WATER-QUALITY ASSESSMENT OF THE KENTUCKY RIVER BASIN, KENTUCKY: NUTRIENTS, SEDIMENTS, AND PESTICIDES IN STREAMS, 1987-90

By Kim H. Haag and Stephen D. Porter

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
ounce, fluid (oz)	0.02957	liter
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32)/1.8$$

Abbreviated water-quality units used in this report: Various measurements associated with water quality are given in metric units. Sample volumes are given in liters (L) and milliliters (mL). Descriptions of some sampling equipment are given in millimeters (mm), and pore sizes of filters are given in micrometers (μm). Chemical concentrations are given in milligrams per liter (mg/L), micrograms per liter (μg/L), milligrams per kilogram (mg/kg), or micrograms per kilogram (μg/kg). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same for concentrations in parts per million (ppm).

Total analyses of constituent concentrations in the suspended-sediment fraction are reported either as a ratio of constituent weight in micrograms (μg) to sediment weight in grams (g) or as a percentage by weight. Sediment fraction surface area is reported as square meters (m^2) per gram (g) of sediment.

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

Standard abbreviations used in station names:

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

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ABSTRACT

Data were collected to describe the spatial and temporal variability of nutrients, suspended sediment, and pesticides in the Kentucky River Basin, Kentucky, from April 1987 through March 1990. Nutrient and suspended-sediment samples were collected monthly at seven fixed stations in the 7,000-square-mile basin. Synoptic studies of nutrients and suspended sediments included water-sample collection at a total of 74 sites in both August 1987 and August 1988. The distribution of pesticides was studied by collecting samples at a limited number of fixed stations and synoptic sites during the 3-year period. Efforts were made to identify the causative factors affecting instream concentrations and loads of target constituents.

Nutrient concentrations did not vary significantly from year to year at the fixed stations. Although no statistically significant correlations were found between concentrations of nutrients and discharge, high concentrations of phosphorus were found at high discharges in nonurban areas, and high concentrations of total nitrogen were found at the upper and lower extremes of discharge near the mouth of the Kentucky River. Significant correlations were found between concentrations of total phosphorus and suspended sediment. At many sampling sites in urban areas, most of the stream nitrogen load was primarily attributable to wastewater-treatment-plant (WWTP) effluent, even where only a small proportion of the total stream discharge was attributable to WWTP effluent. At synoptic sites downstream from WWTP's, instream nitrogen concentrations were among the highest measured in the Kentucky River Basin.

No significant correlations were found among land-use types and concentrations of nitrogen at the fixed sites. Concentrations of phosphorus were positively correlated with urban and agricultural land use but negatively correlated with forest and mining land use. The high phosphorus content of Bluegrass Region soils was an important source of phosphorus in streams draining that area. Correlations between forms of phosphorus and nitrogen and land-use type were similar at synoptic sites but were not significant statistically.

Phytoplankton chlorophyll _a_ concentrations in the Kentucky River main stem were positively correlated with concentrations of total phosphorus and total ammonia plus organic nitrogen during low flows. The positive correlation of chlorophyll _a_ with total ammonia plus organic nitrogen indicates that a considerable proportion of total nitrogen was transported as algal biomass during periods of low discharge. The highest algal-cell densities and the highest concentrations of chlorophyll _a_ were found in the lower Kentucky River, downstream from river mile 180. In tributary streams, phytoplankton chlorophyll _a_ concentrations were also positively correlated with concentrations of total phosphorus and total ammonia plus organic nitrogen. In August 1987 and August 1988, several streams receiving urban sources of nutrients contained low concentrations of phytoplankton

chlorophyll *a*, but demonstrated high levels of algal productivity, an indication that periphyton probably dominated the algal community in those streams. Streams affected by agricultural sources of nutrients contained higher densities of phytoplankton than streams that drained forested areas. Median chlorophyll *a* concentrations and algal cell densities were substantially lower in streams that drained surface-mined areas than in streams that drained agricultural and urban areas.

