Lake, located in Perry County, is on the Middle Fork of the Kentucky River. The lake covers 1,230 acres and has a drainage area of 409 square miles. Carr Fork Lake, located in Knott County, is located on Carr Fork, a tributary of the North Fork of the Kentucky River. The lake covers 710 acres and has a drainage area of 58 square miles (U.S. Department of Agriculture, 1981). Herrington Lake (230,500 acre-feet) is maintained and operated by a private utility for use in electric power generation for public consumption. Herrington Lake is also a source of water for the public water-supply systems for the city of Danville and the Kentucky State Hospital. The lake, which lies in the Dix River basin, contains a usable storage volume of 123,200 acre-feet, covers 2,940 acres, and has a drainage area of 439 square miles (Miller and others, [no date]; U.S. Department of Agriculture, 1981).

Operation of reservoirs for flood control and low-flow augmentation in the basin has resulted in moderation of flow extremes downstream. Each spring, reservoir storage is increased to prepare for low-flow augmentation during mid to late summer, and each fall reservoir storage is decreased to prepare for winter high-flow periods. Regulation has resulted in lower high-flow periods and higher low-flow periods. Flow-duration curves prior to and since regulation reflect this flow moderation. Flow-duration curves for the Kentucky River at Lock 14 (site 3.0) are typical of those for regulated streams in the basin (fig. 5).

Table 1.—*Streamflow and basin characteristics at selected sites in the Kentucky River basin*

[ft/mi, feet per mile; ft^3/s, cubic feet per second; $ft^3/s/mi^2$, cubic feet per second per square mile]

Site number	USGS station name	Drainage area (square miles)	Channel slope (ft/mi)[1]	Period of record (water years)	Average discharge (ft^3/s)	Average runoff ($ft^3/s/mi^2$)	Peak 100-year unit discharge ($ft^3/s/mi^2$)[1]	7-day, 10-year low flow, (ft^3/s)[1]
0.2	Carr Fork near Sassafras	60.6	17	1965-86	75.5	1.25	105	0.02
1.0	North Fork Kentucky River at Hazard	466	7.4	1941-86	575	1.23	115	2.1
2.0	North Fork Kentucky River at Jackson	1,101	4.6	1929-31, 1939-86	1,350	1.22	66.1	3.1
2.1	Middle Fork Kentucky River near Hyden	202	29	1958-86	293	1.45	318	.28
2.2	Cutshin Creek at Wooton	61.3	45	1958-86	94.2	1.54	344	.09
2.3	Middle Fork Kentucky River at Tallega	537	4.7	1931, 1940-86	722	1.34	95.7	.64
2.4	Red Bird River near Big Creek	155	18	1973-86	274	1.77		.1
2.5	Goose Creek at Manchester	163	14	1965-86	262	1.61	224	.73
2.6	South Fork Kentucky River at Booneville	722	5.1	1926-31, 1940-86	1,050	1.45	114	1.1
3.0	Kentucky River at Lock 14, at Heidelberg	2,657	3.2	1926-31, 1939-86	3,610	1.36	60.2	22
3.1	Red River near Hazel Green	65.8	8.2	1955-86	87.4	1.33	142	0
3.3	Red River at Clay City	362	6.0	1931, 1939-86	477	1.32	90.9	3.7
4.0	Kentucky River at Lock 10, near Winchester	3,955	20	1908-86	5,230	1.32	28.3	42
5.2	Dix River near Danville	318	4.1	1943-86	461	1.45	108	0
6.0	Kentucky River at Lock 6, near Salvisa	5,102	1.6	1926-86	6,670	1.31	24.5	136
8.0	Kentucky River at Lock 4, at Frankfort	5,411	1.5	1926-86	7,030	1.30	20.9	175
9.2	South Elkhorn Creek at Fort Spring	24.0	16.5	1951-86	32.2	1.34	114	0
10.0	Kentucky River at Lock 2, at Lockport	6,180	1.4	1926-86	8,220	1.33	18.3	206

[1]From Melcher and Ruhl (1984).

Table 2.—*Streamflow statistics at selected sites in the Kentucky River basin, based on available data for water years 1976-86*

[ft^3/s, cubic feet per second; exceedance frequency, percentage of time that indicated discharge was equaled or exceeded; index of variability, dimensionless, is the 10th minus the 90th percent exceedance frequency discharge divided by the median discharge]

Site number	USGS station name	Mean annual discharge (ft^3/s)	Lowest 7-day mean discharge (ft^3/s)	Discharge for indicated exceedance frequency (ft^3/s)			Index of variability
				90	50	10	
0.2	Carr Fork near Sassafras	66.9	0.62	4.5	25	167	6.5
1.0	North Fork Kentucky River at Hazard	541	11	47	242	1,170	4.6
2.0	North Fork Kentucky River at Jackson	1,300	34	117	591	2,950	4.8
2.1	Middle Fork Kentucky River near Hyden	266	0	9.5	100	606	6.0
2.2	Cutshin Creek at Wooton	83	.08	2.6	31	181	5.8
2.3	Middle Fork Kentucky River at Tallega	678	15	56	272	2,150	7.7
2.4	Red Bird River near Big Creek	240	.94	7.0	74	524	7.0
2.5	Goose Creek at Manchester	252	.16	5.9	91	557	6.1
2.6	South Fork Kentucky River at Booneville	1,010	1.9	37	348	2,300	6.5
3.0	Kentucky River at Lock 14, at Heidelberg	3,480	58	273	1,460	8,730	5.8
3.1	Red River near Hazel Green	83.5	0	2.5	33	180	5.4
3.3	Red River at Clay City	461	3.6	30	185	1,040	5.5
4.0	Kentucky River at Lock 10, near Winchester	4,900	122	309	2,160	12,510	5.6
5.2	Dix River near Danville	497	0	7.6	138	1,161	8.4
6.0	Kentucky River at Lock 6, near Salvisa	6,270	130	437	2,840	15,900	5.4
8.0	Kentucky River at Lock 4, at Frankfort	6,620	166	511	3,040	16,100	5.1
9.2	South Elkhorn Creek at Fort Spring	32	.78	2.9	13	74	5.5
10.0	Kentucky River at Lock 2, at Lockport	7,790	184	671	3,610	18,700	5.0

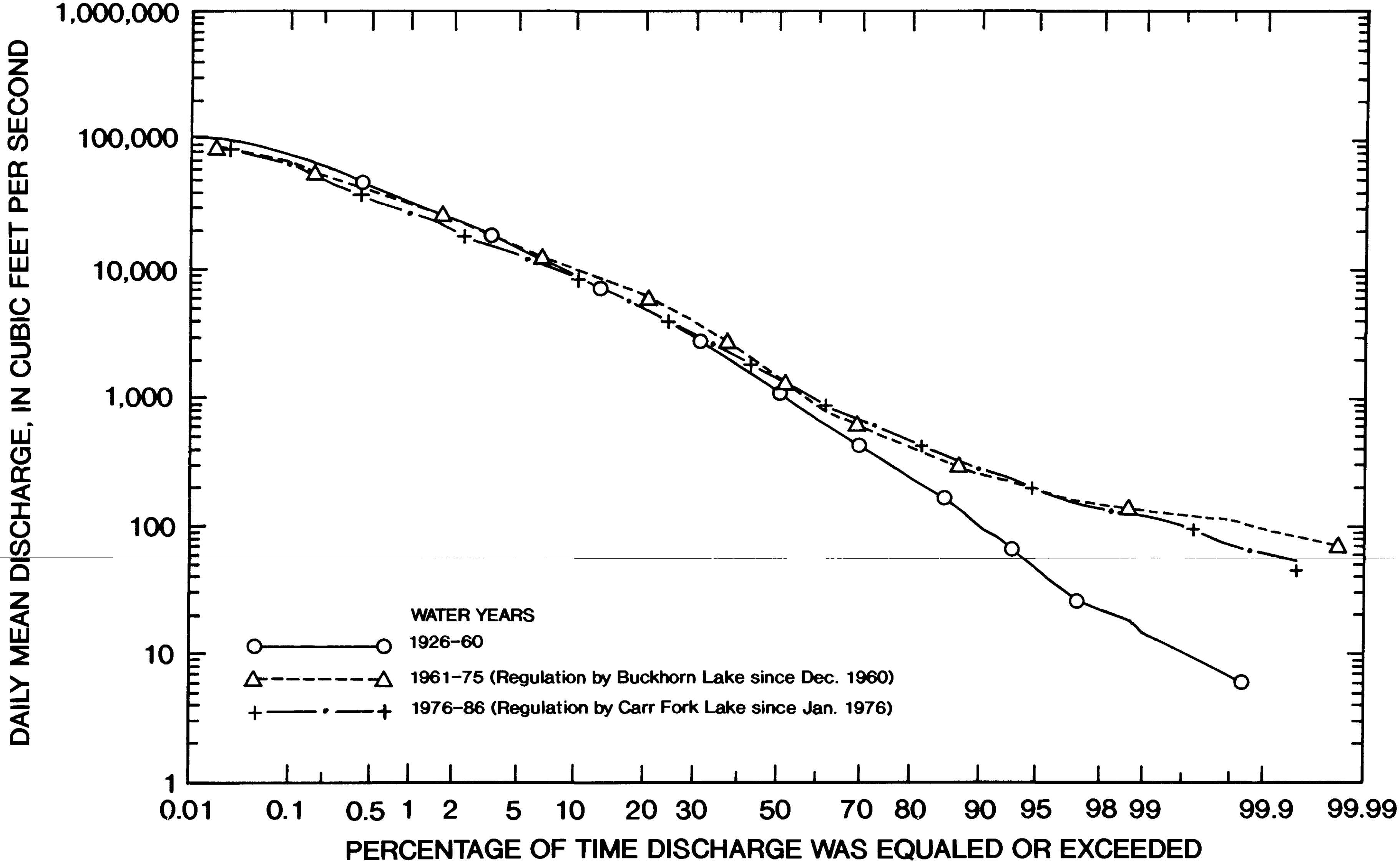


Figure 5.--Flow duration at Kentucky River at Lock 14, at Heidelberg, water years 1926-60, 1961-75, and 1976-86.

Water Use

The Kentucky River and its tributaries are used extensively for public and industrial water supply, recreation, propagation of fish and wildlife, and municipal and industrial waste discharge and assimilation. Surface water from the Kentucky River and its tributaries including Herrington Lake is the source for more than 95 percent of the water supplied by public water-supply systems in the basin. Twenty municipalities use the Kentucky River for public water supply. The largest of these municipalities are Lexington, Frankfort, and Richmond.

The potential for substantial and wide-spread water-supply shortages is greater in the Kentucky River basin than any other river basin in the State. Water withdrawals in the Kentucky River basin were about 253 Mgal/d in 1985. About 95 percent of this amount (240 Mgal/d) was obtained from surface-water sources (fig. 6) (Sholar, 1988; Sholar and Lee, 1988). The Kentucky River and its major tributaries, and the reservoirs within the basin supplied most of this water. The flow at the mouth of the Kentucky River is less than the average annual surface-water withdrawal rate in the basin about 4 percent of the time (Quiñones and others, 1980).

Offstream water-use estimates are available for the following withdrawal categories: thermoelectric power; public supply; and domestic, industrial, commercial, livestock, irrigation, and mining uses. Of these eight categories, about 64 percent (153 Mgal/d) of the surface-water withdrawals was used for cooling purposes in the production of thermoelectric power (Sholar, 1988).

Public supplies accounted for 70.1 Mgal/d, or 29 percent of the total surface water withdrawn in the Kentucky River basin in 1985. More than 99 percent of the withdrawals for public water supply in this basin were from surface-water sources. Four public suppliers in Fayette, Franklin, Boyle, and Clark Counties withdrew 49.1 Mgal/d or 70 percent of the surface water withdrawn. More than 50 percent of the withdrawals for public supply in the basin are for the Lexington-Fayette County area (Sholar, 1988). Surface-water withdrawal points for public, industrial, and commercial supply are shown in figure 7.

Domestic, industrial, and commercial water users depended on public-supplied deliveries for most of their water. Domestic water use in the basin was estimated to be 40.9 Mgal/d in 1985. Of this amount, 30.9 Mgal/d was delivered to more than 466,000 people from public suppliers. Per capita use was estimated to be 50 gallons per day (gal/d) for self-supplied domestic users and 66 gal/d for domestic users of public supply. A summary of public-supplied deliveries is shown in figure 6.

The amount of water consumed, or no longer readily available for reuse in the Kentucky River basin in 1985, was 35.2 Mgal/d (fig. 6). Domestic use accounted for about 44 percent (15.4 Mgal/d) of the total consumptive use.

Eleven municipal wastewater treatment facilities are permitted to discharge more than 1 million gallons per day (Mgal/d) of effluent in the Kentucky River basin. The locations of these treatment facilities are shown in figure 8. Another 30 municipal wastewater treatment facilities are permitted to discharge wastewater quantities of less than 1 million gallons per day. In addition, there are 293 small domestic wastewater treatment facilities permitted to operate within the Kentucky River basin.

Twenty-nine industrial facilities are permitted to discharge more than 1 Mgal/d of wastewater to surface water in the Kentucky River basin. The location of these industrial facilities are shown in figure 9. Forty-seven industries and one landfill are permitted to discharge more than 50,000 gallons per day but less than 1 Mgal/d. Additionally, 48 industrial facilities, 12 agricultural operations, and two landfills have wastewater treatment facilities that are excluded from State permitting procedures (R. Ware, Kentucky Natural Resources and Environmental Protection Cabinet, written commun., 1986).

Water-Quality Criteria and Stream Classification

Primary water-quality criteria for public health, aquatic life, and recreation are established by the Federal government. The Federal criteria are then used by the states as a guideline to establish criteria for local conditions based on site-specific analyses.

Federal

Federal authority for the protection of water-quality is provided by the Clean Water Act, which was most recently amended in 1987. The U.S. Environmental Protection Agency is the principal Federal agency responsible for the development and implementation of the programs called for by this statute. Section 304(a)(1) of the Act requires the U.S. Environmental Protection Agency to publish and periodically update ambient water-quality criteria. A water-quality criterion is a numerical or narrative statement for a single contaminant reflecting the latest scientific knowledge on the identifiable effects of the pollutant on public health and welfare, aquatic life, and recreation. The criteria are not rules and they have no regulatory effect. Rather, these criteria present scientific data and guidance which can be used to derive regulatory requirements based on considerations of water-quality effects (U.S. Environmental Protection Agency, 1980).

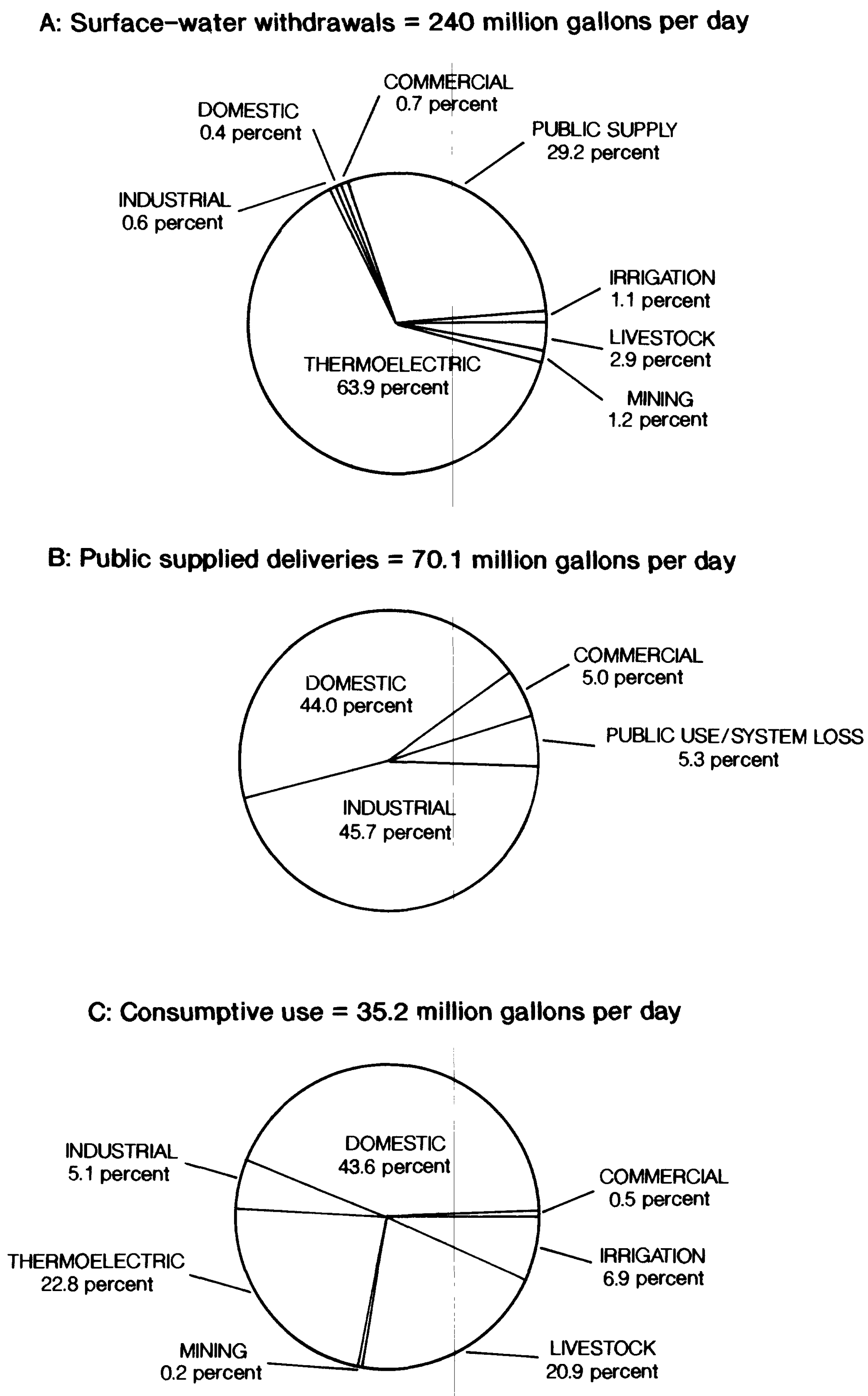


Figure 6.--Surface-water withdrawals, public-supplied deliveries, and consumptive use for offstream water-use categories in the Kentucky River basin, 1985.

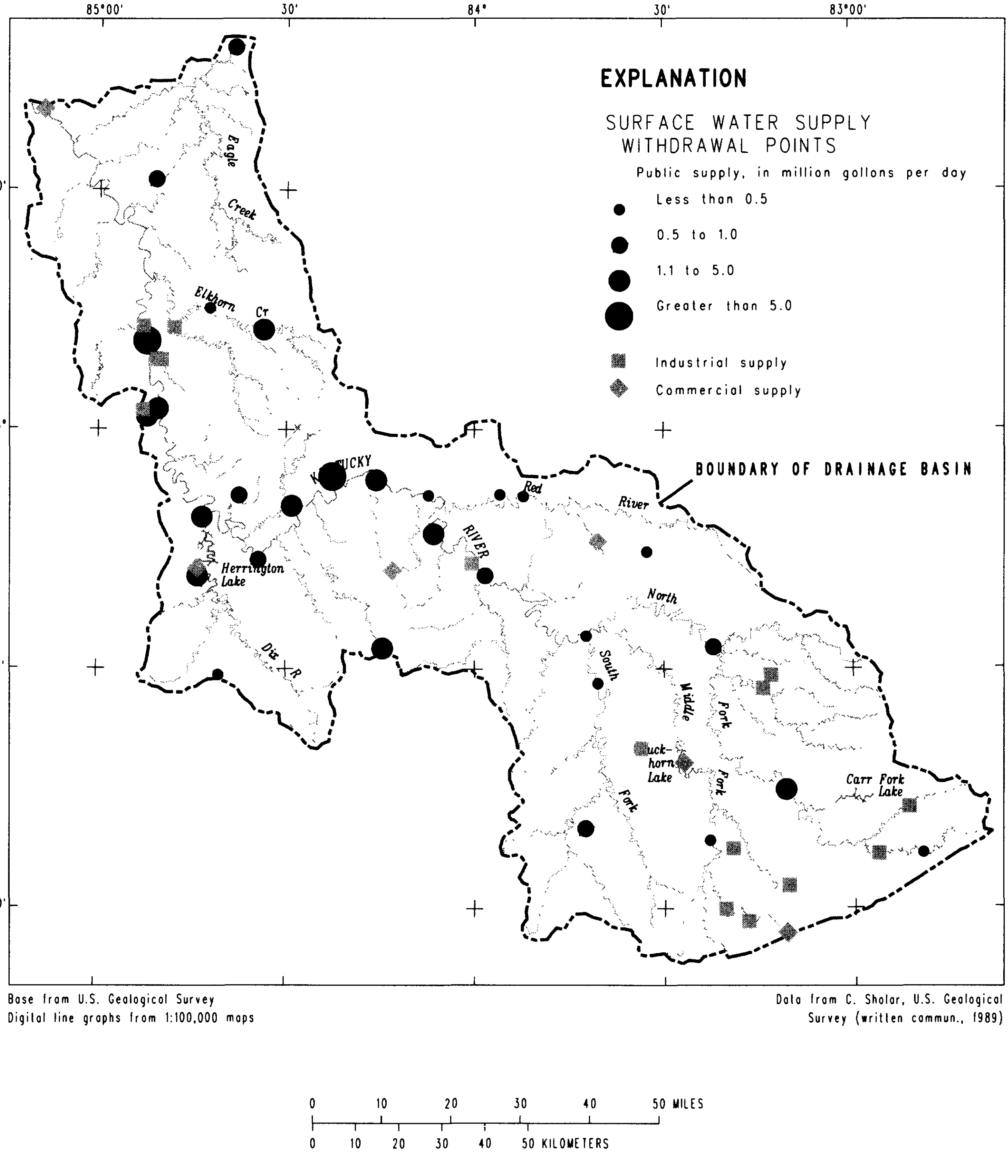


Figure 7.--Locations of surface-water withdrawals for public, industrial, and commercial supply in the Kentucky River basin, 1985.

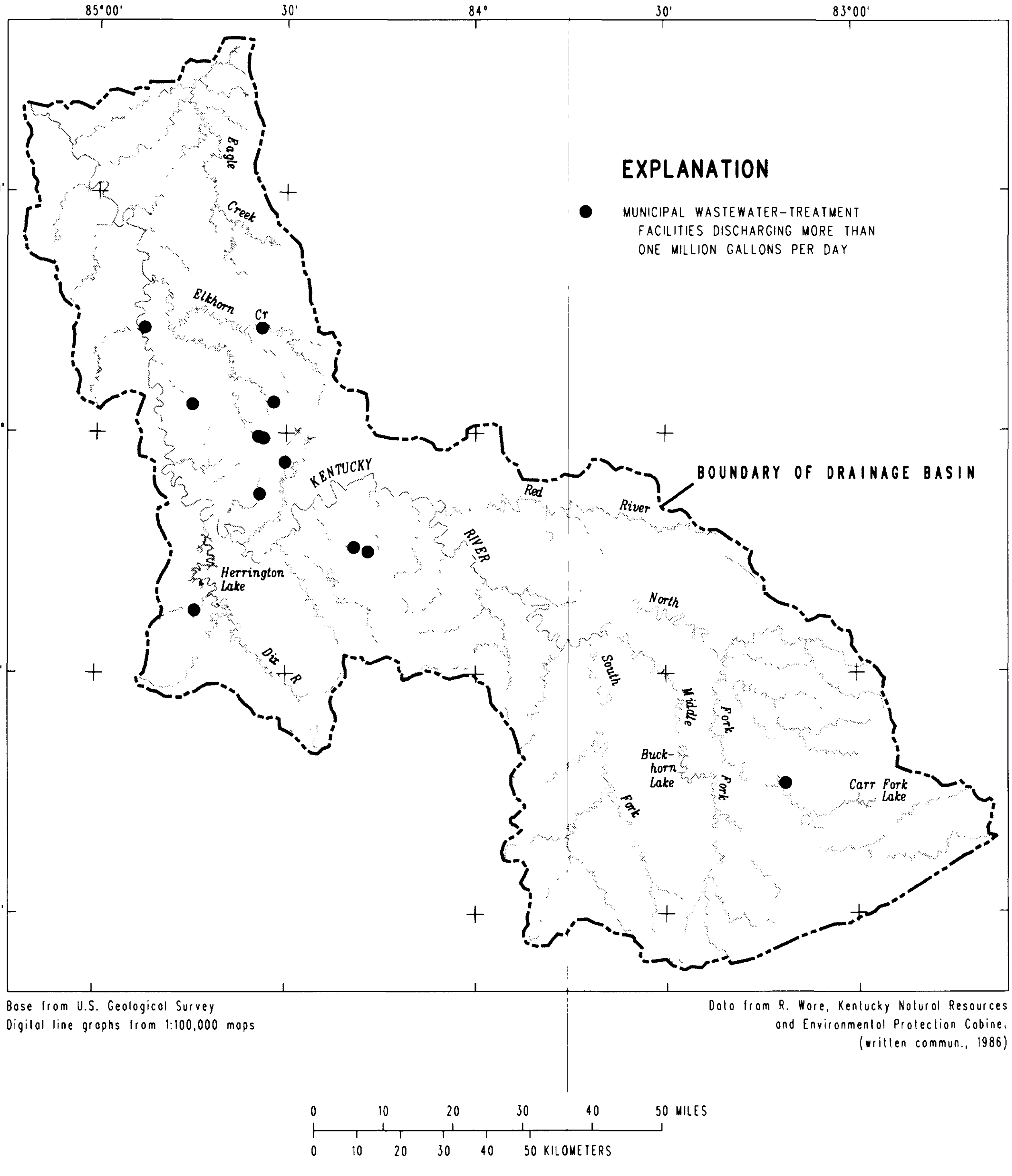


Figure 8.--Locations of municipal wastewater-treatment facilities that discharge more than one million gallons of effluent per day in the Kentucky River basin, 1986.

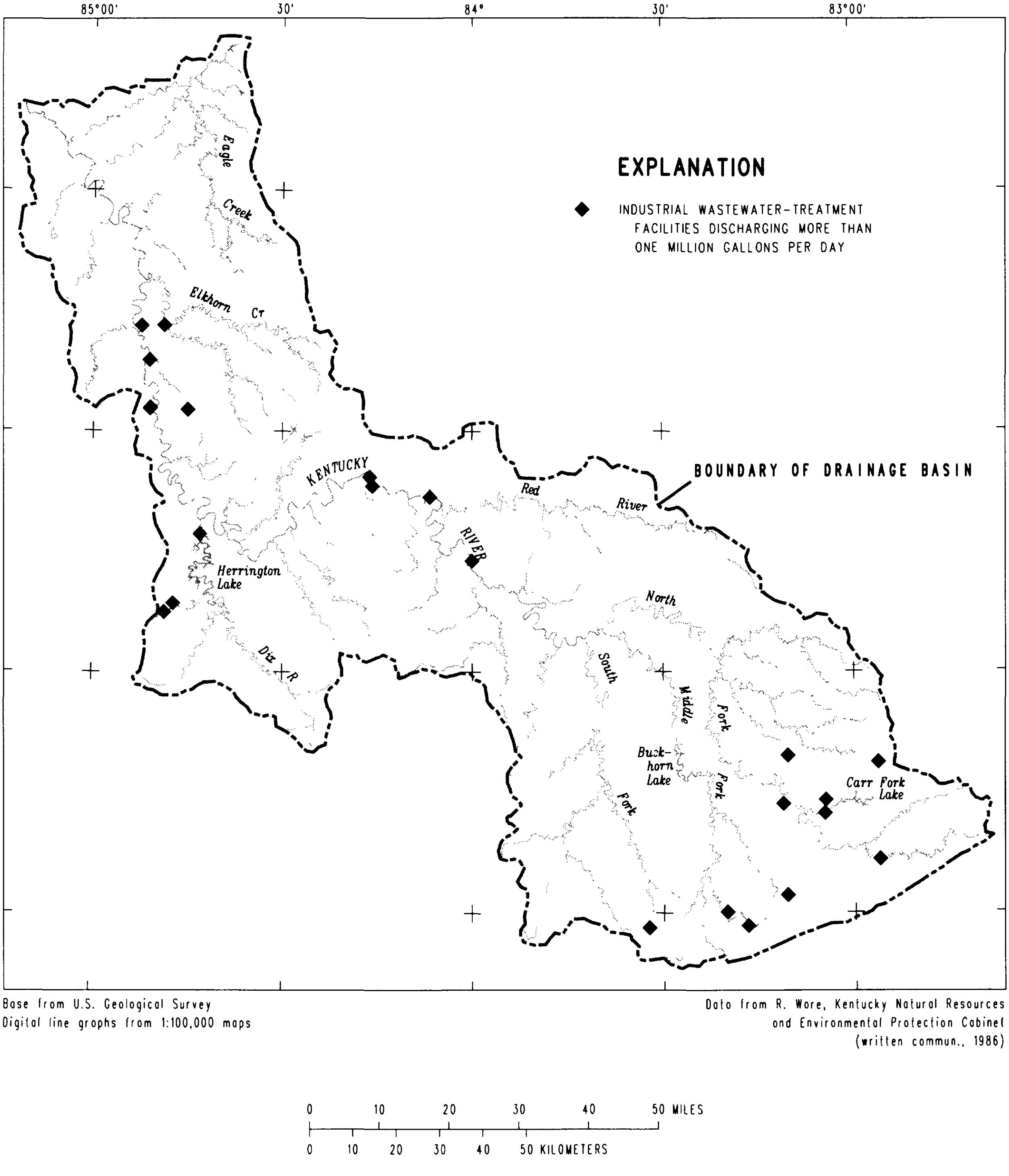


Figure 9.--Locations of industrial wastewater-treatment facilities that discharge more than one million gallons of effluent per day in the Kentucky River basin, 1986.

Table 3.—*Selected Federal water-quality criteria for freshwater aquatic life*

[U.S. Environmental Protection Agency, 1986a]

[mg/L, milligrams per liter; <, less than; µg/L, micrograms per liter; *, hardness level of 100 mg/L used to calculate criteria; **, lowest observed effect level]

Constituent or property	Aquatic life acute[1]	Aquatic life chronic[2]
Alkalinity, in mg/L as $CaCO_3$		< 20
Ammonia, total, in mg/L	Criteria pH and temperature dependent	
Arsenic, total trivalent, in µg/L as As	360	190
Cadmium, total, in µg/L as Cd	3.9*	1.1*
Chromium, total, in µg/L as Cr		
Chromium, hexavalent	16	11
Chromium, trivalent	1,700*	210*
Copper, total, in µg/L as Cu	18*	12*
Cyanide, total, in mg/L as Cn	.022	.0052
Dissolved oxygen, in mg/L	<3.0-4.0	<5.5
Iron, total, in µg/L as Fe		1,000
Lead, total, in µg/L as Pb	82*	3.2*
Mercury, total, in µg/L as Hg	2.4	.012
Nickel, total, in µg/L as Ni	1,800*	96*
pH, in standard units		6.5-9.0
Phenol, in µg/L	10,200**	2,560**
Phthalate esters, in µg/L	940**	9**
Selenium, total, in µg/L as Se	260	35
Silver, total, in µg/L as Ag	4.1*	.12
Temperature, in degrees Celsius	Species dependent criteria	
Zinc, total, in µg/L as Zn	320*	47

[1]Highest 1-hour average concentration that should not cause unacceptable toxicity to aquatic organisms during short-term exposure.

[2]Highest 4-day average concentration that should not cause unacceptable toxicity to aquatic organisms during long-term exposure.

Section 303 of the Act specifies that water-quality standards be developed for all surface water of the United States. Development of standards involves two steps. First, a stream segment is designated for a specific use(s). Second, water-quality criteria, similar to those discussed above, are established to preserve or achieve the designated use. The water-quality standard is developed through rulemaking proceedings by State and Federal agencies. Thus, the criteria for a specific stream use become standards when, through rulemaking proceedings, the criteria are applied to a specific stream segment designated for that use.

The water-quality criteria for freshwater aquatic life are divided into two categories based on toxicity: acute and chronic. Acute toxicity refers to short-term effects on the biotic system that often result in the death of organisms. Chronic toxicity refers to long-term effects on aquatic organisms including bioaccumulation and reduction in population viability (U.S. Environmental Protection Agency, 1986a). A summary of the freshwater aquatic life criteria published in 1986 for those water-quality characteristics for which data are available for the Kentucky River basin during the 1976-86 water years is provided in table 3.

Current and proposed Federal drinking-water standards are listed in table 4. A maximum contaminant level goal (MCLG) is a nonenforceable health goal which is set at the level at which no known or anticipated adverse effects on the health of humans occur and which allows an adequate margin of safety. A maximum contaminant level (MCL) is an enforceable standard which must be set as close to the MCLG as is feasible. In this context, "feasible" is defined in the Safe Drinking Water Act to mean "with the use of the best technology, treatment techniques, and other means, which the Administrator of the U.S. Environmental Protection Agency finds generally available (taking costs into consideration)." Finally, a secondary maximum contaminant level (SMCL) represents a reasonable goal for drinking water which is intended as a guideline for the States and which is not a Federally enforceable standard. When a constituent exists at a level much greater than the SMCL, health implications as well as aesthetic degradation may exist.

State of Kentucky

The Federal water-quality criteria represent a guideline for use by the States for the development of State-specific, water-quality criteria. States may adjust the published criteria to appropriately represent local conditions based on a site-specific analysis. Using the State promulgated criteria, the State and the U.S. Environmental Protection Agency can develop water-quality standards which serve the dual purposes of establishing the water-quality goals for a specific stream segment and serving as the regulatory basis for the establishment of wastewater-treatment requirements.

All surface water in Kentucky has been assigned an aquatic life use (either warmwater or coldwater aquatic habitat) and a recreational use (primary and secondary contact recreation) by the Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water. In addition, part of the Red River, a tributary of the Kentucky River, is classified as an outstanding resource water (Kentucky Natural Resources and Environmental Protection Cabinet, 1986). The designated uses for specific streams or stream segments in the Kentucky River basin, are listed in table 5. Streams or stream segments not specifically listed in the table are designated for the use of warmwater aquatic habitat, primary contact recreation, secondary contact recreation, and domestic water supply.

Surface-water-quality criteria adopted by Kentucky are defined as the minimum criteria applicable to all surface water to protect public health and welfare, protect and enhance the quality of water, and fulfill Federal and State requirements for the establishment of water-quality standards. The surface-water-quality criteria, as adopted by Kentucky and approved by the U.S. Environmental Protection Agency, are listed by category in table 6.

ASSESSMENT APPROACH

Organizations which have or are currently collecting water-quality data in the Kentucky River basin were identified through retrieval of water-quality records contained in the U.S. Environmental Protection Agency's water-data management system (STORET) and through contacts with representatives from Federal, State, and local agencies and communities within Kentucky. Data searches focused on those ambient water-quality data collection programs having a documented quality-assurance program in force during the period of data collection. Effluent data were excluded from quantitative statistical analysis.

Table 4.—*Selected Federal drinking-water standards*

[U.S. Environmental Protection Agency, 1986b, 1986c, and 1987]

[MCL, maximum contaminant level; MCLG, maximum contaminant level goal; PMCL, proposed MCL; PMCLG, proposed MCLG; SMCL, secondary MCL; μg/L, micrograms per liter; mg/L, milligrams per liter]

Constituent or property	MCL	MCLG	PMCL	PMCLG	SMCL
Arsenic, total, in μg/L as As	50			50	
Barium, total, in μg/L as Ba	1,000			1,500	
Cadmium, total, in μg/L as Cd	10			5	
Chloride, dissolved, in mg/L as Cl					250
Chromium, total, in μg/L as Cr	50			120	
Copper, total, in μg/L as Cu			1,300	1,300	1,000
Dissolved solids, total, in mg/L					500
Fluoride, dissolved, in mg/L as F	4	4			2
Iron, total, in μg/L as Fe					300
Lead, total, in μg/L as Pb	50		5	0	
Manganese, total, in μg/L as Mn					50
Mercury, total, in μg/L as Hg	2			3	
Nitrogen, total nitrate, in mg/L	10			10	
Nitrite, total nitrite, in mg/L				1	
pH, in standard units					6.5-8.5
Selenium, total, in μg/L as Se	10			45	
Silver, total, in μg/L as Ag	50				
Sulfate, dissolved, in mg/L as SO_4					250
Zinc, total, in μg/L as Zn					5,000
2,4-D, total, in μg/L	.1			.07	

Biological Data

Biological data have been collected in the Kentucky River basin by Federal, State, and academic organizations for more than a century. Early investigations of aquatic organisms were reported by Rafinesque (1820), Woolman (1892), and Danglade (1922). Later studies by university graduate students (Giovannoli, 1926; and Neel, 1938) added to the limited historical biological data for the Kentucky River.

Although some historical records were obtained, most of the biological data used in this report are from studies conducted by Kentucky Division of Water (KDOW), Kentucky Nature Preserves Commission (KNPC), Kentucky Department of Fish and Wildlife Resources (KDFWR), and the Geological Survey. Several notable research papers on specific groups of organisms were also consulted and are included in the reference list. Of particular note are comprehensive works on the distribution of fish species (Kuehne, 1962a; Branson and Batch, 1974, 1981a; Kuehne and Barbour, 1983; Burr and Warren, 1986; and Mills, 1988) and on aquatic and wetland plants of Kentucky (Beal and Thieret, 1986).

Available biological data were evaluated to provide a more complete discussion of water-quality conditions in the Kentucky River basin, to determine the effects of various land uses on aquatic-biological communities, and to identify degraded stream reaches within the basin, as well as streams that have exceptional water quality and abundant aquatic habitat.

Selection of Constituents and Properties for Analysis

Selection of water-quality constituents and properties for analysis was based on several criteria. Inorganic constituents were selected from the National target variable list for the NAWQA program (table 7) (Hirsch and others, 1988) and supplemented based on local water-quality issues. Organic compounds were selected based on Federal and State water-quality criteria and on knowledge of the use and disposal of certain chemical products and substances in the Kentucky River basin.

Evaluation of Water-Quality Data

Many agencies collect water-quality data for a host of purposes, including: compliance with permits and water-quality standards; development of remediation plans for specific contamination problems; operational decisions for industrial, wastewater, or water-supply facilities; resource characterization; and research on water-quality processes. Collectively, these data constitute a sizable source of information that may be suitable for regional-scale water-quality assessments. Such data, however, need to be carefully screened before use. The needs, uses, and types of water-quality data vary widely, and data collected for one purpose are not necessarily suitable for other purposes.

Table 5.—*Stream-use designations in the Kentucky River basin*

[Kentucky Natural Resources and Environmental Protection Cabinet, 1985a]

[WAH, warmwater aquatic habitat;
CAH, coldwater aquatic habitat;
PCR, primary contact recreation;
SCR, secondary contact recreation;
ORW, outstanding resource water]

Stream name	Stream segment	Use designation
Chimney Top Creek	Basin	CAH, PCR, SCR
East Fork Indian Creek	Source to Indian Creek	CAH, PCR, SCR
Gladie Creek	Basin	CAH, PCR, SCR
Middle Fork Red River	Source to river mile 10.6	CAH, PCR, SCR
Red River	River mile 68.6 to 59.5	WAH, PCR, SCR, ORW
Silver Creek	Source to Kentucky River	WAH, PCR, SCR
South Fork Elkhorn Creek	Source to North Fork Elkhorn Creek	WAH, PCR, SCR
Swift Camp Creek	Source to Red River	CAH, PCR, SCR
Town Branch	Source to South Fork Elkhorn Creek	WAH, PCR, SCR

Table 6.—*Selected Kentucky surface water-quality criteria*

[Kentucky Natural Resources and Environmental Protection Cabinet, 1985b]

[mg/L, milligrams per liter; μg/L, micrograms per liter; <, less than; mL, milliliters; *, primary contact recreation; **, secondary contact recreation; ***, not to exceed natural seasonal variations; (soft), water has an equivalent concentration of calcium carbonate of 0 to 75 milligrams per liter; (hard), water has an equivalent concentration of calcium carbonate of over 75 milligrams per liter]

Constituent or property	Domestic water supply	Warmwater aquatic habitat	Coldwater aquatic habitat[1]	Recreational waters
Ammonia, total un-ionized, in mg/L		0.05		
Arsenic, total, in μg/L as As		50		
Barium, total, in μg/L as Ba	1,000			
Beryllium, total, in μg/L as Be		11 (soft) 1,100 (hard)		
Cadmium, total, in μg/L as Cd		4 (soft) 12 (hard)		
Chloride, dissolved, in mg/L as Cl	250	600		
Chromium, total, in μg/L as Cr	50	100		
Copper, total, in μg/L as Cu	1,000			
Cyanide, total, in μg/L as Cn		5		
Dissolved oxygen, in mg/L		< 4	< 5	
Dissolved solids, total, in mg/L	750			
Fecal coliform bacteria, colonies/100 mL	2,000			200* 1,000**
Fluoride, dissolved, in mg/L as F	1			
Iron, total, in μg/L as Fe		1,000		
Lead, total, in μg/L as Pb	50			
Manganese, total, in μg/L as Mn	50			
Mercury, total, in μg/L as Hg		.2		
Nitrogen, total nitrate, in mg/L as N	10			
pH, in standard units		6.0–9.0		6.0–9.0* 6.0–9.0**
Selenium, total, in μg/L as Se	10			
Silver, total, in μg/L as Ag	50			
Sulfate, dissolved, in mg/L as SO_4	250			
Temperature, in degrees Celsius		< 31.7	***	
Zinc, total, in μg/L as Zn		47		

[1]Warmwater aquatic habitat criteria apply where none established for coldwater aquatic habitat.

All available water-quality data were initially screened to remove those data which did not meet specified criteria prior to analysis and interpretation. Screening criteria included consideration of the type of site (for example, instream ambient versus wastewater discharge); methods of sample collection, handling, preservation, and analysis; quality-assurance practices; number of samples available and their relation to the full range of expected flow conditions; availability of concurrent streamflow measurements; and availability of information on site location. In addition to the above, chemical-logic programs were used to screen data to eliminate impossible values.

Many State and Federal agencies have collected water-quality data in Kentucky and have entered these data into STORET computer files. All available water-quality analyses of surface-water streams in the Kentucky River basin were obtained from STORET and the U.S. Geological Survey water data storage system (WATSTORE) and stored on a mainframe computer as a merged file. Data for 3,400 water samples collected from 167 surface-water sites were obtained from WATSTORE; and 4,800 samples collected from 418 sites were obtained from STORET. These data were stored and processed using the Statistical Analyses System (SAS)[1] data base management system (SAS Institute, 1985).

[1]The use of brand/firm/trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Table 7.—*National Water Quality Assessment Program target variable list for inorganic constituents and physical properties*
[Hirsch and others, 1988]

Constituent or property	Principal effects: Human health	Principal effects: Eco-systems	Principal effects: Agri-culture	Water-quality issues: Toxic contami-nation	Water-quality issues: Nutrient enrich-ment	Water-quality issues: Acidification (acid precipita-tion and mine drainage)	Water-quality issues: Soil erosion sedimentation	Water-quality issues: Salinity	Water-quality issues: General suitability
Aluminum	+	+	+	+		+			
Antimony	+	+		+					
Arsenic	+	+	+	+				+	
Barium	+			+					
Beryllium	+			+					
Boron			+					+	
Cadmium	+	+		+		+			
Chromium	+	+		+		+			
Copper		+	+	+		+			
Iron									+
Lead	+	+		+		+			
Manganese									+
Mercury	+	+	+	+		+			
Molybdenum	+		+	+				+	
Nickel	+			+		+			
Selenium	+	+	+	+				+	
Silver		+		+					
Zinc		+		+					
Vanadium	+			+					
Ammonium		+		+	+				
Nitrate	+	+	+	+	+	+			
Nitrite	+	+	+	+	+				
Kjeldahl Nitrogen		+		+	+				
Orthophosphate		+			+				
Total phosphorus		+			+				
Calcium		+	+			+		+	+
Magnesium		+	+			+		+	+
Sodium	+	+				+		+	+
Sulfate	+	+			+			+	+
Chloride		+			+			+	+
Alkalinity		+			+			+	+
Bromide	+		+						
Fluoride	+		+						
Total dissolved solids		+	+					+	+
Suspended sediment		+					+		
pH		+				+			
Specific conductance								+	
Temperature		+							+
Dissolved oxygen		+							+
Gross Alpha	+		+						
Gross Beta	+		+						
Radon-222	+		+						

Extensive screening of data retrieved from STORET was necessary. The U.S. Environmental Protection Agency does not accept responsibility for the quality control on data stored on STORET. Rather, quality control is left to each agency contributing data and the system has no internal edits. Much unedited data were identified from the STORET retrievals.

Several problems were encountered in the retrieval of water-quality data from the STORET data system. Latitude-longitude information for many sites was inaccurate and although efforts were made to resolve site location questions wherever possible, the locations of several sites could not be determined and the associated data could not be used. About 7 percent of the pH values for the study area placed in STORET during the 1976-86 water years exceeded a value of 14 (the maximum possible value for pH is 14.0).

Communication with water-data agencies contributing information to STORET for the study area indicated that some data were stored under incorrect parameter codes. For example, "total recoverable" analyses were commonly stored as "total" for several parameters and some sampling medium codes were stored under other variables, such as sampling depth.

Water-quality data entered into WATSTORE are routinely passed through an alert system and chemical-logic programs that identify data not meeting established edit criteria. Edit messages thus obtained are analyzed and data are updated if appropriate. STORET data from the study area were edited in a similar manner by developing computer software that would duplicate the WATSTORE alert system and chemical logic edit procedures as described in the WATSTORE User's Guide (Hutchinson, 1975). The alert system identifies values for selected water-quality constituents that exceed specified limits based upon Federal and State criteria and standards.

Each sample was checked for anomalous values, which were flagged for future correction or possible removal from the data base. Anomalous values included those that are outside the range of possible environmental values, for example, dissolved constituent concentrations greater than the total constituent concentration. The chemical logic editing consisted of checking constituent ratios, relations, and calculations. Data were accepted if the reported values were within 10 percent of the expected value.

After initial data screening and site merges, available water-quality data in the Kentucky River basin consisted of about 8,100 samples from 550 sites.

Selection of Current Record Period

For purposes of this report, water years 1976 through 1986 were selected as the "current-record" period. The last major reservoir within the Kentucky River basin (Carr Fork Reservoir) was placed into operation in January 1976. Thus, the hydrologic system was reasonably stable for the subsequent 11-year period. The "current-record" period also coincides with the period of record for Kentucky Division of Water's ambient monitoring network and the Geological Survey's National Stream Quality Accounting Network (NASQAN) program. The term "historical record" refers to all water-quality and associated streamflow data obtained during the period 1951 through September 1986. Biological data collected prior to 1951 were used when available, but only for comparison to that of the "current-record" period.

Methods of Analysis

Various methods of analysis, mostly of mathematical or statistical nature, were used to manipulate water-quality and streamflow data to obtain values for comparison. The results are presented in tabular and graphical formats. Biological data were assembled to qualitatively assess abundance and distribution of aquatic organisms for determination of "stream health" in the Kentucky River basin.

Treatment of Censored Data

Because of limitations in laboratory analytical techniques and equipment, there is a lower limit, below which the concentrations of a constituent or compound cannot be accurately determined. It can only be said, in such a case, that the concentration is less than the detection limit. Such data are referred to as censored. Because techniques differ among laboratories and over time, data for a given constituent may contain censored values having several different detection limits.

For this report, several methods for treating less-than, or censored values, were used depending on the type of analysis to be performed. In each case, a method was adopted which maximized information without sacrificing statistical integrity. The specific treatment of values less than the detection limits is discussed separately in the descriptions of statistical methods.

Descriptive Statistics

Descriptive statistics were applied to two groups of data. "Basin-wide" statistics represent the historical record (1951-86) for all sites, regardless of the number of samples at a site. These statistics were used to report the range of constituent concentrations in the basin and to show the spatial distribution of median constituent concentrations. Observations which were censored because their concentrations were less than the lower limit of the analytical methods used were set equal to the detection limit. "Individual-site" statistics were computed for only those sites that had at least 10 determinations for a given constituent at a specific site during the "current-record" period (1976-86). While there is no single number of determinations that is ideal for all conditions, at least 10 determinations were required to reduce the influence of unverified outliers and to increase the degrees of freedom.

Statistical summary tables were prepared that list the individual site period of record, the number of sample observations, and selected data-percentiles. A minimum of 30 observations was required for the computation of the 10th and 90th percentiles because percentiles computed from small sample sizes (less than 30 observations) may be affected by outliers. If censored values were present, the data were fit to a log-normal distribution prior to computation of quantiles. This log-normal-fitting procedure (D.R. Helsel, U.S. Geological Survey, written commun., 1988), was used to synthesize a "most probable" data distribution. Resultant quantiles computed from these synthesized distributions are noted in the tables. The number of censored values and the highest detection limit values are also reported.

Boxplots

Boxplots (Tukey, 1977) were constructed to graphically display the median, interquartile range, quartile skew, and extreme data values for 1976-86 water year data from main-channel sites for selected constituents and physical properties. A boxplot was not constructed if less than 10 observations for a site were available.

Boxplots consist of a box drawn from the 25th percentile to the 75th percentile, comprising the interquartile range. A horizontal line is drawn across the box at the median and the two box portions thus depict 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 than these values are plotted individually. Those from 1.5 to 3.0 times the interquartile range (outside values) are plotted with an asterisk. Data more extreme than 3.0 times the interquartile range (far-outside values) are plotted with a circle.

Boxplots constructed for sites with censored data were modified as follows: The data were fit to a log-normal distribution prior to computation of medians and quartiles (D.R. Helsel, U.S. Geological Survey, written commun., 1988). A heavy horizontal line was drawn across the boxplot at the highest detection limit value, and any part of the box below the highest detection limit was shown with dashed lines. If the highest detection limit was greater than the upper adjacent value, then no upper whisker was drawn. If the highest detection limit was greater than the 25th percentile, no lower whisker was drawn. If the highest detection limit was less than the 25th percentile value, but greater than the lower adjacent value, the lower whisker was not extended below the highest detection limit. Any outside or far-outside values that were less than the highest detection limit were not plotted.

Trend Analysis

The seasonal Kendall test is a nonparametric test for trend detection applicable to data sets with seasonality (Hirsch and others, 1982). With this test, the effect of seasonal variation is reduced by comparing observations from the same season of the year. The null hypothesis for the seasonal Kendall test is that no trend in the data exists (the variable values are random and are independent and identically distributed). The test statistic (tau) has a value between -1 and +1. Negative values indicate decreasing trends, whereas positive values indicate increasing trends. If no trend exists in the data, then tau approaches zero. A significance probability (p-level) of the trend is computed that indicates the probability of erroneously rejecting the null hypothesis (that no trend exists). The seasonal Kendall test is monotonic and specifically designed to provide a single summary statistic for the entire record. It should be noted that the selection of the period of record for trend analysis may significantly affect the outcome of the trend test.

The seasonal Kendall slope estimator is an estimate of the magnitude of the slope of the trend line. This statistic is computed by taking the difference of the data values and dividing by the period of time separating the data values. The median of these differences (expressed as slopes) is defined as the change per year due to the trend. Use of the median of these individual slope values reduces the effect of extreme values on the trend estimate. The statistic is also unaffected by seasonality because the slopes are always computed between values that are multiples of 12 months apart (Hirsch and others, 1982).

Eleven sites were selected for trend analysis, based on the number of determinations, number of constituents, and period of record. Four seasons per year were selected, effectively breaking the year into quarters for the seasonal Kendall test. Results are reported in table form, including the period of record, number of determinations and seasonal comparisons, probability level, and the slope of the trend line, or magnitude of the trend. Trend analyses based on less than 10 seasonal comparisons were not reported. Trend-line slopes that were not significant at the 0.20 p-level were not reported. The trend-line slope for pH was reported only as increasing or decreasing because it is inappropriate to compute the trend slope magnitude on the basis of logarithmic units.

For censored data sets, sensitivity was tested by applying the seasonal Kendall test after setting less-than values to zero, then to the detection limit, and comparing the results of the two trend tests. If the results were similar, it was assumed that the presence of less-than values in the data set did not affect the trend results, and the smaller magnitude trend and the larger probability were reported. Criteria for similarity were (1) both trend slopes had to have the same numeric sign, and (2) each slope had to be bounded by the 95-percent confidence limits of the other slope. If the slopes were not similar, then it was assumed that the presence of less-than values altered the trend results. For these data sets, any values less than the maximum detection limit were set equal to each other at the detection limit before the trend test was applied, and it was only reported that the trend was increasing or decreasing.

Flow-Adjusted Trends

In many streams, some water-quality characteristics are related to stream discharge. For example, much of the constituent loadings may be from point sources and any increase in flow would tend to be accompanied by a decrease in concentration. Conversely, some constituents are transported on suspended sediment, which tends to increase as discharge increases; and an increase in flow might be accompanied by an increase in total concentration.

If the rate of streamflow has changed with time, then the concentration of a constituent may indicate a trend entirely as a result of the change in streamflow. Compensation for the effects of discharge is necessary to identify trends in water-quality constituents caused by some process (source) change. To minimize the effects of discharge, the residuals method of flow adjustment was used. In this method, a best-fit relation between the constituent and discharge is derived. The seasonal Kendall trend test procedure is then applied to the residuals, or the actual concentrations minus the estimated conditional expected concentration. The residuals represent the best-attempt to remove the effects of discharge from the constituent value. Some common models used for defining the relation between a water-quality variable and discharge include the following (Crawford and others, 1983):

Linear	$C = a + bQ$	equation 1
Ln-linear	$C = a + b(\text{Ln } Q)$	equation 2
Quadratic	$C = a + b_1Q + b_2Q^2$	equation 3
Inverse	$C = a + b(1/Q)$	equation 4
Ln-Ln	$\text{Ln } C = a + b(\text{Ln } Q)$	equation 5

where C is the constituent value;
Ln is the natural logarithm;
Q is the discharge; and
a and b are the constant and coefficient of the relation, determined by least squares regression analysis.

Stream discharge in the Kentucky River basin has exhibited trends during the period of record due to periods of prolonged drought followed by periods of average or above-average precipitation. An analysis of trends in discharge was made for continuous-record stations in the study area using the seasonal Kendall test. Results of this analysis are given in table 8. Discharge data throughout the Kentucky River basin display a slight increasing overall trend since the mid-1920's. Two periods of significant discharge trend in opposite directions are defined within this long-term data. A strong increasing trend in flow occurred from the early 60's to the mid-70's, and a strong decreasing flow trend is indicated since the mid-70's. These periods correspond with completion of streamflow regulation structures on Buckhorn Lake (December 1960) and Carr Fork Lake (January 1976), but the flow trends are considered a reflection of precipitation trends rather than reservoir operations. Precipitation records from Lexington (fig. 10) were tested with the seasonal Kendall procedures and indicated similar trends as the streamflow data (increasing trend during water years 1961-75 and decreasing trend during water years 1976-86).

For each constituent at each of 11 sites, the best model of the relation between the constituent and discharge was determined using least-squares regression. At least 10 determinations of concurrent constituent values and discharge were required. The null hypothesis was that there was no relation between constituent values and discharge. If the regression analysis indicated a relation existed, the best model was chosen on the basis of probability level of the regression. If none of the models was significant at the 0.20 probability level, then a flow-adjusted trend was not determined. Data sets containing less-than values were not used, because of the uncertainty of deriving residuals from less-than values. Residuals from the best-fit model were evaluated for trends using the seasonal Kendall test.

Table 8. —*Trend test results for monthly average discharge for selected sites in the Kentucky River basin*

[P, probability; ft^3/mi^2, cubic feet per square mile. Test based on monthly comparisons (season = 12). Trend-line slopes significant at the 0.1 probability level are underlined]

Site number	USGS station name	Period of record (water years)	Beginning year of streamflow regulation	Period of record: P level	Period of record: Trend-line slope in ft^3/mi^2 per year	Water years 1961-75: P level	Water years 1961-75: Trend-line slope in ft^3/mi^2 per year	Water years 1976-86: P level	Water years 1976-86: Trend-line slope in ft^3/mi^2 per year
				Results of seasonal Kendall tests for time trend[1]					
0.2	Carr Fork near Sassafras	1965-86	1976	0.666	0.002	0.000	0.045	0.544	-0.011
1.0	North Fork Kentucky River at Hazard	1941-86	1976	.000	.004	.001	.022	.185	-.013
2.0	North Fork Kentucky River at Jackson	1929-31, 1939-86	1976	.000	.003	.004	.019	.051	-.021
2.1	Middle Fork Kentucky River near Hyden	1958-86	1968	.638	-.001	.021	.014	.051	-.015
2.2	Cutshin Creek at Wooton	1958-86		.824	-.001	.000	.038	.011	-.030
2.3	Middle Fork Kentucky River at Tallega	1931, 1940-86	1961	.000	.006	.002	.023	.037	-.025
2.4	Red Bird River near Big Creek	1973-86						.026	-.025
2.5	Goose Creek at Manchester	1965-86		1.00	.000	.009	.036	.037	-.030
2.6	South Fork Kentucky River at Booneville	1926-31, 1940-86		.041	.002	.021	.017	.007	-.032
3.0	Kentucky River at Lock 14, at Heidelberg	1926-31, 1939-86	1961, 1976	.008	.002	.002	.021	.026	-.026
3.1	Red River near Hazel Green	1955-86		.155	.002	.004	.014	.051	-.019
3.3	Red River at Clay City	1931, 1939-86		.006	.003	.015	.017	.185	-.017
4.0	Kentucky River at Lock 10, near Winchester	1926-86	1961, 1976	.038	.001	.002	.017	.014	-.027
5.2	Dix River near Danville	1943-86		.025	.002	.010	.023	.200	-.002
6.0	Kentucky River at Lock 6, near Salvisa	1926-86	1925, 1961, 1976	.200	.001	.016	.016	.010	-.028
8.0	Kentucky River at Lock 4, at Frankfort	1926-86	1925, 1961, 1976	.445	.001	.010	.016	.018	-.026
9.3	South Elkhorn Creek near Midway	1951-86		.000	.008	.000	.025	.235	-.018
10.0	Kentucky River at Lock 2, at Lockport	1926-86	1925, 1961, 1976	.275	.001	.012	.018	.037	-.024

[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 (1) 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 (2) the null hypothesis was not rejected and it was declared that a trend could not be discerned.

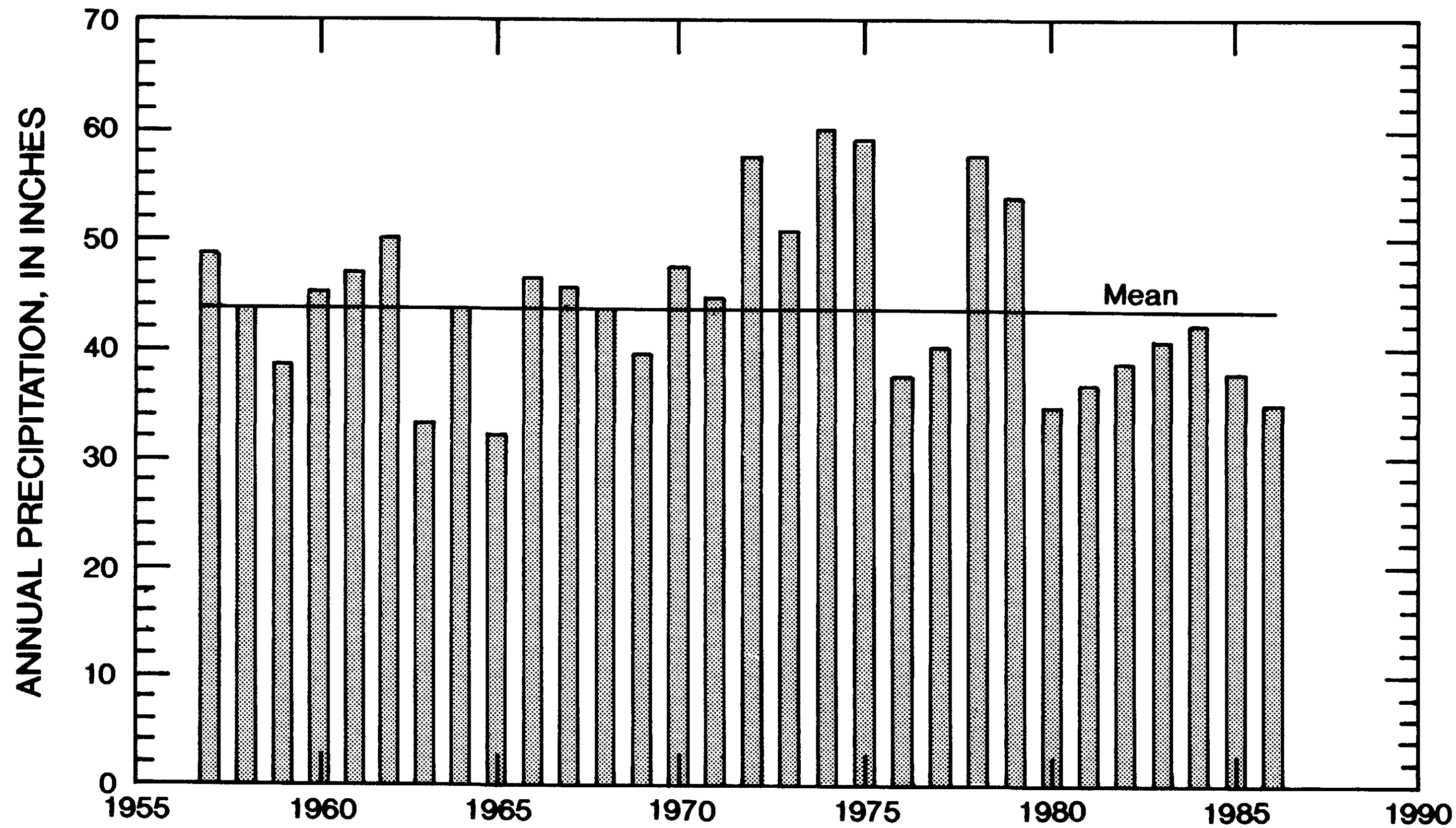


Figure 10.--Annual and mean annual precipitation at Lexington, Kentucky, 1957-86.

In most of the regression models, the residuals have the same units as the constituents—for example, mg/L. With the Ln-Ln model, however, residuals would be reported as natural logs, such as natural log (mg/L). Residuals from the Ln-Ln model were estimated in original units using equations to compare residuals from all models on the same terms:

$$r = C - D\, e^{a}\, Q^{b} \qquad \text{equation 6}$$

where r is the residual;
D is the Duan smearing estimate; and
e is the base for the natural logarithm.

The Duan smearing estimate is a correction factor for the bias introduced in detransforming dependent variables (Duan, 1983).

Loads

The instantaneous load of a constituent in a stream is simply the concentration of that constituent times the discharge. The load of a constituent over time is more difficult to estimate. Estimates based on mean concentration multiplied by the mean discharge are not accurate, for the same reason that the sum of products does not equal the product of sums. In the Kentucky River basin, quarterly or even monthly samples are not likely to include the major runoff events that normally carry a large percentage of the total load of a stream.

Mean-annual loads for a selected period (water years 1983-85) were estimated using periodic water-quality samples and daily discharge values available for water years 1976-86. Censored values were set equal to one-half of the detection limit. Loads were estimated for the same sites as for trend analysis, with the exception of site 10.1, which had no discharge record for the period. On the basis of the data for the current-record period, a best-fit model was developed:

$$\begin{aligned} Ln(CQ) = I + at + b(\text{sine}\ \theta) \\ + c(\text{cosine}\ \theta) + d(Ln\ Q) \end{aligned} \qquad \text{equation 7}$$

where C is the concentration in milligrams per liter;
Q is the discharge in cubic feet per second;
I is the regression intercept;
Ln is the natural logarithm;
t is the time, in decimal years, using September 30, 1975, at 2400 hours as t = 0;
θ is the fractional part of the year, in radians; and
a, b, c, and d are the regression coefficients.

The sum (b sine θ + c cosine θ) is a seasonality term, and is the functional equivalent of applying a phase shift and amplitude to a linear regression model. The best combination of independent variables was chosen as the best model, based on the Mallows C_p statistic (Mallows, 1964). The regression coefficients and associated probability values of models that were used to estimate constituent transport for selected sites in the Kentucky River basin for water years 1983-85 are summarized in table 9.

The best-fit model based on available data for water years 1976-86 was applied to the selected 3 years of daily-values of discharge, the predicted log value was detransformed and multiplied by the Duan smearing estimate, and the 3 years of daily loads were summed and averaged into a mean-annual load for 1983-85 water years. All loads are reported regardless of the significance of the regression, and several uncertainty statistics are also reported for the reader. 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 gives an idea of the adequacy of the sampling regime at high flow, when the largest loads occur. The percentage of load estimated using discharge above the highest sampled flow is a measure of the load that results from extrapolation beyond the range of data used to derive the regression relation. Because load increases with discharge and because the true nature of the relation beyond the range of data used is unknown, load estimates for which a large percentage of the load was estimated by extrapolation should be used with caution. It should be noted that, occasionally because of differences in the number of samples available or the discharge at which the sample was taken, the estimated load of a dissolved constituent is greater that that of the total concentration of the constituent, which in nature is a physical impossibility.

Precipitation wetfall analyses from the National Atmospheric Deposition Program were used to estimate the relative effect of precipitation chemistry on stream yield of major ions in the basin. These transport estimates from the National Atmospheric Deposition Program data represent total load assuming all constituent inputs from precipitation are transported from the basin annually.

Table 9.—*Regression coefficients and associated probability values of models used to estimate constituent transport for selected sites in the Kentucky River basin, water years 1983-85*

[Ln (C Q) = I + a t + b(sine θ) + c(cosine θ) + d(Ln Q): where C is concentration in milligrams per liter; Q is discharge in cubic feet per second; I is the regression intercept; Ln is natural logarithm; t is time, in decimal years using September 30, 1975, as t = 0; θ is the fractional part of the year, in radians; and a, b, c, and d are regression coefficients]

Site number	I	Regression coefficients				Probability values			
		a	b	c	d	a	b	c	d
Aluminum, dissolved									
3.0	0.1627				0.4771				0.0153
3.1	-2.4511				.6605				.0011
5.0	-2.0441				.8170				.0009
7.0	-.3185				.6086				.0355
9.0	-4.4930				1.1712				.0000
10.0	-2.6550				.8180				.0000
Aluminum, total									
2.0	-8.9311		-1.1949	1.0165	2.2394		0.0000	0.0020	.0000
2.3	-14.7400	0.9247	-1.1229	-.0466	1.7405	0.0381	.0181	.9160	.0000
2.6	-6.9638		-1.1994	.7329	1.8741		.0072	.1315	.0000
3.0	-7.3739		-.7474	.0816	1.7996		.0002	.7305	.0000
3.1	-2.3514		-.3633	.4614	1.2611		.1070	.1068	.0000
5.0	-11.1451	.2470	-.4565	.5436	1.9623	.0677	.0147	.0256	.0000
7.0	-9.0453		-.4378	.0845	1.9459		.0051	.6466	.0000
9.0	-8.2548		-.5412	.1350	1.8585		.0020	.6246	.0000
9.3	-11.0853	.6947	-.8566	.0631	1.4913	.0517	.0270	.8537	.0003
Arsenic, dissolved									
3.0	-7.7020	.5565			.8472	.0722			.0000
9.3	-5.9736		-.1838	.3611	.8651		.1092	.0372	.0001
10.0	-7.1156	.0512			.9846	.0611			.0000
Arsenic, total									
2.0	-9.2341	.1144			1.1956	.1366			.0000
2.6	-7.4978				1.0626				.0000
3.0	-6.3179	-.3016			1.2597	.0000			.0000
3.1	-6.4462	-.0862			1.0232	.0040			.0000
5.0	-6.1554	-.1533			1.0753	.0003			.0000
7.0	-6.0220	-.1511			1.0640	.0000			.0000
9.0	-5.9818	-.1997			1.1017	.0001			.0000
9.3	-4.9767				.6393				.0000
10.0	-7.5651				1.1198				.0000
Barium, dissolved									
3.0	-1.0596				.6024				.0001
3.1	-3.5914				.7454				.0002
9.3	-6.4872	.3346	-.1261	.2470	1.1327	.0060	.0571	.0151	.0000
10.0	-4.1129				1.1160				.0000
Barium, total									
2.0	-.2164	-.3729			1.0694	.0004			.0000
2.3	-1.3912	-.2898			1.1248	.0043			.0000
2.6	-1.1894	-.2004			.9616	.0015			.0000
3.0	-1.1040	-.2161			.9724	.0115			.0000
3.1	-2.1955	-.1841			1.0576	.0021			.0000
5.0	-1.4034	-.1321			.9867	.0138			.0000
7.0	-2.9281				1.0045				.0000
9.0	-2.2961	-.0994			1.0331	.1007			.0000
9.3	2.3041	-.6909			1.0694	.0000			.0000
Cadmium, dissolved									
3.0	-4.8673	-.4558	-.6121	.3762	1.1795	.0000	.0071	.2008	.0000
3.1	-4.3419	-.3767			1.0622	.0000			.0000
5.0	-.0735	-.6527			.7544	.0000			.0000
7.0	-2.0637	-.3788			.7495	.0003			.0000
9.0	-2.1890	-.4186			.7945	.0000			.0000
10.0	-7.3789	-.0956			1.1154	.1322			.0000

Table 9.—*Regression coefficients and associated probability values of models used to estimate constituent transport for selected sites in the Kentucky River basin, water years 1983-85*—Continued

[Ln (C Q) = I + a t + b(sine θ) + c(cosine θ) + d(Ln Q): where C is concentration in milligrams per liter; Q is discharge in cubic feet per second; I is the regression intercept; Ln is natural logarithm; t is time, in decimal years using September 30, 1975, as t = 0; θ is the fractional part of the year, in radians; and a, b, c, and d are regression coefficients]

Site number	I	Regression coefficients a	b	c	d	Probability values a	b	c	d
Cadmium, total									
9.0	-2.0684	-0.6425			1.0407	0.0000			0.0000
10.0	-8.5265				1.2197				.0001
Calcium, dissolved									
2.0	5.1927				.7563				.0000
2.3	6.1870	-.2909			.7565	.0444			.0000
2.6	4.0595				.7769				.0000
3.0	4.4680	.1176			.6984	.0029			.0000
3.1	2.8542				.7476				.0000
5.0	2.5414	.1398	0.0831	0.2741	.9854	.0009	0.4438	0.1217	.0000
7.0	3.0230		.3533	.4172	1.0604		.0036	.0009	.0000
9.0	2.1026	.0572	.1561	.4509	1.1417	.0395	.1233	.0003	.0000
9.3	3.9468				1.0615				.0000
10.0	3.8024	.0168	.0521	.0981	.9682	.0032	.0379	.0002	.0000
Calcium, total									
2.0	5.1777				.7880				.0000
2.3	2.0817	.2126	.2907	.1979	.7993	.0278	.0078	.0473	.0000
2.6	3.6187				.8909				.0000
3.0	2.8164	.1921	.0313	.2879	.8594	.0030	.6993	.0155	.0000
3.1	2.3891		.0297	.6824	1.0084		.8780	.0090	.0000
5.0	4.2488		.0936	.1463	.9168		.2571	.1703	.0000
7.0	3.6725		.1128	.2182	.9995		.1427	.0268	.0000
9.0	3.4356		.1703	.2535	1.0366		.0392	.0792	.0000
9.3	4.2144				1.0051				.0000
Carbon, total organic									
2.0	1.4152		-.2045	.3245	.8838		.0837	.0426	.0000
2.3	.0135		-.3849	.4146	1.1009		.0001	.0000	.0000
2.6	-1.7827	.1923	-.3771	.5911	1.0729	.0872	.0043	.0003	.0000
3.0	2.2193	-.2538	-.2681	.4493	1.1317	.0104	.0366	.0111	.0000
3.1	1.0125		-.2060	.4655	.9287		.2697	.0567	.0000
5.0	2.0483	-.2289	-.1082	.5200	1.1351	.0102	.3432	.0014	.0000
7.0	2.3231	-.2118	-.1012	.3489	1.0904	.0063	.2971	.0080	.0000
9.0	5.5226	-.2684			.7330	.1197			.0000
9.3	.8328	.1821	-.0866	.3301	.8202	.1064	.4613	.0067	.0000
10.0	.9316	-.0966			1.1300	.0357			.0000
Chloride, dissolved									
2.0	3.6534		.1211	.1592	.7178		.0510	.0464	.0000
2.3	2.5703				.8342				.0000
2.6	5.2172				.4763				.0000
3.0	.8923	.3273	.0610	.4302	.9004	.0000	.5279	.0001	.0000
3.1	1.3012	.0490	.1668	.1716	.9314	.0524	.0349	.0707	.0000
5.0	3.4831	.1361	.1845	.3726	.7979	.0004	.0841	.0071	.0000
7.0	3.1377	.1289	.0843	.2995	.8309	.0000	.2778	.0013	.0000
9.0	3.2934	.1307	.1768	.2128	.8052	.0000	.0304	.0358	.0000
9.3	4.0609	.1020	.0528	.2807	.7281	.0167	.5143	.0015	.0000
10.0	3.0635	.0764	.0177	.2644	.8850	.0000	.7983	.0003	.0000
Chromium, dissolved									
9.3	-7.1564		-.1295	.5023	1.5584		.3011	.0132	.0000
Chromium, total									
2.0	-7.7564	-.3305	-.2989	.8146	1.8026	.0197	.3049	.0486	.0000
2.3	-3.2940	-.4039			1.1760	.0014			.0000
2.6	-2.7738	-.4203			1.1041	.0026			.0000
3.0	-7.8838		-.3661	.0565	1.2125		.0125	.7288	.0000
3.1	-5.3377	-.1570			1.0601	.0013			.0000
5.0	-7.6693				1.1758				.0000

Table 9.—*Regression coefficients and associated probability values of models used to estimate constituent transport for selected sites in the Kentucky River basin, water years 1983-85*—Continued

[Ln (C Q) = I + a t + b(sine θ) + c(cosine θ) + d(Ln Q): where C is concentration in milligrams per liter; Q is discharge in cubic feet per second; I is the regression intercept; Ln is natural logarithm; t is time, in decimal years using September 30, 1975, as t = 0; θ is the fractional part of the year, in radians; and a, b, c, and d are regression coefficients]

Site number	I	Regression coefficients a	b	c	d	Probability values a	b	c	d
Chromium, total–Continued									
7.0	-7.7298				1.2071				0.0000
9.0	-6.7443	-0.1675			1.1850	0.0058			.0000
9.3	-.7124	-.6050			1.0963	.0001			.0000
10.0	-4.7358				1.0433				.0000
Cobalt, dissolved									
9.3	-13.9966	.8945			1.2390	.0374			.0001
Cobalt, total									
9.3	-5.8358		-0.3479	-0.5001	.9439		0.1145	0.1187	.0087
10.0	-12.8082				1.7143				.0000
Copper, dissolved									
2.0	-6.3821		.2554	.9512	1.1024		.4293	.0280	.0010
2.3	-.1170	-.5516			.7097	.0773			.0011
2.6	1.6048	-.8196			.7574	.0498			.0022
3.0	-3.7614				.7861				.0000
3.1	-5.3756				.9225				.0000
5.0	-6.8992		-.1526	.6911	1.2403		.4800	.0255	.0000
7.0	-4.6599				.9378				.0000
9.0	-5.5550				1.0408				.0000
9.3	-5.8755				1.0280				.0005
10.0	-6.2378				1.0970				.0000
Copper, total									
2.0	-8.7153	-.2164	-.6857	.9224	1.8000	.0199	.0010	.0013	.0000
2.3	-3.4490	-.3279			1.0892	.0014			.0000
2.6	-2.7863	-.4394			1.1290	.0000			.0000
3.0	-4.3981	-.1720			1.0413	.0002			.0000
3.1	-4.8434	-.1279			1.0045	.0018			.0000
5.0	-5.1184	-.1856			1.1446	.0002			.0000
7.0	-3.1671	-.2495			.9795	.0000			.0000
9.0	-5.4817	-.1307			1.1308	.0116			.0000
9.3	-2.2127	-.4383			1.0935	.0000			.0000
10.0	-7.3113	.1195			1.2954	.0489			.0000
Dissolved solids, residue at 180 degrees Celsius									
2.0	6.6956	.0575	-.0916	.0216	.7642	.0000	.0030	.5696	.0000
2.3	4.6394	.0644	.0341	.1980	.9486	.0000	.3435	.0000	.0000
2.6	5.4438	.0420	.0338	.1559	.8600	.0235	.5009	.0408	.0000
3.0	5.1600	.1045	-.1337	.1576	.9106	.0000	.0017	.0010	.0000
3.1	4.2395		-.1012	.1933	.9764		.0330	.0007	.0000
5.0	5.2759	.0488	.0344	.2555	.9565	.0315	.5196	.0014	.0000
7.0	5.1811	.0565	.0251	.1380	.9556	.0002	.5258	.0071	.0000
9.0	5.2045	.0562	.0275	.1279	.9524	.0005	.5117	.0180	.0000
9.3	5.9669		-.0315	.2318	.9685		.5181	.0002	.0000
10.0	5.3138	.0354	-.0223	.1023	.9664	.0000	.3596	.0001	.0000
Fluoride, dissolved									
2.0	-1.3943		-.0190	.2815	.8815		.8642	.0621	.0000
3.0	-2.3067		-.1117	.3545	.9617		.1372	.0001	.0000
5.0	-1.7358	-.0416	.0910	.4329	.9434	.1258	.1704	.0000	.0000
7.0	-1.5928		.0967	.2558	.8917		.1247	.0017	.0000
9.0	-1.5189		.1831	.2401	.8924		.0076	.0055	.0000
9.3	1.7056				.5331				.0001
10.0	-.8302		.0963	.1638	.8672		.1280	.0123	.0000
Iron, dissolved									
2.0	-2.4894		.7408	-.1446	.8786		.0177	.6894	.0001
2.3	-2.3455				.8849				.0000

Table 9. —*Regression coefficients and associated probability values of models used to estimate constituent transport for selected sites in the Kentucky River basin, water years 1983-85* —Continued

[Ln (C Q) = I + a t + b(sine θ) + c(cosine θ) + d(Ln Q): where C is concentration in milligrams per liter; Q is discharge in cubic feet per second; I is the regression intercept; Ln is natural logarithm; t is time, in decimal years using September 30, 1975, as t = 0; θ is the fractional part of the year, in radians; and a, b, c, and d are regression coefficients]

Site number	I	Regression coefficients				Probability values			
		a	b	c	d	a	b	c	d
Iron, dissolved–Continued									
2.6	-1.2766	-0.3065	0.4763	0.0661	1.0796	0.0012	0.0262	0.8085	0.0000
3.0	-2.1554	-.3277			1.1324	.0000			.0000
3.1	-.1024	-.2727			.8585	.0000			.0000
5.0	-3.0026	-.3120			1.2221	.0005			.0000
7.0	-2.4131	-.2086			1.0431	.0197			.0000
9.0	-4.9082				1.2058				.0000
9.3	-3.4323				.8294				.0186
10.0	-7.8381				1.4388				.0000
Iron, total									
2.0	-5.2499	-.0945	-.6768	.8014	1.9902	.0383	.0000	.0001	.0000
2.3	-1.2733	-.1751	-.2494	.1132	1.4857	.0000	.0470	.3860	.0000
2.6	-2.4632	-.1102	-.2763	.6867	1.5137	.0105	.0535	.0005	.0000
3.0	-4.8028	-.1330	-.4426	.5089	1.7525	.0088	.0018	.0073	.0000
3.1	-.7875		-.3472	.4622	1.2246		.0034	.0010	.0000
5.0	-6.8064				1.7798				.0000
7.0	-5.6306				1.5994				.0000
9.0	-5.4157	-.1336			1.7123	.1084			.0000
9.3	-2.0845		-.3199	.3141	1.2283		.0060	.0085	.0000
10.0	-3.2262	-.1494			1.4957	.0998			.0000
Lead, dissolved									
2.0	-4.8511	-.5113	-.6077	-.1712	1.2467	.1064	.0612	.7117	.0013
2.3	-7.1524				1.0653				.0001
2.6	-8.2726				1.2565				.0000
3.0	-.6725	-.5610			.8805	.0000			.0000
3.1	-4.1476	-.2757			1.0633	.0003			.0000
5.0	4.5679	-.9287			.6096	.0000			.0005
7.0	.7329	-.5708			.7205	.0000			.0000
9.0	.5107	-.6039			.8062	.0002			.0000
9.3	-2.1512	-.4838			.8500	.1583			.0131
10.0	-6.9287				1.0772				.0000
Lead, total									
2.0	-7.0256	-.2038	-.7436	.5075	1.4920	.0349	.0007	.0723	.0000
2.3	-4.9488	-.2403			1.2403	.0123			.0000
2.6	-4.7674	-.3233	-.7463	.4026	1.3491	.0158	.0088	.2540	.0000
3.0	-1.2427	-.5309			1.0275	.0000			.0000
3.1	-3.2294	-.3644			1.1037	.0000			.0000
5.0	.9230	-.5392	.1956	-.5360	.8113	.0000	.3609	.0516	.0000
7.0	-.6746	-.5436			.9743	.0000			.0000
9.0	.9741	-.6922			.9245	.0000			.0000
9.3	-1.1771	-.4542			.8478	.0003			.0001
10.0	-6.2114				1.1978				.0000
Magnesium, dissolved									
2.0	3.1903	.1390			.7938	.0661			.0000
2.3	1.7560	.1206			.8953	.0518			.0000
2.6	3.0354				.8374				.0000
3.0	3.0266	.1222			.7978	.0001			.0000
3.1	1.6588				.8519				.0000
5.0	2.5098	.1029			.8889	.0003			.0000
7.0	2.7179				.9301				.0000
9.0	2.5227				.9515				.0000
9.3	3.0239		.0733	.1584	.7693		.1236	.0317	.0000
10.0	2.4024	.0324	.0116	.0744	.9366	.0000	.6708	.0088	.0000

Table 9.—*Regression coefficients and associated probability values of models used to estimate constituent transport for selected sites in the Kentucky River basin, water years 1983-85*—Continued

[$Ln(CQ) = I + at + b(\text{sine } \theta) + c(\text{cosine } \theta) + d(Ln\ Q)$: where C is concentration in milligrams per liter; Q is discharge in cubic feet per second; I is the regression intercept; Ln is natural logarithm; t is time, in decimal years using September 30, 1975, as $t = 0$; θ is the fractional part of the year, in radians; and a, b, c, and d are regression coefficients]

Site number	I	Regression coefficients a	b	c	d	Probability values a	b	c	d
Magnesium, total									
2.0	3.9951				0.8654				0.0000
2.3	2.9471		0.1968	0.0400	.8689		0.0381	0.6399	.0000
2.6	2.7400				.9154				.0000
3.0	3.1257	0.1067			.8044	0.0567			.0000
3.1	1.4577		.0753	.1084	.9505		.2661	.2001	.0000
5.0	3.4509				.8757				.0000
7.0	2.9191				.9280				.0000
9.0	2.9254				.9255				.0000
9.3	2.8424		.0657	.1556	.8408		.5240	.1065	.0000
Manganese, dissolved									
2.0	-1.2089		.9551	-.3998	.7565		.0003	.1736	.0000
2.3	-.9131		.4261	-.3563	.6939		.0157	.0697	.0000
2.6	-1.4497		.5510	-.2926	.7875		.0450	.4141	.0001
3.0	-2.3384				.9642				.0000
3.1	-2.4211	.1124	.0833	.4814	.8720	.0656	.5685	.0059	.0000
5.0	-.9273		.5668	-.5578	.6776		.0008	.0157	.0000
7.0	-1.3475		.4144	-.2653	.6397		.0542	.3135	.0000
9.0	-3.3203		.5666	-.2188	.9028		.0038	.3494	.0000
9.3	.3326				.4607				.0057
10.0	-4.5915		.7339	-.7704	.9863		.0191	.0253	.0000
Manganese, total									
2.0	-5.3744		-.0677	.4473	1.5499		.5980	.0070	.0000
2.3	-2.2488	-.0717			1.1313	.0188			.0000
2.6	-2.6375		.1356	.2319	1.0962		.2403	.1331	.0000
3.0	-3.1268				1.1801				.0000
3.1	-1.8394		.1611	.3854	1.0035		.1011	.0014	.0000
5.0	-3.8597		.3150	-.1636	1.1830		.0016	.1917	.0000
7.0	-4.0063		.3342	-.0126	1.1673		.0169	.9424	.0000
9.0	-4.4665		.1953	-.1236	1.2255		.0489	.3674	.0000
9.3	-2.5325	.1412	-.2587	.3834	.9040	.0157	.0220	.0019	.0000
10.0	-6.6522		.0915	.2922	1.5515		.5227	.0559	.0000
Mercury, dissolved									
2.0	-9.6240				1.0950				.0005
2.3	-8.4857		.6345	-.3380	.9528		.0748	.4146	.0007
2.6	-10.0831				1.1867				.0000
3.0	-5.2226	-.2354			.8238	.0147			.0000
3.1	-7.2397	-.1147			.9604	.0705			.0000
5.0	-6.9803	-.3371			1.1680	.0333			.0000
7.0	-6.9072	-.3059			1.1317	.0197			.0000
9.0	-4.8131	-.4268			.9976	.0078			.0000
9.3	-14.0395	.6276			1.0327	.0063			.0000
Mercury, total									
2.0	-8.8520				.9872				.0000
2.3	-9.8288				1.1031				.0000
2.6	-11.1361		-.2709	.7113	1.3429		.2876	.0319	.0000
3.0	-5.0319	-.3611			.9637	.0000			.0000
3.1	-6.2983	-.2632			.9737	.0000			.0000
5.0	-4.2218	-.5124			1.0166	.0000			.0000
7.0	-5.8804	-.3728			1.0898	.0000			.0000
9.0	-5.3893	-.3803			1.0186	.0000			.0000
9.3	-8.9542				1.0048				.0000

Table 9.—*Regression coefficients and associated probability values of models used to estimate constituent transport for selected sites in the Kentucky River basin, water years 1983-85*—Continued

[Ln (C Q) = I + a t + b(sine θ) + c(cosine θ) + d(Ln Q): where C is concentration in milligrams per liter; Q is discharge in cubic feet per second; I is the regression intercept; Ln is natural logarithm; t is time, in decimal years using September 30, 1975, as t = 0; θ is the fractional part of the year, in radians; and a, b, c, and d are regression coefficients]

Site number	I	Regression coefficients a	b	c	d	Probability values a	b	c	d
Nickel, dissolved									
3.0	-3.2760				0.7018				0.0000
3.1	-5.1651				.8027				.0002
7.0	-3.3361				.7388				.0014
9.0	-4.3685				.8468				.0026
9.3	-1.9987				.2461				.2956
10.0	-8.9148	0.3102			.9938	0.0169			.0000
Nickel, total									
2.0	-10.3819		-0.7946	1.1587	1.7952		0.0007	0.0016	.0000
2.3	-.6627	-.7132			1.0512	.0002			.0000
2.6	-2.4916	-.5231			1.1793	.0074			.0000
3.0	.4041	-.8935			1.2724	.0650			.0000
3.1	8.0940	-1.6626			1.0815	.0135			.0000
5.0	.1058	-.8321			1.2164	.0132			.0000
7.0	4.4093	-1.2187			1.0877	.0491			.0000
9.0	7.3189	-1.6555	.5838	.2128	1.1182	.0060	.0702	.7248	.0047
9.3	.2756	-.5246			.7204	.0049			.0007
10.0	-8.5937				1.4181				.0000
Nitrogen, dissolved as N									
10.0	-1.5564	.2486	.1399	.2621	1.0616	.0511	.1927	.0439	.0000
Nitrogen, total as N									
2.0	-2.4006		-.2472	.3347	1.3439		.0364	.0345	.0000
2.3	-1.5709				1.1236				.0000
2.6	-1.0536				1.0715				.0000
3.0	-1.2158		-.0166	.1623	1.1243		.8066	.0387	.0000
3.1	-.7962				1.1049				.0000
5.0	-.6104	-.0654	.1377	.1471	1.1537	.0169	.0823	.1439	.0000
7.0	-1.5542	.0399			1.1754	.0964			.0000
9.0	-.4181		.2058	.0553	1.0853		.0019	.4864	.0000
9.3	2.4688	.1393			.6601	.1189			.0000
10.0	-.6092	.0481	.0569	.1841	1.0888	.0097	.2325	.0003	.0000
Nitrogen, dissolved ammonia as N									
2.0	5.2349	-.8763			.6109	.1653			.0087
2.3	-4.0319		.1531	.9067	1.0089		.5643	.0342	.0008
2.6	-1.9453				.6917				.0007
9.3	7.6010		.5900	-.1666	-.4694		.0130	.5864	.1482
10.0	-5.3287		.5349	.8991	1.2379		.0801	.0086	.0000
Nitrogen, total ammonia as N									
3.0	-1.6358	-.2196	-.0627	.3657	1.0783	.0000	.6232	.0133	.0000
3.1	-1.5732	-.1856			1.0310	.0000			.0000
5.0	-.1336	-.3673			1.0523	.0000			.0000
7.0	-1.4844	-.2442			1.0924	.0000			.0000
9.0	.5300	-.2783	.2658	-.1411	.8748	.0000	.0498	.3966	.0000
9.3	5.9000		.3393	.0931			.0060	.4588	
10.0	-3.5983	.1933			.9527	.0415			.0000
Nitrogen, dissolved organic as N									
10.0	-1.6293				.9744				.0088
Nitrogen, total organic as N									
10.0	-3.1662	.1110	-.1666	.2994	1.2069	.0116	.1274	.0092	.0000
Nitrogen, dissolved ammonia + organic, as N									
10.0	-1.9930		-.1275	.4825	1.0781		.4552	.0185	.0000

Table 9.—*Regression coefficients and associated probability values of models used to estimate constituent transport for selected sites in the Kentucky River basin, water years 1983-85*—Continued

[Ln (C Q) = I + a t + b(sine θ) + c(cosine θ) + d(Ln Q): where C is concentration in milligrams per liter; Q is discharge in cubic feet per second; I is the regression intercept; Ln is natural logarithm; t is time, in decimal years using September 30, 1975, as t = 0; θ is the fractional part of the year, in radians; and a, b, c, and d are regression coefficients]

Site number	I	Regression coefficients a	b	c	d	Probability values a	b	c	d
Nitrogen, total ammonia + organic, as N									
2.0	-3.9721		-0.5241	0.6541	1.4235		0.0022	0.0034	0.0000
2.3	1.7237	-0.2765			.8551	0.0158			.0000
2.6	-1.8359		-.5932	.5683	1.0342		.0022	.0281	.0000
3.0	-1.4203	-.0973	-.3021	.2921	1.1556	.0009	.0015	.0067	.0000
3.1	-.2008	-.1370			.9968	.0013			.0000
5.0	-.2885	-.1360			1.0667	.0004			.0000
7.0	-.8478	-.0559			1.0676	.0287			.0000
9.0	.2656	-.0943			.9652	.0007			.0000
9.3	4.5336	.1705	.2687	.0672		.0112	.0190	.5695	
10.0	-2.6732	.0595	-.1626	.2232	1.2089	.0003	.0225	.0026	.0000
Nitrogen, dissolved nitrate + nitrite, as N									
2.0	-3.1945				1.3202				.0000
2.3	-2.3950				1.1055				.0000
2.6	-2.4958				1.1999				.0000
9.3	6.7164	-.9863			1.3908	.0206			.0000
10.0	-1.0097		.3527	.0132	1.1013		.0076	.9218	.0000
Nitrogen, total nitrate + nitrite, as N									
2.0	-0.5694	-.1328			1.1737	.1139			.0000
2.3	-1.1413	-.1860			1.2493	.1307			.0000
2.6	-1.2032	-.2337			1.3853	.0445			.0000
3.0	-2.5146	.0733	.2870	.0968	1.1097	.0341	.0111	.4485	.0000
3.1	-3.2087				1.4981				.0000
5.0	-1.9853		.2801	.1348	1.1806		.0069	.3036	.0000
7.0	-3.7598	.1080	.2962	-.0362	1.2987	.0104	.0238	.8109	.0000
9.0	-3.2635	.1169	.3539	.1168	1.2595	.0044	.0021	.3982	.0000
9.3	-.2197				1.3072				.0000
10.0	-.5442	.0670	.1724	.0951	1.0151	.0044	.0055	.1243	.0000
Phosphorus, dissolved as P									
2.0	12.4875	-1.9198			.6289	.0275			.0305
2.6	23.3464	-2.9744	-.3630	-1.9877		.0003	.2719	.0001	
9.3	4.6331		.2508	-.1475			.0537	.2465	
10.0	-3.0445		.2167	.2910	1.0705		.0209	.0063	.0000
Phosphorus, dissolved ortho as P									
9.3	3.7382				.2033				.0641
10.0	-3.3265		.7345	.0757	1.0662		.0152	.7892	.0000
Phosphorus, total as P									
2.0	-5.4920	-.1664	-.6770	.7379	1.5753	.0753	.0012	.0066	.0000
2.3	-5.8186		-.5357	.3241	1.3707		.0114	.1441	.0000
2.6	-1.2299	-.3425			1.0792	.0008			.0000
3.0	-5.2308	-.1399	-.3909	.1413	1.3851	.0019	.0069	.3871	.0000
3.1	-4.0325		-.3218	.4367	1.1545		.0714	.0573	.0000
5.0	-3.7616	-.0847	.2262	.4139	1.2498	.0373	.0522	.0067	.0000
7.0	-3.9578		.1943	.0480	1.1939		.0357	.6541	.0000
9.0	-3.1255		.2349	.1764	1.1287		.0041	.0774	.0000
9.3	1.3388	.0848	.0961	.2394	.6309	.1081	.3199	.0242	.0000
10.0	-3.7900		.0841	.2360	1.2344		.2622	.0028	.0000
Potassium, dissolved									
2.0	2.3605		-.0919	.1332	.8037		.0255	.0156	.0000
2.3	1.1154	-.0528	-.0743	.2507	.9761	.1385	.0815	.0005	.0000
2.6	1.3676		-.1281	.1874	.8841		.0224	.0366	.0000
3.0	1.4085	.0639	-.0724	.2262	.8742	.0015	.2312	.0077	.0000
3.1	.1580	.1020	-.1364	.4221	.9634	.0001	.0780	.0000	.0000

Table 9.—*Regression coefficients and associated probability values of models used to estimate constituent transport for selected sites in the Kentucky River basin, water years 1983-85*—Continued

[Ln (C Q) = I + a t + b(sine θ) + c(cosine θ) + d(Ln Q): where C is concentration in milligrams per liter; Q is discharge in cubic feet per second; I is the regression intercept; Ln is natural logarithm; t is time, in decimal years using September 30, 1975, as t = 0; θ is the fractional part of the year, in radians; and a, b, c, and d are regression coefficients]

Site number	I	Regression coefficients				Probability values			
		a	b	c	d	a	b	c	d
Potassium, dissolved–Continued									
5.0	1.2477	0.0329	0.0149	0.3180	0.9351	0.1286	0.8242	0.0100	0.0000
7.0	1.0957	.0427	.1070	.2535	.9331	.0033	.0230	.0000	.0000
9.0	1.6534	.0241	.1446	.1230	.8866	.1433	.0173	.0589	.0000
9.3	3.8341		.0032	.2464	.4818		.9424	.0010	.0000
10.0	.9543		-.0584	.2879	.9861		.0364	.0000	.0000
Potassium, total									
2.0	1.9517		-.1008	.1967	.8790		.0439	.0060	.0000
2.3	-.3248	.1024	-.1226	.3362	1.0003	.0048	.0024	.0000	.0000
2.6	1.2476		-.1129	.2710	.9067		.1096	.0037	.0000
3.0	1.6611		-.0607	.2833	.9127		.1446	.0000	.0000
3.1	1.8032	-.1070	-.0771	.3973	.9654	.0339	.2335	.0000	.0000
5.0	1.7923	-.0622	-.0507	.3221	.9672	.1191	.3519	.0001	.0000
7.0	.6614		-.0674	.3363	1.0297		.1737	.0000	.0000
9.0	.8445		-.0007	.3493	1.0091		.9897	.0021	.0000
9.3	2.7193		-.0673	.3948	.7589		.5081	.0003	.0000
Silica, dissolved as SiO_2									
2.0	-1.2991				1.4489				.0000
2.3	1.8615		.0590	-.2410	.9640		.4530	.0478	.0000
2.6	.4184				1.2060				.0000
3.0	1.6954		.2568	-.1439	.9901		.0610	.2269	.0000
3.1	1.8948		.2099	-.1299	.9758		.0407	.1467	.0000
7.0	-1.5142				1.3341				.0002
9.0	-.0697				1.1599				.0010
9.3	1.4140		-.0069	.3409	1.1125		.9215	.0049	.0000
10.0	.1374	-.0265			1.1856	.0347			.0000
Silver, total									
10.0	-12.6829	.8423			.9496	.0003			.0000
Sodium, dissolved									
2.0	6.0387	-.1111	.0960	.0693	.5888	.0217	.0887	.3574	.0000
2.3	2.2728		.0480	.2700	.8869		.5469	.0239	.0000
2.6	4.5285				.6225				.0000
3.0	3.8946	.0878			.6711	.0277			.0000
3.1	1.3133				.8911				.0000
5.0	4.5566		.3182	.1098	.7081		.0978	.7068	.0005
7.0	4.0716		.3664	.0881	.7462		.0103	.5170	.0000
9.0	4.2152		.3530	-.0529	.7218		.0172	.7093	.0000
9.3	5.8507		.0699	.2279	.4333		.2852	.0212	.0002
10.0	3.0387	.0624	.0095	.2358	.8566	.0000	.8755	.0002	.0000
Sodium, total									
2.0	4.7185				.6623				.0000
2.3	2.7782		.2252	.3211	.8326		.2428	.0851	.0000
2.6	4.3010				.6597				.0000
3.0	-.6790	.5924	.1554	.3969	.7306	.0000	.2190	.0214	.0000
3.1	1.0744				.9839				.0000
5.0	.7409	.2887	.0292	.4837	.9032	.0138	.8490	.0195	.0000
7.0	.0576	.3087	-.0304	.3726	.9362	.0038	.8204	.0342	.0000
9.0	-2.6020	.6679	.2483	.2515	.8817	.0000	.0413	.1961	.0000
9.3	4.7689		-.0137	.2787	.7089		.9167	.0280	.0000
Strontium, dissolved									
10.0	-.5382	.1527			.7295	.0377			.0000

Table 9. —*Regression coefficients and associated probability values of models used to estimate constituent transport for selected sites in the Kentucky River basin, water years 1983-85* — Continued

[Ln (C Q) = I + a t + b(sine θ) + c(cosine θ) + d(Ln Q): where C is concentration in milligrams per liter; Q is discharge in cubic feet per second; I is the regression intercept; Ln is natural logarithm; t is time, in decimal years using September 30, 1975, as t = 0; θ is the fractional part of the year, in radians; and a, b, c, and d are regression coefficients]

Site number	I	Regression coefficients a	Regression coefficients b	Regression coefficients c	Regression coefficients d	Probability values a	Probability values b	Probability values c	Probability values d
Sulfate, dissolved as SO_4									
2.0	6.2046	0.0589	-0.1016	-0.0695	0.7137	0.0124	0.0279	0.2158	0.0000
2.3	3.3265	.0997	.0400	.1367	.9681	.0001	.3733	.0120	.0000
2.6	4.2353	.0938			.8432	.0064			.0000
3.1	2.7757		.1627	-.0824	.9801		.0593	.2739	.0000
9.3	4.3014	.1352	.0857	.2057	.7007	.1426	.1211	.0175	.0000
10.0	4.0929	.0436			.9253	.0000			.0000
Sulfate, total as SO_4									
2.0	6.2653				.7961				.0000
2.3	4.8207		.1656	.0515	.8507		.0140	.3245	.0000
2.6	4.7845				.8817				.0000
3.0	4.8876	.0975			.8173	.0000			.0000
3.1	2.6943		.0300	.1153	1.0155		.5344	.0492	.0000
5.0	4.7098	.0490	.0549	.1365	.8661	.0049	.2598	.0324	.0000
7.0	4.3557	.0580			.8768	.0001			.0000
9.0	4.3454	.0735	.1153	-.0458	.8647	.0001	.0194	.4470	.0000
9.3	4.9352		-.0252	.2172	.7898		.7752	.0127	.0000
Suspended sediment									
2.0	-4.0779		-1.1890	1.0091	2.2080		.0000	.0000	.0000
2.3	-.1575	-.1669	-.5379	.5143	1.8222	.0020	.0011	.0043	.0000
2.6	-1.9466		-1.0628	1.0887	1.7915		.0000	.0000	.0000
3.0	-.8332	-.1296	-.5187	.1547	1.6810	.0035	.0006	.3305	.0000
3.1	1.7298		-.5596	.3400	1.3748		.0015	.0728	.0000
5.0	-4.3920		-.3090	.2456	1.9385		.0420	.2088	.0000
7.0	-1.0868	-.0824	-.2208	-.2255	1.5870	.0567	.0996	.1523	.0000
9.0	-2.3398				1.6724				.0000
9.3	.8639		-.4485	.1991	1.2866		.0085	.2515	.0000
10.0	-1.1040	-.1256			1.6491	.0000			.0000
Zinc, dissolved									
2.0	.7416	-.7283			.9170	.1496			.0265
2.3	-9.4985		-.9739	2.6863	1.6930		.1619	.0351	.0047
2.6	-6.9261		.3536	1.8282	1.3247		.5205	.0486	.0045
3.0	-.4491	-.2301			.7126	.0172			.0000
3.1	-3.1253	-.1474			.9083	.0268			.0000
5.0	-3.7000				.9299				.0000
7.0	-2.8195				.8160				.0000
9.0	-5.1832				1.1273				.0000
9.3	2.7928	-.7279			.6866	.0057			.0028
10.0	-6.3769				1.1339				.0000
Zinc, total									
2.0	-8.0363		-.5254	.8888	1.6647		.0052	.0007	.0000
2.3	-5.7982		-.4806	.6834	1.2570		.1534	.0598	.0000
2.6	-1.4985	-.2827			.9039	.0862			.0000
3.0	-3.4723	-.2871	-.4753	.2893	1.2320	.0006	.0163	.3108	.0000
3.1	-3.7797	-.0977			1.0230	.0175			.0000
5.0	-5.1921				1.1370				.0000
7.0	-3.9030	-.1052			1.0856	.1580			.0000
9.0	-3.4857	-.1697			1.0799	.0702			.0000
9.3	2.1197	-.4030			.5036	.0003			.0057
10.0	-6.6301	.0834	-.1956	.3707	1.3511	.0963	.2129	.0277	.0000

Biological Data

Aquatic biological communities are important in stream assessments because the abundance and distribution of aquatic species or groups of organisms reflect intermediate to long-term changes in water-quality conditions, as well as the influences of drainage basin physiography. Algal communities can reflect relatively short-term (days to months) changes in water quality and aquatic habitat. For example, streams affected by oil-field brines frequently are dominated by halophilic ("salt-loving") diatoms, and streams which receive discharges of sewage effluents are characterized by dense growths of algal taxa associated with nutrient enrichment. Alterations of aquatic environments may also be detected by changes in the community composition of benthic macroinvertebrates. Streams with rocky substrata and well-oxygenated water usually support communities dominated by aquatic insects (Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)). A shift in dominance to more tolerant taxa such as Dipterans (midges) and Oligochaetes (worms) often occurs in response to increases in sedimentation or nutrient enrichment.

The number and types of fish species are also an indication of water-quality conditions. For example, the number of darter species usually decreases in streams with degraded water quality and large amounts of sediment (Clay, 1975). Clean-water streams support a variety of sensitive taxa, including game species such as trout and muskellunge (muskie). In contrast, fish communities found in polluted water are frequently limited to tolerant species such as carp, and mosquito fish (*Gambusia* sp.).

Streams draining similar physical environments should support similar organisms and consequently provide a more realistic comparison of water- quality conditions in the basin. Because environmental disturbances frequently affect the entire aquatic community, groups of organisms commonly sampled in water-quality surveys will be discussed collectively for a particular stream.

SOURCES AND CHARACTERISTICS OF AVAILABLE SURFACE WATER-QUALITY DATA

All possible sources of surface water-quality data for the "historical" (1951-86) and "current-record" (1976-86) periods were evaluated for inclusion in the assessment. Principal sources were governmental agencies, but data collected by universities and other nongovernmental agencies were also used when available. Compilation of the available data indicated some spatial and temporal variability resulting from the unique mission and objectives for sampling for each of the different agencies. Some data consisted of numerous samples collected only one time throughout the basin; others were periodic, collected at specific sites. Similarly, some samples were analyzed for a specific constituent, others for multiple constituents. The majority of the water-quality data characterizes the physical properties, major ions, trace elements, major metals, and nutrients of surface water in the basin; whereas synthetic organic chemical, radio-chemical, and bacteriological data are relatively limited.

Sources of Data

Six principal agencies were identified as having sampled water-quality in the Kentucky River basin. These agencies are:

- Kentucky Division of Water
- Kentucky Department for Surface Mining Reclamation and Enforcement
- U.S. Army Corps of Engineers
- U.S. Environmental Protection Agency
- U.S. Geological Survey
- U.S. Office of Surface Mining Reclamation and Enforcement

Spatial Distribution of Sampling Sites

The locations of the sampling sites of each agency are dependent on the sponsoring agency's mission, purpose, and their particular goals for sampling. Locations of sampling sites are also affected by the level of knowledge of the factors influencing water quality and the accessibility and suitability of sites for sampling. The U.S. Army Corps of Engineers has collected water-quality data generally related to operation of reservoirs in the basin. Both the Kentucky Department for Surface Mining Reclamation and Enforcement and the U.S. Office of Surface Mining Reclamation and Enforcement have collected water-quality data primarily in relation to coal-mining activities in the Eastern Coal Fields. The U.S. Environmental Protection Agency has sampled in the basin in response to its regulatory and assessment mandates. The Kentucky Division of Water maintains a network of sampling stations throughout the basin and has collected monthly data to assess water-quality conditions. The Geological Survey also maintains a network of streamflow-monitoring stations throughout the Kentucky River basin, has obtained periodic water-quality samples at one site as part of the National Stream Quality Accounting Network (NASQAN), and has obtained miscellaneous samples at other sites as part of special investigative projects.

Water-quality data at several sites were collected by more than one agency and these data were pooled prior to analysis as described earlier in the report. The locations of surface water-quality data-collection sites through 1986 are shown in figure 11.

Temporal and Hydrologic Distribution of Samples

In addition to site location, the degree of sample repetition is dependent on the purpose of sampling. Numerous factors need to be considered when designing a sampling strategy and protocol. Some of these include: program goals and objectives; environmental factors affecting the constituents of interest and their variation with time; time scales of interest (short term or long term); statistical procedures to be used when addressing goals and objectives; the error that can be tolerated in results; and practical constraints, such as costs. Samples obtained for monitoring purposes are generally collected on some periodic schedule, but those obtained for regulatory purposes may not always be repeated. About 80 percent of the sampling sites in the Kentucky River basin have been sampled fewer than 10 times. Only 30 sites in the basin had 10 or more measurements of one or more constituents obtained during the "current-record" period of the 1976-86 water years (fig. 12, table 10). The current-record period data base from these 30 sites consisted of about 2,300 samples, containing 34,000 individual determinations for 93 different constituents or properties. The land uses upstream from 13 of these 30 current-period sites are listed in table 11.

The number of surface water-quality samples collected in the basin each water year has increased from less than 40 per year in the 1950's to more than 700 in the early 1980's (fig. 13). The Geological Survey collected data at many sites for special studies related to coal mining in the late 1970's and early 1980's. The water-quality monitoring program of the Kentucky Division of Water was started in the mid-1970's and accounts for most of the data available for individual site statistical analyses for the "current-record" period. The other sources of data obtained during this period were from the Geological Survey NASQAN station, which began operation in 1973, and miscellaneous data obtained during streamflow monitoring by the Survey.

Figure 14 shows that the temporal distribution of sample collection during the period 1951-86 in the Kentucky River basin has seasonal bias, with fewer samples collected in winter than during any other season. Data obtained for monitoring purposes show less seasonal bias because sampling schedules are usually fairly rigid.

Because streamflow and related constituent concentrations vary throughout the year, a sampling of water quality should ideally represent the entire range of streamflow conditions. High-flow conditions are representative of surface runoff and contribute a large proportion of the annual constituent load. Low-flow conditions are generally indicative of baseflow contributions from ground water and usually contain the highest concentrations of dissolved constituents. The distribution of samples collected over the flow-duration curve for selected sites within the basin is shown in figures 15, 16, and 17. The solid line shows the flow-duration curve of daily streamflow during the water years 1976-86. The points represent instantaneous discharge at the time of sampling. Sampling that is perfectly representative of the flow regime would be evident in two ways. First, the points would extend to each end of the flow-duration curve. In practice, this can be achieved only by collecting many more samples or scheduling sampling to meet specified flow conditions. Second, the points would lie exactly on the curve. Figures 15, 16, and 17 show that, in general, sampling is not biased toward a particular flow condition. Low-flow sampling has been adequate. However, the figures also show that relatively few high-flow events were sampled at these sites. High-flow sampling has been adequate at sites 3.1 and 7.0, and consistently less-than-adequate at site 2.0. For a given exceedance probability at site 2.0, sampled discharge toward the upper end of the curve is only half of that expected from the distribution of daily flows. The flow duration at times of sampling for selected constituents and properties for sites based on available data for water years 1976-86 is shown in table 12.

Types of Water-Quality Determinations

The number of samples obtained in the Kentucky River basin by major property and constituent groups are shown in figure 18 for the historical and current-record periods. The major ions group had the largest number of samples during both periods whereas synthetic organic chemical and radio-chemical data represented a small portion of samples collected in the basin. Thus, the data base contains a relatively large number of analyses useful in addressing issues such as salinity but relatively few analyses that are needed to address issues of more recent concern, such as contamination of water by potentially toxic organic compounds or radionuclides.

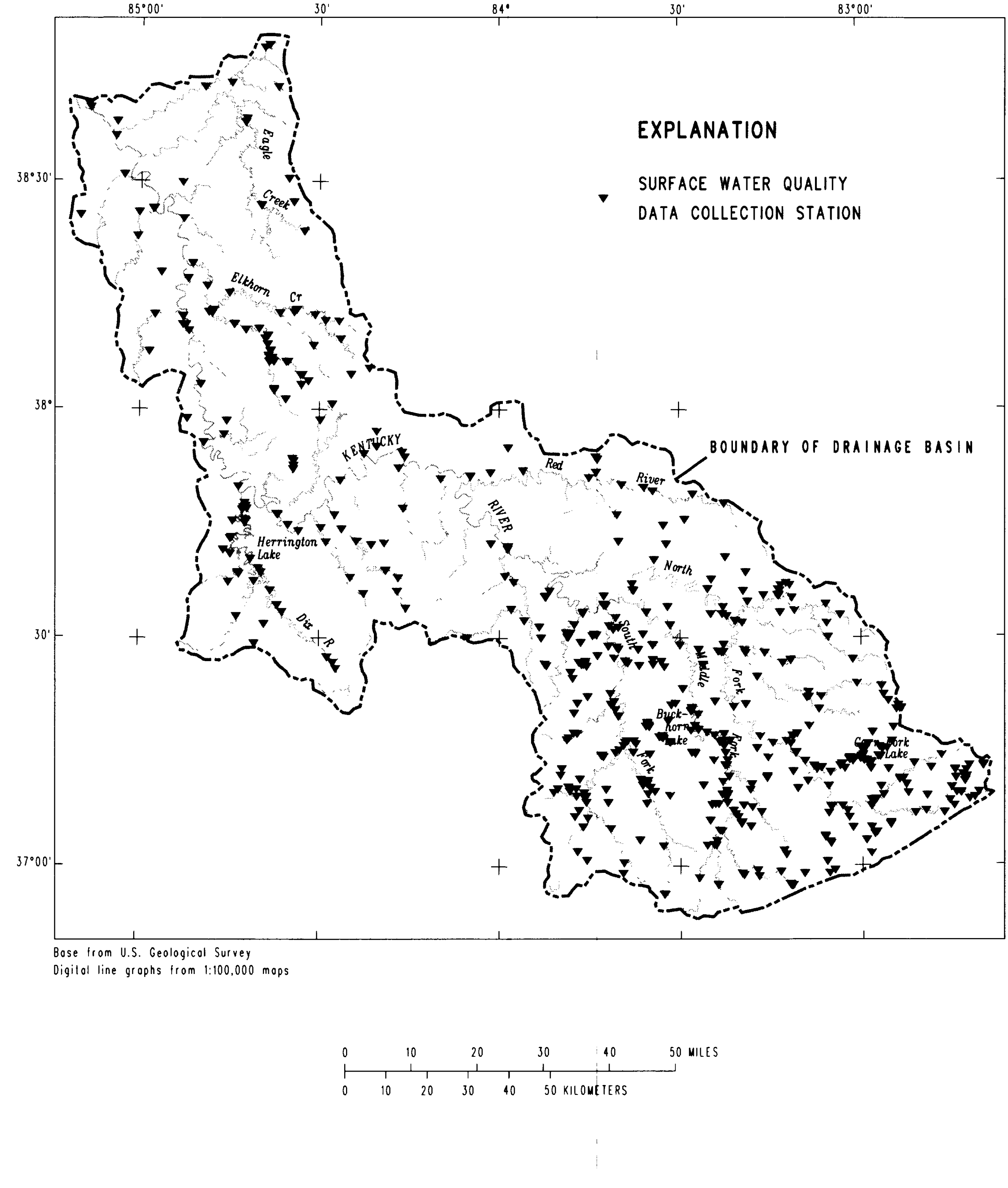


Figure 11.--Locations of surface water-quality stations in the Kentucky River basin, through 1986.

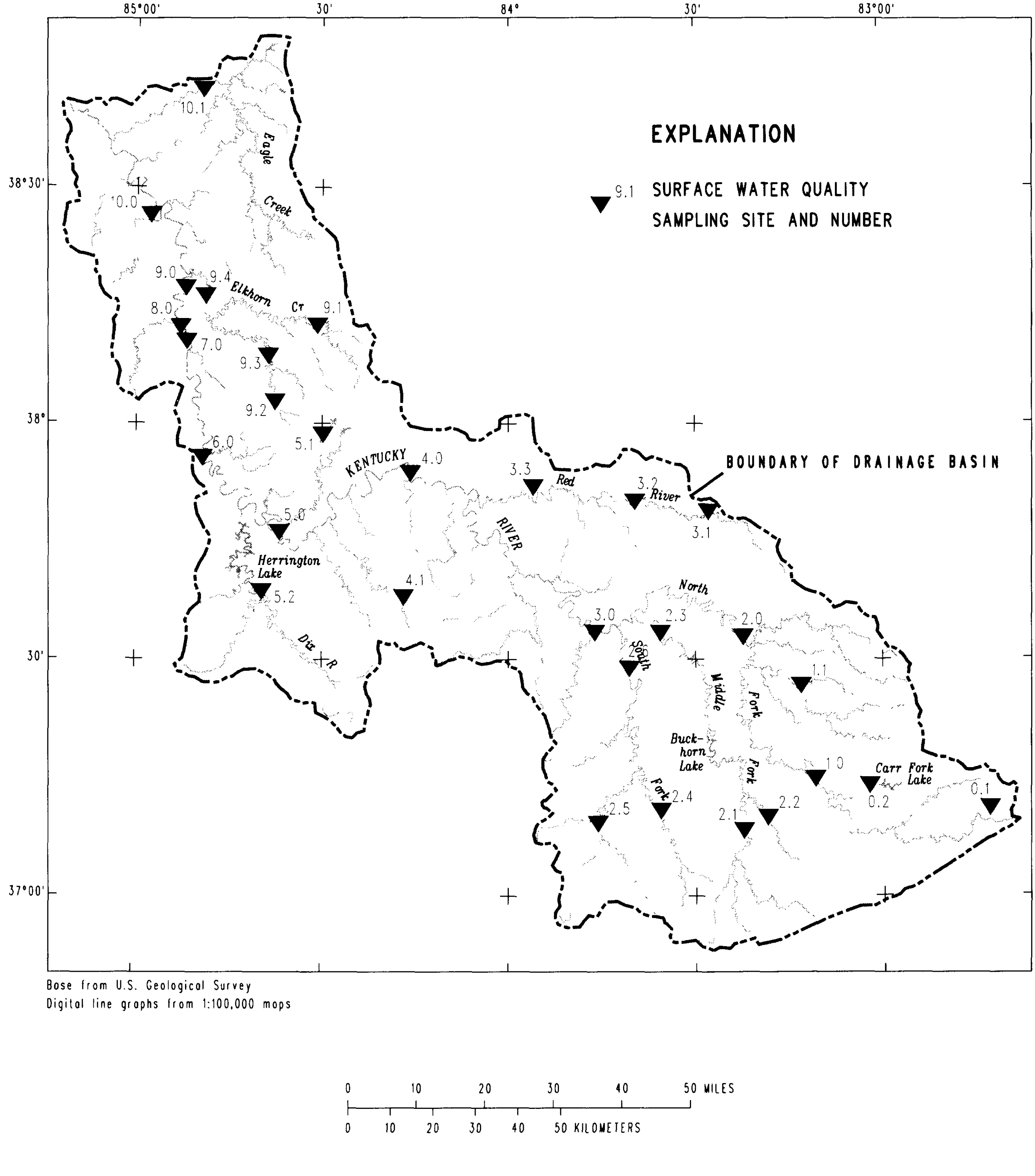


Figure 12.--Locations of surface water-quality sampling sites in the Kentucky River basin at which 10 or more samples were collected, water years 1976-86.

Table 10.—*Surface water-quality sampling sites in the Kentucky River basin at which ten or more measurements of one or more constituents were obtained during water years 1976-86*

[Kentucky River mile is at mouth of listed basin or at site on main stem]

Site number	Kentucky River mile	U.S. Geological Survey station name and number		Drainage area (square miles)
	417.3		**BOONE FORK BASIN**	19.4
0.1		03277260	Yonts Fork near Neon	12.4
	367.8		**CARR FORK BASIN**	85.5
0.2		03277450	Carr Fork near Sassafras	60.6
1.0	361	03277500	North Fork Kentucky River at Hazard	466
	317.7		**TROUBLESOME CREEK BASIN**	246
1.1		03278500	Troublesome Creek at Noble	177
2.0	304.5	03280000	North Fork Kentucky River at Jackson	1,101
	258.6		**MIDDLE FORK KENTUCKY RIVER BASIN**	559
2.1		03280600	Middle Fork Kentucky River near Hyden	202
2.2		03280700	Cutshin Creek at Wooton	61.3
2.3		03281000	Middle Fork Kentucky River at Tallega	537
	254.8		**SOUTH FORK KENTUCKY RIVER BASIN**	748
2.4		03281040	Red Bird River near Big Creek	155
2.5		03281100	Goose Creek at Manchester	163
2.6		03281500	South Fork Kentucky River at Booneville	722
3.0	249	03282000	Kentucky River at Lock 14, at Heidelberg	2,657
	190.8		**RED RIVER BASIN**	487
3.1		03282500	Red River near Hazel Green	65.8
3.2		03283200	Red River at Highway 77 near Bowen	184
3.3		03283500	Red River at Clay City	362
4.0	176.4	03284000	Kentucky River at Lock 10, near Winchester	3,955
	150.3		**SILVER CREEK BASIN**	126
4.1		03284300	Silver Creek near Kingston	28.6
5.0	135.9	03284500	Kentucky River at Camp Nelson	4,425
	135.3		**HICKMAN CREEK BASIN**	101
5.1		03284550	West Hickman Creek at Jonestown	11.0
	118.2		**DIX RIVER BASIN**	442
5.2		03285000	Dix River near Danville	318
6.0	96.2	03287000	Kentucky River at Lock 6, near Salvisa	5,102
7.0	68.4	03287400	Kentucky River above Frankfort	5,292
8.0	65.8	03287500	Kentucky River at Lock 4, at Frankfort	5,411
9.0	56.0	03287570	Kentucky River below Frankfort	5,420
	51.9		**ELKHORN CREEK BASIN**	500
9.1		03288000	North Elkhorn Creek near Georgetown	119
9.2		03289000	South Elkhorn Creek at Fort Spring	24.0
9.3		03289300	South Elkhorn Creek near Midway	105
9.4		03289500	Elkhorn Creek near Frankfort	473
10.0	31.0	03290500	Kentucky River at Lock 2, at Lockport	6,180
	11.0		**EAGLE CREEK BASIN**	519
10.1		03291500	Eagle Creek at Glencoe	437

Table 11.—*Land use upstream from selected stream sites in the Kentucky River basin*

Site number	USGS station name	Drainage area, in square miles	Land use, in percent: Urban	Agri-culture	Forest	Lakes and reservoirs	Mining activities
2.0	North Fork Kentucky River at Jackson	1,101	0.3	0.2	95.2	0.1	4.2
2.3	Middle Fork Kentucky River at Tallega	537	.1	1.2	96.0	.1	2.6
2.6	South Fork Kentucky River at Booneville	722	.2	5.9	92.8	.0	1.0
3.0	Kentucky River at Lock 14, at Hiedelberg	2,657	.3	3.0	94.0	.1	2.6
3.1	Red River near Hazel Green	65.8	.2	12.0	87.8	.0	.1
4.0	Kentucky River at Lock 10, near Winchester	3,955	1.3	12.3	84.5	.1	1.9
5.0	Kentucky River at Camp Nelson	4,425	1.5	19.6	77.1	.1	1.7
5.2	Dix River near Danville	318	3.4	68.4	27.9	.0	.4
8.0	Kentucky River at Lock 4, at Frankfort	5,411	2.4	29.0	66.9	.1	1.5
9.3	South Elkhorn Creek near Midway	105	23.1	75.4	.1	.0	.8
10.0	Kentucky River at Lock 2, at Lockport	6,180	3.4	34.4	60.7	.1	1.3
10.1	Eagle Creek at Glencoe	437	4.7	57.3	37.8	.1	.0
	Kentucky River at Mouth	6,964	3.6	37.0	58.0	.1	1.2

National Uranium Resource Evaluation Program Data

The National Uranium Resource Evaluation (NURE) program was established by the U.S. Department of Energy to evaluate domestic uranium resources in the continental United States. Samples of stream water and streambed sediments were obtained during the period 1978 through 1980 at thousands of sites in 37 States. Data obtained as a result of the NURE program were intended for use in identifying broad areas for further study. The following discussion of NURE sampling data and methodology is an excerpt from Sargent and others (1982).

Stream-water and streambed-sediment samples were obtained in many but not all counties in the Kentucky River basin. Field measurements of pH, specific conductance, and alkalinity were obtained at stream sites. About 1,450 stream-water samples were analyzed for concentrations of major ions (sodium, magnesium, bromide, chloride, fluoride, and aluminum) and selected trace elements (manganese, dysprosium, vanadium, and uranium). About 1,200 streambed-sediment samples were analyzed for total or total-recoverable concentrations of aluminum, barium, beryllium, boron, calcium, cesium, chromium, cobalt, copper, dysprosium, europium, hafnium, iron, lanthanum, lead, lithium, lutetium, magnesium, manganese, miobium, molybdenum, nickel, phosphorus, potassium, samarium, scandium, selenium, sodium, strontium, thorium, titanium, uranium, vanadium, yttrium, ytterbium, zinc, and zirconium.

National Atmospheric Deposition Program

The National Atmospheric Deposition Program (NADP) is a program to determine regional geographical patterns and long-term trends in the chemical composition of wet atmospheric deposition (Bigelow, 1986). Collection of data began in 1978 at seven sites. By 1983, the collection network contained 190 sites. Three sites are near the Kentucky River basin, in Boyle, Letcher, and Rowan counties. Analyses of weekly precipitation samples for the period 1984-86 were obtained for the three sites. Data included precipitation amounts, pH, specific conductance, and concentrations of major dissolved ions. Descriptive statistics were compiled for each site, and annual precipitation loadings were computed. Because the three sites are not located near urban areas, loadings projected to the Kentucky River basin, which includes several urban areas, are probably conservative. Trends were not analyzed because of the short period of record. Because results were basically the same at all three sites, discussion in this and later sections is limited to only one site-Perryville Battlefield in Boyle County, about 30 miles southwest of Lexington.

Pollutant-Discharge Estimates

Estimates of current average annual pollutant discharges in the Kentucky River basin were compiled by Gianessi (1986). Both point and nonpoint sources were considered. For nonurban-nonpoint sources, the estimates were developed cooperatively

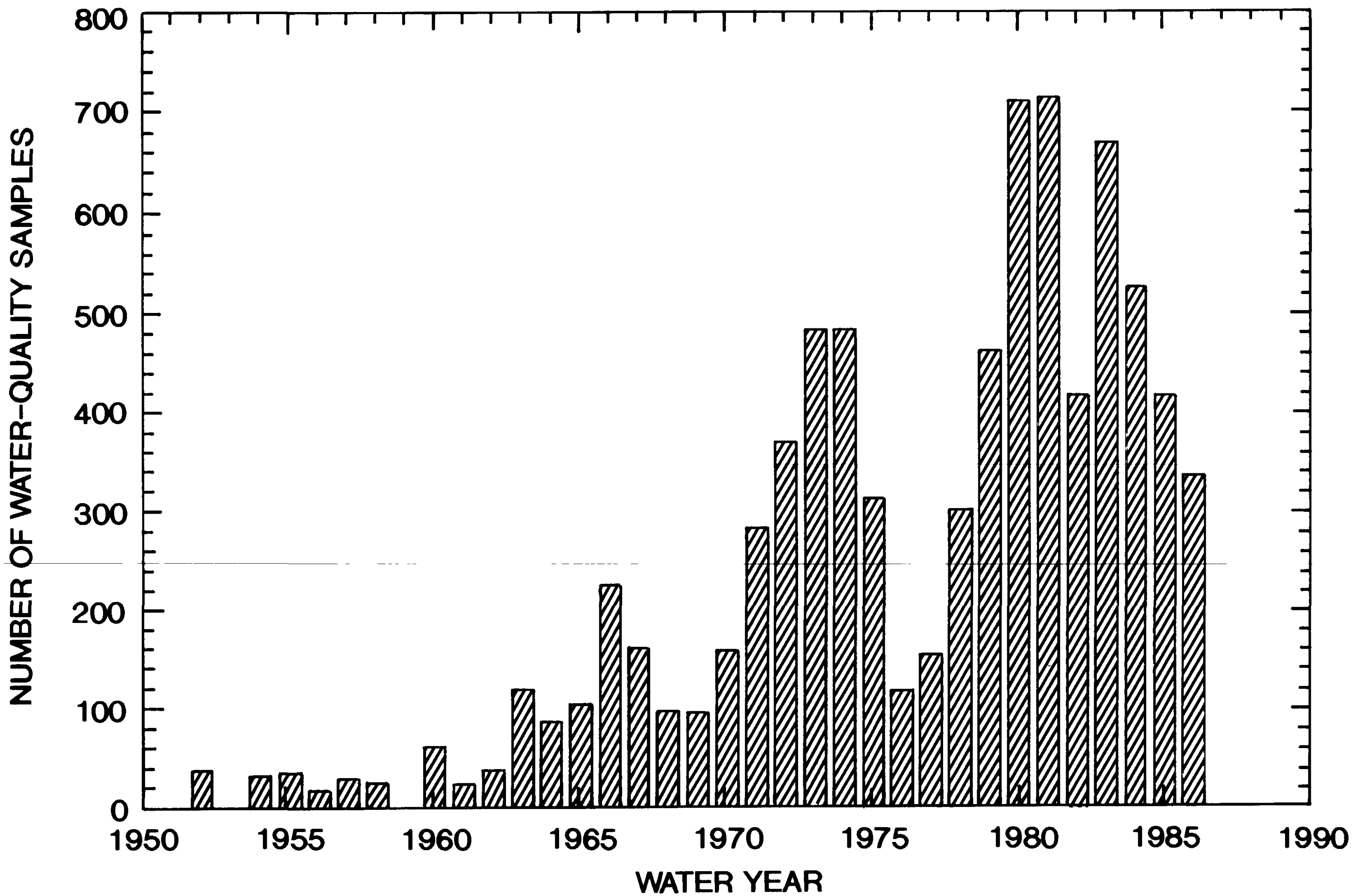


Figure 13.--Number of surface water-quality samples collected in the Kentucky River basin, water years 1951-86.

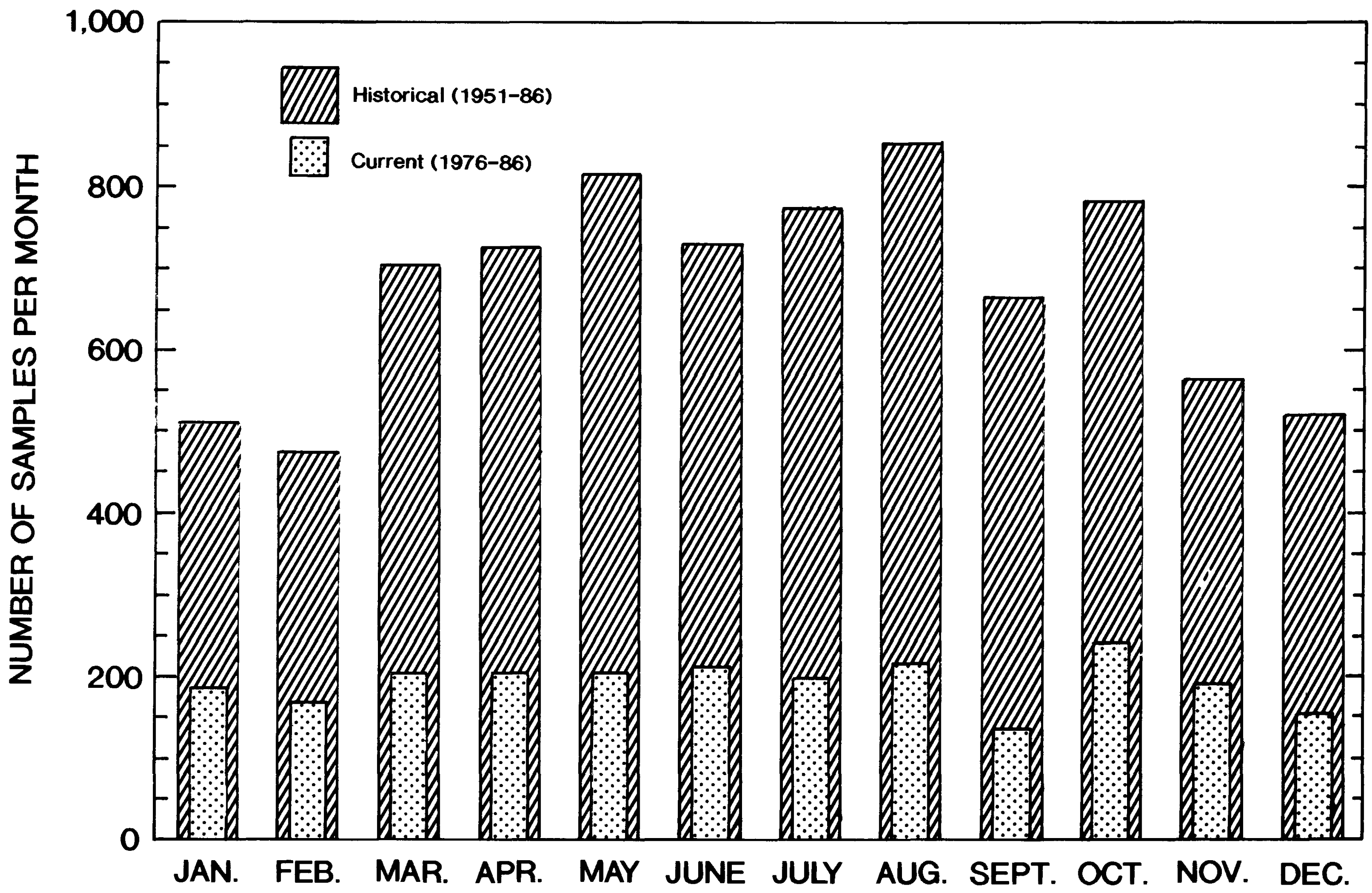


Figure 14.--Number of surface water-quality samples collected in the Kentucky River basin by month.

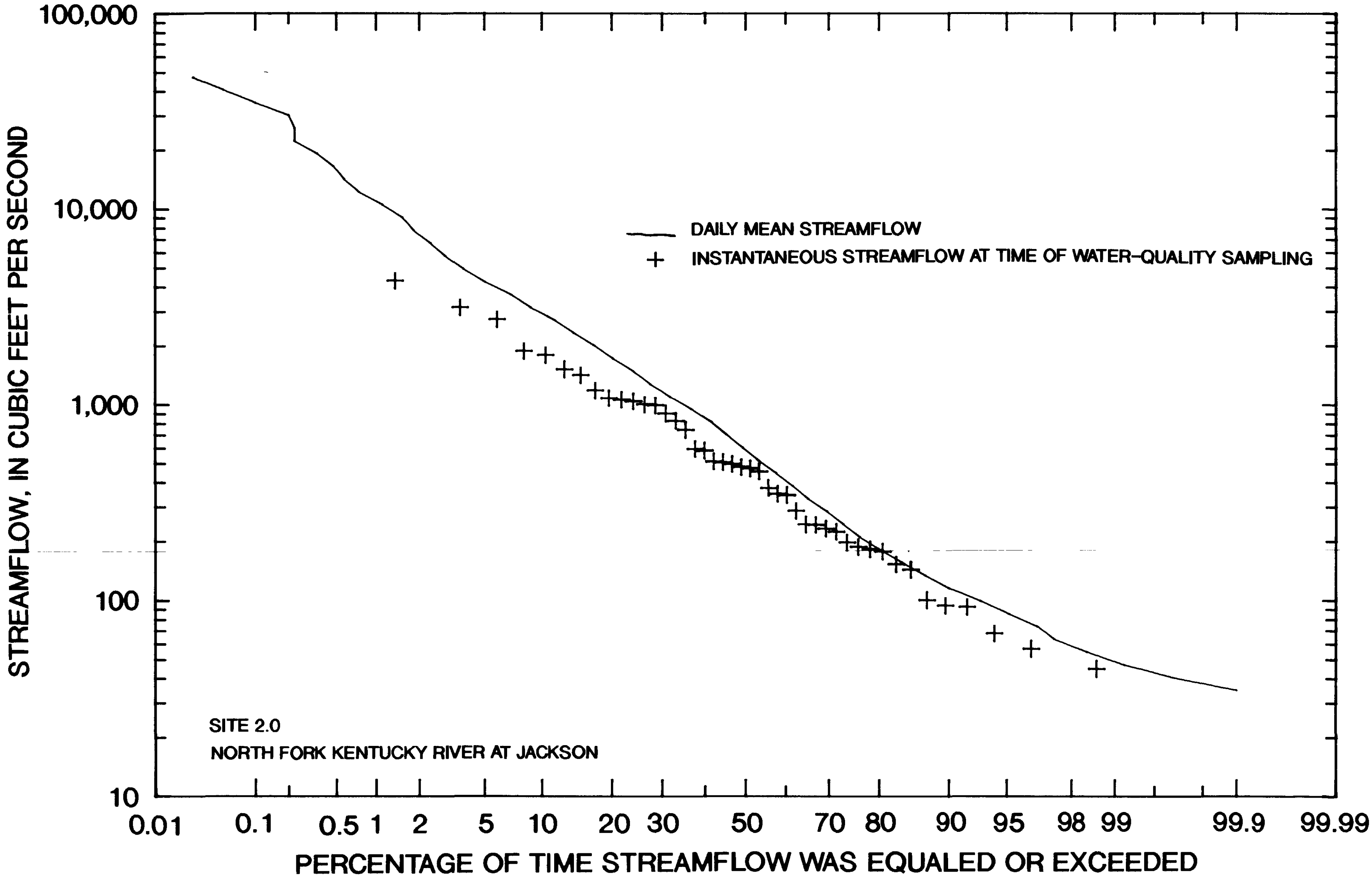


Figure 15.--Streamflow duration and instantaneous streamflow at time of sampling for the North Fork Kentucky River at Jackson, water years 1976-86.

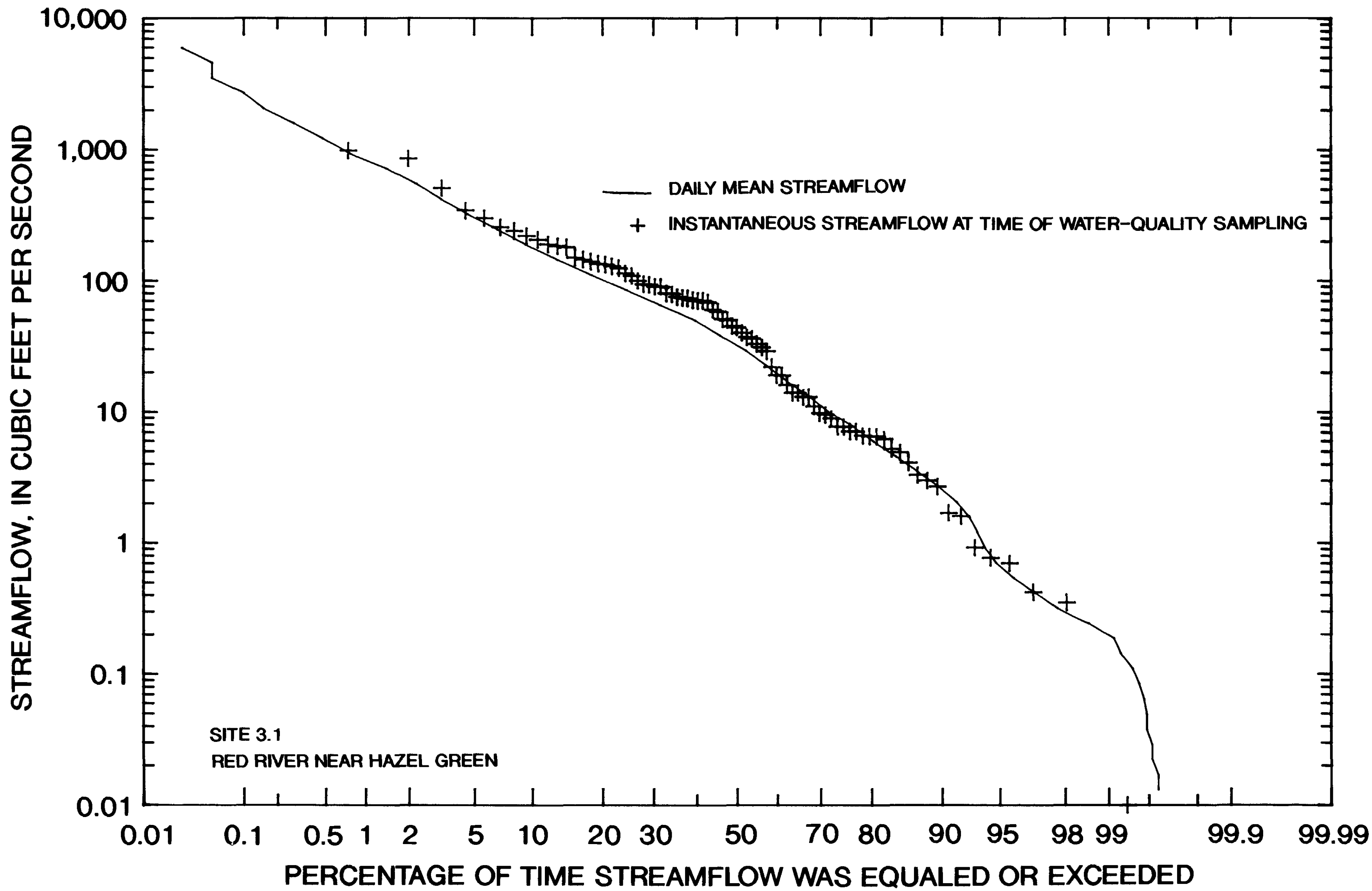


Figure 16.--Streamflow duration and instantaneous streamflow at time of sampling for the Red River near Hazel Green, water years 1976-86.

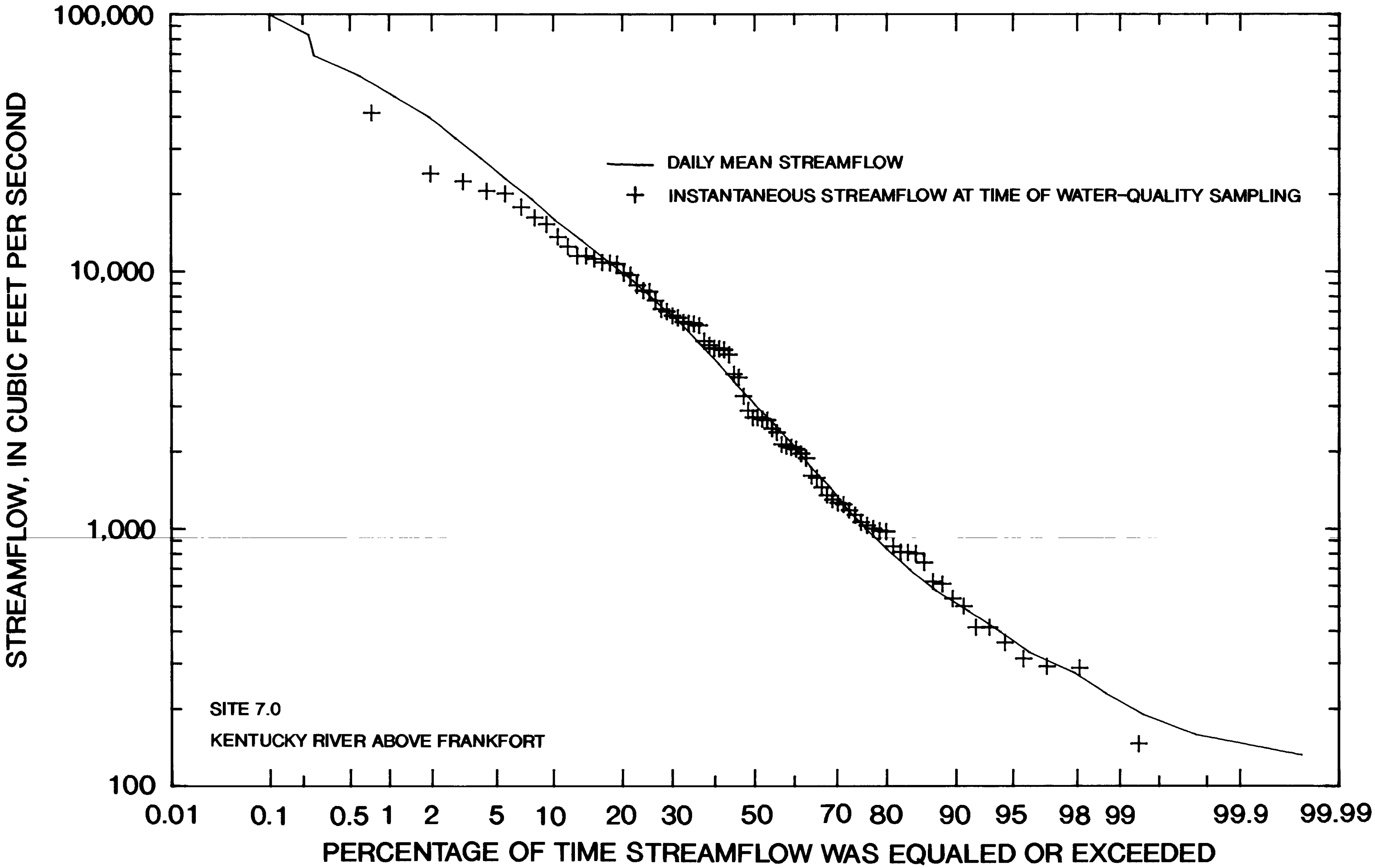


Figure 17.--Streamflow duration and instantaneous streamflow at time of sampling for the Kentucky River above Frankfort, water years 1976-86.

Table 12.—*Percentage of water-quality samples obtained during specified flow-duration ranges for selected constituents, properties, and sites in the Kentucky River basin, based on available data for water years 1976-86*

[NQ, number of samples with corresponding discharge information; <, less than; >, greater than]

Site number	USGS station name	NQ	Percentage of samples obtained in indicated flow duration			
			< 90	< 75	> 25	> 10
Specific conductance, in microsiemens per centimeter						
0.2	Carr Fork near Sassafras	72	4.2	15.3	29.2	16.7
1.0	North Fork Kentucky River at Hazard	64	3.1	12.5	25.0	15.6
1.1	Troublesome Creek at Noble	24	4.2	37.5	8.3	4.2
2.0	North Fork Kentucky River at Jackson	89	3.4	10.1	22.5	6.7
2.1	Middle Fork Kentucky River near Hyden	63	12.7	25.4	27.0	6.3
2.2	Cutshin Creek at Wooton	68	11.8	23.5	29.4	5.9
2.3	Middle Fork Kentucky River at Tallega	92	0.0	12.0	26.1	14.1
2.4	Red Bird River near Big Creek	62	9.7	33.9	17.7	9.7
2.5	Goose Creek at Manchester	68	7.4	26.5	25.0	17.6
2.6	South Fork Kentucky River at Booneville	89	6.7	18.0	19.1	6.7
3.0	Kentucky River at Lock 14, at Heidelberg	116	6.0	19.0	25.9	12.1
3.1	Red River near Hazel Green	148	8.8	18.2	32.4	12.2
3.3	Red River at Clay City	73	6.8	21.9	30.1	9.6
4.0	Kentucky River at Lock 10, near Winchester	47	4.3	14.9	17.0	2.1
4.1	Silver Creek near Kingston	41	17.1	26.8	14.6	9.8
5.0	Kentucky River at Camp Nelson	12	16.7	25.0	25.0	16.7
5.1	West Hickman Creek at Jonestown	45	15.6	28.9	31.1	8.9
5.2	Dix River near Danville	60	8.3	30.0	20.0	6.7
6.0	Kentucky River at Lock 6, near Salvisa	47	4.3	25.5	23.4	6.4
8.0	Kentucky River at Lock 4, at Frankfort	53	13.2	30.2	24.5	3.8
9.1	North Elkhorn Creek near Georgetown	48	2.1	14.6	18.8	10.4
9.2	South Elkhorn Creek at Fort Spring	61	3.3	11.5	27.9	9.8
9.4	Elkhorn Creek near Frankfort	46	2.2	10.9	28.3	15.2
10.0	Kentucky River at Lock 2, at Lockport	101	4.9	17.6	32.4	10.8
10.1	Eagle Creek at Glencoe	20	10.0	20.0	30.0	10.0
Chloride, dissolved, in milligrams per liter						
2.0	North Fork Kentucky River at Jackson	44	2.3	13.6	13.6	2.3
2.3	Middle Fork Kentucky River at Tallega	43	0.0	14.0	16.3	7.0
2.6	South Fork Kentucky River at Booneville	43	2.3	18.6	14.0	4.7
3.0	Kentucky River at Lock 14, at Heidelberg	86	7.0	19.8	25.6	14.0
3.1	Red River near Hazel Green	81	9.9	18.5	32.1	11.1
5.0	Kentucky River at Camp Nelson	12	16.7	25.0	25.0	16.7
10.0	Kentucky River at Lock 2, at Lockport	101	4.9	17.6	32.4	10.8
10.1	Eagle Creek at Glencoe	19	10.5	21.1	31.6	10.5
Lead, total, in micrograms per liter						
2.0	North Fork Kentucky River at Jackson	36	0.0	11.1	13.9	2.8
2.3	Middle Fork Kentucky River at Tallega	35	0.0	14.3	17.1	8.6
2.6	South Fork Kentucky River at Booneville	35	2.9	20.0	14.3	5.7
3.0	Kentucky River at Lock 14, at Heidelberg	69	4.3	14.5	27.5	14.5
3.1	Red River near Hazel Green	75	10.7	17.3	36.0	16.0
5.0	Kentucky River at Camp Nelson	12	16.7	25.0	25.0	16.7
10.0	Kentucky River at Lock 2, at Lockport	25	7.7	19.2	46.2	11.5
10.1	Eagle Creek at Glencoe	11	18.2	27.3	36.4	18.2

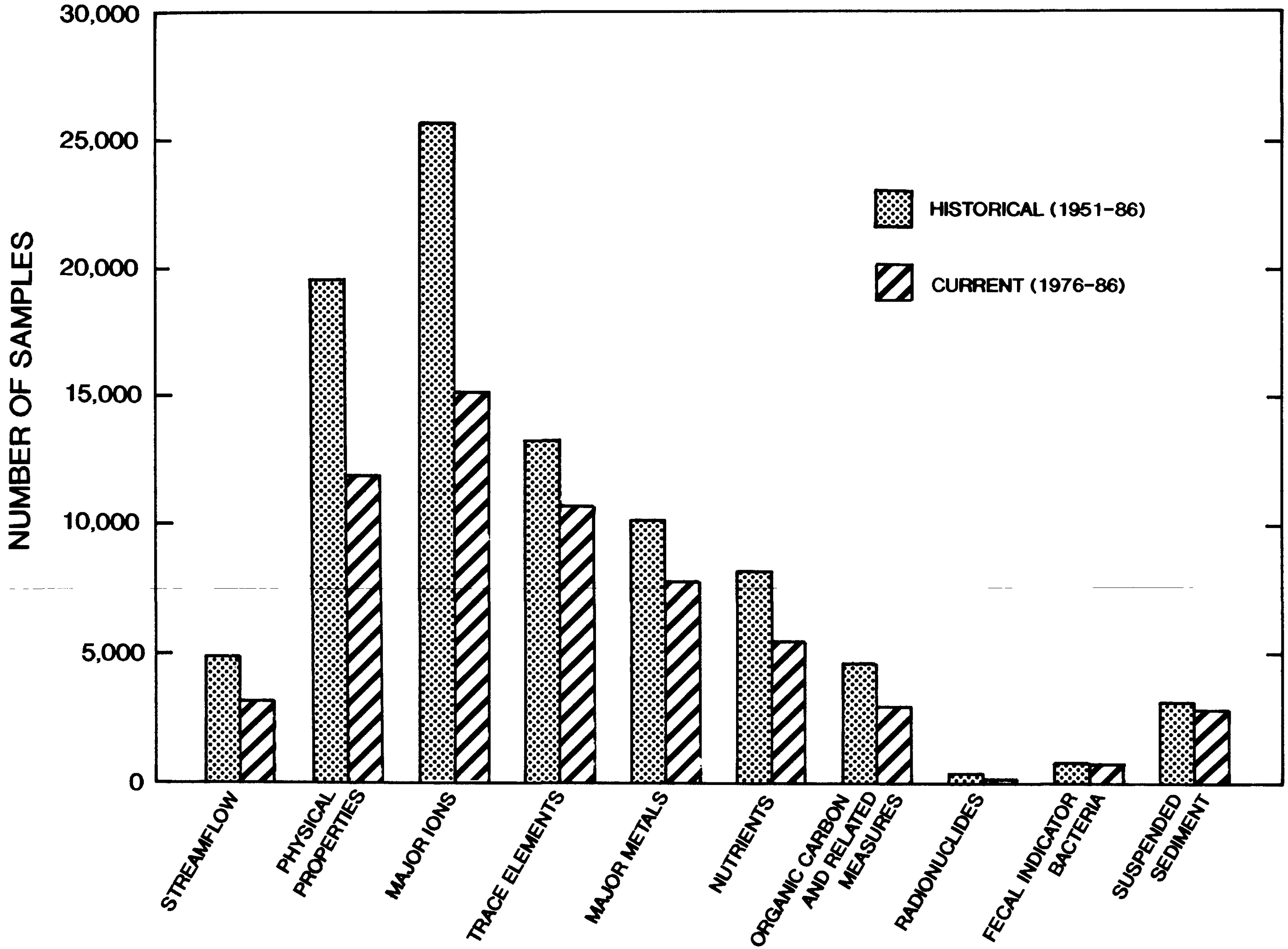


Figure 18.--Numbers of surface-water samples analyzed for selected property and constituent groups in the Kentucky River basin, 1951-86.

with the Geological Survey, the U.S. Department of Agriculture Soil Conservation Service, and the U.S. Environmental Protection Agency. The primary sources of data for point sources in the Kentucky River basin were the facilities files of the Kentucky Division of Water, and the National Pollution Discharge Elimination System files of the U.S. Environmental Protection Agency (Gianessi, 1986). The point-source inventory compiled from these files includes industrial facilities, power plants, and wastewater-treatment facilities (municipal and privately owned) discharging pollutants to surface water on a regular basis. Average discharge levels of pollutants were compiled from the files or were estimated from technical wastewater treatment literature for each industrial category, or for various water uses such as cooling water. Values of pollutants not specifically reported were estimated based on the industrial category, type of wastewater, and treatment level.

Nonpoint sources include runoff from such land uses as urban areas, cropland, pastureland, forests, and mining. Pollution estimates for the Kentucky River basin from these sources pertain to nutrients and trace metals from urban runoff, sediment and sediment attached pollutants from rural lands, dissolved nutrient and pesticide discharges from agricultural lands, and mine drainage.

The procedures used for making nonpoint-source estimates generally involved starting with a county-based inventory of source activity, such as gross soil erosion from rural lands as estimated in the U.S. Department of Agriculture's 1982 National Resources Inventory. The principal sources of pesticide usage data were various State, regional, and national usage surveys conducted by the Economic Research Service of the U.S. Department of Agriculture, and the Office of Pesticide Programs of the U.S. Environmental Protection Agency. The fraction of the activity that results in a loss to waterways was then estimated. In the case of sediment arising from gross soil erosion, sediment delivery to waterways was estimated on the basis of soil texture and drainage density using methods described by Gianessi (1986). In the case of nutrient loss from fertilizer applications, the Cornell Nutrient Simulation Model was used (Gianessi, 1986). Next, the quantities of pollutants associated with each activity were estimated. Using sediment as an example, the nutrient and heavy metal content of soils throughout each county were estimated using Soil Conservation Service county soil inventory documents and Geological Survey reports that characterize the content of surface soils.

A more complete discussion of these point- and nonpoint-source, pollution-discharge estimates, with emphasis on estimation procedures, is made by Gianessi (1986). Most of the loads listed in the data base are estimates rather than measurements. Because of the degree to which nonpoint source load estimates were dependent on uncertain estimation procedures that could result in significant error, for this report more emphasis was placed on the point source load estimates made by Gianessi (1986).

CURRENT WATER-QUALITY CONDITIONS AND LONG-TERM TRENDS

The assessment of water-quality conditions and trends in the Kentucky River basin utilized data from both the "current" and "historical" periods, and employed a variety of graphical and statistical methods for data analysis. Although some useful information was available from the historical period (streamflow and precipitation, for example), data necessary to make meaningful statistical determinations were primarily available from the "current" time period for most constituents and properties. When possible, the data were compared to applicable Federal and State water-quality criteria.

Available historical data (1951-86), were used to describe occurrence and relative concentration of constituents throughout the basin. Typically, median values at specific sites were plotted on a basin map to show spatial distributions. Maximum and minimum values observed during the historical period were often compared to values observed during the current period. Comparison of historical data to applicable water-quality criteria were also made, when appropriate. Because of insufficient data for most constituents, detailed statistical summaries, load calculations, and trend analyses for the historical period were not possible.

Current data (1976-86) were more extensively used to describe recent water-quality conditions because of the availability of data. Statistical summaries, load calculations, trend analyses, and comparisons to applicable water-quality criteria were performed and were used to describe, to the extent possible, current water-quality conditions. Data from the current record period are not without limitations, however. For example, estimation of annual constituent loads can be significantly affected by the limited data available for characterization of high-flow conditions. Descriptions of water-quality conditions and trends in the Kentucky River basin are presented below.

Temperature

Federal water-quality criteria for temperature for the protection of aquatic life are species dependent. However, the Kentucky criteria for aquatic habitat require water temperature to be less than 31.7 °C for streams classified as warmwater habitat and for water temperatures not to exceed natural seasonal variations for water classified for coldwater habitat. No site for which 10 or more observations were available had a 90-percentile value greater than the applicable Kentucky criteria of 31.7 °C (table 13). Also evident from table 13 is that little spatial variability is present between the sites represented. This seems to apply to sites on the main stem of the Kentucky River as well as tributary sites. Streamwater temperatures generally reflect daily mean air temperatures and because little spatial variability occurs in daily mean air temperatures, little variability occurs in water temperatures. Low temperatures are moderated somewhat on the main stem due to the additional thermal storage and lower levels of heat transfer between the water and the atmosphere caused by greater depths of water in the streams and sluggish flows.

In addition to air temperatures, water temperatures can be influenced by geothermal sources and by various land- and water-use and waste-management practices. For instance, reservoir management and release practices can affect downstream water temperatures. Instream water use for hydropower and offstream uses for cooling and other purposes can affect water temperatures as can disposal of heated or temperature-altered waste, such as sewage effluent. Apparent evidence of the latter can be seen at South Elkhorn Creek near Midway (site 9.3). During lower flows, the composition of stream water is dominated by sewage effluent and the water is warmer than would be expected under natural conditions.

Seasonality of air temperature does cause a corresponding seasonal pattern in water temperature as shown in figure 19. No highly significant long-term trends in water temperature are apparent from available data for water years 1976-86 (table 14). However, several flow-adjusted decreasing temperature trends were statistically significant. The increasing temperature trend at South Elkhorn Creek near Midway (site 9.3) apparently is related to increases in effluent discharge to the creek.

pH, Alkalinity, and Acidity

The pH of a solution is defined as the negative base-10 logarithm of the hydrogen-ion activity and can range from 0 (very acidic) to 14 (very alkaline). The pH of most natural water is in the range of 6.0 to 8.5 units (Hem, 1985). Alkalinity is a measure of the capacity of a water to neutralize a strong acid and acidity is a measure of the capacity of a water to neutralize a strong base.

The pH of natural water is a measure of the acid-base equilibrium achieved by various dissolved salts and gases. The principal system regulating pH in natural water is the carbonate system which consists of carbon dioxide, carbonic acid, and bicarbonate and carbonate ions. A departure from near-neutral pH may be caused by the influx of acidic or alkaline wastes, or, for poorly buffered water, fluctuations in algal photosynthesis. Water with a pH in the range from 6.5 to 9.0 units generally provides adequate protection for freshwater fish and bottom-dwelling invertebrates (U.S. Environmental Protection Agency, 1986a).

Streams in the Kentucky River basin generally are well buffered and slightly alkaline – median pH values ranged from 7.1 to 7.8 units (based on available data for water years 1976-86), owing in part, to an abundance of carbonate minerals in the soil. Statistical summaries of pH and concentrations of alkalinity and acidity are presented in table 15. The distribution of pH values along the main stem of the Kentucky River are shown in figure 20. Lowest median pH values generally occurred in the upper part of the basin (fig. 21) and were associated with coal mining, according to Dyer (1983). However, many of these low values of pH were still greater than 6.0 units, the Kentucky criterion for warmwater aquatic habitat. Most of the acid-mine drainage produced in the North Fork basin is rapidly neutralized by carbonate minerals or replaced by exchangeable bases from aquifer material before it reaches a stream. Water of the Kentucky River basin generally becomes increasingly alkaline from the Eastern Coal Fields region to the Bluegrass region.

About 10 percent of the pH measurements made in the basin (based on available data for water years 1976-86) were less than the range of 6.5 to 9.0 units specified in the Federal SMCL and criterion for the protection of aquatic life (chronic) (table 16). Also, about 10 percent of the pH measurements made throughout the basin during this period were greater than the specified range. Measurements exceeding the range of 6.5 to 9.0 units typically occurred in the Bluegrass region, and measurements less than this range typically occurred in coal producing areas of the upper basin (table 17). Values of pH at some downstream sites occasionally exceeded the upper pH criterion, which may be due in part to algal

Table 13.—*Statistical summary of water temperature data from selected sites in the Kentucky River basin*

[N, number of observations. 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	USGS station name	Period of record (water years)	N	Temperature at indicated percentile (in degrees Celsius) 10	25	50 (median)	75	90
0.1	Yonts Fork near Neon	1979-84	13		8.5	12	16	
0.2	Carr Fork near Sassafras	1976-85	73	5.2	7.0	14	21	24
1.0	North Fork Kentucky River at Hazard	1978-85	65	4.8	7.5	17	24	26
1.1	Troublesome Creek at Noble	1977-82	27		8.5	15	22	
2.0	North Fork Kentucky River at Jackson	1976-86	92	4.0	7.7	17	23	26
2.1	Middle Fork Kentucky River near Hyden	1976-85	68	4.4	7.2	14	23	27
2.2	Cutshin Creek at Wooton	1976-85	71	3.8	7.0	14	22	26
2.3	Middle Fork Kentucky River at Tallega	1978-86	95	4.3	8.4	16	22	25
2.4	Red Bird River near Big Creek	1978-85	64	3.7	7.4	14	22	26
2.5	Goose Creek at Manchester	1977-85	72	4.0	6.4	14	22	24
2.6	South Fork Kentucky River at Booneville	1978-86	93	4.3	7.9	18	24	26
3.0	Kentucky River at Lock 14, at Heidelberg	1978-86	113	4.0	7.7	14	23	26
3.1	Red River near Hazel Green	1976-86	153	3.0	7.0	14	21	25
3.2	Red River near Bowen	1980-83	25		4.0	10	23	
3.3	Red River at Clay City	1978-86	74	2.2	7.0	12	22	25
4.0	Kentucky River at Lock 10, near Winchester	1978-85	50	2.2	9.4	15	25	26
4.1	Silver Creek near Kingston	1978-83	43	1.7	7.0	14	21	23
5.0	Kentucky River at Camp Nelson	1980-86	74	5.1	8.3	15	24	27
5.1	West Hickman Creek at Jonestown	1978-83	47	3.3	8.0	15	22	25
5.2	Dix River near Danville	1979-86	60	3.5	6.9	15	23	26
6.0	Kentucky River at Lock 6, near Salvisa	1978-85	49	6.0	8.7	15	22	26
7.0	Kentucky River above Frankfort	1979-86	80	5.0	8.0	15	24	27
8.0	Kentucky River at Lock 4, at Frankfort	1978-85	53	3.9	10	15	25	27
9.0	Kentucky River below Frankfort	1979-85	71	5.0	9.0	16	24	27
9.1	North Elkhorn Creek near Georgetown	1978-84	48	1.4	6.0	14	22	25
9.2	South Elkhorn Creek at Fort Spring	1978-85	63	3.5	8.0	13	21	24
9.3	South Elkhorn Creek near Midway	1982-86	52	5.3	10	15	22	25
9.4	Elkhorn Creek near Frankfort	1977-83	52	1.2	8.6	16	24	25
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101	5.0	8.7	15	22	27
10.1	Eagle Creek at Glencoe	1976-86	93	1.7	6.0	15	22	26

productivity and associated reduction of carbon-dioxide concentrations. Significant decreases in pH were detected at 4 and an increase at 1 of 11 sites in the Kentucky River basin (based on available data for water years 1976-86) (table 18). These nonflow adjusted decreasing and increasing trends occurred throughout the basin and could not be clearly associated with any specific causative factor.

The Federal criterion for alkalinity is set at a level of not less than 20 mg/L as $CaCO_3$ for protection of aquatic life (chronic). Samples from several locations in the basin did not meet the criterion for alkalinity (table 17) which may be due to limited availability of carbonate minerals for stream buffering or may be a result of acid-mine drainage from coal-mined areas in the basin. Most of the significant trends in alkalinity were positive and related to decreases in discharge. Significant flow-adjusted trends for alkalinity were detected at two sites. Both of these trends were increasing at a rate of about 3 percent per year.

No major flow-adjusted trends in acidity were detected (based on available data for water years 1976-86).

Major Cations and Anions, and Related Water-Quality Characteristics

The presence of chemical constituents dissolved in water results from: (1) the physical and chemical characteristics of the material over which or through which the water moves, (2) natural weathering

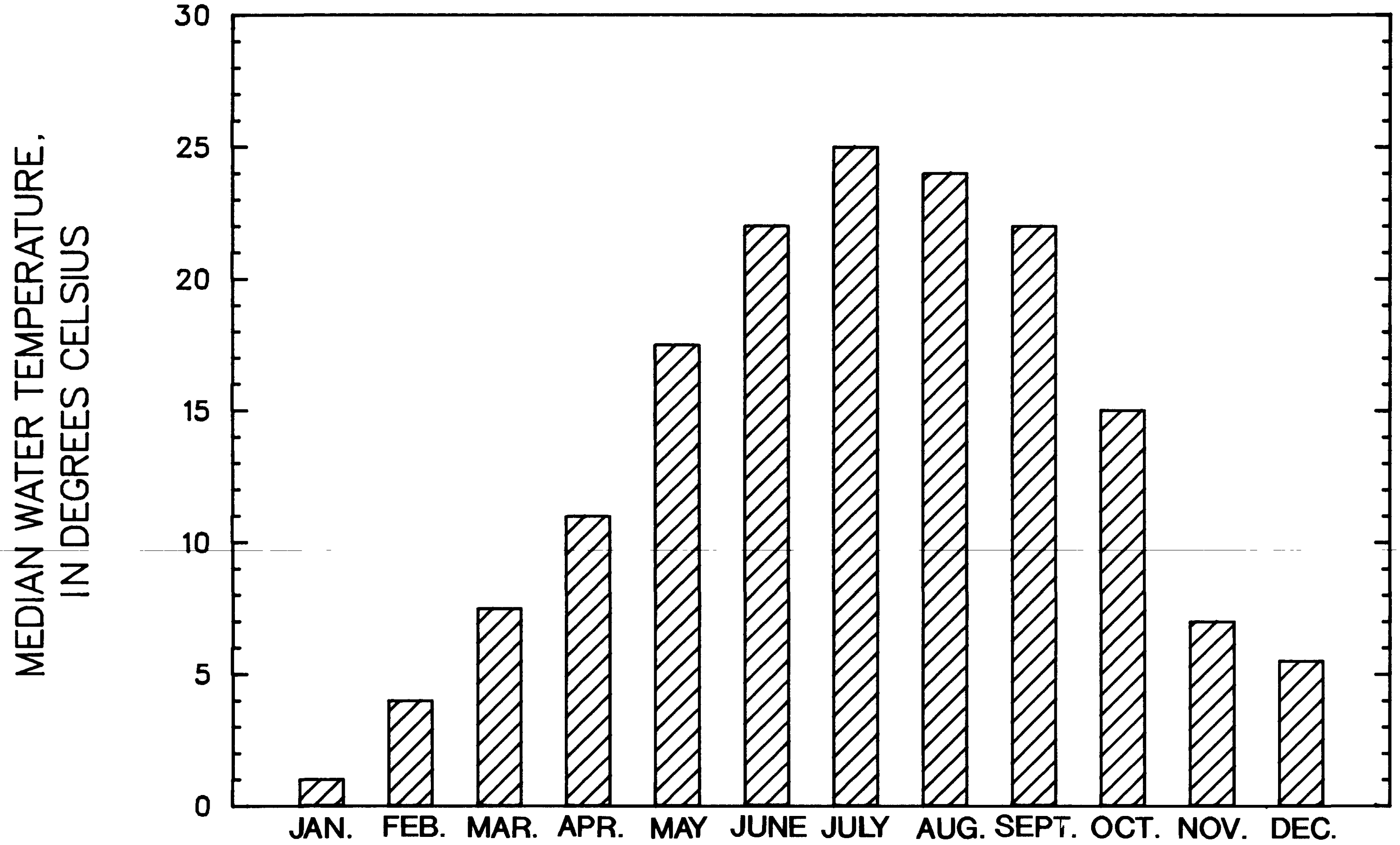


Figure 19.--Median monthly water temperature for Red River near Hazel Green, Kentucky, 1976-86.

Table 14.—*Trend test results for water temperature measurements for selected sites in the Kentucky River basin*

[N, number of water-temperature measurements; SC, number of seasonal comparisons; P, probability. Trend-line slopes not significant at 0.2 probability level are not reported, and those significant at the 0.1 probability level are underlined]

Site number	USGS station name	Period of record (water years)	N	SC	Results of seasonal Kendall tests for time trend[1]: Trends, unadjusted for flow: P level	Trends, unadjusted for flow: Trend-line slope: Degrees Celsius per year	Trends, unadjusted for flow: Trend-line slope: Percent of median water temperature, in degrees Celsius per year	Flow-adjusted trends[2]: P level	Flow-adjusted trends[2]: Trend-line slope: Degrees Celsius per year	Flow-adjusted trends[2]: Trend-line slope: Percent of median water temperature, in degrees Celsius per year
2.0	North Fork Kentucky River at Jackson	1976-86	92	44	0.182	-0.32	-2.2	0.110	-0.23	-1.6
2.3	Middle Fork Kentucky River at Tallega	1978-86	95	36	.480			.358		
2.6	South Fork Kentucky River at Booneville	1978-86	93	36	.415			.058	<u>- .31</u>	<u>-2.1</u>
3.0	Kentucky River at Lock 14, at Heidelberg	1978-86	113	36	.820			.284		
3.1	Red River near Hazel Green	1976-86	153	44	.330			.172	- .16	-1.1
5.0	Kentucky River at Camp Nelson	1980-86	74	28	.617			.455		
7.0	Kentucky River above Frankfort	1979-86	80	32	.176	-.34	-2.2	.091	<u>- .49</u>	<u>-3.2</u>
9.0	Kentucky River below Frankfort	1979-85	71	32	.277			.561		
9.3	South Elkhorn Creek near Midway	1982-86	52	20	.284			.047	<u>1.2</u>	<u>7.9</u>
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101	44	.355			.383		
10.1	Eagle Creek at Glencoe	1976-86	93	44	.905					

[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 (1) 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 (2) 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.