The median concentration of suspended sediment was lowest in Elkhorn Creek at Frankfort and highest in the North Fork of the Kentucky River, where mining is a principal land use. The trend in suspended-sediment concentrations during the 3-year study period was a downstream decrease in the Kentucky River main stem from the headwaters to the mouth during the 3-year study period. Mean suspended-sediment concentrations for the study period were correlated with discharge at the fixed sites; concentrations were always lower in summer, typically a low-flow period. No significant correlations were found among suspended-sediment concentrations and any of the nutrient forms studied in the Kentucky River Basin, with the exception of phosphorus. No correlations were found between land use and total suspended-sediment concentrations, but the level of resolution of land-use data may not have been adequate to reflect differences at the subbasin scale. A significant 15-year-long downward flow-adjusted trend in suspended-sediment concentrations was indicated at a site near the mouth of the Kentucky River.

Atrazine was found in water samples throughout the Kentucky River Basin. Other herbicides frequently found were 2,4-D, alachlor, metoalchlor, and dicamba. Diazinon, malathion, and parathion were the most frequently detected organophosphate insecticides in water samples, particularly in the Elkhorn Creek Basin. Analyses of streambed-sediment samples resulted in frequent detections of several organochlorine insecticides, including aldrin, chlordane, DDT, DDE, dieldrin, endrin, endosulfan, heptachlor, heptachlor epoxide, and lindane. Many of the pesticides detected in the Kentucky River Basin were in counties of the Bluegrass Region, where agricultural land use is dominant. Residential pesticide application in urban areas in several counties in the Bluegrass Region might also affect the presence of pesticides in surface streams.

INTRODUCTION

Elevated concentrations of nutrients, suspended sediments, and pesticides cause many problems in surface-water systems at local, regional, and national scales. Issues associated with these three classes of water-quality constituents are related to one another in many respects. These classes of constituents commonly have urban and rural point and nonpoint sources in common, they interact in various ways depending on ambient surface-water conditions, and they directly and indirectly affect the biotic community in streams. Although nutrients, sediments, and pesticides also affect other water-quality characteristics individually and collectively, the importance of these interactions warrants their treatment together in a single report.

Nutrients and suspended sediments are among the most well studied of the numerous characteristics used to assess water quality. As used in this report, the term "nutrients" refers to that group of constituents that are essential for plant growth, including various forms of nitrogen and phosphorus. Surface waters differ in background concentrations of nutrients and suspended sediments as a function of basin geology, geomorphology, and geochemistry. Basin topography, soil type, and land cover also dictate, in large measure, the erosional capacity of drainage areas and, consequently, the amount and size of suspended sediments in receiving streams in the basin. The input of nutrients and suspended sediments to surface waters is increased by human activities associated primarily with agriculture, wastewater treatment, industrial effluent, urban runoff, coal mining and oil production, and construction. Furthermore, interactions among suspended sediments and nutrients are significant because of the ability of sediment particles to adsorb some nutrient forms.

Much less well studied are the various pesticides that reach surface waters in runoff largely from cropland, pastureland, and residential property. In addition, knowledge of the fate and transport of herbicides and insecticides and their effects on the biological communities in aquatic systems is incomplete. The ability of sediment particles to adsorb and transport organic compounds increases the distribution of pesticides and may affect their concentration in surface waters.

The U.S. Geological Survey (USGS), as part of the USGS National Water-Quality Assessment (NAWQA) program, has studied the streams in the Kentucky River Basin to assess surface-water quality. Data were collected for assessments of the sources, occurrence, distribution, and fate of nutrients, sediments, and pesticides in the basin. The information generated in these studies is available to water managers, policymakers, and the public to improve the effectiveness of water-quality management and the assessment of proposed changes in land- and water-management practices.

Purpose and Scope

This report presents results of the Kentucky River Basin pilot NAWQA project. The report includes descriptions of (1) the distributions and trends in concentrations of selected nutrients, sediments, and pesticides in streams, (2) the distributions and trends of these constituents to natural physical and chemical processes as well as human factors that affect water quality, and (3) the possible interactions of these constituents and potential effects of observed water-quality on aquatic biota.