Table 15.—*Statistical summary of pH, alkalinity, and acidity data from selected sites in the Kentucky River basin*

[N, number of observations; *, value was estimated from log-normal-fit program. 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	USGS station name	Period of record (water years)	N	Value at indicated percentile 10	25	50 (median)	75	90
pH, in standard units								
0.1	Yonts Fork near Neon	1979-84	13		7.4	7.6	7.9	
1.0	North Fork Kentucky River at Hazard	1979-81	18		7.6	7.8	8.0	
2.0	North Fork Kentucky River at Jackson	1979-86	64	7.0	7.2	7.5	7.8	8.0
2.1	Middle Fork Kentucky River near Hyden	1979-81	19		7.4	7.5	7.7	
2.3	Middle Fork Kentucky River at Tallega	1979-86	61	6.5	6.7	7.1	7.4	7.7
2.5	Goose Creek at Manchester	1979-81	19		7.0	7.1	7.5	
2.6	South Fork Kentucky River at Booneville	1979-86	58	6.5	6.7	7.1	7.4	7.7
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	91	6.9	7.1	7.3	7.6	7.9
3.1	Red River near Hazel Green	1979-86	102	6.6	6.8	7.1	7.3	7.7
3.2	Red River near Bowen	1978-83	68	6.8	7.1	7.3	7.6	7.7
5.0	Kentucky River at Camp Nelson	1980-86	75	7.0	7.3	7.5	7.7	7.9
7.0	Kentucky River above Frankfort	1979-86	83	6.9	7.4	7.6	7.9	8.1
9.0	Kentucky River below Frankfort	1979-85	73	7.1	7.3	7.6	7.9	8.1
9.3	South Elkhorn Creek near Midway	1982-86	44	6.6	6.9	7.2	7.7	7.9
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101	7.0	7.3	7.6	7.8	8.1
10.1	Eagle Creek at Glencoe	1979-86	88	6.9	7.2	7.6	7.9	8.1
Alkalinity, total, in milligrams per liter as $CaCO_3$								
0.1	Yonts Fork near Neon	1979-84	13		88	142	198	
1.0	North Fork Kentucky River at Hazard	1979-81	18		39	68	86	
2.0	North Fork Kentucky River at Jackson	1979-86	63	38	48	70	84	96
2.1	Middle Fork Kentucky River near Hyden	1976-81	21		23	36	54	
2.2	Cutshin Creek at Wooton	1976-81	10		22	45	76	
2.3	Middle Fork Kentucky River at Tallega	1979-86	60	18	25	37	46	54
2.5	Goose Creek at Manchester	1979-81	19		16	31	42	
2.6	South Fork Kentucky River at Booneville	1979-86	57	19	25	35	47	53
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	89	24	31	48	62	70
3.1	Red River near Hazel Green	1979-86	99	13	18	26	41	54
5.0	Kentucky River at Camp Nelson	1980-86	73	46	53	69	80	90
7.0	Kentucky River above Frankfort	1979-86	81	54	67	77	91	99
9.0	Kentucky River below Frankfort	1979-85	71	57	69	80	95	105
9.3	South Elkhorn Creek near Midway	1982-86	42	110	128	151	172	191
10.0	Kentucky River at Lock 2, at Lockport	1976-86	100	63	72	83	97	113
10.1	Eagle Creek at Glencoe	1976-86	95	101	124	146	170	202
Acidity, in milligrams per liter as $CaCO_3$								
2.0	North Fork Kentucky River at Jackson	1984-85	15		1.0	2.0	2.5	
2.3	Middle Fork Kentucky River at Tallega	1984-85	14		2.3	2.5	2.8	
2.6	South Fork Kentucky River at Booneville	1984-85	15		2.0	2.5	3.0	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-85	71	1.8	2.5	3.6	5.6	8.0
3.1	Red River near Hazel Green	1979-85	71	2.0	2.6	3.2	4.4	6.3
5.0	Kentucky River at Camp Nelson	1980-85	63	1.0	2.0	3.6	6.0	11
7.0	Kentucky River above Frankfort	1979-85	71	1.5	2.2	3.6	6.0	9.4
9.0	Kentucky River below Frankfort	1979-85	68	1.5	2.0	4.0	6.4	9.3
9.3	South Elkhorn Creek near Midway	1984-85	15		3.5	6.4	9.4	
10.1	Eagle Creek at Glencoe	1979-85	75	.1*	2.0	4.4	8.0	16

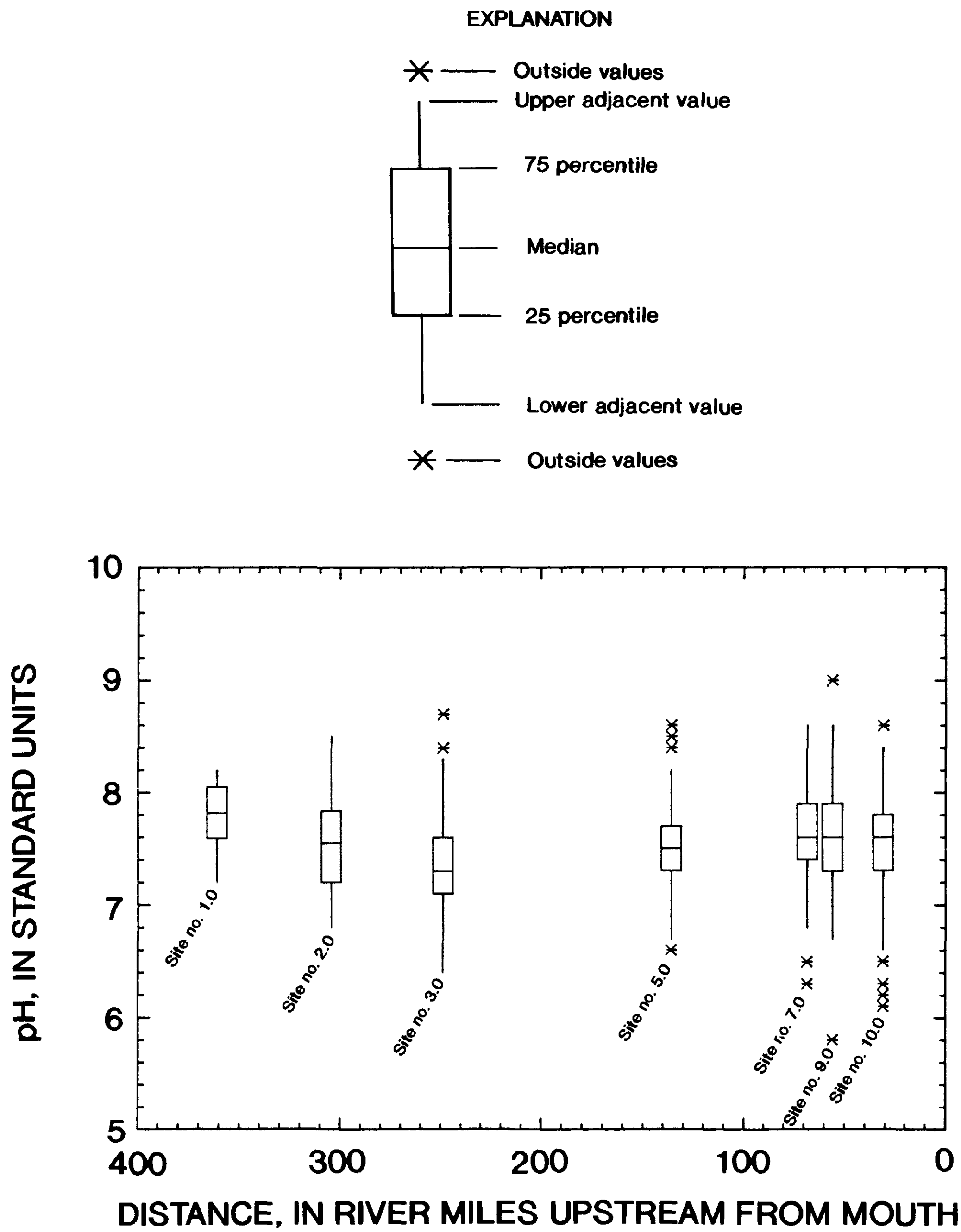


Figure 20.--Statistical summary of pH data at sites along the Kentucky River, based on available data for water years 1976-86.

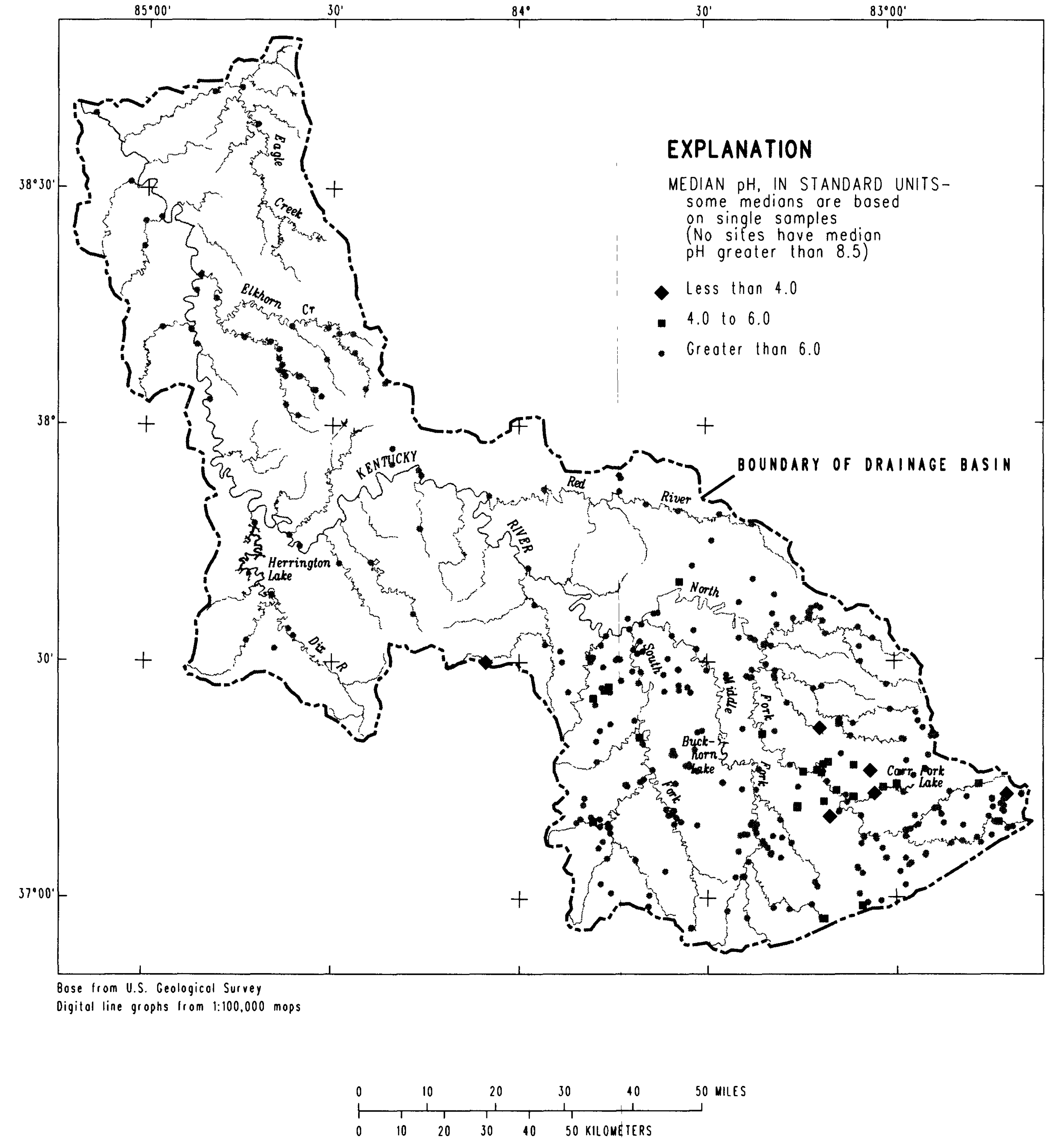


Figure 21.--Median pH at sites in the Kentucky River basin, through 1986.

Table 16.—*Number of pH and alkalinity measurements made in the Kentucky River basin and percentage not meeting indicated water-quality criteria, based on available data for water years 1976-86*

[Censored values greater than the water-quality criteria were not included in the percentage computations]

U.S. ENVIRONMENTAL PROTECTION AGENCY		KENTUCKY
MCL = maximum contaminant level	SMCL = secondary MCL	KYDWS = domestic water supply
MCLG = maximum contaminant level goal	ALA = aquatic life acute	KYAH = warmwater aquatic habitat
PMCLG = proposed MCLG	ALC = aquatic life chronic	KYR = recreational waters

Constituent or property	Number of measurements	Percentage not meeting indicated criteria								
		MCL	MCLG	PMCLG	SMCL	ALA	ALC	KYDWS	KYAH	KYR
pH, below water-quality criteria	2,705				10		10		4	4
pH, above water-quality criteria	2,705				10		9		9	9
Alkalinity	2,176						23			

processes, and (3) point and nonpoint sources of the constituents. These dissolved constituents can be either positively charged (cations) or negatively charged (anions). Major cations present in the surface water of the basin are calcium, magnesium, sodium, and potassium; major anions are bicarbonate, chloride, sulfate, and nitrate.

Specific Conductance and Dissolved Solids

Specific conductance is a measure of the ability of water to conduct an electrical current and is related to the quantity and types of ionized substances in water. Multiplied by 0.6, specific conductance, in microsiemens per centimeter, can be used to estimate dissolved-solids concentrations, in milligrams per liter, for most natural water. Because of its simplicity of measurement, more observations for specific conductance are in the data base than for dissolved-solids concentration.

Because of its relation to ionized substances, specific conductance can be used to estimate concentrations of some individual dissolved constituents in water. Regression statistics describing the relation between specific conductance and several dissolved water-quality constituents were determined for selected sites in the basin (table 19). The concentration of a particular constituent can be estimated by the linear regression equation:

$$Y = a + bX$$

where Y is the estimated constituent concentration, in milligrams per liter;
a is the regression constant (y-intercept of regression equation);
b is the regression coefficient (slope of regression equation); and
X is the specific conductance, in microsiemens per centimeter.

The regression equation can be reduced to the following form:

$$Y = bX$$

because as specific conductances approach zero, concentrations of individual dissolved constituents in water also approach zero (the y-intercept of the linear regression equation is equal to zero).

Note: The regression equations should be used with caution in estimating concentrations of constituents because of relatively small numbers of regression data pairs used to derive the equations and the degree of variability of data at some sites.

Dissolved solids consist of inorganic salts, small amounts of organic matter, and dissolved materials. Equivalent terminology is "filterable residue." Excessive dissolved-solids concentrations (greater than 500 mg/L) in drinking water are objectionable because of possible physiological effects, unpalatable mineral taste, and higher cost associated with corrosion or the need for additional treatment. The physiological effects directly related to dissolved solids include laxative effects principally from sodium sulfate and magnesium sulfate, and the adverse effect of sodium on certain patients afflicted with cardiac disease and women with toxemia associated with pregnancy (U.S. Environmental Protection Agency, 1986a).

The dissolved-solids concentrations in most streams in the Kentucky River basin were less than 750 mg/L, the Kentucky maximum criterion for domestic water supplies. However, the dissolved-solids concentration exceeded 2,000 mg/L in some of the 2,900 samples for which analyses are available. Based on specific-conductance measurements, the estimated dissolved-solids concentration at one site in the oil-producing area of Lee County in the south-central part of the basin has been as high as 9,000 mg/L.

Table 17.—*Number of pH and alkalinity measurements made at selected sites in the Kentucky River basin and percentage not meeting indicated water-quality criteria, based on available data for water years 1976-86*

[Censored values greater than the water-quality criteria were not included in the percentage computations]

U.S. ENVIRONMENTAL PROTECTION AGENCY

MCL = maximum contaminant level
MCLG = maximum contaminant level goal
PMCLG = proposed MCLG
SMCL = secondary MCL
ALA = aquatic life acute
ALC = aquatic life chronic

KENTUCKY

KYDWS = domestic water supply
KYAH = warmwater aquatic habitat
KYR = recreational waters

Site number	USGS station name	No. of measure-ments	Percentage not meeting indicated criteria								
			MCL	MCLG	PMCLG	SMCL	ALA	ALC	KYDWS	KYAH	KYR
pH, below water-quality criteria											
0.1	Yonts Fork near Neon	13				15		15		8	8
2.3	Middle Fork Kentucky River at Tallega	61				8		8			
2.6	South Fork Kentucky River at Booneville	58				5		5			
3.0	Kentucky River at Lock 14, at Heidelberg	91				1		1			
3.1	Red River near Hazel Green	102				5		5			
7.0	Kentucky River above Frankfort	83				1		1			
9.0	Kentucky River below Frankfort	73				1		1		1	1
9.3	South Elkhorn Creek near Midway	44				4		4		2	2
10.0	Kentucky River at Lock 2, at Lockport	101				3		3			
pH, above water-quality criteria											
3.0	Kentucky River at Lock 14, at Heidelberg	91				1					
3.2	Red River near Bowen	68				2		2		2	2
5.0	Kentucky River at Camp Nelson	75				1					
7.0	Kentucky River above Frankfort	83				1					
9.0	Kentucky River below Frankfort	73				3					
10.0	Kentucky River at Lock 2, at Lockport	101				1					
Alkalinity											
2.1	Middle Fork Kentucky River near Hyden	21						19			
2.2	Cutshin Creek at Wooton	10						10			
2.3	Middle Fork Kentucky River at Tallega	60						12			
2.5	Goose Creek at Manchester	19						37			
2.6	South Fork Kentucky River at Booneville	57						12			
3.1	Red River near Hazel Green	99						28			
7.0	Kentucky River above Frankfort	81						1			

Table 18.—*Trend test results for pH, alkalinity, and acidity measurements for selected sites in the Kentucky River basin*

[N, number of observations; SC, number of seasonal comparisons; P, probability; *, censored values used in analysis; incr., increasing; decr., decreasing; mg/L, milligrams per liter. Trend-line slopes not significant at 0.2 probability level are not reported, and those significant at the 0.1 probability level are underlined]

					Results of seasonal Kendall tests for time trend[1]					
					Trends, unadjusted for flow			Flow-adjusted trends[2]		
						Trend-line slope[3]			Trend-line slope[3]	
Site number	USGS station name	Period of record (water years)	N	SC	P level	pH units per year	Percent of median pH units per year	P level	pH units per year	Percent of median pH units per year
pH										
2.0	North Fork Kentucky River at Jackson	1979-86	64	32	0.373			0.293		
2.3	Middle Fork Kentucky River at Tallega	1979-86	61	32	1.00			.933		
2.6	South Fork Kentucky River at Booneville	1979-86	58	32	.488					
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	91	32	.729			.946		
3.1	Red River near Hazel Green	1979-86	102	32	.021	decr.	decr.	.013	decr.	decr.
5.0	Kentucky River at Camp Nelson	1980-86	75	28	.866					
7.0	Kentucky River above Frankfort	1979-86	83	32	.053	decr.	decr.			
9.0	Kentucky River below Frankfort	1979-85	73	32	.935					
9.3	South Elkhorn Creek near Midway	1982-86	44	20	.032	decr.	decr.			
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101	44	.001	incr.	incr.			
10.1	Eagle Creek at Glencoe	1979-86	88	32	.004	decr.	decr.			
						Milligrams per liter per year	Percent of median concentration (mg/L) per year		Milligrams per liter per year	Percent of median concentration (mg/L per year)
Alkalinity, total										
2.0	North Fork Kentucky River at Jackson	1979-86	63	32	.004	3.2	4.5	.001	2.4	3.5
2.3	Middle Fork Kentucky River at Tallega	1979-86	60	32	.111	1.1	3.0	.242		
2.6	South Fork Kentucky River at Booneville	1979-86	57	32	.863			1.00		
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	89	32	.009	1.9	3.9	.200	1.0	2.1
3.1	Red River near Hazel Green	1979-86	99	32	1.00			.380		
5.0	Kentucky River at Camp Nelson	1980-86	73	28	.804			.362		
7.0	Kentucky River above Frankfort	1979-86	81	32	.736			.946		
9.0	Kentucky River below Frankfort	1979-85	71	32	.813			.813		
9.3	South Elkhorn Creek near Midway	1982-86	42	20	.003	11	6.9			
10.0	Kentucky River at Lock 2, at Lockport	1976-86	100	44	.000	2.7	3.2	.000	2.7	3.2
10.1	Eagle Creek at Glencoe	1976-86	95	44	.080	-2.3	-1.7			
Acidity, total										
2.0	North Fork Kentucky River at Jackson	1984-85	15	12*	1.00					
2.3	Middle Fork Kentucky River at Tallega	1984-85	14	12	.480			.480		
2.6	South Fork Kentucky River at Booneville	1984-85	15	12	.480					
3.0	Kentucky River at Lock 14, at Heidelberg	1979-85	71	32	.340			.181	-.22	-7.0
3.1	Red River near Hazel Green	1979-85	71	32	1.00			1.00		
5.0	Kentucky River at Camp Nelson	1980-85	63	28*	.058	-.64	-16			
7.0	Kentucky River above Frankfort	1979-85	71	32*	.135	-.30	-8.3			
9.0	Kentucky River below Frankfort	1979-85	68	32*	.206					
9.3	South Elkhorn Creek near Midway	1984-85	15	12	.480			.480		
10.1	Eagle Creek at Glencoe	1979-85	75	32*	.238					

[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 (1) 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 (2) 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.

[3]The trend-line slope for pH was reported only as increasing or decreasing because it is inappropriate to compute the trend slope magnitude on the basis of logarithmic units.

Table 19.—*Regression statistics describing the relations between specific conductance and concentrations of several water-quality constituents and properties at selected sites in the Kentucky River basin, based on available data for water years 1976-86*

[N, number of regression data pairs; b, regression coefficient; R^2, coefficient of determination; CVAR, coefficient of variation]

Equation used in regression analysis: $y = a + bx$
where y is the estimated constituent concentration, in milligrams per liter;
a is the regression constant (y-intercept of regression equation);
b is the regression coefficient (slope of regression equation); and
x is the specific conductance, in microsiemens per centimeter.

Site number	USGS station name	Regression statistics[1] N	b	R^2	CVAR
Alkalinity, in milligrams per liter as $CaCO_3$					
1.0	North Fork Kentucky River at Hazard	18	0.18	0.858	0.169
2.0	North Fork Kentucky River at Jackson	63	.15	.708	.183
2.1	Middle Fork Kentucky River near Hyden	21	.22	.860	.190
2.3	Middle Fork Kentucky River at Tallega	60	.18	.656	.212
10.1	Eagle Creek at Glencoe	95	.38	.606	.191
Calcium, dissolved, in milligrams per liter					
2.0	North Fork Kentucky River at Jackson	20	.09	.763	.187
2.3	Middle Fork Kentucky River at Tallega	19	.09	.564	.245
2.6	South Fork Kentucky River at Booneville	21	.07	.762	.212
3.0	Kentucky River at Lock 14, at Heidelberg	33	.08	.537	.416
5.0	Kentucky River at Camp Nelson	18	.09	.770	.195
Calcium, total recoverable, in milligrams per liter					
2.0	North Fork Kentucky River at Jackson	24	.10	.577	.241
3.0	Kentucky River at Lock 14, at Heidelberg	32	.09	.917	.129
Chloride, dissolved, in milligrams per liter					
2.0	North Fork Kentucky River at Jackson	44	.02	.633	.273
5.0	Kentucky River at Camp Nelson	74	.09	.575	.700
7.0	Kentucky River above Frankfort	82	.06	.519	.517
9.3	South Elkhorn Creek near Midway	43	.08	.614	.288
Hardness, in milligrams per liter as $CaCO_3$					
2.0	North Fork Kentucky River at Jackson	45	.46	.593	.243
2.3	Middle Fork Kentucky River at Tallega	44	.42	.530	.222
3.0	Kentucky River at Lock 14, at Heidelberg	87	.35	.592	.325
5.0	Kentucky River at Camp Nelson	75	.36	.673	.181
10.0	Kentucky River at Lock 2, at Lockport	100	.42	.659	.106
Magnesium, dissolved, in milligrams per liter					
2.0	North Fork Kentucky River at Jackson	22	.04	.612	.231
2.6	South Fork Kentucky River at Booneville	21	.03	.668	.212
3.1	Red River near Hazel Green	29	.03	.766	.344
5.0	Kentucky River at Camp Nelson	19	.03	.707	.162
9.3	South Elkhorn Creek near Midway	18	.01	.798	.136
10.0	Kentucky River at Lock 2, at Lockport	101	.03	.687	.133
10.1	Eagle Creek at Glencoe	32	.03	.712	.272
Magnesium, total, in milligrams per liter					
3.0	Kentucky River at Lock 14, at Heidelberg	33	.03	.654	.203
9.3	South Elkhorn Creek near Midway	25	.01	.658	.198
10.1	Eagle Creek at Glencoe	33	.03	.501	.283
Potassium, dissolved, in milligrams per liter					
2.0	North Fork Kentucky River at Jackson	21	.01	.895	.105
2.3	Middle Fork Kentucky River at Tallega	19	.01	.666	.143
2.6	South Fork Kentucky River at Booneville	21	.01	.730	.181
5.0	Kentucky River at Camp Nelson	19	.01	.726	.186

Table 19.—*Regression statistics describing the relations between specific conductance and concentrations of several water-quality constituents and properties at selected sites in the Kentucky River basin, based on available data for water years 1976-86*—Continued

[N, number of regression data pairs; b, regression coefficient; R^2, coefficient of determination; CVAR, coefficient of variation]

Equation used in regression analysis: $y = a + bx$
where y is the estimated constituent concentration, in milligrams per liter;
a is the regression constant (y-intercept of regression equation);
b is the regression coefficient (slope of regression equation); and
x is the specific conductance, in microsiemens per centimeter.

Site number	USGS station name	Regression statistics[1] N	b	R^2	CVAR
Potassium, dissolved, in milligrams per liter–Continued					
7.0	Kentucky River above Frankfort	23	.01	.699	.156
9.0	Kentucky River below Frankfort	21	.01	.661	.153
9.3	South Elkhorn Creek near Midway	20	.01	.535	.326
Potassium, total, in milligrams per liter					
2.0	North Fork Kentucky River at Jackson	24	.01	.726	.157
2.3	Middle Fork Kentucky River at Tallega	24	.01	.580	.173
2.6	South Fork Kentucky River at Booneville	24	.01	.582	.250
7.0	Kentucky River above Frankfort	32	.01	.543	.185
9.0	Kentucky River below Frankfort	24	.01	.585	.178
9.3	South Elkhorn Creek near Midway	25	.01	.537	.321
Silica, dissolved, in milligrams per liter as SiO_2					
9.3	South Elkhorn Creek near Midway	17	.01	.647	.124
Sodium, total, in milligrams per liter					
2.0	North Fork Kentucky River at Jackson	25	.03	.665	.248
2.6	South Fork Kentucky River at Booneville	25	.05	.739	.370
3.0	Kentucky River at Lock 14, at Heidelberg	33	.06	.742	.404
5.0	Kentucky River at Camp Nelson	33	.05	.705	.470
7.0	Kentucky River above Frankfort	33	.04	.527	.459
9.0	Kentucky River below Frankfort	24	.04	.530	.436
9.3	South Elkhorn Creek near Midway	25	.06	.601	.316
10.1	Eagle Creek at Glencoe	33	.01	.603	.229
Sodium, dissolved, in milligrams per liter					
2.0	North Fork Kentucky River at Jackson	20	.04	.738	.256
2.3	Middle Fork Kentucky River at Tallega	19	.03	.781	.151
2.6	South Fork Kentucky River at Booneville	19	.06	.811	.311
3.1	Red River near Hazel Green	29	.03	.735	.313
9.3	South Elkhorn Creek near Midway	20	.06	.507	.378
10.1	Eagle Creek at Glencoe	30	.01	.609	.226
Solids, dissolved, residue at 180 degrees Celsius, in milligrams per liter					
0.1	Yonts Fork near Neon	10	.62	.829	.114
1.0	North Fork Kentucky River at Hazard	16	.67	.991	.034
2.0	North Fork Kentucky River at Jackson	52	.69	.965	.071
2.1	Middle Fork Kentucky River near Hyden	18	.66	.960	.080
2.3	Middle Fork Kentucky River at Tallega	49	.63	.826	.107
2.5	Goose Creek at Manchester	17	.64	.965	.100
2.6	South Fork Kentucky River at Booneville	46	.60	.925	.108
3.0	Kentucky River at Lock 14, at Heidelberg	80	.60	.756	.233
5.0	Kentucky River at Camp Nelson	64	.60	.873	.145
7.0	Kentucky River above Frankfort	72	.60	.803	.129
9.0	Kentucky River below Frankfort	71	.60	.824	.126
9.3	South Elkhorn Creek near Midway	33	.58	.746	.114
10.0	Kentucky River at Lock 2, at Lockport	100	.61	.833	.087
10.1	Eagle Creek at Glencoe	84	.62	.805	.114

Table 19.—*Regression statistics describing the relations between specific conductance and concentrations of several water-quality constituents and properties at selected sites in the Kentucky River basin, based on available data for water years 1976-86*—Continued

[N, number of regression data pairs; b, regression coefficient; R^2, coefficient of determination; CVAR, coefficient of variation]

Equation used in regression analysis: $y = a + bx$
where y is the estimated constituent concentration, in milligrams per liter;
a is the regression constant (y-intercept of regression equation);
b is the regression coefficient (slope of regression equation); and
x is the specific conductance, in microsiemens per centimeter.

Site number	USGS station name	Regression statistics[1] N	b	R^2	CVAR
Sulfate, dissolved, in milligrams per liter as SO_4					
1.0	North Fork Kentucky River at Hazard	18	0.28	0.963	0.074
2.0	North Fork Kentucky River at Jackson	36	.32	.930	.115
2.1	Middle Fork Kentucky River near Hyden	21	.24	.781	.185
2.3	Middle Fork Kentucky River at Tallega	34	.23	.757	.120
2.5	Goose Creek at Manchester	19	.23	.956	.113
2.6	South Fork Kentucky River at Booneville	31	.23	.845	.157
9.3	South Elkhorn Creek near Midway	17	.11	.734	.184
10.0	Kentucky River at Lock 2, at Lockport	101	.14	.579	.191
Sulfate, total, in milligrams per liter as SO_4					
2.0	North Fork Kentucky River at Jackson	27	.31	.836	.099
7.0	Kentucky River above Frankfort	83	.14	.516	.236
9.0	Kentucky River below Frankfort	73	.14	.562	.230
9.3	South Elkhorn Creek near Midway	27	.09	.641	.232

[1]All regression equations were statistically significant at a probability (p) level = 0.05. The regression coefficient (b) is the slope of the regression equation. The coefficient of determination (R^2) is a measure of the amount of variation in the dependent variable that can be accounted for by the regression model. The coefficient of variation (CVAR) is a unitless measure of the amount of variation in the population. It is equal to the standard deviation of the dependent variable divided by the mean of the dependent variable, times 100.

The median dissolved-solids concentrations for sites sampled through 1986 are shown in figure 22 (some medians are based on single samples). Two subbasins have elevated dissolved-solids concentrations—the North Fork Kentucky River basin which is heavily mined for coal, and the more urban Elkhorn Creek Basin. Dissolved-solids concentrations measured at sites where 10 or more samples were collected during the period 1976-86 are summarized in table 20. Median concentrations of dissolved solids in the Kentucky River decreased from 295 mg/L at the station on the North Fork at Jackson (site 2.0) in the upper basin to 177 mg/L at Lock 2 (site 10.0) in the lower basin (fig. 23). Only about 3 percent of the more than 1,600 dissolved solids measurements made in the basin during the 1976-86 period exceeded the secondary MCL criterion of 500 mg/L (table 21). Of the sites used to describe current conditions, only 4 of 30 sites had concentrations in excess of the Federal MCL criterion (table 22). Three of these four sites are in watersheds that drain coal mining areas in the upper basin.

Mass transport for dissolved solids was estimated for 10 sites in the basin. The estimated mean annual dissolved-solids load transported from the basin is about 1.4 million tons per year (table 23). The mean-annual yield of dissolved solids for the North Fork Kentucky River at Jackson (site 2.0) was substantially greater than the yields for the Middle Fork and South Fork Kentucky River, although topography and geology in these basins are similar. The North Fork basin is the area most affected by coal mining and oil and gas production. The site least affected by human activities is Red River near Hazel Green (site 3.1), which had a correspondingly small yield of dissolved solids. The site with the largest yield of dissolved solids in the basin was South Elkhorn Creek near Midway (site 9.3), which receives wastewater effluent and urban-stormwater runoff from the Lexington area. The reliability of the transport estimates in table 23 are considered good on the basis of uncertainty factors presented in the table.

Dissolved-solids concentrations were generally inversely related to discharge. Largest concentrations typically occurred during late-summer or early fall low flows when there was less dilution of more highly mineralized base-flow water and point-source effluents. Conversely, the smallest concentrations typically occurred during high-flow periods, such as spring runoff. An example of this typical seasonal pattern is shown in figure 24.

Dissolved-solids concentrations increased at many sites in the basin downstream from coal-mining activities during the period 1976-86 (table 24). The magnitude of the unadjusted trends and flow-adjusted trends were almost the same, indicating little effect due to discharge. The trends ranged from about 3 to 10 percent per year. The increase in coal production during 1976-86 is thought to be a causative factor for those trends. The sharp increase in flow-adjusted trend slope from the North Fork Kentucky River at Jackson (site 2.0) and the Kentucky River at Lock 14 (site 3.0) may be related to oil and gas production in the lower North Fork Kentucky River basin. Specific-conductance measurements that reflect the dissolved-solids concentrations of the Kentucky River at Lock 14 (site 3.0) are shown in figure 25 along with superimposed trend and flow-adjusted trend lines fitted using the median values and slope.

Ionic Composition

The major cations in water of the Kentucky River basin are calcium, magnesium, sodium, and potassium. The major anions are bicarbonate, sulfate, and chloride. Ionic composition of water during high- and low-flow periods during the 1976-86 period for selected sites in the basin is given in table 25. The ionic composition of water from four of these sites is also depicted by a Piper diagram in figure 26.

Water from the Eastern Coal Field region (sites 0.2, 2.0, 2.1, 2.2, 2.3, 2.6, 3.0, and 3.1) is of a calcium-sulfate-bicarbonate type with a significant magnesium component. During high-flow conditions, sulfate is more dominant than during low-flow conditions, which indicates that sulfate is associated with the overland-runoff component of flow and may be related to coal mining (site 0.2 in fig. 26).

Water in the Knobs region (site 3.3) is classified as a calcium-bicarbonate type, but with substantial sodium and chloride components during low-flow conditions (table 25). The greater percent composition of sodium and chloride at site 3.3 during low-flow conditions indicates point source discharges, which are believed to be attributable to brine releases associated with oil and gas production in the drainage basin.

Water in the Inner and Outer Bluegrass region (sites 5.2 and 10.1, table 25) is a calcium-bicarbonate type which reflects the limestone strata in these regions. Little difference in composition is seen between low- and high-flow conditions at site 10.1 (fig. 26).

The water type of the Kentucky River main stem changes from a calcium-sulfate-bicarbonate type with a significant magnesium component in the upper basin at site 3.0 to a calcium-bicarbonate type with a substantial sulfate component in the lower basin at sites 5.0 and 10.0 (table 25). The most downstream site on the main stem (site 10.0) is a composite of the different water types present in the basin. Site 10.0 is nearly at the center of the values for sites 0.2, 3.3, and 10.1 in all plots shown in figure 26.

Calcium and Magnesium

Calcium and magnesium are the cations most often responsible for water hardness although hardness may be due to other divalent cations as well. Because hardness can not be attributed to a single cation, it is reported as a chemical equivalent concentration of calcium carbonate. Water with hardness less than 60 mg/L is considered "soft;" water with 61 to 120 mg/L is considered "moderately hard;" water with 121 to 180 mg/L is considered "hard," and water with over 180 mg/L is considered "very hard" (Hem, 1985).

For domestic use, hardness may be objectionable if it exceeds 100 mg/L. Hardness may greatly exceed this concentration in areas where water comes in contact with limestone (Hem, 1985). Water within the Kentucky River basin is generally classified as hard to very hard (table 20). Exceptions to this generalization are streams of the Eastern Coal Field region that are unaffected by mining activities. Three such streams are the Middle Fork and South Fork Kentucky River and the Red River which have soft to moderately hard water. Long-term trends in hardness at selected sites in the basin were detected (table 24). Flow-adjusted trends on the main stem and the Middle and South forks were increasing with magnitude ranging from about 2- to 10-percent per year.

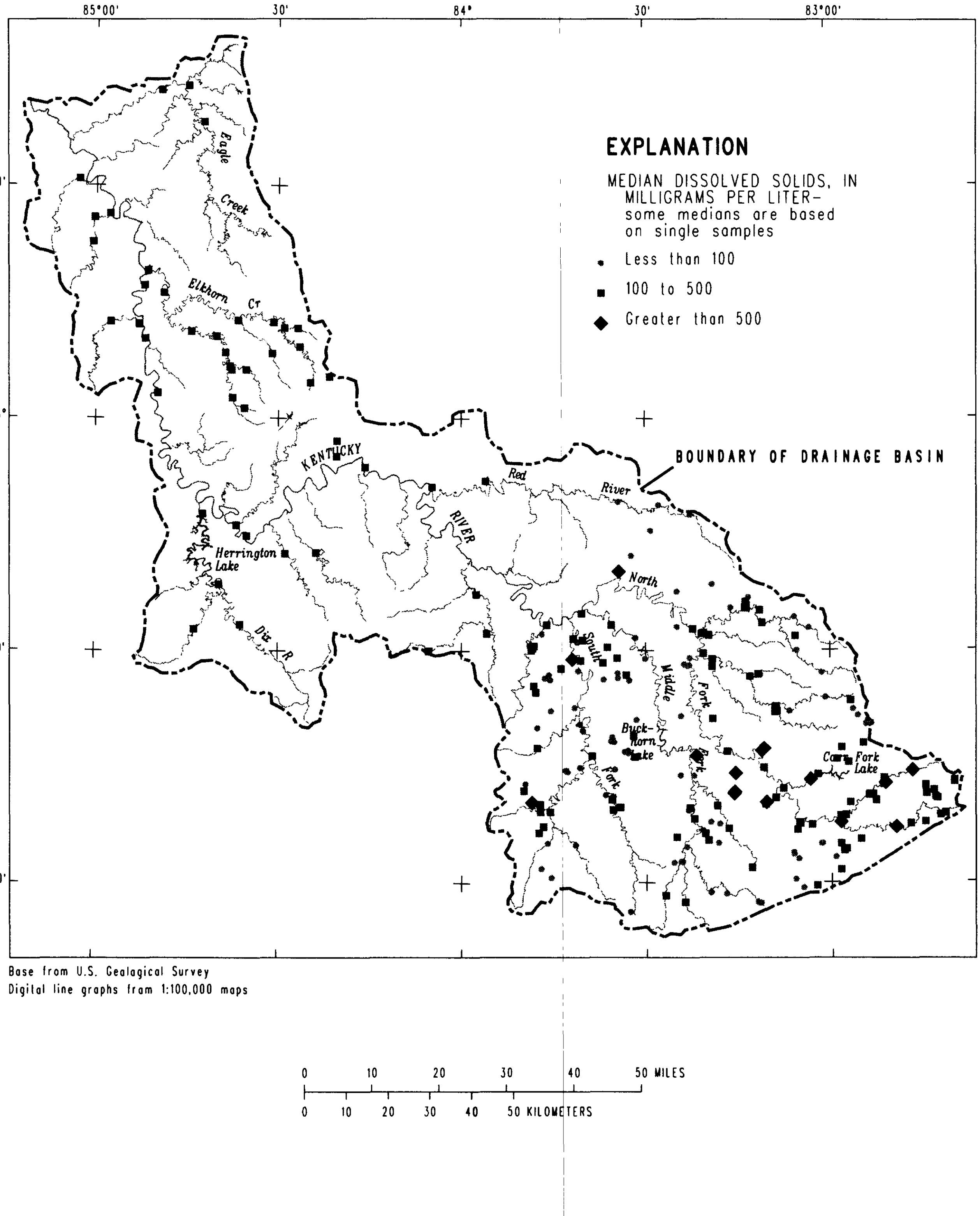


Figure 22.--Median concentrations of dissolved solids at sites in the Kentucky River basin, through 1986.

Table 20.—*Statistical summary of concentrations of major cations and anions and related water-quality characteristics for selected sites in the Kentucky River basin*

[N, number of observations; DL, detection limit; *, value was estimated from log-normal fit program. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL	Value at indicated percentile: 10	25	50 (median)	75	90
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius										
0.1	Yonts Fork near Neon	1979-84	11				370	499	700	
0.2	Carr Fork near Sassafras	1976-85	72			220	235	265	295	339
1.0	North Fork Kentucky River at Hazard	1978-85	64			228	290	388	479	580
1.1	Troublesome Creek at Noble	1978-82	24				301	410	559	
2.0	North Fork Kentucky River at Jackson	1978-86	89			265	335	423	541	608
2.1	Middle Fork Kentucky River near Hyden	1976-85	63			100	125	195	280	330
2.2	Cutshin Creek at Wooton	1976-85	68			155	181	280	370	481
2.3	Middle Fork Kentucky River at Tallega	1978-86	92			136	160	195	246	290
2.4	Red Bird River near Big Creek	1978-85	62			125	159	213	336	394
2.5	Goose Creek at Manchester	1978-85	68			100	133	200	307	459
2.6	South Fork Kentucky River at Booneville	1978-86	89			141	184	228	312	375
3.0	Kentucky River at Lock 14, at Heidelberg	1978-86	116			152	201	298	390	571
3.1	Red River near Hazel Green	1976-86	148			67	80	101	140	155
3.3	Red River at Clay City	1978-86	73			137	170	230	315	438
4.0	Kentucky River at Lock 10, near Winchester	1978-85	48			199	231	295	368	520
4.1	Silver Creek near Kingston	1978-83	41			270	295	340	403	444
5.0	Kentucky River at Camp Nelson	1980-86	75			208	260	325	418	514
5.1	West Hickman Creek at Jonestown	1978-83	45			302	365	420	460	580
5.2	Dix River near Danville	1979-86	60			241	270	303	348	375
6.0	Kentucky River at Lock 6, near Salvisa	1978-85	47			219	255	290	360	454
7.0	Kentucky River above Frankfort	1979-86	83			231	255	304	367	442
8.0	Kentucky River at Lock 4, at Frankfort	1978-85	53			230	260	295	355	416
9.0	Kentucky River below Frankfort	1979-85	73			232	258	306	374	437
9.1	North Elkhorn Creek near Georgetown	1978-84	48			300	350	385	418	431
9.2	South Elkhorn Creek at Fort Spring	1978-85	61			320	373	430	511	556
9.3	South Elkhorn Creek near Midway	1982-86	53			452	511	578	719	834
9.4	Elkhorn Creek near Frankfort	1978-83	46			297	375	423	505	613
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101			230	260	285	333	390
10.1	Eagle Creek at Glencoe	1976-86	97			286	330	372	468	535
Dissolved solids, residue on evaporation at 180 degrees Celsius, in milligrams per liter										
0.1	Yonts Fork near Neon	1980-84	10				271	331	391	
1.0	North Fork Kentucky River at Hazard	1979-81	16				172	249	340	
2.0	North Fork Kentucky River at Jackson	1979-85	52			157	210	295	381	474
2.1	Middle Fork Kentucky River near Hyden	1976-81	18				78	119	182	
2.3	Middle Fork Kentucky River at Tallega	1979-85	49			83	101	124	159	173
2.5	Goose Creek at Manchester	1979-81	17				84	140	175	
2.6	South Fork Kentucky River at Booneville	1979-85	46			80	114	145	200	208

Table 20.—*Statistical summary of concentrations of major cations and anions and related water-quality characteristics for selected sites in the Kentucky River basin*—Continued

[N, number of observations; DL, detection limit; *, value was estimated from log-normal fit program. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL	Value at indicated percentile: 10	25	50 (median)	75	90
Dissolved solids, residue on evaporation at 180 degrees Celsius, in milligrams per liter—Continued										
3.0	Kentucky River at Lock 14, at Heidelberg	1979-85	80			104	131	173	244	315
3.1	Red River near Hazel Green	1979-85	90			46	50	63	82	96
5.0	Kentucky River at Camp Nelson	1980-85	64			120	147	199	240	327
7.0	Kentucky River above Frankfort	1979-85	72			126	151	176	222	277
9.0	Kentucky River below Frankfort	1979-85	71			126	156	180	222	260
9.3	South Elkhorn Creek near Midway	1982-85	33			255	284	358	400	480
10.0	Kentucky River at Lock 2, at Lockport	1976-86	100			139	158	177	207	239
10.1	Eagle Creek at Glencoe	1976-85	84			182	202	231	284	343
Dissolved solids, calculated, sum of constituents, in milligrams per liter										
2.0	North Fork Kentucky River at Jackson	1980-83	12				170	260	300	
2.3	Middle Fork Kentucky River at Tallega	1980-83	11				100	110	140	
2.6	South Fork Kentucky River at Booneville	1980-83	11				95	120	200	
10.0	Kentucky River at Lock 2, at Lockport	1976-86	82			130	140	160	180	200
Hardness (Ca, Mg), in milligrams per liter as $CaCO_3$										
2.0	North Fork Kentucky River at Jackson	1980-86	45			120	170	220	270	340
2.3	Middle Fork Kentucky River at Tallega	1980-86	44			56	69	91	110	120
2.6	South Fork Kentucky River at Booneville	1980-86	44			58	71	86	120	160
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	87			55	82	120	150	210
3.1	Red River near Hazel Green	1979-86	84			19	32	44	58	67
5.0	Kentucky River at Camp Nelson	1980-86	75			82	100	130	160	190
7.0	Kentucky River above Frankfort	1979-86	79			93	110	130	160	180
9.0	Kentucky River below Frankfort	1979-85	69			96	110	130	150	190
9.3	South Elkhorn Creek near Midway	1982-86	44			180	190	210	220	260
10.0	Kentucky River at Lock 2, at Lockport	1976-86	100			100	110	120	140	160
10.1	Eagle Creek at Glencoe	1976-86	89			140	160	180	230	290
Calcium, dissolved, in milligrams per liter										
2.0	North Fork Kentucky River at Jackson	1980-84	20				27	43	60	
2.3	Middle Fork Kentucky River at Tallega	1980-84	19				13	18	22	
2.6	South Fork Kentucky River at Booneville	1980-84	21				13	19	26	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	33			7.0	11	21	36	46
3.1	Red River near Hazel Green	1979-84	30			2.5	3.9	6.7	14	25
5.0	Kentucky River at Camp Nelson	1980-84	18				19	29	41	
7.0	Kentucky River above Frankfort	1979-84	20				21	32	56	
9.0	Kentucky River below Frankfort	1979-84	20				25	32	53	
9.3	South Elkhorn Creek near Midway	1982-84	19				61	67	72	

Table 20.—*Statistical summary of concentrations of major cations and anions and related water-quality characteristics for selected sites in the Kentucky River basin*—Continued

[N, number of observations; DL, detection limit; *, value was estimated from log-normal fit program. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL	Value at indicated percentile: 10	25	50 (median)	75	90
Calcium, dissolved, in milligrams per liter—Continued										
10.0	Kentucky River at Lock 2, at Lockport	1976-86	100			30	34	37	41	45
10.1	Eagle Creek at Glencoe	1976-84	32			39	47	60	74	85
Calcium, total, in milligrams per liter										
2.0	North Fork Kentucky River at Jackson	1984-86	24				41	54	63	
2.3	Middle Fork Kentucky River at Tallega	1984-86	24				16	23	27	
2.6	South Fork Kentucky River at Booneville	1984-86	24				18	22	25	
3.0	Kentucky River at Lock 14, at Heidelberg	1983-86	32			21	25	35	52	69
3.1	Red River near Hazel Green	1983-86	32	1	1.0	4.7	8.2	14	16	24
5.0	Kentucky River at Camp Nelson	1983-86	32			22	31	35	49	57
7.0	Kentucky River above Frankfort	1983-86	32			23	34	39	47	58
9.0	Kentucky River below Frankfort	1983-85	23				35	43	52	
9.3	South Elkhorn Creek near Midway	1984-86	24				65	73	77	
10.1	Eagle Creek at Glencoe	1983-86	32			40	48	62	75	82
Magnesium, dissolved, in milligrams per liter										
2.0	North Fork Kentucky River at Jackson	1980-84	22				14	21	29	
2.3	Middle Fork Kentucky River at Tallega	1980-84	18				6.5	7.6	9.3	
2.6	South Fork Kentucky River at Booneville	1980-84	21				6.2	7.5	12	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	31			5.1	6.1	9.6	13	20
3.1	Red River near Hazel Green	1979-84	29				2.2	2.7	4.2	
5.0	Kentucky River at Camp Nelson	1980-84	19				8.4	11	14	
7.0	Kentucky River above Frankfort	1979-84	23				7.2	8.4	10	
9.0	Kentucky River below Frankfort	1979-84	22				7.3	8.4	9.8	
9.3	South Elkhorn Creek near Midway	1982-84	18				6.0	7.6	9.3	
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101			6.0	6.5	7.4	8.5	10
10.1	Eagle Creek at Glencoe	1976-84	32			6.7	8.0	11	15	20
Magnesium, total, in milligrams per liter										
2.0	North Fork Kentucky River at Jackson	1984-86	25				20	24	30	
2.3	Middle Fork Kentucky River at Tallega	1984-86	25				7.4	10	11	
2.6	South Fork Kentucky River at Booneville	1984-86	25				8.3	10	12	
3.0	Kentucky River at Lock 14, at Heidelberg	1983-86	33			9.7	12	15	21	25
3.1	Red River near Hazel Green	1983-86	33			2.4	3.0	4.0	4.4	5.3
5.0	Kentucky River at Camp Nelson	1983-86	33			8.6	9.3	13	15	19
7.0	Kentucky River above Frankfort	1983-86	33			7.8	9.0	11	13	14
9.0	Kentucky River below Frankfort	1983-85	24				8.7	11	12	
9.3	South Elkhorn Creek near Midway	1984-86	25				6.4	8.1	11	
10.1	Eagle Creek at Glencoe	1983-86	33			6.1	8.0	10	12	19

Table 20.—*Statistical summary of concentrations of major cations and anions and related water-quality characteristics for selected sites in the Kentucky River basin* — Continued

[N, number of observations; DL, detection limit; *, value was estimated from log-normal fit program. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL	Value at indicated percentile: 10	25	50 (median)	75	90
Sodium, dissolved, in milligrams per liter										
2.0	North Fork Kentucky River at Jackson	1980-84	20				9.5	17	25	
2.3	Middle Fork Kentucky River at Tallega	1980-84	19				4.0	5.6	6.6	
2.6	South Fork Kentucky River at Booneville	1980-84	19				6.4	10	18	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	33			2.9	4.3	7.2	13	20
3.1	Red River near Hazel Green	1979-84	29				1.8	2.1	3.4	
5.0	Kentucky River at Camp Nelson	1980-84	18				5.5	8.8	16	
7.0	Kentucky River above Frankfort	1979-84	22				4.7	7.3	11	
9.0	Kentucky River below Frankfort	1979-84	20				5.8	7.5	11	
9.3	South Elkhorn Creek near Midway	1982-84	20				21	32	48	
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101			4.5	5.6	8.1	12	17
10.1	Eagle Creek at Glencoe	1976-84	30			3.3	3.7	5.7	7.6	8.0
Sodium, total, in milligrams per liter										
2.0	North Fork Kentucky River at Jackson	1984-86	25				11	14	18	
2.3	Middle Fork Kentucky River at Tallega	1984-86	25				4.2	5.9	8.2	
2.6	South Fork Kentucky River at Booneville	1984-86	25				7.8	11	15	
3.0	Kentucky River at Lock 14, at Heidelberg	1983-86	33			5.3	11	20	32	58
3.1	Red River near Hazel Green	1983-86	33			1.5	2.1	3.1	3.8	4.7
5.0	Kentucky River at Camp Nelson	1983-86	33			7.2	8.6	12	21	49
7.0	Kentucky River above Frankfort	1983-86	33			5.3	7.5	9.2	18	27
9.0	Kentucky River below Frankfort	1983-85	24				7.6	10	18	
9.3	South Elkhorn Creek near Midway	1984-86	25				20	34	45	
10.1	Eagle Creek at Glencoe	1983-86	33			2.6	3.2	4.6	6.0	7.2
Chloride, dissolved, in milligrams per liter										
2.0	North Fork Kentucky River at Jackson	1980-86	44			3.6	5.2	6.8	9.3	13
2.3	Middle Fork Kentucky River at Tallega	1980-86	43			3.0	4.4	5.4	6.8	11
2.6	South Fork Kentucky River at Booneville	1980-86	43			3.2	6.3	8.8	17	30
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	86			3.6	6.2	9.5	19	49
3.1	Red River near Hazel Green	1979-86	81			2.0	3.0	4.2	6.0	7.2
5.0	Kentucky River at Camp Nelson	1980-86	74			7.6	12	18	28	59
7.0	Kentucky River above Frankfort	1979-86	82			7.3	9.7	14	23	37
9.0	Kentucky River below Frankfort	1979-85	73			7.0	8.8	13	22	32
9.3	South Elkhorn Creek near Midway	1982-86	43			23	31	41	61	81
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101			6.0	7.2	11	18	24
10.1	Eagle Creek at Glencoe	1976-86	95			4.0	5.2	6.6	8.2	10
Potassium, dissolved, in milligrams per liter										
2.0	North Fork Kentucky River at Jackson	1980-84	21				2.4	3.5	4.4	
2.3	Middle Fork Kentucky River at Tallega	1980-84	19				1.5	1.7	2.4	
2.6	South Fork Kentucky River at Booneville	1980-84	21				1.6	1.9	2.9	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	31			1.3	1.7	2.1	3.5	4.2

Table 20.—*Statistical summary of concentrations of major cations and anions and related water-quality characteristics for selected sites in the Kentucky River basin*—Continued

[N, number of observations; DL, detection limit; *, value was estimated from log-normal fit program. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL	Value at indicated percentile: 10	25	50 (median)	75	90
Potassium, dissolved, in milligrams per liter—Continued										
3.1	Red River near Hazel Green	1979-84	29				1.1	1.8	2.8	
5.0	Kentucky River at Camp Nelson	1980-84	19				1.8	2.5	3.3	
7.0	Kentucky River above Frankfort	1979-84	23				1.7	2.2	2.9	
9.0	Kentucky River below Frankfort	1979-84	21				1.9	2.3	3.0	
9.3	South Elkhorn Creek near Midway	1982-84	20				3.3	5.4	7.5	
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101			1.6	1.8	2.4	2.9	3.3
10.1	Eagle Creek at Glencoe	1976-84	31			2.0	2.3	2.9	3.5	4.0
Potassium, total, in milligrams per liter										
2.0	North Fork Kentucky River at Jackson	1984-86	24				2.7	3.3	4.7	
2.3	Middle Fork Kentucky River at Tallega	1984-86	24				1.6	1.8	2.6	
2.6	South Fork Kentucky River at Booneville	1984-86	24				1.6	2.0	2.7	
3.0	Kentucky River at Lock 14, at Heidelberg	1983-86	32			2.0	2.1	2.7	3.8	4.7
3.1	Red River near Hazel Green	1983-86	32			1.2	1.3	1.9	3.0	4.3
5.0	Kentucky River at Camp Nelson	1983-86	32			1.7	2.0	2.3	3.5	4.1
7.0	Kentucky River above Frankfort	1983-86	32			1.6	2.0	2.4	3.1	3.5
9.0	Kentucky River below Frankfort	1983-85	23				1.9	2.6	3.4	
9.3	South Elkhorn Creek near Midway	1984-86	24				3.4	4.9	7.4	
10.1	Eagle Creek at Glencoe	1983-86	32			1.8	2.0	2.7	3.4	4.8
Sulfate, dissolved, in milligrams per liter as SO_4										
1.0	North Fork Kentucky River at Hazard	1979-81	18				70	90	130	
2.0	North Fork Kentucky River at Jackson	1979-83	36			61	79	120	150	200
2.1	Middle Fork Kentucky River near Hyden	1976-81	21				27	40	59	
2.3	Middle Fork Kentucky River at Tallega	1979-83	34			32	35	42	54	60
2.5	Goose Creek at Manchester	1979-81	19				32	45	68	
2.6	South Fork Kentucky River at Booneville	1979-83	31			34	43	48	69	78
3.1	Red River near Hazel Green	1979-81	20				13	14	16	
9.3	South Elkhorn Creek near Midway	1982-84	17				41	63	77	
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101			28	32	39	46	56
Sulfate, total, in milligrams per liter as SO_4										
2.0	North Fork Kentucky River at Jackson	1984-86	27				130	150	180	
2.3	Middle Fork Kentucky River at Tallega	1984-86	26				49	56	66	
2.6	South Fork Kentucky River at Booneville	1984-86	27				50	60	77	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	84			38	53	75	91	130
3.1	Red River near Hazel Green	1979-86	84			12	14	15	17	19
5.0	Kentucky River at Camp Nelson	1980-86	75			37	42	51	79	95
7.0	Kentucky River above Frankfort	1979-86	83			30	36	43	56	73
9.0	Kentucky River below Frankfort	1979-85	73			28	35	43	56	68
9.3	South Elkhorn Creek near Midway	1984-86	27				38	51	67	
10.1	Eagle Creek at Glencoe	1979-86	88			27	34	44	59	86

Table 20. —*Statistical summary of concentrations of major cations and anions and related water-quality characteristics for selected sites in the Kentucky River basin* — Continued

[N, number of observations; DL, detection limit; *, value was estimated from log-normal fit program. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL	Value at indicated percentile 10	25	50 (median)	75	90
Fluoride, dissolved, in milligrams per liter										
2.0	North Fork Kentucky River at Jackson	1980-85	34	4	0.10	0.08*	0.10	0.12	0.20	0.20
2.3	Middle Fork Kentucky River at Tallega	1980-85	34	21	.10	.04*	.05*	.07*	.10	.14
2.6	South Fork Kentucky River at Booneville	1980-85	34	19	.10	.05*	.06*	.08*	.10	.15
3.0	Kentucky River at Lock 14, at Heidelberg	1979-85	77	31	.10	.05*	.06*	.08*	.12	.14
3.1	Red River near Hazel Green	1979-85	74	48	.10	.03*	.04*	.06*	.08*	.10
5.0	Kentucky River at Camp Nelson	1980-85	65	19	.10	.05*	.07*	.09*	.13	.16
7.0	Kentucky River above Frankfort	1979-85	73	21	.10	.06*	.08*	.10	.12	.14
9.0	Kentucky River below Frankfort	1979-85	72	18	.10	.06*	.08*	.11	.14	.15
9.3	South Elkhorn Creek near Midway	1982-85	34			.31	.40	.80	1.3	1.6
10.0	Kentucky River at Lock 2, at Lockport	1976-86	100	2	.10	.10	.10	.10	.20	.30
10.1	Eagle Creek at Glencoe	1976-85	87	6	.10	.09*	.12	.15	.18	.21
Silica, dissolved, in milligrams per liter as SiO_2										
2.0	North Fork Kentucky River at Jackson	1980-84	18				2.2	6.1	6.7	
2.3	Middle Fork Kentucky River at Tallega	1980-83	17				4.1	5.1	6.1	
2.6	South Fork Kentucky River at Booneville	1980-83	17				3.4	5.1	6.4	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-83	22				3.3	5.9	6.7	
3.1	Red River near Hazel Green	1979-80	19				4.8	6.4	7.4	
7.0	Kentucky River above Frankfort	1979-80	15	2	1.0		4.1	5.3	6.0	
9.0	Kentucky River below Frankfort	1979-80	14	1	.10		3.4	5.2	5.5	
9.3	South Elkhorn Creek near Midway	1982-84	17				6.6	7.0	8.0	
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101			2.7	4.7	5.4	5.9	6.2
10.1	Eagle Creek at Glencoe	1976-80	27	1	1.0		1.9	3.7	5.5	

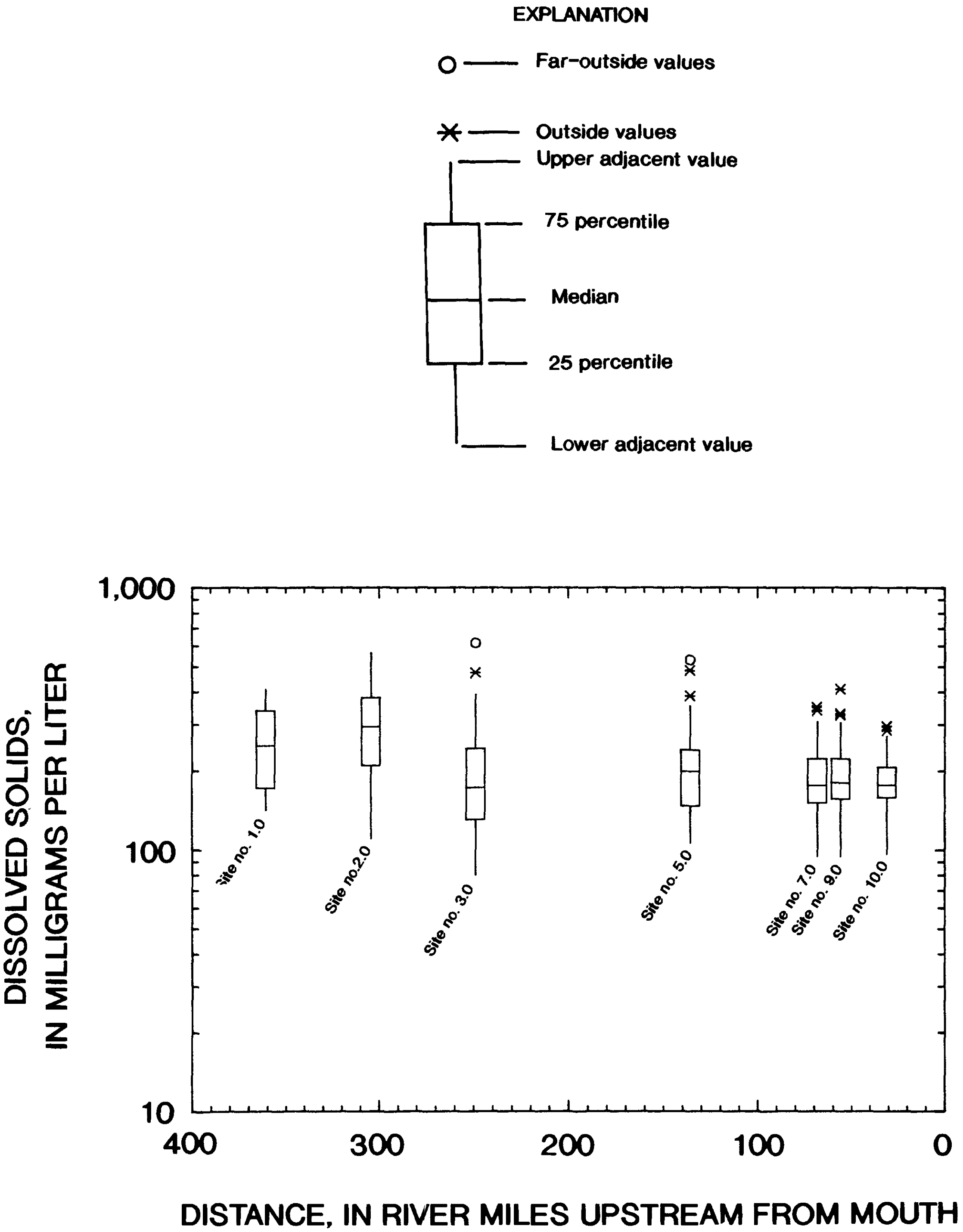


Figure 23.--Statistical summary of dissolved-solids concentrations at sites along the Kentucky River, based on available data for water years 1976-86.

Table 21.—*Number of dissolved-solids, sulfate, and fluoride measurements in the Kentucky River basin and percentage not meeting indicated water-quality criteria, based on available data for water years 1976-86*

[Censored values greater than the water-quality criteria were not included in the percentage computations]

U.S. ENVIRONMENTAL PROTECTION AGENCY		KENTUCKY
MCL = maximum contaminant level	SMCL = secondary MCL	KYDWS = domestic water supply
MCLG = maximum contaminant level goal	ALA = aquatic life acute	KYAH = warmwater aquatic habitat
PMCLG = proposed MCLG	ALC = aquatic life chronic	KYR = recreational waters

Constituent or property	Number of measurements	Percentage not meeting indicated criteria								
		MCL	MCLG	PMCLG	SMCL	ALA	ALC	KYDWS	KYAH	KYR
Dissolved solids	1,657				3			1		
Sulfate, dissolved	822				3			3		
Fluoride, dissolved	764							2		

Table 22.—*Number of dissolved-solids and fluoride measurements at selected sites in the Kentucky River basin and percentage not meeting indicated water-quality criteria, based on available data for water years 1976-86*

[Censored values greater than the water-quality criteria were not included in the percentage computations]

U.S. ENVIRONMENTAL PROTECTION AGENCY		KENTUCKY
MCL = maximum contaminant level	SMCL = secondary MCL	KYDWS = domestic water supply
MCLG = maximum contaminant level goal	ALA = aquatic life acute	KYAH = warmwater aquatic habitat
PMCLG = proposed MCLG	ALC = aquatic life chronic	KYR = recreational waters

Site number	USGS station name	Number of measurements	Percentage not meeting indicated criteria								
			MCL	MCLG	PMCLG	SMCL	ALA	ALC	KYDWS	KYAH	KYR
Dissolved solids, residue on evaporation at 180 degrees Celsius											
2.0	North Fork Kentucky River at Jackson	52				6					
3.0	Kentucky River at Lock 14, at Heidelberg	80				1					
5.0	Kentucky River at Camp Nelson	64				2					
10.1	Eagle Creek at Glencoe	84				1					
Fluoride, dissolved											
9.3	South Elkhorn Creek near Midway	34							32		

Table 23.—*Estimates of mean annual loads and mean annual yields for water years 1983-85 for major cations and anions for selected sites in the Kentucky River basin*

[N, number of observations; tons/mi^2, tons per square mile]

Site number	USGS station name	N	Mean annual load, in tons	Mean annual yield, in tons/mi^2	Standard error of regression	Flow duration of greatest sampled discharge, in percent	Percentage of load estimated beyond range of sampled discharge
Dissolved solids, residue on evaporation at 180 degrees Celsius							
2.0	North Fork Kentucky River at Jackson	52	258,000	234	13.6	0.5	6.98
2.3	Middle Fork Kentucky River at Tallega	49	75,200	140	16.4	1.1	6.29
2.6	South Fork Kentucky River at Booneville	46	104,000	144	22.4	5.2	32.9
3.0	Kentucky River at Lock 14, at Heidelberg	80	613,000	231	24.0	.6	7.96
3.1	Red River near Hazel Green	90	4,450	67.6	29.5	.5	10.9
5.0	Kentucky River at Camp Nelson	64	1,010,000	227	28.7	5.1	28.2
7.0	Kentucky River above Frankfort	72	1,150,000	217	22.4	4.2	25.4
9.0	Kentucky River below Frankfort	71	1,150,000	211	23.5	4.6	26.7
9.3	South Elkhorn Creek near Midway	33	45,400	432	17.6	6.4	29.9
10.0	Kentucky River at Lock 2, at Lockport	100	1,400,000	227	15.5	0	0
Calcium, dissolved							
2.0	North Fork Kentucky River at Jackson	20	34,500	31.4	32.0	7.9	32.3
2.3	Middle Fork Kentucky River at Tallega	19	5,380	10.0	49.1	1.7	8.43
2.6	South Fork Kentucky River at Booneville	21	11,200	15.6	72.0	7.2	36.1
3.0	Kentucky River at Lock 14, at Heidelberg	33	62,000	23.3	43.2	1.7	10.2
3.1	Red River near Hazel Green	30	464	7.05	85.7	3.7	23.2
5.0	Kentucky River at Camp Nelson	18	182,000	41.2	24.4	5.1	28.6
7.0	Kentucky River above Frankfort	20	215,000	40.6	25.8	4.6	25.2
9.0	Kentucky River below Frankfort	20	279,000	51.5	20.9	4.6	29.9
9.3	South Elkhorn Creek near Midway	19	10,800	103.0	8.17	15.7	54.4
10.0	Kentucky River at Lock 2, at Lockport	100	272,000	44.1	16.0	0	0
Calcium, total							
2.0	North Fork Kentucky River at Jackson	24	43,200	39.2	31.3	3.9	22.7
2.3	Middle Fork Kentucky River at Tallega	24	7,820	14.6	27.9	1.7	6.0
2.6	South Fork Kentucky River at Booneville	24	16,100	22.4	33.8	5.2	35.7
3.0	Kentucky River at Lock 14, at Heidelberg	32	77,800	29.3	29.8	3.1	18.2
3.1	Red River near Hazel Green	32	782	11.9	81.6	.5	8.73
5.0	Kentucky River at Camp Nelson	32	174,000	39.2	29.2	12.3	10.6
7.0	Kentucky River above Frankfort	32	235,000	44.4	27.3	1.5	12.8
9.0	Kentucky River below Frankfort	23	260,000	48.0	23.3	4.6	27.4
9.3	South Elkhorn Creek near Midway	24	10,400	99.4	21.7	6.4	33.1
Magnesium, dissolved							
2.0	North Fork Kentucky River at Jackson	22	20,200	18.3	29.1	7.9	34.1
2.3	Middle Fork Kentucky River at Tallega	18	4,990	9.29	18.2	15.1	54.9
2.6	South Fork Kentucky River at Booneville	21	5,960	8.26	30.6	7.2	39.3

Table 23.—*Estimates of mean annual loads and mean annual yields for water years 1983-85 for major cations and anions for selected sites in the Kentucky River basin*—Continued

[N, number of observations; tons/mi², tons per square mile]

Site number	USGS station name	N	Mean annual load, in tons	Mean annual yield, in tons/mi²	Standard error of regression	Flow duration of greatest sampled discharge, in percent	Percentage of load estimated beyond range of sampled discharge
Magnesium, dissolved–Continued							
3.0	Kentucky River at Lock 14, at Heidelberg	31	34,400	13.0	30.4	1.7	12.4
3.1	Red River near Hazel Green	29	205	3.12	42.1	2.0	19.6
5.0	Kentucky River at Camp Nelson	19	58,000	13.1	17.7	5.1	27.4
7.0	Kentucky River above Frankfort	23	50,800	9.60	26.3	4.6	27.0
9.0	Kentucky River below Frankfort	22	51,100	9.42	24.9	4.6	27.8
9.3	South Elkhorn Creek near Midway	18	844	8.03	12.9	15.7	40.2
10.0	Kentucky River at Lock 2, at Lockport	101	57,100	9.24	17.6	0	0
Magnesium, total							
2.0	North Fork Kentucky River at Jackson	25	23,700	21.5	24.4	5.9	26.0
2.3	Middle Fork Kentucky River at Tallega	25	5,080	9.46	27.0	1.7	8.02
2.6	South Fork Kentucky River at Booneville	25	8,040	11.1	28.8	5.2	37.0
3.0	Kentucky River at Lock 14, at Heidelberg	33	35,100	13.2	27.5	3.1	18.4
3.1	Red River near Hazel Green	33	251	3.81	25.3	.5	9.53
5.0	Kentucky River at Camp Nelson	33	56,100	12.7	26.7	1.3	11.0
7.0	Kentucky River above Frankfort	33	60,700	11.5	25.1	1.5	13.0
9.0	Kentucky River below Frankfort	24	59,900	11.1	26.7	4.6	26.9
9.3	South Elkhorn Creek near Midway	25	1,060	10.1	30.6	6.4	25.3
Sodium, dissolved							
2.0	North Fork Kentucky River at Jackson	20	8,760	7.95	15.0	7.9	24.2
2.3	Middle Fork Kentucky River at Tallega	19	2,620	4.88	21.9	1.7	8.57
2.6	South Fork Kentucky River at Booneville	19	5,480	7.58	33.7	7.2	28.4
3.0	Kentucky River at Lock 14, at Heidelberg	33	21,700	8.17	45.3	1.7	9.66
3.1	Red River near Hazel Green	29	179	2.72	46.0	2.0	21.0
5.0	Kentucky River at Camp Nelson	18	39,200	8.86	43.6	5.1	19.1
7.0	Kentucky River above Frankfort	22	37,700	7.13	34.0	4.6	17.7
9.0	Kentucky River below Frankfort	20	36,200	6.68	32.7	4.6	17.9
9.3	South Elkhorn Creek near Midway	20	2,610	24.9	18.7	15.8	26.6
10.0	Kentucky River at Lock 2, at Lockport	101	65,500	10.6	40.3	0	0
Sodium, total							
2.0	North Fork Kentucky River at Jackson	25	10,400	9.47	19.1	3.9	18.0
2.3	Middle Fork Kentucky River at Tallega	25	3,730	6.95	60.4	1.7	6.58
2.6	South Fork Kentucky River at Booneville	25	5,680	7.87	30.7	5.2	24.5
3.0	Kentucky River at Lock 14, at Heidelberg	33	27,000	10.2	47.4	3.1	12.8
3.1	Red River near Hazel Green	33	224	3.41	42.3	.5	11.2
5.0	Kentucky River at Camp Nelson	33	53,000	12.0	57.7	1.3	9.18
7.0	Kentucky River above Frankfort	33	48,800	9.22	50.8	1.5	11.3
9.0	Kentucky River below Frankfort	24	49,600	9.14	33.8	4.6	20.9
9.3	South Elkhorn Creek near Midway	25	3,620	34.5	39.8	6.4	20.1

Table 23. —*Estimates of mean annual loads and mean annual yields for water years 1983-85 for major cations and anions for selected sites in the Kentucky River basin* —Continued

[N, number of observations; tons/mi², tons per square mile]

Site number	USGS station name	N	Mean annual load, in tons	Mean annual yield, in tons/mi²	Standard error of regression	Flow duration of greatest sampled discharge, in percent	Percentage of load estimated beyond range of sampled discharge
Chloride, dissolved							
2.0	North Fork Kentucky River at Jackson	44	5,250	4.76	24.0	3.9	18.3
2.3	Middle Fork Kentucky River at Tallega	43	3,240	6.04	64.8	1.7	9.21
2.6	South Fork Kentucky River at Booneville	43	4,970	6.89	76.4	5.2	17.2
3.0	Kentucky River at Lock 14, at Heidelberg	86	56,800	21.4	63.1	.6	5.75
3.1	Red River near Hazel Green	81	309	4.69	47.7	.5	8.34
5.0	Kentucky River at Camp Nelson	74	93,500	21.1	62.8	1.3	7.21
7.0	Kentucky River above Frankfort	82	89,600	16.9	47.2	1.5	9.19
9.0	Kentucky River below Frankfort	73	87,800	16.2	47.2	4.6	20.1
9.3	South Elkhorn Creek near Midway	43	4,660	44.4	32.4	6.4	20.2
10.0	Kentucky River at Lock 2, at Lockport	101	100,000	16.2	46.8	0	0
Potassium, dissolved							
2.0	North Fork Kentucky River at Jackson	21	2,670	2.42	10.8	7.9	33.8
2.3	Middle Fork Kentucky River at Tallega	19	964	1.79	11.0	1.7	10.9
2.6	South Fork Kentucky River at Booneville	21	1,420	1.96	15.0	7.2	41.1
3.0	Kentucky River at Lock 14, at Heidelberg	31	7,180	2.70	18.7	1.7	14.0
3.1	Red River near Hazel Green	29	148	2.25	22.1	2.0	22.9
5.0	Kentucky River at Camp Nelson	19	12,200	2.76	15.7	5.1	27.2
7.0	Kentucky River above Frankfort	23	13,300	2.51	11.8	4.6	24.5
9.0	Kentucky River below Frankfort	21	13,600	2.50	13.9	4.6	23.4
9.3	South Elkhorn Creek near Midway	20	433	4.12	12.9	15.7	27.9
10.0	Kentucky River at Lock 2, at Lockport	101	15,000	2.42	17.9	0	0
Potassium, total							
2.0	North Fork Kentucky River at Jackson	24	3,090	2.80	13.3	3.9	25.7
2.3	Middle Fork Kentucky River at Tallega	24	970	1.81	9.88	1.7	11.0
2.6	South Fork Kentucky River at Booneville	24	1,460	2.02	19.7	5.2	35.6
3.0	Kentucky River at Lock 14, at Heidelberg	32	7,320	2.76	14.8	3.1	20.9
3.1	Red River near Hazel Green	32	134	2.04	23.9	.5	9.66
5.0	Kentucky River at Camp Nelson	32	12,600	2.85	19.0	1.3	12.0
7.0	Kentucky River above Frankfort	32	14,100	2.67	17.5	1.5	14.5
9.0	Kentucky River below Frankfort	23	14,000	2.58	16.7	4.6	27.5
9.3	South Elkhorn Creek near Midway	24	574	5.46	29.4	6.4	21.0
Sulfate, dissolved as SO_4							
2.0	North Fork Kentucky River at Jackson	36	114,000	103	17.9	0.5	6.26
2.3	Middle Fork Kentucky River at Tallega	34	32,100	59.7	17.0	1.1	6.52
2.6	South Fork Kentucky River at Booneville	31	45,100	62.5	24.0	7.3	39.6
3.1	Red River near Hazel Green	20	1,210	18.4	21.9	1.2	17.7
9.3	South Elkhorn Creek near Midway	17	6,670	63.5	14.5	15.8	36.5
10.0	Kentucky River at Lock 2, at Lockport	101	318,000	51.5	22.7	0	0

Table 23. —*Estimates of mean annual loads and mean annual yields for water years 1983-85 for major cations and anions for selected sites in the Kentucky River basin* — Continued

[N, number of observations; tons/mi^2, tons per square mile]

Site number	USGS station name	N	Mean annual load in tons	Mean annual yield, in tons/mi^2	Standard error of regression	Flow duration of greatest sampled discharge, in percent	Percentage of load estimated beyond range of sampled discharge
Sulfate, total as SO_4							
2.0	North Fork Kentucky River at Jackson	27	133,000	120	12.5	3.9	23.0
2.3	Middle Fork Kentucky River at Tallega	26	28,300	52.7	16.5	3.7	16.5
2.6	South Fork Kentucky River at Booneville	27	47,200	65.4	21.8	5.2	35.2
3.0	Kentucky River at Lock 14, at Heidelberg	84	213,000	80.0	29.9	.6	6.20
3.1	Red River near Hazel Green	84	1,240	18.9	29.1	.5	11.4
5.0	Kentucky River at Camp Nelson	75	261,000	59.0	27.7	1.3	9.93
7.0	Kentucky River above Frankfort	83	260,000	49.1	26.4	1.5	11.9
9.0	Kentucky River below Frankfort	73	272,000	50.1	27.5	4.6	23.9
9.3	South Elkhorn Creek near Midway	27	6,360	60.6	27.3	6.4	23.3
Fluoride, dissolved							
2.0	North Fork Kentucky River at Jackson	34	114	.103	39.5	3.9	24.6
3.0	Kentucky River at Lock 14, at Heidelberg	77	224	.084	45.0	.6	8.23
5.0	Kentucky River at Camp Nelson	65	363	.082	35.9	5.1	26.2
7.0	Kentucky River above Frankfort	73	450	.085	36.3	4.2	21.9
9.0	Kentucky River below Frankfort	72	501	.093	38.6	4.6	22.5
9.3	South Elkhorn Creek near Midway	34	77.7	.740	56.1	6.4	16.8
10.0	Kentucky River at Lock 2, at Lockport	101	929	.150	42.1	0	0
Silica, dissolved as SiO_2							
2.0	North Fork Kentucky River at Jackson	18	17,100	15.6	70.5	7.9	68.6
2.3	Middle Fork Kentucky River at Tallega	17	3,660	6.81	19.1	15.1	59.8
2.6	South Fork Kentucky River at Booneville	17	8,340	11.6	33.1	7.2	59.9
3.0	Kentucky River at Lock 14, at Heidelberg	22	19,600	7.36	38.7	1.7	16.0
3.1	Red River near Hazel Green	19	504	7.66	21.4	6.5	42.0
7.0	Kentucky River above Frankfort	15	49,400	9.33	213.0	5.8	47.2
9.0	Kentucky River below Frankfort	14	36,100	6.67	206.0	5.8	40.2
9.3	South Elkhorn Creek near Midway	17	1,040	9.87	19.7	15.8	53.2
10.0	Kentucky River at Lock 2, at Lockport	101	43,300	7.01	36.6	0	0

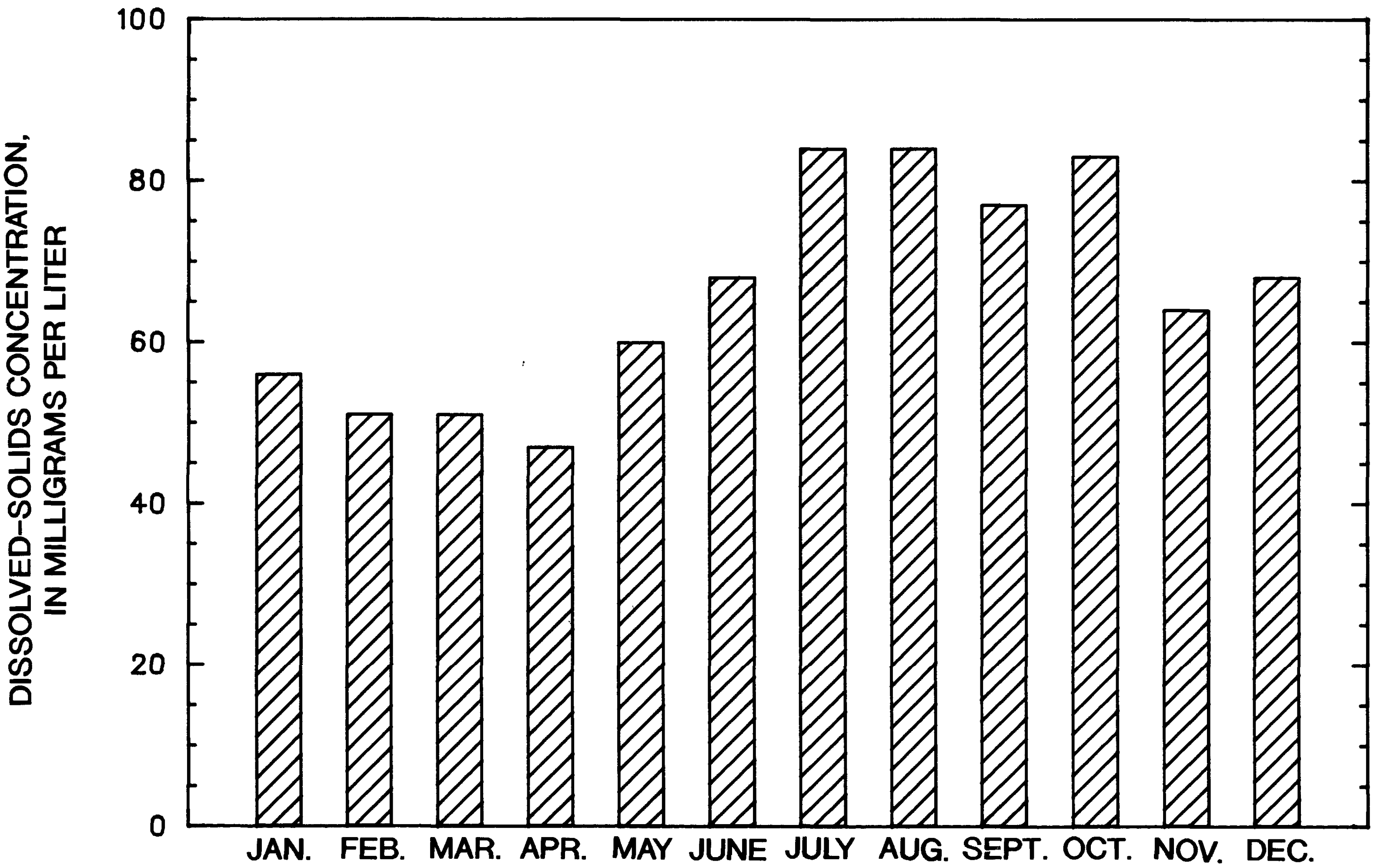


Figure 24.--Mean monthly dissolved-solids concentrations, for the Red River near Hazel Green (site 3.1), 1979-85.