The temporal and spatial distribution of nutrients, sediments, and pesticides was evaluated by use of several sources of data. Water and suspended-sediment samples were collected monthly at seven fixed stations during April 1987-March 1990. Water and sediment samples were also collected during low-flow synoptic (spatial distribution) surveys at 74 stations in August 1987 and 74 stations in August 1988. Water-quality data collected by the Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water (KDOW) during 1986-89 at 11 fixed stations in the Kentucky River Basin (4 of which were also being monitored by the USGS) were analyzed in conjunction with NAWQA data to enhance the understanding of the spatial distribution of constituent concentrations, loads, and trends.

Surface-Water-Quality Issues in the Kentucky River Basin

The following brief overview of the historical data on water-quality conditions in the Kentucky River Basin provides a context for the discussion of relevant issues related to nutrients, sediments, and pesticides.

Concentrations of total phosphorus ranged from 10 to 3,700 $\mu g/L$ in 251 water samples collected in the basin during 1951-86 (Smoot and others, 1991). Highest total phosphorus concentrations were found in streams receiving sewage effluent. High total phosphorus concentrations were also found throughout the Bluegrass Region, which is underlain by phosphatic limestone (Smoot and others, 1991). Spatially, total phosphorus concentrations increase steadily from the headwater reaches to the river mouth; temporally, however, no trends are evident from the available data.

The high phosphorus content of soils in the Inner Bluegrass Region (>150 ppm) promotes growth of nitrogen-fixing plant species, which are responsible for relatively high ambient nitrogen concentrations. The few data available for the period 1979-86 indicate a slightly upward trend in total nitrogen concentrations from the headwaters to the mouth of the river.

In the Kentucky River Basin, suspended-sediment concentrations ranged from less than 1.0 to 18,000 mg/L in surface-water samples collected during 1979-86 (Smoot and others, 1991). More than 90 percent of the suspended sediment in the basin is silt and clay (Flint, 1983). The basin includes about 1,070 mi^2 of disturbed land and 1,700 mi of eroding streambanks and roadbanks that contribute to stream-sediment loads. Such nonpoint-source runoff has noticeably degraded about 40 percent of the streams in the basin (Kentucky Environmental Quality Commission, 1992). Decreases in suspended-sediment concentrations were found at 7 of 11 sites during 1976-86 (Smoot and others, 1991). These decreases may reflect the recent adoption of no-till practices for tobacco, corn, and soybeans, which are the major crops in the basin. Stream reaches draining areas disturbed by mining and the associated deforestation exhibited higher suspended-sediment concentrations than streams in areas devoted to pasture and row-crop agriculture.

Herbicide and insecticide use has increased in recent years in the Kentucky River Basin (Gianessi, 1986). Only one analysis of a water sample for herbicides was identified in the compiled data base for 1976-86. Of the three target analytes in that sample, 2,4,5-T and 2,4-D were detected but silvex was not. In the Kentucky River Basin, atrazine and butylate together account for more than half of all herbicide used (Smoot and others, 1991); however, analyses for these and other common herbicides are not available. Organochlorine insecticides, including benzene hexachloride, chlordane, lindane, dieldrin, P,P-DDD, and P,P-DDE, were detected in numerous samples of stream sediment and fish tissue during 1976-86 (Smoot and others, 1991). Analyses for organophosphorus insecticides were limited to two samples, in which no detectable concentrations were found.