Table 24. —*Trend test results for major cations and anions for selected sites in the Kentucky River basin*

[N, number of observations; SC, number of seasonal comparisons; P, probability; *, censored values used in analysis; **, censored values affect trend analysis; mg/L, milligrams per liter. Trend-line slopes not significant at 0.2 probability level are not reported, and those significant at the 0.1 probability level are underlined]

					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	USGS station name	Period of record (water years)	N	SC	P level	Microsiemens per centimeter per year	Percent of median specific conductance per year	P level	Microsiemens per centimeter per year	Percent of median specific conductance per year
Specific conductance										
0.1	Yonts Fork near Neon	1979-84	11	24	1.00					
0.2	Carr Fork near Sassafras	1976-85	72	44	.003	7.0	2.6			
1.0	North Fork Kentucky River at Hazard	1978-85	64	36	.013	11	3.0			
1.1	Troublesome Creek at Noble	1978-82	24	20	.054	52	13			
2.0	North Fork Kentucky River at Jackson	1978-86	89	36	.004	14	3.5	0.001	14	3.5
2.1	Middle Fork Kentucky River near Hyden	1976-85	63	44	.001	14	6.7			
2.2	Cutshin Creek at Wooton	1976-85	68	44	.723					
2.3	Middle Fork Kentucky River at Tallega	1978-86	92	36	.005	7.5	3.7	.058	5.1	2.6
2.4	Red Bird River near Big Creek	1978-85	62	36	.606					
2.5	Goose Creek at Manchester	1978-85	68	36	.041	15	7.4			
2.6	South Fork Kentucky River at Booneville	1978-86	89	36	.027	10	4.5	.027	7.7	3.4
3.0	Kentucky River at Lock 14, at Heidelberg	1978-86	116	36	.000	35	13	.000	23	8.5
3.1	Red River near Hazel Green	1976-86	148	44	.005	2.9	2.9	.025	1.3	1.3
3.3	Red River at Clay City	1978-86	73	36	.142	5.0	2.1			
4.0	Kentucky River at Lock 10, near Winchester	1978-85	48	36	.030	9.7	3.3			
4.1	Silver Creek near Kingston	1978-83	41	28	.050	14	3.8			
5.0	Kentucky River at Camp Nelson	1980-86	75	28	.010	18	5.6	.004	16	4.8
5.1	West Hickman Creek at Jonestown	1978-83	45	28	.567					
5.2	Dix River near Danville	1979-86	60	32	.882					
6.0	Kentucky River at Lock 6, near Salvisa	1978-85	47	36	.124	10	3.3			
7.0	Kentucky River above Frankfort	1979-86	83	32	.000	17	5.4	.000	12	3.8
8.0	Kentucky River at Lock 4, at Frankfort	1978-85	53	36	.016	12	3.6			
9.0	Kentucky River below Frankfort	1979-85	73	32	.001	19	6.2	.001	17	5.5
9.1	North Elkhorn Creek near Georgetown	1978-84	48	28	.132	-8.7	-2.2			
9.2	South Elkhorn Creek at Fort Spring	1978-85	61	36	.420					
9.3	South Elkhorn Creek near Midway	1982-86	53	20	.878			.444		
9.4	Elkhorn Creek near Frankfort	1978-83	46	28	.511					
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101	44	.000	11	3.7	.000	11	3.8
10.1	Eagle Creek at Glencoe	1976-86	97	44	.778					
						Milligrams per liter per year	Percent of median concentration (mg/L) per year		Milligrams per liter per year	Percent of median concentration (mg/L) per year
Dissolved solids, residue on evaporation at 180 degrees Celsius										
2.0	North Fork Kentucky River at Jackson	1979-85	52	32	.007	21	7.1	.004	12	4.1
2.3	Middle Fork Kentucky River at Tallega	1979-85	49	32	.001	7.1	6.0	.000	6.7	5.6
2.6	South Fork Kentucky River at Booneville	1979-85	46	32	.089	4.0	3.0	.047	4.9	3.8
3.0	Kentucky River at Lock 14, at Heidelberg	1979-85	80	32	.001	17	10	.000	15	9.1
3.1	Red River near Hazel Green	1979-85	90	32	.636			.937		

Table 24. – *Trend test results for major cations and anions for selected sites in the Kentucky River basin* – Continued

[N, number of observations; SC, number of seasonal comparisons; P, probability; *, censored values used in analysis; **, censored values affect trend analysis; mg/L, milligrams per liter. Trend-line slopes not significant at 0.2 probability level are not reported, and those significant at the 0.1 probability level are underlined]

					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	USGS station name	Period of record (water years)	N	SC	P level	Milligrams per liter per year	Percent of median concentration (mg/L) per year	P level	Milligrams per liter per year	Percent of median concentration (mg/L) per year
Dissolved solids, residue on evaporation at 180 degrees Celsius–Continued										
5.0	Kentucky River at Camp Nelson	1980-85	64	28	0.321			0.047	12	6.0
7.0	Kentucky River above Frankfort	1979-85	72	32	.001	16	8.3	.006	11	5.8
9.0	Kentucky River below Frankfort	1979-85	71	32	.018	12	6.7	.006	13	7.0
9.3	South Elkhorn Creek near Midway	1982-85	33	20	.286			1.00		
10.0	Kentucky River at Lock 2, at Lockport	1976-86	100	44	.000	6.8	3.8	.000	7.2	4.0
10.1	Eagle Creek at Glencoe	1976-85	84	44	.897					
Hardness, (Ca, Mg)										
2.0	North Fork Kentucky River at Jackson	1980-86	45	24	.018	25	11	.001	16	7.2
2.3	Middle Fork Kentucky River at Tallega	1980-86	44	24	.019	8.3	9.9	.019	7.7	9.3
2.6	South Fork Kentucky River at Booneville	1980-86	44	24	.158	9.5	11	.085	2.6	3.1
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	87	32	.000	13	12	.000	12	10
3.1	Red River near Hazel Green	1979-86	84	32	.309			.311		
5.0	Kentucky River at Camp Nelson	1980-86	75	28	.005	9.4	7.0	.001	8.2	6.1
7.0	Kentucky River above Frankfort	1979-86	79	32	.005	6.0	4.5	.001	6.5	4.9
9.0	Kentucky River below Frankfort	1979-85	69	32	.001	8.6	6.4	.002	9.4	7.0
9.3	South Elkhorn Creek near Midway	1982-86	44	20	.328					
10.0	Kentucky River at Lock 2, at Lockport	1976-86	100	44	.000	3.1	2.4	.000	3.2	2.5
10.1	Eagle Creek at Glencoe	1976-86	89	44	.043	-4.2	-2.4			
Calcium, dissolved										
2.0	North Fork Kentucky River at Jackson	1980-84	20	20	.411			.411		
2.3	Middle Fork Kentucky River at Tallega	1980-84	19	20	.255			.569		
2.6	South Fork Kentucky River at Booneville	1980-84	21	20	1.00			.569		
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	33	28	.332			.628		
3.1	Red River near Hazel Green	1979-84	30	28	1.00			1.00		
5.0	Kentucky River at Camp Nelson	1980-84	18	20	.248			.248		
7.0	Kentucky River above Frankfort	1979-84	20	28	1.00					
9.0	Kentucky River below Frankfort	1979-84	20	24	.699					
9.3	South Elkhorn Creek near Midway	1982-84	19	12	1.00			1.00		
10.0	Kentucky River at Lock 2, at Lockport	1976-86	100	44	.000	.60	1.6	.001	.64	1.7
10.1	Eagle Creek at Glencoe	1976-84	32	40	.546					
Calcium, total										
2.0	North Fork Kentucky River at Jackson	1984-86	24	12	1.00			.245		
2.3	Middle Fork Kentucky River at Tallega	1984-86	24	12	.245			.699		
2.6	South Fork Kentucky River at Booneville	1984-86	24	12	1.00			.699		
3.0	Kentucky River at Lock 14, at Heidelberg	1983-86	32	12	.279			.192	4.4	12
3.1	Red River near Hazel Green	1983-86	32	12*	.794					
5.0	Kentucky River at Camp Nelson	1983-86	32	12	.433			1.00		

Table 24.—*Trend test results for major cations and anions for selected sites in the Kentucky River basin*—Continued

[N, number of observations; SC, number of seasonal comparisons; P, probability; *, censored values used in analysis; **, censored values affect trend analysis; mg/L, milligrams per liter. Trend-line slopes not significant at 0.2 probability level are not reported, and those significant at the 0.1 probability level are underlined]

Site number	USGS station name	Period of record (water years)	N	SC	Results of seasonal Kendall tests for time trend[1]: Trends, unadjusted for flow: P level	Trend-line slope: Milligrams per liter per year	Trend-line slope: Percent of median concentration (mg/L) per year	Flow-adjusted trends[2]: P level	Trend-line slope: Milligrams per liter per year	Trend-line slope: Percent of median concentration (mg/L) per year
Calcium, total–Continued										
7.0	Kentucky River above Frankfort	1983-86	32	12	0.794					
9.0	Kentucky River below Frankfort	1983-85	23	12	.699					
9.3	South Elkhorn Creek near Midway	1984-86	24	12	.699					
10.1	Eagle Creek at Glencoe	1983-86	32	12	.433					
Magnesium, dissolved										
2.0	North Fork Kentucky River at Jackson	1980-84	22	20	.411			0.411		
2.3	Middle Fork Kentucky River at Tallega	1980-84	18	16	.712			.712		
2.6	South Fork Kentucky River at Booneville	1980-84	21	20	.766			1.00		
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	31	24	.043	<u>1.6</u>	<u>17</u>	.043	<u>1.6</u>	<u>17</u>
3.1	Red River near Hazel Green	1979-84	29	24	.149	.21	7.6	.773		
5.0	Kentucky River at Camp Nelson	1980-84	19	20	.248			.248		
7.0	Kentucky River above Frankfort	1979-84	23	28	.743			.743		
9.0	Kentucky River below Frankfort	1979-84	22	28	.743					
9.3	South Elkhorn Creek near Midway	1982-84	18	12	1.00			.401		
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101	44	.00	<u>.30</u>	<u>4.0</u>	.000	<u>.30</u>	<u>4.1</u>
10.1	Eagle Creek at Glencoe	1976-84	32	36	1.00					
Magnesium, total										
2.0	North Fork Kentucky River at Jackson	1984-86	25	12	.699			.699		
2.3	Middle Fork Kentucky River at Tallega	1984-86	25	12	1.00			1.00		
2.6	South Fork Kentucky River at Booneville	1984-86	25	12	1.00			.699		
3.0	Kentucky River at Lock 14, at Heidelberg	1983-86	33	12	1.00			.192	.83	5.2
3.1	Red River near Hazel Green	1983-86	33	12	.433			.433		
5.0	Kentucky River at Camp Nelson	1983-86	33	12	.794			1.00		
7.0	Kentucky River above Frankfort	1983-86	33	12	.794			.433		
9.0	Kentucky River below Frankfort	1983-85	24	12	1.00			.053	<u>.80</u>	<u>7.1</u>
9.3	South Elkhorn Creek near Midway	1984-86	25	12	.699			.245		
10.1	Eagle Creek at Glencoe	1983-86	33	12	.794					
Sodium, dissolved										
2.0	North Fork Kentucky River at Jackson	1980-84	20	20	.784			.171	-2.1	-12
2.3	Middle Fork Kentucky River at Tallega	1980-84	19	16	.712			.712		
2.6	South Fork Kentucky River at Booneville	1980-84	19	16	.427			1.00		
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	33	28	.146	.74	10	.332		
3.1	Red River near Hazel Green	1979-84	29	24	1.00			.387		
5.0	Kentucky River at Camp Nelson	1980-84	18	20	1.00			1.00		
7.0	Kentucky River above Frankfort	1979-84	22	28	1.00			.326		

Table 24.—*Trend test results for major cations and anions for selected sites in the Kentucky River basin*—Continued

[N, number of observations; SC, number of seasonal comparisons; P, probability; *, censored values used in analysis; **, censored values affect trend analysis; mg/L, milligrams per liter. Trend-line slopes not significant at 0.2 probability level are not reported, and those significant at the 0.1 probability level are underlined]

					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	USGS station name	Period of record (water years)	N	SC	P level	Milligrams per liter per year	Percent of median concentration (mg/L) per year	P level	Milligrams per liter per year	Percent of median concentration (mg/L) per year
Sodium, dissolved–Continued										
9.0	Kentucky River below Frankfort	1979-84	20	28	1.00			0.743		
9.3	South Elkhorn Creek near Midway	1982-84	20	12	1.00			1.00		
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101	44	.00	0.60	7.6	.000	0.68	8.5
10.1	Eagle Creek at Glencoe	1976-84	30	36	1.00					
Sodium, total										
2.0	North Fork Kentucky River at Jackson	1984-86	25	12	.699			.245		
2.3	Middle Fork Kentucky River at Tallega	1984-86	25	12	.699			.699		
2.6	South Fork Kentucky River at Booneville	1984-86	25	12	1.00			1.00		
3.0	Kentucky River at Lock 14, at Heidelberg	1983-86	33	12	.004	12	56	.004	7.7	37
3.1	Red River near Hazel Green	1983-86	33	12	.399			.433		
5.0	Kentucky River at Camp Nelson	1983-86	33	12	.192	3.8	34	1.00		
7.0	Kentucky River above Frankfort	1983-86	33	12	.794			.794		
9.0	Kentucky River below Frankfort	1983-85	24	12	.053	6.6	58	.053	7.8	68
9.3	South Elkhorn Creek near Midway	1984-86	25	12	.699			1.00		
10.1	Eagle Creek at Glencoe	1983-86	33	12	.794					
Chloride, dissolved										
2.0	North Fork Kentucky River at Jackson	1980-86	44	24	.375			.237		
2.3	Middle Fork Kentucky River at Tallega	1980-86	43	24	.638			.638		
2.6	South Fork Kentucky River at Booneville	1980-86	43	24	.875			.875		
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	86	32	.000	3.6	38	.000	3.1	32
3.1	Red River near Hazel Green	1979-86	81	32	.055	.18	4.3	.039	.16	4.0
5.0	Kentucky River at Camp Nelson	1980-86	74	28	.006	1.6	8.9	.010	2.5	14
7.0	Kentucky River above Frankfort	1979-86	82	32	.002	1.2	8.2	.001	1.1	7.7
9.0	Kentucky River below Frankfort	1979-85	73	32	.007	1.3	8.8	.004	1.6	11
9.3	South Elkhorn Creek near Midway	1982-86	43	20	.515			.192	2.8	6.6
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101	44	.000	1.1	9.6	.000	1.1	9.9
10.1	Eagle Creek at Glencoe	1976-86	95	44	.366					
Potassium, dissolved										
2.0	North Fork Kentucky River at Jackson	1980-84	21	20	.784			.784		
2.3	Middle Fork Kentucky River at Tallega	1980-84	19	16	.065	-.10	-5.6	.712		
2.6	South Fork Kentucky River at Booneville	1980-84	21	20	.255			.255		
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	31	24	.149	.16	7.6	.228		
3.1	Red River near Hazel Green	1979-84	29	24	.009	.17	12	.387		
5.0	Kentucky River at Camp Nelson	1980-84	19	20	1.00			.248		
7.0	Kentucky River above Frankfort	1979-84	23	28	.326			.102	.09	4.0

Table 24.—*Trend test results for major cations and anions for selected sites in the Kentucky River basin*—Continued

[N, number of observations; SC, number of seasonal comparisons; P, probability; *, censored values used in analysis; **, censored values affect trend analysis; mg/L, milligrams per liter. Trend-line slopes not significant at 0.2 probability level are not reported, and those significant at the 0.1 probability level are underlined]

Site number	USGS station name	Period of record (water years)	N	SC	Results of seasonal Kendall tests for time trend[1]: Trends, unadjusted for flow: P level	Trend-line slope: Milligrams per liter per year	Trend-line slope: Percent of median concentration (mg/L) per year	Flow-adjusted trends[2]: P level	Trend-line slope: Milligrams per liter per year	Trend-line slope: Percent of median concentration (mg/L) per year
Potassium, dissolved–Continued										
9.0	Kentucky River below Frankfort	1979-84	21	28	0.743			0.102	0.09	4.4
9.3	South Elkhorn Creek near Midway	1982-84	20	12	1.00			1.00		
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101	44	.379			.506		
10.1	Eagle Creek at Glencoe	1976-84	31	40	.831					
Potassium, total										
2.0	North Fork Kentucky River at Jackson	1984-86	24	12	.699			1.00		
2.3	Middle Fork Kentucky River at Tallega	1984-86	24	12	.699			.245		
2.6	South Fork Kentucky River at Booneville	1984-86	24	12	.699			1.00		
3.0	Kentucky River at Lock 14, at Heidelberg	1983-86	32	12	1.00			.794		
3.1	Red River near Hazel Green	1983-86	32	12	.068	<u>-0.44</u>	<u>-23</u>	.068	<u>-.23</u>	<u>-12</u>
5.0	Kentucky River at Camp Nelson	1983-86	32	12	1.00			.068	<u>-.25</u>	<u>-10</u>
7.0	Kentucky River above Frankfort	1983-86	32	12	1.00			.433		
9.0	Kentucky River below Frankfort	1983-85	23	12	1.00			.699		
9.3	South Elkhorn Creek near Midway	1984-86	24	12	.245			.699		
10.1	Eagle Creek at Glencoe	1983-86	32	12	.433					
Sulfate, dissolved										
2.0	North Fork Kentucky River at Jackson	1979-83	36	24	.525			.638		
2.3	Middle Fork Kentucky River at Tallega	1979-83	34	24	.019	<u>4.0</u>	<u>10</u>	.042	<u>4.8</u>	<u>12</u>
2.6	South Fork Kentucky River at Booneville	1979-83	31	24	.256			.015	<u>4.2</u>	<u>8.8</u>
3.1	Red River near Hazel Green	1979-81	20	16	1.00					
9.3	South Elkhorn Creek near Midway	1982-84	17	12	1.00			.248		
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101	44	.00	<u>2.0</u>	<u>5.2</u>	.000	<u>2.1</u>	<u>5.3</u>
Sulfate, total										
2.0	North Fork Kentucky River at Jackson	1984-86	27	12	.699			1.00		
2.3	Middle Fork Kentucky River at Tallega	1984-86	26	12	1.00			.699		
2.6	South Fork Kentucky River at Booneville	1984-86	27	12	1.00			.699		
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	84	32	.009	<u>5.4</u>	<u>7.5</u>	.000	<u>5.8</u>	<u>8.1</u>
3.1	Red River near Hazel Green	1979-86	84	32	.499					
5.0	Kentucky River at Camp Nelson	1980-86	75	28	.010	<u>3.6</u>	<u>7.2</u>	.082	<u>2.0</u>	<u>3.9</u>
7.0	Kentucky River above Frankfort	1979-86	83	32	.010	<u>2.3</u>	<u>5.5</u>	.006	<u>1.9</u>	<u>4.5</u>
9.0	Kentucky River below Frankfort	1979-85	73	32	.022	<u>2.0</u>	<u>4.9</u>	.006	<u>2.8</u>	<u>6.9</u>
9.3	South Elkhorn Creek near Midway	1984-86	27	12	.699			.699		
10.1	Eagle Creek at Glencoe	1979-86	88	32	.380					

Table 24. -- *Trend test results for major cations and anions for selected sites in the Kentucky River basin* -- Continued

[N, number of observations; SC, number of seasonal comparisons; P, probability; *, censored values used in analysis; **, censored values affect trend analysis; mg/L, milligrams per liter. Trend-line slopes not significant at 0.2 probability level are not reported, and those significant at the 0.1 probability level are underlined]

Site number	USGS station name	Period of record (water years)	N	SC	Results of seasonal Kendall tests for time trend[1]: Trends, unadjusted for flow: P level	Trend-line slope: Milligrams per liter per year	Trend-line slope: Percent of median concentration (mg/L) per year	Flow-adjusted trends[2]: P level	Trend-line slope: Milligrams per liter per year	Trend-line slope: Percent of median concentration (mg/L) per year
Fluoride, dissolved										
2.0	North Fork Kentucky River at Jackson	1980-85	34	24*	0.842					
2.3	Middle Fork Kentucky River at Tallega	1980-85	34	24*	.579					
2.6	South Fork Kentucky River at Booneville	1980-85	34	24*	.579					
3.0	Kentucky River at Lock 14, at Heidelberg	1979-85	77	32*	.479					
3.1	Red River near Hazel Green	1979-85	75	32**	1.00					
5.0	Kentucky River at Camp Nelson	1980-85	65	28*	.114	-0.01	-5.0			
7.0	Kentucky River above Frankfort	1979-85	73	32*	.484					
9.0	Kentucky River below Frankfort	1979-85	72	32**	.852					
9.3	South Elkhorn Creek near Midway	1982-85	34	20	.663			0.522		
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101	44*	.751					
10.1	Eagle Creek at Glencoe	1976-85	87	44*	.032	<u>-.01</u>	<u>-6.7</u>			
Silica, dissolved										
2.0	North Fork Kentucky River at Jackson	1980-84	18	16	.401			1.00		
2.3	Middle Fork Kentucky River at Tallega	1980-83	17	16	1.00			.643		
2.6	South Fork Kentucky River at Booneville	1980-83	17	16	.643			.643		
3.0	Kentucky River at Lock 14, at Heidelberg	1979-83	22	24	.401					
3.1	Red River near Hazel Green	1979-80	19	12	.248			1.00		
7.0	Kentucky River above Frankfort	1979-80	15	12*	1.00					
9.0	Kentucky River below Frankfort	1979-80	14	12*	1.00					
9.3	South Elkhorn Creek near Midway	1982-84	17	12	1.00			1.00		
10.0	Kentucky River at Lock 2, at Lockport	1976-86	101	44	.086	<u>-.05</u>	<u>-.94</u>	.034	<u>-0.08</u>	<u>-1.5</u>
10.1	Eagle Creek at Glencoe	1976-80	27	24*	.773					

[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 (1) 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 (2) 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.

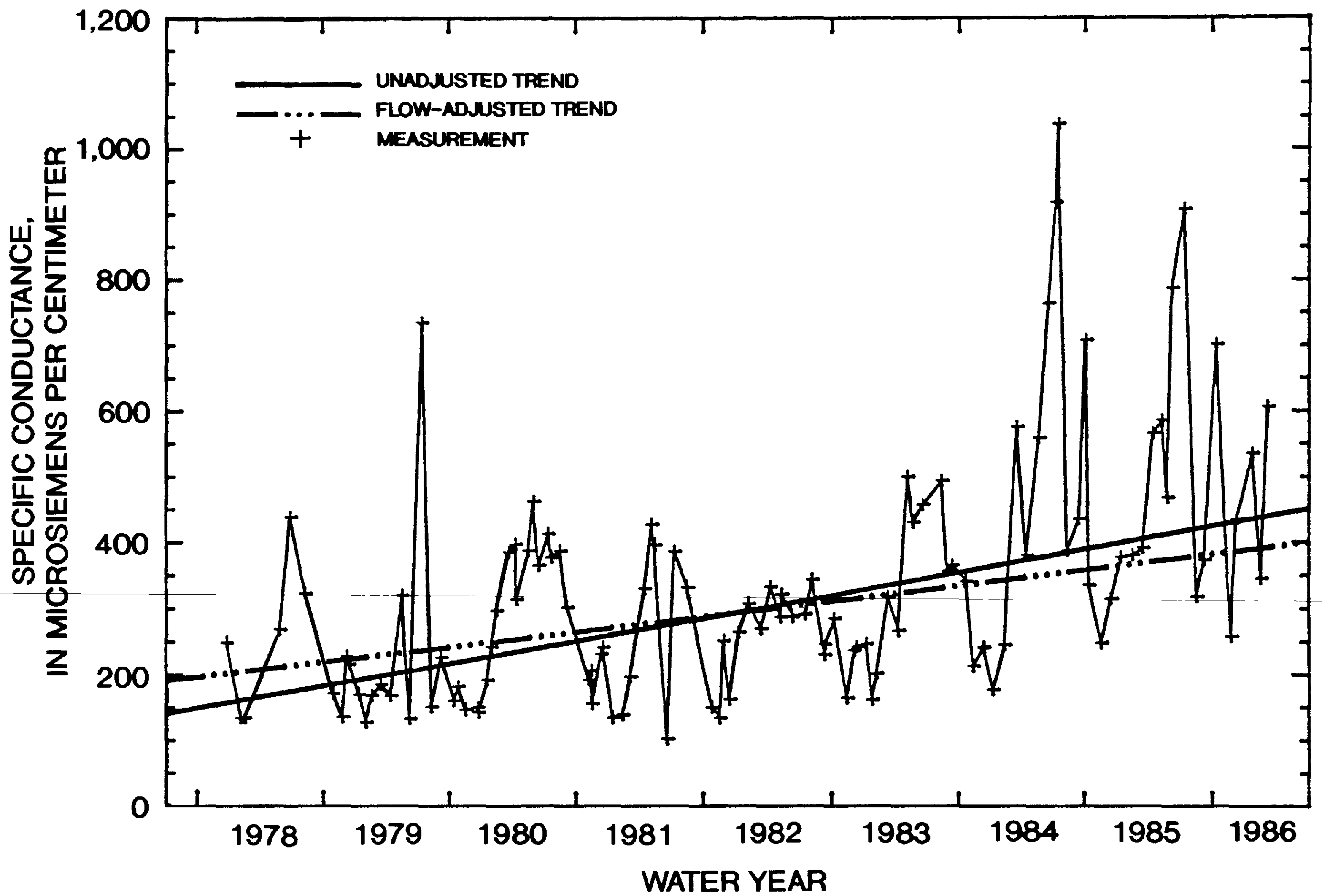


Figure 25.--Specific conductance for the Kentucky River at Lock 14, at Heidelberg (site 3.0), water years 1978-86.

Table 25.—*Mean milliequivalent ratios expressed as percent of total for major cations and anions in water samples from selected sites in the Kentucky River basin, based on available data for water years 1976-86*

[Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; SO_4, sulfate; Cl, chloride; CO_3, carbonate; HCO_3, bicarbonate. Milliequivalent ratios expressed as percentage of cations (Ca + Mg + Na + K) or anions (SO_4 + Cl + CO + HCO_3)]

Site number	USGS station name	Mean milliequivalent ratio: Percentage of cations: Ca	Mg	Na + K	Percentage of anions: SO_4	Cl	CO_3 + HCO_3
High Flow (upper 25-percent flow duration)							
0.2	Carr Fork near Sassafras	57.0	31.6	11.4	63.9	4.1	32.0
2.0	North Fork Kentucky River at Jackson	48.9	37.8	13.3	65.8	4.1	30.1
2.1	Middle Fork Kentucky River near Hyden	58.3	27.4	14.3	49.9	5.8	44.4
2.2	Cutshin Creek at Wooton	53.0	34.4	12.6	64.2	3.6	32.1
2.3	Middle Fork Kentucky River at Tallega	50.5	36.3	13.2	57.9	13.3	28.8
2.6	South Fork Kentucky River at Booneville	45.6	35.5	18.9	62.0	7.7	30.3
3.0	Kentucky River at Lock 14, at Heidelberg	41.8	41.0	17.1	57.3	10.2	32.5
3.1	Red River near Hazel Green	42.3	36.0	21.7	41.4	13.4	45.1
3.3	Red River at Clay City	44.8	27.3	27.8	19.0	16.8	64.2
5.0	Kentucky River at Camp Nelson	52.9	33.1	14.0	40.4	12.5	47.1
5.2	Dix River near Danville	73.0	21.5	5.5	17.4	3.5	79.0
10.0	Kentucky River at Lock 2, at Lockport	66.4	20.6	13.0	27.4	10.6	62.1
10.1	Eagle Creek at Glencoe	74.6	19.3	6.1	22.5	4.8	72.7
Low Flow (lower 25-percent flow duration)							
0.2	Carr Fork near Sassafras	48.4	30.5	21.1	49.7	4.1	46.2
2.0	North Fork Kentucky River at Jackson	48.2	33.4	18.4	66.8	5.4	27.7
2.1	Middle Fork Kentucky River near Hyden	62.0	25.7	12.3	48.4	5.2	46.4
2.2	Cutshin Creek at Wooton	51.2	24.1	24.7	47.9	10.2	42.0
2.3	Middle Fork Kentucky River at Tallega	51.5	32.9	15.5	50.9	8.8	40.3
2.6	South Fork Kentucky River at Booneville	38.0	28.1	33.9	47.3	24.5	28.2
3.0	Kentucky River at Lock 14, at Heidelberg	46.1	31.8	22.1	53.8	14.0	32.2
3.1	Red River near Hazel Green	54.9	29.1	16.1	20.3	11.2	68.5
3.3	Red River at Clay City	56.6	16.4	27.0	11.1	36.8	52.1
4.0	Kentucky River at Lock 10, near Winchester	50.6	30.1	19.3	51.4	13.0	35.6
5.0	Kentucky River at Camp Nelson	49.2	28.3	22.5	41.7	20.3	38.0
5.2	Dix River near Danville	54.8	32.8	12.4	15.7	8.6	75.7
10.0	Kentucky River at Lock 2, at Lockport	59.3	20.9	19.8	29.0	15.5	55.6
10.1	Eagle Creek at Glencoe	70.7	20.2	9.2	23.0	6.2	70.8

Calcium and magnesium are both essential elements for plant and animal life forms. Calcium is usually the dominate cation in most natural water, followed by magnesium (Hem, 1985). Concentrations of these constituents in the Kentucky River basin ranged from less than 0.01 to 323 mg/L for dissolved calcium and from less than 0.04 to 120 mg/L for dissolved magnesium. The data in table 20 indicate that elevated concentrations of dissolved calcium and magnesium occur in the North Fork Kentucky River at Jackson (site 2.0). However, the calcium and magnesium concentrations are diluted by water from other tributaries upstream of Lock 14 (site 3.0). This pattern is also seen in transport yields shown in table 23. The elevated yields in the North Fork Kentucky River at Jackson (site 2.0) are thought to be due to disturbances of calcium- and magnesium-bearing overburden during surface mining. These yields contrast sharply to those of the relatively undisturbed basin of the Red River near Hazel Green (site 3.1), even though geology of the basins is similar.

Yields of calcium in the main stem of the Kentucky River increase as the river flows into the limestone rich Bluegrass region. The increase of both dissolved and total calcium transport estimates upstream and downstream of Frankfort (sites 7.0 and 9.0, respectively) may be due to limestone quarry operations in that vicinity. The South Elkhorn Creek basin (site 9.3), in the Bluegrass region, where land use is predominantly urban and agricultural, contributes yields of total and dissolved calcium that are twice that of the Kentucky River (table 23).

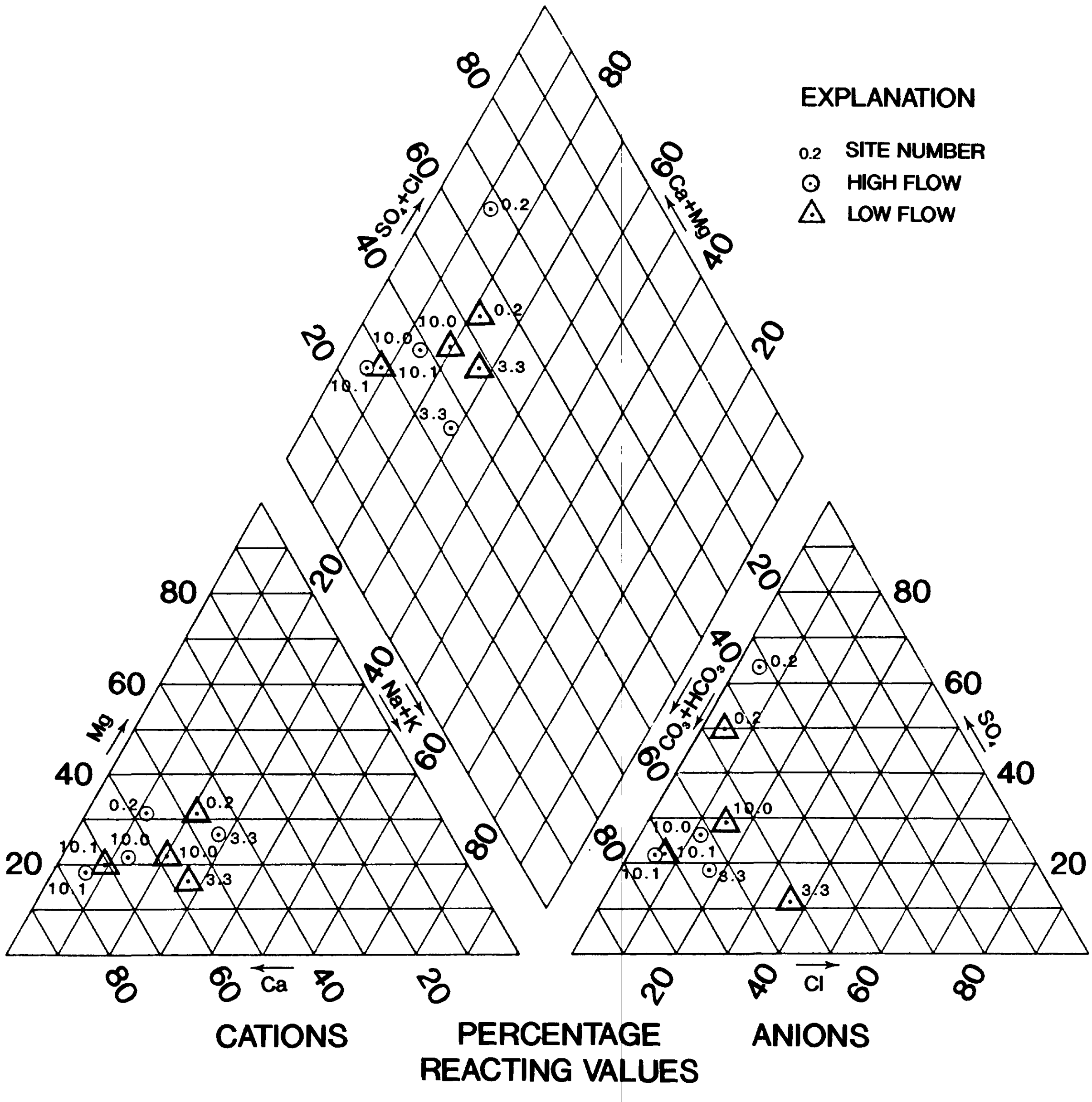


Figure 26.--Ionic composition of water from selected sites in the Kentucky River basin during high-and low-flow conditions, based on available data for water years 1976-86.

Table 26.—*Annual yields of selected constituents in atmospheric deposition and in surface runoff in the Kentucky River basin*

[Kentucky River loads based on data from Lock 2 near Lockport; atmospheric deposition loads based on National Atmospheric Deposition Program data from Perryville, Kentucky]

Source	Computation period	Yield of indicated constituent, in tons per square mile per year					
		Calcium	Magnesium	Potassium	Sodium	Sulfate	Chloride
Atmospheric deposition	1984-86 calendar years	0.354	0.066	0.060	0.214	5.67	0.399
Kentucky River basin	1983-85 water years	44.0	9.24	2.42	10.6	51.5	16.2

About one-third of the annual load of dissolved magnesium at Lock 2 (site 10.0) originates in the North Fork Kentucky River basin upstream of Jackson (site 2.0). In contrast, only about one-tenth of the annual dissolved calcium load originates upstream of Jackson. Less than one percent of the annual load of dissolved calcium and magnesium in the Kentucky River basin can be attributed to atmospheric deposition (table 26).

Statistically significant increasing trends were determined for both dissolved calcium and magnesium (table 24). The trend in calcium concentrations for the Kentucky River at Lock 2 (site 10.0) amounted to less than 2 percent per year. The magnesium trend amounted to 17 percent for the Kentucky River at Lock 14 (site 3.0) and 4 percent at Lock 2 (site 10.0). Flow adjustments to the concentrations accounted for little of the trend slope.

Sodium and Chloride

Sodium and chloride are ubiquitous in the water environment and their concentrations in natural water show considerable variation, regionally and locally. In addition to natural sources of these constituents, other sources include domestic sewage, industrial effluents, de-icing salts, and oil brines. Removal of sodium or chloride is costly and is not a common practice by the public water supply industry (U.S. Environmental Protection Agency, 1972).

A restricted sodium intake is recommended by physicians for individuals with certain health problems. Diets for these individuals may permit only 20 mg/L sodium in drinking water and water used for cooking (U.S. Environmental Protection Agency, 1972). However, neither Kentucky nor the U.S. Environmental Protection Agency have established a water-quality criterion for sodium. The Kentucky criteria for chloride are 250 mg/L for domestic-water supply (the same value for the Federal SMCL) and 600 mg/L for warmwater aquatic habitat.

Eleven sites in the basin had more than 10 observations of dissolved sodium or chloride (table 20). Sufficient chloride data are not available from the oil and gas areas of the basin to define the extent of brine effects (fig. 27). Figure 28 shows that median dissolved-chloride concentrations increase in the Kentucky River in the central part of the basin due to tributary flow draining the oil-producing areas (from 9.5 mg/L at Lock 14 (site 3.0) to 18 mg/L at Camp Nelson (site 5.0)).

Elevated dissolved-chloride concentrations related to wastewater discharges and possibly road salting are evident in South Elkhorn Creek (site 9.3) which receives wastewater and stormwater from the Lexington area (table 20). The median dissolved-chloride concentration of 41 mg/L and 90-percentile value of 81 mg/L from South Elkhorn Creek are the largest median and 90-percentile concentrations determined in streams draining large areas of the Kentucky River basin. Dissolved sodium and chloride concentrations ranged from less than 0.08 to 1,000 mg/L and less than 1 to 3,000 mg/L, respectively, in all samples collected during the period 1951-86. Less than 0.5 percent of the samples analyzed for chloride exceeded the 250 mg/L criterion.

Transport estimates of sodium and chloride for selected sites in the basin suggest several possible source areas for these constituents. Loads for both constituents at Lock 14 (site 3.0) on the Kentucky River are greater than the sum of the loads represented by the three upstream sites (2.0, 2.3, and 2.6) (table 23). These unaccounted for loads are thought to be from brine discharges associated with oil and gas production in the North Fork Kentucky River basin downstream from site 2.0 at Jackson. Additional inflow from areas of oil and gas production between Lock 14 (site 3.0) and the Kentucky River at Camp Nelson (site 5.0) contribute to the loads of sodium and chloride in the central part of the basin. The increase in the load of these constituents in the Kentucky River downstream from site 5.0 at Camp Nelson, is relatively small (table 23). As was seen with concentration, the yields of sodium and chloride at site 9.3 in the South Elkhorn Creek basin are greater than yields on the Kentucky River because of point- and nonpoint-source discharges from the Lexington area, but contribute little to the total basin loads. Again, as with several other constituents, the upper Red River basin near Hazel Green (site 3.1), which is largely unaffected by human activities, has small concentrations and yields of sodium.

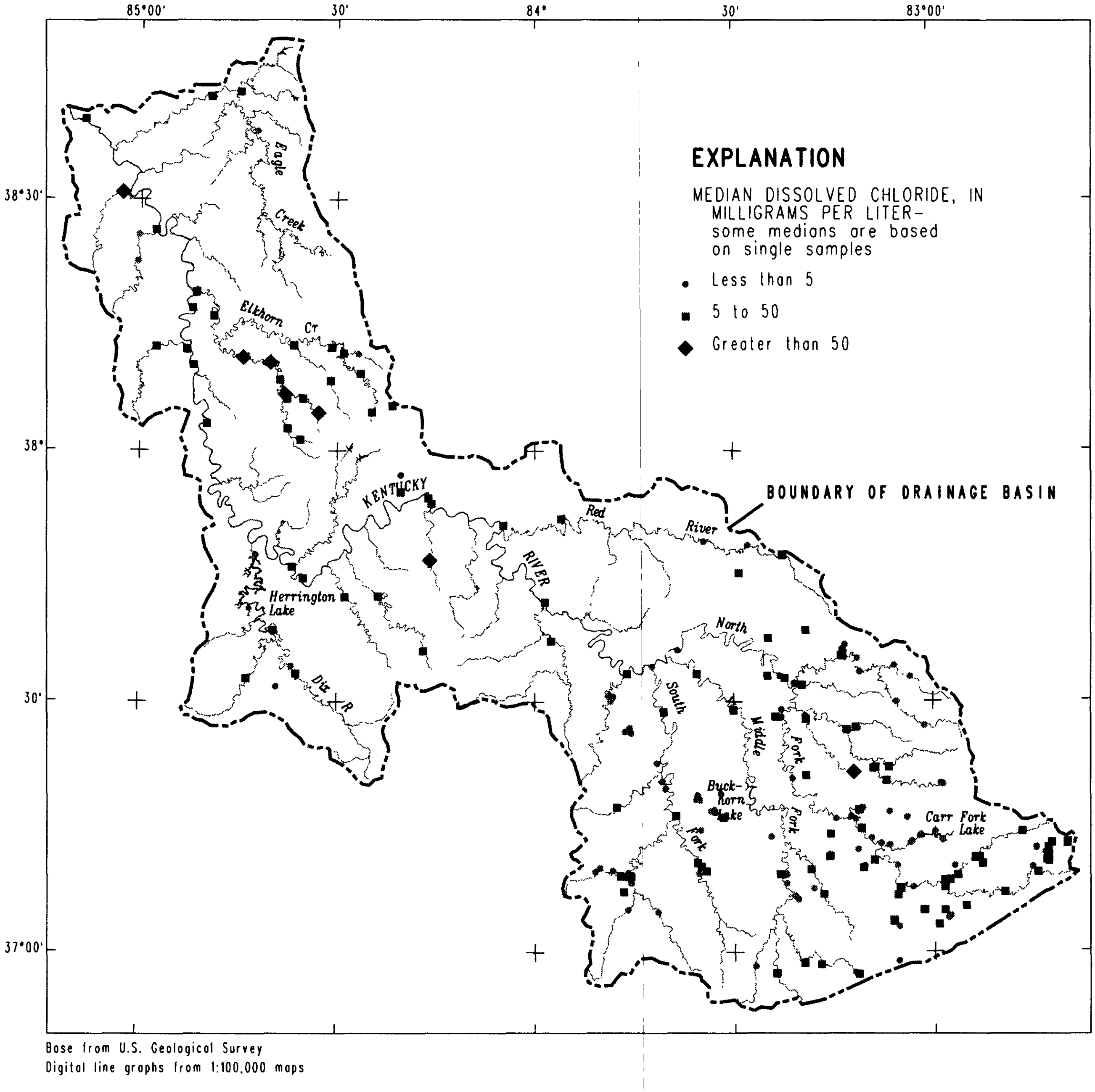


Figure 27.--Median concentrations of dissolved chloride at sites in the Kentucky River basin, through 1986.

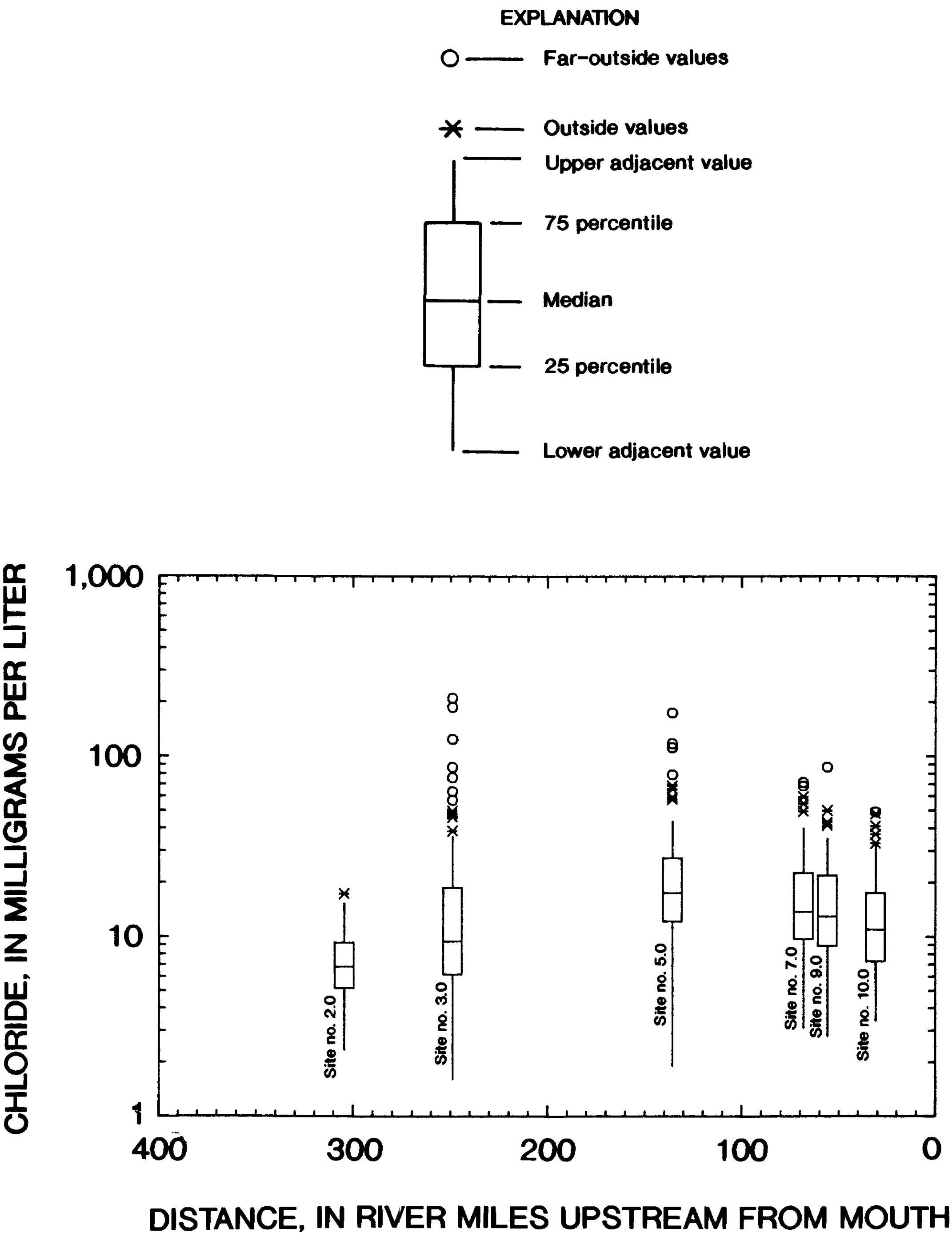


Figure 28.--Statistical summary of dissolved chloride concentrations at sites along the Kentucky River, based on available data for water years 1976-86.

About 2 percent of the annual load of dissolved sodium and chloride may originate from atmospheric deposition (table 26).

Significant increasing trends in dissolved-chloride concentrations were identified at all sites on the main stem from the Kentucky River at Lock 14 (site 3.0) downstream (table 24, fig. 29). These trends are due, in part, to decreasing trends in flow and an increase in oil and gas related brine discharges. The estimated flow-adjusted trend slope at Lock 14 (site 3.0) was greater than 30 percent per year based on available data for water years 1979-86 (table 24). This trend slope diminished downstream with effects of dilution but was constant in the more urbanized lower basin presumably due to a general increase in road-salting practices (Smith and others, 1987).

Figure 30 shows sodium-chloride, road-salt usage in Kentucky by the State highway districts. From 1980 to 1986, the increase in salt application averaged about 12 percent per year. About 20 percent of the total amount used was applied in the Kentucky River basin. Some additional road salt was applied by municipal road departments. Assuming that all road salt applied is carried into a stream, road salt might account for 11 percent of the chloride load estimated at Lock 2 (site 10.0) on the Kentucky River. In the Red River basin upstream of Hazel Green (site 3.1), which is not affected by sewage or oil-brine discharges, the trend in chloride concentration could be related to a trend in road-salt application.

Significant increasing trends in sodium were determined for three sites in the basin (table 24). Only 12 seasonal comparisons were possible for two of the three sites, which limits the extent of interpretation. However, a significant increasing trend in dissolved sodium concentration with a slope of about 8 percent per year was determined for the main stem of the Kentucky River at Lock 2 (site 10.0). Probable causes for the trend, as with chloride, could include increases in the release of oil and gas production brines and use of road salt.

Potassium

Potassium, an essential element for both plants and animals, is abundant in nature but seldom occurs in high concentrations in natural water (Hem, 1985). In the 11 sites in the basin that had 10 or more observations of dissolved potassium, median concentrations generally were less than 3 mg/L (table 20). In general, little spatial or downstream variability is reflected in either concentration or transport data. Slightly elevated values of both concentration and yield occur in streams affected by coal mining or sewage effluent discharges. Long-term trends presented in table 24, while statistically significant, are not conclusive due to different periods of record.

Sulfate

Sulfate is one of the oxidized forms of sulfur and is one of the major anions occurring in natural water. There are 2,137 analyses of dissolved sulfate and 1,368 analyses of total sulfate in the compiled "historical-record" data set for the Kentucky River basin. Dissolved sulfate concentrations ranged from less than 0.02 to 1,820 mg/L and total sulfate concentrations ranged from less than 0.1 to 1,000 mg/L. The Kentucky criterion for public water supply and the Federal secondary MCL for dissolved sulfate are 250 mg/L. About 3 percent of the analyses in the "historical-record" data set exceeded this criterion (table 21). Several small streams in the Eastern Coal Field region had dissolved sulfate concentrations exceeding this value (fig. 31). Few determinations of dissolved-sulfate concentration exceeded 250 mg/L for the Kentucky River or its major tributaries during the water years 1976-86.

The largest dissolved-sulfate concentrations in the basin are in streams draining the North Fork Kentucky River basin, which is intensively mined for coal (fig. 31 and table 20). Most of the effects of coal mining on downstream water chemistry relate either directly or indirectly to the acid-mine drainage that is produced during mining when earth-moving activities expose sulfides to accelerated weathering and oxidation. Concentrations decrease downstream of the North Fork on the Kentucky River due to dilution. Slightly elevated dissolved sulfate concentrations occurred at South Elkhorn Creek near Midway (site 9.3), which drains the extensively urbanized Lexington area.

Emissions of sulfur dioxide (SO_2) into the atmosphere increased by 48 percent from 1965 to 1970 in Kentucky, but remained relatively constant through 1980 (Smith and Alexander, 1983), when the State ranked fifth in the Nation in the quantity of SO_2 emissions. Smith and Alexander (1983) noted that trends in sulfate concentration of streams in undeveloped basins were generally consistent with trends in SO_2 emissions. Peters (1984) estimated that atmospheric deposition of sulfate upstream from the Kentucky River at Lock 2 totaled 11 percent of the stream yield of sulfate.

More than one-third of the load of dissolved sulfate computed for the Kentucky River at Lock 2 (site 10.0) originated in the North Fork basin upstream of site 2.0 at Jackson (table 23). The yield estimated for site 2.0 was nearly twice that of any other site listed in the table. Again, as with several other constituents, the measured concentrations and transport estimates for the upper Red River basin were low. Positive trends in sulfate concentrations were significant on all main stem Kentucky River sites with a lengthy period of record (table 24). The greatest trend magnitudes were computed for sites on streams in areas that have undergone increased coal production.

Bromide, Fluoride, and Silica

Bromine, fluoride, and silica commonly occur in natural water but usually in small concentrations. Bromine is present in natural water as the bromide ion. It is similar in chemical characteristics to the chlorine ion but is much less abundant. Manmade sources of bromide can be significant in many urbanized areas. The most frequent use of this element is as ethylene dibromide, a gasoline additive, but bromine compounds are also used in some fumigants and fire-retardant agents.

Bromide occurs naturally in brines which are present at depth in many parts of the basin. They may be released to surface water through seeps or springs and through the discharge of brines produced by the oil and gas industry.

Although water-quality criteria or drinking-water standards currently do not exist for bromide, its presence in water used for drinking-water supplies has been shown to play a key role in the development of brominated trihalomethane (THM) organic compounds which are hazardous to human health (Carswell and Symons, 1981). The only available bromide analyses for the Kentucky River basin were made in conjunction with the NURE program. Bromide concentrations in the samples collected in the basin ranged from 0.002 to 7.5 mg/L. The higher concentrations generally occurred in areas affected by brines from oil and gas production.

Fluoride has beneficial human health effects, but excessive fluoride in drinking-water supplies produces objectionable dental fluorosis (U.S. Environmental Protection Agency, 1972). The Federal MCL for fluoride is 4.0 mg/L. Concentrations of dissolved fluoride in the Kentucky River basin ranged from less than 0.20 to 3.70 mg/L during the period 1951-86. Two percent of observed concentrations in the basin exceeded the Kentucky domestic water supply criterion of 1.0 mg/L (table 21). The higher concentrations and yields of fluoride generally occurred in the South Elkhorn Creek basin downstream from the Lexington area (tables 20, 22, and 23). The elevated concentrations and yield may be due, in part, to the discharge of fluoridated drinking water and industrial sources. No major trends were determined from the data collected during the 1976-86 period.

Silica ranks next to oxygen in abundance in the Earth's crust. Degradation of silica-containing rocks results in the presence of silica in natural water as suspended particles, in colloidal or polymeric state, and as the silicate ion. A more complete discussion of silica chemistry in natural water is given in Hem (1985). The silica content of natural water is commonly in the 1 to 30 mg/L range, although concentrations as large as 100 mg/L are not unusual and concentrations exceeding 1,000 mg/L may occur in brackish water and brines. Silica in water is undesirable for a number of industrial users because it forms a difficult-to-remove scale on various forms of equipment. Concentrations of dissolved silica in the Kentucky River basin are summarized in table 20. Median concentrations determined at 10 sites ranged from 3.7 to 7.0 mg/L and are within the range for natural water. Yields of silica, although subject to considerable uncertainty, do not suggest any large sources (table 23). A slight decreasing trend was identified at the Kentucky River at Lock 2 (site 10.0) (table 24). The cause for this trend is undetermined.

Suspended Sediment

Suspended sediment may affect water quality in several ways: (1) streams with high suspended-sediment concentrations are aesthetically unsatisfactory for swimming and other recreation; (2) suspended-sediment particles are effective in sorbing and transporting some metals, pesticides and other organic compounds, and nutrients in streams; and (3) increases in sediment loads in streams can adversely affect the biological community of the streams. The quantity of natural sediments transported or available for transport from a drainage area by streams is affected by the form and intensity of precipitation and by other climatic conditions, character of the soil mantle, plant cover, topography, and land use in the drainage area.

Suspended-sediment concentrations from 3,098 analyses in the basin range from less than 1.0 to 18,000 mg/L. Concentrations of suspended sediment display a broad range throughout the study area (fig. 32). Suspended-sediment concentrations also indicate high variabilities from site to site (table 27). Suspended-sediment concentrations in the Kentucky River generally decrease in the pooled reaches downstream from the subbasins draining the Eastern Coal Field region, but then increase in downstream reaches due to drainage from agricultural areas of the Bluegrass region (fig. 33).

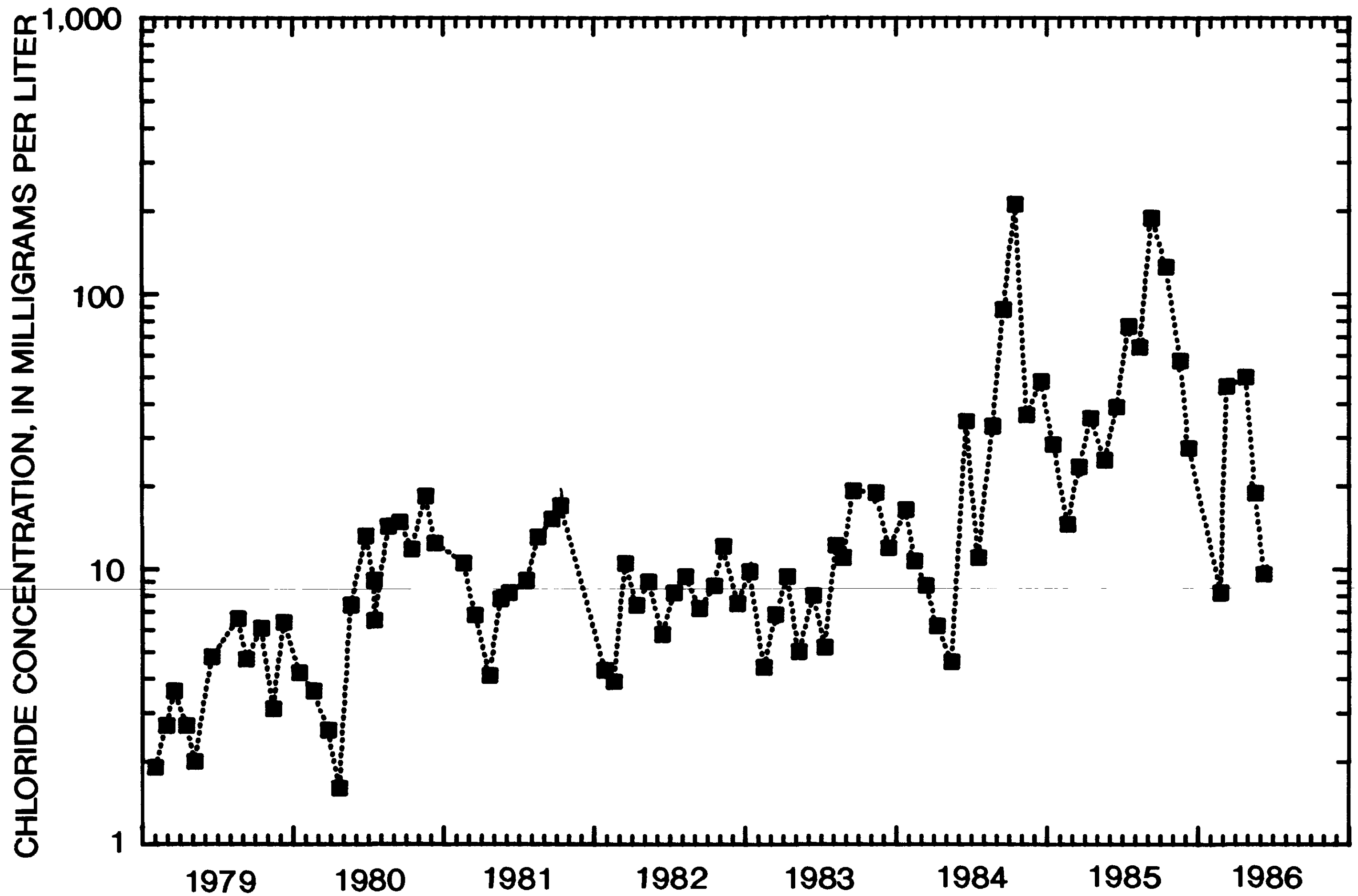


Figure 29.--Dissolved chloride concentrations for the Kentucky River at Lock 14, at Heidelberg (site 3.0), 1979-86.

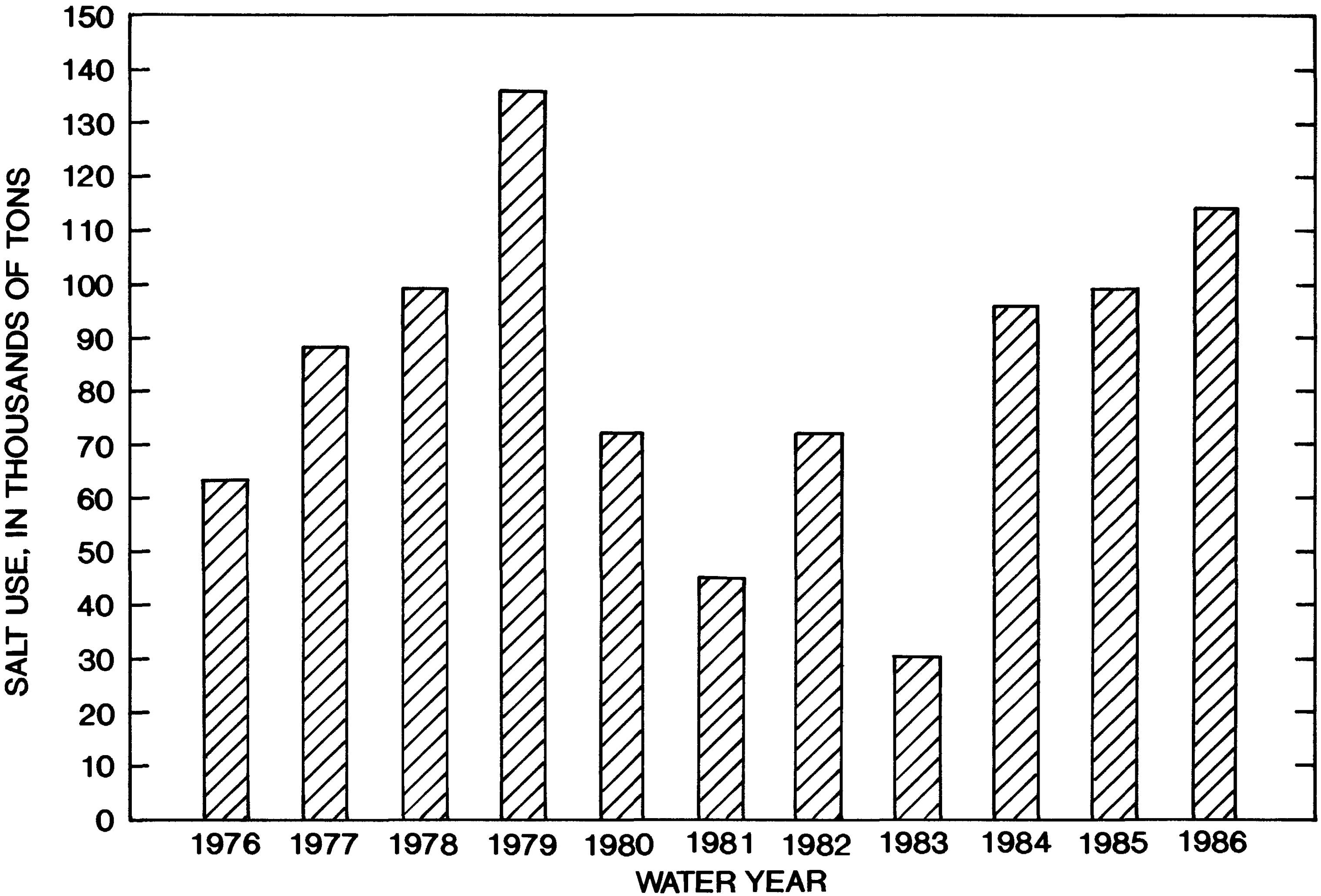


Figure 30.--Sodium chloride road salt usage in Kentucky, water years 1976-86.

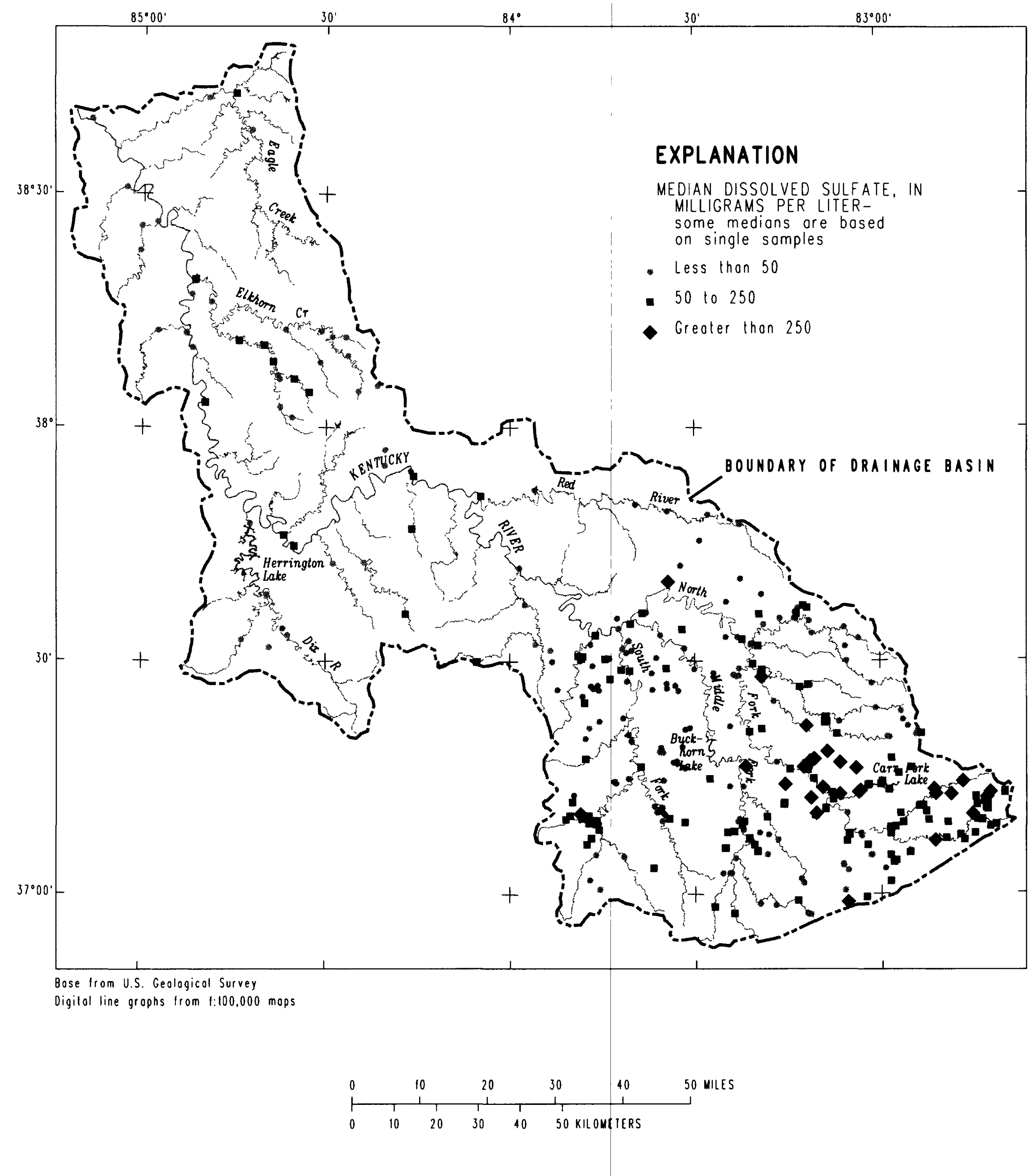


Figure 31.--Median concentrations of dissolved sulfate at sites in the Kentucky River basin, through 1986.

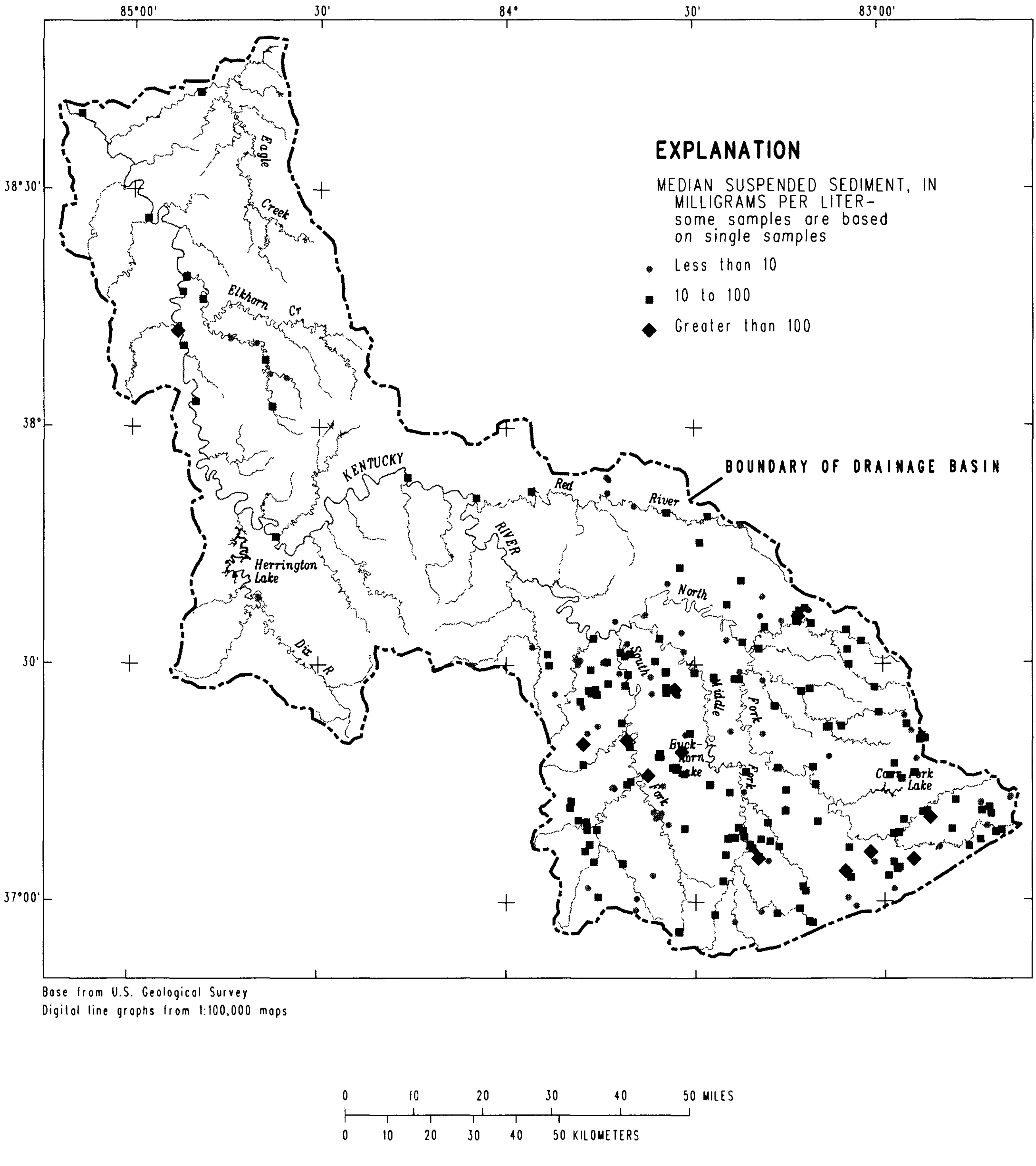


Figure 32.--Median concentrations of suspended sediment at sites in the Kentucky River basin, through 1986.

Table 27.—*Statistical summary of suspended-sediment concentrations for selected sites in the Kentucky River basin*

[N, number of observations; DL, detection limit. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL, in milligrams per liter	Concentration at indicated percentile, in milligrams per liter				
						10	25	50 (median)	75	90
0.1	Yonts Fork near Neon	1979-84	13				17	26	71	
1.0	North Fork Kentucky River at Hazard	1979-81	19				10	70	159	
1.1	Troublesome Creek at Noble	1977-81	17				17	30	47	
2.0	North Fork Kentucky River at Jackson	1976-86	61			7	15	27	82	406
2.1	Middle Fork Kentucky River near Hyden	1977-81	28				20	56	1,620	
2.3	Middle Fork Kentucky River at Tallega	1979-86	60	1	1.0	5	10	22	55	130
2.4	Red Bird River near Big Creek	1979-81	11				7	9	22	
2.5	Goose Creek at Manchester	1977-81	38			5	8	15	35	226
2.6	South Fork Kentucky River at Booneville	1979-86	60			4	6	12	34	54
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	90			6	9	18	61	192
3.1	Red River near Hazel Green	1978-86	116	1	1.0	6	8	17	33	120
3.2	Red River near Bowen	1978-83	70			3	4	9	25	63
3.3	Red River at Clay City	1979-86	10				8	24	81	
5.0	Kentucky River at Camp Nelson	1980-86	74			4	6	15	40	99
7.0	Kentucky River above Frankfort	1979-86	82			5	9	20	51	98
9.0	Kentucky River below Frankfort	1979-85	72			5	9	18	39	110
9.3	South Elkhorn Creek near Midway	1982-86	43			4	7	10	16	18
9.4	Elkhorn Creek near Frankfort	1977-81	34			4	7	15	34	97
10.0	Kentucky River at Lock 2, at Lockport	1976-85	83			11	21	37	100	234
10.1	Eagle Creek at Glencoe	1979-86	87	1	1.0	7	10	19	43	103

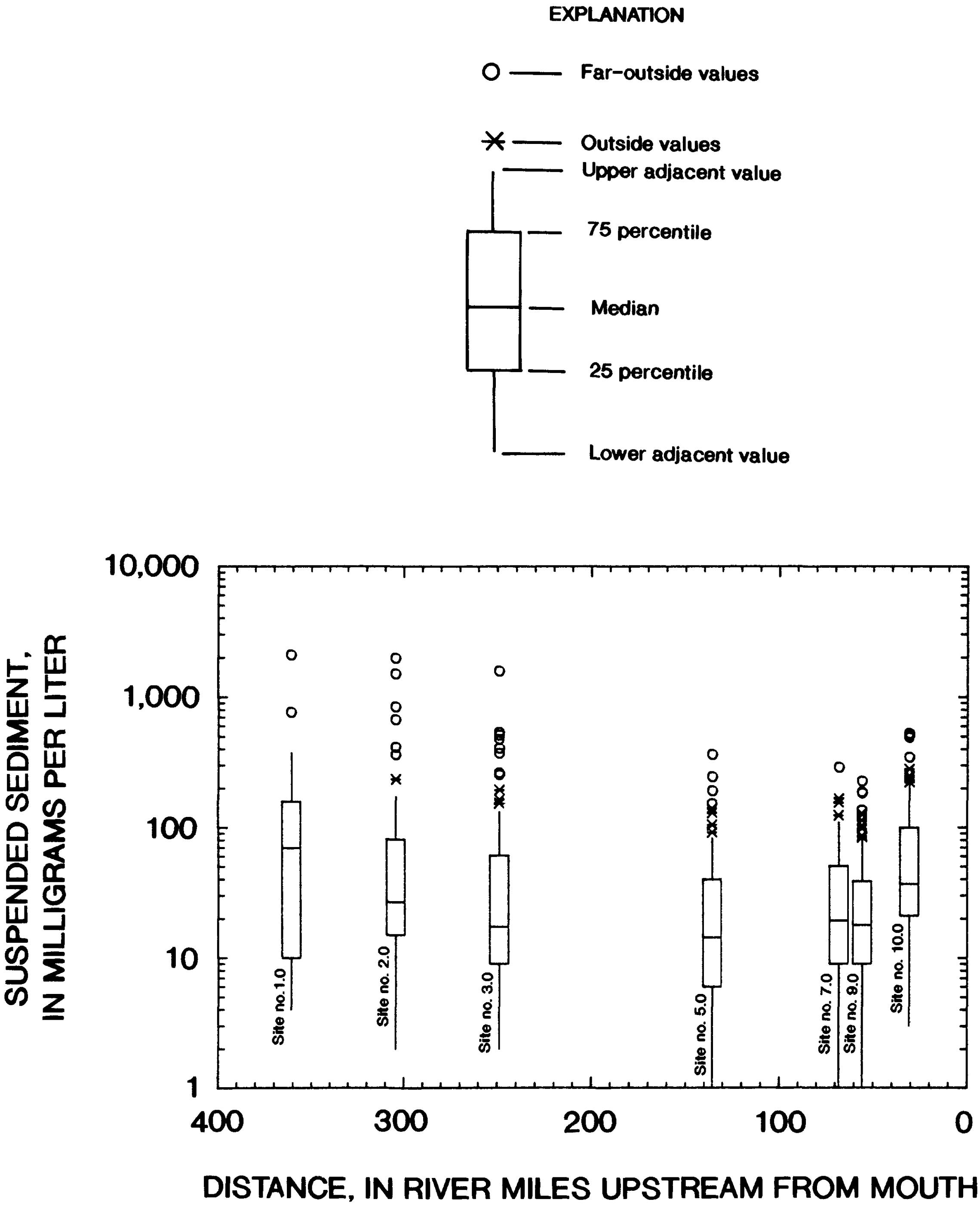


Figure 33.--Statistical summary of suspended-sediment concentrations at sites along the Kentucky River, based on available data for water years 1976-86.

Table 28.—*Average percentages of sand, silt, and clay in suspended sediment in streams in the Kentucky River basin*

[Flint, 1983]

Site number	USGS station name	Sediment composition, in percent		
		Sand	Silt	Clay
1.0	North Fork Kentucky River at Hazard	4	52	44
2.0	North Fork Kentucky River at Jackson	14	43	43
2.1	Middle Fork Kentucky River near Hyden	3	44	53
2.3	Middle Fork Kentucky River at Tallega	3	32	65
2.5	Goose Creek at Manchester	8	42	50
3.1	Red River near Hazel Green	1		
8.0	Kentucky River at Lock 4, at Frankfort	3	44	53
9.4	Elkhorn Creek near Frankfort	2	44	54
10.0	Kentucky River at Lock 2, at Lockport	3		
10.1	Eagle Creek at Glencoe	1	34	65

Approximately 90 percent of the suspended sediment transported in the basin is silt and clay (table 28). Flint (1983) suggested that land use is the most important factor affecting sediment transport in the Kentucky River basin. Large sediment yields in the coal regions of Kentucky would be expected because one of the most damaging effects of strip mining and associated forest cutting is soil erosion (Dyer, 1983).

Transport estimates for suspended sediment for selected sites in the Kentucky River basin are given in tables 29 and 30. Sediment yield estimates computed by Flint (1983) and presented in table 29 differ from those in table 30 in part because they represent different periods of data collection, and in part due to differences in computational methods. Transport estimates for selected sites for the period 1983-85 (table 30) may be subject to significant error due to limited sampling during high-flow conditions. For example, at the North Fork Kentucky River at Jackson (site 2.0) almost 80 percent of the sediment load was estimated beyond the range of sampled discharge during water years 1983-85. Therefore, the majority of the sediment load may have been transported by high flows that occurred less than 0.5 percent of the time, but there were no samples collected under these flow conditions for verification.

Although the methods and periods of record used to calculate the transport estimates differ, results from both transport estimate methods show a similar pattern. Based on the estimates from tables 29 and 30, the estimated sediment yield for the North Fork Kentucky River basin at Jackson (site 2.0), which has about 4 percent of the area disturbed by mining, is about 1,500 tons per square mile. In contrast, the estimated sediment yield of the headwater area of the Red River basin near Hazel Green (site 3.1), which has less than 0.1 percent of the area disturbed by mining, is only about 150 tons per square mile.

Two predominant types of agricultural land exist in the Kentucky River basin, pasture land and row-crop land. Minimal land disturbance is generally associated with pasture land. However, exposure of the soil to erosion during the cultivation of fields in row-crop agricultural areas can yield large quantities of sediment to nearby streams. Sediment yields from lands disturbed by row-crop cultivation generally are smaller than those from strip mining activities, but agricultural activities are more widespread. Sediment yield from the Eagle Creek basin, in which more than 50 percent of the land use is for mixed row-crop and pasture, was estimated by Flint (1983) to be about 1,100 tons per square mile (table 29).

Transport estimates indicate that approximately three-fourths of the suspended sediment load transported by the North Fork Kentucky River is deposited between Jackson (site 2.0) and Lock 14 at Heidelberg (site 3.0). The pool behind Lock 14 (site 3.0) on the Kentucky River is the most likely area for this deposition. The data in table 30 show that the amount of sediment transported past Lock 2 (site 10.0) on the main stem of the Kentucky River exceeded 650,000 tons annually which is only about one-half as much as the annual dissolved solids load transported past the site (table 23).

Flint (1983) estimated an annual suspended-sediment load from the basin of about 2 million tons per year. Gianessi (1986) estimated an annual load of suspended solids of about 20 million tons per year, however, this load was based on many assumptions and estimates. Suspended-sediment load estimates by the authors agree more closely with those by Flint.

Decreases in suspended-sediment concentrations occurred at 7 of the 11 sites during the 1976-86 period (table 31). At six of these sites showing trends, these decreases seem to be largely due to decreases in streamflow. However, the decrease in suspended-sediment concentrations of the Kentucky River at Lock 2 (site 10.0) apparently is due in part to factors other than decreasing streamflow.

Nutrients

Plants, including algae, require nitrogen, phosphorus, and potassium as well as trace amounts of other elements to grow. Forms of nitrogen in water include organic nitrogen, ammonia, nitrite, and nitrate. Of these forms, nitrate is usually predominant and most readily available for plant growth. Forms of phosphorus in water include the simple ionic orthophosphate and bound phosphate in soluble or particulate form. Bound phosphate may be released by bacterial action. Dissolved forms of nitrate and phosphate are more-readily available to plants. Consequently, their concentrations in natural water are usually relatively low. Potassium, a common constituent in streams, seldom limits plant growth.

Nutrient enrichment may encourage blooms of nuisance algae. Such phytoplankton blooms are common in lakes but are seldom seen in free-flowing streams. The effects of nutrient enrichment from agricultural practices and wastewater effluent seem to be reduced by increased stream turbidity from erosion and effluents (Wetzel, 1975).

Nitrogen

Some of the major point-source discharges of nitrogen into natural water are municipal and industrial wastewater, and feedlot runoff. Diffuse sources of nitrogen include fertilizers, leachate from waste disposed of in dumps or in landfills, atmospheric fallout, and natural sources such as mineralization of soil organic matter. Septic tanks are another significant diffuse source of nitrogen (U.S. Environmental Protection Agency, 1976).

High intake of nitrates can pose a hazard to warmblooded animals. Under certain conditions, nitrate can be reduced to nitrite in the gastrointestinal tract. Nitrite reaching the bloodstream reacts directly with hemoglobin, with a resulting impairment of oxygen transport (U.S. Environmental Protection Agency, 1976).

Smith and others (1987) reported that increases in atmospheric nitrogen emissions in the Ohio Valley region were consistent with stream nitrogen increases measured at NASQAN stations. However, these increases are also consistent with increased use of nitrogen compounds for agricultural purposes.

Data from the main stem of the Kentucky River indicate slightly increasing total-nitrogen concentrations from the headwater reaches to the mouth, but data are too limited to accurately develop cause and effect relations (fig. 34 and table 32). This increase is assumed due to increase in population density and agricultural activities in the lower part of the basin.

Kentucky's criterion for nitrate in water used for domestic-water supply has been set at 10 mg/L as N. The Federal MCL for nitrate is also set at this concentration, while a Federal MCL goal for nitrite has been proposed at 1.0 mg/L as N. Relatively few samples in the basin have been analyzed specifically for nitrate, but total nitrogen concentrations and nitrite plus nitrate concentrations indicate that nitrate concentrations probably are higher in South Elkhorn Creek which receives sewage and industrial effluents from the Lexington area than in other streams in the basin (table 32).

In this report, nitrogen data are in milligrams per liter as N, unless otherwise noted. However, because Federal and Kentucky water-quality criteria for ammonia are established for the un-ionized form of ammonia, the total ammonia concentrations reported in milligrams per liter as N were converted to total un-ionized ammonia concentrations in milligrams per liter as NH_3 using methods described in Snoeyink and Jenkins (1980) and Chemical Rubber Handbook (1983). The converted ammonia concentrations were then compared with the Federal and State criteria. About 2 percent of the 660 samples analyzed for ammonia throughout the basin during water years 1976-86 had concentrations that exceeded the Kentucky un-ionized warmwater aquatic habitat criterion of 0.05 mg/L. More than 20 percent of the samples collected from South Elkhorn Creek at Midway (site 9.3) exceeded this criterion (table 33).

The transport of nitrogen in the main stem of the Kentucky River increases downstream due, most likely, to inflow from urban and agricultural areas (table 34). The yields of all forms of nitrogen were greatest on South Elkhorn Creek at Midway (site 9.3) which receives sewage effluent. Transport estimates of ammonia and organic nitrogen by Gianessi (1986) indicate that about 4 percent of the annual load from the upper basin and as much as 21 percent of the total basin load may be from point sources.

Results of trend analyses of nitrogen concentrations for selected sites in the basin are given in table 35. No statistically significant trends in total nitrogen were identified based on available data for the period 1976-86. However, concentrations of total ammonia decreased at 6 of 11 sites while total nitrite plus nitrate concentrations increased at many of the same sites.

Table 29.—*Summary of sediment discharge for selected streams in the Kentucky River basin*

[Flint, 1983]

[tons/mi^2, tons per square mile; D, daily record; P, partial record]

Site number	USGS station name	Sediment record period	Record type	Sediment concentrations, in milligrams per liter		Sediment discharge, in tons per day		Annual suspended-sediment yield, in tons/mi^2
				low	high	low	high	
1.0	North Fork Kentucky River at Hazard	1979-81	D	2	640	0.11	3,400	75
1.1	Troublesome Creek at Noble	1977-81	P	6	623	.48	1,800	600
2.0	North Fork Kentucky River at Jackson	1979-81	D	2	4,660	.51	328,000	750
2.1	Middle Fork Kentucky River near Hyden	1976-81	D	1	3,010	0	126,000	600
2.3	Middle Fork Kentucky River at Tallega	1979-81	D	2	2,470	.15	52,100	260
2.5	Goose Creek at Manchester	1977-81	P,D	0	590	0	5,420	240
2.6	South Fork Kentucky River at Booneville	1979-81	D	2	668	.91	66,000	370
3.1	Red River near Hazel Green	1977-81	P	2	2,940	.05	2,140	150
8.0	Kentucky River at Lock 4, at Frankfort	1952-73	D	1	2,420	.53	420,000	370
9.4	Elkhorn Creek near Frankfort	1977-81	P	3	348	.62	10,900	115
10.0	Kentucky River at Lock 2, at Lockport	1973-81	P	7	529	1.3	154,000	220
10.1	Eagle Creek at Glencoe	1961-68	D	0	3,890	0	231,000	1,100

Table 30.—*Estimates of mean annual loads and mean annual yields for water years 1983-85 for suspended sediment for selected sites in the Kentucky River basin*

[N, number of observations; tons/mi^2, tons per square mile]

Site number	USGS station name	N	Mean annual load, in tons	Mean annual yield, in tons/mi^2	Standard error of regression	Flow duration of greatest sampled discharge, in percent	Percentage of load estimated beyond range of sampled discharge
2.0	North Fork Kentucky River at Jackson	61	1,630,000	1,480	114	0.5	78.2
2.3	Middle Fork Kentucky River at Tallega	60	71,500	133	95.8	0	0
2.6	South Fork Kentucky River at Booneville	60	124,000	172	92.5	.2	40.2
3.0	Kentucky River at Lock 14, at Heidelberg	90	466,000	175	109	.6	36.1
3.1	Red River near Hazel Green	116	8,730	133	169	.5	27.9
5.0	Kentucky River at Camp Nelson	74	873,000	197	101	1.3	45.9
7.0	Kentucky River above Frankfort	82	545,000	103	92.2	1.5	36.3
9.0	Kentucky River below Frankfort	72	583,000	108	93.1	4.6	55.7
9.3	South Elkhorn Creek near Midway	43	1,960	18.7	76.1	6.4	47.1
10.0	Kentucky River at Lock 2, at Lockport	83	652,000	105	67.3	0	0

Table 31.—*Trend test results for suspended-sediment concentrations for selected sites in the Kentucky River basin*

[N, number of observations; SC, number of seasonal comparisons; *, censored values used in analysis; P, probability; mg/L, milligrams per liter. Trend-line slopes not significant at 0.2 probability level are not reported, and those significant at the 0.1 probability level are underlined]

Site number	USGS station name	Period of record (water years)	N	SC	Results of seasonal Kendall tests for time trend[1]: Trends, unadjusted for flow: P level	Trend-line slope: Milligrams per liter per year	Trend-line slope: Percent of median concentration (mg/L) per year	Flow-adjusted trends[2]: P level	Trend-line slope: Milligrams per liter per year	Trend-line slope: Percent of median concentration (mg/L) per year
2.0	North Fork Kentucky River at Jackson	1976-86	61	44	0.061	-10	-32	0.312		
2.3	Middle Fork Kentucky River at Tallega	1979-86	60	32*	.021	-5.5	-20			
2.6	South Fork Kentucky River at Booneville	1979-86	60	32	.066	-4.0	-35	.867		
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	90	32	.156	-1.7	-11	.839		
3.1	Red River near Hazel Green	1978-86	116	36*	.445					
5.0	Kentucky River at Camp Nelson	1980-86	74	28	.933			1.00		
7.0	Kentucky River above Frankfort	1979-86	82	32	.047	-1.5	-7.3	.311		
9.0	Kentucky River below Frankfort	1979-85	72	32	.874			.582		
9.3	South Elkhorn Creek near Midway	1982-86	43	20	.004	-1.0	-11			
10.0	Kentucky River at Lock 2, at Lockport	1976-85	83	44	.000	-7.4	-17	.001	-5.6	-13
10.1	Eagle Creek at Glencoe	1979-86	87	32*	.637					

[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 (1) 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 (2) 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.

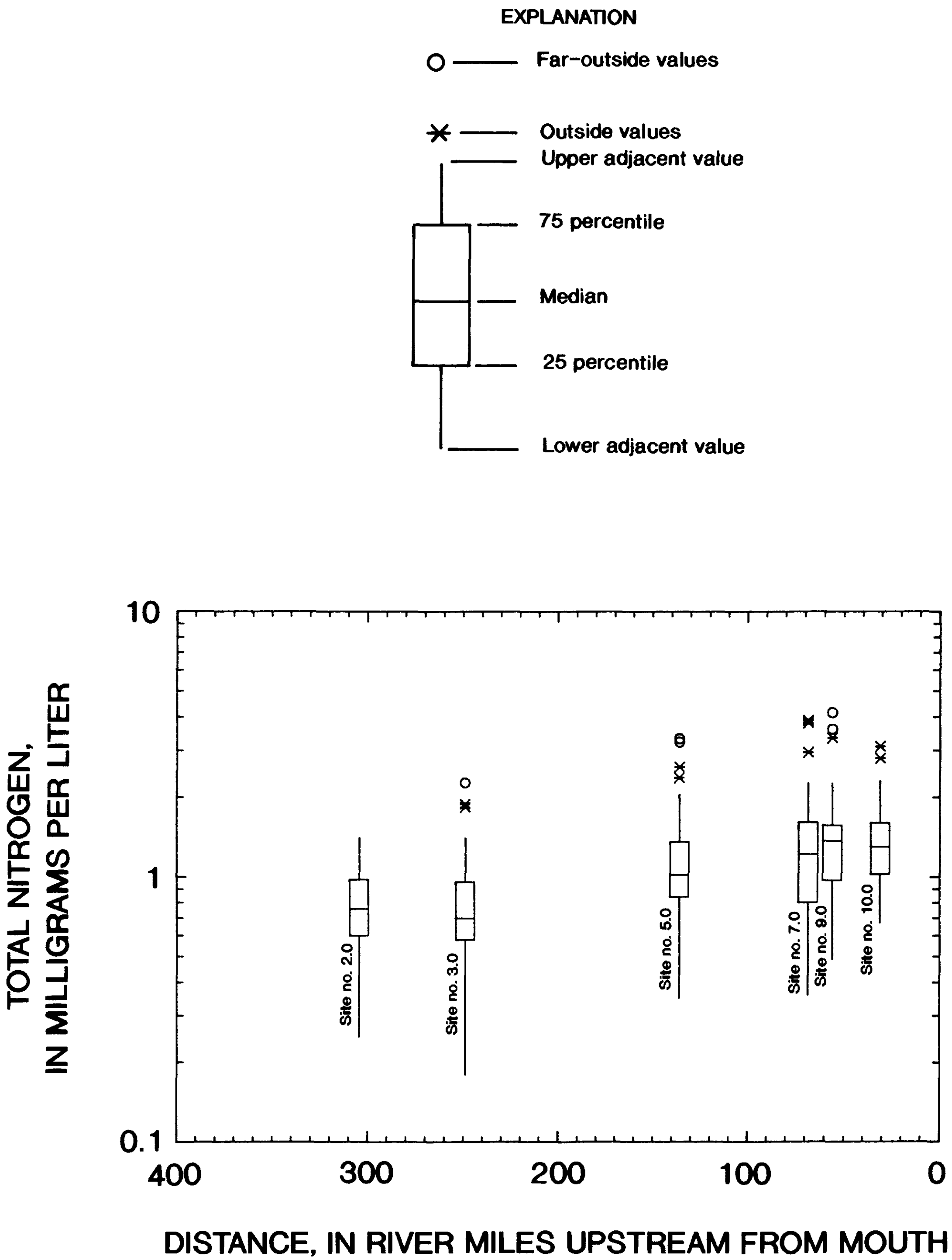


Figure 34.--Statistical summary of total nitrogen concentrations at sites along the Kentucky River, based on available data for water years 1976-86.

Table 32. —*Statistical summary of nutrient concentrations for selected sites in the Kentucky River basin*

[N, number of observations; DL, detection limit; *, value estimated from log-normal-fit program; <, less than.
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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL, in milligrams per liter	Concentration at indicated percentile, in milligrams per liter: 10	25	50 (median)	75	90
Nitrogen, total, as N										
2.0	North Fork Kentucky River at Jackson	1984-86	27				0.60	0.76	0.98	
2.3	Middle Fork Kentucky River at Tallega	1984-86	27				.27	.46	.57	
2.6	South Fork Kentucky River at Booneville	1984-86	24				.39	.52	.65	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	82			0.46	.58	.70	.96	1.2
3.1	Red River near Hazel Green	1979-86	81			.30	.46	.66	.87	1.4
5.0	Kentucky River at Camp Nelson	1980-86	74			.54	.84	1.0	1.4	1.9
7.0	Kentucky River above Frankfort	1979-86	82			.59	.80	1.2	1.6	2.0
9.0	Kentucky River below Frankfort	1979-85	73			.78	.97	1.4	1.6	1.9
9.3	South Elkhorn Creek near Midway	1984-86	22				7.2	9.3	12	
10.0	Kentucky River at Lock 2, at Lockport	1976-81	68			.90	1.0	1.3	1.6	1.9
10.1	Eagle Creek at Glencoe	1979-86	86			.55	.66	1.1	1.6	2.1
Nitrogen, dissolved, as N										
10.0	Kentucky River at Lock 2, at Lockport	1979-82	24				.87	1.2	1.6	
Nitrogen, nitrite plus nitrate, dissolved, as N										
2.0	North Fork Kentucky River at Jackson	1982-84	17	1	0.10		.19	.29	.50	
2.3	Middle Fork Kentucky River at Tallega	1982-83	16				.11	.14	.24	
2.6	South Fork Kentucky River at Booneville	1982-83	16	1	.10		.15	.32	.44	
9.3	South Elkhorn Creek near Midway	1982-84	17				2.7	3.8	4.4	
10.0	Kentucky River at Lock 2, at Lockport	1979-86	50	1	.10	.40	.73	.94	1.3	1.5
Nitrogen, nitrite plus nitrate, total, as N										
2.0	North Fork Kentucky River at Jackson	1980-86	28				.43	.51	.62	
2.3	Middle Fork Kentucky River at Tallega	1980-86	28				.14	.27	.35	
2.6	South Fork Kentucky River at Booneville	1980-86	27				.14	.30	.49	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	83			.09	.25	.34	.46	.55
3.1	Red River near Hazel Green	1979-86	83			.05	.18	.33	.45	.59
5.0	Kentucky River at Camp Nelson	1980-86	75			.27	.39	.54	.70	1.2
7.0	Kentucky River above Frankfort	1979-86	82			.13	.36	.68	.94	1.3
9.0	Kentucky River below Frankfort	1979-85	73			.29	.46	.72	.98	1.3
9.3	South Elkhorn Creek near Midway	1984-86	27				2.8	3.8	4.8	
10.0	Kentucky River at Lock 2, at Lockport	1976-82	71			.45	.63	.82	1.0	1.3
10.1	Eagle Creek at Glencoe	1979-86	86			.01	.05	.49	.74	1.3

Table 32. —*Statistical summary of nutrient concentrations for selected sites in the Kentucky River basin* —Continued

[N, number of observations; DL, detection limit; *, value estimated from log-normal-fit program; <, less than. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL, in milligrams per liter	Concentration at indicated percentile, in milligrams per liter: 10	25	50 (median)	75	90
Nitrogen, organic, total, as N										
10.0	Kentucky River at Lock 2, at Lockport	1978-86	42			0.19	0.27	0.38	0.55	0.79
Nitrogen, organic, dissolved, as N										
10.0	Kentucky River at Lock 2, at Lockport	1980-81	20				.11	.34	.40	
Nitrogen, ammonia, total, as N										
2.0	North Fork Kentucky River at Jackson	1984-86	27	20	0.05		.03	.04*	.05*	
2.3	Middle Fork Kentucky River at Tallega	1984-86	27	24	.05	.05	.05	.05	.05	.05
2.6	South Fork Kentucky River at Booneville	1984-86	25	22	.05		.02*	.03*	.04*	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	81	27	.05	.02*	.04*	.08	.12	.25
3.1	Red River near Hazel Green	1979-86	81	30	.05	.02*	.04*	.06	.12	.17
5.0	Kentucky River at Camp Nelson	1980-86	74	23	.05	.03*	.05*	.09	.16	.26
7.0	Kentucky River above Frankfort	1979-86	83	24	.05	.02*	.04*	.09	.16	.24
9.0	Kentucky River below Frankfort	1979-85	73	18	.05	.03*	.05*	.11	.18	.29
9.3	South Elkhorn Creek near Midway	1984-86	22				2.1	4.4	6.5	
10.0	Kentucky River at Lock 2, at Lockport	1978-86	48			.02	.03	.05	.08	.15
10.1	Eagle Creek at Glencoe	1979-86	86	27	.05	.02*	.04*	.08	.13	.23
Nitrogen, ammonia, dissolved, as N										
2.0	North Fork Kentucky River at Jackson	1982-84	17	2	.01		.01	.04	.06	
2.3	Middle Fork Kentucky River at Tallega	1982-83	16	3	.01		.01	.02	.04	
2.6	South Fork Kentucky River at Booneville	1982-83	16	3	.01		.01	.02	.06	
9.3	South Elkhorn Creek near Midway	1982-84	17				2.0	4.4	7.5	
10.0	Kentucky River at Lock 2, at Lockport	1980-86	49	2	.01	.01	.03	.05	.08	.12
Nitrogen, ammonia plus organic, dissolved, as N										
10.0	Kentucky River at Lock 2, at Lockport	1978-81	39	1	.10	.12	.19	.29	.42	.49
Nitrogen, ammonia plus organic, total, as N										
2.0	North Fork Kentucky River at Jackson	1982-86	44	2	.10	.10	.17	.31	.40	.68
2.3	Middle Fork Kentucky River at Tallega	1982-86	43	3	.05	.09	.16	.20	.40	.70
2.6	South Fork Kentucky River at Booneville	1982-86	40	4	.10	.07*	.12	.24	.40	.69
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	83			.17	.22	.37	.58	.90
3.1	Red River near Hazel Green	1979-86	81	1	.05	.09	.16	.35	.50	.84
5.0	Kentucky River at Camp Nelson	1980-86	74	1	.05	.23	.33	.46	.67	.97

Table 32.—*Statistical summary of nutrient concentrations for selected sites in the Kentucky River basin*—Continued

[N, number of observations; DL, detection limit; *, value estimated from log-normal-fit program; <, less than. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL, in milligrams per liter	Concentration at indicated percentile, in milligrams per liter: 10	25	50 (median)	75	90
Nitrogen, ammonia plus organic, total, as N–Continued										
7.0	Kentucky River above Frankfort	1979-86	83			0.25	0.37	0.46	0.66	0.98
9.0	Kentucky River below Frankfort	1979-85	73			.29	.39	.53	.70	.91
9.3	South Elkhorn Creek near Midway	1982-86	38			1.6	2.8	5.1	8.1	15
10.0	Kentucky River at Lock 2, at Lockport	1976-86	96			.29	.40	.50	.70	.99
10.1	Eagle Creek at Glencoe	1979-86	86			.27	.44	.64	.80	1.3
Phosphorus, total, as P										
2.0	North Fork Kentucky River at Jackson	1980-86	45			.01	.02	.03	.04	.14
2.3	Middle Fork Kentucky River at Tallega	1980-86	44	1	0.01	.01	.01	.02	.04	.06
2.6	South Fork Kentucky River at Booneville	1980-86	43	1	.01	.01	.01	.02	.04	.12
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	84			.01	.01	.03	.06	.16
3.1	Red River near Hazel Green	1979-86	83			.01	.02	.03	.05	.10
5.0	Kentucky River at Camp Nelson	1980-86	75			.03	.05	.07	.12	.24
7.0	Kentucky River above Frankfort	1979-86	83			.04	.06	.09	.13	.19
9.0	Kentucky River below Frankfort	1979-85	73			.07	.08	.12	.17	.21
9.3	South Elkhorn Creek near Midway	1982-86	43			.74	.98	1.5	2.1	3.4
10.0	Kentucky River at Lock 2, at Lockport	1976-86	100			.08	.10	.15	.22	.40
10.1	Eagle Creek at Glencoe	1976-86	94			.04	.06	.10	.15	.24
Phosphorus, dissolved, as P										
2.0	North Fork Kentucky River at Jackson	1982-84	17	4	.03		.01*	.02*	.05*	
2.3	Middle Fork Kentucky River at Tallega	1982-83	16	10	.01		< .01*	< .01*	.02	
2.6	South Fork Kentucky River at Booneville	1982-83	16	6	.01		.01*	.01	.04	
9.3	South Elkhorn Creek near Midway	1982-84	16				.96	1.4	2.0	
10.0	Kentucky River at Lock 2, at Lockport	1978-86	71			.04	.06	.08	.14	.18
Phosphorus, orthophosphate, dissolved, as P										
2.0	North Fork Kentucky River at Jackson	1982-84	16	10	.01		.01*	.01*	.01	
2.3	Middle Fork Kentucky River at Tallega	1982-83	15	14	.01		< .01	< .01	< .01	
2.6	South Fork Kentucky River at Booneville	1982-83	15	12	.01		< .01	< .01	< .01	
9.3	South Elkhorn Creek near Midway	1982-84	15				1.0	1.4	2.0	
10.0	Kentucky River at Lock 2, at Lockport	1982-86	24	1	.01		.05	.07	.12	

Table 33.—*Number of nutrient measurements made at selected sites in the Kentucky River basin and percentage not meeting indicated water-quality criteria, based on available data for water years 1976-86*

Site number	USGS station name	Number of measurements	Percentage not meeting Kentucky criteria for protection of warmwater aquatic habitat
Nitrogen, total un-ionized ammonia			
3.0	Kentucky River at Lock 14, at Heidelberg	78	1
9.0	Kentucky River below Frankfort	71	1
9.3	South Elkhorn Creek near Midway	22	23
10.1	Eagle Creek at Glencoe	83	1

Phosphorus

Phosphorus in streams is contributed from a number of sources, both natural and anthropogenic. Some of the more important of these are breakdown and erosion of phosphorus-bearing minerals in the soil, decaying plant and animal material, agricultural and domestic fertilizers, synthetic detergents, sewage effluents, and septic-tank leachates. Elevated concentrations of phosphorus are of concern because of the role this nutrient often plays in nuisance algal blooms. Of the major nutrients, phosphorus is most frequently determined to be limiting to plant growth.

Concentrations of naturally occurring dissolved phosphorus in streams of the United States are normally no more than a few tenths of a milligram per liter (Hem, 1985). For the 251 water samples in the Kentucky River basin, analyzed for dissolved phosphorus during the period 1951-86, concentrations ranged from 10 to 3,700 μg/L. In this report, phosphorus concentrations are reported in milligrams per liter as P, unless otherwise noted.

The higher total phosphorus concentrations in the Kentucky River basin were found in streams that receive sewage effluents (fig. 35 and table 32). Elevated total phosphorus concentrations occur throughout the study area, but predominately in the Bluegrass region which is underlain by phosphatic limestone. Agricultural and urban land uses are believed to be an additional causative factor for these elevated phosphorus concentrations. Data from the main stem of the Kentucky River indicate that total-phosphorus concentrations increase steadily from the headwater reaches to the river mouth (fig. 36).

The yield of phosphorus generally increases downstream (table 34). However, due to the probable large error associated with these transport estimates, as seen in the uncertainty factors, little detailed interpretation can be made. The elevated yield of total phosphorus in the North Fork Kentucky River at Jackson (site 2.0) may be associated with the elevated suspended-sediment yield (table 30) resulting from land disturbance and erosion related to coal mining in the basin. As with nitrogen yields, the yields of phosphorus from South Elkhorn Creek which receives sewage-effluent discharges were the largest in the basin. Transport estimates of total phosphorus by Gianessi (1986) indicate that less than 5 percent of the annual load from the upper basin but as much as 22 percent of the annual load from the entire basin may be from point sources.

Few long-term trends in total phosphorus concentration and no trends in dissolved phosphorus concentrations were identified in the Kentucky River basin for the period 1976-86. At South Elkhorn Creek (site 9.3), total phosphorus concentrations increased at an average rate of about 5 percent per year (table 35). Concentrations of total phosphorus at the Kentucky River at Lock 14 (site 3.0) decreased at an average rate of about 13 percent per year (table 35); however, the decrease in concentration per year was small. No other trends in phosphorus concentration were identified at sites on the main stem of the Kentucky River.

Table 34. —*Estimates of mean annual loads and mean annual yields for water years 1983-85 for nutrients for selected sites in the Kentucky River basin*

[N, number of observations; tons/mi², tons per square mile]

Site number	USGS station name	N	Mean annual load, in tons	Mean annual yield, in tons/mi²	Standard error of regression	Flow duration of greatest sampled discharge, in percent	Percentage of load estimated beyond range of sampled discharge
Nitrogen, total as N							
2.0	North Fork Kentucky River at Jackson	27	1,750	1.59	34.1	3.9	51.6
2.3	Middle Fork Kentucky River at Tallega	27	360	.670	48.0	1.7	13.0
2.6	South Fork Kentucky River at Booneville	24	646	.894	40.4	5.2	45.6
3.0	Kentucky River at Lock 14, at Heidelberg	82	3,040	1.14	42.0	.6	11.7
3.1	Red River near Hazel Green	81	70.4	1.07	55.7	.5	14.6
5.0	Kentucky River at Camp Nelson	74	7,560	1.71	45.3	1.3	15.3
7.0	Kentucky River above Frankfort	82	11,000	2.08	46.5	1.5	19.2
9.0	Kentucky River below Frankfort	73	9,960	1.84	36.9	4.6	30.0
9.3	South Elkhorn Creek near Midway	22	951	9.06	28.6	6.4	22.2
10.0	Kentucky River at Lock 2, at Lockport	68	13,500	2.18	26.0	0	0
Nitrogen, dissolved as N							
10.0	Kentucky River at Lock 2, at Lockport	24	22,200	3.58	34.2	2.7	19.0
Nitrogen, total organic as N							
10.0	Kentucky River at Lock 2, at Lockport	42	5,540	.897	46.8	0	0
Nitrogen, dissolved organic as N							
10.0	Kentucky River at Lock 2, at Lockport	20	1,970	.319	675	2.7	20.5
Nitrogen, ammonia, dissolved as N							
2.0	North Fork Kentucky River at Jackson	17	12.6	.011	115	7.9	23.6
2.3	Middle Fork Kentucky River at Tallega	16	11.6	.022	70.8	15.1	49.9
2.6	South Fork Kentucky River at Booneville	16	18.3	.025	116	7.2	31.7
9.3	South Elkhorn Creek near Midway	17	296	2.82	62.9	15.8	9.61
10.0	Kentucky River at Lock 2, at Lockport	49	490	.079	223	.4	2.76
Nitrogen, ammonia, total as N							
3.0	Kentucky River at Lock 14, at Heidelberg	81	244	.092	87.0	.6	10.2
3.1	Red River near Hazel Green	81	5.2	.079	82.1	.5	12.4
5.0	Kentucky River at Camp Nelson	74	448	.101	71.0	1.3	14.7
7.0	Kentucky River above Frankfort	83	674	.127	97.0	1.5	17.0
9.0	Kentucky River below Frankfort	73	459	.085	86.3	4.6	23.2
9.3	South Elkhorn Creek near Midway	22	398	3.79	39.4	6.4	7.54
10.0	Kentucky River at Lock 2, at Lockport	48	923	.149	164	0	0

Table 34. —*Estimates of mean annual loads and mean annual yields for water years 1983-85 for nutrients for selected sites in the Kentucky River basin* — Continued

[N, number of observations; tons/mi², tons per square mile]

Site number	USGS station name	N	Mean annual load, in tons	Mean annual yield, in tons/mi²	Standard error of regression	Flow duration of greatest sampled discharge, in percent	Percentage of load estimated beyond range of sampled discharge
Nitrogen, ammonia plus organic, dissolved as N							
10.0	Kentucky River at Lock 2, at Lockport	39	2,040	0.330	80.8	0.8	9.28
Nitrogen, ammonia plus organic, total as N							
2.0	North Fork Kentucky River at Jackson	44	741	.673	74.7	3.9	56.2
2.3	Middle Fork Kentucky River at Tallega	43	184	.343	111	1.7	9.67
2.6	South Fork Kentucky River at Booneville	40	208	.288	86.6	5.2	43.8
3.0	Kentucky River at Lock 14, at Heidelberg	83	1,470	.554	59.0	.6	14.3
3.1	Red River near Hazel Green	81	26.0	.395	91.2	.5	11.5
5.0	Kentucky River at Camp Nelson	74	2,830	.640	64.7	1.3	15.2
7.0	Kentucky River above Frankfort	83	3,590	.679	49.8	1.5	16.4
9.0	Kentucky River below Frankfort	73	2,920	.538	43.6	4.6	28.4
9.3	South Elkhorn Creek near Midway	38	445	4.24	50.5	6.4	7.46
10.0	Kentucky River at Lock 2, at Lockport	96	6,260	1.01	46.5	0	0
Nitrogen, nitrite plus nitrate, total as N							
2.0	North Fork Kentucky River at Jackson	28	1,010	.921	47.7	3.9	41.6
2.3	Middle Fork Kentucky River at Tallega	28	321	.597	77.1	1.7	15.0
2.6	South Fork Kentucky River at Booneville	27	1,190	1.64	69.2	5.2	63.0
3.0	Kentucky River at Lock 14, at Heidelberg	83	1,600	.601	74.3	.6	9.19
3.1	Red River near Hazel Green	83	84.2	1.28	161	.5	29.6
5.0	Kentucky River at Camp Nelson	75	4,720	1.07	61.5	1.3	14.5
7.0	Kentucky River above Frankfort	82	8,540	1.61	88.3	1.5	18.9
9.0	Kentucky River below Frankfort	73	9,180	1.69	68.4	4.6	33.9
9.3	South Elkhorn Creek near Midway	27	767	7.30	57.5	6.4	46.5
10.0	Kentucky River at Lock 2, at Lockport	71	8,940	1.45	34.3	0	0
Nitrogen, nitrite plus nitrate, dissolved as N							
2.0	North Fork Kentucky River at Jackson	17	861	.782	70.0	7.9	61.9
2.3	Middle Fork Kentucky River at Tallega	16	137	.255	44.6	15.1	64.0
2.6	South Fork Kentucky River at Booneville	16	492	.681	75.6	7.2	59.5
9.3	South Elkhorn Creek near Midway	17	456	4.34	70.5	15.8	71.5
10.0	Kentucky River at Lock 2, at Lockport	50	8,390	1.36	62.7	.4	4.03
Phosphorus, total as P							
2.0	North Fork Kentucky River at Jackson	45	224	.203	93.6	3.9	66.4
2.3	Middle Fork Kentucky River at Tallega	44	50.5	.094	98.5	1.7	22.0

Table 34. —*Estimates of mean annual loads and mean annual yields for water years 1983-85 for nutrients for selected sites in the Kentucky River basin* —Continued

[N, number of observations; tons/mi^2, tons per square mile]

Site number	USGS station name	N	Mean annual load, in tons	Mean annual yield, in tons/mi^2	Standard error of regression	Flow duration of greatest sampled discharge, in percent	Percentage of load estimated beyond range of sampled discharge
Phosphorus, total as P–Continued							
2.6	South Fork Kentucky River at Booneville	43	44.4	.062	103	5.2	45.9
3.0	Kentucky River at Lock 14, at Heidelberg	84	305	.115	103	.6	23.1
3.1	Red River near Hazel Green	83	4.3	0.065	143	0.5	16.6
5.0	Kentucky River at Camp Nelson	75	711	.161	71.9	1.3	15.4
7.0	Kentucky River above Frankfort	83	883	.167	58.6	1.5	17.2
9.0	Kentucky River below Frankfort	73	993	.183	46.7	4.6	30.4
9.3	South Elkhorn Creek near Midway	43	167	1.59	41.6	6.4	17.6
10.0	Kentucky River at Lock 2, at Lockport	100	1,640	.265	50.9	0	0
Phosphorus, dissolved as P							
2.0	North Fork Kentucky River at Jackson	17	12.3	.011	178	7.9	20.3
2.6	South Fork Kentucky River at Booneville	16	3.0	.004	110	7.2	10.9
9.3	South Elkhorn Creek near Midway	16	108	1.03	33.9	15.8	17.8
10.0	Kentucky River at Lock 2, at Lockport	71	707	.114	53.7	.4	3.85
Phosphorus, orthophosphate, dissolved as P							
9.3	South Elkhorn Creek near Midway	15	108	1.03	26.8	15.8	21.2
10.0	Kentucky River at Lock 2, at Lockport	24	735	.119	93.5	.4	2.55

Table 35. — *Trend test results for nutrient concentrations for selected sites in the Kentucky River basin*

[N, number of observations; SC, number of seasonal comparisons; P, probability; mg/L, milligrams per liter; *, censored values used in analysis; **, censored values affect trend analysis; decr., decreasing; incr., increasing. 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 reported only as increasing or decreasing]

					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	USGS station name	Period of record (water years)	N	SC	P level	Milligrams per liter per year	Percent of median concentration (mg/L) per year	P level	Milligrams per liter per year	Percent of median concentration (mg/L) per year
Nitrogen, total as N										
2.0	North Fork Kentucky River at Jackson	1984-86	27	12	0.245			0.245		
2.3	Middle Fork Kentucky River at Tallega	1984-86	27	12	1.00			.699		
2.6	South Fork Kentucky River at Booneville	1984-86	24	12	1.00			.699		
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	82	32	.574			.482		
3.1	Red River near Hazel Green	1979-86	81	32	.397			.107	-0.02	-3.2
5.0	Kentucky River at Camp Nelson	1983-86	74	28	.405			.617		
7.0	Kentucky River above Frankfort	1979-86	82	32	.499			.200	.05	4.6
9.0	Kentucky River below Frankfort	1979-85	73	32	.479			.387		
9.3	South Elkhorn Creek near Midway	1984-86	22	12	.245			1.00		
10.0	Kentucky River at Lock 2, at Lockport	1976-81	68	28	.214			.341		
10.1	Eagle Creek at Glencoe	1979-86	86	32	.946					
Nitrogen, dissolved as N										
10.0	Kentucky River at Lock 2, at Lockport	1979-82	24	12	.102	0.20	15			
Nitrogen, organic, total as N										
10.0	Kentucky River at Lock 2, at Lockport	1978-86	42	36	.206			.256		
Nitrogen, organic, dissolved as N										
10.0	Kentucky River at Lock 2, at Lockport	1980-81	20	12	.617					
Nitrogen, ammonia, dissolved as N										
2.0	North Fork Kentucky River at Jackson	1982-84	17	12**	1.00					
2.3	Middle Fork Kentucky River at Tallega	1982-83	16	12**	.480					
2.6	South Fork Kentucky River at Booneville	1982-83	16	12*	1.00					
9.3	South Elkhorn Creek near Midway	1982-84	17	12	1.00			1.00		
10.0	Kentucky River at Lock 2, at Lockport	1980-86	49	28*	.552					
Nitrogen, ammonia, total as N										
2.0	North Fork Kentucky River at Jackson	1984-86	27	12*	1.00					
2.3	Middle Fork Kentucky River at Tallega	1984-85	27	12*	1.00					
2.6	South Fork Kentucky River at Booneville	1984-86	25	12*	1.00					
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	81	32**	.000	decr.	decr.			
3.1	Red River near Hazel Green	1979-86	81	32**	.004	decr.	decr.			
5.0	Kentucky River at Camp Nelson	1980-86	74	28**	.000	decr.	decr.			
7.0	Kentucky River above Frankfort	1979-86	83	32**	.016	decr.	decr.			

Table 35.—*Trend test results for nutrient concentrations for selected sites in the Kentucky River basin*—Continued

[N, number of observations; SC, number of seasonal comparisons; P, probability; mg/L, milligrams per liter; *, censored values used in analysis; **, censored values affect trend analysis; decr., decreasing; incr., increasing. 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 reported only as increasing or decreasing]

Site number	USGS station name	Period of record (water years)	N	SC	Trends, unadjusted for flow: P level	Trends, unadjusted for flow: Trend-line slope, Milligrams per liter per year	Trends, unadjusted for flow: Trend-line slope, Percent of median concentration (mg/L) per year	Flow-adjusted trends[2]: P level	Flow-adjusted trends[2]: Trend-line slope, Milligrams per liter per year	Flow-adjusted trends[2]: Trend-line slope, Percent of median concentration (mg/L) per year
					Results of seasonal Kendall tests for time trend[1]					
Nitrogen, ammonia, total as N–Continued										
9.0	Kentucky River below Frankfort	1979-85	73	32*	0.064	-0.02	-15			
9.3	South Elkhorn Creek near Midway	1984-86	22	12	.245			1.00		
10.0	Kentucky River at Lock 2, at Lockport	1978-86	48	36	.021	.01	26			
10.1	Eagle Creek at Glencoe	1979-86	86	32**	.000	decr.	decr.			
Nitrogen, ammonia plus organic, dissolved as N										
10.0	Kentucky River at Lock 2, at Lockport	1978-81	39	20*	.704					
Nitrogen, ammonia plus organic, total as N										
2.0	North Fork Kentucky River at Jackson	1982-86	44	20*	.315					
2.3	Middle Fork Kentucky River at Tallega	1982-86	43	20*	.382					
2.6	South Fork Kentucky River at Booneville	1982-86	40	20*	.600					
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	83	32	.068	-.03	-7.8	.183	-0.01	-3.2
3.1	Red River near Hazel Green	1979-86	81	32*	.035	-.03	-8.8			
5.0	Kentucky River at Camp Nelson	1980-86	74	28*	.025	-.06	-13			
7.0	Kentucky River above Frankfort	1979-86	83	32	.223			.380		
9.0	Kentucky River below Frankfort	1979-85	73	32	.178	-.03	-6.4	.155	-.04	-6.8
9.3	South Elkhorn Creek near Midway	1982-86	38	20	.745			1.00		
10.0	Kentucky River at Lock 2, at Lockport	1976-86	96	44	.006	.02	3.1	.009	.02	3.9
10.1	Eagle Creek at Glencoe	1979-86	86	32	.839					
Nitrogen, nitrite plus nitrate, total as N										
2.0	North Fork Kentucky River at Jackson	1980-86	28	24	.743			.743		
2.3	Middle Fork Kentucky River at Tallega	1980-86	28	24	1.00			1.00		
2.6	South Fork Kentucky River at Booneville	1980-86	27	24	.743			1.00		
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	83	32	.002	.03	9.1	.014	.03	8.4
3.1	Red River near Hazel Green	1979-86	83	32	.360			.325		
5.0	Kentucky River at Camp Nelson	1980-86	75	28	.678			1.00		
7.0	Kentucky River above Frankfort	1979-86	82	32	.036	.06	8.5	.009	.07	9.3
9.0	Kentucky River below Frankfort	1979-85	73	32	.003	.06	7.8	.002	.08	11
9.3	South Elkhorn Creek near Midway	1984-86	27	12	.699			.699		
10.0	Kentucky River at Lock 2, at Lockport	1976-82	71	28	.043	.04	5.1			
10.1	Eagle Creek at Glencoe	1979-86	86	32	.892					
Nitrogen, nitrite plus nitrate, dissolved as N										
2.0	North Fork Kentucky River at Jackson	1982-84	17	12**	.248					
2.3	Middle Fork Kentucky River at Tallega	1982-83	16	12	1.00			.480		
2.6	South Fork Kentucky River at Booneville	1982-83	16	12*	.480					
9.3	South Elkhorn Creek near Midway	1982-84	17	12	1.00			1.00		
10.0	Kentucky River at Lock 2, at Lockport	1979-86	50	28*	.427					

Table 35. — *Trend test results for nutrient concentrations for selected sites in the Kentucky River basin* — Continued

[N, number of observations; SC, number of seasonal comparisons; P, probability; mg/L, milligrams per liter; *, censored values used in analysis; **, censored values affect trend analysis; decr., decreasing; incr., increasing. 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 reported only as increasing or decreasing]

Site number	USGS station name	Period of record (water years)	N	SC	Results of seasonal Kendall tests for time trend[1]: Trends, unadjusted for flow: P level	Trend-line slope: Milligrams per liter per year	Trend-line slope: Percent of median concentration (mg/L) per year	Flow-adjusted trends[2]: P level	Trend-line slope: Milligrams per liter per year	Trend-line slope: Percent of median concentration (mg/L) per year
Phosphorus, total as P										
2.0	North Fork Kentucky River at Jackson	1980-86	45	24	0.272					
2.3	Middle Fork Kentucky River at Tallega	1980-86	44	24*	.230					
2.6	South Fork Kentucky River at Booneville	1980-86	43	24*	.007	-0.01	-50			
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	84	32	.044	-.01	-17	0.060	0.00	-13
3.1	Red River near Hazel Green	1979-86	83	32	.599			.826		
5.0	Kentucky River at Camp Nelson	1980-86	75	28	.091	-.01	-13	.355		
7.0	Kentucky River above Frankfort	1979-86	83	32	.245			.403		
9.0	Kentucky River below Frankfort	1979-85	73	32	.874			.577		
9.3	South Elkhorn Creek near Midway	1982-86	43	20	.328			.023	.08	4.8
10.0	Kentucky River at Lock 2, at Lockport	1976-86	100	44	.966			.835		
10.1	Eagle Creek at Glencoe	1976-86	94	44	.864					
Phosphorus, dissolved as P										
2.0	North Fork Kentucky River at Jackson	1982-84	17	12*	1.00					
2.3	Middle Fork Kentucky River at Tallega	1982-83	16	12*	1.00					
2.6	South Fork Kentucky River at Booneville	1982-83	16	12**	.480					
9.3	South Elkhorn Creek near Midway	1982-84	16	12	1.00			.248		
10.0	Kentucky River at Lock 2, at Lockport	1978-86	71	36	.678					
Phosphorus, orthophosphate, dissolved as P										
2.0	North Fork Kentucky River at Jackson	1982-84	16	12**	1.00					
2.3	Middle Fork Kentucky River at Tallega	1982-83	15	12*	1.00					
2.6	South Fork Kentucky River at Booneville	1982-83	15	12**	1.00					
9.3	South Elkhorn Creek near Midway	1982-84	15	12	1.00			.248		
10.0	Kentucky River at Lock 2, at Lockport	1982-86	24	20*	1.00					

[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 (1) 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 (2) 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.

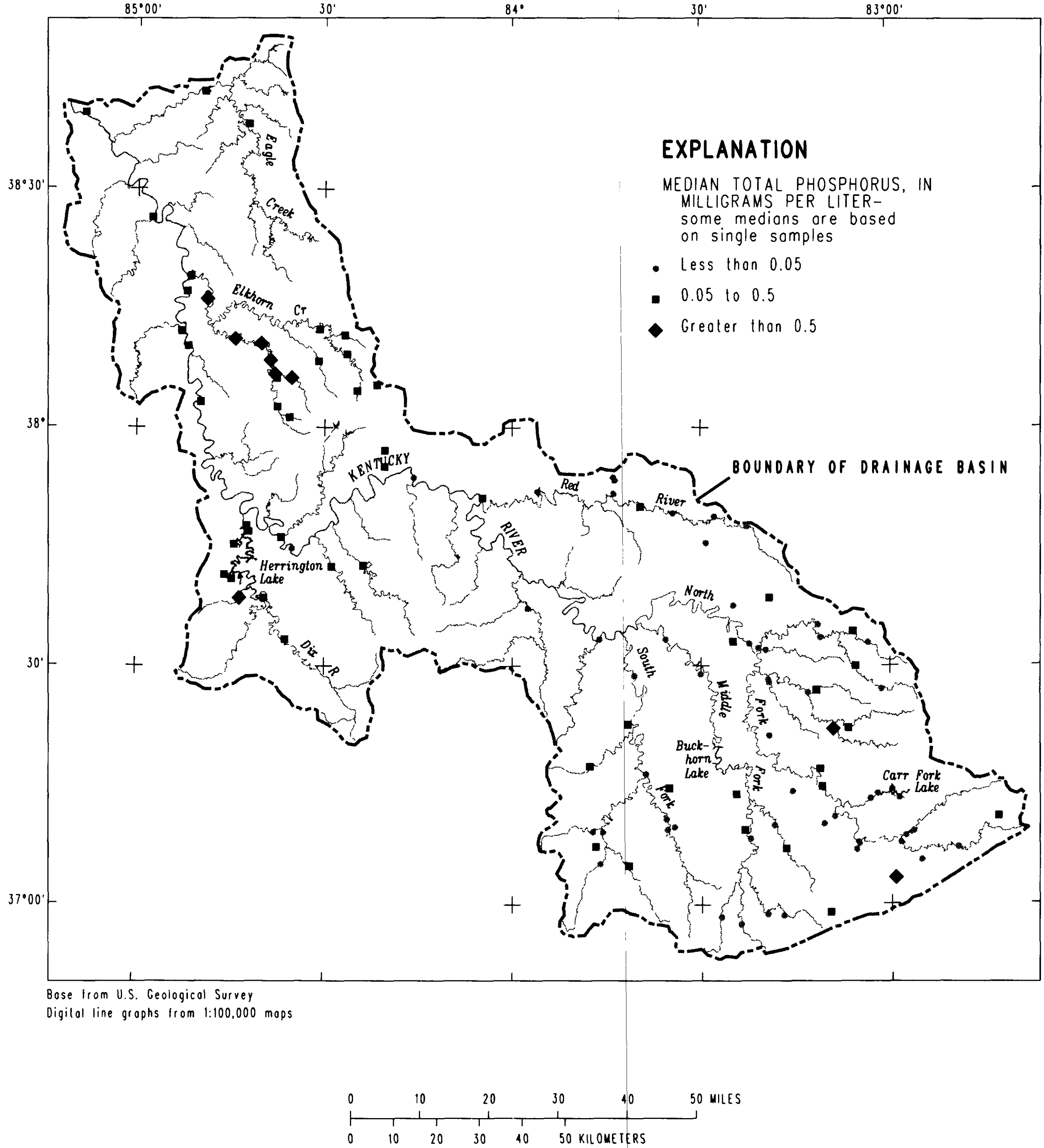


Figure 35.--Median concentrations of total phosphorus at sites in the Kentucky River basin, through 1986.

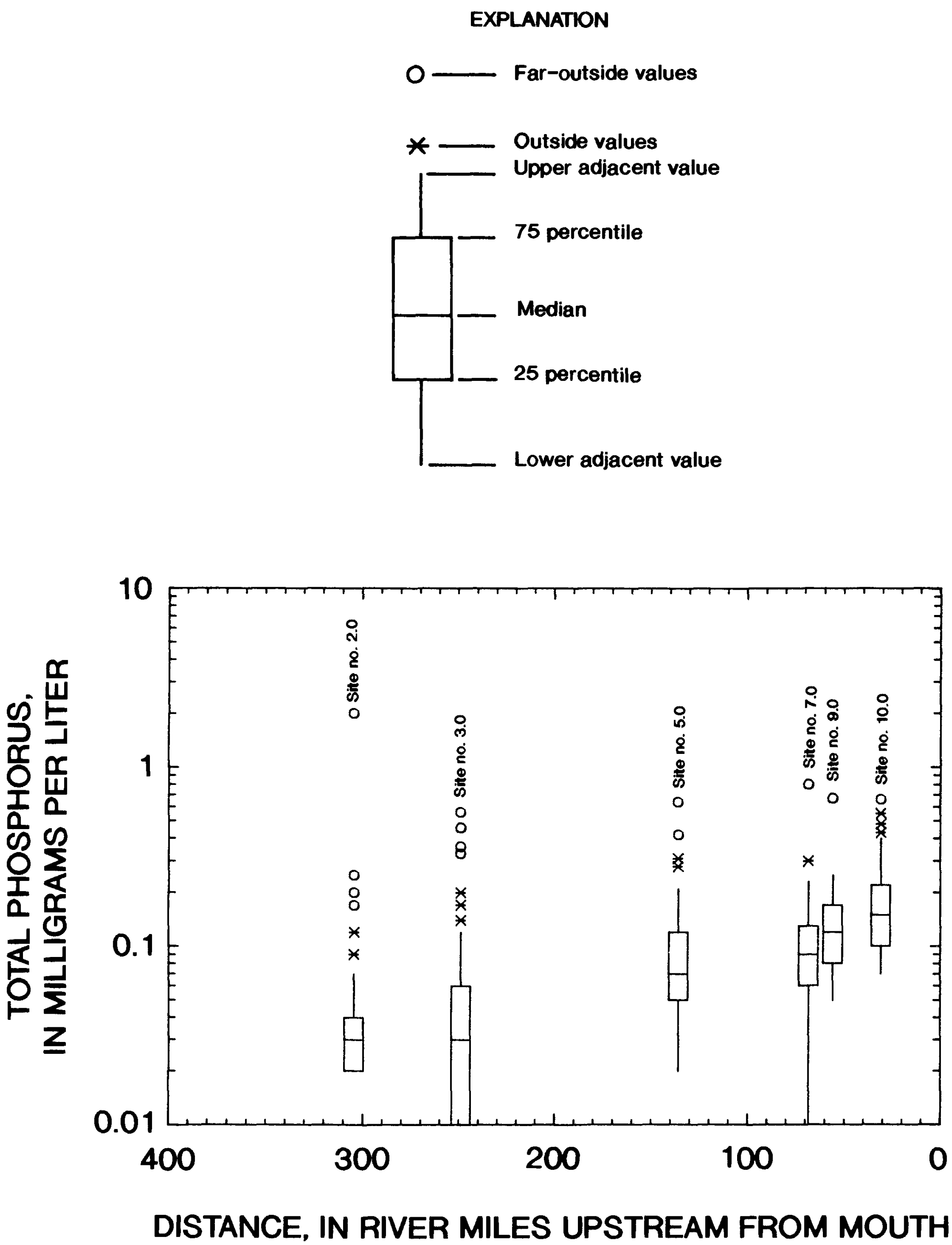


Figure 36.--Statistical summary of total phosphorus concentrations at sites along the Kentucky River, based on available data for water years 1976-86.

Table 36.—*Statistical summary of dissolved-oxygen concentrations for selected sites in the Kentucky River basin*

[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	USGS station name	Period of record (water years)	Concentration at indicated percentile, in milligrams per liter: 10	25	50 (median)	75	90
2.0	North Fork Kentucky River at Jackson	1982-84		7.7	8.3	12	
2.3	Middle Fork Kentucky River at Tallega	1982-83		6.8	8.0	12	
2.6	South Fork Kentucky River at Booneville	1982-83		6.6	7.7	12	
9.3	South Elkhorn Creek near Midway	1982-84		3.0	4.3	8.3	
10.0	Kentucky River at Lock 2, at Lockport	1980-86	6.5	7.7	9.0	11	12

Dissolved Oxygen

Fish and other desirable clean-water organisms require dissolved oxygen to survive and propagate. A minimum dissolved-oxygen concentration of 4.0 mg/L is required in Kentucky to ensure conditions for the maintenance of a well-balanced, warmwater-fish community (Kentucky Natural Resources and Environmental Protection Cabinet, 1985b).

Dissolved-oxygen concentrations of streams and rivers may vary significantly over time and space in response to several environmental processes. Oxygen solubility in water is a function of temperature and atmospheric pressure. At 10 °C, water is saturated with oxygen when it contains about 11.3 mg/L of dissolved oxygen. At 30 °C, water is saturated with oxygen when it contains about 7.6 mg/L of dissolved oxygen. Thus, dissolved-oxygen concentrations in streams are typically lower during the summer than during the winter. Oxygen in rivers is consumed during bacterial decomposition of organic matter, oxidation of ammonia and nitrite by nitrifying bacteria (nitrification), and respiration of aquatic organisms. Oxygen is replenished in natural water primarily by diffusion of oxygen into the water from the atmosphere and by photosynthesis. Atmospheric diffusion cannot result in dissolved-oxygen concentrations greater than the saturation concentration (the concentration of oxygen in the water that is in equilibrium with the oxygen concentration in the atmosphere). During summer months, when streamflows are low and water temperatures are high, the dissolved-oxygen concentrations of streams can be depleted by high organic loadings. The seasonal pattern of dissolved-oxygen concentration for the Kentucky River at Lock 2 (site 10.0) is shown in figure 37.

Dissolved-oxygen concentrations in streams may also vary significantly during a 24-hour period in response to algal and macrophyte photosynthesis and respiration. During days with adequate sunlight, algae and other green plants, consume carbon dioxide and produce oxygen. In some favorable stream environments, photosynthesis can result in dissolved-oxygen concentrations much higher than the saturation concentration. Dissolved-oxygen concentrations exceeding saturation often occur in deep, slow-moving rivers with an adequate nutrient supply. During the summer months, algae can become a larger contributor of oxygen to the river than atmospheric diffusion. At night, in the absence of light, oxygen is consumed by algae and other aquatic organisms. Where photosynthesis has resulted in oxygen concentrations that exceed saturation, oxygen diffuses from the water attempting to reach equilibrium with the atmosphere. Because of the diel variation in algal productivity, dissolved-oxygen concentrations typically are higher during the day than at night.

Five sites in the Kentucky River basin had 10 or more observations of dissolved-oxygen concentration during the period 1976-86 (table 36). The spatial distribution of these sites and the low number of observations severely limit the extent to which dissolved-oxygen conditions in the basin can be described. Another limitation is that observations at these five sites were made as part of a fixed station network, and as such, typically were made during the daylight hours. Given the diel variability in dissolved-oxygen concentration due to algal photosynthesis and respiration by the aquatic biota, an accurate assessment of dissolved-oxygen conditions at a site would entail measurements throughout the 24-hour day.

About 12 percent of the 426 dissolved-oxygen concentrations measured throughout the basin during the 1976-86 water years were less than 5.5 mg/L (the Federal minimum chronic criterion for protection of aquatic life) and about 8 percent were less than 4.0 mg/L (the Kentucky warmwater aquatic habitat criterion) (table 37). Median concentrations less than 4.0 mg/L occurred in streams near Lexington (fig. 38). Of the sites with 10 or more observations,

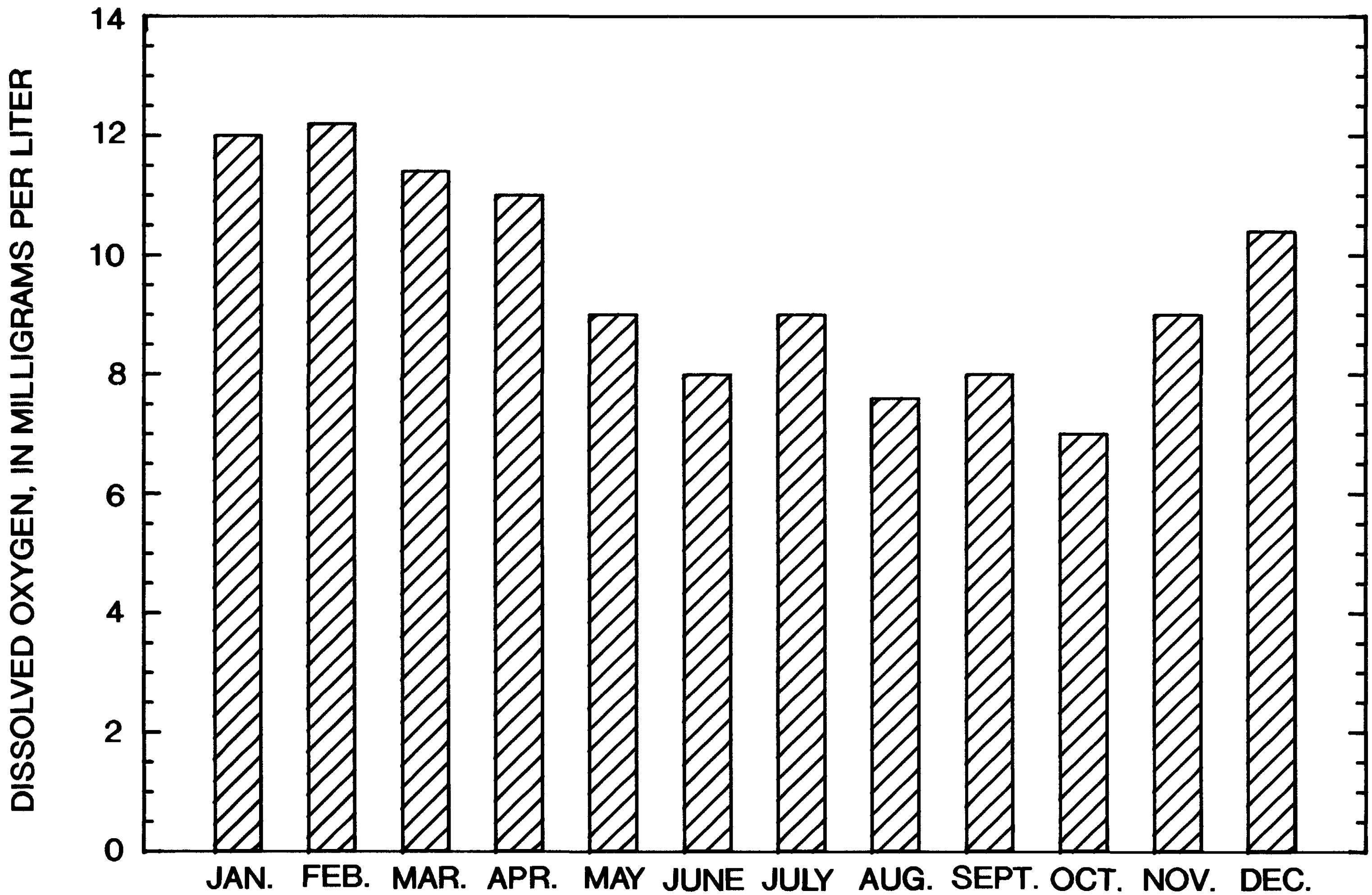


Figure 37.--Mean monthly dissolved-oxygen concentrations for the Kentucky River at Lock 2, at Lockport, 1980-86.

Table 37.—*Number of dissolved-oxygen concentration measurements made in the Kentucky River basin and percentage not meeting indicated water-quality criteria, based on available data for water years 1976-86*

U.S. ENVIRONMENTAL PROTECTION AGENCY	KENTUCKY
ALA = aquatic life acute	KYWAH = warmwater aquatic habitat
ALC = aquatic life chronic	KYCAH = coldwater aquatic habitat

Constituent or property	Number of measurements	Percentage not meeting indicated criteria ALA	ALC	KYWAH	KYCAH
Dissolved oxygen	426	5	12	8	10

the lowest dissolved-oxygen concentrations were detected in South Elkhorn Creek and were probably due to biochemical oxidation of organic matter and nitrogen compounds in wastewater effluents from the Lexington urban area (table 38). Only two sites on the Kentucky River main stem had dissolved-oxygen data suitable for describing current water-quality conditions. No long-term trends in dissolved-oxygen concentration at either of these sites were detected based on available data for the period 1976-86 (table 39).

Organic Carbon and Oxygen Demand

The intimate relation between water in the hydrologic cycle and living matter and its waste products ensures that all natural water contains organic material. Living systems are made up of many types of organic compounds, including proteins, carbohydrates, amino acids, alcohols, and many other natural compounds. Organic compounds also include synthetic substances such as pesticides, polychlorinated biphenyls, and literally thousands of other chemicals used in everyday life. The amounts of organic compounds present in most water are small compared with amounts of dissolved-inorganic substances, but even small amounts can have significant effects on the chemical, physical, and biological properties of aqueous systems, and in some instances can cause severe ecological and human health hazards.

Three gross measures of organic carbon are used for assessment purposes. They are total organic carbon (TOC), biochemical oxygen demand (BOD), and chemical oxygen demand (COD). The "historical-record" data base for TOC in the Kentucky River basin consists of 1,423 analyses through 1986 with concentrations ranging from less than 1.0 to 636 mg/L. Median concentrations of TOC at sites with ten or more analyses during the 1976-86 water years ranged from 1.7 to 6.3 mg/L. The highest median concentrations of TOC occurred at sites 9.3 and 10.1 on South Elkhorn Creek and Eagle Creek, respectively (table 40). The principal sources of these large concentrations were probably wastewater effluent from the Lexington area in South Elkhorn Creek, and agricultural runoff in the Eagle Creek basin. Additional TOC data in the basin were very limited. Available data for the main stem of the Kentucky River indicate slightly increasing TOC concentrations from the headwater reaches to the lower basin, then sharply increased concentrations in the lower river basin where major urban and agricultural areas are located (fig. 39). Transport estimates for TOC indicate the highest basin yield is for South Elkhorn Creek (table 41). Decreasing trends in TOC concentration were detected for several sites on the Kentucky River main stem during the period 1976-86. However, these trends could be accounted for by decreasing streamflow during the period (table 42).

BOD is a laboratory measure of the oxygen consumed through biochemical oxidation of organic substances in water. A test duration of five days is commonly used to measure BOD and results are expressed as the 5-day BOD in milligrams per liter (of oxygen consumed). COD, reported in milligrams per liter, is a measure of the oxygen required to oxidize organic and reduced inorganic substances in a sample by a strong chemical oxidant.

The highest BOD and COD values occurred at South Elkhorn Creek (site 9.3) which receives wastewater discharges (table 40). This site had correspondingly low dissolved-oxygen concentrations.

Calculations of BOD and COD from point sources (Gianessi, 1986) indicate that as little as 5 percent of the biochemical and chemical oxygen demand of the basin was due to point source discharges in the upper basin.

Decreasing long-term trends in both BOD and COD were determined for several sites in the basin (table 42). These decreases in the oxygen demand were primarily at sites affected by nonpoint source discharges and could be associated with a decreasing trend in flow. However, because some of the sample

Table 38.—*Number of dissolved-oxygen concentration measurements made at selected sites in the Kentucky River basin and percentage not meeting indicated water-quality criteria, based on available data for water years 1976-86*

U.S. ENVIRONMENTAL PROTECTION AGENCY
ALA = aquatic life acute
ALC = aquatic life chronic

KENTUCKY
KYWAH = warmwater aquatic habitat
KYCAH = coldwater aquatic habitat

Site number	USGS station name	Number measurements	Percentage not meeting indicated criteria			
			ALA	ALC	KYWAH	KYCAH
9.3	South Elkhorn Creek near Midway	17	18	59	47	53

concentrations were below laboratory reporting levels (censored data), flow adjustment of the data was not appropriate and the effect of flow trend is unknown. The decreasing trends of BOD and COD could be due to continuing improvement in the treatment of point sources of oxygen-demanding wastewater discharges.

Major Metals, Trace Elements, and Miscellaneous Inorganic Compounds

Concern about the contamination of receiving water by metals has increased substantially during the last 15 years. Many metals, such as cadmium, copper, lead, and mercury, can be toxic to aquatic organisms when present in high concentrations. These constituents are nondegradable and may persist in the environment for extended periods of time.

Metals and other trace elements may enter receiving water from a variety of sources. Rocks and soils exposed to surface and ground water are usually the largest natural source. Decomposing vegetation and animal matter also contribute small amounts of the constituents to the environment. High concentrations of some metals have been observed in both dry- and wet-atmospheric precipitation. Many of these metals were associated with the combustion of fossil fuels and the processing of metals.

Urban stormwater runoff has also been shown to contain substantial concentrations of lead, zinc, and other metals (Martin and Smoot, 1986). Sources of these metals include automobile exhausts, and various commercial and industrial activities in the watershed. Other human-induced sources of metals to streams include domestic and industrial wastewater, paints, biocides, and fertilizers.

Metals are concentrated in the solid phases of aquatic systems and commonly are associated with particulate matter in the water and bottom materials.

Suspended sediment can act as a vehicle to transport some metals, pesticides and other organic compounds, and nutrients in streams. Correlations of suspended sediment to metals such as aluminum, iron, and manganese were significant at nearly all sites in the basin with enough data for analysis (table 43). Other metals were significantly correlated to suspended sediment at individual sites; for example, aluminum, barium, lead, nickel, and zinc concentrations were correlated with suspended-sediment concentrations in the North Fork Kentucky River at Jackson (site 2.0), and chromium concentrations correlated with suspended-sediment concentrations in Eagle Creek at Glencoe (site 10.1, table 43).

Major metals, trace elements, and miscellaneous inorganic constituents analyzed as part of the NAWQA program, for which some data exist in the Kentucky River basin, include aluminum, arsenic, barium, beryllium, cadmium, chromium, copper, cyanide, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, vanadium, and zinc. Some data also exist for antimony and boron, but the data are insufficient for statistical analysis and interpretation.

Trace-element concentrations in streambed sediments are usually much higher than those in water, and may be used as indicators of potential sources of these constituents in the overlying water. The most extensive data on streambed sediments in the Kentucky River basin were collected by the U.S. Department of Energy for the National Uranium Resource Evaluation (NURE) program. R-mode factor analysis was performed on these NURE streambed material data using the Geological Survey RASS-STATPAC system (Van Trump and Miesch, 1977) to group trace-element associations and reduce the number of variables within the data set into discreet suites of constituents, called factors. The calculated factor score indicates the relative influence of the subbasin geology on trace-element concentrations in streambed sediments. Background information on the use of factor analysis can be obtained from Harman (1967).

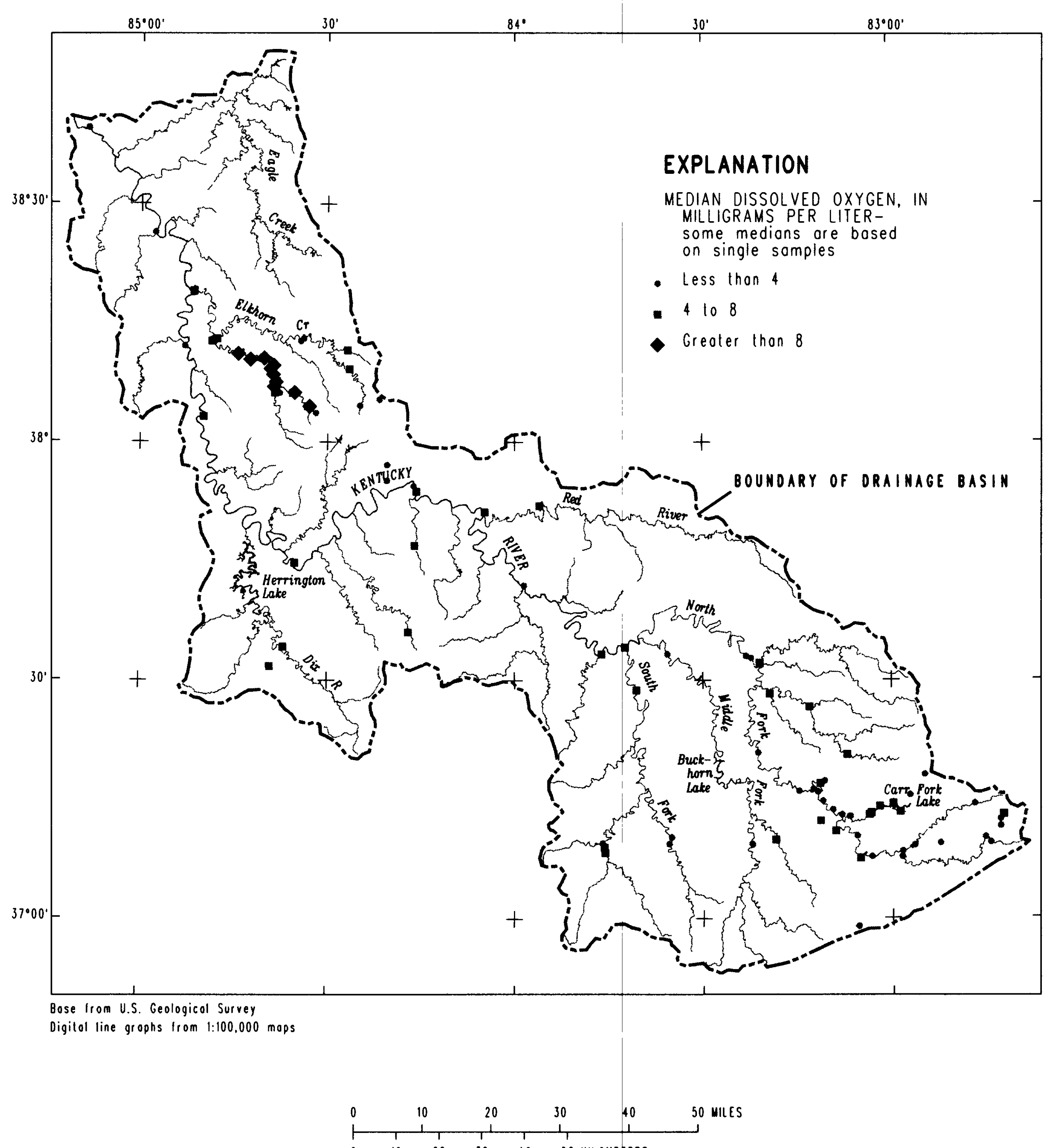


Figure 38.--Median concentrations of dissolved oxygen at sites in the Kentucky River basin, through 1986.

Table 39. — *Trend test results for dissolved-oxygen concentrations for selected sites in the Kentucky River basin*

[N, number of observations; SC, number of seasonal comparisons; P, probability; mg/L, milligrams per liter. Trend-line slopes not significant at 0.2 probability level are not reported]

Site number	USGS station name	Period of record (water years)	N	SC	Results of seasonal Kendall tests for time trend[1]: Trends, unadjusted for flow: P level	Trend-line slope: Milligrams per liter per year	Trend-line slope: Percent of median concentration (mg/L) per year	Flow-adjusted trends[2]: P level	Trend-line slope: Milligrams per liter per year	Trend-line slope: Percent of median concentration (mg/L) per year
9.3	South Elkhorn Creek near Midway	1982-84	17	12	1.00			1.00		
10.0	Kentucky River at Lock 2, at Lockport	1980-86	38	28	.685			.428		

[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 (1) 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 (2) 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.

Table 40. —*Statistical summary of organic carbon concentrations and oxygen demand for selected sites in the Kentucky River basin*

[N, number of observations; DL, detection limit; *, value estimated from log-normal-fit program.
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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL, in milligrams per liter	Concentration at indicated percentile, in milligrams per liter: 10	25	50 (median)	75	90
Organic carbon, total										
2.0	North Fork Kentucky River at Jackson	1984-86	25				1.6	2.2	2.7	
2.3	Middle Fork Kentucky River at Tallega	1984-86	26				1.4	2.0	2.6	
2.6	South Fork Kentucky River at Booneville	1984-86	26				1.1	1.7	2.5	
3.0	Kentucky River at Lock 14, at Heidelberg	1983-86	34			1.0	1.4	2.4	3.3	4.9
3.1	Red River near Hazel Green	1983-86	34			1.0	1.5	2.3	4.1	5.8
5.0	Kentucky River at Camp Nelson	1983-86	34			1.4	1.9	2.5	3.5	5.6
7.0	Kentucky River above Frankfort	1983-86	34			1.7	2.0	2.7	4.6	5.7
9.0	Kentucky River below Frankfort	1983-85	25				2.0	2.9	4.4	
9.3	South Elkhorn Creek near Midway	1984-86	26				4.2	5.7	8.7	
10.0	Kentucky River at Lock 2, at Lockport	1976-82	39			2.5	4.0	5.3	7.5	11
10.1	Eagle Creek at Glencoe	1983-86	35			3.2	4.5	6.3	8.1	12
Biochemical oxygen demand (BOD), 5-day at 20 degrees Celsius										
2.0	North Fork Kentucky River at Jackson	1984-85	16	1	0.10		.4	.8	1.2	
2.3	Middle Fork Kentucky River at Tallega	1984-85	16	1	.10		.4	.6	.7	
2.6	South Fork Kentucky River at Booneville	1984-85	16	1	.10		.4	.6	1.1	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-85	73	3	.10	.1	.4	.8	1.5	2.1
3.1	Red River near Hazel Green	1979-85	70	5	.10	.2	.4	.8	1.4	3.5
5.0	Kentucky River at Camp Nelson	1980-85	65	2	.10	.2	.7	1.0	1.5	2.1
7.0	Kentucky River above Frankfort	1979-85	72	2	1.0	.2*	.4*	1.0	1.4	2.1
9.0	Kentucky River below Frankfort	1979-85	71	3	1.0	.3*	.5*	1.2	1.7	2.5
9.3	South Elkhorn Creek near Midway	1984-86	23				1.0	2.0	2.5	
10.1	Eagle Creek at Glencoe	1979-85	77			.4	.7	1.2	1.8	2.3
Chemical oxygen demand (COD), 0.25 N dichromate										
2.0	North Fork Kentucky River at Jackson	1982-85	30	1	10	4*	8*	12	29	60
2.3	Middle Fork Kentucky River at Tallega	1982-85	29	7	10		4*	7*	15	
2.6	South Fork Kentucky River at Booneville	1982-85	29	4	10		5*	9*	22	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-85	73	2	1.0	3	6	9	12	21
3.1	Red River near Hazel Green	1979-85	72			3	4	7	10	16
5.0	Kentucky River at Camp Nelson	1980-85	62			5	7	9	12	17
7.0	Kentucky River above Frankfort	1979-85	71			5	8	10	13	18
9.0	Kentucky River below Frankfort	1979-85	70			6	8	10	13	17
9.3	South Elkhorn Creek near Midway	1982-85	30	1	10	10*	12	24	34	44
10.1	Eagle Creek at Glencoe	1979-85	76			7	14	18	21	25

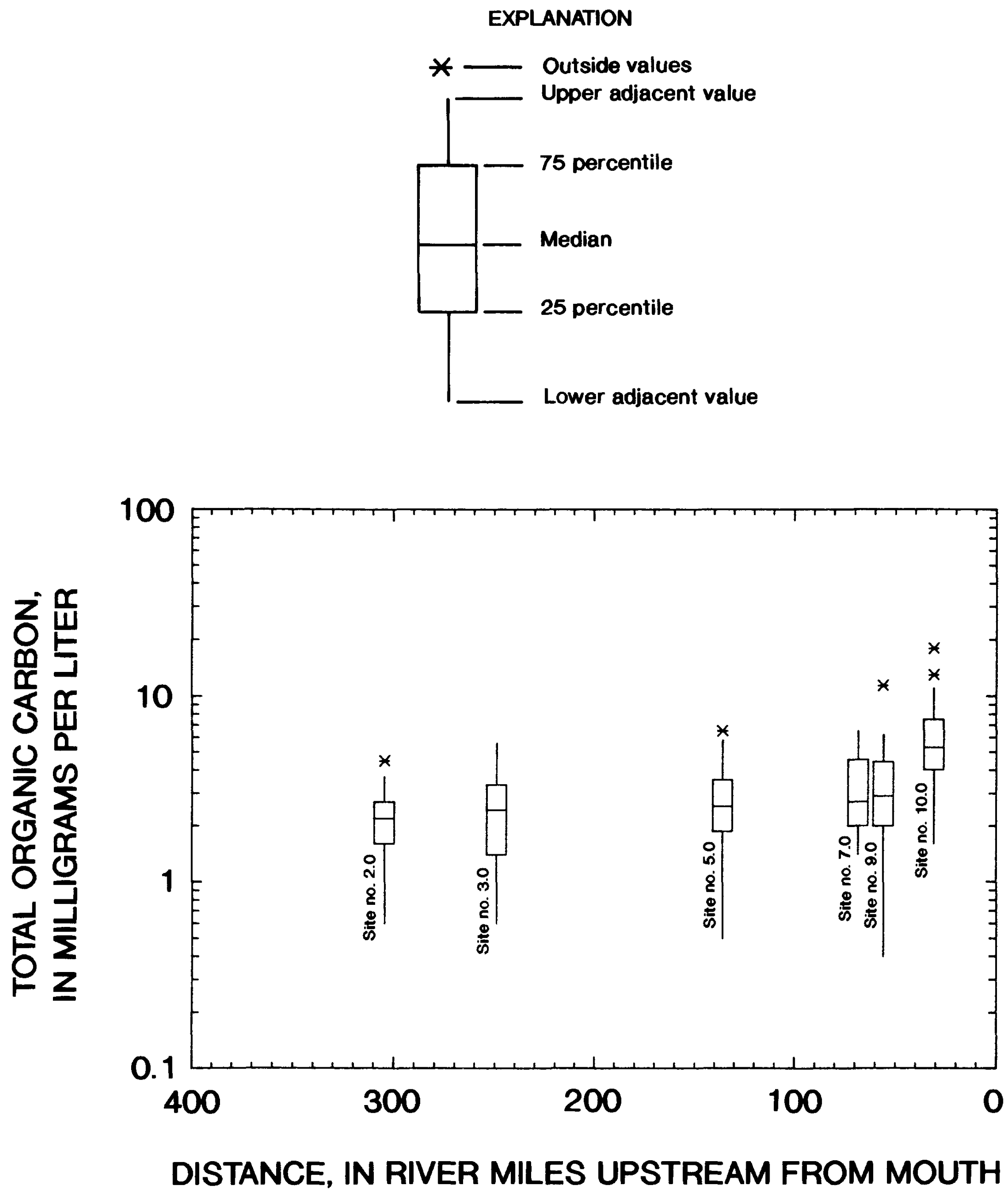


Figure 39.--Statistical summary of total organic carbon concentrations at sites along the Kentucky River, based on available data for water years 1976-86.

Table 41.—*Estimates of mean annual loads and mean annual yields for water years 1983-85 for total organic carbon for selected sites in the Kentucky River basin*

[N, number of observations; tons/mi^2, tons per square mile]

Site number	USGS station name	N	Mean annual load, in tons	Mean annual yield, in tons/mi^2	Standard error of regression	Flow duration of greatest sampled discharge, in percent	Percentage of load estimated beyond range of sampled discharge
2.0	North Fork Kentucky River at Jackson	25	1,850	1.68	33.7	3.9	25.5
2.3	Middle Fork Kentucky River at Tallega	26	1,150	2.15	25.3	1.7	14.9
2.6	South Fork Kentucky River at Booneville	26	1,170	1.62	35.9	5.2	43.9
3.0	Kentucky River at Lock 14 at Heidelberg	34	10,700	4.03	48.3	3.1	30.3
3.1	Red River near Hazel Green	34	146	2.22	80.6	.5	9.22
5.0	Kentucky River at Camp Nelson	34	18,900	4.26	42.4	1.3	15.5
7.0	Kentucky River above Frankfort	34	23,200	4.38	36.4	1.5	16.4
9.0	Kentucky River below Frankfort	25	15,500	2.86	56.8	4.6	20.6
9.3	South Elkhorn Creek near Midway	26	577	5.50	34.9	6.4	22.6
10.0	Kentucky River at Lock 2, at Lockport	39	31,600	5.11	45.6	0	0

Table 42.—*Trend test results for total organic carbon concentrations and oxygen demand for selected sites in the Kentucky River basin*

[N, number of observations; SC, number of seasonal comparisons; P, probability; mg/L, milligrams per liter; *, censored values used in analysis; **, censored values affect trend analysis. Trend-line slopes not significant at 0.2 probability level are not reported, and those significant at the 0.1 probability level are underlined]

Site number	USGS station name	Period of record (water years)	N	SC	Trends, unadjusted for flow[1]: P level	Trends, unadjusted for flow: Trend-line slope: Milligrams per liter per year	Trends, unadjusted for flow: Trend-line slope: Percent of median concentration (mg/L) per year	Flow-adjusted trends[2]: P level	Flow-adjusted trends: Trend-line slope: Milligrams per liter per year	Flow-adjusted trends: Trend-line slope: Percent of median concentration (mg/L) per year
Organic carbon, total										
2.0	North Fork Kentucky River at Jackson	1984-86	25	12	0.699			0.245		
2.3	Middle Fork Kentucky River at Tallega	1984-86	26	12	.401			1.00		
2.6	South Fork Kentucky River at Booneville	1984-86	26	12	.699			.245		
3.0	Kentucky River at Lock 14, at Heidelberg	1983-86	34	12	.192	-0.70	-29	.433		
3.1	Red River near Hazel Green	1983-86	34	12	.794			1.00		
5.0	Kentucky River at Camp Nelson	1983-86	34	12	.433			.192	-0.83	-32
7.0	Kentucky River above Frankfort	1983-86	34	12	.192	-.65	-25			
9.0	Kentucky River below Frankfort	1983-85	25	12	.699			.699		
9.3	South Elkhorn Creek near Midway	1984-86	26	12	.053	1.4	23	.699		
10.0	Kentucky River at Lock 2, at Lockport	1976-82	39	28	.145	-.44	-8.3	.207		
10.1	Eagle Creek at Glencoe	1983-86	35	16	.652					
Biochemical oxygen demand (BOD), 5-day at 20 degrees Celsius										
2.0	North Fork Kentucky River at Jackson	1984-85	16	12*	1.00					
2.3	Middle Fork Kentucky River at Tallega	1984-85	16	12*	1.00					
2.6	South Fork Kentucky River at Booneville	1984-85	16	12*	1.00					
3.0	Kentucky River at Lock 14, at Heidelberg	1979-85	73	32*	.112	-.10	-11			
3.1	Red River near Hazel Green	1979-85	70	32*	.096	-.05	-6.7			
5.0	Kentucky River at Camp Nelson	1980-85	65	28*	.841					
7.0	Kentucky River above Frankfort	1979-85	72	32*	.874					
9.0	Kentucky River below Frankfort	1979-85	71	32*	.018	-.12	-9.2			
9.3	South Elkhorn Creek near Midway	1984-86	23	12	.699					
10.1	Eagle Creek at Glencoe	1979-85	77	32	.200	-.05	-4.2			
Chemical oxygen demand (COD), 0.25 N dichromate										
2.0	North Fork Kentucky River at Jackson	1982-85	30	20*	.055	-8.5	-85			
2.3	Middle Fork Kentucky River at Tallega	1982-85	29	20**	.358					
2.6	South Fork Kentucky River at Booneville	1982-85	29	16*	.113	-5.2	-50			
3.0	Kentucky River at Lock 14, at Heidelberg	1979-85	73	32*	.813					
3.1	Red River near Hazel Green	1979-85	72	32	.582			.694		
5.0	Kentucky River at Camp Nelson	1980-85	62	28	1.00			1.00		
7.0	Kentucky River above Frankfort	1979-85	71	32	1.00			.238		
9.0	Kentucky River below Frankfort	1979-85	70	32	.135	-.48	-4.7			
9.3	South Elkhorn Creek near Midway	1982-85	30	20*	.495					
10.1	Eagle Creek at Glencoe	1979-85	76	32	.694					

[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 (1) 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 (2) 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.

Table 43.—*Correlation statistics describing the relations between suspended-sediment concentration and selected major metals and trace elements for selected sites in the Kentucky River basin, based on available data for water years 1976-86*

[NVAL, number of correlation data pairs; r, correlation coefficient (a measure of the strength of the linear relation between the dependent and independent variables. r lies between -1 and +1. r >0 indicates a positive linear relation between the dependent and independent variables.); P, probability (A low P-level, P less than 0.05, for example, indicates that there is a statistically significant correlation between the dependent and independent variables. A high P-level indicates that there is probably little chance that a correlation between the two variables exists.)]

Site number	USGS station name	NVAL	r	P
Aluminum, total				
2.0	North Fork Kentucky River at Jackson	25	0.946	0.000
2.3	Middle Fork Kentucky River at Tallega	25	.599	.002
2.6	South Fork Kentucky River at Booneville	25	.859	.000
3.0	Kentucky River at Lock 14, at Heidelberg	33	.594	.000
3.1	Red River near Hazel Green	32	.509	.003
5.0	Kentucky River at Camp Nelson	33	.873	.000
7.0	Kentucky River above Frankfort	33	.837	.000
9.0	Kentucky River below Frankfort	24	.955	.000
9.3	South Elkhorn Creek near Midway	25	.414	.040
10.1	Eagle Creek at Glencoe	31	.833	.000
Arsenic, total				
2.0	North Fork Kentucky River at Jackson	33	.022	.903
2.3	Middle Fork Kentucky River at Tallega	34	.186	.291
2.6	South Fork Kentucky River at Booneville	34	.130	.465
3.0	Kentucky River at Lock 14, at Heidelberg	74	.262	.024
3.1	Red River near Hazel Green	76	.017	.885
5.0	Kentucky River at Camp Nelson	67	.371	.002
7.0	Kentucky River above Frankfort	72	.238	.044
9.0	Kentucky River below Frankfort	63	.316	.012
9.3	South Elkhorn Creek near Midway	41	.100	.533
10.0	Kentucky River at Lock 2, at Lockport	20	.003	.992
10.1	Eagle Creek at Glencoe	73	.242	.039
Barium, total				
2.0	North Fork Kentucky River at Jackson	33	.642	.000
2.3	Middle Fork Kentucky River at Tallega	34	.257	.142
2.6	South Fork Kentucky River at Booneville	34	.273	.119
3.0	Kentucky River at Lock 14, at Heidelberg	42	.511	.001
3.1	Red River near Hazel Green	44	.113	.466
5.0	Kentucky River at Camp Nelson	42	.088	.578
7.0	Kentucky River above Frankfort	43	.026	.868
9.0	Kentucky River below Frankfort	34	.033	.854
9.3	South Elkhorn Creek near Midway	41	.197	.218
10.0	Kentucky River at Lock 2, at Lockport	15	.455	.088
10.1	Eagle Creek at Glencoe	44	.215	.162
Cadmium, total				
2.0	North Fork Kentucky River at Jackson	34	.348	.044
2.3	Middle Fork Kentucky River at Tallega	34	.308	.076
2.6	South Fork Kentucky River at Booneville	35	.089	.612
3.0	Kentucky River at Lock 14, at Heidelberg	60	.059	.654
3.1	Red River near Hazel Green	62	.058	.654
5.0	Kentucky River at Camp Nelson	61	.077	.553
7.0	Kentucky River above Frankfort	61	.065	.619
9.0	Kentucky River below Frankfort	54	.088	.528

Table 43.—*Correlation statistics describing the relations between suspended-sediment concentration and selected major metals and trace elements for selected sites in the Kentucky River basin, based on available data for water years 1976-86*—Continued

[NVAL, number of correlation data pairs; r, correlation coefficient (a measure of the strength of the linear relation between the dependent and independent variables. r lies between -1 and +1. r >0 indicates a positive linear relation between the dependent and independent variables.); P, probability (A low P-level, P less than 0.05, for example, indicates that there is a statistically significant correlation between the dependent and independent variables. A high P-level indicates that there is probably little chance that a correlation between the two variables exists.)]