Many streams in the basin continue to support a large and diverse aquatic faunal community. These include reaches of Eagle Creek and Elkhorn Creek; parts of the Dix River system; Red River; and reaches of the Middle and South Forks of the Kentucky River. Extensive data are available on the abundance and distribution of aquatic biota in the Kentucky River Basin. Bradfield and Porter (1990) reviewed and summarized much of this information, including biological data collected by Federal, State, and private institutions. Surface-water quality is generally suitable to support designated uses, according to Federal and State water-quality criteria (Kentucky Natural Resources and Environmental Protection Cabinet, 1992). The 1986 report to Congress for Kentucky (Kentucky Natural Resources and Environmental Protection Cabinet, 1986) assessed water-quality conditions for approximately 900 of the 3,450 river miles in the Kentucky River Basin and found that only 6 percent of the river miles assessed were significantly contaminated (White and others, 1987). However, expected increases in population and industrial growth will increase water use, and several municipal dischargers will require additional treatment facilities to prevent water-quality violations (Kentucky Environmental Quality Commission, 1992). Moreover, continued agricultural development could potentially increase inputs of nutrients, sediments, and pesticides. Accelerated eutrophication of surface waters from nutrient inputs from municipal point sources and agricultural nonpoint sources is possible. The effects of these changing conditions on aquatic life are not yet determined.

Acknowledgments

The NAWQA project liaison committee for the Kentucky River Basin provided continued guidance and input to this project. Members of the committee included representatives from the U.S. Fish and Wildlife Services; Kentucky Department of Agriculture; Kentucky Natural Resources and Environmental Protection Cabinet; Kentucky Department of Fish and Wildlife Resources; Kentucky Geological Survey; and Kentucky Water Resources Research Institute.

Many people and organizations assisted in the preparation of this report. The authors are especially grateful to Ernest Collins of the Kentucky Division of Pesticides, Vicki Ray of the Kentucky Natural Resources and Environmental Protection Cabinet, and Corine Wells of the Kentucky Division of Water.

DESCRIPTION OF THE KENTUCKY RIVER BASIN

The Kentucky River Basin, located in east-central Kentucky, has a drainage area of about 7,000 mi^2 and includes about 3,500 mi of streams (Smoot and others, 1991). The main stem of the Kentucky River originates in southeastern Kentucky and flows northwestward approximately 405 mi to its confluence with the Ohio River at Carrollton (fig. 1). Major tributaries include the North, Middle, and South Forks Kentucky River; Red River; Dix River; Elkhorn Creek; and Eagle Creek. The Kentucky River drains all or parts of 39 counties in the state and serves as a source of drinking water for 95 percent of the basin population.