Site number	USGS station name	NVAL	r	P
Cadmium, total–Continued				
9.3	South Elkhorn Creek near Midway	42	0.134	0.397
10.0	Kentucky River at Lock 2, at Lockport	14	.257	.376
10.1	Eagle Creek at Glencoe	56	.072	.598
Chromium, total				
2.0	North Fork Kentucky River at Jackson	34	.218	.215
2.3	Middle Fork Kentucky River at Tallega	35	.245	.156
2.6	South Fork Kentucky River at Booneville	34	.519	.002
3.0	Kentucky River at Lock 14, at Heidelberg	68	.669	.000
3.1	Red River near Hazel Green	67	.030	.808
5.0	Kentucky River at Camp Nelson	65	.316	.010
7.0	Kentucky River above Frankfort	70	.073	.547
9.0	Kentucky River below Frankfort	61	.130	.316
9.3	South Elkhorn Creek near Midway	41	.258	.103
10.0	Kentucky River at Lock 2, at Lockport	20	.192	.418
10.1	Eagle Creek at Glencoe	72	.708	.000
Copper, total				
2.0	North Fork Kentucky River at Jackson	34	.775	.000
2.3	Middle Fork Kentucky River at Tallega	35	.236	.172
2.6	South Fork Kentucky River at Booneville	35	.634	.000
3.0	Kentucky River at Lock 14, at Heidelberg	83	.400	.000
3.1	Red River near Hazel Green	82	.185	.096
5.0	Kentucky River at Camp Nelson	73	.096	.419
7.0	Kentucky River above Frankfort	81	.103	.359
9.0	Kentucky River below Frankfort	71	.044	.714
9.3	South Elkhorn Creek near Midway	41	.326	.038
10.0	Kentucky River at Lock 2, at Lockport	20	.562	.010
10.1	Eagle Creek at Glencoe	85	.153	.161
Iron, total				
0.1	Yonts Fork near Neon	13	.875	.000
1.0	North Fork Kentucky River at Hazard	18	.915	.000
2.0	North Fork Kentucky River at Jackson	48	.991	.000
2.1	Middle Fork Kentucky River near Hyden	18	.990	.000
2.3	Middle Fork Kentucky River at Tallega	47	.964	.000
2.5	Goose Creek at Manchester	19	.841	.000
2.6	South Fork Kentucky River at Booneville	46	.969	.000
3.0	Kentucky River at Lock 14, at Heidelberg	65	.883	.000
3.1	Red River near Hazel Green	77	.247	.031
5.0	Kentucky River at Camp Nelson	63	.889	.000
7.0	Kentucky River above Frankfort	64	.644	.000
9.0	Kentucky River below Frankfort	55	.755	.000
9.3	South Elkhorn Creek near Midway	39	.649	.000
10.0	Kentucky River at Lock 2, at Lockport	20	.615	.004
10.1	Eagle Creek at Glencoe	64	.849	.000

Table 43.—*Correlation statistics describing the relations between suspended-sediment concentration and selected major metals and trace elements for selected sites in the Kentucky River basin, based on available data for water years 1976-86*—Continued

[NVAL, number of correlation data pairs; r, correlation coefficient (a measure of the strength of the linear relation between the dependent and independent variables. r lies between -1 and +1. r > 0 indicates a positive linear relation between the dependent and independent variables.); P, probability (A low P-level, P less than 0.05, for example, indicates that there is a statistically significant correlation between the dependent and independent variables. A high P-level indicates that there is probably little chance that a correlation between the two variables exists.)]

Site number	USGS station name	NVAL	r	P
Lead, total				
2.0	North Fork Kentucky River at Jackson	34	0.847	0.000
2.3	Middle Fork Kentucky River at Tallega	34	.395	.021
2.6	South Fork Kentucky River at Booneville	35	.955	.000
3.0	Kentucky River at Lock 14, at Heidelberg	68	.043	.726
3.1	Red River near Hazel Green	66	.294	.016
5.0	Kentucky River at Camp Nelson	65	.129	.305
7.0	Kentucky River above Frankfort	70	.066	.590
9.0	Kentucky River below Frankfort	62	.007	.958
9.3	South Elkhorn Creek near Midway	42	.398	.009
10.0	Kentucky River at Lock 2, at Lockport	20	.344	.138
10.1	Eagle Creek at Glencoe	74	.102	.387
Manganese, total				
0.1	Yonts Fork near Neon	13	.251	.409
1.0	North Fork Kentucky River at Hazard	18	.812	.000
2.0	North Fork Kentucky River at Jackson	48	.930	.000
2.1	Middle Fork Kentucky River near Hyden	18	.693	.001
2.3	Middle Fork Kentucky River at Tallega	47	.671	.000
2.5	Goose Creek at Manchester	19	.448	.055
2.6	South Fork Kentucky River at Booneville	46	.871	.000
3.0	Kentucky River at Lock 14, at Heidelberg	63	.821	.000
3.1	Red River near Hazel Green	76	.042	.722
5.0	Kentucky River at Camp Nelson	61	.846	.000
7.0	Kentucky River above Frankfort	63	.580	.000
9.0	Kentucky River below Frankfort	54	.828	.000
9.3	South Elkhorn Creek near Midway	40	.133	.413
10.0	Kentucky River at Lock 2, at Lockport	20	.941	.000
10.1	Eagle Creek at Glencoe	62	.877	.000
Mercury, total				
2.0	North Fork Kentucky River at Jackson	35	.037	.834
2.3	Middle Fork Kentucky River at Tallega	34	.064	.720
2.6	South Fork Kentucky River at Booneville	35	.049	.782
3.0	Kentucky River at Lock 14, at Heidelberg	67	.011	.930
3.1	Red River near Hazel Green	62	.277	.029
5.0	Kentucky River at Camp Nelson	57	.073	.591
7.0	Kentucky River above Frankfort	69	.062	.612
9.0	Kentucky River below Frankfort	55	.070	.614
9.3	South Elkhorn Creek near Midway	42	.088	.580
10.0	Kentucky River at Lock 2, at Lockport	18	.450	.061
10.1	Eagle Creek at Glencoe	59	.104	.433
Nickel, total				
2.0	North Fork Kentucky River at Jackson	19	.926	.000
2.3	Middle Fork Kentucky River at Tallega	20	.364	.115
2.6	South Fork Kentucky River at Booneville	20	.790	.000

Table 43.—*Correlation statistics describing the relations between suspended-sediment concentration and selected major metals and trace elements for selected sites in the Kentucky River basin, based on available data for water years 1976-86*—Continued

[NVAL, number of correlation data pairs; r, correlation coefficient (a measure of the strength of the linear relation between the dependent and independent variables. r lies between -1 and +1. r >0 indicates a positive linear relation between the dependent and independent variables.); P, probability (A low P-level, P less than 0.05, for example, indicates that there is a statistically significant correlation between the dependent and independent variables. A high P-level indicates that there is probably little chance that a correlation between the two variables exists.)]

Site number	USGS station name	NVAL	r	P
Nickel, total–Continued				
3.0	Kentucky River at Lock 14, at Heidelberg	16	0.303	0.254
3.1	Red River near Hazel Green	15	.117	.678
5.0	Kentucky River at Camp Nelson	16	.249	.351
7.0	Kentucky River above Frankfort	16	.355	.177
9.0	Kentucky River below Frankfort	16	.025	.927
9.3	South Elkhorn Creek near Midway	27	.250	.208
10.0	Kentucky River at Lock 2, at Lockport	9	.831	.006
10.1	Eagle Creek at Glencoe	16	.236	.379
Selenium, total				
2.3	Middle Fork Kentucky River at Tallega	20	.010	.965
2.6	South Fork Kentucky River at Booneville	20	.004	.985
3.0	Kentucky River at Lock 14, at Heidelberg	28	.098	.618
3.1	Red River near Hazel Green	29	.017	.929
5.0	Kentucky River at Camp Nelson	27	.130	.518
7.0	Kentucky River above Frankfort	28	.105	.596
9.0	Kentucky River below Frankfort	28	.024	.902
10.0	Kentucky River at Lock 2, at Lockport	20	.115	.630
10.1	Eagle Creek at Glencoe	29	.036	.852
Silver, total				
2.0	North Fork Kentucky River at Jackson	20	.031	.897
2.3	Middle Fork Kentucky River at Tallega	21	.011	.964
2.6	South Fork Kentucky River at Booneville	21	.038	.869
3.0	Kentucky River at Lock 14, at Heidelberg	30	.062	.745
3.1	Red River near Hazel Green	30	.074	.697
5.0	Kentucky River at Camp Nelson	29	.101	.600
7.0	Kentucky River above Frankfort	30	.098	.606
9.0	Kentucky River below Frankfort	30	.116	.541
9.3	South Elkhorn Creek near Midway	27	.247	.213
10.0	Kentucky River at Lock 2, at Lockport	12	.326	.301
10.1	Eagle Creek at Glencoe	31	.042	.821
Zinc, total				
2.0	North Fork Kentucky River at Jackson	32	.811	.000
2.3	Middle Fork Kentucky River at Tallega	32	.240	.187
2.6	South Fork Kentucky River at Booneville	33	.390	.025
3.0	Kentucky River at Lock 14, at Heidelberg	60	.287	.026
3.1	Red River near Hazel Green	62	.444	.000
5.0	Kentucky River at Camp Nelson	63	.307	.015
7.0	Kentucky River above Frankfort	64	.074	.561
9.0	Kentucky River below Frankfort	55	.042	.763
9.3	South Elkhorn Creek near Midway	40	.187	.247
10.0	Kentucky River at Lock 2, at Lockport	20	.646	.002
10.1	Eagle Creek at Glencoe	64	.135	.289

Three factor groupings of trace-element, streambed-sediment data were shown to be highly correlated with the composition of the bedrock in the Kentucky River basin. A factor grouping relating to Devonian New Albany Shale contained the constituents vanadium, nickel, zinc, chromium, cobalt, copper, iron, lithium, boron, scandium, molybdenum, aluminum, and potassium in decreasing order of significance (fig. 40). Ordovician carbonate rocks were correlated with a factor grouping containing the constituents phosphorus, calcium, yttrium, manganese, strontium, magnesium, lead, cerium, iron, boron, and niobium in decreasing order of significance (fig. 41). A factor grouping relating to the underclays of coal seams (fireclays) in Pennsylvanian rocks in the basin contained the constituents titanium, lanthanum, aluminum, barium, cerium, sodium, potassium, zirconium, scandium, niobium, and lithium in decreasing order of significance (fig. 42).

Aluminum

Aluminum is one of the most abundant elements in the earth's crust, but does not occur in its elemental form in nature. It is a constituent of all soils, plants, and animal tissues. Aluminum is present in substantial amounts in many silicate minerals.

Water with pH less than 4.0 may contain several hundred to several thousand milligrams of aluminum per liter. Such water occurs in some springs and in drainage from mines. Elevated aluminum concentrations have been observed in runoff and lake water in areas affected by precipitation of low pH (acid rain) (Hem, 1985).

Aluminum may be adsorbed on plant organisms, but very little ingested by animals is actually absorbed through the alimentary canal. However, aluminum has been consistently detected at greater levels in benthic algae, plankton, mollusks, and fish. In fresh water, the toxicity of aluminum salts varies with water hardness, turbidity, and pH (Hem, 1985).

Concentrations of dissolved aluminum in the Kentucky River basin ranged from below detection limits to 53,000 μg/L in 320 samples collected. Total aluminum concentrations were as high as 160,000 μg/L in 538 samples. Streambed material collected for the NURE program had aluminum concentrations ranging from 0.71 to 8.11 percent. The largest concentrations observed in both streambed sediments and water occurred in basins which were mined for coal.

Based on the site summaries given in table 44, elevated concentrations of total aluminum were common at two sites—North Fork Kentucky River at Jackson (site 2.0) and Eagle Creek at Glencoe (site 10.1). Total aluminum concentrations at these two sites were strongly correlated with suspended-sediment concentrations (table 43) and suspended-sediment loads were relatively high at these sites (table 30). Insufficient data are available for interpretation of dissolved aluminum concentrations. The transport estimates for total aluminum presented in table 45 for the North Fork Kentucky River at Jackson (site 2.0) exceed yields farther downstream. This indicates that aluminum was being deposited along with sediment downstream of Jackson during 1983-85. Based on the highly variable concentrations and the small number of samples collected during the 1976-86 period, no statistically significant trends in aluminum concentrations were detected even when adjusted for decreasing flow (table 46).

Arsenic

Small concentrations of arsenic can be toxic to humans and other organisms. Therefore, it is considered highly undesirable in surface water. The Federal MCL has been set at 50 μg/L. The same criterion has been adopted by Kentucky for protection of warmwater aquatic habitat.

Of 748 observations of total recoverable arsenic in the "historical-record" data base for the basin, concentrations ranged from less than 0.1 to 76 μg/L. The range of concentrations for dissolved arsenic in 224 samples analyzed was from less than 0.01 to 12 μg/L. Concentrations of arsenic in 58 samples of streambed material ranged from less than detection limits to 200 μg/g.

Based on statistical summaries of total and dissolved arsenic concentrations by site, presented in table 44, there was little site-to-site variability in arsenic concentration. Only two of the selected sites had concentrations in excess of water-quality criteria (table 47). The transport estimates in table 45 suggest a major source of arsenic upstream of the Kentucky River at Lock 14 (site 3.0). However, due to the short period of record and the small number of observations, the load estimates may be unreliable and no meaningful interpretation is possible. Arsenic was not strongly correlated with suspended sediment (table 43). Based on load estimates by Gianessi (1986) for point sources in the basin, about two-thirds of the arsenic transported from the basin originates from municipal and industrial wastewater effluents. No long-term trends in dissolved arsenic concentrations were detected in the basin (table 46). Evidence of a decreasing trend in total arsenic was indicated at several sites. However, flow adjustment was not possible, and the trends could be a reflection of decreasing flow over the period of analysis.

Barium and Beryllium

Barium is an alkaline-earth metal which occurs in low concentrations in most surface water, and in treated drinking water. Barium occurs in igneous and carbonate sedimentary rocks. The Federal MCL and Kentucky criterion for total barium in domestic water supplies is 1,000 μg/L.

The available "historical-record" data for the study area indicate that total barium concentrations in surface water have been within the criterion. Concentrations have ranged from less than 1.0 to 425 μg/L in 597 samples. The range of dissolved barium concentration in 248 samples was from less than 0.01 to 130 μg/L. Median concentrations of total barium at sites with 10 or more observations ranged from 23 to about 84 μg/L. The elevated concentrations shown in figure 43 in the North Fork Kentucky River basin may be associated with underclay units disturbed during coal mining. Total barium concentrations show significant correlation to suspended-sediment concentrations in the North Fork Kentucky River basin at site 2.0 (table 43). Barium concentrations as high as 80,000 μg/L have been reported for an eastern Kentucky stream affected by oil-field brines (Sidhu and Mitsch, 1987). However, similar concentrations in the major oil production areas of the Kentucky River basin have not been observed in the limited data for these areas (fig. 43). Streambed materials analyzed during the NURE program in the basin had barium concentrations ranging from 51 to 1,027 μg/g.

Barium concentration data for the Kentucky River indicate increasing barium concentrations between Heidelberg (site 3.0) and Camp Nelson (site 5.0, fig. 44 and table 44). The Red River downstream of Hazel Green (site 3.1) and Millers Creek (pl. 1), which drain the major oil production areas of the basin, join the Kentucky River between Heidelberg (site 3.0) and Camp Nelson (site 5.0) and may represent the source of barium. Oil-brine discharge as a source of barium is also indicated by load and yield estimates computed for selected sites (table 45).

Long-term trends for total barium concentration were decreasing for several sites in the basin during the period 1976-86. The most significant decreasing trends were for sites on the Kentucky River main stem at Jackson (site 2.0) and at Lock 14 (site 3.0) (table 46). These decreasing trends downstream from coal-mined basins may be due to implementation of mining regulations and procedures or may be a reflection of decreasing streamflow and associated decreasing sediment transport. No trends for dissolved barium are indicated in table 46, but few data were available.

Beryllium is a component of the mineral beryl and is almost nonexistent in natural water. It is used in a number of manufacturing processes, such as electroplating, and as a catalyst in the synthesis of organic chemicals. Beryllium has also been used experimentally in rocket fuels and in nuclear reactors (U.S. Environmental Protection Agency, 1972). Beryllium is not likely to occur at toxic levels in natural water. However, it is possible that beryllium could enter water in effluents from certain metallurgical plants.

Streambed material collected in support of the NURE program indicated that beryllium concentrations did not vary spatially and generally ranged from 1.0 to 3.0 μg/g. From 221 water samples collected historically in the Kentucky River basin, the range of total beryllium concentrations was from less than 1.0 to 5.0 μg/L which is less than the Kentucky criterion of 11 μg/L for the protection of aquatic life in soft, fresh water. Almost all data from sites at which 10 or more analyses for beryllium were available during the 1976-86 period were below detection limits (table 44). No highly significant trends in either dissolved or total beryllium were detected (table 46).

Cadmium, Chromium, and Copper

The natural occurrence of cadmium in water in more than minute amounts is almost unknown. In the past, detectable concentrations were usually the result of contamination from mining or industrial wastes.

In the Kentucky River basin, analysis of 680 samples collected through 1986 indicated a minimum total cadmium concentration of less than 0.10 μg/L and a maximum concentration of 52 μg/L. Dissolved cadmium concentrations ranged from less than 0.05 to 40 μg/L in 510 samples. Cadmium concentration in 58 streambed-material samples ranged from below detection limits to 200 μg/g. Concentrations in water at selected sites along the Kentucky River main stem during the 1976-86 period did not vary substantially (table 44). However, smaller concentrations were noted at sites on several major tributaries.

The Federal MCL for cadmium in drinking water is 10 μg/L. The Federal criterion for aquatic life (chronic) is 1.1 μg/L based on a hardness of 100 mg/L as $CaCO_3$. This criterion was exceeded for about 22 percent of the data collected during water years 1976-86 (table 48). Elevated concentrations of cadmium, which occurred at many sites within the basin, can not be readily related to a single causative factor. Total cadmium was not strongly correlated with suspended sediment in the basin (table 43). The strongest correlation with suspended sediment was detected at sites in the headwater reaches of the basin.

Because of the limited number of observations and generally poor regressions of cadmium concentration to streamflow, transport estimates for cadmium given in table 45 for selected sites in the basin should be used with caution. The spatial variability in yield of cadmium cannot be adequately assessed. On the basis of point-source load estimates by Gianessi (1986), at least 85 percent of the cadmium exiting the basin originates from nonpoint sources including weathering of geologic materials.

Several long-term trends were detected for total cadmium at selected sites in the basin (table 46). The direction of these trends, however, are not consistent. Observations at these selected sites contained censored values and the apparent trends could not be adjusted for the trend in flow.

Natural water contains only trace amounts of chromium because it is held in rocks in virtually insoluble forms of trivalent chromium. Under strongly oxidizing conditions chromium can be converted to the hexavalent state (Cr^{+6}) and occur as chromate and dichromate anions. Chromium is used in metal plating, steel manufacturing, leather tanning, paints, dyes, explosives, ceramics, and photography. Industrial uses of chromium produce waste solutions containing chromate ions. Acute systematic poisoning can result from high exposure to hexavalent chromium. The chronic health effects are respiratory and dermatologic. Chromium, in certain forms, is also known to be carcinogenic.

Concentrations of chromium in natural water that has not been affected by waste disposal are commonly less than 10 $\mu g/L$ (Hem, 1985). A study by Kharkar and others (1968) estimated an average chromium concentration for river water of 1.4 $\mu g/L$. An investigation by Durum and others (1971) found chromium concentrations generally less than 5 $\mu g/L$ in samples from surface water in the United States, and many samples in this study were probably affected by waste disposal.

Streambed-material samples collected during the NURE program had chromium concentrations ranging from 7 to 73 $\mu g/g$. No geographic patterns in concentration were observed in the Kentucky River basin. Concentrations for total chromium in 728 water samples collected in the basin through 1986 ranged from less than 0.05 to 64 $\mu g/L$. Dissolved chromium in 201 samples ranged from less than 0.03 to 20 $\mu g/L$.

Kentucky's surface water-quality criterion for total chromium is 50 $\mu g/L$ for domestic water supply, and 100 $\mu g/L$ for protection of warmwater aquatic habitats. Few samples from the Kentucky River basin had chromium concentrations that exceeded the 50 $\mu g/L$ criterion, which is also the Federal MCL.

A statistical summary of chromium data for selected sites (table 44), indicates that median concentrations for total chromium in the basin range from 2 to 14 $\mu g/L$. Elevated total chromium concentrations and yields (table 45) occur in the North Fork Kentucky River at Jackson (site 2.0), and may be associated with coal mining. The limited total chromium data at site 2.0 do not correlate strongly with suspended sediment (table 43). However, the correlation of total chromium to suspended sediment is significant at a site farther downstream—Kentucky River at Lock 14 (site 3.0)—where more data are available for comparison. The relatively high concentration and load for total chromium at the Kentucky River at Lock 2 (site 10.0) as compared to the upstream sites may be related to the sampling procedure used, which was different than that used for the upstream sites.

Depth-integrated sampling techniques were used at Kentucky River at Lock 2 (site 10.0) and are designed to collect a sample that is more representative of the suspended-sediment size distribution and concentration than does surface-grab sampling, which was used predominately at the other sites. Suspended-sediment concentrations usually vary vertically in a stream, with more of the largest-size fraction and highest concentrations being near the streambed and lower concentrations being near the water surface. Total chromium, if adsorbed to the suspended sediment, would then be expected to be at a higher concentration in a depth-integrated sample than in one collected by surface-grab sampling. However, this would not be the case for dissolved chromium. Concentrations and load estimates for dissolved chromium for Lock 2 (site 10.0) were similar to those for the other sites. Another possible explanation for higher total chromium concentrations and load estimates at Lock 2 (site 10.0) could be that the period of record and degree of hydrologic coverage of sampling is slightly different from that at the other sites.

Based on point source load estimates by Gianessi (1986), of the estimated 106 tons per year of total chromium transport by the Kentucky River at Lock 2 (site 10.0) (table 45), only about 6 percent originates from point sources. Six sites showed significant trends in total chromium concentration (table 46). Five of the detected trends were negative and one was positive; decreasing flow is a possible explanation for the decreasing trends. Flow-adjusted trends were not possible because of the presence of censored values in the data set.

Copper, which is a native metal and occurs in various mineral forms such as cuprite and chalcopyrite, has been mined and used in a variety of products since prehistoric times (U.S. Environmental Protection Agency, 1976). Copper and its salts have bactericidal properties and can also be used to eliminate algae (U.S. Environmental Protection Agency, 1972). Copper is essential for plants because it is involved in the synthesis of chlorophyll. It is essential for animal metabolism as well because it is used for the production of hemoglobin. Copper in water is not known to have an adverse effect on humans (U.S. Environmental Protection Agency, 1976).

The toxicity of copper to various aquatic biota is dependent on the alkalinity of the water because the copper ions are complexed by anions that contribute to alkalinity. Copper is more toxic to aquatic life in water with low alkalinity than in water with high alkalinity (U.S. Environmental Protection Agency, 1976).

The Federal freshwater aquatic life (chronic) criterion for copper is 12 μg/L. However, no aquatic life criterion has been set by the State of Kentucky. The Federal secondary MCL and Kentucky criterion for copper in water used for domestic-water supply has been set at 1,000 μg/L. Total copper concentrations ranged from less than detection limits to 25,000 μg/L in 1,501 water samples collected in the Kentucky River basin. Dissolved copper analyses for 507 samples for the same period indicated concentrations ranging from less than 0.02 to 208 μg/L. Concentrations of total copper in river water are commonly about 10 μg/L (Hem, 1985). Streambed-material samples collected during the NURE program indicated a range of 2.0 to 436 μg/g of copper in the basin. Basinwide, 2 percent of all observations in the "historical-record" data base exceed the water-supply criterion for copper in water and 37 percent of these samples exceed the chronic aquatic life criterion. Of the 983 samples collected during the "current-record" period of 1976-86 and analyzed for total copper concentration, less than one percent exceeded the secondary MCL criterion and 22 percent exceeded the Federal chronic aquatic life criterion (table 48).

Copper concentrations in stream water during 1976-86 do not seem to be associated with any single land use or physiographic region (table 44). The data indicate that the Federal water-quality criterion for protection of aquatic life (chronic) of 12 μg/L is exceeded at many sites having quite different land uses (table 47). Load estimates for total copper, given in table 45, indicate elevated yields for coal mining areas drained by the North Fork Kentucky River at Jackson (site 2.0). Total copper concentrations are significantly correlated with suspended sediment at several sites in the basin, but not consistently at sites on the same stream (table 43). Differing methods of sampling and analysis (p. 142) may contribute to those differences. This is likely the reason that total copper transport estimates are much higher at Kentucky River at Lock 2 (site 10.0) than at other sites in the basin (table 45). No statistically significant long-term trends in dissolved copper were detected for sites in the basin (table 46). In contrast for total copper, all sites but site 10.0 showed a significant decreasing trend ranging from about 10 to more than 60 percent per year. These decreasing trends could be partially accounted for by decreasing flow during the period of analysis, but also may be due to changes in the use or disposal of products containing copper. On the basis of point-source load estimates by Gianessi (1986), less than 1 percent of the total copper transported out of the basin originates from point sources in the basin.

Cyanide

The warmwater aquatic habitat criterion for cyanide adopted by Kentucky is 5.0 μg/L. In the Kentucky River basin, concentrations of cyanide from 50 samples ranged from less than detection limits to 10.0 μg/L. Insufficient information is available to compute descriptive summaries, load estimates, or trends for cyanide.

Iron, Lead, and Manganese

Kentucky has set a criterion of 1,000 μg/L for iron in streams for the protection of warmwater aquatic habitats. Ferric hydroxide flocs may coat fish gills and the smothering effects of settled iron precipitates may be particularly detrimental to fish eggs and bottom-dwelling organisms. Iron is an objectionable constituent in water supplies primarily due to taste or stain problems at concentrations greater than approximately 300 μg/L. For this reason, the Federal secondary MCL is set at 300 μg/L.

Observations from 2,529 samples for total iron in streams in the basin ranged from below detection limits to 257,000 μg/L. Dissolved iron in 2,764 samples ranged from less than detection limits to 140,000 μg/L. Streambed-material samples collected during the NURE program showed a concentration range from 0.32 to 8.33 percent. The highest concentrations in water have occurred in Perry County in the heart of coal-mining activity in the basin. Basinwide, more than 70 percent of the water samples analyzed for total iron had concentrations in excess of the Federal secondary MCL value of 300 μg/L (table 48).

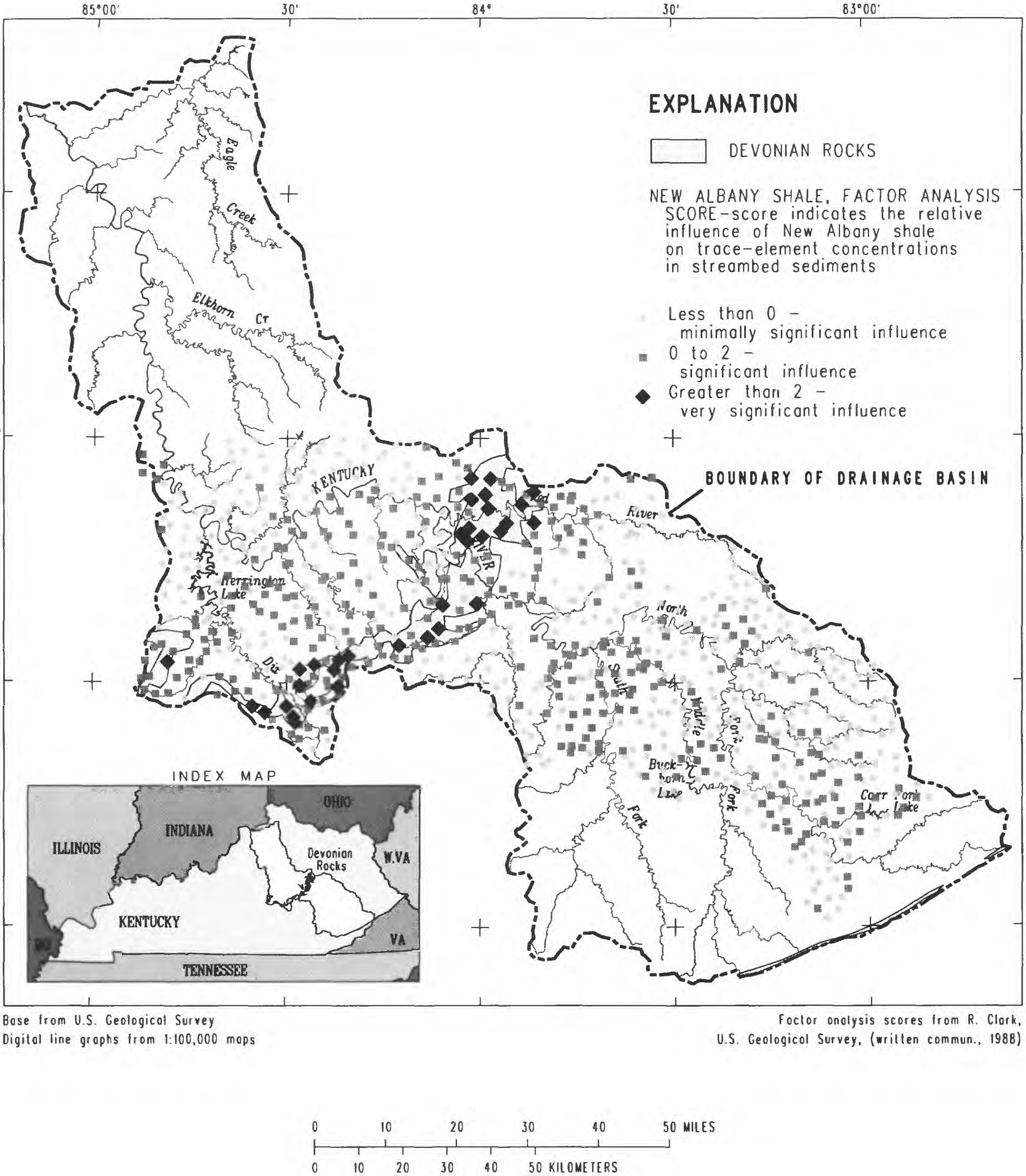


Figure 40.--Factor analysis scores showing the relative influence of New Albany Shale on trace-element concentrations in streambed sediments in the Kentucky River basin.

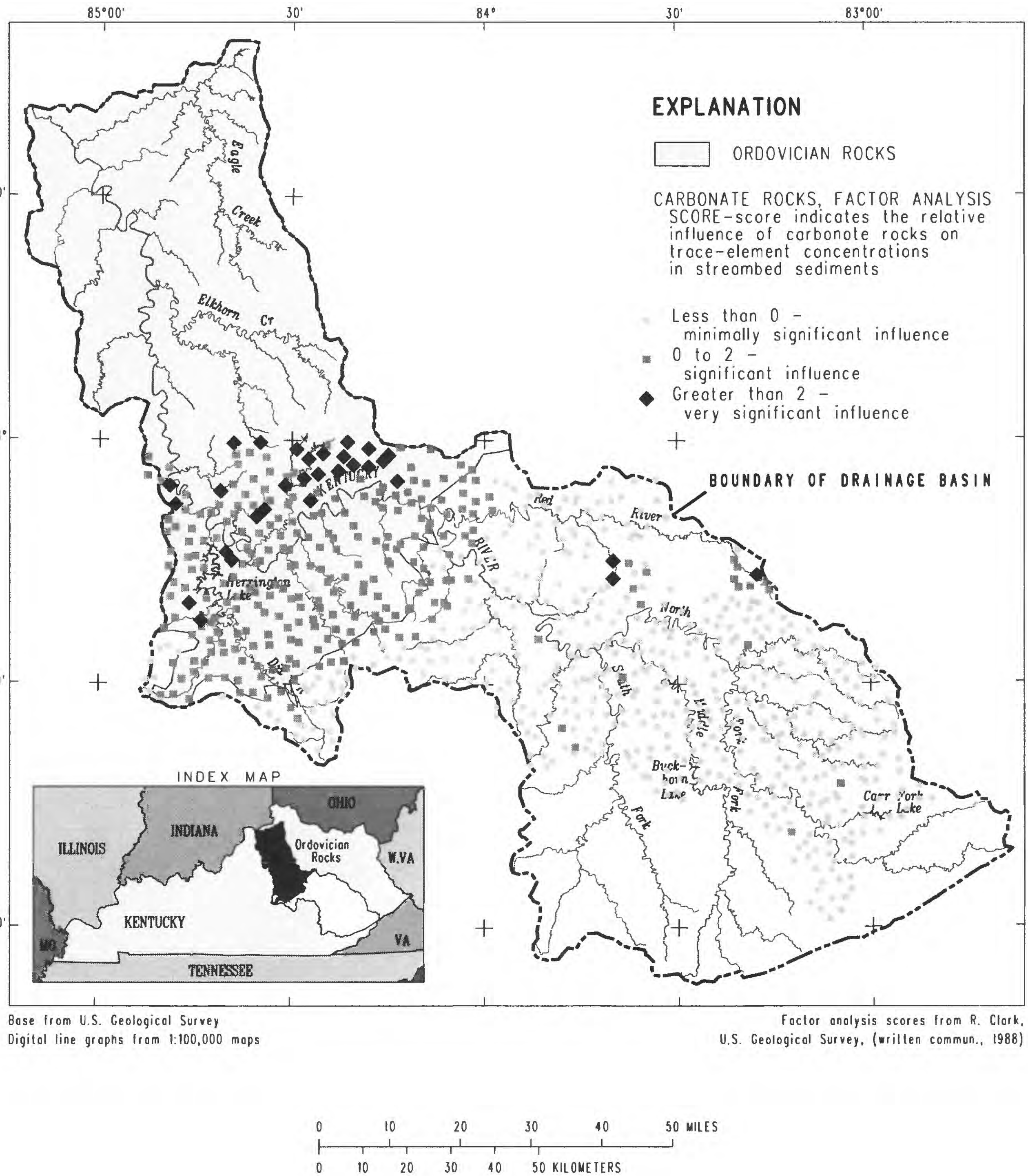


Figure 41.--Factor analysis scores showing the relative influence of carbonate rocks on trace-element concentrations in streambed sediments in the Kentucky River basin.

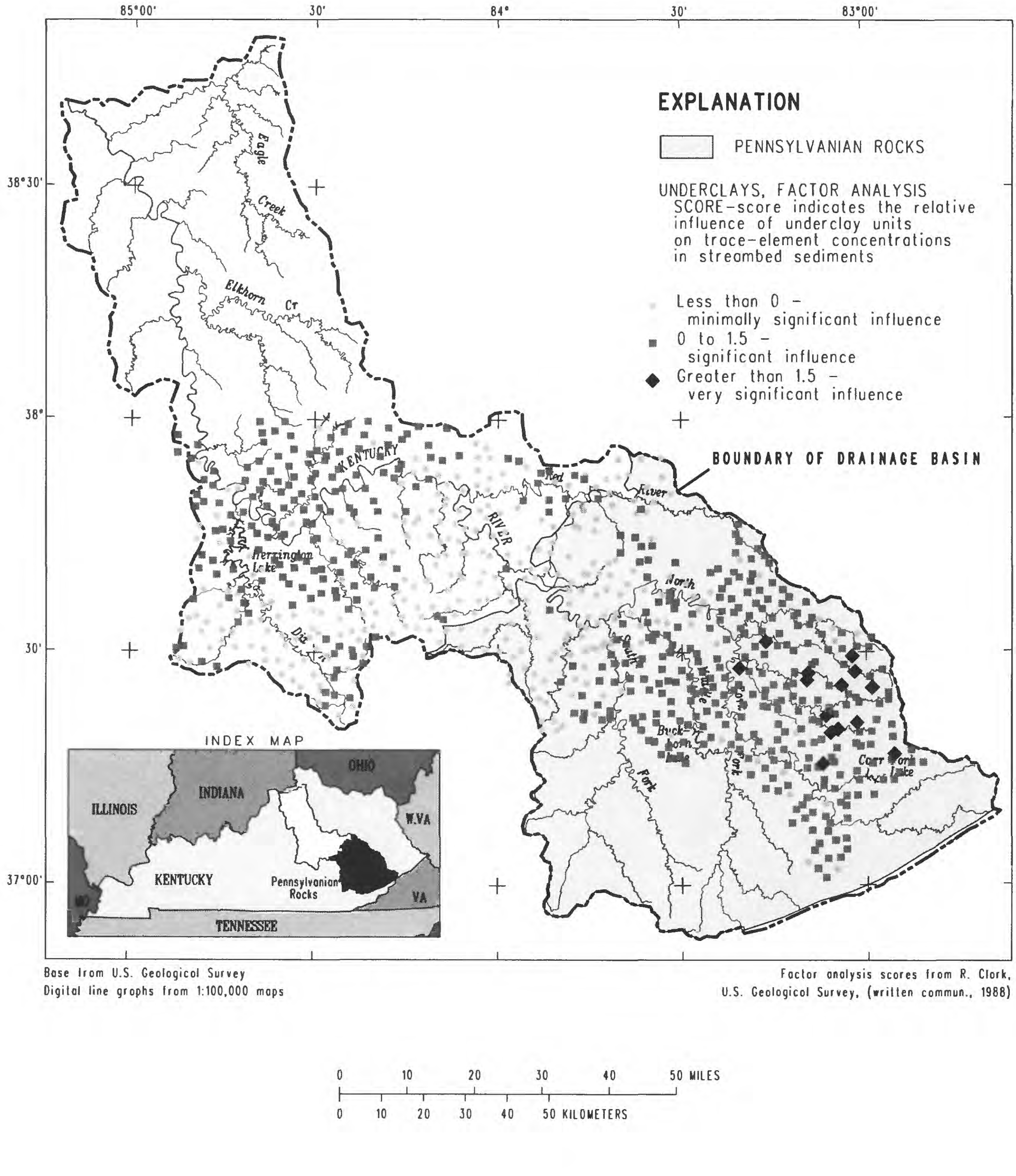


Figure 42.--Factor analysis scores showing the relative influence of underclay units on trace-element concentrations in streambed sediments in the Kentucky River basin.

Table 44. —*Statistical summary of concentrations of major metals and trace elements for selected sites in the Kentucky River basin*

[N, number of observations; DL, detection limit; *, value estimated from log-normal-fit program; <, less than. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL, in micrograms per liter	Concentration at indicated percentile, in micrograms per liter: 10	25	50 (median)	75	90
Aluminum, total										
2.0	North Fork Kentucky River at Jackson	1984-86	26				110	320	520	
2.3	Middle Fork Kentucky River at Tallega	1984-86	26	1	1		120	180	500	
2.6	South Fork Kentucky River at Booneville	1984-86	25	1	1		90	140	280	
3.0	Kentucky River at Lock 14, at Heidelberg	1983-86	34			40	80	190	370	740
3.1	Red River near Hazel Green	1983-86	34			70	100	180	330	930
5.0	Kentucky River at Camp Nelson	1983-86	34			50	90	180	580	870
7.0	Kentucky River above Frankfort	1983-86	34			50	90	180	320	1,000
9.0	Kentucky River below Frankfort	1983-85	25				120	200	390	
9.3	South Elkhorn Creek near Midway	1984-86	26				80	150	200	
10.1	Eagle Creek at Glencoe	1983-86	35			100	180	300	730	2,800
Aluminum, dissolved										
3.0	Kentucky River at Lock 14, at Heidelberg	1983-84	12				20	40	50	
3.1	Red River near Hazel Green	1983-84	12				20	40	60	
5.0	Kentucky River at Camp Nelson	1983-84	12				20	40	50	
7.0	Kentucky River above Frankfort	1983-84	12				30	40	70	
9.0	Kentucky River below Frankfort	1983-84	12				30	40	80	
10.0	Kentucky River at Lock 2, at Lockport	1983-86	16	4	10		10*	20	30	
10.1	Eagle Creek at Glencoe	1983-84	11				30	60	80	
Arsenic, dissolved										
3.0	Kentucky River at Lock 14, at Heidelberg	1979-80	10	2	1		1*	1	2	
3.1	Red River near Hazel Green	1976-80	19	14	1		<1	<1	1	
9.3	South Elkhorn Creek near Midway	1982-84	17				1	2	2	
10.0	Kentucky River at Lock 2, at Lockport	1976-86	42	12	1	1*	1*	1	1	2
Arsenic, total										
2.0	North Fork Kentucky River at Jackson	1980-86	35	12	1	<1*	<1*	1	1	2
2.3	Middle Fork Kentucky River at Tallega	1980-86	35	20	1	1*	1*	1*	1	1
2.6	South Fork Kentucky River at Booneville	1980-86	34	14	1	<1*	<1*	1	1	2
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	75	27	5	<1*	1*	1*	3*	9
3.1	Red River near Hazel Green	1976-86	84	35	5	<1*	1*	1*	2*	2*
5.0	Kentucky River at Camp Nelson	1980-86	68	22	5	1*	1*	1*	2*	3*
7.0	Kentucky River above Frankfort	1979-86	73	15	5	1*	1*	1*	2*	3*
9.0	Kentucky River below Frankfort	1979-85	64	16	5	1*	1*	1*	2*	4*

Table 44. —*Statistical summary of concentrations of major metals and trace elements for selected sites in the Kentucky River basin* —Continued

[N, number of observations; DL, detection limit; *, value estimated from log-normal-fit program; <, less than. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL, in micrograms per liter	Concentration at indicated percentile, in micrograms per liter				
						10	25	50 (median)	75	90
Arsenic, total–Continued										
9.3	South Elkhorn Creek near Midway	1982-86	42	6	1	1*	1	2	2	3
10.0	Kentucky River at Lock 2, at Lockport	1976-82	27	2	1		1	1	2	
10.1	Eagle Creek at Glencoe	1979-86	74	25	5	<1*	1*	1*	2*	4*
Barium, dissolved										
3.0	Kentucky River at Lock 14, at Heidelberg	1979-83	13	3	10		10*	19	34	
3.1	Red River near Hazel Green	1979-80	11	4	10		8*	10	20	
9.3	South Elkhorn Creek near Midway	1982-84	17				29	32	43	
10.0	Kentucky River at Lock 2, at Lockport	1978-86	30			32	40	50	69	76
Barium, total										
2.0	North Fork Kentucky River at Jackson	1980-86	35	2	100	13*	23*	44*	83*	100
2.3	Middle Fork Kentucky River at Tallega	1980-86	32	1	50	11*	19*	36*	55	100
2.6	South Fork Kentucky River at Booneville	1980-86	31	1	50	20*	28*	42*	66	100
3.0	Kentucky River at Lock 14, at Heidelberg	1980-86	43	2	50	15*	25*	43*	59	89
3.1	Red River near Hazel Green	1980-86	45	1	50	12*	18*	28*	43*	65*
5.0	Kentucky River at Camp Nelson	1981-86	43			38	57	68	99	130
7.0	Kentucky River above Frankfort	1981-86	44			29	43	52	78	100
9.0	Kentucky River below Frankfort	1981-85	35			32	43	53	88	110
9.3	South Elkhorn Creek near Midway	1982-86	42	7	100	7*	14*	30*	100	100
10.0	Kentucky River at Lock 2, at Lockport	1978-82	19	10	100		63*	84*	100	
10.1	Eagle Creek at Glencoe	1981-86	45	1	1	10	18	23	41	95
Beryllium, dissolved										
10.0	Kentucky River at Lock 2, at Lockport	1983-86	16	11	1.0		< .1*	< .1*	.3*	
Beryllium, total										
2.0	North Fork Kentucky River at Jackson	1984-85	10	10	1.0		<1.0	<1.0	<1.0	
2.3	Middle Fork Kentucky River at Tallega	1984-85	10	10	1.0		<1.0	<1.0	<1.0	
2.6	South Fork Kentucky River at Booneville	1984-85	10	10	1.0		<1.0	<1.0	<1.0	
3.0	Kentucky River at Lock 14, at Heidelberg	1981-85	28	27	1.0		<1.0	<1.0	<1.0	
3.1	Red River near Hazel Green	1981-85	29	28	1.0		<1.0	<1.0	<1.0	
5.0	Kentucky River at Camp Nelson	1981-85	28	27	1.0		<1.0	<1.0	<1.0	
9.0	Kentucky River below Frankfort	1981-85	29	28	1.0		<1.0	<1.0	<1.0	
9.3	South Elkhorn Creek near Midway	1984-85	10	10	1.0		<1.0	<1.0	<1.0	
10.1	Eagle Creek at Glencoe	1981-85	33	28	1.0	< .1*	< .1*	< .1*	.1*	.3*

Table 44.—*Statistical summary of concentrations of major metals and trace elements for selected sites in the Kentucky River basin*—Continued

[N, number of observations; DL, detection limit; *, value estimated from log-normal-fit program; <, less than. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL, in micrograms per liter	Concentration at indicated percentile, in micrograms per liter: 10	25	50 (median)	75	90
Cadmium, dissolved										
2.3	Middle Fork Kentucky River at Tallega	1982-84	13	9	1		<1*	<1*	1	
2.6	South Fork Kentucky River at Booneville	1982-84	13	11	1		<1	<1	<1	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	51	18	2	<1*	<1*	2*	5	15
3.1	Red River near Hazel Green	1976-84	53	24	2	<1*	<1*	1*	6	10
5.0	Kentucky River at Camp Nelson	1980-84	40	17	2	<1*	<1*	1*	6	23
7.0	Kentucky River above Frankfort	1979-84	48	18	2	<1*	<1*	1*	2	22
9.0	Kentucky River below Frankfort	1979-84	47	17	2	<1*	<1*	1*	3	14
9.3	South Elkhorn Creek near Midway	1982-84	21	18	1		<1	<1	<1	
10.0	Kentucky River at Lock 2, at Lockport	1976-86	34	15	2	<1*	<1*	<1*	2	3
10.1	Eagle Creek at Glencoe	1979-84	46	10	2	<1*	1*	4	9	15
Cadmium, total										
2.0	North Fork Kentucky River at Jackson	1980-86	36	25	1	<1*	<1*	<1*	1	1
2.3	Middle Fork Kentucky River at Tallega	1980-86	35	23	1	<1*	<1*	<1*	1	2
2.6	South Fork Kentucky River at Booneville	1980-86	35	24	1	<1*	<1*	<1*	1	2
3.0	Kentucky River at Lock 14, at Heidelberg	1980-86	61	38	2	<1*	<1*	<1*	2*	4
3.1	Red River near Hazel Green	1976-86	68	49	2	<1*	<1*	<1*	<1*	3
5.0	Kentucky River at Camp Nelson	1981-86	62	36	2	<1*	<1*	<1*	2*	11
7.0	Kentucky River above Frankfort	1981-86	62	38	2	<1*	<1*	<1*	2	13
9.0	Kentucky River below Frankfort	1981-85	55	26	2	<1*	<1*	1*	2	18
9.3	South Elkhorn Creek near Midway	1982-86	43	26	1	<1*	<1*	<1*	1	2
10.0	Kentucky River at Lock 2, at Lockport	1976-82	19	3	2		<1*	2	2	
10.1	Eagle Creek at Glencoe	1981-86	57	36	2	<1*	<1*	<1*	2	8
Chromium, dissolved										
9.3	South Elkhorn Creek near Midway	1982-84	17	4	10		9*	10	10	
10.0	Kentucky River at Lock 2, at Lockport	1977-86	32	22	10	<1*	<1*	<1*	2*	10
Chromium, total										
2.0	North Fork Kentucky River at Jackson	1980-86	36	7	1	<1*	1	4	10	20
2.3	Middle Fork Kentucky River at Tallega	1980-86	36	7	10	<1*	1*	3*	6*	10
2.6	South Fork Kentucky River at Booneville	1980-86	34	9	10	<1*	1*	3*	10	10
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	69	11	2	<1*	1*	2	3	6
3.1	Red River near Hazel Green	1976-86	76	19	20	<1*	<1*	2*	4*	7*
5.0	Kentucky River at Camp Nelson	1981-86	66	14	2	<1*	1*	2	4	5

Table 44.—*Statistical summary of concentrations of major metals and trace elements for selected sites in the Kentucky River basin*—Continued

[N, number of observations; DL, detection limit; *, value estimated from log-normal-fit program; <, less than. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL, in micrograms per liter	Concentration at indicated percentile, in micrograms per liter: 10	25	50 (median)	75	90
Chromium, total–Continued										
7.0	Kentucky River above Frankfort	1979-86	71	9	2	<1*	1*	2	4	7
9.0	Kentucky River below Frankfort	1979-85	62	15	2	<1*	<1*	2	3	4
9.3	South Elkhorn Creek near Midway	1982-86	42	7	10	<1*	2*	4*	10	20
10.0	Kentucky River at Lock 2, at Lockport	1976-82	27	10	20		11*	14*	20	
10.1	Eagle Creek at Glencoe	1979-86	73	18	2	<1*	1*	2	4	6
Copper, dissolved										
2.0	North Fork Kentucky River at Jackson	1982-84	13	1	3		2*	3	6	
2.3	Middle Fork Kentucky River at Tallega	1982-84	13	2	7		1*	3*	5*	
2.6	South Fork Kentucky River at Booneville	1982-84	11	1	1		1	4	6	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	53	3	2	2*	2	5	9	20
3.1	Red River near Hazel Green	1977-84	55	3	2	1*	2	4	6	11
5.0	Kentucky River at Camp Nelson	1980-84	43	3	20	2*	3*	6*	11*	25
7.0	Kentucky River above Frankfort	1979-84	53	3	3	1*	3	6	9	31
9.0	Kentucky River below Frankfort	1979-84	50	3	16	2*	3*	5*	10*	22
9.3	South Elkhorn Creek near Midway	1982-84	20	1	3		2*	3*	6	
10.0	Kentucky River at Lock 2, at Lockport	1976-86	41	1	10	2*	3*	4*	7*	13
10.1	Eagle Creek at Glencoe	1979-84	56	4	7	3*	4*	8	12	18
Copper, total										
2.0	North Fork Kentucky River at Jackson	1980-86	36	2	1	1	2	4	7	12
2.3	Middle Fork Kentucky River at Tallega	1980-86	36	2	1	1	1	3	5	9
2.6	South Fork Kentucky River at Booneville	1980-86	35	2	1	1	1	2	5	11
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	84	4	2	2*	3	5	11	16
3.1	Red River near Hazel Green	1976-86	90	6	2	1*	2	4	6	15
5.0	Kentucky River at Camp Nelson	1980-86	74	4	2	2*	3	5	8	11
7.0	Kentucky River above Frankfort	1979-86	82	1	2	2	2	6	11	29
9.0	Kentucky River below Frankfort	1979-85	72	3	2	2	3	4	8	11
9.3	South Elkhorn Creek near Midway	1982-86	42	1	10	1*	2*	4*	6*	11
10.0	Kentucky River at Lock 2, at Lockport	1976-82	27	1	20		7*	12*	21	
10.1	Eagle Creek at Glencoe	1979-86	86	1	2	2*	3	5	9	14

Table 44.—*Statistical summary of concentrations of major metals and trace elements for selected sites in the Kentucky River basin*—Continued

[N, number of observations; DL, detection limit; *, value estimated from log-normal-fit program; <, less than. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL, in micrograms per liter	Concentration at indicated percentile, in micrograms per liter: 10	25	50 (median)	75	90
Iron, total										
0.1	Yonts Fork near Neon	1979-84	13	1	10		220	1,200	2,600	
1.0	North Fork Kentucky River at Hazard	1979-81	18				600	1,800	7,300	
2.0	North Fork Kentucky River at Jackson	1979-86	53			410	660	1,200	2,400	13,000
2.1	Middle Fork Kentucky River near Hyden	1976-81	21				780	1,100	2,600	
2.3	Middle Fork Kentucky River at Tallega	1979-86	51			350	540	930	2,100	3,600
2.5	Goose Creek at Manchester	1979-81	19				1,100	1,300	1,700	
2.6	South Fork Kentucky River at Booneville	1979-86	47			240	360	550	1,200	1,800
3.0	Kentucky River at Lock 14, at Heidelberg	1980-86	66			180	340	610	1,200	4,700
3.1	Red River near Hazel Green	1979-86	80			360	590	860	1,600	2,400
5.0	Kentucky River at Camp Nelson	1981-86	64			110	170	420	1,100	2,600
7.0	Kentucky River above Frankfort	1981-86	65			90	160	340	1,000	2,700
9.0	Kentucky River below Frankfort	1981-85	56			140	190	400	1,100	2,900
9.3	South Elkhorn Creek near Midway	1982-86	40			200	270	350	520	680
10.0	Kentucky River at Lock 2, at Lockport	1976-82	27				600	1,100	4,000	
10.1	Eagle Creek at Glencoe	1976-86	73			170	280	620	1,600	3,400
Iron, dissolved										
1.0	North Fork Kentucky River at Hazard	1979-81	18	1	10		20	55	95	
2.0	North Fork Kentucky River at Jackson	1979-84	33	3	10	8*	19	30	55	120
2.1	Middle Fork Kentucky River near Hyden	1976-81	21				20	30	80	
2.3	Middle Fork Kentucky River at Tallega	1979-84	31	1	10	12	30	60	81	170
2.5	Goose Creek at Manchester	1979-81	19				60	80	300	
2.6	South Fork Kentucky River at Booneville	1979-84	28	1	10		32	55	100	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	67	1	10	10	25	40	78	120
3.1	Red River near Hazel Green	1979-84	78			32	69	130	200	330
5.0	Kentucky River at Camp Nelson	1980-84	52			10	20	37	72	100
7.0	Kentucky River above Frankfort	1979-84	61	3	10	9*	23	42	71	110
9.0	Kentucky River below Frankfort	1979-84	58			10	20	40	76	120
9.3	South Elkhorn Creek near Midway	1982-84	21	3	10		11	19	31	
10.0	Kentucky River at Lock 2, at Lockport	1976-86	44	8	10	3*	7*	16	30	85
10.1	Eagle Creek at Glencoe	1976-84	73	1	10	20	39	60	100	210

Table 44.--*Statistical summary of concentrations of major metals and trace elements for selected sites in the Kentucky River basin*--Continued

[N, number of observations; DL, detection limit; *, value estimated from log-normal-fit program; <, less than.
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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL, in micrograms per liter	Concentration at indicated percentile, in micrograms per liter: 10	25	50 (median)	75	90
Lead, dissolved										
2.0	North Fork Kentucky River at Jackson	1982-84	13	6	1		<1*	1	2	
2.3	Middle Fork Kentucky River at Tallega	1982-84	12	4	1		<1*	1	3	
2.6	South Fork Kentucky River at Booneville	1982-84	13	5	1		<1*	1	2	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	39	9	10	<1*	2*	5*	11	21
3.1	Red River near Hazel Green	1976-84	42	10	10	<1*	2*	3*	8*	18
5.0	Kentucky River at Camp Nelson	1980-84	36	7	10	<1*	2*	7*	13	260
7.0	Kentucky River above Frankfort	1979-84	42	10	10	<1*	2*	5*	13	40
9.0	Kentucky River below Frankfort	1979-84	41	7	10	<1*	2*	7*	16	120
9.3	South Elkhorn Creek near Midway	1982-84	21	6	1		<1*	1	4	
10.0	Kentucky River at Lock 2, at Lockport	1976-86	36	2	10	<1*	<1*	1*	5*	17*
10.1	Eagle Creek at Glencoe	1979-84	45	8	10	<1*	3*	12	47	110
Lead, total										
2.0	North Fork Kentucky River at Jackson	1980-86	36	3	1	1*	2	4	7	10
2.3	Middle Fork Kentucky River at Tallega	1980-86	35	3	1	1*	2	3	5	9
2.6	South Fork Kentucky River at Booneville	1980-86	35	4	1	<1*	2	4	8	13
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	69	10	10	<1*	2*	7*	16	50
3.1	Red River near Hazel Green	1976-86	75	16	10	<1*	1*	4*	10	30
5.0	Kentucky River at Camp Nelson	1980-86	66	6	10	1*	3*	9*	14	150
7.0	Kentucky River above Frankfort	1979-86	71	6	10	<1*	2*	7*	16	78
9.0	Kentucky River below Frankfort	1979-85	63	7	10	1*	3*	12	30	260
9.3	South Elkhorn Creek near Midway	1982-86	43	7	1	<1*	1	5	7	9
10.0	Kentucky River at Lock 2, at Lockport	1976-82	25				6	10	20	
10.1	Eagle Creek at Glencoe	1979-86	75	13	10	<1*	2*	10	45	170
Manganese, total										
0.1	Yonts Fork near Neon	1979-84	13				160	210	240	
1.0	North Fork Kentucky River at Hazard	1979-81	18				120	180	240	
2.0	North Fork Kentucky River at Jackson	1979-86	53			74	100	110	200	530
2.1	Middle Fork Kentucky River near Hyden	1976-81	21				75	90	120	
2.3	Middle Fork Kentucky River at Tallega	1979-86	50			70	90	120	170	260
2.5	Goose Creek at Manchester	1979-81	19				250	470	650	
2.6	South Fork Kentucky River at Booneville	1979-86	47			58	80	130	160	200
3.0	Kentucky River at Lock 14, at Heidelberg	1980-86	64			77	120	150	210	490

Table 44. —*Statistical summary of concentrations of major metals and trace elements for selected sites in the Kentucky River basin* — Continued

[N, number of observations; DL, detection limit; *, value estimated from log-normal-fit program; <, less than. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL, in micrograms per liter	Concentration at indicated percentile, in micrograms per liter: 10	25	50 (median)	75	90
Manganese, total–Continued										
3.1	Red River near Hazel Green	1979-86	79			80	96	160	220	370
5.0	Kentucky River at Camp Nelson	1981-86	62			40	54	84	130	180
7.0	Kentucky River above Frankfort	1981-86	64			30	40	59	120	200
9.0	Kentucky River below Frankfort	1981-85	55			30	46	60	90	160
9.3	South Elkhorn Creek near Midway	1982-86	41			100	130	180	250	400
10.0	Kentucky River at Lock 2, at Lockport	1976-82	27				70	90	210	
10.1	Eagle Creek at Glencoe	1976-86	74	1	10	19	38	60	100	220
Manganese, dissolved										
1.0	North Fork Kentucky River at Hazard	1979-81	18				37	70	160	
2.0	North Fork Kentucky River at Jackson	1979-84	33	2	10	14*	40	60	85	170
2.1	Middle Fork Kentucky River near Hyden	1976-81	21	1	10		30	70	75	
2.3	Middle Fork Kentucky River at Tallega	1979-84	30			21	47	70	100	220
2.5	Goose Creek at Manchester	1979-81	18	1	10		180	410	560	
2.6	South Fork Kentucky River at Booneville	1979-84	28	1	10		40	70	130	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	65			32	49	80	120	160
3.1	Red River near Hazel Green	1979-84	76			38	62	100	190	300
5.0	Kentucky River at Camp Nelson	1980-84	50	1	10	10	19	37	67	110
7.0	Kentucky River above Frankfort	1979-84	60	3	10	3*	7*	15	29	58
9.0	Kentucky River below Frankfort	1979-84	57	3	10	5*	10	18	30	45
9.3	South Elkhorn Creek near Midway	1982-84	21				90	150	200	
10.0	Kentucky River at Lock 2, at Lockport	1976-86	44	8	10	<1*	2*	6*	30	45
10.1	Eagle Creek at Glencoe	1976-84	71	11	10	4*	7*	14	20	37
Mercury, dissolved										
2.0	North Fork Kentucky River at Jackson	1982-84	13	5	.1		< .1*	.1	.2	
2.3	Middle Fork Kentucky River at Tallega	1982-84	13	4	.1		< .1*	.1	.2	
2.6	South Fork Kentucky River at Booneville	1982-84	13	4	.1		< .1*	.1	.2	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	34	1	.1	.1	.2	.4	.7	1.2
3.1	Red River near Hazel Green	1976-84	37	5	.5	.1*	.2*	.3*	.6	1.5
5.0	Kentucky River at Camp Nelson	1980-84	22	1	.1		.2	.2	.4	
7.0	Kentucky River above Frankfort	1979-84	32	1	.1	.1	.2	.3	.7	2.1
9.0	Kentucky River below Frankfort	1979-84	28	1	.1		.2	.3	.8	
9.3	South Elkhorn Creek near Midway	1982-84	21	7	.1		< .1*	.1	.2	
10.0	Kentucky River at Lock 2, at Lockport	1976-86	24	16	.1		< .1*	< .1*	.2	
10.1	Eagle Creek at Glencoe	1979-84	20	2	.1		.1	.3	1.0	

Table 44.—*Statistical summary of concentrations of major metals and trace elements for selected sites in the Kentucky River basin*—Continued

[N, number of observations; DL, detection limit; *, value estimated from log-normal-fit program; <, less than. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL, in micrograms per liter	Concentration at indicated percentile, in micrograms per liter: 10	25	50 (median)	75	90
Mercury, total										
2.0	North Fork Kentucky River at Jackson	1980-86	37	14	.10	.02*	.05*	.10	.30	.58
2.3	Middle Fork Kentucky River at Tallega	1980-86	35	14	.10	.04*	.06*	.10	.10	.24
2.6	South Fork Kentucky River at Booneville	1980-86	35	15	.10	.02*	.04*	.10	.10	.34
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	68	8	.10	.06*	.10	.30	1.1	2.4
3.1	Red River near Hazel Green	1976-86	71	19	.50	.04*	.10*	.27*	.80	1.8
5.0	Kentucky River at Camp Nelson	1980-86	58	14	.10	.04*	.11*	.25	.90	2.0
7.0	Kentucky River above Frankfort	1979-86	70	10	.10	.06*	.17	.30	.90	2.2
9.0	Kentucky River below Frankfort	1979-85	56	9	.10	.06*	.20	.30	.80	1.9
9.3	South Elkhorn Creek near Midway	1982-86	43	13	.10	.03*	.06*	.10	.20	.36
10.0	Kentucky River at Lock 2, at Lockport	1976-82	24	16	.50		.10*	.16*	.25*	
10.1	Eagle Creek at Glencoe	1979-86	60	11	.10	.05*	.10	.40	1.5	3.0
Nickel, dissolved										
3.0	Kentucky River at Lock 14, at Heidelberg	1979-80	19	3	5		2*	4*	7	
3.1	Red River near Hazel Green	1979-80	18	4	5		1*	2*	6	
7.0	Kentucky River above Frankfort	1979-80	16	4	5		2*	4*	10	
9.0	Kentucky River below Frankfort	1979-80	13	2	2		2*	5	8	
9.3	South Elkhorn Creek near Midway	1982-84	17	1	1		4	7	11	
10.0	Kentucky River at Lock 2, at Lockport	1980-86	26	2	1		<1*	2	3	
10.1	Eagle Creek at Glencoe	1979-80	19	3	5		3*	6	11	
Nickel, total										
2.0	North Fork Kentucky River at Jackson	1982-85	20				4	4	8	
2.3	Middle Fork Kentucky River at Tallega	1982-85	20	4	1		1	2	4	
2.6	South Fork Kentucky River at Booneville	1982-85	20	1	1		1	4	6	
3.0	Kentucky River at Lock 14, at Heidelberg	1984-85	16				2	6	10	
3.1	Red River near Hazel Green	1984-85	15	4	1		<1*	2	5	
5.0	Kentucky River at Camp Nelson	1984-85	16	1	10		3*	4*	6*	
7.0	Kentucky River above Frankfort	1984-85	16	2	10		2*	4*	7*	
9.0	Kentucky River below Frankfort	1984-85	15	3	1		1	3	5	
9.3	South Elkhorn Creek near Midway	1982-85	28	2	1		5	7	10	
10.0	Kentucky River at Lock 2, at Lockport	1980-82	12				3	4	14	
10.1	Eagle Creek at Glencoe	1984-85	18	6	1		<1*	2*	4	

Table 44.—*Statistical summary of concentrations of major metals and trace elements for selected sites in the Kentucky River basin*—Continued

[N, number of observations; DL, detection limit; *, value estimated from log-normal-fit program; <, less than. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL, in micrograms per liter	Concentration at indicated percentile, in micrograms per liter: 10	25	50 (median)	75	90
Selenium, dissolved										
9.3	South Elkhorn Creek near Midway	1982-84	17	17	1		<1	<1	<1	
Selenium, total										
2.0	North Fork Kentucky River at Jackson	1980-85	20	19	1		<1	<1	<1	
2.3	Middle Fork Kentucky River at Tallega	1980-85	20	19	1		<1	<1	<1	
2.6	South Fork Kentucky River at Booneville	1980-85	20	19	1		<1	<1	<1	
3.0	Kentucky River at Lock 14, at Heidelberg	1980-85	28	22	2		<1*	<1*	<1*	
3.1	Red River near Hazel Green	1980-85	29	21	3		<1*	<1*	<1*	
5.0	Kentucky River at Camp Nelson	1981-85	26	21	2		<1	<1	<1	
7.0	Kentucky River above Frankfort	1981-85	27	20	2		<1*	<1*	<1*	
9.0	Kentucky River below Frankfort	1981-85	26	21	1		<1	<1	<1	
9.3	South Elkhorn Creek near Midway	1982-85	27	27	1		<1	<1	<1	
10.0	Kentucky River at Lock 2, at Lockport	1976-82	27	19	1		<1	<1	<1	
10.1	Eagle Creek at Glencoe	1981-85	26	20	1		<1*	<1*	<1*	
Silver, dissolved										
3.0	Kentucky River at Lock 14, at Heidelberg	1979-83	19	12	1		<1*	<1*	1	
7.0	Kentucky River above Frankfort	1979-80	16	11	1		<1	<1	1	
9.3	South Elkhorn Creek near Midway	1982-84	17	15	1		<1	<1	<1	
10.0	Kentucky River at Lock 2, at Lockport	1980-86	28	19	1		<1*	<1*	<1*	
10.1	Eagle Creek at Glencoe	1979-80	19	6	1		<1*	1	1	
Silver, total										
2.0	North Fork Kentucky River at Jackson	1980-85	21	20	1		<1	<1	<1	
2.3	Middle Fork Kentucky River at Tallega	1980-85	21	20	1		<1	<1	<1	
2.6	South Fork Kentucky River at Booneville	1980-85	21	18	1		<1*	<1*	<1*	
3.0	Kentucky River at Lock 14, at Heidelberg	1980-85	30	25	1	<1*	<1*	<1*	<1*	2
3.1	Red River near Hazel Green	1980-85	31	28	1	<1	<1	<1	<1	<1
5.0	Kentucky River at Camp Nelson	1981-85	29	26	1		<1	<1	<1	
7.0	Kentucky River above Frankfort	1981-85	30	27	1	<1*	<1*	<1*	<1*	1*
9.0	Kentucky River below Frankfort	1981-85	30	25	1	<1*	<1*	<1*	<1*	1
9.3	South Elkhorn Creek near Midway	1982-85	28	24	1		<1*	<1*	<1*	
10.0	Kentucky River at Lock 2, at Lockport	1978-82	23	22	1		<1	<1	<1	
10.1	Eagle Creek at Glencoe	1981-85	31	26	1	<1*	<1*	<1*	<1*	2

Table 44. —*Statistical summary of concentrations of major metals and trace elements for selected sites in the Kentucky River basin*—Continued

[N, number of observations; DL, detection limit; *, value estimated from log-normal-fit program; <, less than. 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	USGS station name	Period of record (water years)	N	N less than DL	Maximum DL, in micrograms per liter	Concentration at indicated percentile, in micrograms per liter: 10	25	50 (median)	75	90
Zinc, dissolved										
2.0	North Fork Kentucky River at Jackson	1982-84	13	5	10		2*	4*	14	
2.3	Middle Fork Kentucky River at Tallega	1982-84	11	3	20		3*	7*	32	
2.6	South Fork Kentucky River at Booneville	1982-84	12	3	4		3*	8	17	
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	54	1	1	4	8	20	35	100
3.1	Red River near Hazel Green	1976-84	58	3	20	4*	7*	13*	30	56
5.0	Kentucky River at Camp Nelson	1980-84	42			5	10	16	25	49
7.0	Kentucky River above Frankfort	1979-84	53	4	3	2*	8	18	30	56
9.0	Kentucky River below Frankfort	1979-84	48	1	1	5	8	21	34	46
9.3	South Elkhorn Creek near Midway	1982-84	20				10	24	29	
10.0	Kentucky River at Lock 2, at Lockport	1976-86	39	10	20	<1*	<1*	2*	13*	20
10.1	Eagle Creek at Glencoe	1979-84	56	1	10	6*	10	16	29	47
Zinc, total										
2.0	North Fork Kentucky River at Jackson	1980-86	34			<10	10	20	30	70
2.3	Middle Fork Kentucky River at Tallega	1980-86	33	2	1	<10	<10	20	40	50
2.6	South Fork Kentucky River at Booneville	1980-86	33	3	1	<10*	<10	10	40	60
3.0	Kentucky River at Lock 14, at Heidelberg	1980-86	61	2	1	<10	10	20	40	70
3.1	Red River near Hazel Green	1976-86	70	1	20	<10*	<10*	10*	20	30
5.0	Kentucky River at Camp Nelson	1981-86	64			<10	10	20	30	40
7.0	Kentucky River above Frankfort	1981-86	65			<10	10	20	40	60
9.0	Kentucky River below Frankfort	1981-85	56	1	1	<10	10	20	30	50
9.3	South Elkhorn Creek near Midway	1982-86	41			<10	20	30	70	100
10.0	Kentucky River at Lock 2, at Lockport	1976-82	27	1	20		20	30	50	
10.1	Eagle Creek at Glencoe	1981-86	65			<10	<10	10	20	60

Table 45.—*Estimates of mean annual loads and mean annual yields for water years 1983-85 for major metals and trace elements for selected sites in the Kentucky River basin*

[N, number of observations; tons/mi^2, tons per square mile]

Site number	USGS station name	N	Mean annual load, in tons	Mean annual yield, in tons/mi^2	Standard error of regression	Flow duration of greatest sampled discharge, in percent	Percentage of load estimated beyond range of sampled discharge
Aluminum, total							
2.0	North Fork Kentucky River at Jackson	26	14,000	12.7	69.2	3.9	92.3
2.3	Middle Fork Kentucky River at Tallega	26	374	.696	219	1.7	32.6
2.6	South Fork Kentucky River at Booneville	25	2,680	3.71	177	5.2	89.8
3.0	Kentucky River at Lock 14, at Heidelberg	34	5,600	2.11	73.5	3.1	68.7
3.1	Red River near Hazel Green	34	34.8	.529	101	.5	20.6
5.0	Kentucky River at Camp Nelson	34	7,950	1.80	70.6	1.3	47.1
7.0	Kentucky River above Frankfort	34	11,000	2.08	57.6	1.5	50.8
9.0	Kentucky River below Frankfort	25	9,470	1.75	50.9	4.6	69.6
9.3	South Elkhorn Creek near Midway	26	23.9	.228	144	6.4	49.5
Aluminum, dissolved							
3.0	Kentucky River at Lock 14, at Heidelberg	12	56.6	.021	99.2	3.1	10.0
3.1	Red River near Hazel Green	12	1.6	.024	129	2	13.2
5.0	Kentucky River at Camp Nelson	12	157	.035	95.5	3.1	25.1
7.0	Kentucky River above Frankfort	12	173	.033	156	4.6	16.7
9.0	Kentucky River below Frankfort	12	460	.085	87.0	4.6	36.0
10.0	Kentucky River at Lock 2, at Lockport	16	111	.018	84.3	.4	3.15
Arsenic, dissolved							
3.0	Kentucky River at Lock 14, at Heidelberg	13	51.2	.019	42.4	1.7	12.3
9.3	South Elkhorn Creek near Midway	17	.2	.002	30.8	15.8	41.6
10.0	Kentucky River at Lock 2, at Lockport	42	9.1	.001	55.2	.4	4.39
Arsenic, total							
2.0	North Fork Kentucky River at Jackson	35	1.9	.002	69.7	10.5	61.1
2.6	South Fork Kentucky River at Booneville	34	1.0	.001	67.7	7.2	51.9
3.0	Kentucky River at Lock 14, at Heidelberg	75	6.8	.003	82.3	.6	15.4
3.1	Red River near Hazel Green	84	.1	.001	76.8	.5	12.2
5.0	Kentucky River at Camp Nelson	68	7.8	.002	65.9	1.3	15.4
7.0	Kentucky River above Frankfort	73	9.4	.002	64.3	1.5	16.3
9.0	Kentucky River below Frankfort	64	10.0	.002	76.7	4.6	33.6
9.3	South Elkhorn Creek near Midway	42	.2	.002	66.5	6.4	19.9
10.0	Kentucky River at Lock 2, at Lockport	27	13.9	.002	60.0	2.7	25.0
Barium, dissolved							
3.0	Kentucky River at Lock 14, at Heidelberg	13	44.6	.017	72.7	1.7	8.45
3.1	Red River near Hazel Green	11	.7	.010	64.9	6.5	31.7
9.3	South Elkhorn Creek near Midway	17	7.5	.072	17.0	15.8	52.9
10.0	Kentucky River at Lock 2, at Lockport	36	456	.074	150	.4	5.48

Table 45.—*Estimates of mean annual loads and mean annual yields for water years 1983-85 for major metals and trace elements for selected sites in the Kentucky River basin*—Continued

[N, number of observations; tons/mi², tons per square mile]

Site number	USGS station name	N	Mean annual load, in tons	Mean annual yield, in tons/mi²	Standard error of regression	Flow duration of greatest sampled discharge, in percent	Percentage of load estimated beyond range of sampled discharge
Barium, total							
2.0	North Fork Kentucky River at Jackson	35	91.2	0.083	93.0	10.5	53.3
2.3	Middle Fork Kentucky River at Tallega	35	42.9	.080	93.8	1.7	13.3
2.6	South Fork Kentucky River at Booneville	34	45.1	.062	51.5	7.2	46.1
3.0	Kentucky River at Lock 14, at Heidelberg	43	172	.065	98.2	.6	8.87
3.1	Red River near Hazel Green	45	2.9	.044	66.6	.5	13.1
5.0	Kentucky River at Camp Nelson	43	440	.099	55.3	1.3	13.4
7.0	Kentucky River above Frankfort	44	396	.075	51.6	1.5	14.8
9.0	Kentucky River below Frankfort	35	419	.077	50.4	4.6	30.9
9.3	South Elkhorn Creek near Midway	42	9.3	.088	106	6.4	39.9
Cadmium, dissolved							
3.0	Kentucky River at Lock 14, at Heidelberg	51	4.0	.002	113	1.2	25.0
3.1	Red River near Hazel Green	53	.1	.002	142	.5	12.9
5.0	Kentucky River at Camp Nelson	40	4.7	.001	142	5.1	23.1
7.0	Kentucky River above Frankfort	48	7.2	.001	163	4.2	20.3
9.0	Kentucky River below Frankfort	47	5.4	.001	112	4.6	22.5
10.0	Kentucky River at Lock 2, at Lockport	34	8.3	.001	107	.4	5.37
Cadmium, total							
9.0	Kentucky River below Frankfort	55	9.6	.002	126	4.6	30.7
10.0	Kentucky River at Lock 2, at Lockport	19	24.0	.004	229	2.7	28.3
Chromium, dissolved							
9.3	South Elkhorn Creek near Midway	17	2.6	.025	34.8	15.8	71.3
Chromium, total							
2.0	North Fork Kentucky River at Jackson	36	35.9	.033	137	3.9	73.1
2.3	Middle Fork Kentucky River at Tallega	36	4.6	.009	127	1.7	14.0
2.6	South Fork Kentucky River at Booneville	34	6.5	.009	146	5.2	47.1
3.0	Kentucky River at Lock 14, at Heidelberg	69	11.9	.004	95.6	.6	17.5
3.1	Red River near Hazel Green	76	.3	.004	136	.5	13.2
5.0	Kentucky River at Camp Nelson	66	18.5	.004	100	1.3	17.9
7.0	Kentucky River above Frankfort	71	28.6	.005	102	1.5	20.1
9.0	Kentucky River below Frankfort	62	14.1	.003	85.6	4.6	36.8
9.3	South Elkhorn Creek near Midway	42	1.4	.013	152	6.4	40.8
10.0	Kentucky River at Lock 2, at Lockport	27	106	.017	44.0	2.7	22.6

Table 45.—*Estimates of mean annual loads and mean annual yields for water years 1983-85 for major metals and trace elements for selected sites in the Kentucky River basin*—Continued

[N, number of observations; tons/mi^2, tons per square mile]

Site number	USGS station name	N	Mean annual load, in tons	Mean annual yield, in tons/mi^2	Standard error of regression	Flow duration of greatest sampled discharge, in percent	Percentage of load estimated beyond range of sampled discharge
Copper, dissolved							
2.0	North Fork Kentucky River at Jackson	13	4.1	0.004	68.1	16.7	56.9
2.3	Middle Fork Kentucky River at Tallega	13	1.0	.002	92.7	1.7	7.76
2.6	South Fork Kentucky River at Booneville	11	1.2	.002	93.8	6.2	33.4
3.0	Kentucky River at Lock 14, at Heidelberg	53	17.6	.007	116	1.2	9.55
3.1	Red River near Hazel Green	55	.3	.005	100	.5	9.70
5.0	Kentucky River at Camp Nelson	43	61.3	.014	124	5.1	37.9
7.0	Kentucky River above Frankfort	53	72.0	.014	159	4.2	26.0
9.0	Kentucky River below Frankfort	50	56.9	.010	127	4.6	31.1
9.3	South Elkhorn Creek near Midway	20	.6	.006	85.5	15.8	52.9
10.0	Kentucky River at Lock 2, at Lockport	42	45.8	.007	73.0	.4	5.31
Copper, total							
2.0	North Fork Kentucky River at Jackson	36	30.3	.028	75.9	3.9	76.5
2.3	Middle Fork Kentucky River at Tallega	36	3.3	.006	93.4	1.7	12.8
2.6	South Fork Kentucky River at Booneville	35	5.5	.008	86.9	5.2	48.4
3.0	Kentucky River at Lock 14, at Heidelberg	84	21.3	.008	111	.6	10.3
3.1	Red River near Hazel Green	90	.3	.005	117	.5	11.7
5.0	Kentucky River at Camp Nelson	74	36.1	.008	86.8	1.3	17.1
7.0	Kentucky River above Frankfort	82	47.7	.009	131	1.5	14.3
9.0	Kentucky River below Frankfort	72	44.0	.008	91.2	4.6	34.6
9.3	South Elkhorn Creek near Midway	42	.8	.008	64.9	6.4	39.9
10.0	Kentucky River at Lock 2, at Lockport	27	283	.046	66.8	2.7	30.3
Iron, total							
2.0	North Fork Kentucky River at Jackson	53	19,500	17.7	80.6	.5	66.7
2.3	Middle Fork Kentucky River at Tallega	51	1,670	3.12	60.4	1.1	14.4
2.6	South Fork Kentucky River at Booneville	47	2,060	2.86	68.1	5.2	68.8
3.0	Kentucky River at Lock 14, at Heidelberg	66	10,600	3.98	81.0	.6	36.1
3.1	Red River near Hazel Green	80	121	1.83	75.5	.5	19.1
5.0	Kentucky River at Camp Nelson	64	18,600	4.20	154	1.3	36.6
7.0	Kentucky River above Frankfort	65	13,400	2.54	138	1.5	32.3
9.0	Kentucky River below Frankfort	56	13,400	2.48	106	4.6	57.3
9.3	South Elkhorn Creek near Midway	40	64.3	.613	46.0	6.4	42.2
10.0	Kentucky River at Lock 2, at Lockport	27	15,700	2.53	115	2.7	38.8
Iron, dissolved							
2.0	North Fork Kentucky River at Jackson	33	121	.110	153	.5	5.22
2.3	Middle Fork Kentucky River at Tallega	31	36.2	.067	106	1.1	6.46
2.6	South Fork Kentucky River at Booneville	28	49.7	.069	74.7	7.2	48.8
3.0	Kentucky River at Lock 14, at Heidelberg	67	126	.047	88.1	.6	12.1

Table 45.—*Estimates of mean annual loads and mean annual yields for water years 1983-85 for major metals and trace elements for selected sites in the Kentucky River basin*—Continued

[N, number of observations; tons/mi², tons per square mile]

Site number	USGS station name	N	Mean annual load, in tons	Mean annual yield, in tons/mi²	Standard error of regression	Flow duration of greatest sampled discharge, in percent	Percentage of load estimated beyond range of sampled discharge
Iron, dissolved–Continued							
3.1	Red River near Hazel Green	78	4.3	0.066	83.4	0.5	8.15
5.0	Kentucky River at Camp Nelson	52	211	.048	90.8	5.1	40.8
7.0	Kentucky River above Frankfort	61	211	.040	140	4.2	30.2
9.0	Kentucky River below Frankfort	58	482	.089	121	4.6	37.4
9.3	South Elkhorn Creek near Midway	21	2.5	.024	128	15.8	44.3
10.0	Kentucky River at Lock 2, at Lockport	44	383	.062	136	.4	8.94
Lead, dissolved							
2.0	North Fork Kentucky River at Jackson	13	1.4	.001	60.4	16.7	77.8
2.3	Middle Fork Kentucky River at Tallega	12	1.1	.002	95.2	1.7	12.2
2.6	South Fork Kentucky River at Booneville	13	3.4	.005	122	7.2	62.6
3.0	Kentucky River at Lock 14, at Heidelberg	39	10.2	.004	132	1.2	11.9
3.1	Red River near Hazel Green	42	.3	.004	131	.5	13.1
5.0	Kentucky River at Camp Nelson	36	14.6	.003	195	5.1	18.1
7.0	Kentucky River above Frankfort	42	17.8	.003	173	4.2	19.3
9.0	Kentucky River below Frankfort	41	24.9	.005	239	4.6	22.6
9.3	South Elkhorn Creek near Midway	21	.2	.002	117	15.8	46.5
10.0	Kentucky River at Lock 2, at Lockport	36	23.6	.004	146	.4	5.13
Lead, total							
2.0	North Fork Kentucky River at Jackson	36	13.6	.012	80.5	3.9	64.6
2.3	Middle Fork Kentucky River at Tallega	35	4.6	.009	89.1	1.7	14.9
2.6	South Fork Kentucky River at Booneville	35	13.2	.018	121	5.2	66.9
3.0	Kentucky River at Lock 14, at Heidelberg	69	25.4	.010	132	.6	9.55
3.1	Red River near Hazel Green	75	.5	.008	145	.5	14.1
5.0	Kentucky River at Camp Nelson	66	64.1	.014	159	1.3	9.50
7.0	Kentucky River above Frankfort	71	56.7	.011	177	1.5	13.8
9.0	Kentucky River below Frankfort	63	62.9	.012	226	4.6	26.4
9.3	South Elkhorn Creek near Midway	43	.6	.006	113	6.4	29.2
10.0	Kentucky River at Lock 2, at Lockport	25	124	.020	79.8	2.7	27.6
Manganese, total							
2.0	North Fork Kentucky River at Jackson	53	580	.527	66.6	.5	36.3
2.3	Middle Fork Kentucky River at Tallega	50	108	.202	50.2	1.1	8.79
2.6	South Fork Kentucky River at Booneville	47	156	.217	54.5	5.2	44.3
3.0	Kentucky River at Lock 14, at Heidelberg	64	925	.348	75.4	.6	13.5
3.1	Red River near Hazel Green	79	12.6	.192	62.1	.5	9.12
5.0	Kentucky River at Camp Nelson	62	832	.188	54.0	1.3	15.3
7.0	Kentucky River above Frankfort	64	810	.153	85.1	1.5	15.3
9.0	Kentucky River below Frankfort	55	770	.142	52.7	4.6	36.2
9.3	South Elkhorn Creek near Midway	41	22.3	.213	46.0	6.4	25.7
10.0	Kentucky River at Lock 2, at Lockport	27	2,100	.339	49.3	2.7	36.5

Table 45.—*Estimates of mean annual loads and mean annual yields for water years 1983-85 for major metals and trace elements for selected sites in the Kentucky River basin*—Continued

[N, number of observations; tons/mi², tons per square mile]

Site number	USGS station name	N	Mean annual load, in tons	Mean annual yield, in tons/mi²	Standard error of regression	Flow duration of greatest sampled discharge, in percent	Percentage of load estimated beyond range of sampled discharge
Manganese, dissolved							
2.0	North Fork Kentucky River at Jackson	33	112	0.101	108	0.5	3.26
2.3	Middle Fork Kentucky River at Tallega	30	43.5	.081	65.6	1.1	3.80
2.6	South Fork Kentucky River at Booneville	28	72.4	.100	107	7.2	36.9
3.0	Kentucky River at Lock 14, at Heidelberg	65	322	.121	91.7	.6	8.73
3.1	Red River near Hazel Green	76	9.6	.146	96.4	.5	6.55
5.0	Kentucky River at Camp Nelson	50	211	.048	87.9	5.1	19.3
7.0	Kentucky River above Frankfort	60	113	.021	151	4.2	15.0
9.0	Kentucky River below Frankfort	57	160	.029	122	4.6	21.9
9.3	South Elkhorn Creek near Midway	21	13.2	.126	47.5	15.8	29.7
10.0	Kentucky River at Lock 2, at Lockport	44	212	.034	189	.4	2.92
Mercury, dissolved							
2.0	North Fork Kentucky River at Jackson	13	.2	0	101	16.7	67.2
2.3	Middle Fork Kentucky River at Tallega	13	.2	0	67.4	1.7	6.54
2.6	South Fork Kentucky River at Booneville	13	.2	0	82.0	7.2	58.8
3.0	Kentucky River at Lock 14, at Heidelberg	34	.8	0	103	1.2	10.6
3.1	Red River near Hazel Green	37	0	0	112	.5	10.6
5.0	Kentucky River at Camp Nelson	22	1.8	0	77.3	5.1	38.7
7.0	Kentucky River above Frankfort	32	2.6	0	126	4.2	33.6
9.0	Kentucky River below Frankfort	28	5.0	.001	155	4.6	29.5
9.3	South Elkhorn Creek near Midway	21	0	0	62.3	15.8	49.0
Mercury, total							
2.0	North Fork Kentucky River at Jackson	37	.4	0	170	3.9	31.7
2.3	Middle Fork Kentucky River at Tallega	35	.1	0	79.2	1.7	12.8
2.6	South Fork Kentucky River at Booneville	35	.3	0	123	5.2	59.0
3.0	Kentucky River at Lock 14, at Heidelberg	68	2.0	.001	174	.6	8.60
3.1	Red River near Hazel Green	71	0	0	158	.5	10.8
5.0	Kentucky River at Camp Nelson	58	2.6	.001	127	1.3	13.6
7.0	Kentucky River above Frankfort	70	8.0	.002	171	1.5	16.8
9.0	Kentucky River below Frankfort	56	4.7	.001	170	4.6	30.4
9.3	South Elkhorn Creek near Midway	43	0	0	134	6.4	33.1
Nickel, dissolved							
3.0	Kentucky River at Lock 14, at Heidelberg	19	10.6	.004	55.6	1.7	10.4
3.1	Red River near Hazel Green	18	.2	.004	131	6.5	34.5
7.0	Kentucky River above Frankfort	16	28.2	.005	125	5.8	24.2

Table 45.—*Estimates of mean annual loads and mean annual yields for water years 1983-85 for major metals and trace elements for selected sites in the Kentucky River basin*—Continued

[N, number of observations; tons/mi^2, tons per square mile]

Site number	USGS station name	N	Mean annual load, in tons	Mean annual yield, in tons/mi^2	Standard error of regression	Flow duration of greatest sampled discharge, in percent	Percentage of load estimated beyond range of sampled discharge
Nickel, dissolved–Continued							
9.0	Kentucky River below Frankfort	13	25.7	0.005	122	10	39.1
9.3	South Elkhorn Creek near Midway	17	.5	.005	68.1	15.8	22.5
10.0	Kentucky River at Lock 2, at Lockport	26	20.5	.003	163	.4	4.54
Nickel, total							
2.0	North Fork Kentucky River at Jackson	20	28.8	.026	59.4	3.9	74.3
2.3	Middle Fork Kentucky River at Tallega	20	1.7	.003	71.2	1.7	11.9
2.6	South Fork Kentucky River at Booneville	20	5.6	.008	85.6	5.2	51.0
3.0	Kentucky River at Lock 14, at Heidelberg	16	48.7	.018	77.1	3.1	34.0
3.1	Red River near Hazel Green	16	.9	.013	106	2.0	20.4
5.0	Kentucky River at Camp Nelson	16	55.5	.013	46.8	5.1	39.6
7.0	Kentucky River above Frankfort	16	81.5	.015	105	4.6	30.0
9.0	Kentucky River below Frankfort	16	69.6	.013	85.5	4.6	16.3
9.3	South Elkhorn Creek near Midway	28	.7	.006	83.1	6.4	24.5
10.0	Kentucky River at Lock 2, at Lockport	12	94.6	.015	61.3	2.7	35.3
Zinc, dissolved							
2.0	North Fork Kentucky River at Jackson	13	6.0	.005	209	16.7	56.5
2.3	Middle Fork Kentucky River at Tallega	11	7.1	.013	153	1.7	11.0
2.6	South Fork Kentucky River at Booneville	12	13.7	.019	147	7.2	50.3
3.0	Kentucky River at Lock 14, at Heidelberg	54	51.9	.020	170	1.2	8.41
3.1	Red River near Hazel Green	58	.9	.014	139	.5	9.33
5.0	Kentucky River at Camp Nelson	42	112	.025	175	5.1	29.2
7.0	Kentucky River above Frankfort	53	163	.031	250	4.2	22.0
9.0	Kentucky River below Frankfort	48	179	.033	150	4.6	34.4
9.3	South Elkhorn Creek near Midway	20	1.2	.012	63.9	15.8	39.1
10.0	Kentucky River at Lock 2, at Lockport	39	82.8	.013	306	.4	5.65
Zinc, total							
2.0	North Fork Kentucky River at Jackson	34	99.3	.090	71.0	3.9	68.0
2.3	Middle Fork Kentucky River at Tallega	33	14.3	.027	168	1.7	17.2
2.6	South Fork Kentucky River at Booneville	33	16.3	.023	224	5.2	36.4
3.0	Kentucky River at Lock 14, at Heidelberg	61	100	.038	132	.6	17.8
3.1	Red River near Hazel Green	70	1.2	.018	100	.5	12.2
5.0	Kentucky River at Camp Nelson	64	144	.033	91.9	1.3	16.9
7.0	Kentucky River above Frankfort	65	178	.034	129	1.5	16.9
9.0	Kentucky River below Frankfort	56	147	.027	126	4.6	32.7
9.3	South Elkhorn Creek near Midway	41	4.1	.039	97.0	6.4	17.2
10.0	Kentucky River at Lock 2, at Lockport	27	560	.091	53.9	2.7	32.9

Table 46. — *Trend test results for concentrations of major metals and trace elements for selected sites in the Kentucky River basin*

[N, number of observations; SC, number of seasonal comparisons; P, probability; µg/L, micrograms per liter; *, censored values used in analysis; **, censored values affect trend analysis; decr., decreasing; incr., increasing. 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 reported only as increasing or decreasing]

Site number	USGS station name	Period of record (water years)	N	SC	Results of seasonal Kendall tests for time trend[1]: Trends, unadjusted for flow: P level	Trends, unadjusted for flow: Trend-line slope: Micrograms per liter per year	Trends, unadjusted for flow: Trend-line slope: Percent of median concentration (µg/L) per year	Flow-adjusted trends[2]: P level	Flow-adjusted trends[2]: Trend-line slope: Micrograms per liter per year	Flow-adjusted trends[2]: Trend-line slope: Percent of median concentration (µg/L) per year
Aluminum, total										
2.0	North Fork Kentucky River at Jackson	1984-86	26	12	0.245			0.245		
2.3	Middle Fork Kentucky River at Tallega	1984-86	26	12*	.699					
2.6	South Fork Kentucky River at Booneville	1984-86	25	12*	.245					
3.0	Kentucky River at Lock 14, at Heidelberg	1983-86	34	12	1.00			.433		
3.1	Red River near Hazel Green	1983-86	34	12	.433			.794		
5.0	Kentucky River at Camp Nelson	1983-86	34	12	1.00			.794		
7.0	Kentucky River above Frankfort	1983-86	34	12	1.00			.433		
9.0	Kentucky River below Frankfort	1983-85	25	12	1.00			1.00		
9.3	South Elkhorn Creek near Midway	1984-86	26	12	.245					
10.1	Eagle Creek at Glencoe	1983-86	35	12	1.00					
Arsenic, dissolved										
3.1	Red River near Hazel Green	1976-80	21	20*	1.00					
9.3	South Elkhorn Creek near Midway	1982-84	17	12	1.00			1.00		
10.0	Kentucky River at Lock 2, at Lockport	1976-86	42	44*	.197					
Arsenic, total										
2.0	North Fork Kentucky River at Jackson	1980-86	35	24*	1.00					
2.3	Middle Fork Kentucky River at Tallega	1980-86	35	24**	.006	decr.	decr.			
2.6	South Fork Kentucky River at Booneville	1980-86	34	24*	1.00					
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	75	32*	.008	-.18	-18			
3.1	Red River near Hazel Green	1976-86	84	44*	.204					
5.0	Kentucky River at Camp Nelson	1980-86	68	28*	.076	-.17	-17			
7.0	Kentucky River above Frankfort	1979-86	73	32*	.063	-.00				
9.0	Kentucky River below Frankfort	1979-85	64	32*	.070	-.25	-14			
9.3	South Elkhorn Creek near Midway	1982-86	42	20*	.710					
10.0	Kentucky River at Lock 2, at Lockport	1976-82	27	32*	.394					
10.1	Eagle Creek at Glencoe	1979-86	74	32*	.024					
Barium, dissolved										
3.0	Kentucky River at Lock 14, at Heidelberg	1979-83	13	24*	.248					
9.3	South Elkhorn Creek near Midway	1982-84	17	12	.248					
10.0	Kentucky River at Lock 2, at Lockport	1978-86	36	36**	.663					
Barium, total										
2.0	North Fork Kentucky River at Jackson	1980-86	35	24*	.049	-17	-30			
2.3	Middle Fork Kentucky River at Tallega	1980-86	35	24*	.525					
2.6	South Fork Kentucky River at Booneville	1980-86	34	24*	.751					

Table 46. -- *Trend test results for concentrations of major metals and trace elements for selected sites in the Kentucky River basin* -- Continued

[N, number of observations; SC, number of seasonal comparisons; P, probability; μg/L, micrograms per liter; *, censored values used in analysis; **, censored values affect trend analysis; decr., decreasing; incr., increasing. 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 reported only as increasing or decreasing]

					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	USGS station name	Period of record (water years)	N	SC	P level	Micrograms per liter per year	Percent of median concentration (μg/L) per year	P level	Micrograms per liter per year	Percent of median concentration (μg/L) per year
Barium, total--Continued										
3.0	Kentucky River at Lock 14, at Heidelberg	1980-86	43	24*	0.070	-5.0	-9.8			
3.1	Red River near Hazel Green	1980-86	45	24*	.159	-2.7	-8.3			
5.0	Kentucky River at Camp Nelson	1981-86	43	24	.171	-6.6	-10			
7.0	Kentucky River above Frankfort	1981-86	44	24	.113	-4.5	-8.6			
9.0	Kentucky River below Frankfort	1981-85	35	24	.805					
9.3	South Elkhorn Creek near Midway	1982-86	42	20*	.248					
10.0	Kentucky River at Lock 2, at Lockport	1978-82	19	24**	.151	incr.	incr.			
10.1	Eagle Creek at Glencoe	1981-86	45	24*	.370					
Beryllium, dissolved										
10.0	Kentucky River at Lock 2, at Lockport	1983-86	16	16**	.149	incr.	incr.			
Beryllium, total										
3.0	Kentucky River at Lock 14, at Heidelberg	1981-85	28	20*	.371					
3.1	Red River near Hazel Green	1981-85	29	20*	1.00					
5.0	Kentucky River at Camp Nelson	1981-85	28	20*	1.00					
7.0	Kentucky River above Frankfort	1983-86	29	20*	1.00					
9.0	Kentucky River below Frankfort	1981-85	29	20*	1.00					
10.1	Eagle Creek at Glencoe	1981-85	33	24*	1.00					
Cadmium, dissolved										
2.0	North Fork Kentucky River at Jackson	1980-84	13	16*	1.00					
2.3	Middle Fork Kentucky River at Tallega	1982-84	13	16*	1.00					
2.6	South Fork Kentucky River at Booneville	1982-84	13	16*	1.00					
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	51	28*	.001	-.88	-70			
3.1	Red River near Hazel Green	1976-84	53	40*	.018	-.61	-61			
5.0	Kentucky River at Camp Nelson	1980-84	40	24*	.009	-1.1	-75			
7.0	Kentucky River above Frankfort	1979-84	48	28**	.145	incr.	incr.			
9.0	Kentucky River below Frankfort	1979-84	47	28**	.132	decr.	decr.			
9.3	South Elkhorn Creek near Midway	1982-84	21	16*	1.00					
10.0	Kentucky River at Lock 2, at Lockport	1976-86	34	40*	.283					
10.1	Eagle Creek at Glencoe	1979-84	46	28*	.004	-1.5	-55			
Cadmium, total										
2.0	North Fork Kentucky River at Jackson	1980-86	36	24*	.580					
2.3	Middle Fork Kentucky River at Tallega	1980-86	35	24*	1.00					
2.6	South Fork Kentucky River at Booneville	1980-86	35	24**	.082	decr.	decr.			

Table 46.—*Trend test results for concentrations of major metals and trace elements for selected sites in the Kentucky River basin*—Continued

[N, number of observations; SC, number of seasonal comparisons; P, probability; μg/L, micrograms per liter; *, censored values used in analysis; **, censored values affect trend analysis; decr., decreasing; incr., increasing. 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 reported only as increasing or decreasing]

Site number	USGS station name	Period of record (water years)	N	SC	Trends, unadjusted for flow: P level	Trends, unadjusted for flow: Trend-line slope: Micrograms per liter per year	Trends, unadjusted for flow: Trend-line slope: Percent of median concentration (μg/L) per year	Flow-adjusted trends[2]: P level	Flow-adjusted trends[2]: Trend-line slope: Micrograms per liter per year	Flow-adjusted trends[2]: Trend-line slope: Percent of median concentration (μg/L) per year
Cadmium, total–Continued										
3.0	Kentucky River at Lock 14, at Heidelberg	1980-86	61	24**	0.067	incr.	incr.			
3.1	Red River near Hazel Green	1976-86	68	44*	.027					
5.0	Kentucky River at Camp Nelson	1981-86	62	24**	.007	decr.	decr.			
7.0	Kentucky River above Frankfort	1981-86	62	24*	.001	-0.33	-33			
9.0	Kentucky River below Frankfort	1981-85	55	24**	.063	incr.	incr.			
9.3	South Elkhorn Creek near Midway	1982-86	43	20**	.009	decr.	decr.			
10.0	Kentucky River at Lock 2, at Lockport	1976-82	19	32**	.877					
10.1	Eagle Creek at Glencoe	1981-86	57	24**	.001	decr.	decr.			
Chromium, dissolved										
9.3	South Elkhorn Creek near Midway	1982-84	17	12*	1.00					
10.0	Kentucky River at Lock 2, at Lockport	1977-86	35	40**	1.00					
Chromium, total										
2.0	North Fork Kentucky River at Jackson	1980-86	36	24*	.057	-3.3	-73			
2.3	Middle Fork Kentucky River at Tallega	1980-86	36	24*	.067	-2.1	-61			
2.6	South Fork Kentucky River at Booneville	1980-86	34	24*	.067	-2.3	-58			
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	69	32*	.251					
3.1	Red River near Hazel Green	1976-86	76	44**	.019	incr.	incr.			
5.0	Kentucky River at Camp Nelson	1981-86	66	24*	.912					
7.0	Kentucky River above Frankfort	1979-86	71	32*	.171					
9.0	Kentucky River below Frankfort	1979-85	62	32*	.017	-.20	-10			
9.3	South Elkhorn Creek near Midway	1982-86	42	20*	.019	-3.7	-62			
10.0	Kentucky River at Lock 2, at Lockport	1976-82	27	32*	.929					
10.1	Eagle Creek at Glencoe	1979-86	73	32*	.589					
Copper, dissolved										
2.0	North Fork Kentucky River at Jackson	1982-84	13	16*	.427					
2.3	Middle Fork Kentucky River at Tallega	1982-84	13	16*	.268					
2.6	South Fork Kentucky River at Booneville	1982-84	11	12*	1.00					
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	53	28*	.616					
3.1	Red River near Hazel Green	1977-84	55	36*	.621					
5.0	Kentucky River at Camp Nelson	1980-84	43	24*	1.00					
7.0	Kentucky River above Frankfort	1979-84	53	28*	.418					
9.0	Kentucky River below Frankfort	1979-84	50	28**	.211					
9.3	South Elkhorn Creek near Midway	1982-84	20	12*	1.00					
10.0	Kentucky River at Lock 2, at Lockport	1976-86	42	44*	.454					
10.1	Eagle Creek at Glencoe	1979-84	56	28*	.175	-1.0	-13			

Table 46.—*Trend test results for concentrations of major metals and trace elements for selected sites in the Kentucky River basin*—Continued

[N, number of observations; SC, number of seasonal comparisons; P, probability; µg/L, micrograms per liter; *, censored values used in analysis; **, censored values affect trend analysis; decr., decreasing; incr., increasing. 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 reported only as increasing or decreasing]

Site number	USGS station name	Period of record (water years)	N	SC	Results of seasonal Kendall tests for time trend[1]: Trends, unadjusted for flow: P level	Trend-line slope: Micrograms per liter per year	Trend-line slope: Percent of median concentration (µg/L) per year	Flow-adjusted trends[2]: P level	Trend-line slope: Micrograms per liter per year	Trend-line slope: Percent of median concentration (µg/L) per year
Copper, total recoverable										
2.0	North Fork Kentucky River at Jackson	1980-86	36	24*	0.077	-2.0	-50			
2.3	Middle Fork Kentucky River at Tallega	1980-86	36	24*	.037	-.75	-25			
2.6	South Fork Kentucky River at Booneville	1980-86	35	24*	.057	-2.3	-67			
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	84	32*	.013	-.79	-14			
3.1	Red River near Hazel Green	1976-86	90	44*	.006	-.33	-9.5			
5.0	Kentucky River at Camp Nelson	1980-86	74	28*	.034	-.67	-13			
7.0	Kentucky River above Frankfort	1979-86	82	32*	.006	-1.0	-17			
9.0	Kentucky River below Frankfort	1979-85	72	32*	.028	-.50	-10			
9.3	South Elkhorn Creek near Midway	1982-86	42	20*	.026	-1.7	-48			
10.0	Kentucky River at Lock 2, at Lockport	1976-82	27	32*	.244					
10.1	Eagle Creek at Glencoe	1979-86	86	32*	.083	-.45	-9.0			
Iron, total										
2.0	North Fork Kentucky River at Jackson	1979-86	53	32	.030	-210	-14	0.132	-150	-9.8
2.3	Middle Fork Kentucky River at Tallega	1979-86	51	32	.003	-270	-19	.000	-240	-17
2.6	South Fork Kentucky River at Booneville	1979-86	47	32	.070	-60	-9.5	.302		
3.0	Kentucky River at Lock 14, at Heidelberg	1980-86	66	28	.046	-97	-16	.281		
3.1	Red River near Hazel Green	1979-86	80	32	.570			.156	-35	-4.6
5.0	Kentucky River at Camp Nelson	1981-86	64	24	.843			.843		
7.0	Kentucky River above Frankfort	1981-86	65	24	.618			.428		
9.0	Kentucky River below Frankfort	1981-85	56	24	.713			.270		
9.3	South Elkhorn Creek near Midway	1982-86	40	20	.051	-68	-19			
10.0	Kentucky River at Lock 2, at Lockport	1976-82	27	32	.213			.561		
10.1	Eagle Creek at Glencoe	1976-86	73	44	.387					
Iron, dissolved										
2.0	North Fork Kentucky River at Jackson	1979-84	33	28*	1.00					
2.3	Middle Fork Kentucky River at Tallega	1979-84	31	28*	.525					
2.6	South Fork Kentucky River at Booneville	1979-84	28	28*	.014	-18	-29			
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	67	28*	.000	-15	-30			
3.1	Red River near Hazel Green	1979-84	78	28	.090	-19	-16	.029	-23	-19
5.0	Kentucky River at Camp Nelson	1980-84	52	24	.090	-11	-29	.050	-7.7	-21
7.0	Kentucky River above Frankfort	1979-84	61	28*	.007	-9.2	-22			
9.0	Kentucky River below Frankfort	1979-84	58	28	.056	-6.5	-16	.246		
9.3	South Elkhorn Creek near Midway	1982-84	21	16*	.488					
10.0	Kentucky River at Lock 2, at Lockport	1976-86	44	44*	.703					
10.1	Eagle Creek at Glencoe	1976-84	73	40*	.269					

Table 46.—*Trend test results for concentrations of major metals and trace elements for selected sites in the Kentucky River basin*—Continued

[N, number of observations; SC, number of seasonal comparisons; P, probability; µg/L, micrograms per liter; *, censored values used in analysis; **, censored values affect trend analysis; decr., decreasing; incr., increasing. 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 reported only as increasing or decreasing]

					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	USGS station name	Period of record (water years)	N	SC	P level	Micrograms per liter per year	Percent of median concentration (µg/L) per year	P level	Micrograms per liter per year	Percent of median concentration (µg/L) per year
Lead, dissolved										
2.0	North Fork Kentucky River at Jackson	1982-84	13	16*	0.427					
2.3	Middle Fork Kentucky River at Tallega	1982-84	12	16*	1.00					
2.6	South Fork Kentucky River at Booneville	1982-84	13	16**	.194	decr.	decr.			
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	39	28*	.002	-3.3	-33			
3.1	Red River near Hazel Green	1976-84	42	40*	.126	-.84	-17			
5.0	Kentucky River at Camp Nelson	1980-84	36	24*	.032	-5.5	-76			
7.0	Kentucky River above Frankfort	1979-84	42	28*	.007	-2.3	-34			
9.0	Kentucky River below Frankfort	1979-84	41	28*	.013	-4.1	-45			
9.3	South Elkhorn Creek near Midway	1982-84	21	16*	1.00					
10.0	Kentucky River at Lock 2, at Lockport	1976-86	36	40*	.098	-.25	-9.1			
10.1	Eagle Creek at Glencoe	1979-84	45	28*	.002	-9.7	-98			
Lead, total										
2.0	North Fork Kentucky River at Jackson	1980-86	36	24*	.077	-1.4	-42			
2.3	Middle Fork Kentucky River at Tallega	1980-86	35	24*	.204					
2.6	South Fork Kentucky River at Booneville	1980-86	35	24*	.134	-1.0	-21			
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	69	32*	.000	-3.2	-33			
3.1	Red River near Hazel Green	1976-86	75	44*	.001	-1.4	-20			
5.0	Kentucky River at Camp Nelson	1980-86	66	28*	.001	-2.8	-31			
7.0	Kentucky River above Frankfort	1979-86	71	32*	.000	-3.7	-37			
9.0	Kentucky River below Frankfort	1979-85	63	32*	.000	-4.0	-33			
9.3	South Elkhorn Creek near Midway	1982-86	43	20*	.051	-1.5	-37			
10.0	Kentucky River at Lock 2, at Lockport	1976-82	25	32	.925					
10.1	Eagle Creek at Glencoe	1979-86	75	32*	.000	-5.5	-55			
Manganese, total										
2.0	North Fork Kentucky River at Jackson	1979-86	53	32	.272			0.503		
2.3	Middle Fork Kentucky River at Tallega	1979-86	50	32	.206			.156	-4.2	-3.5
2.6	South Fork Kentucky River at Booneville	1979-86	47	32	.377			.731		
3.0	Kentucky River at Lock 14, at Heidelberg	1980-86	64	28	.678			1.00		
3.1	Red River near Hazel Green	1979-86	79	32	.253			.156	4.5	2.9
5.0	Kentucky River at Camp Nelson	1981-86	62	24	.317			.552		
7.0	Kentucky River above Frankfort	1981-86	64	24	.130	-5.0	-8.3	.843		
9.0	Kentucky River below Frankfort	1981-85	55	24	.903			.903		
9.3	South Elkhorn Creek near Midway	1982-86	41	20	.869			.515		
10.0	Kentucky River at Lock 2, at Lockport	1976-82	27	32	.667			.159	8.4	9.3
10.1	Eagle Creek at Glencoe	1976-86	74	44*	.812					

Table 46. —*Trend test results for concentrations of major metals and trace elements for selected sites in the Kentucky River basin* —Continued

[N, number of observations; SC, number of seasonal comparisons; P, probability; μg/L, micrograms per liter; *, censored values used in analysis; **, censored values affect trend analysis; decr., decreasing; incr., increasing. 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 reported only as increasing or decreasing]

Site number	USGS station name	Period of record (water years)	N	SC	Results of seasonal Kendall tests for time trend[1]: Trends, unadjusted for flow: P level	Trend-line slope: Micrograms per liter per year	Trend-line slope: Percent of median concentration (μg/L) per year	Flow-adjusted trends[2]: P level	Trend-line slope: Micrograms per liter per year	Trend-line slope: Percent of median concentration (μg/L) per year
Manganese, dissolved										
2.0	North Fork Kentucky River at Jackson	1979-84	33	28**	1.00					
2.3	Middle Fork Kentucky River at Tallega	1979-84	30	28	.675			1.00		
2.6	South Fork Kentucky River at Booneville	1979-84	28	28*	1.00					
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	65	28	.234			.165	-8.6	-13
3.1	Red River near Hazel Green	1979-84	76	28	.135	7.2	7.2	.165	8.6	8.6
5.0	Kentucky River at Camp Nelson	1980-84	50	24*	1.00					
7.0	Kentucky River above Frankfort	1979-84	60	28*	.485					
9.0	Kentucky River below Frankfort	1979-84	57	28*	.241					
9.3	South Elkhorn Creek near Midway	1982-84	21	16	1.00			.166	11	7.4
10.0	Kentucky River at Lock 2, at Lockport	1976-86	44	44**	.951					
10.1	Eagle Creek at Glencoe	1976-84	71	40*	.745					
Mercury, dissolved										
2.0	North Fork Kentucky River at Jackson	1982-84	13	16*	.427					
2.3	Middle Fork Kentucky River at Tallega	1982-84	13	16*	1.00					
2.6	South Fork Kentucky River at Booneville	1982-84	13	16*	1.00					
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	34	28*	.074	-.07	-18			
3.1	Red River near Hazel Green	1976-84	37	40*	.699					
5.0	Kentucky River at Camp Nelson	1980-84	22	24*	.558					
7.0	Kentucky River above Frankfort	1979-84	32	28*	.089	-.10	-29			
9.0	Kentucky River below Frankfort	1979-84	28	24*	.026	-.10	-25			
9.3	South Elkhorn Creek near Midway	1982-84	21	16*	.166	.05	50			
10.0	Kentucky River at Lock 2, at Lockport	1976-86	37	44**	.646					
10.1	Eagle Creek at Glencoe	1979-84	20	28*	.332					
Mercury, total recoverable										
2.0	North Fork Kentucky River at Jackson	1980-86	37	24*	.868					
2.3	Middle Fork Kentucky River at Tallega	1980-86	35	24**	.391					
2.6	South Fork Kentucky River at Booneville	1980-86	35	24*	.499					
3.0	Kentucky River at Lock 14, at Heidelberg	1979-86	68	32*	.001	-.10	-24			
3.1	Red River near Hazel Green	1976-86	71	44*	.083	-.04	-11			
5.0	Kentucky River at Camp Nelson	1980-86	58	28*	.002	-.13	-42			
7.0	Kentucky River above Frankfort	1979-86	70	32*	.000	-.15	-30			
9.0	Kentucky River below Frankfort	1979-85	56	32*	.001	-.13	-31			
9.3	South Elkhorn Creek near Midway	1982-86	43	20*	.860					
10.0	Kentucky River at Lock 2, at Lockport	1976-82	24	32**	1.00					
10.1	Eagle Creek at Glencoe	1979-86	60	32*	.058	-.13	-33			

Table 46. —*Trend test results for concentrations of major metals and trace elements for selected sites in the Kentucky River basin* —Continued

[N, number of observations; SC, number of seasonal comparisons; P, probability; μg/L, micrograms per liter; *, censored values used in analysis; **, censored values affect trend analysis; decr., decreasing; incr., increasing. 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 reported only as increasing or decreasing]

					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	USGS station name	Period of record (water years)	N	SC	P level	Micrograms per liter per year	Percent of median concentration (μg/L) per year	P level	Micrograms per liter per year	Percent of median concentration (μg/L) per year
Nickel, dissolved										
3.0	Kentucky River at Lock 14, at Heidelberg	1979-80	19	12*	1.00					
3.1	Red River near Hazel Green	1979-80	18	12**	1.00					
7.0	Kentucky River above Frankfort	1979-80	16	12**	1.00					
9.0	Kentucky River below Frankfort	1979-80	13	12*	1.00					
9.3	South Elkhorn Creek near Midway	1982-84	17	12*	1.00					
10.0	Kentucky River at Lock 2, at Lockport	1980-86	26	28*	.200					
10.1	Eagle Creek at Glencoe	1979-80	19	12*	.248					
Nickel, total										
2.0	North Fork Kentucky River at Jackson	1982-85	20	16	.488			0.326		
2.3	Middle Fork Kentucky River at Tallega	1982-85	20	16*	.102	-1.4	-55			
2.6	South Fork Kentucky River at Booneville	1982-85	20	16*	.102	-2.7	-69			
9.3	South Elkhorn Creek near Midway	1982-85	28	16*	.343					
10.0	Kentucky River at Lock 2, at Lockport	1980-82	12	16	1.00			.794		
10.1	Eagle Creek at Glencoe	1984-85	19	12*	1.00					
Selenium, dissolved										
9.3	South Elkhorn Creek near Midway	1982-84	17	12*	1.00					
10.0	Kentucky River at Lock 2, at Lockport	1976-86	42	44*	.935					
Selenium, total										
2.0	North Fork Kentucky River at Jackson	1980-85	20	20*	1.00					
2.3	Middle Fork Kentucky River at Tallega	1980-85	20	20*	1.00					
2.6	South Fork Kentucky River at Booneville	1980-85	20	20*	1.00					
3.0	Kentucky River at Lock 14, at Heidelberg	1980-85	28	20*	.546					
3.1	Red River near Hazel Green	1980-85	29	20*	.473					
5.0	Kentucky River at Camp Nelson	1981-85	27	20*	.652					
7.0	Kentucky River above Frankfort	1981-85	28	20*	.840					
9.0	Kentucky River below Frankfort	1981-85	28	20*	.806					
9.3	South Elkhorn Creek near Midway	1982-85	27	16*	1.00					
10.0	Kentucky River at Lock 2, at Lockport	1976-86	27	32*	.558					
10.1	Eagle Creek at Glencoe	1981-85	29	20*	.840					
Silver, dissolved										
3.0	Kentucky River at Lock 14, at Heidelberg	1979-83	19	24*	1.00					
3.1	Red River near Hazel Green	1979-86	17	12*	1.00					
7.0	Kentucky River above Frankfort	1979-80	16	12**	.480					

Table 46.—*Trend test results for concentrations of major metals and trace elements for selected sites in the Kentucky River basin*—Continued

[N, number of observations; SC, number of seasonal comparisons; P, probability; μg/L, micrograms per liter; *, censored values used in analysis; **, censored values affect trend analysis; decr., decreasing; incr., increasing. 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 reported only as increasing or decreasing]

Site number	USGS station name	Period of record (water years)	N	SC	Results of seasonal Kendall tests for time trend[1]: Trends, unadjusted for flow: P level	Trend-line slope: Micrograms per liter per year	Trend-line slope: Percent of median concentration (μg/L) per year	Flow-adjusted trends[2]: P level	Trend-line slope: Micrograms per liter per year	Trend-line slope: Percent of median concentration (μg/L) per year
Silver, dissolved–Continued										
9.0	Kentucky River below Frankfort	1979-80	13	12**	1.00					
9.3	South Elkhorn Creek near Midway	1982-84	17	12*	1.00					
10.0	Kentucky River at Lock 2, at Lockport	1980-86	28	28**	1.00					
10.1	Eagle Creek at Glencoe	1979-80	19	12*	1.00					
Silver, total										
2.0	North Fork Kentucky River at Jackson	1980-85	21	20*	.371					
2.3	Middle Fork Kentucky River at Tallega	1980-85	21	20*	1.00					
2.6	South Fork Kentucky River at Booneville	1980-85	21	20*	1.00					
3.0	Kentucky River at Lock 14, at Heidelberg	1980-85	30	20*	1.00					
3.1	Red River near Hazel Green	1980-85	31	20*	1.00					
5.0	Kentucky River at Camp Nelson	1981-85	29	20*	1.00					
7.0	Kentucky River above Frankfort	1981-85	30	20*	1.00					
9.0	Kentucky River below Frankfort	1981-85	30	20*	1.00					
9.3	South Elkhorn Creek near Midway	1982-85	28	16*	.540					
10.0	Kentucky River at Lock 2, at Lockport	1980-82	15	16**	1.00					
10.1	Eagle Creek at Glencoe	1981-85	31	20*	.529					
Zinc, dissolved										
2.0	North Fork Kentucky River at Jackson	1982-84	13	16*	1.00					
2.3	Middle Fork Kentucky River at Tallega	1982-84	11	16*	1.00					
2.6	South Fork Kentucky River at Booneville	1982-84	12	16*	.268					
3.0	Kentucky River at Lock 14, at Heidelberg	1979-84	54	28*	.622					
3.1	Red River near Hazel Green	1976-84	58	40*	.383					
5.0	Kentucky River at Camp Nelson	1980-84	42	24	.646					
7.0	Kentucky River above Frankfort	1979-84	53	28*	.306					
9.0	Kentucky River below Frankfort	1979-84	48	28*	.178	-1.6	-7.5			
9.3	South Elkhorn Creek near Midway	1982-84	20	12	.401			0.401		
10.0	Kentucky River at Lock 2, at Lockport	1976-86	39	44**	.911					
10.1	Eagle Creek at Glencoe	1979-84	56	28*	.426					
Zinc, total										
2.0	North Fork Kentucky River at Jackson	1980-86	34	24	.272			.433		
2.3	Middle Fork Kentucky River at Tallega	1980-86	33	24*	.421					
2.6	South Fork Kentucky River at Booneville	1980-86	33	24*	.272					
3.0	Kentucky River at Lock 14, at Heidelberg	1980-86	61	24*	.011	<u>-5.7</u>	<u>-32</u>			
3.1	Red River near Hazel Green	1976-86	70	44*	.360					

Table 46. – *Trend test results for concentrations of major metals and trace elements for selected sites in the Kentucky River basin* – Continued

[N, number of observations; SC, number of seasonal comparisons; P, probability; μg/L, micrograms per liter; *, censored values used in analysis; **, censored values affect trend analysis; decr., decreasing; incr., increasing. 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 reported only as increasing or decreasing]

					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	USGS station name	Period of record (water years)	N	SC	P level	Micrograms per liter per year	Percent of median concentration (μg/L) per year	P level	Micrograms per liter per year	Percent of median concentration (μg/L) per year
Zinc, total–Continued										
5.0	Kentucky River at Camp Nelson	1981-86	64	24	0.195	-1.0	-6.2	0.428		
7.0	Kentucky River above Frankfort	1981-86	65	24	.921					
9.0	Kentucky River below Frankfort	1981-85	56	24*	.323					
9.3	South Elkhorn Creek near Midway	1982-86	41	20	.069	<u>-14</u>	<u>-56</u>	.009	<u>-13</u>	<u>-53</u>
10.0	Kentucky River at Lock 2, at Lockport	1976-82	27	32*	.225					
10.1	Eagle Creek at Glencoe	1981-86	65	24	.481					

[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 (1) 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 (2) 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.

Table 47.—*Number of major metals and trace elements measurements made at selected sites in the Kentucky River basin and percentage not meeting indicated water-quality criteria, based on available data for water years 1976-86*

[Censored values greater than the water-quality criteria were not included in the percentage computations]

U.S. ENVIRONMENTAL PROTECTION AGENCY

MCL = maximum contaminant level
MCLG = maximum contaminant level goal
PMCLG = proposed MCLG
SMCL = secondary MCL
ALA = aquatic life acute
ALC = aquatic life chronic

KENTUCKY

KYDWS = domestic water supply
KYAH = warmwater aquatic habitat
KYR = recreational waters

Site number	USGS station name	No. of measurements	Percentage not meeting indicated criteria								
			MCL	MCLG	PMCLG	SMCL	ALA	ALC	KYDWS	KYAH	KYR
Arsenic, total											
3.0	Kentucky River at Lock 14, at Heidelberg	75	1		1					1	
10.0	Kentucky River at Lock 2, at Lockport	101	1		1					1	
Cadmium, total recoverable											
2.0	North Fork Kentucky River at Jackson	36			3		3	6			
2.3	Middle Fork Kentucky River at Tallega	35						11			
2.6	South Fork Kentucky River at Booneville	35						11			
3.0	Kentucky River at Lock 14, at Heidelberg	61	2		7		10	19		2	
3.1	Red River near Hazel Green	68	3		4		6	26		3	
5.0	Kentucky River at Camp Nelson	62	10		13		18	25		8	
7.0	Kentucky River above Frankfort	62	11		13		16	28		10	
9.0	Kentucky River below Frankfort	55	14		20		20	33		14	
9.3	South Elkhorn Creek near Midway	43					2	19			
10.1	Eagle Creek at Glencoe	74	1		1		1	35		5	
Chromium, total recoverable											
3.1	Red River near Hazel Green	76	1						1		
Copper, total recoverable											
2.0	North Fork Kentucky River at Jackson	36					6	8			
2.3	Middle Fork Kentucky River at Tallega	36					3	6			
2.6	South Fork Kentucky River at Booneville	35					3	6			
3.0	Kentucky River at Lock 14, at Heidelberg	84					7	16			
3.1	Red River near Hazel Green	90					3	11			
5.0	Kentucky River at Camp Nelson	74					3	8			
7.0	Kentucky River above Frankfort	82					17	21			
9.0	Kentucky River below Frankfort	72					4	8			
10.0	Kentucky River at Lock 2, at Lockport	27					35	46			
10.1	Eagle Creek at Glencoe	86					7	10			
Iron, total recoverable											
0.1	Yonts Fork near Neon	13				77		54		54	
1.0	North Fork Kentucky River at Hazard	18				100		72		72	
2.0	North Fork Kentucky River at Jackson	53				96		58		58	
2.1	Middle Fork Kentucky River near Hyden	21				100		52		52	
2.3	Middle Fork Kentucky River at Tallega	51				92		47		47	
2.5	Goose Creek at Manchester	19				100		84		84	
2.6	South Fork Kentucky River at Booneville	47				87		28		28	

Table 47.—*Number of major metals and trace elements measurements made at selected sites in the Kentucky River basin and percentage not meeting indicated water-quality criteria, based on available data for water years 1976-86*—Continued

[Censored values greater than the water-quality criteria were not included in the percentage computations]

U.S. ENVIRONMENTAL PROTECTION AGENCY		KENTUCKY
MCL = maximum contaminant level	SMCL = secondary MCL	KYDWS = domestic water supply
MCLG = maximum contaminant level goal	ALA = aquatic life acute	KYAH = warmwater aquatic habitat
PMCLG = proposed MCLG	ALC = aquatic life chronic	KYR = recreational waters

Site number	USGS station name	No. of measure-ments	Percentage not meeting indicated criteria								
			MCL	MCLG	PMCLG	SMCL	ALA	ALC	KYDWS	KYAH	KYR
Iron, total recoverable–Continued											
3.0	Kentucky River at Lock 14, at Heidelberg	66				80		30		30	
3.1	Red River near Hazel Green	80				94		35		35	
5.0	Kentucky River at Camp Nelson	64				59		28		28	
7.0	Kentucky River above Frankfort	65				57		25		25	
9.0	Kentucky River below Frankfort	56				59		25		25	
9.3	South Elkhorn Creek near Midway	40				70		2		2	
10.0	Kentucky River at Lock 2, at Lockport	27				96		52		52	
10.1	Eagle Creek at Glencoe	73				73		34		34	
Lead, total recoverable											
2.0	North Fork Kentucky River at Jackson	36			100			50			
2.3	Middle Fork Kentucky River at Tallega	35			100			49			
2.6	South Fork Kentucky River at Booneville	35	3		100		3	60	3		
3.0	Kentucky River at Lock 14, at Heidelberg	69	9		100		4	70	9		
3.1	Red River near Hazel Green	75	7		100		4	58	7		
5.0	Kentucky River at Camp Nelson	66	12		100		12	81	12		
7.0	Kentucky River above Frankfort	71	13		100		8	68	13		
9.0	Kentucky River below Frankfort	63	22		100		19	73	22		
9.3	South Elkhorn Creek near Midway	43			100			58			
10.0	Kentucky River at Lock 2, at Lockport	25			100			96			
10.1	Eagle Creek at Glencoe	75	23		100		19	66	23		
Manganese, total recoverable											
0.1	Yonts Fork near Neon	13				100			100		
1.0	North Fork Kentucky River at Hazard	18				94			94		
2.0	North Fork Kentucky River at Jackson	53				94			94		
2.1	Middle Fork Kentucky River near Hyden	21				86			86		
2.3	Middle Fork Kentucky River at Tallega	50				96			96		
2.5	Goose Creek at Manchester	19				100			100		
2.6	South Fork Kentucky River at Booneville	47				92			92		
3.0	Kentucky River at Lock 14, at Heidelberg	64				94			94		
3.1	Red River near Hazel Green	79				99			99		
5.0	Kentucky River at Camp Nelson	62				76			76		
7.0	Kentucky River above Frankfort	64				56			56		
9.0	Kentucky River below Frankfort	55				64			64		
9.3	South Elkhorn Creek near Midway	41				100			100		
10.0	Kentucky River at Lock 2, at Lockport	27				96			96		
10.1	Eagle Creek at Glencoe	74				57			57		

Table 47.—*Number of major metals and trace elements measurements made at selected sites in the Kentucky River basin and percentage not meeting indicated water-quality criteria, based on available data for water years 1976-86*—Continued

[Censored values greater than the water-quality criteria were not included in the percentage computations]

U.S. ENVIRONMENTAL PROTECTION AGENCY

MCL = maximum contaminant level
MCLG = maximum contaminant level goal
PMCLG = proposed MCLG
SMCL = secondary MCL
ALA = aquatic life acute
ALC = aquatic life chronic

KENTUCKY

KYDWS = domestic water supply
KYAH = warmwater aquatic habitat
KYR = recreational waters

Site number	USGS station name	No. of measure-ments	Percentage not meeting indicated criteria								
			MCL	MCLG	PMCLG	SMCL	ALA	ALC	KYDWS	KYAH	KYR
Mercury, total recoverable											
2.0	North Fork Kentucky River at Jackson	37	5		3		5	100		30	
2.3	Middle Fork Kentucky River at Tallega	35						100		14	
2.6	South Fork Kentucky River at Booneville	35	3		3		3	100		17	
3.0	Kentucky River at Lock 14, at Heidelberg	68	10		9		9	100		56	
3.1	Red River near Hazel Green	71	4		3		3	100		54	
5.0	Kentucky River at Camp Nelson	58	9		5		7	100		50	
7.0	Kentucky River above Frankfort	70	10		6		9	100		64	
9.0	Kentucky River below Frankfort	56	7		4		7	100		64	
9.3	South Elkhorn Creek near Midway	43	5		5		5	100		26	
10.0	Kentucky River at Lock 2, at Lockport	24						100		60	
10.1	Eagle Creek at Glencoe	60	15		8		13	100		57	
Silver, total recoverable											
2.0	North Fork Kentucky River at Jackson	21						100			
2.6	South Fork Kentucky River at Booneville	21						67			
3.0	Kentucky River at Lock 14, at Heidelberg	30						80			
3.1	Red River near Hazel Green	31						100			
5.0	Kentucky River at Camp Nelson	29						100			
7.0	Kentucky River above Frankfort	30						100			
9.0	Kentucky River below Frankfort	30						100			
9.3	South Elkhorn Creek near Midway	28						100			
10.0	Kentucky River at Lock 2, at Lockport	15						9			
10.1	Eagle Creek at Glencoe	31						100			
Zinc, total recoverable											
2.0	North Fork Kentucky River at Jackson	34						18		18	
2.3	Middle Fork Kentucky River at Tallega	33						15		15	
2.6	South Fork Kentucky River at Booneville	33						12		12	
3.0	Kentucky River at Lock 14, at Heidelberg	61						20		20	
3.1	Red River near Hazel Green	70						3		3	
5.0	Kentucky River at Camp Nelson	64						8		8	
7.0	Kentucky River above Frankfort	65						14		14	
9.0	Kentucky River below Frankfort	56						9		9	
9.3	South Elkhorn Creek near Midway	41						34		34	
10.0	Kentucky River at Lock 2, at Lockport	27						37		37	
10.1	Eagle Creek at Glencoe	65					2	12		12	

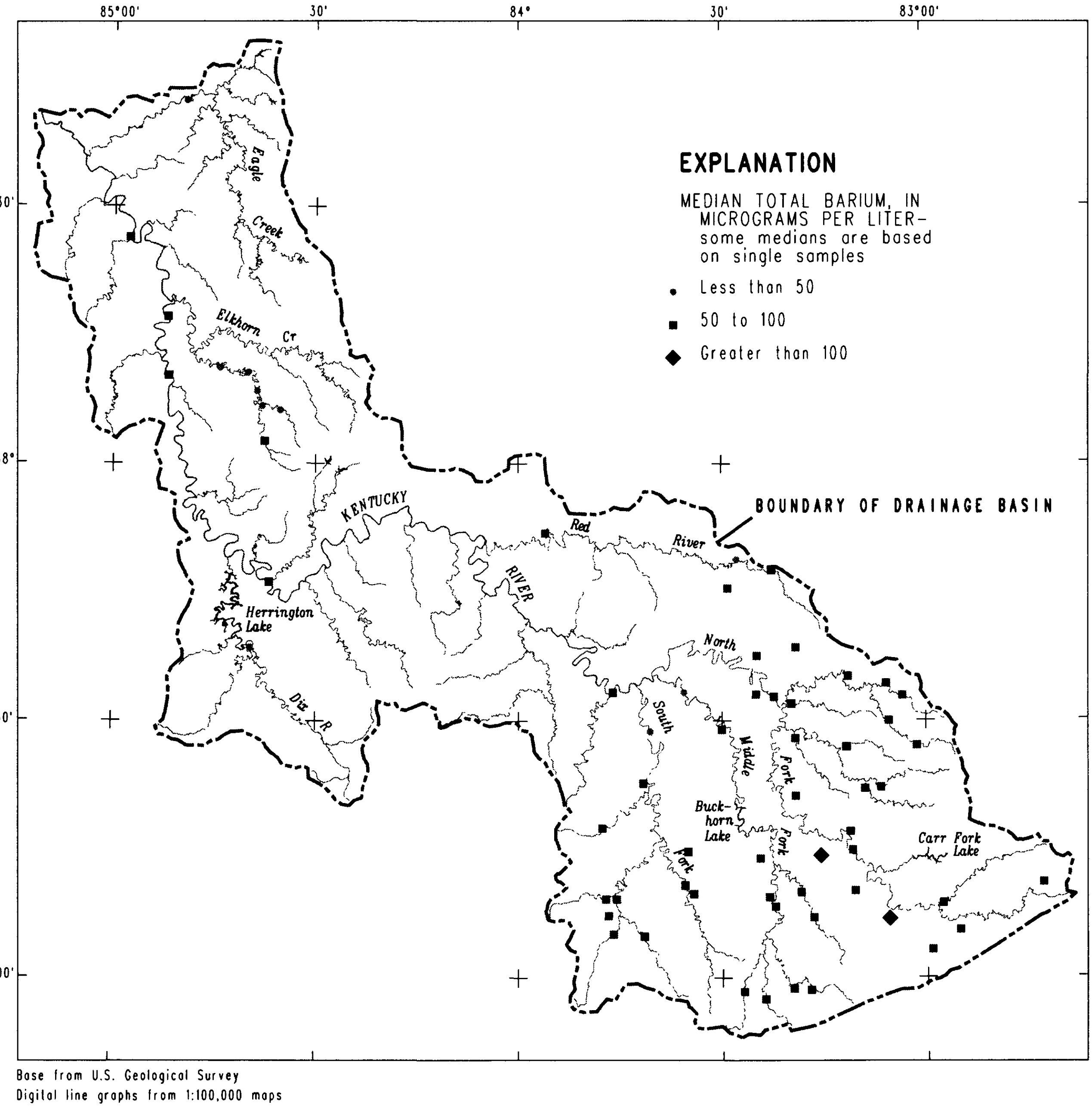


Figure 43.--Median concentrations of total barium at sites in the Kentucky River basin, through 1986.

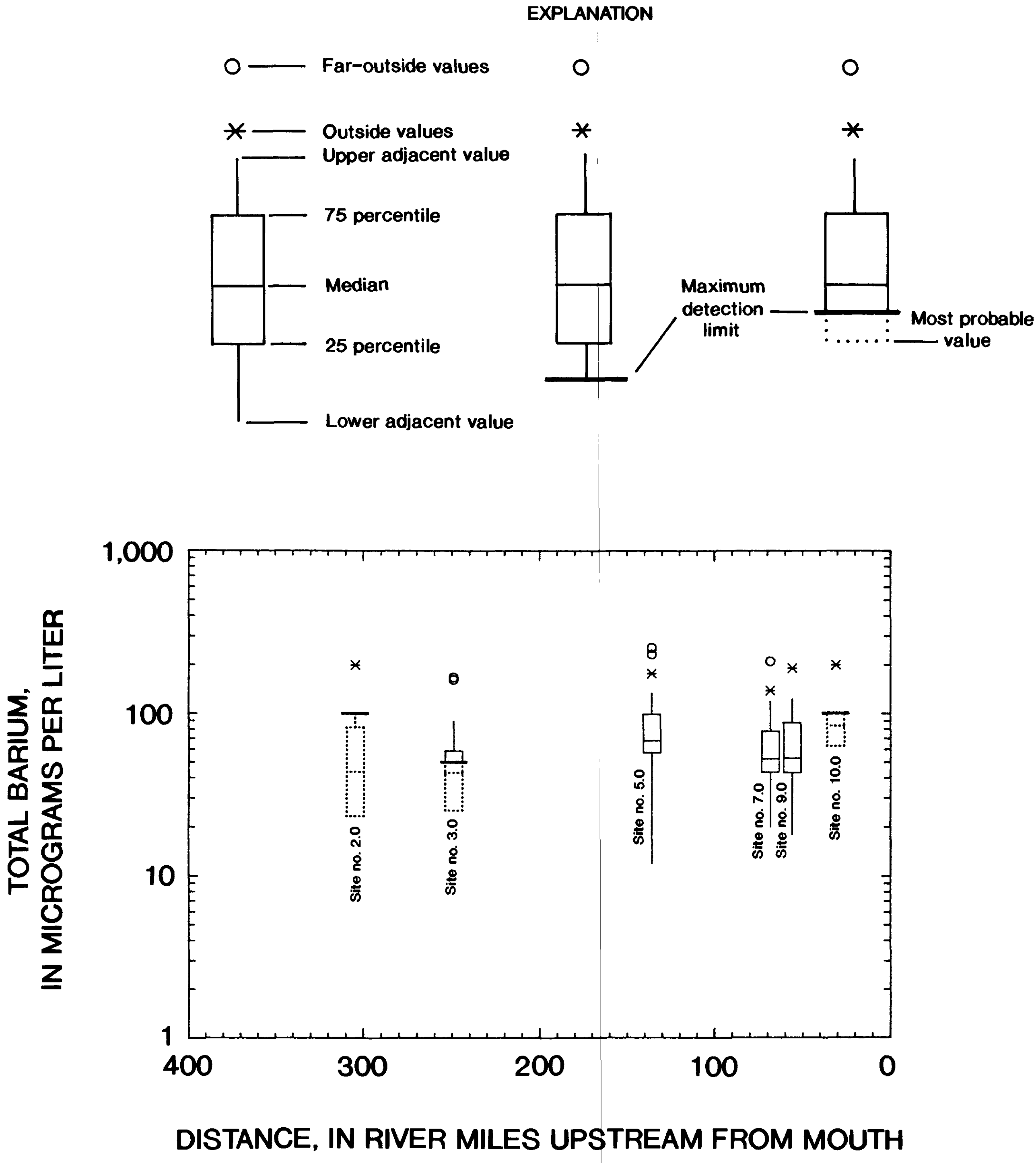


Figure 44.--Statistical summary of total barium concentrations at sites along the Kentucky River, based on available data for water years 1976-86.

Table 48.—*Number of major metals and trace elements measurements made in the Kentucky River basin and percentage not meeting indicated water-quality criteria, based on available data for water years 1976-86*

[<, less than. Censored values greater than the water-quality criteria were not included in the percentage computations]

U.S. ENVIRONMENTAL PROTECTION AGENCY		KENTUCKY
MCL = maximum contaminant level	SMCL = secondary MCL	KYDWS = domestic water supply
MCLG = maximum contaminant level goal	ALA = aquatic life acute	KYAH = warmwaer aquatic habitat
PMCLG = proposed MCLG	ALC = aquatic life chronic	KYR = recreational waters

Constituent	Number of measurements	Percentage not meeting indicated criteria								
		MCL	MCLG	PMCLG	SMCL	ALA	ALC	KYDWS	KYAH	KYR
Arsenic, total	679	<1		<1					<1	
Cadmium, total recoverable	606	5		7		10	22		4	
Chromium, total recoverable	654	<1						<1		
Copper, total recoverable	983			<1	<1	18	22	<1		
Cyanide, total	50						4		4	
Iron, total recoverable	1,953				74		36		36	
Lead, total recoverable	662	9		100		7	66	9		
Manganese, total recoverable	1,891				73			73		
Mercury, total recoverable	623	7		4		6	100		46	
Silver, total recoverable	344						56			
Zinc, total recoverable	727					<1	16		16	

Median concentrations of total iron at many sites in the Eastern Coal Field region exceed the Kentucky criterion of 1,000 $\mu g/L$ (fig. 45 and table 44). Coal-mine drainage seems to be a principal source of iron in streams in the basin. When coal mines are developed, the strata covering the coal are disturbed and iron disulfides (pyrite and marcasite), normally associated with coal deposits, are exposed and able to oxidize to ferrous sulfate and sulfuric acid. The ferrous sulfate in the mine drainage can oxidize further to ferric hydroxide "yellow boy" or ferric oxide forming "red waters."

Total iron concentrations in almost all of the samples from the main stem of the Kentucky River and its major tributaries exceed Kentucky's criterion of 1,000 $\mu g/L$ at the 90-percentile level for most of the available data, and some even exceed the criterion at the 50-percentile (fig. 46 and table 44). The exceedances of the iron criterion by site are given in table 47. Some sites had concentrations exceeding 300 $\mu g/L$ (Federal secondary MCL criterion) for all samples collected.

Total iron data for the main stem of the Kentucky River suggest that concentrations decrease downstream of the Eastern Coal Field region but then increase at Lock 2 (site 10.0). No major iron sources are known to exist immediately upstream from Lock 2 (site 10.0) and these higher values are possibly a reflection of the sampling procedures used (p. 142). Total iron concentrations were highly correlated with suspended sediment at nearly all sites in the basin with enough data for analysis (table 43). Dissolved iron concentrations, like total iron concentrations, decreased downstream from the Eastern Coal Field region (table 44). Dissolved iron concentrations in the Kentucky River and its major tributaries were much lower than total iron concentrations, indicating that the main transport mechanism for iron in the Kentucky River basin is by suspended material.

Load estimates for dissolved and total iron were made for 10 sites (table 45). The yield of total iron at the North Fork Kentucky River at Jackson (site 2.0) was more than four times that for any other site. This enrichment appears to be related to the intense coal-mining activity in this part of the basin. As with several other constituents which are associated with suspended sediment, the estimated load of total iron transported at the North Fork at Jackson (site 2.0) during the selected 1983-85 period exceeded that of any site downstream. This reduction of iron load downstream from Jackson (site 2.0) is probably due in part to deposition of iron-rich suspended material as the river gradient lessens and the flow is controlled by locks and dams. Of the estimated 15,700 tons per year of total iron passing Lock 2 (site 10.0, table 45), only an estimated 40 tons per year originate from point sources in the basin (Gianessi, 1986).

Trend analysis indicates a reduction over time in both dissolved and total iron concentrations at many sites (table 46). Most of the trends that were statistically significant were apparently due to a flow trend because flow adjustment of concentrations removed the detected trend. However, even after flow adjustment, a few sites still showed decreasing iron concentrations over time. This may be due to the inability of flow adjustment to fully account for a relation not easily fit with a common model or it may be due to improved mining and reclamation techniques.

Lead is common in sedimentary rocks, but owing to the low solubility of lead hydroxy carbonates, its natural mobility is low (Hem, 1985). Lead has been dispersed widely through the environment mainly from the combustion of leaded gasoline. Large amounts of lead can also be released in the burning of coal, which is a fuel commonly used in the study basin.

The Federal MCL and Kentucky's domestic water supply criterion for lead is 50 μg/L. The Federal MCL has been proposed to be revised downward to 5 μg/L. From 739 samples collected in streams throughout the basin, the total lead concentration was as high as 1,700 μg/L. However, the 90-percentile value of total lead concentration of these samples was only 37 μg/L, and the median values for all sites in the basin were less than 50 μg/L (fig. 47). In 465 samples, the maximum dissolved lead concentration was 424 μg/L with a 90-percentile value of 23.4 μg/L. Streambed-material data collected by the NURE program indicated maximum lead concentrations of 900 μg/g in samples from the heavily urbanized Lexington area and other areas in the Bluegrass area. Lead concentrations greater than the 50 μg/L criteria have occasionally been noted in water samples from the Kentucky River and some major tributaries (fig. 48, table 44). Total lead data from the Kentucky River main stem indicate slightly increasing concentrations from the headwater reaches to the river mouth. This increase may correspond to increasing urbanization downstream as well as the presence of limestone (containing lead) at or near the ground surface in the lower basin.

Exceedances of the Federal and State water-quality criteria of 50 μg/L for lead occur throughout the basin (tables 44 and 47). However, the frequency of exceedance generally increases in the lower basin.

Yields of total lead generally increase slightly downstream along the main stem of the Kentucky River (table 45). In comparing these total load estimates with point source load estimates from Gianessi (1986), only about 3 percent of the load of total lead transported by the Kentucky River at Lock 2 (site 10.0) can be attributed to point sources in the basin.

Based on trend analysis, both dissolved and total lead concentrations at many sites in the basin have decreased during the 1976-86 period (table 46). Because of the presence of censored values in the data base, flow adjustment was not possible. Therefore, it is not known how much of the trend is caused by decreasing discharge and how much may be due to other factors, such as the introduction of unleaded gasoline or improvements in wastewater treatment.

Manganese does not occur naturally as a metal but is present in various salts and minerals, frequently in association with iron compounds. Manganese is an undesirable impurity in water supplies, mainly owing to deposition of black oxide stains. The Federal secondary MCL and Kentucky criterion for domestic water supply sources for total manganese is 50 μg/L. Total manganese concentrations in 2,293 stream samples in the "historical-record" data base for the basin ranged from below detection limits to about 43,000 μg/L. Dissolved manganese concentrations show a similar range. NURE program streambed-sediment samples indicated a range from 38 to more than 3,600 μg/g of manganese.

Seventy-three percent of the total manganese concentrations for samples collected in the basin exceed the Federal and Kentucky criterion of 50 μg/L (table 48). Manganese concentrations at many sites throughout the Eastern Coal Field region exceed 1,000 μg/L (fig. 49). These high concentrations appear due to mine drainage. Coal-mining activities may account for large inputs of manganese to the Kentucky River headwater reaches, but concentrations of manganese from unmined basins also exceed the criterion (fig. 50 and table 47). Manganese data for the Kentucky River basin indicate that concentrations greater than 50 μg/L are common. Several sites on the main stem of the Kentucky River and major tributaries have manganese concentrations exceeding 50 μg/L even at the 10-percentile of available data, and all sites exceeded 50 μg/L at the 50-percentile (fig. 50 and table 44).

Manganese concentrations, like iron concentrations, correlate strongly with suspended-sediment concentrations except in the unmined basins and at sites with little data for comparison (table 43). These data show that concentrations decrease downstream of the Eastern Coal Field region almost to the river mouth, then possibly increase at the Kentucky River at Lock 2 (site 10.0). Because manganese is partially transported by suspended materials, the apparent increase in total manganese concentration at Lock 2 (site 10.0) may be due to the sampling methods used (p. 142) which may result in the collection of a greater suspended material fraction.

Load estimates developed for selected sites in the basin (table 45) indicate that the highest yield of total manganese is in the coal-producing area upstream from the North Fork Kentucky River at Jackson (site 2.0). However, the highest yield of dissolved manganese was in the upper Red River basin (site 3.1) which is largely unaffected by mining or other land uses and where total manganese concentration does not correlate with suspended-sediment concentration. Dissolved manganese therefore may be contributed naturally to streams from weathered geologic materials in relatively large quantities.

Seasonal variability of total manganese occurs at many of the sites. Figure 51 shows this variation for the relatively unaffected upper Red River basin (Red River near Hazel Green, site 3.1). This pattern relates well to that for total dissolved solids (fig. 24). No highly significant long-term temporal trends in concentration or flow-adjusted concentration of dissolved or total manganese were determined based on available data for water years 1976-86 (table 46).

Mercury, Molybdenum, and Nickel

There are several forms of mercury, ranging from elemental to dissolved inorganic and organic species, that occur in the environment. Mercury enters natural water in many ways, such as discharge from chlorine-caustic soda plants and pulp mills. It is used in electrical devices, thermometers, fungicides, dental fillings, drugs, and paints (ReVelle and ReVelle, 1984).

The Kentucky criterion for total mercury for warmwater aquatic habitats is 0.2 μg/L and the Federal MCL has been established at 2.0 μg/L. Fish tissue having more than 1 μg/g of mercury are considered unsafe for human consumption (ReVelle and ReVelle, 1984). Basinwide, about half of the data collected historically for total mercury exceeded the 0.2 μg/L Kentucky warmwater aquatic habitat criterion and all exceeded the newly established Federal criteria of 0.012 μg/L for protection of aquatic life (chronic). The table of exceedances for selected sites (table 47) indicates that several criteria are exceeded at many sites throughout the basin. No clear causative factor is indicated.

In the Kentucky River basin, total mercury concentration in 704 historical water samples ranged from less than detection limits to 113 μg/L. Dissolved mercury concentrations in 2,293 samples collected in the basin was from below detection limits to 40 μg/L. In 58 streambed-sediment samples collected in the basin, mercury concentrations were as high as 15 μg/g, although the median concentration was 0.1 μg/g.

Statistical summaries of mercury concentrations at sites in the basin are given in table 44. The highest concentrations occurred at sites not specifically affected by urban land uses or coal mining. The spatial coverage indicated by the data indicates that mercury may be associated with geological formations or could be contributed by atmospheric deposition. The data in table 45 indicate that only a few tons of mercury are transported out of the basin each year. Because the values are low and large errors are possible as indicated by the uncertainty factors presented, little interpretation of the mercury data can be made. Of nine statistically significant, long-term trends determined for either dissolved or total mercury at selected sites in the basin, all were decreasing and at rates ranging in magnitude from about 10 to 40 percent per year (table 46). Due to the presence of censored values, flow adjustment was not possible, and it is not known whether the reduction in flow during the period of analysis could have explained the reductions in concentrations observed.

Molybdenum is a fairly rare element. It is most commonly found in fossil fuels and can be spread through the environment by burning these materials. Surface-water concentrations of molybdenum in the Kentucky River basin ranged from less than detection limits to 10 μg/L for 34 samples. Concentrations in streambed material collected during the NURE program ranged from less than 4 to 121 μg/g. The highest concentrations in streambed material in the basin were in areas with outcrops of Devonian black shale. The site on the Kentucky River at Lock 2 (site 10.0) was the only site having 10 or more molybdenum analyses during water years 1976-86. Concentrations of molybdenum at that site for the 75-percentile value were below detection limits. No load estimates could be made due to the predominance of censored values. No trends were detected in molybdenum concentrations at Lock 2 (site 10.0).

Nickel is present as a constituent in various ores, minerals, and soils (Hem, 1985). It is comparatively inert and is used in corrosion-resistant materials, long-lived batteries, electrical contacts, spark plugs, and electrodes. It is also used as a catalyst in the hydrogenation of oils and other organic substances. Nickel enters water predominately from mine wastes, electroplating wastes, and atmospheric emissions (Hem, 1985).

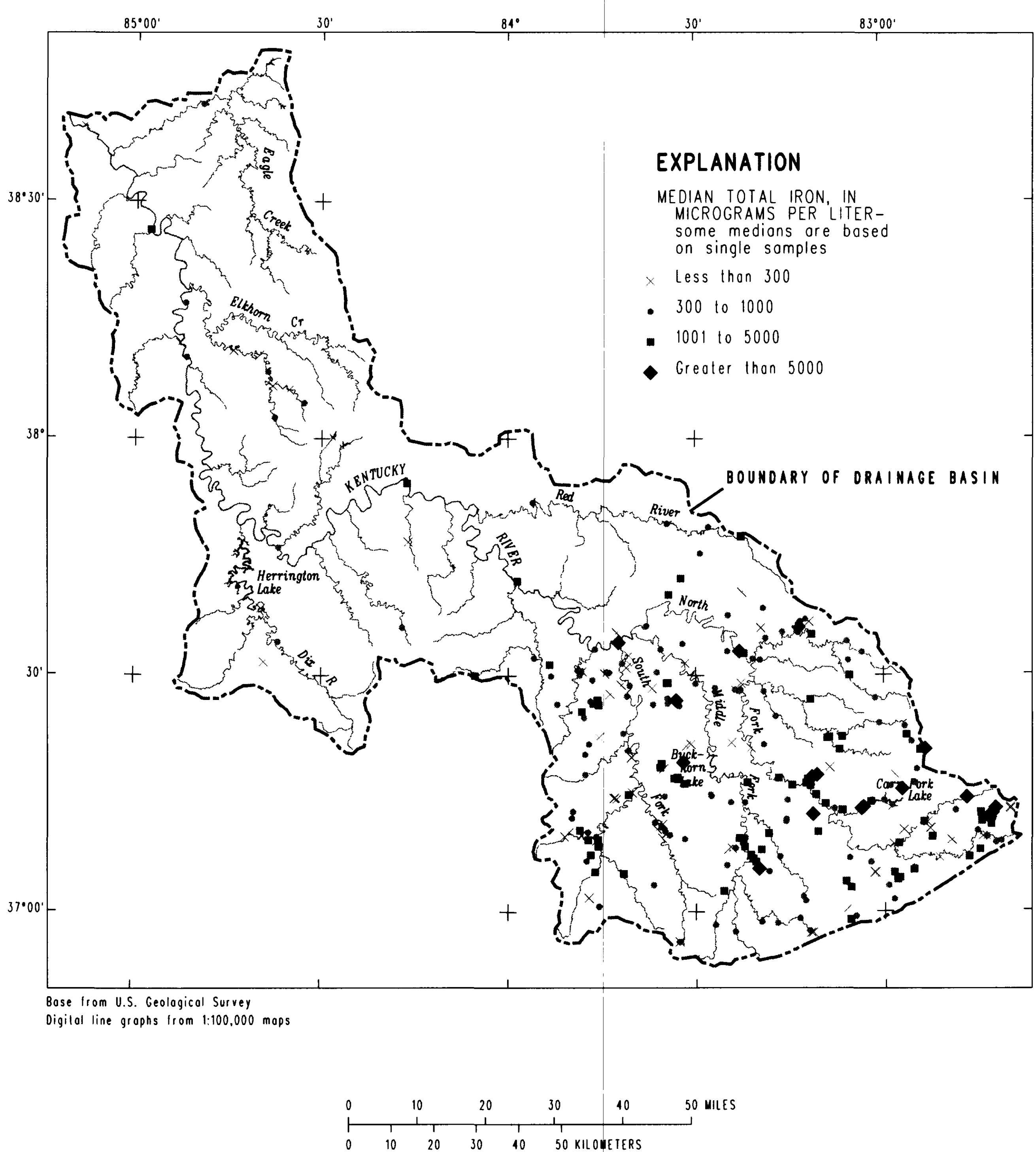


Figure 45.--Median concentrations of total iron at sites in the Kentucky River basin, through 1986.

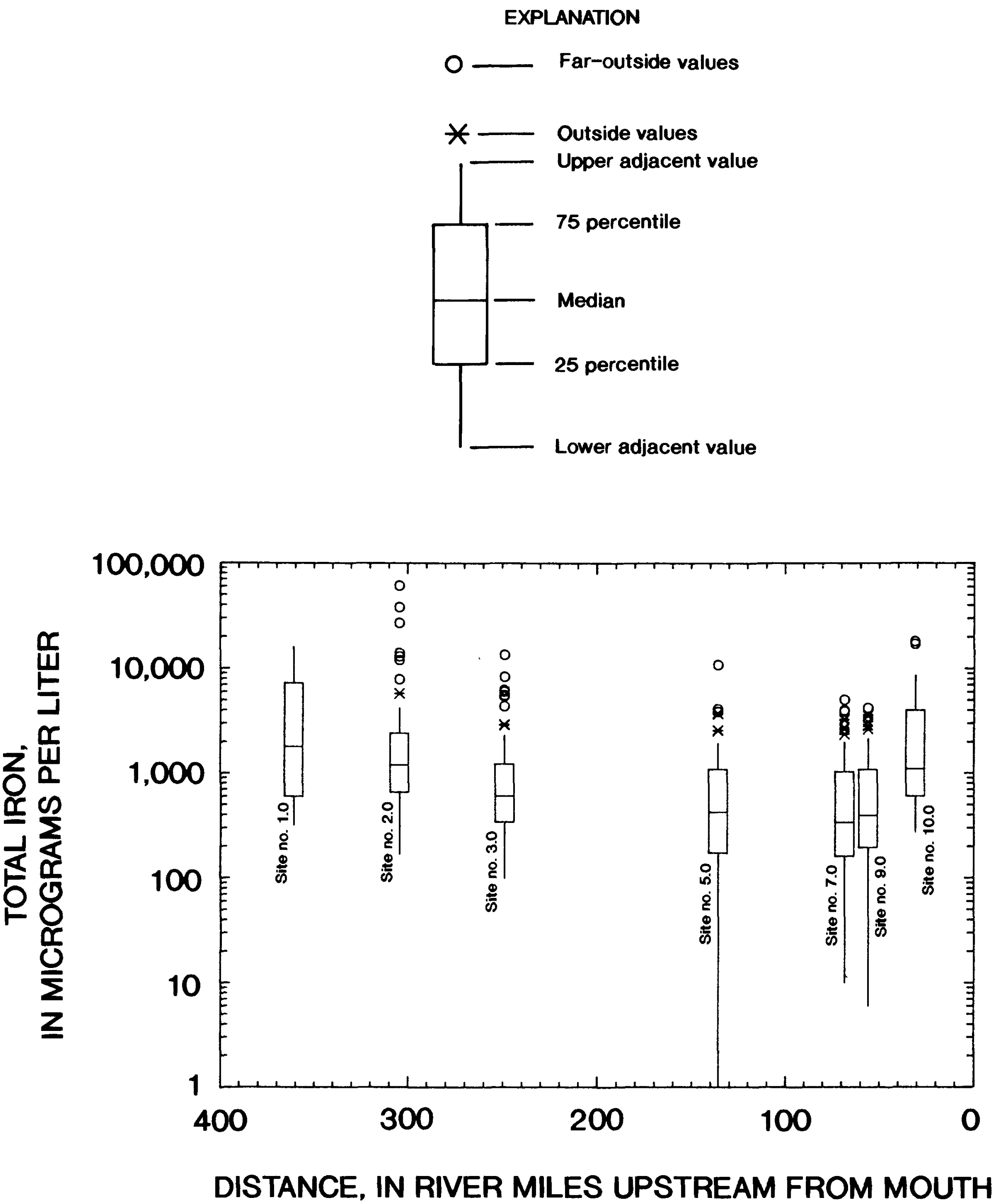


Figure 46.--Statistical summary of total iron concentrations at sites along the Kentucky River, based on available data for water years 1976-86.

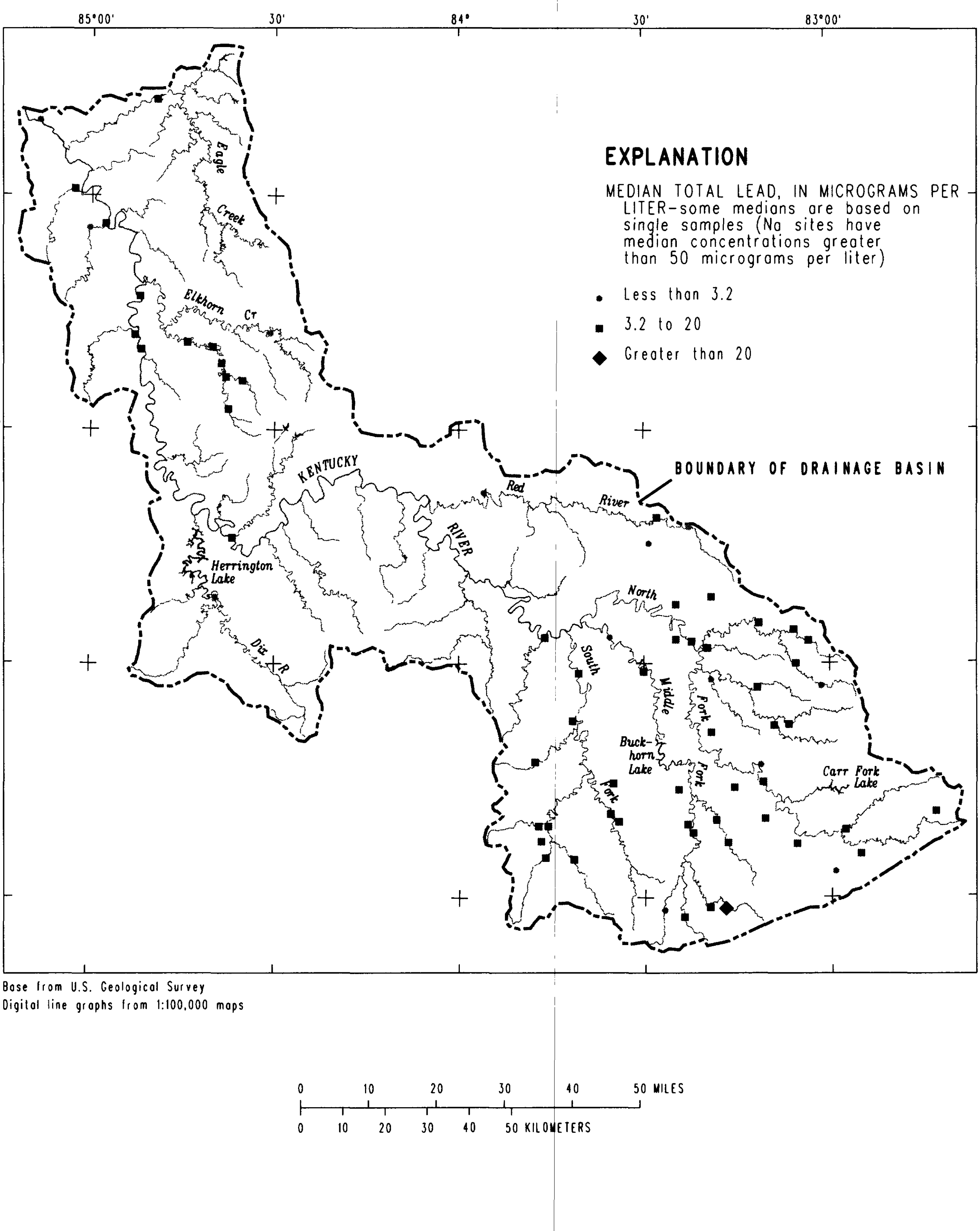


Figure 47.--Median concentrations of total lead at sites in the Kentucky River basin, through 1986.

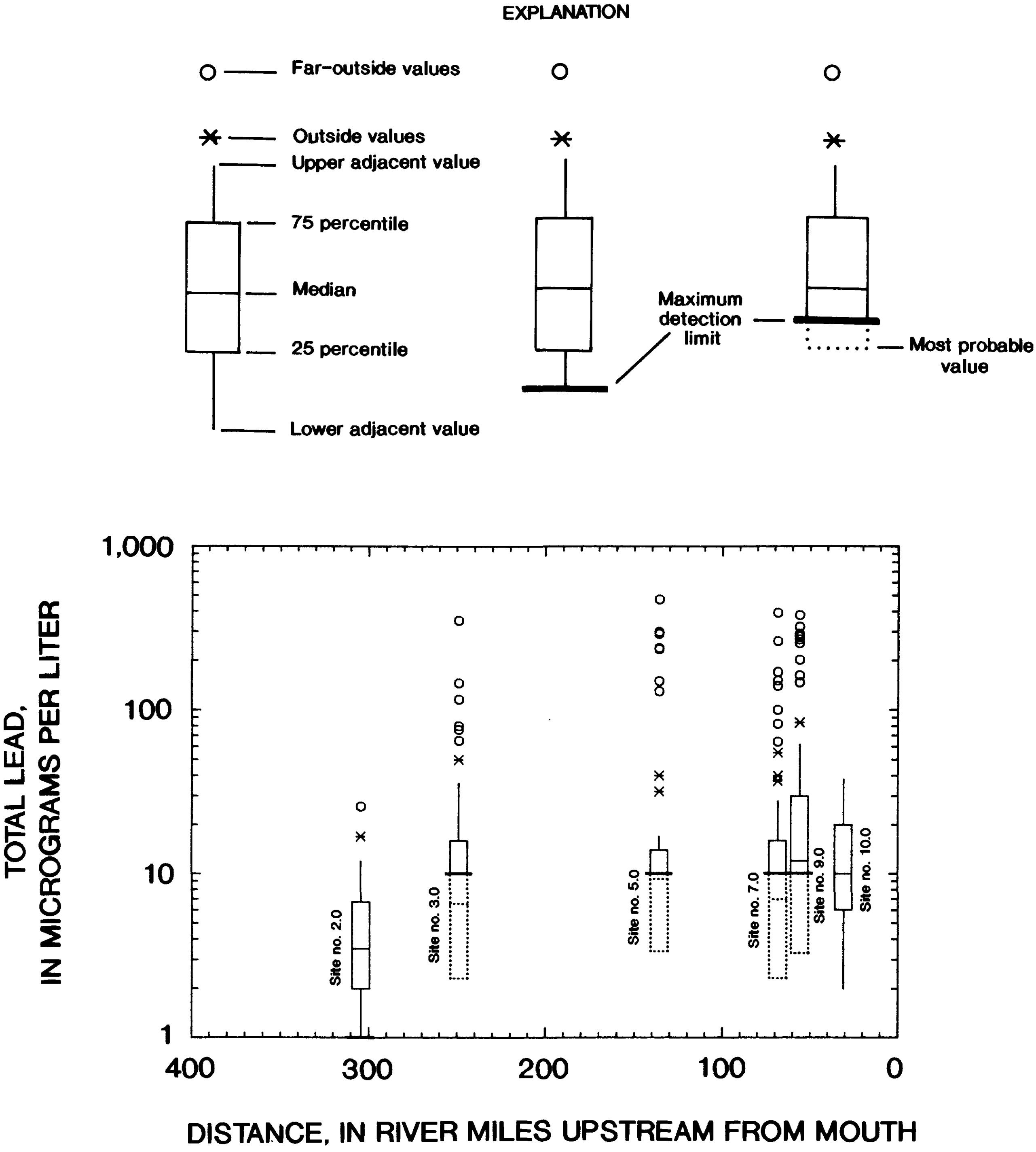


Figure 48.--Statistical summary of total lead concentrations at sites along the Kentucky River, based on available data for water years 1976-86.

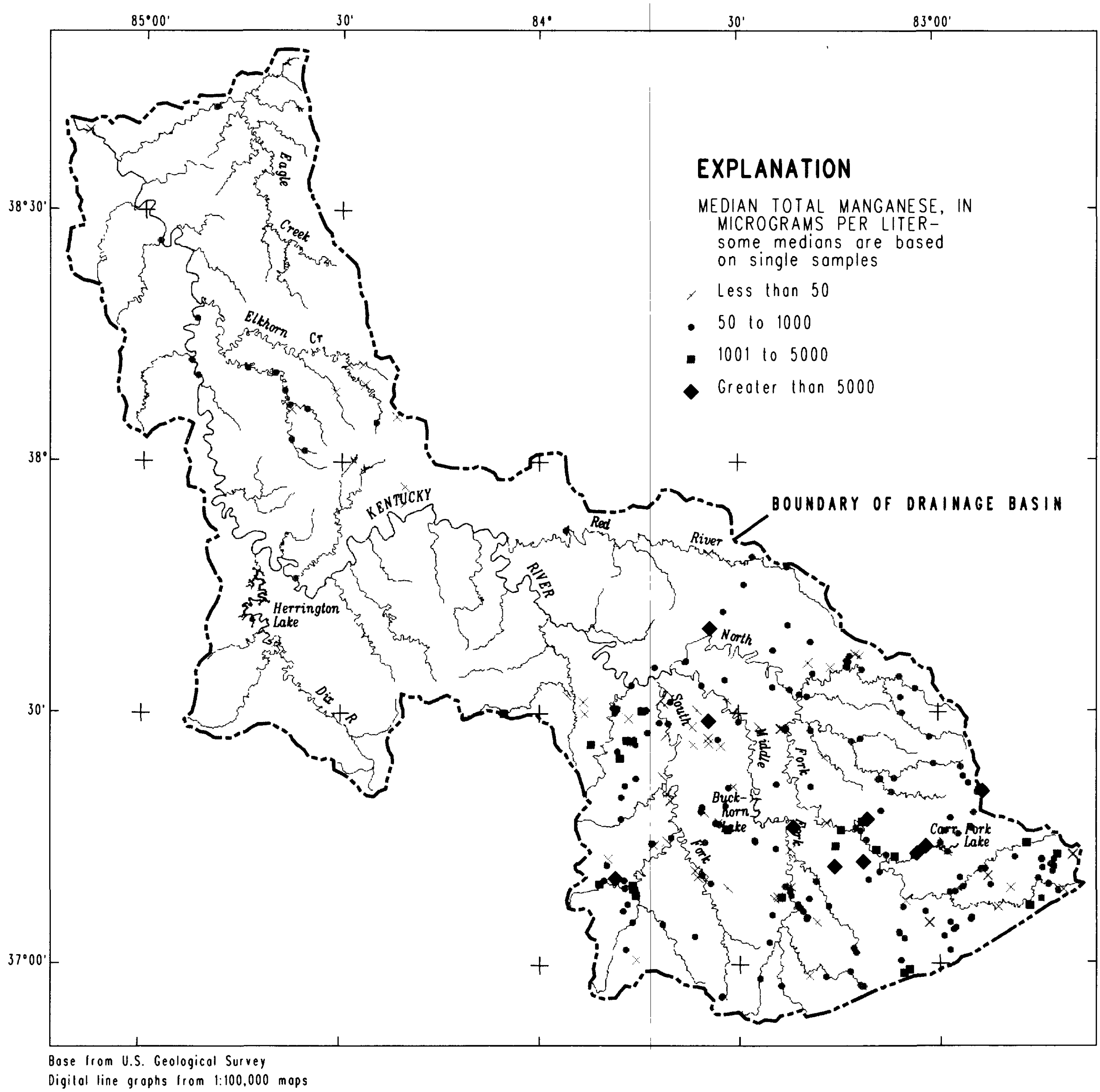


Figure 49.--Median concentrations of total manganese at sites in the Kentucky River basin, through 1986.

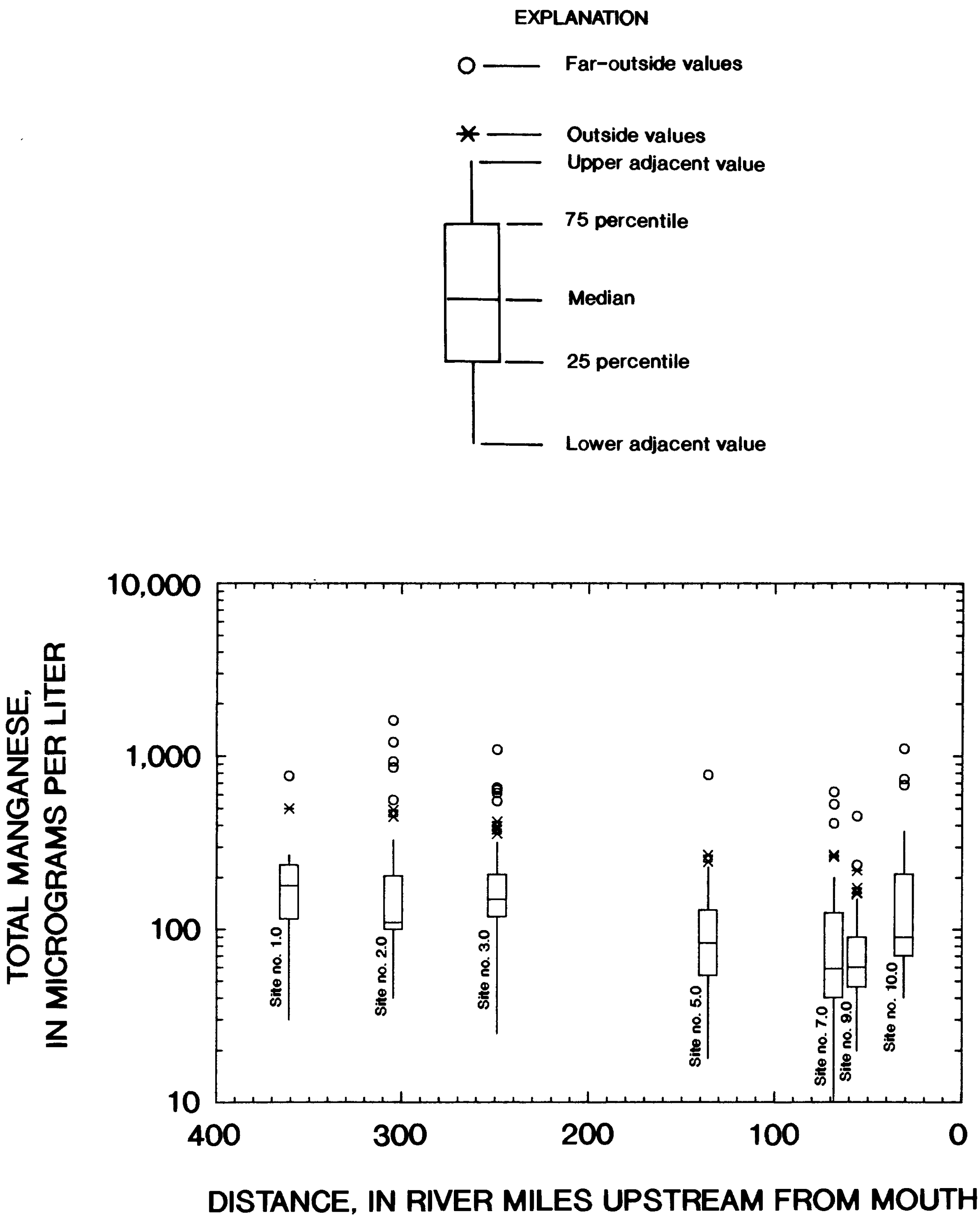


Figure 50.--Statistical summary of total manganese concentrations at sites along the Kentucky River, based on available data for water years 1976-86.