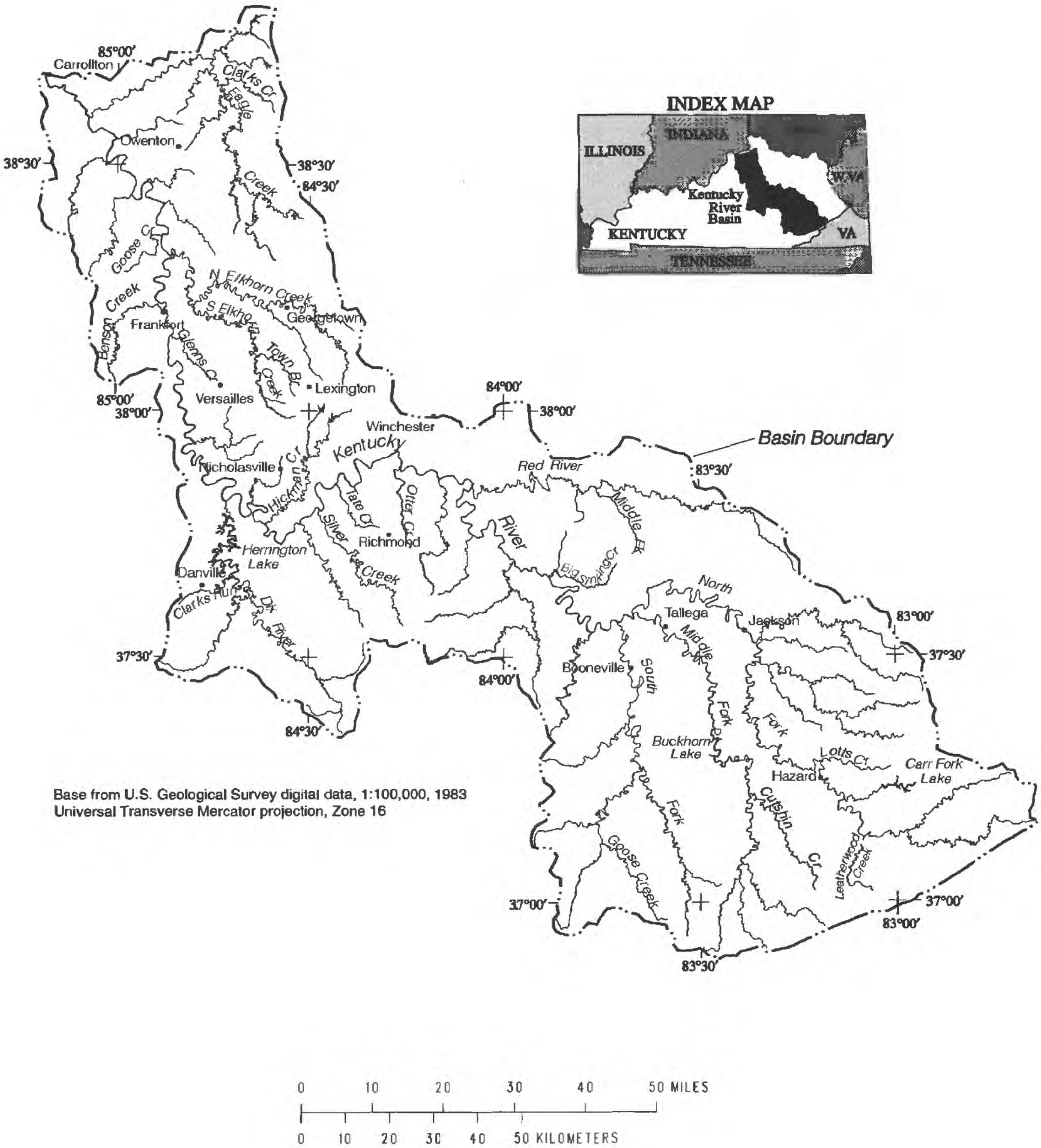

Figure 1. Kentucky River Basin.

Physiography and Topography

Detailed descriptions of the physiography, geology, and land-use patterns in the Kentucky River Basin are given by Smoot and others (1991) and S.D. Porter (U.S. Geological Survey, written commun., 1993). The basin consists of four physiographic regions: the Eastern Kentucky Coal Field, the Knobs, the Inner Bluegrass, and the Outer Bluegrass (fig. 2). Surface-water characteristics, land-use patterns, and population distribution differ among the regions. These variations are discussed with respect to their effects on water quality.

The southern part of the basin lies within the Eastern Coal Field Region. Elevations range from 1,000 to 3,200 ft above sea level, and terrain consists of narrow valleys and narrow, steep-sided ridges. Soils, which are moderately deep and generally well drained, are formed from siltstones, sandstones, and shales. Approximately 98,000 acres of land have been directly affected by coal-mining activities.

The Knobs Region, characterized by its distinctive conical and flat-topped hills, separates the Eastern Coal Fields Region from the Bluegrass Region in Kentucky. Broad valleys underlain by shale separate the sandy limestone and sandstone caprock of the hills. Elevations range from 600 to more than 1,600 ft above sea level. Soils are shallow and clayey and are poorly drained because of a dense subsurface layer of compacted silt overlying shale (U.S. Department of Agriculture, 1981).

The Inner Bluegrass Region is in the north-central part of the basin and is characterized by gently rolling upland underlain by thick-bedded phosphatic limestone. Elevations range from 800 to 1,000 ft above sea level. Considerable surface and subsurface solution of bedrock has resulted in extensive karst topography in this region. Soils developed from the phosphatic limestone are moderately deep, are fairly well drained and consist of silty loam over a clayey subsoil.

The remaining, northern part of the basin lies within the Outer Bluegrass Region. Elevations range from 800 to 1,000 ft above sea level, and areas near streams are dissected and rugged. The Outer Bluegrass Region is underlain by thin-bedded limestone interbedded with considerable shale. Some surface and subsurface solution has resulted in small sinkholes and subdued karst topography. Soils are moderately deep, fairly well drained, and generally suitable for farming.

Climate and Hydrology

The climate and hydrology of the Kentucky River Basin are described in detail by Smoot and others (1991). In brief, the climate is temperate and humid. Mean annual temperature is 56°F (13°C); daily mean temperatures vary from 25°F (-4°C) in January and February to 87°F (31°C) in July and August (U.S. Department of Agriculture, 1981). Annual precipitation averages 46 in. and ranges from 40 in. in the northern part of the basin to 48 in. in the

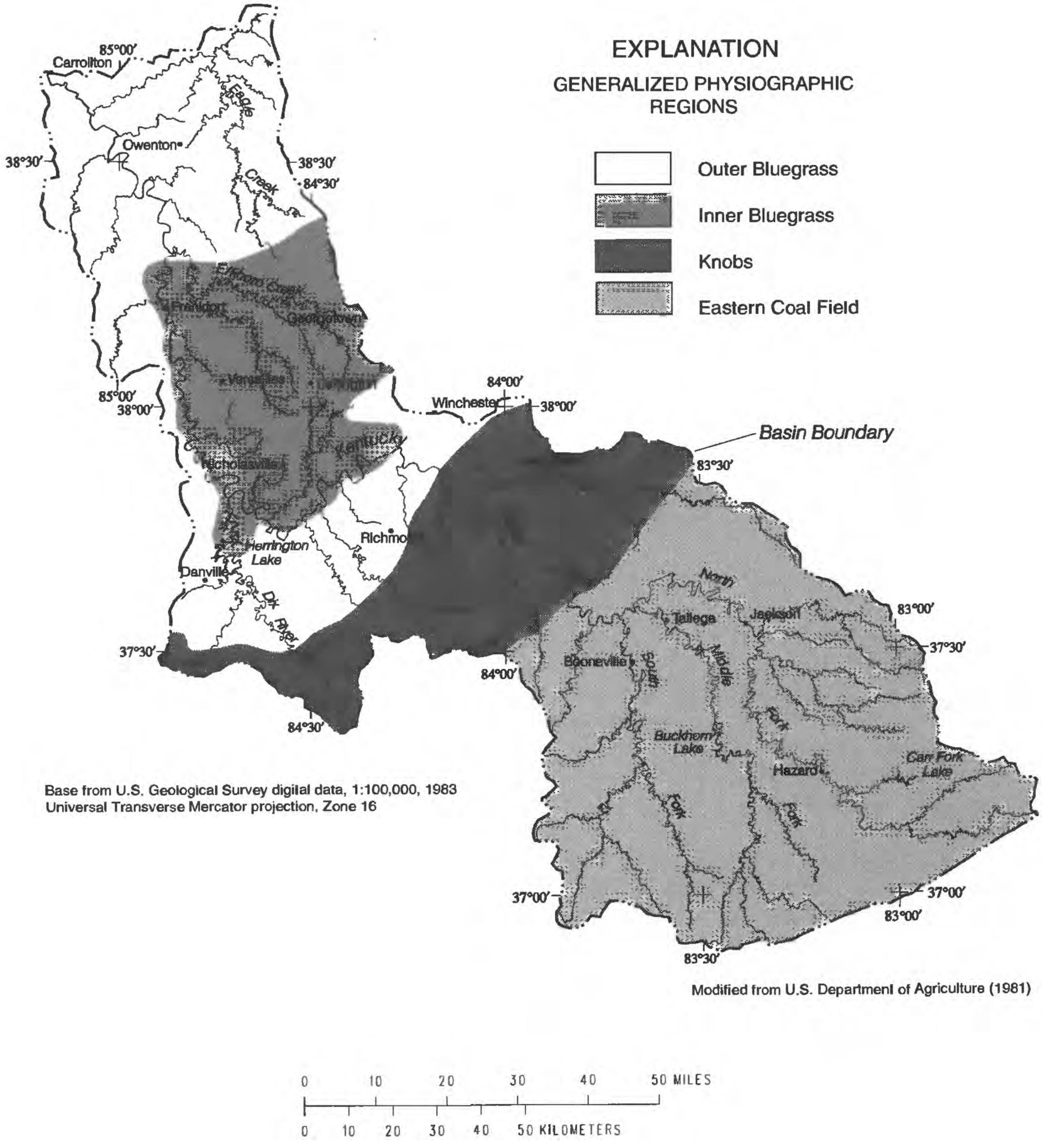

Figure 2. Physiographic regions of the Kentucky River Basin.

southern part (Elam and others, 1972). Mean annual precipitation at Lexington during 1975-90 was 44.4 in. March is typically the wettest month, and October is the driest.

Runoff and ground-water recharge in the basin vary temporally and spatially (Smoot and others, 1991). Basinwide, 28 percent of the annual precipitation results in surface runoff, and 9 percent enters the ground. Runoff is greater in the mountains of the Eastern Coal Field Region than in the Inner and Outer Bluegrass Regions. Within the Bluegrass Region, considerable rainfall enters the ground water directly through sinkholes.

Streamflow varies throughout the basin, in response to differences in geology, topography, and land use. Streams flowing across the highly permeable karst terrain of the Bluegrass regions commonly consist of dry and flowing reaches, depending on the extent of karst development. The average annual unit flow of streams in the study area is 1.4 $(ft^3/s)/mi^2$. During hydrologic extremes, however, unit flows differ substantially. Unit peak flow in the basin ranged from 344 $(ft^3/s)/mi^2$ at