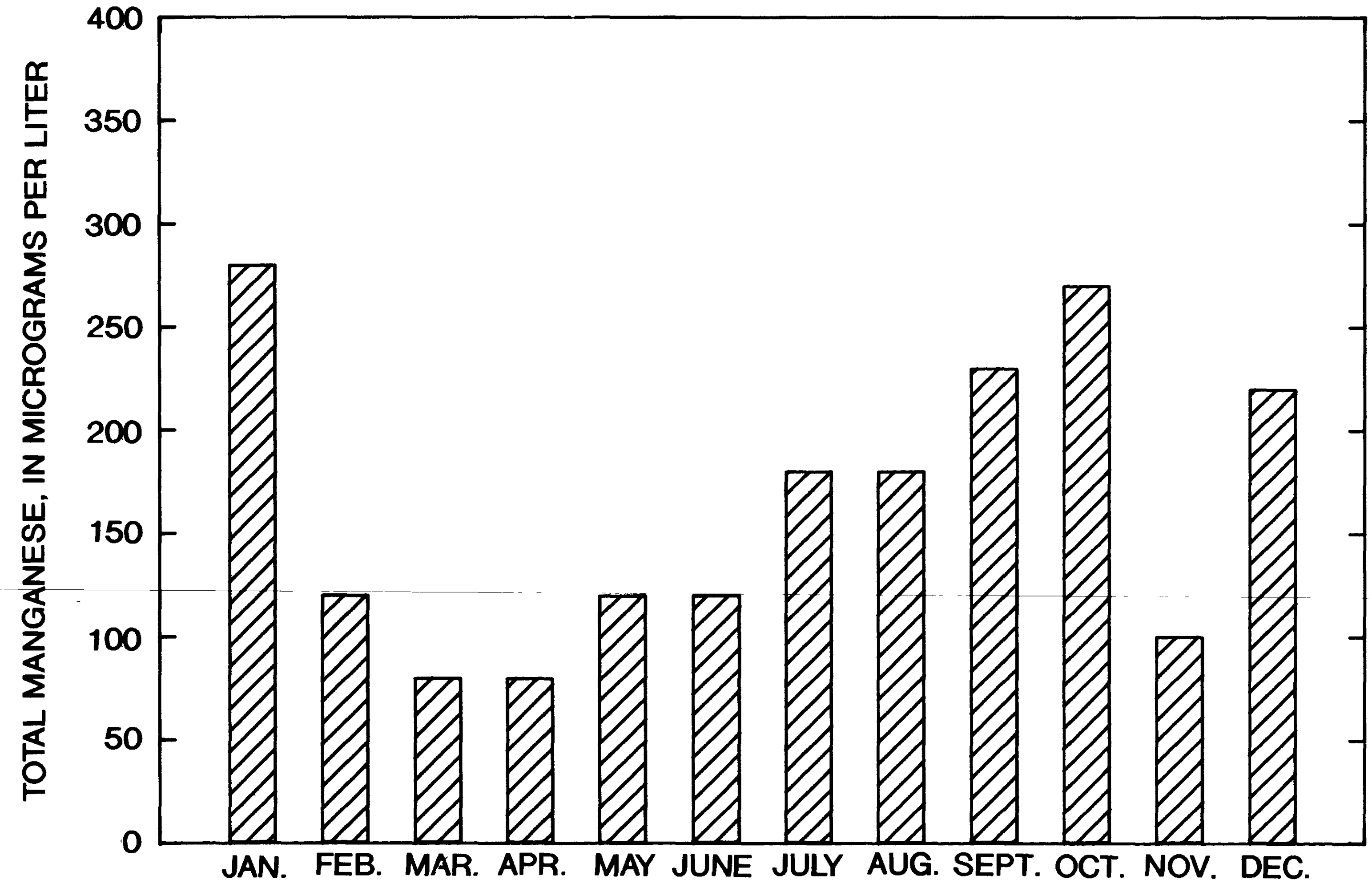


Figure 51.--Mean monthly total manganese concentrations for the Red River near Hazel Green, Kentucky, 1979-86.

While nickel is considered to be relatively nontoxic to man, the toxicity to aquatic life indicates tolerances that vary widely and are influenced by species, pH, and synergistic effects (U.S. Environmental Protection Agency, 1976). Nickel is toxic to plant life at concentrations as low as 500 μg/L and reproduction of fathead minnows is considerably affected by concentrations as low as 730 μg/L (U.S. Environmental Protection Agency, 1976). For water with hardness of 100 mg/L as $CaCO_3$, the Federal aquatic life criteria for acute and chronic considerations are 1,800 and 96 μg/L, respectively.

Of 201 samples collected in streams in the basin, the concentration of total nickel ranged from less than detection limits to 30 μg/L. Dissolved nickel analyses of 175 samples ranged from less than detection limits to 1,300 μg/L, but the 90-percentile value was 10 μg/L. Samples of streambed material collected in the basin in support of the NURE program had nickel concentrations ranging from 2 to 300 μg/g. As with molybdenum, high concentrations of nickel in water seem to correlate with the presence of surface rocks of Devonian age (black shale).

Less than 1 percent of all nickel concentrations determined for surface water in the basin were greater than the 96 μg/L Federal criterion for aquatic life (chronic). The range of concentrations for selected sites is given in table 44. Because of the relatively small number of observations, little interpretation is possible.

Transport estimates for nickel indicate that total nickel yield at the North Fork Kentucky River at Jackson (site 2.0) is elevated (table 45). This may be due to the transport of sediment carrying nickel because total nickel concentrations are highly correlated with suspended sediment at this site (table 43). Other headwater streams appear to have much lower total nickel yields. No significant long-term trends were determined for nickel concentrations in the basin (table 46).

Selenium, Silver, and Strontium

Selenium is an element, naturally occurring in soils derived from sedimentary rocks. It is used in rectifiers, as a semiconductor, and in xerography (U.S. Environmental Protection Agency, 1972). Selenium also occurs in the fly ash from coal-fired power plants that operate in Kentucky. Much of this selenium is in the smallest fly ash particles, which often elude capture by electrostatic precipitators (ReVelle and ReVelle, 1984).

Selenium is a biologically essential element recognized as a metabolic requirement in trace amounts for animals but toxic to them when ingested in amounts ranging from about 0.1 to 10 mg/kg of food (U.S. Environmental Protection Agency, 1976).

The Federal MCL and the Kentucky criterion for domestic water supply sources for selenium is 10 μg/L. In the Kentucky River basin, the historical range of values for dissolved selenium for 128 samples are from less than detection limits to 18.0 μg/L. The range of values for total selenium in 349 samples are from less than detection limits to 16.0 μg/L. Fewer than 1 percent of these analyses exceed the 10 μg/L criteria.

Selenium is seldom detected in surface water in the Kentucky River basin. Because of the high frequency of values less than the detection limit in the data set, transport estimates were not possible. Long-term trend analysis did not indicate any statistically significant increases or decreases in concentrations (table 46).

Silver is used for various chemical and photographic purposes, for jewelry, and in silver plating. It can be used as a disinfectant for water, and concentrations as low as 10 μg/L in alkaline water are toxic to *Escherichia coli* bacteria. Silver iodide has also been used in seeding clouds with condensation nuclei to induce rain or snowfall (Hem, 1985). Silver is accumulated in aquatic vertebrates, especially in the gills and internal organs of fish (U.S. Environmental Protection Agency, 1976).

The Federal MCL for silver is 50 μg/L. The Federal criterion for the protection of aquatic life (chronic) is set at 0.12 μg/L. In the Kentucky River basin, the range of values from 348 historical samples for total silver are from less than detection limits to 4.0 μg/L. More than 50 percent of the samples obtained in the basin during the 1976-86 water years had total silver concentrations that exceeded the 0.12 μg/L criterion (table 48). Dissolved silver had a similar range. Silver concentrations in streambed material collected during the NURE program were all less than the detection limit of 2.0 μg/g.

A summary of concentrations of silver in water samples from selected sites in the basin during the 1976-86 water years is presented in table 44. As is evident from the data, concentrations were well below the Federal MCL of 50 μg/L but many exceeded the Federal aquatic life (chronic) criterion of 0.12 μg/L (table 47).

Transport estimates for total silver were possible only for the Kentucky River at Lock 2 (site 10.0), due to the presence of censored values at the other sites. From 15 observations, a regression-based load for the 1983-85 water years was estimated at 24 tons per year (or a yield of 0.004 tons per year per square mile). No statistically significant long-term trends were determined for concentrations of silver during the 1976-86 assessment period (table 46).

Strontium is fairly common and is similar to calcium in chemical structure. For these reasons, strontium may replace calcium and potassium in igneous rocks in minor amounts. The carbonate (strontianite) and sulfate (celesite) forms are common in sedimentary rocks. Because strontium concentrations in most natural water do not reach the solubility limits for either strontianite or celesite, it is usually not a water-quality factor (Hem, 1985).

Concentrations of dissolved strontium ranged from 36 to 470 µg/L for 34 stream samples collected in the Kentucky River basin. Streambed-material samples collected during the NURE program had concentrations ranging from 7 to 339 µg/g of strontium. From 17 water samples collected at the Kentucky River at Lock 2 (site 10.0), the upper and lower quantile values for dissolved strontium were 165 and 295 µg/L, respectively, and the median value was 230 µg/L. Regression-based load estimates for water years 1983-85 indicated an annual transport rate of about 1,250 tons per year of dissolved strontium. These samples also indicated a statistically significant positive trend with an increase of 35 µg/L (13 percent) per year. However, flow adjustment trend procedures described no significant trend, indicating that changes in strontium concentration over time were associated with flow change.

Vanadium and Zinc

Vanadium is used in the manufacture of vanadium steel and eighteen compounds of vanadium are used in commercial processes. Little is known of the effects of vanadium on aquatic organisms, however it accumulates in certain organs of animals (U.S. Environmental Protection Agency, 1972).

Dissolved vanadium concentrations ranged from less than detection limits to 67.0 µg/L in 37 samples from the Kentucky River basin. Streambed material collected during the NURE program was analyzed and indicated a range in vanadium concentration of 7 to 320 µg/g. Only the Kentucky River at Lock 2 (site 10.0) had 10 or more vanadium analyses during water years 1976-86, but no vanadium was detected in any of these analyses. Because of the limited data for vanadium, load estimates and trend analysis were not possible.

Zinc is a fairly common element often associated with lead in sedimentary rocks such as limestones. Zinc tends to be substantially more soluble in natural water than copper and nickel (Hem, 1985). High concentrations of zinc in surface water may indicate the presence of industrial and urban wastes from such sources as galvanized pipes and the dumping of plating baths. Streams that drain areas with mining activities may also be enriched in zinc (U.S. Environmental Protection Agency, 1979).

The Kentucky warmwater aquatic habitat and the Federal aquatic life (chronic) criterion for total zinc is 47 µg/L. The Federal secondary MCL is 5,000 µg/L. In the Kentucky River basin, the range of concentrations of total zinc for the "historical-record" data base were from less than the detection limit to 465 µg/L for 786 samples. About 16 percent of total zinc observations obtained in the basin during water years 1976-86 exceeded the 47 µg/L criterion (table 48). Dissolved zinc ranged from less than the detection limit to 604 µg/L in 609 samples. The NURE program streambed-material samples collected in the basin indicated a range of zinc concentrations from 9 to 545 µg/g.

The 47 µg/L criterion was exceeded at the 90-percentile value for dissolved and total zinc concentrations at nearly all sites in the basin, for which 10 or more samples were obtained during water years 1976-86 (table 44). Spatial variability in zinc concentrations was small. Two water-quality criteria were exceeded for most sites from the headwater site on the North Fork Kentucky River at Jackson (site 2.0) to the farthest downstream site on the Kentucky River at Lock 2 (site 10.0) (table 47). Differences in yield of dissolved zinc from one site to another could not be verified, given the uncertainty in the estimation procedure (table 45). Yields of total zinc were elevated at several sites on the main stem of the Kentucky River and at South Elkhorn Creek (site 9.3). Total zinc concentrations correlated strongly with suspended sediment at the North Fork Kentucky River at Jackson (site 2.0) (table 43). The relatively large yield for total zinc at the Kentucky River at Lock 2 (site 10.0) may result from different sampling techniques used at that site (p. 142). Based on point-source load estimates reported by Gianessi (1986), about 1 or 2 percent of the load of total zinc at the Kentucky River at Lock 2 (site 10.0) is attributable to point sources in the basin.

Long-term trends in dissolved zinc were not determined to be highly significant for any site (table 46). Decreasing trends in total zinc, however, were noted to be statistically significant for two sites. An explanation for the decreasing trend in flow-adjusted concentrations of total zinc at South Elkhorn Creek near Midway (site 9.3) is not known but improvements in wastewater-treatment practices may be a contributing factor.

Radionuclides

Radioactivity is the release of energy from decaying atomic or nuclear structures and is biologically significant because of its adverse effects on body tissues. The occurrence of nuclides, such as potassium-40 and rubidium-87, account for much of the radiochemical properties of natural water. Isotopes resulting from the fission process of nuclear-energy production, such as strontium-90, may also contribute to the radioactivity of water (Hem, 1985).

Three types of radiation are of principal interest in natural-water chemistry. They are: alpha radiation which is caused by the release of a positively charged helium nuclei from a decaying atom, beta particles which result from discharged electrons and protons, and gamma radiation which is due to the emission of electromagnetic wave-type energy, similar to X-rays, during atomic degradation (Lippmann and Schlesinger, 1979). Isotopes of uranium and thorium give rise to most of the radioactivity in water with uranium-238 being the most significant. Each of these isotopes decay in a series of steps producing several radionuclide "daughters," that are usually short lived, finally resulting in a stable isotope of lead. Radium and radon isotopes, members of the uranium and thorium series, are strong alpha-particle emitters. Beta and gamma radiation is characteristic of some series members, especially potassium-40 and rubidium-87. The strongest beta and gamma emitters are fission products such as strontium-90 (Hem, 1985).

To make comparison of samples possible, the radioactivity of water is most often expressed in equivalent quantities of radium, or in terms of radium's rate of decay, usually in picocuries (pCi). For biologic purposes the rad, absorbed radiation dose, is the unit of measurement and is based on the amount of energy absorbed by 1 gram of tissue. For sampling data, gross alpha or beta and gamma activity is often reported and when possible the concentration of specific nuclides is made available (Hem, 1985). The Federal MCL for gross alpha particle activity is 15 pCi/L. The gross-beta radioactivity level above which detailed evaluation is recommended is 50 pCi/L (U.S. Environmental Protection Agency, 1972, p. 85).

Nearly all radio-chemical data available in the Kentucky River basin were obtained since 1976. Available data, although limited in spatial and temporal coverage, indicate that gross alpha particle activity is generally within the criterion of 15 pCi/L (table 49). Available data on beta-particle activity are generally less than the 50 pCi/L level.

Pesticides and Other Synthetic Organic Compounds

Although production and use of synthetic organic compounds in the United States has increased dramatically over the past 50 years, the environmental effects of the compounds are largely unknown. Many of these compounds are persistent and can be transported by air, water, sediment, and biota. Residues of some organic compounds have been observed even in such remote areas as Antarctica (Smith and others, 1987).

The estimated amount of synthetic organic compounds entering the surface water of the Kentucky River basin has been organized by source (point and nonpoint), by compound class (petroleum hydrocarbons, polychlorinated biphenyls, and chlorinated hydrocarbons), and by subbasin. As presented in table 50, total petroleum hydrocarbons entering streams of the Kentucky River basin (from point and nonpoint sources) was estimated to be 1,143 tons per year by Gianessi (1986). About 80 percent of this total was estimated to originate from nonpoint sources. These compounds occur in the lower subbasin, where land use is primarily urban and agricultural. Similarly, most of the polychlorinated biphenyl (PCB) entering the streams of the Kentucky River basin also occurs in the lower part of the basin; however, all 0.9 tons per year were estimated to originate from point sources. Virtually all of the estimated 436 tons annually of chlorinated hydrocarbons entering the streams of the Kentucky River basin per year comes from nonpoint sources, primarily in the lower basin. Agricultural land use (agricultural-chemical application) in this part of the basin is a likely source.

Data for description of the occurrence of organic compounds in streams of the Kentucky River basin generally are limited. Table 51 summarizes the "historical-record" data collected by medium (water column, streambed material, or fish tissue) and by organic-compound class. The discussion is organized by general class of organic compound. These include: polychlorinated biphenyls, pesticides (insecticides and herbicides), phenols, phthalate esters, and polycyclic aromatic hydrocarbons (Smith and others, 1987). A statistical summary of concentrations of pesticides and other synthetic organic compounds in the water, bottom sediments, and biota in the Kentucky River basin is provided in table 52. Data for other classes of compounds including halogenated aliphatic and monocyclic aromatic hydrocarbons, and polychlorinated dibenzo-p-dioxins were not available.

Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) are synthetically produced compounds that are characterized by their chemical and thermal stability, toxicity, inertness, and dielectric nature. Once in the environment, PCB compounds tend to accumulate in living tissue, and concentrations increase in organisms higher up the food chain (biological magnification). In addition, because PCB compounds are characteristically hydrophobic, they are highly persistent and can remain sorbed with sediment and tissue for many years. Because of environmental persistence and toxicity, PCB compounds were first regulated under provisions of the Toxic Substances Control Act of 1976, and their manufacture was banned in 1979.

Only one analysis for PCB compounds in water was made in the Kentucky River basin during water years 1976-86. PCB compounds were not detected (table 52). This is not surprising because of the hydrophobic nature of these compounds. Of 18 streambed-material samples analyzed during this period, PCB compounds were detected in only one sample (0.23 μg/kg). PCB compounds were detected in 4 of 32 fish tissue samples analyzed between 1976-86. Concentrations in fish tissue ranged from less than 0.10 to 0.81 μg/kg. The U.S. Food and Drug Administration (FDA) has set a concentration limit of 2 μg/kg for PCB compounds in edible fish fillets. The relatively few PCB analyses in the Kentucky River basin are insufficient to develop conclusions on the occurrence and distribution of PCB compounds.

Pesticides

Pesticides are chemicals designed to control various pests that damage agricultural and horticultural crops. These compounds are typically classified by the types of pests that are to be controlled and include insecticides, herbicides, fungicides, and rodenticides. Pesticides enter natural water through many routes, including run-off, direct application, spills, and faulty waste disposal techniques. Movement by erosion of soil particles with adsorbed pesticides is one of the principal means of entry into surface water (U.S. Environmental Protection Agency, 1972).

The use of organochlorine insecticides was initiated with the discovery of DDT by Paul Muller in 1939. Organochlorine insecticides tend to accumulate in living organisms and sediment, biomagnify, and are highly persistent. For example, DDT has a half life of approximately 20 years. Other organochlorine insecticides include lindane, chlordane, heptachlor, aldrin, dieldrin, and toxaphene (Smith and others, 1987).

Table 49.—*Statistical summary of radionuclide concentrations in the Kentucky River basin, based on available data for water years 1976-86*

[N, number of observations; NL, number of observations below detection limit; ND, not detected (detection limit unknown); pCi/g, picocuries per gram; pCi/L, picocuries per liter; μg/L, micrograms per liter]

Radionuclide	N	NL	Minimum	Median	Maximum
Alpha, dissolved, in pCi/g	8	1	ND	1.5	8.0
Alpha, dissolved, in pCi/L	27	21	ND	ND	2.0
Alpha, gross dissolved, in μg/L as U-natural	8	0	0.9	3.8	8.3
Alpha, gross dissolved, in pCi/L as U-natural	1	0	2.8	2.8	2.8
Alpha, gross suspended, in pCi/L as U-natural	2	0	.4	6.2	12
Alpha, gross suspended, in μg/L as U-natural	8	0	.4	.6	18
Alpha, specific activity, pCi/g suspended solids	8	1	ND	3.5	16
Alpha, suspended, in pCi/L	27	13	ND	1.0	10
Alpha, total, in pCi/g	8	1	ND	2.5	10
Alpha, total, in pCi/L	27	12	ND	1.0	11
Beta, dissolved, in pCi/g	8	0	15	26	60
Beta, dissolved, in pCi/L	27	0	1.0	6.0	18
Beta, gross dissolved, in pCi/L as Cs-137	8	0	1.7	2.9	5.2
Beta, gross dissolved, in pCi/L as Sr-Y-90	7	0	2.0	2.1	5.0
Beta, gross suspended, in pCi/L as Cs-137	8	0	.4	1.0	14
Beta, gross suspended, in pCi/L as Sr-Y-90	7	0	.4	.9	13
Beta, specific activity, pCi/g suspended solids	8	0	1.0	50	96
Beta, suspended, in pCi/L	27	2	ND	4.0	38
Beta, total, in pCi/g	8	0	24	27	43
Beta, total, in pCi/L	27	0	.11	8.0	56
Potassium 40, dissolved, in pCi/L	13	0	1.3	2.1	3.1

Table 50.—*Average annual pollutant discharge estimates for point and nonpoint sources in the Kentucky River basin*

[Gianessi, 1986]

Subbasin	Pollutant discharge estimates, in tons per year		
	Petroleum hydro-carbons	Poly-chlorinated biphenyls	Chlorinated hydro-carbons
Point sources			
Upper basin (North Fork)	2.827582	0.000000	0.000365
Upper basin (Middle Fork)	.198177	.000000	.000036
Upper basin (South Fork)	1.170372	.002628	.000237
Middle basin	1.968554	.000000	.000402
Lower basin	213.380770	.901076	.020550
Source total	219.545455	0.903704	0.021590
Nonpoint sources			
Upper basin (North Fork)	0.000000	0.000000	1.418554
Upper basin (Middle Fork)	.000000	.000000	.233344
Upper basin (South Fork)	.000000	.000000	2.799860
Middle basin	.000000	.000000	16.453486
Lower basin	923.590434	0.000000	415.285482
Source total	923.590434	0.000000	436.190726
Basin total	1,143.135889	0.903704	436.212316

Because of the hydrophobic nature of organochlorine pesticides, most of the samples collected in the Kentucky River basin for water years 1976-86 were in the form of fish tissue and streambed material (table 52). As expected, organochlorine pesticides were not detected in water samples. However, a number of streambed material and fish tissue samples contained detectable concentrations of these compounds (table 52). Maximum concentrations of selected compounds in bottom deposits were 71 μg/kg for benzene hexachloride (BHC), 30 μg/kg for chlordane, 30 μg/kg for DDT, and 120 μg/kg for lindane. Chlordane (cis-isomer), DDT (total), dieldrin, P,P-DDD, and P,P-DDE were frequently detected (in 25 percent or more of the samples) in fish tissue. The maximum chlordane concentration detected in fish tissue of 0.44 mg/kg (440 μg/kg) exceeds the U.S. Food and Drug Administration's action level of 300 μg/kg in edible fish tissue. The maximum BHC concentration detected in fish tissue was 400 μg/kg. While a U.S. Food and Drug Administration action level for BHC in fish tissue does not exist, the action level in frog legs is 300 μg/kg. The fact that organochlorine pesticides have been frequently detected, sometimes in concentrations exceeding U.S. Food and Drug Administration action levels, indicates the persistence of this compound class. The existing data are insufficient for an adequate assessment of the areal distribution.

The use of organophosphorus insecticides has increased over the last 20 years because of their relatively short environmental half-life and their effective replacement of many persistent organochlorine insecticides. The short persistence of these compounds is primarily due to their rapid chemical and biological degradation, both in soil and surface-water systems. These compounds, as a group, are highly soluble in water and thus, do not generally tend to adsorb to sediment or bioaccumulate. However, aquatic organisms with high lipid content and sediment with high organic content may accumulate significant residues if aqueous concentrations are high (Smith and others, 1987). Only two samples were analyzed for organophosphorus compounds in the Kentucky River basin during the 1976-86 time period—one water column sample and one streambed-material sample (table 52). Organophosphorus insecticides were not detected in either of these two samples.

While there has been a decline in the use of insecticides in recent years, there has been an increase in the use of herbicides on crops in the United States (Gilliam and others, 1985). Most herbicides are characterized by high aqueous solubilities and high vapor pressures. Based on these characteristics, they generally do not bioconcentrate, sorb to sediments, or volatilize from solution to an appreciable extent. Herbicides enter natural water primarily through surface runoff. Consequently, herbicide concentrations in surface water commonly are high if a heavy rain immediately follows the application of the herbicide. Major herbicides used in the United States include Atrazine, dichlorophenoxyacetic acid (2,4-D), Paraquat, and Diquat (Smith and others, 1988).

Table 51.—*Number of samples analyzed for pesticides and other synthetic organic compounds in the Kentucky River basin, based on available data for water years 1976-86*

Compound class	Sample type		
	Water	Bed material	Fish tissue
Polychlorinated biphenyls	1	18	32
Organochlorine pesticides	2	30	61
Organophosphorus pesticides	1	1	—
Herbicides	1	—	—
Phenols	2	31	47
Phthalate esters	3	—	—

Table 52. —*Statistical summary of concentrations of pesticides and other synthetic organic compounds in the Kentucky River basin, based on available data for water years 1976-86*

[N, number of observations; NL, number of observations less than detection limit; mg/L, milligrams per liter; ND, not detected; <, less than; mg/kg, milligrams per kilogram; μg/L, micrograms per liter, μg/kg, micrograms per kilogram]

Compound	N	NL	Maximum
Polychlorinated biphenyls			
PCB, total, in mg/L	1	1	ND
PCB, μg/kg in fish tissue	32	28	0.81
PCB, μg/kg in bottom deposits	18	17	<100
Organochlorine pesticides			
Aldrin, mg/kg in fish tissue	32	29	.03
Aldrin, total, in μg/L	2	2	<5.0
Aldrin, μg/kg in bottom deposits	18	17	19
B-BHC-Beta, mg/kg in tissue	15	15	<.01
B-BHC-Beta, μg/kg in bottom deposits	10	10	<10
BHC-Alpha Isomer, μg/kg in bottom deposits	17	16	71
BHC-Alpha Isomer, mg/kg in tissue	32	26	.04
Chlordane (Tech Mix & Metabs), total, in μg/L	2	2	<10
Chlordane (Tech mix & Metabs), mg/kg in tissue	31	19	.44
Chlordane, total, μg/kg in bottom deposits	1	0	2.0
Chlordane, *cis* isomer, mg/kg in tissue	31	19	.05
Chlordane, *cis* isomer, μg/kg in bottom deposits	17	15	30
Chlordane-Nonachlor, *trans* isomer, μg/kg bottom	17	16	<10
Chlordane-Nonachlor, *trans* isomer, mg/kg in tissue	31	26	.06
Chlordane-Tech mix & Metabs, μg/kg bottom deposits	16	15	<46
Chlordane, *trans* isomer, μg/kg in bottom deposits	17	15	30
Chlordane, *trans* isomer, mg/kg in tissue	31	25	.15
DDD, in μg/L	2	2	<5.0
DDD, total, μg/kg in bottom deposits	1	1	ND
DDE, in μg/L	2	2	<5.0
DDE, total, μg/kg in bottom deposits	1	1	ND
DDT sum analogs, μg/kg in bottom deposits	18	16	30
DDT, in μg/L	2	2	<10
DDT, total, mg/kg in tissue	32	15	.10
Delta Benzene Hexachloride, μg/kg bottom deposits	10	10	<10
Delta Benzene Hexachloride, mg/kg in tissue	15	15	<.01
Dieldrin, mg/kg in tissue	32	18	<.05
Dieldrin, total, in μg/L	2	2	<5.0
Dieldrin, μg/kg in bottom deposits	18	17	<10
Endosulfan Sulfate, μg/kg in bottom deposits	10	10	<10
Endosulfan Sulfate, mg/kg in tissue	14	14	<.01
Endosulfan, Alpha, μg/kg in bottom deposits	10	10	<10
Endosulfan, Alpha, mg/kg in tissue	14	14	<.01
Endosulfan, Beta, μg/kg in bottom deposits	10	10	<10
Endosulfan, Beta, mg/kg in tissue	14	14	<.01
Endrin Aldehyde, μg/kg in bottom deposits	5	5	<10
Endrin Aldehyde, mg/kg in tissue	14	14	<.01
Endrin Ketone, mg/kg in bottom deposits	10	10	<10
Endrin Ketone, mg/kg in fish tissue	14	14	<.01
Endrin, mg/kg in tissue	31	31	<.01
Endrin, total, in μg/L	2	2	<10
Endrin, μg/kg in bottom deposits	18	18	<10
Gamma-BHC (Lindane), total, in μg/L	1	1	<5.0
Gamma-BHC (Lindane), μg/kg in bottom deposits	2	1	<40
Gamma-BHC (Lindane), mg/kg in tissue	32	29	.01
Heptachlor Epoxide, total, in μg/L	2	2	<5.0
Heptachlor Epoxide, total, μg/kg in bottom deposits	1	1	ND
Heptachlor Epoxide, μg/kg in shellfish	14	14	<.01
Heptachlor, total, in μg/L	2	2	<5.0
Heptachlor, total, μg/kg in bottom deposits	1	1	ND
Heptachlor, μg/kg in shellfish	14	14	<.01
Hexachlorobenzene, μg/kg in bottom deposits	17	17	<40

Table 52.—*Statistical summary of concentrations of pesticides and other synthetic organic compounds in the Kentucky River basin, based on available data for water years 1976-86*—Continued

[N, number of observations; NL, number of observations less than detection limit; mg/L, milligrams per liter; ND, not detected; <, less than; mg/kg, milligrams per kilogram; μg/L, micrograms per liter, μg/kg, micrograms per kilogram]

Compound	N	NL	Maximum
Organochlorine pesticides–Continued			
Hexachlorobenzene, mg/kg in tissue	31	28	0.40
Lindane, total, in μg/L	1	1	ND
Lindane, μg/kg in bottom deposits	16	14	120
Methoxychlor, in μg/L	2	2	<25
Methoxychlor, μg/kg in bottom deposits	18	18	<50
Methoxychlor, μg/kg in fish	32	32	<.20
Mirex, mg/kg in fish tissue	15	15	<.01
Mirex, μg/kg in bottom deposits	10	10	<10
O P DDD, mg/kg in tissue	32	32	<.10
O P DDD, μg/kg in bottom deposits	17	16	13
O P DDE, mg/kg in tissue	32	32	<.05
O P DDE, μg/kg in bottom deposits	17	17	<10
O P DDT, mg/kg in tissue	32	31	.14
O P DDT, μg/kg in bottom deposits	17	17	<10
P P DDD, mg/kg in tissue	32	22	<.05
P P DDD, μg/kg in bottom deposits	17	16	13
P P DDE, mg/kg in tissue	32	16	<.10
P P DDE, μg/kg in bottom deposits	17	16	<10
P P DDT, mg/kg in tissue	32	28	.03
P P DDT, μg/kg in bottom deposits	17	17	<10
Toxaphene, mg/kg in tissue	32	32	<1.0
Toxaphene, total, in μg/L	2	2	<1.0
Toxaphene, μg/kg in bottom deposits	18	18	<100
Organophosphorus pesticides			
Diazinon, total, in μg/L	1	1	ND
Diazinon, total, μg/kg in bottom deposits	1	1	ND
Ethion, total, in μg/L	1	1	ND
Ethion, total, μg/kg in bottom deposits	1	1	ND
Malathion, total, in μg/L	1	1	ND
Malathion, μg/kg in bottom deposits	1	1	ND
Methyl Parathion, total, in μg/L	1	1	ND
Methyl Parathion, total, μg/kg in bottom deposits	1	1	ND
Methyl Trithion, total, in μg/L	1	1	ND
Methyl Trithion, total, μg/kg in bottom deposits	1	1	ND
Parathion, total, in μg/L	1	1	ND
Parathion, total, μg/kg in bottom deposits	1	1	ND
Trithion, total, in μg/L	1	1	ND
Trithion, total, μg/kg in bottom deposits	1	1	ND
Herbicides			
2,4,5-T, total, in μg/L	1	0	.03
2,4-D, total, in μg/L	1	0	.04
Silvex, total, in μg/L	1	1	ND
Phenols			
2,3,4,5-Tetrachlorophenol, mg/kg in bottom deposits	14	14	<10
2,3,4,5-Tetrachlorophenol, mg/kg in fish tissue	15	15	<.01
2,3,4,6-Tetrachlorophenol, mg/kg in bottom deposits	14	14	<100
2,3,4,6-Tetrachlorophenol, mg/kg in fish tissue	15	15	<.01
Pentachlorophenol, μg/kg in bottom deposits	17	15	180
Pentachlorophenol, mg/kg in tissue	32	31	<.01
Phenolics, total, in μg/L	2	0	3.0
Phthalate esters			
Bis (2-Ethylhexyl) Phthalate, in μg/L	2	2	<1.0
Diethyl Phthalate, in μg/L	2	2	<1.0
Dimethyl Phthalate, in μg/L	2	2	<1.0
N-Butyl Benzyl Phthalate, in μg/L	2	0	5.0
Phthlate Esters, in mg/L	1	0	5.0

In Kentucky, herbicides account for about 86 percent of all pesticides applied (University of Kentucky, 1979). Usage estimates, based on a 1982 agriculture census, indicate that approximately 10 million pounds of herbicides are applied annually to agricultural areas in the Kentucky River basin (Gianessi, 1986). Atrazine (2.5 million pounds), alachlor (1.5 million pounds) and butylate (1.4 million pounds) account for more than half of the total herbicide usage. Indicative of its aqueous solubility, it is estimated that almost 2 percent of the atrazine applied (43,000 lbs) to agricultural areas is contributed to runoff during rainfall or snowmelt (Gianessi, 1986).

The compiled 1976-86 database contained one water sample from the Kentucky River basin that was analyzed for herbicides. Silvex was not detected, but 2,4,5-T and 2,4-D were detected at concentrations of 0.03 and 0.04 $\mu g/L$, respectively. The sample was not analyzed for other commonly applied herbicides such as atrazine, alachlor, and butylate.

Phenols

Phenols are a class of organic compounds characterized by a benzene ring with one or more hydroxyl groups. Phenolic compounds are formed as byproducts during the production of pesticides, pharmaceuticals, plastics, and explosives (Smith and others, 1988).

Phenols may enter surface-water systems directly through wastewater discharges and indirectly as transformation products of other compounds. Having high aqueous solubility, in general, phenols can occur at relatively high concentrations in natural water. Phenols are primarily removed from the environment through biodegradation and photolysis. Except for highly chlorinated compounds, most phenols do not tend to sorb to sediments or bioaccumulate (Smith and others, 1988).

Table 52 summarizes the results of phenol analyses of samples collected in the Kentucky River basin during water years 1976-86. Although concentrations of most chlorinated phenols in streambed material and fish tissue were less than detection limits, pentachlorophenol was detected in two streambed-material samples (maximum concentration, 180 $\mu g/kg$). Two water samples collected during this period both contained phenol concentrations of 3.0 $\mu g/L$. There is no Federal criterion for phenols; however, the smallest concentration affecting freshwater aquatic life (chronic) has been reported to be 2,560 $\mu g/L$ (U.S. Environmental Protection Agency, 1986a).

Phthalate Esters

Phthalate esters are compounds principally used in association with polyvinyl chloride (PVC) plastics. The manufacture of phthalates in the United States has increased dramatically during the last 25 years. As a result of their large scale production, phthalates are frequently identified as contaminants in the water, sediment, and biota of surface-water systems (Smith and others, 1988).

The environmental fate of phthalates is not well documented, but biodegradation, sorption, and bioaccumulation seem to be important fate-determining processes. As a result of their low solubilities, some phthalates partition into the lipid reservoirs of aquatic organisms and organic matter in streambed material. Nonbiological hydrolysis, volatilization, and photolysis, do not seem to be significant fate-determining processes for phthalates (Smith and others, 1988).

Phthalates do not seem to be highly toxic to living organisms, over the short term, even in large doses. However, it is not known how small doses over a long period of time would affect living organisms. Some experiments have shown that phthalates interfere with reproduction in aquatic organisms (ReVelle and ReVelle, 1984).

Table 52 summarizes the limited phthalate ester sample data collected in the Kentucky River basin during water years 1976-86. Maximum aqueous phthalate concentrations ranged from less than 1.0 to 5.0 $\mu g/L$. There is not a Federal criterion for phthalate esters; however, the smallest concentration observed to cause an effect on freshwater aquatic life (chronic) has been reported as 9 $\mu g/L$. No data exists from streambed-material or fish-tissue samples. The limited data base prevents adequate determinations of occurrence and distribution.

Polycyclic Aromatic Hydrocarbons

The polycyclic aromatic hydrocarbons (PAH) are a group of environmentally important compounds, that are characterized by two or more fused-ring compounds based upon benzene. PAH compounds originate from both natural and anthropogenic sources. Commercially produced PAH compounds include napthalene, pesticides, dyes, solvents, and lubricants (Smith and others, 1988).

PAH compounds are persistent surface water contaminants, and based on their low solubility they partition from the water into biota, particulate and dissolved organic matter, and sediments. These compounds are known to accumulate in the lipid reservoirs of aquatic organisms (Smith and others, 1988). PAH compounds may enter natural water in a variety of ways, such as atmospheric deposition, surface runoff and soil leaching, industrial discharges, and municipal wastewater effluents (Smith and others, 1988).

Only one polycyclic aromatic hydrocarbon analysis was noted in the 1976-86 data base for the Kentucky River basin. This analysis was for total polychloral naphthalene and none was detected.

Fecal Indicator Bacteria

Fecal coliform bacteria, which comprise a part of the total coliform group, are restricted to the intestinal tract of warm-blooded animals and are commonly used as indicators of fecal contamination in water. Pollution of aquatic systems by the excreta of warm-blooded animals may result in health problems for man and animals and potential disease problems for aquatic life.

Areal fecal coliform data coverage is very limited in the Kentucky River basin. Median concentrations did not exceed 2,000 colonies per 100 mL at any of the selected sites in the basin (table 53). However, some high fecal coliform concentrations were detected in the North Fork Kentucky River at Jackson (site 2.0), immediately upstream of the municipal-wastewater discharge (fig. 52). Data from the main stem of the Kentucky River indicate that coliform concentrations decrease downstream of the North Fork basin, but then increase again in the lower, more populated part of the study area (fig. 53).

The seasonal patterns of fecal-coliform concentrations from sites in the upper basin differ greatly from the seasonal patterns from sites in the lower basin. In the upper basin, largest fecal coliform concentrations generally occur during the summer low-flow period. However, in the lower basin the largest fecal coliform concentrations occurred in the winter during medium to high-flow periods. These patterns indicate that the principal sources of fecal-coliform bacteria in the upper basin are point source discharges, including effluent from municipal wastewater treatment facilities, whereas the principal sources of fecal contamination in the lower basin are nonpoint sources such as agricultural and urban runoff.

Kentucky's domestic water supply criterion for fecal-coliform bacteria is a maximum of 2,000 colonies per 100 mL of water. Five to fourteen percent of the fecal-coliform observations obtained throughout the basin during water years 1976-86 exceeded this criterion (table 54). Colony counts

Table 53.—*Statistical summary of fecal-indicator bacteria concentrations at selected sites in the Kentucky River basin*

[N, number of observations. 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	USGS station name	Period of record (water years)	N	Value at indicated percentile: 10	25	50 (median)	75	90
Coliform, fecal, membrane filtered, M-FC medium at 44.5 degrees Celsius, in colonies per 100 milliliters								
2.0	North Fork Kentucky River at Jackson	1983-85	26		698	1,250	5,400	
2.3	Middle Fork Kentucky River at Tallega	1983-85	25		55	90	205	
2.6	South Fork Kentucky River at Booneville	1983-85	25		37	150	290	
3.0	Kentucky River at Lock 14, at Heidelberg	1980-85	61	20	61	200	650	1,490
3.1	Red River near Hazel Green	1980-85	59	74	140	320	710	1,700
5.0	Kentucky River at Camp Nelson	1980-85	62	6	12	43	200	610
7.0	Kentucky River above Frankfort	1980-85	64	10	20	55	160	645
9.0	Kentucky River below Frankfort	1980-85	61	18	29	100	315	928
9.3	South Elkhorn Creek near Midway	1983-85	26		158	450	740	
10.0	Kentucky River at Lock 2, at Lockport	1976	12		98	680	1,220	
10.1	Eagle Creek at Glencoe	1980-85	68	7	21	71	393	1,100
Coliform, fecal, 0.7 micrometer membrane filtered, in colonies per 100 milliliters								
10.0	Kentucky River at Lock 2, at Lockport	1977-85	80	10	37	210	1,300	2,600
Streptococci, fecal, membrane filtered, KF agar, in colonies per 100 milliliters								
10.0	Kentucky River at Lock 2, at Lockport	1977-85	76	14	47	150	780	3,500

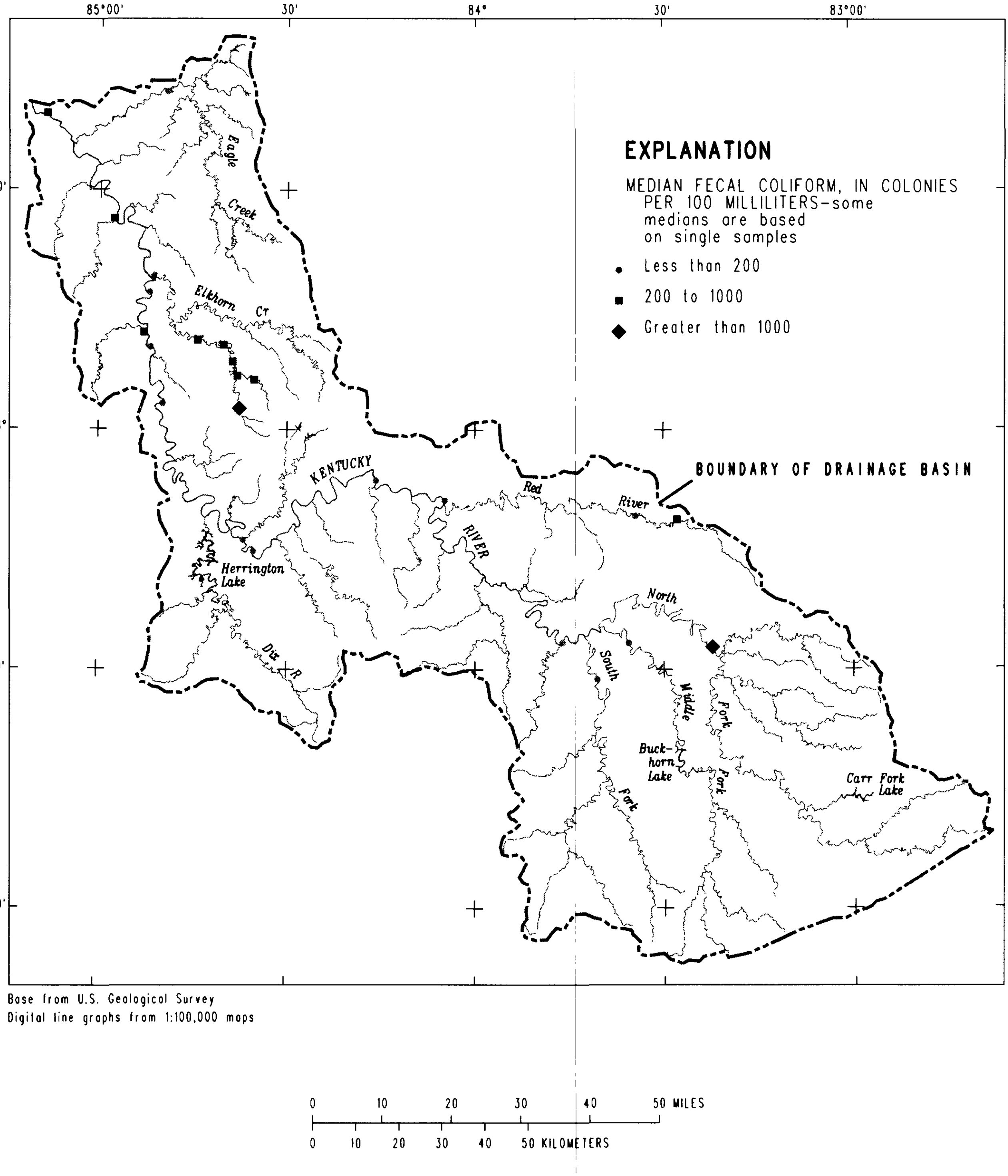


Figure 52.--Median colony counts of fecal coliform bacteria at sites in the Kentucky River basin, through 1986.

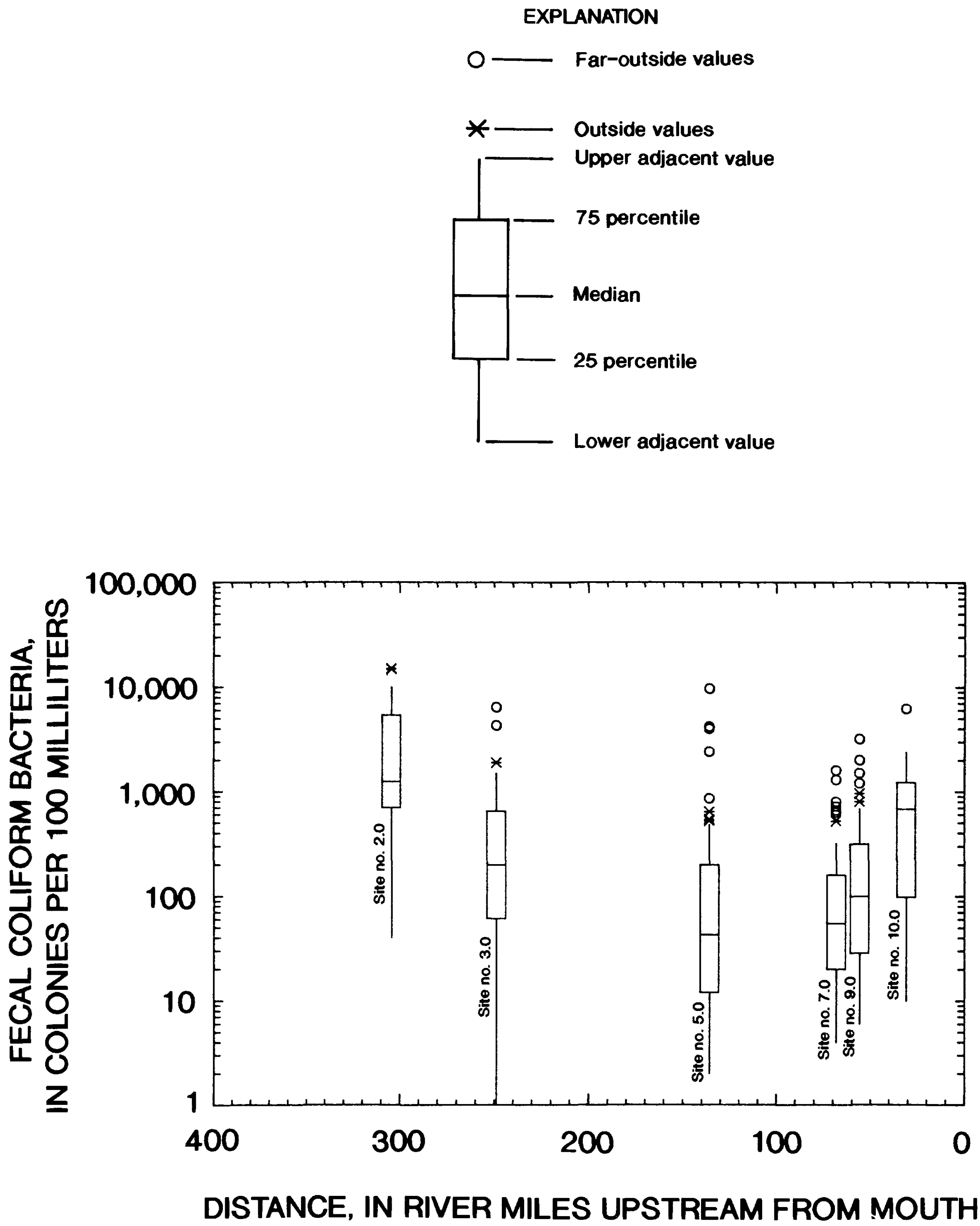


Figure 53.--Statistical summary of fecal coliform bacteria counts at sites along the Kentucky River, based on available data for water years 1976-86.

exceeding the domestic water supply criterion occur in several streams of the Kentucky River basin (table 55). The Kentucky surface water-quality criterion of 200 fecal-coliform colonies per 100 mL for primary contact recreational water has been exceeded at times at all sites in the basin at which 10 or more determinations have been made during water years 1976-86 (tables 53 and 55). Nearly half of the concentrations of fecal coliform bacteria determined throughout the basin during water years 1976-86 exceeded this criterion (table 54).

A decreasing trend in concentration of fecal coliform bacteria is indicated at sites on the lower Kentucky River (table 56). Both flow-adjusted and unadjusted decreasing trends were noted in fecal-coliform bacteria concentrations from the Kentucky River at Camp Nelson (site 5.0) to the Kentucky River at Lock 2 (site 10.0).

Table 54.—*Number of fecal-indicator bacteria measurements made in the Kentucky River basin and percentage not meeting indicated water-quality criteria, based on available data for water years 1976-86*

[Kentucky criteria: KYDWS, domestic water supply; KYRP, recreational water—primary contact; KYRS, recreational water—secondary contact]

Constituent	No. of measurements	Percentage not meeting indicated criteria		
		KYDWS	KYRP	KYRS
Coliform, fecal, membrane filtered, M-FC medium at 44.5 degrees Celsius	517	5	41	12
Coliform, fecal, 0.7 micrometer membrane filtered	122	14	52	25
Streptococci, fecal, membrane filtered, KF agar	76	16	47	20

Table 55.—*Number of fecal-indicator bacteria measurements made at selected sites in the Kentucky River basin and percentage not meeting indicated water-quality criteria, based on available data for water years 1976-86*

[Kentucky criteria: KYDWS, domestic water supply; KYRP, recreational water— primary contact; KYRS, recreational water—secondary contact]

Site number	USGS station name	Number of measurements	Percentage not meeting indicated criteria		
			KYDWS	KYRP	KYRS
Coliform, fecal, membrane filtered, M-FC medium at 44.5 degrees Celsius					
2.0	North Fork Kentucky River at Jackson	26	35	92	58
2.3	Middle Fork Kentucky River at Tallega	25	4	24	8
2.6	South Fork Kentucky River at Booneville	25		40	12
3.0	Kentucky River at Lock 14, at Heidelberg	61	3	49	15
3.1	Red River near Hazel Green	59	7	66	15
5.0	Kentucky River at Camp Nelson	62	6	23	6
7.0	Kentucky River above Frankfort	64		22	3
9.0	Kentucky River below Frankfort	61	2	36	8
9.3	South Elkhorn Creek near Midway	26	8	73	15
10.0	Kentucky River at Lock 2, at Lockport	12	17	75	25
10.1	Eagle Creek at Glencoe	68	2	29	10
Coliform, fecal, 0.7 micrometer membrane filtered					
10.0	Kentucky River at Lock 2, at Lockport	80	11	50	28
Streptococci, fecal, membrane filtered, KF agar					
10.0	Kentucky River at Lock 2, at Lockport	76	16	47	20

Table 56. – *Trend test results for fecal-indicator bacteria concentrations for selected sites in the Kentucky River basin*

[N, number of observations; SC, number of seasonal comparisons; P, probability. Trend-line slopes not significant at 0.2 probability level are not reported, and those significant at the 0.1 probability level are underlined]

					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	USGS station name	Period of record (water years)	N	SC	P level	Colonies per 100 milliliters per year	Percent of median concentration (colonies per 100 milliliters) per year	P level	Colonies per 100 milliliters per year	Percent of median concentration (colonies per 100 milliliters) per year
Coliform, fecal, membrane filtered, M-FC medium at 44.5 degrees Celsius										
2.0	North Fork Kentucky River at Jackson	1983-85	26	16	0.102	-700	-700	0.326		
2.3	Middle Fork Kentucky River at Tallega	1983-85	25	16	1.00					
2.6	South Fork Kentucky River at Booneville	1983-85	25	16	.488			.488		
3.0	Kentucky River at Lock 14, at Heidelberg	1980-85	61	28	.921			.843		
3.1	Red River near Hazel Green	1980-85	59	28	.428			.321		
5.0	Kentucky River at Camp Nelson	1980-85	62	28	.552			.165	-40	-95
7.0	Kentucky River above Frankfort	1980-85	64	28	.428			.047	-13	-25
9.0	Kentucky River below Frankfort	1980-85	61	28	.195	-18	-25	.000	-35	-51
9.3	South Elkhorn Creek near Midway	1983-85	26	16	.102	-200	-39	1.00		
10.1	Eagle Creek at Glencoe	1980-85	68	28	.321					
Coliform, fecal, 0.7 micrometer membrane filtered										
10.0	Kentucky River at Lock 2, at Lockport	1977-85	80	40	.004	-68	-31	.068	-38	-17
Streptococci, fecal, membrane filtered, KF agar										
10.0	Kentucky River at Lock 2, at Lockport	1977-85	76	40	.338			.866		

[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 (1) 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 (2) 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.

Biological Indicators of Water Quality

By A.D. Bradfield

Streams are host to a variety of plants and animals that are dependent upon each other for food. At the base of aquatic food "chains," or trophic structures, are microscopic organisms, such as bacteria, fungi, phytoplankton (suspended algae) and periphyton (attached or benthic algae). Algae provide food for benthic macroinvertebrates (aquatic insects, mussels, and crustaceans) which in turn are a basic food supply for many species of fish.

Because of the complex interactions of aquatic biota, considerable insight regarding water-quality conditions can be gained by examining the types of organisms inhabiting a particular stream or river. Trophic-structure complexity can be estimated by considering the total number of aquatic species in a stream (taxa richness) and the distribution of individuals among different taxonomic groups (diversity and evenness) (Kentucky Natural Resources and Environmental Protection Cabinet, 1987; Ludwig and Reynolds, 1988). In addition to these numerical measures of community structure, the environmental requirements and pollution tolerance of dominant species as well as the presence of any intolerant species are important qualitative measures of community structure. Biological data, along with information on water chemistry and physical-habitat conditions, provide an integrated approach for assessing and monitoring the status of aquatic environments.

The following is a summary of conclusions concerning the biological integrity of selected river systems in the Kentucky River basin. More detailed discussions of the biological data on which these conclusions are based, as well as an extensive reference list, are presented in Bradfield and Porter (1990).

North Fork Kentucky River

Mining of coal and the production of oil and gas are important land-use activities in the basin drained by the North Fork Kentucky River system. The North Fork is influenced by these land uses as well as domestic-sewage effluents. When conducted improperly, these activities have resulted in increased sedimentation, stream acidification, and elevated chloride concentrations in streams. Increased constituent concentrations and sediment loads transported to streams have resulted in the elimination of all but the most tolerant species of aquatic biota in localized areas (Dyer, 1982).

Biological data for the North Fork Kentucky River are presented in Jones (1973), Prather (1985), and Kentucky Natural Resources and Environmental Protection Cabinet (1986). Williams (1975) identified nine species of freshwater mussels in the North Fork Kentucky River although some of these species were probably represented by relic shells. Habitat for mussels has likely been reduced in the North Fork due to "drastic environmental changes that have occurred in the past 50 to 75 years" (Williams, 1975).

Carr Fork begins in Knott County, is impounded by Carr Fork Reservoir and then flows southwesterly before joining the North Fork Kentucky River. Carr Fork Reservoir is considered a eutrophic reservoir (Kentucky Natural Resources and Environmental Protection Cabinet, 1986) and is undergoing accelerated sedimentation (U.S. Army Corps of Engineers, 1986). Recreational uses are impaired due to water turbidity (Kentucky Natural Resources and Environmental Protection Cabinet, 1984b). Extensive mining by strip, auger, and deep methods has occurred in the Carr Fork drainage.

The primary effect on aquatic biota of Carr Fork seems to be loss of habitat due to sediments transported from mined lands (Jones, 1973). Data collected by the Kentucky Nature Preserves Commission in 1978 indicated limited algal flora and a limited number of benthic invertebrate species compared to undisturbed drainages (Harker and others, 1979). Unpublished macroinvertebrate data for Carr Fork upstream from Carr Fork Lake, Trace Fork, Defeated Creek, and the Carr Fork Lake tailwater region are available from the U.S. Army Corps of Engineers, Louisville District.

Buckhorn Creek has historically been affected by mining, however it seems to be one of the largest relatively healthy aquatic systems in the North Fork Kentucky River drainage. Numerous species of algae and benthic invertebrates were collected during previous investigations. Forty-two species of fish have been identified in Buckhorn Creek (Kuehne, 1962a, 1962b; Lotrich, 1973, Harker and others, 1979). Intensive macroinvertebrate investigations were conducted by Phillippi (1984).

Buckhorn Creek, including Clemons Fork and Coles Fork, was recommended as an "Outstanding Resource Water" by the Kentucky Nature Preserves Commission (Hannan and others, 1982). Considering the amount of land disturbance in the North Fork Kentucky River basin, the Buckhorn Creek drainage is an important source for faunal recolonization of Troublesome Creek and other river systems downstream.

Descriptions of pristine conditions of Troublesome Creek in the 1890's are reported by Woolman (1892). These accounts are in sharp contrast to conditions observed in the 1980's. Extensive contour and deep mining in the drainage basin, a mountain top removal project, and sewage effluents from the city of Hindman have severely degraded the aquatic resources of Troublesome Creek (Harker and others, 1979; Miller and others, [no date]). Aquatic communities were usually moderately diverse, but low total numbers indicate unsuitable water quality or limited habitat.

The Quicksand Creek drainage, with the exception of Laurel Fork, has been affected by sedimentation from mining operations for a number of years (Jones, 1973; Miller and others, [no date]). Investigations of aquatic biota in Laurel Fork during 1978 indicated the presence of diverse and productive biotic communities associated with good water quality and habitat diversity. Benthic algal communities were moderately diverse (Harker and others, 1979). Numerous species of invertebrates and fish, some of which are considered intolerant of pollution, were collected from Laurel Fork.

Middle Fork Kentucky River

Streams that make up the Middle Fork Kentucky River basin comprise the smallest subbasin in the Kentucky River system. Primary land use practices in the steep terrain of the Cumberland Plateau include coal mining, oil and gas production, silviculture, and a limited amount of agriculture. One major impoundment, Buckhorn Lake, a mesotrophic reservoir (Kentucky Natural Resources and Environmental Protection Cabinet, 1986), is on the Middle Fork Kentucky River. Built in 1961, the lake occupies approximately 1,200 acres and is operated by the U.S. Army Corps of Engineers primarily as a flood control reservoir (Prather, 1985). Algal blooms have been observed in the headwater area of Buckhorn Lake as a probable result of nutrient loads discharged into the Middle Fork Kentucky River from the city of Hyden wastewater treatment plant (Kentucky Natural Resources and Environmental Protection Cabinet, 1984a). The Middle Fork Kentucky River downstream from Buckhorn Lake benefits from low-flow augmentation and reduced sediment loads. Turner (1967) conducted a survey of conditions of the Middle Fork before and after the dam was constructed. Unpublished macroinvertebrate data for the Middle Fork Kentucky River at three sites upstream from Buckhorn Lake and from the tailwater area are available from the U.S. Army Corps of Engineers, Louisville District. Fisheries data for the Middle Fork Kentucky River are presented in Prather (1985).

Water quality and fishing in Greasy Creek, a fourth-order tributary to the Middle Fork, was reported as excellent by Jones (1973). A study conducted by Kentucky Nature Preserves Commission in 1978 indicated Greasy Creek still supported numerous species of benthic invertebrates and a diverse fishery although conditions had degraded due to mining (Harker and others, 1979). Greasy Creek is an important source for faunal recolonization of downstream areas adversely affected by land-use activities. Greasy Creek was identified as a potential "Outstanding Resource Water," providing habitat for muskellunge spawning and a smallmouth and rock bass habitat and fishery (Hannan and others, 1982).

Cutshin Creek is the largest tributary of the Middle Fork. More than 30 percent of the basin had been surface mined by 1969, resulting in acid-mine drainage and large sediment loads. Aquatic communities were reported as diverse, but were dominated by taxa which can withstand a wide range of environmental conditions (Harker and others, 1979). Cutshin Creek has been subject to recurring fish kills from oil drilling and mining operations initiated during the early to mid-1980's (Kentucky Natural Resources and Environmental Protection Cabinet, 1986).

Squabble Creek is affected by abandoned strip mine drainage and discharges from two small, sewage treatment plants. Biological investigations in Squabble Creek indicated environmental stresses due to poor water quality or reduced habitat (Harker and others, 1979). Because of its location, this stream can be an important source of aquatic flora and fauna to the Middle Fork downstream of Buckhorn Lake.

South Fork Kentucky River

The South Fork Kentucky River basin lies in the Eastern Coal Field region, as do the North and Middle Fork basins. Land use practices are similar to those in other areas in the region, with coal mining and oil and gas production as the primary industries. The South Fork Kentucky River begins with the confluence of the Red Bird River and Goose Creek at Oneida, Kentucky. It then flows north for approximately 40 miles to join the Kentucky River at Beattyville, Kentucky.

Water-quality and biological data were collected at two sites on the South Fork by the Kentucky Department of Fish and Wildlife Resources in 1982 (Jones and Stephens, 1984). Invertebrate-taxa richness and diversity consistently decreased with distance from the headwater reaches to the mouth of the South Fork, indicating a compounding of environmental effects as tributaries with degraded water quality and large sediment loads joined the South Fork. Summer macroinvertebrate samples were dominated by common, more pollution-tolerant species. In another study, phytoplankton diversity and taxa richness increased from upstream to downstream sampling sites (Metzmeier, 1987), possibly due to increased habitat diversity. The South Fork Kentucky River at Booneville (site 2.6) is sampled routinely by the Kentucky Division of Water (Kentucky Natural Resources and Environmental Protection Cabinet, 1986). Fish of the South Fork Kentucky River are described by Branson and Batch (1983).

Because the South Fork Kentucky River downstream of the confluence of Goose Creek and Red Bird River (at Oneida, Kentucky) still provides some muskellunge habitat, this section to the mouth was recommended as an "Outstanding Resource Water" by the Kentucky Nature Preserves Commission (Hannan and others, 1982).

Goose Creek is a moderate gradient, fourth-order stream. The upper reaches of Goose Creek have water quality suitable to support diverse aquatic communities. Major tributaries include Collins Fork and Little Goose Creek. The lower half of Goose Creek is affected by acid-mine drainage and sediment from Horse Creek and Little Goose Creek (Harker and others, 1979).

Mine drainage in the past severely affected the fish of lower Goose Creek (Turner, 1958). Several fish kills attributable to coal-mining discharges occurred at Goose Creek during the period 1969-73, and pH values ranged from 4.2 to 5.1 over much of the stream's length during 1969 (Brewer, 1980). Water-quality conditions seem to have improved in the basin; however, the effects of siltation are still apparent.

The Goose Creek drainage is an important stream in the South Fork Kentucky River system. It provides a source of organisms for recolonization of invertebrate communities and is some of the last muskellunge habitat in the basin. Goose Creek and Collins Fork were identified as "Sport Fishery Resources" by the Kentucky Department of Fish and Wildlife Resources and consequently were recommended as an "Outstanding Resource Water" (Hannan and others, 1982).

The Red Bird River is the largest tributary of the South Fork Kentucky River, draining the area east of the Goose Creek drainage upstream of their confluence. Biological investigations indicated some effects from sediment in the headwater area of Red Bird River, but the biological quality improved in downstream reaches. Metzmeier (1987) reported low phytoplankton chlorophyll *a* concentrations which were typical for small, eastern Kentucky streams. Fewer sensitive species were observed at headwater sites than at sites in the lower reaches of Red Bird River. During the early 1970's, the stream was reported to be affected by silt from strip mines in the headwater area (Jones, 1973).

Forty-four macroinvertebrate taxa were documented by Jones and Stephens (1984). High macroinvertebrate density was noted, particularly during the summer. All major insect groups were represented. The Red Bird River provides some habitat for muskellunge, however it had the lowest catch rate of the five streams supporting muskellunge in the South Fork Kentucky drainage (Jones and Stephens, 1984). This stream, from the confluence with Sugar Creek to the mouth, was designated as a "Sport Fishery Resource" and recommended as an "Outstanding Resource Water" (Hannan and others, 1982).

Although fish populations were said to be adversely affected by acid-mine drainage during the early 1970's (Jones, 1973; Brewer, 1980), water quality and habitat availability of Sexton Creek seem to have improved during the past ten years. Forty-two macroinvertebrate taxa were collected from Sexton Creek during 1982 (Jones and Stephens, 1984). Samples collected during spring were high in diversity but contained relatively few individuals. The opposite was true during summer when samples contained large numbers of common taxa. At least in lower reaches, the effects of mining on stream quality have been reduced since 1982 because Sexton Creek was reported to have one of the highest densities of muskellunge of all South Fork Kentucky River streams (Jones and Stephens, 1984). Because of valuable habitat for muskellunge and golden redhorse, Sexton Creek was recommended as an "Outstanding Resource Water" (Hannan and others, 1982).

Seventy-eight benthic-algal species were identified from Buck Creek during 1978 (Harker and others, 1979). Diatom diversity was moderately low because of the dominance of *Achnanthes minutissima*, which is a common characteristic of many eastern Kentucky streams. Many taxa that are associated with sediments were present but not particularly abundant, indicating some land-disturbance effects. The macroinvertebrate community was represented by all major insect groups. Fish collections were considered typical for eastern Kentucky streams (Harker and others, 1979).

Kentucky River from Beattyville to Red River Confluence

The Kentucky River extending from the confluence of the North, Middle, and South Forks of the river to the confluence with the Red River includes navigational pools 14 through 11 and is a seventh-order river. Land-use effects on aquatic communities relate primarily to brines from oil and gas operations and sedimentation from mining.

Effects of nonpoint sources of agricultural chemicals on biological communities are more apparent in this region than in the steeper terrain of the Eastern Coal Field because of increased farming of wider flood plains. Sewage effluents contributed by the major urban centers also tend to have more detrimental effects on the biological communities in this area because of less natural aeration due to the depth of water and the low velocity of streamflow in the pools behind the locks and dams.

Biological communities of the Kentucky River at Lock 14 (site 3.0) have been routinely sampled by the Kentucky Division of Water since 1978. Blue-green algal blooms were reported upstream from Lock 14 and attached algal biomass and standing crop were elevated. This was partially attributed to wastewater effluent discharges at Beattyville and the impounded nature of the river (Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water, 1986).

Macroinvertebrate communities (on artificial substrata) have remained relatively consistent since the late 1970's. Habitat restrictions have apparently limited the invertebrate community to a greater extent than have poor water-quality conditions (Kentucky Natural Resources and Environmental Protection Cabinet, 1986). While the river has historically supported viable mussel populations (Danglade, 1922), no mussel beds were observed in the Lock 14 pool by Williams (1975).

The fish species at the Lock 14 pool are typical of a large river (Kentucky Natural Resources and Environmental Protection Cabinet, 1982), the pool supports a sport fishery as well as a limited commercial fishery. Thirteen fish species were reported by Williams (1975) and a total of 27 species were collected by Jones (1973) at two sites in the Lock 14 pool.

Sturgeon Creek, which joins the Kentucky River immediately downstream from Lock 14, supported a diverse flora and fauna during 1978 (Harker and others, 1979). Although the total number of algal species observed was relatively low (44 taxa), sensitive diatom species were present in sufficient numbers to indicate a healthy aquatic environment. Forty-one taxa of benthic macroinvertebrates were collected during this investigation, including sensitive taxa commonly observed in small, cool woodland streams. Kornman (1985) reported 36 macroinvertebrate taxa from Sturgeon Creek.

Biological studies were conducted by Kentucky Division of Water in the Ross Creek and Millers Creek basins during the early 1980's as a result of environmental concerns regarding brine discharges from oil and gas operations. Most streams surveyed were moderately to severely affected by brines from oil and gas operations. Chloride concentrations in the upper reaches generally exceeded 2,000 mg/L. Biological samples from most sites sampled in these stream systems contained only a few individuals of very tolerant species (Logan, Call, Houp, Mills, Porter, Schneider, and Walker, 1983; Logan and others, 1989).

No fish fauna were observed in Buck Creek, and reduced numbers of fish taxa and individuals were noted in Ross Creek downstream of Buck Lick Creek (Logan, Call, Houp, Mills, Porter, Schneider, and Walker, 1983).

Station Camp Creek is considered one of the largest, high-quality watersheds in the Kentucky River system and was recommended as an "Outstanding Resource Water" by Kentucky Nature Preserves Commission (Hannan and others, 1982). Macroinvertebrate collections from Station Camp Creek contained all major groups of insects, mollusks, and crustaceans. Sixty-nine taxa, including a diverse population of mayflies, were collected by Kornman (1985), indicating abundant habitat and good water quality conditions at the time of sampling. The Kentucky Department of Fish and Wildlife Resources identified 44 species of fish, bringing the total of known fish fauna in the drainage to at least 55 species (Carter, 1970; Branson and Batch, 1974; Kornman, 1985; and Mills, 1988). The Kentucky Division of Water sampled two sites on Station Camp Creek during 1984 (Logan and others, 1989).

The Red River System drains much of the area of the middle basin east of the Kentucky River. Major tributaries include the Middle and South Forks of the Red River, Swift Camp Creek, and Lulbegrud Creek. The upstream segment of the Red River has been designated as a "Kentucky Wild River" in accordance with State statutes (Miller and others, 1980). The remaining sections provide habitat for muskellunge and were recommended as an "Outstanding Resource Water" (Hannan and others, 1982). Streams in this basin have been the subject of numerous biological investigations because of their unique aquatic environments (Kuehne, 1962a; Branson, 1970; Carter, 1970; Branson and Batch, 1974, 1982; Harker and others, 1979; and Houp, 1980). Hannan and others (1982) presented additional references on the Red River system.

Water-quality conditions in this part of the Kentucky River basin range from high-quality water and diverse biological communities of Swift Camp Creek, Lulbegrud Creek, and upstream reaches of the Red River to severely brine- and sediment-laden reaches of the Middle and South Forks of the Red River. The upstream segment of the Red River, which includes the "Kentucky Wild River" segment, has long been considered one of the highest quality streams in the Kentucky River system. However, investigations by the Kentucky Division of Water indicate that land disturbance in the basin is threatening the integrity of this section of the Red River drainage. Several species of freshwater mussels have already been eliminated from the Wild River segment due to sedimentation of available habitat. Biological and water-quality investigations of the Middle and South Forks of the Red River indicate severe effects associated with oil and gas production, as well as coal mining. Macroinvertebrate communities are dominated by tolerant Dipterans while algal communities are dominated by halophilic (associated with brines) and epipelic (associated with sediments) species. Severely affected streams are either devoid of fish or support only tolerant species.

Kentucky River from Red River to the Ohio River

The Kentucky River from the Red River to the river's mouth at the Ohio River covers approximately 3,200 square miles. Primary effects of land use on aquatic biota in this part of the basin are related to sediment from agricultural sources and nutrient enrichment from wastewater treatment plant effluents. Sewage discharges from large population centers combined with the slow-moving, deep-water conditions in the lock systems have resulted in accelerated eutrophication in some river segments.

Freshwater-mussel investigations conducted during the late 1960's showed that commercially valuable mussel beds were limited to the Lock 3, Lock 5, and Lock 8 pools. Most pools sampled contained from 10 to 15 mussel species; however, fewer species were reported from the Lock 2 and Lock 6 pools (Williams, 1975).

Fisheries data for the Kentucky River were reported by Williams (1975) and Kentucky Natural Resources and Environmental Protection Cabinet (1986). Although Williams reported from 17 to 22 fish species in the Lock 5 through Lock 10 pools, fewer species were observed in the Lock 1 through Lock 4 pools. Fish bioassay studies indicated acute toxicity at two Kentucky Division of Water sampling sites during 1986 and 1987. Annual investigations conducted by Kentucky Division of Water since the early 1980's indicate relatively stable environmental conditions in the Kentucky River between Camp Nelson (site 5.0) and Frankfort (site 8.0).

The species composition of phytoplankton communities in the pools upstream of Locks 2, 3, 4, and Lock 7 of the Kentucky River seem to be similar. Dominant phytoplankton species during summer, low-flow conditions generally were centric diatoms and other taxa indicative of eutrophication. Periodic algal blooms have occurred in various reaches of the Kentucky River during low-flow conditions.

Silver Creek was once a good sport fishery for black and rock bass (Jones, 1973). However, chronic pollution from the discharge of treated domestic wastewater and nutrient enrichment from agricultural runoff has diminished its quality. Water-quality violations were observed by the Kentucky Division of Water in 1982 for undissociated hydrogen sulfide, phthalate esters, aluminum, mercury and fecal-coliform bacteria (Logan and others, 1984). Habitats for aquatic organisms in Silver Creek were reported to be abundant, although dense growths of filamentous algae likely indicative of high nutrient levels, were present at all sampling sites (Logan and others, 1984). The algal community was dominated by taxa associated with nutrient enrichment and high tolerance to a wide variety of water-quality conditions. Macroinvertebrate communities were diverse although localized phosphorus concentrations were elevated downstream of domestic wastewater effluents.

Jessamine Creek was classified as an "Outstanding Resource Water" due to the presence of three species of bats (*Myotis grisescens*, *Myotis sodalis*, and *Myotis keenii*) that inhabit the gorge (Hannan and others, 1982). The first two species are recognized as endangered at the Federal level and *M. keenii* is listed as being of special concern within Kentucky (Warren and others, 1986). *Myotis grisescens* relies on aquatic insect emergence for food, consequently any degradation of water quality in Jessamine Creek could affect their survival (Hannan and others, 1982).

Jessamine Creek and Town Fork were reported to be degraded by effluents from wastewater treatment plants serving Wilmore and Nicholasville, Kentucky (Miller and others, [no date]). Bioassay studies conducted by the Kentucky Division of Water indicated acute toxicity to fathead minnows in the Nicholasville and Wilmore sewage effluents in Town Fork downstream from the Wilmore wastewater treatment plant. Limited biological data are also presented in MacGregor (1973), Howell (1975), and Houp (1981).

The Dix River drains a large part of the Outer Bluegrass region. The lower part of the Dix River is impounded, forming Herrington Lake, a eutrophic reservoir (Kentucky Natural Resources and Environmental Protection Cabinet, 1984a). Algal assays indicated that Herrington Lake was phosphorous limited (Kentucky Natural Resources and Environmental Protection Cabinet, 1984a). The Herrington

Lake dam probably mitigates the effects of nonpoint source (agricultural) sedimentation and nutrient enrichment in the Dix River basin. Hypolimnetic water released from Herrington Lake during summer results in downstream reaches of the Dix River being cooler and less turbid than other major tributaries of the Kentucky River. The Dix River was identified as an important sport fishery resource by Kentucky Department of Fish and Wildlife Resources and was recommended as an "Outstanding Resource Water" by Hannan and others (1982). The fish and gastropods of the Dix River were described by Branson and Batch (1981a, 1981b).

The upper parts of the Dix River system (Dix River and Copper Creek) are affected by nonpoint source agricultural activities. Aquatic biological communities are dominated by taxa that tolerate a wide range of water-quality conditions. Few sensitive species have been collected. Fisheries investigations of Hanging Fork during the early 1970's indicated the presence of more sensitive species than were observed in upstream reaches of the Dix River system. Downstream parts of the system (Clarks Run) were adversely affected by point-source discharges from Danville. Acute toxicity to fathead minnows was documented in 1986 and 1987, with particularly low survival in the summer of 1987 (Kentucky Division of Water, written commun., 1988).

Elkhorn Creek is a major tributary of the Kentucky River system and has been the subject of numerous water-quality investigations. North Elkhorn Creek is affected by agriculture and wastewater discharges from Georgetown, Kentucky, however, biological data collected from the mid-1960's through the 1970's indicated diverse and productive aquatic communities. North Elkhorn Creek was recommended as an "Outstanding Resource Water" because of the occurrence of two sensitive freshwater mussel species. Data collected in 1968 by the Kentucky Department of Fish and Wildlife Resources indicated good water quality and a stable biological environment, however, some industrial and domestic sewage discharges to the stream were noted (Laflin, 1970).

In contrast, South Elkhorn Creek has been adversely affected by point-source discharges and urban runoff for many years (Laflin, 1970; Jones, 1973; Hannan and others, 1982; Kentucky Natural Resources and Environmental Protection Cabinet, 1986; and Miller and others, [no date]). Bioassay investigations indicated acute and chronic toxicity which limited aquatic communities to tolerant organisms downstream from the Lexington wastewater treatment plant effluent (Logan, Beck, Call, Houp, Mills, Porter, Schneider, and Walker, 1983; Kentucky Natural Resources and Environmental Protection Cabinet, 1986). Limited stream recovery was apparent in downstream reaches of South Elkhorn Creek near its confluence with North Elkhorn Creek.

Eagle Creek is the last major tributary to join the Kentucky River before the river discharges into the Ohio River. Eagle Creek seems to be of high quality and is not significantly affected by wastewater effluents and agricultural runoff in the basin (Horseman and Branson, 1973; Kentucky Natural Resources and Environmental Protection Cabinet, 1986). Investigations on Eagle Creek near Glencoe (site 10.1) indicated the presence of diverse, productive aquatic communities (Kentucky Natural Resources and Environmental Protection Cabinet, 1986). Eagle Creek was recommended as an "Outstanding Resource Water" (Hannan and others, 1982).

LIMITATIONS OF AVAILABLE SURFACE WATER-QUALITY DATA

The most extensive water quality data collection program for surface water in the Kentucky River basin is the Kentucky Division of Water's "Ambient Monitoring Program." In the ambient monitoring program, data collection is targeted on water-quality constituents and properties for which current water-quality criteria exist. Samples are not analyzed for all constituents and properties of current scientific interest due to funding limitations and the necessity of sampling on a Statewide basis. Statistical descriptions of concentrations and time trends in concentrations are possible with the data from this program. The data collected by the State of Kentucky, however, are not as useful for estimating transport of constituents associated with suspended sediment because samples are not collected using cross sectionally integrated techniques and no special effort is made to collect samples under high-flow conditions. Much of the transport of constituents (especially those associated with suspended sediment) occurs during periods of extreme high flow. For example, Walling and Webb (1981) estimated that 83 percent of the suspended sediment was transported in the streams they studied during 1 percent of their study period. Because sediment concentrations generally increase with depth during high-flow periods, a surface-grab sample may be biased and result in a lower concentration of sediment-related constituents than a sample taken which represents the entire vertical dimension of the cross section. This is particularly true if much of the constituent is transported by larger size sediment—such as silt- or sand-sized fractions. Additionally, water-quality conditions can vary markedly in the lateral dimension of the stream cross section due to incomplete mixing and variation in suspended-sediment carrying ability. Some variation in the "historical-record" data for copper, chromium, iron, manganese, zinc and other constituents (totals) associated with suspended sediment has been observed between sites using grab-sampling and those using integrated-sampling, indicating sampling-method bias.

To illustrate this point, comparison of the grab and cross-sectionally integrated sampling techniques can be made from the data collected on the main stem of the Kentucky River at Frankfort and at Lock 2. Based on the transport estimates and, to a lesser degree, the descriptive summaries of concentrations, there is little difference between yields of the dissolved forms of the constituents noted in the above paragraph between the Frankfort sites (sites 7.0 and 9.0) and Lock 2 (site 10.0). However, a sharp increase in yield and load is seen for the total forms of these constituents between these sites. Because the Frankfort sites were sampled using a surface-grab technique and the Lock 2 site was sampled using a cross-sectionally integrated (representative) technique, one possible explanation may be a sampling bias as explained above.

Because some of the sites and constituents sampled as part of Kentucky's ambient monitoring program or the Geological Survey NASQAN program were recently added to the networks, long-term trend detection was not always possible unless the trend had a large magnitude or little random scatter. Constituents falling in this category were aluminum, arsenic, barium, beryllium, cadmium, chromium, cobalt, iron, lead, manganese, mercury, nickel, molybdenum, selenium, silver, strontium, thallium, vanadium, zinc, and fecal coliform. Although several of these constituents did have detectable trends for some sites, more (or fewer) trends may have been detected if additional data were available. Constituents which are of interest in the NAWQA program, for which essentially no data exists in the Kentucky River basin, include antimony, bromide, and boron.

A lack of sites immediately downstream of oil and gas producing areas of the basin prevented an adequate assessment of possible effects of brine discharges to surface-water quality. Sites on smaller drainages with more homogeneous land uses and related effects on water-quality are also lacking. If such data were available, it would have facilitated the determination of more specific water-quality, cause-and-effect relations within the basin.

Biological-data collection within the basin has been quite limited in terms of spatial coverage. While very useful for assessing conditions on specific reaches, more data would be needed for more complete biological assessment of the basin.

Physical properties and concentrations of some major inorganic constituents were analyzed for most water samples collected in the basin. Concentrations of trace elements, major metals, and nutrients were analyzed less frequently. Concentrations of organic substances, radio-chemical constituents, and bacteria were rarely determined for samples collected from the basin. Specific organic compounds, such as a specific pesticide, were analyzed in only a few samples collected within the basin.

Table 57.—*Evaluation of available water-quality data for the Kentucky River basin for various types of assessment*

[5, excellent; 4, good; 3, fair; 2, poor; 1, very poor; 0, none; NA, not applicable]

Data type	Rating of available water-quality data for indicated assessment type			
	Occurrence	Distribution		Transport
		Spatial	Temporal	
Streamflow	NA	5	5	NA
Temperature	5	4	4	NA
pH, alkalinity, and acidity	5	4	4	3
Major cations and anions	4	3	3	3
Suspended sediment	4	3	3	2
Nutrients	3	3	3	2
Oxygen	3	2	2	NA
Major metals and trace elements	3	3	2	2
Radionuclides	2	1	0	0
Organic carbon	3	3	3	2
Pesticides and other synthetic organic compounds	1	0	0	0
Fecal indicator bacteria	3	2	2	NA
Aquatic biological community	2	2	0	NA

A subjective evaluation of the data from the "historical- and current-record" periods for various assessment purposes is given in table 57. The existing water-quality information for the basin is adequate for making a generalized assessment of some common water-quality properties and constituents of interest, such as temperature, pH, alkalinity, major ions, nutrients, and major metals and some trace elements. With the exception of synthetic organic compounds and several trace elements, the occurrence of a specific constituent or property in surface water of the Kentucky River basin can be determined using existing information. However, the existing data are not adequate to address questions concerning the distribution in space or over time and transport of many constituents or to associate conditions with causative factors. Data suitable for trend assessment are also lacking for biological indicators of water quality and concentrations of synthetic organic compounds and radionuclides. Trend detection for concentrations of trace elements is also hampered due to the short period of record and presence of values less than laboratory reporting levels.

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