Cutshin Creek at Wooton to 18.3 $(ft^3/s)/mi^2$ in the Kentucky River at Lock 2. The 7-day 10-year low-flow discharges for 1976-86 ranged from zero in the Dix River to 3.7 ft^3/s in the Red River. A hydrograph of daily mean discharge and instantaneous discharge at the time of water-quality sampling during April 1987-March 1990 (Toms and others, 1988; Garcia and others 1989, 1990) at Lock 2 on the Kentucky River is shown in figure 3. The flow-duration curve at Lock 2 (fig. 4) shows the percentage of time that a given discharge was equaled or exceeded at this downstream site at the time of sampling, during the period of the NAWQA sampling, and during the period of record. With the exception of extremely low flows, sampling at the fixed stations during this study covered the entire range of the flow duration.

The flow of the Kentucky River main stem is regulated by 14 lock and dam structures that maintain at least 6 ft of water for navigation from a point just downstream of the confluence of the North, Middle, and South Forks to the mouth. The Kentucky River Basin has no natural lakes. A total of 15 reservoirs in the basin have a combined volume of 286,000 acre-ft and a combined surface area of 6,530 acres (Miller and others, 1975). Three major reservoirs--Herrington, Buckhorn, and Carr Fork (fig. 1)--make up 75 percent of total reservoir surface area and 90 percent of total reservoir volume. The operation of reservoirs for flood control and low-flow augmentation has resulted in moderation of postimpoundment flow extremes, typified by comparatively low high-flow periods and comparatively high low-flow periods (fig. 5).

Population and Land Use

Population in the Kentucky River Basin was estimated at 649,260 in 1990 (Decker, 1991) and is concentrated in a few counties (fig. 5). Population in the basin increased slightly (2.7 percent) from 1980 to 1990. Fourteen counties increased in population (fig. 6), whereas at least 10 counties lost population during that interval. The largest increases were in counties surrounding the Lexington metropolitan area, and the greatest losses were in the Eastern Coal Field Region.

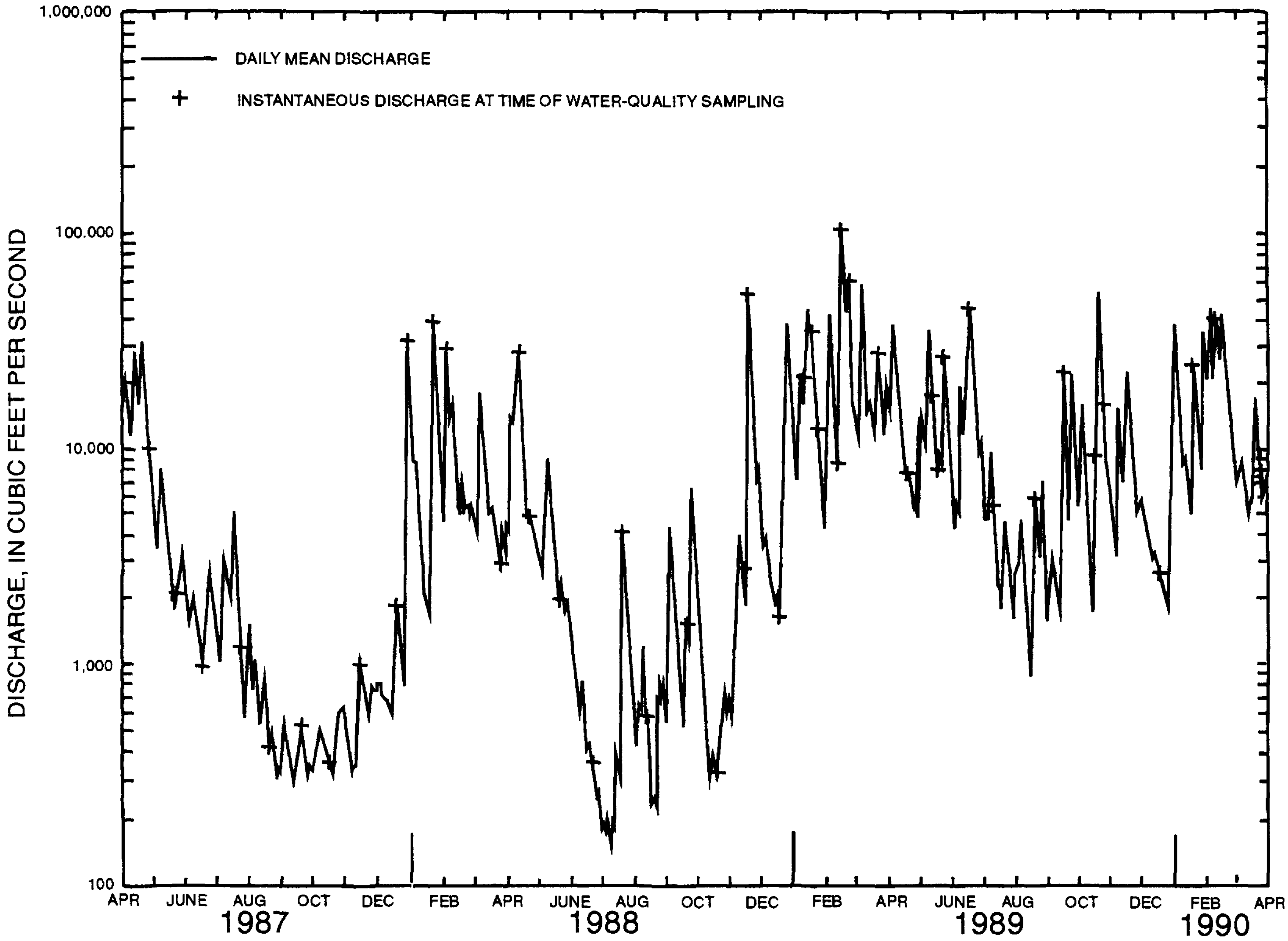

Figure 3. Daily mean discharge and instantaneous discharge at time of sampling for the Kentucky River at Lock 2 (Kentucky River mile 31), April 1987 through March 1990.

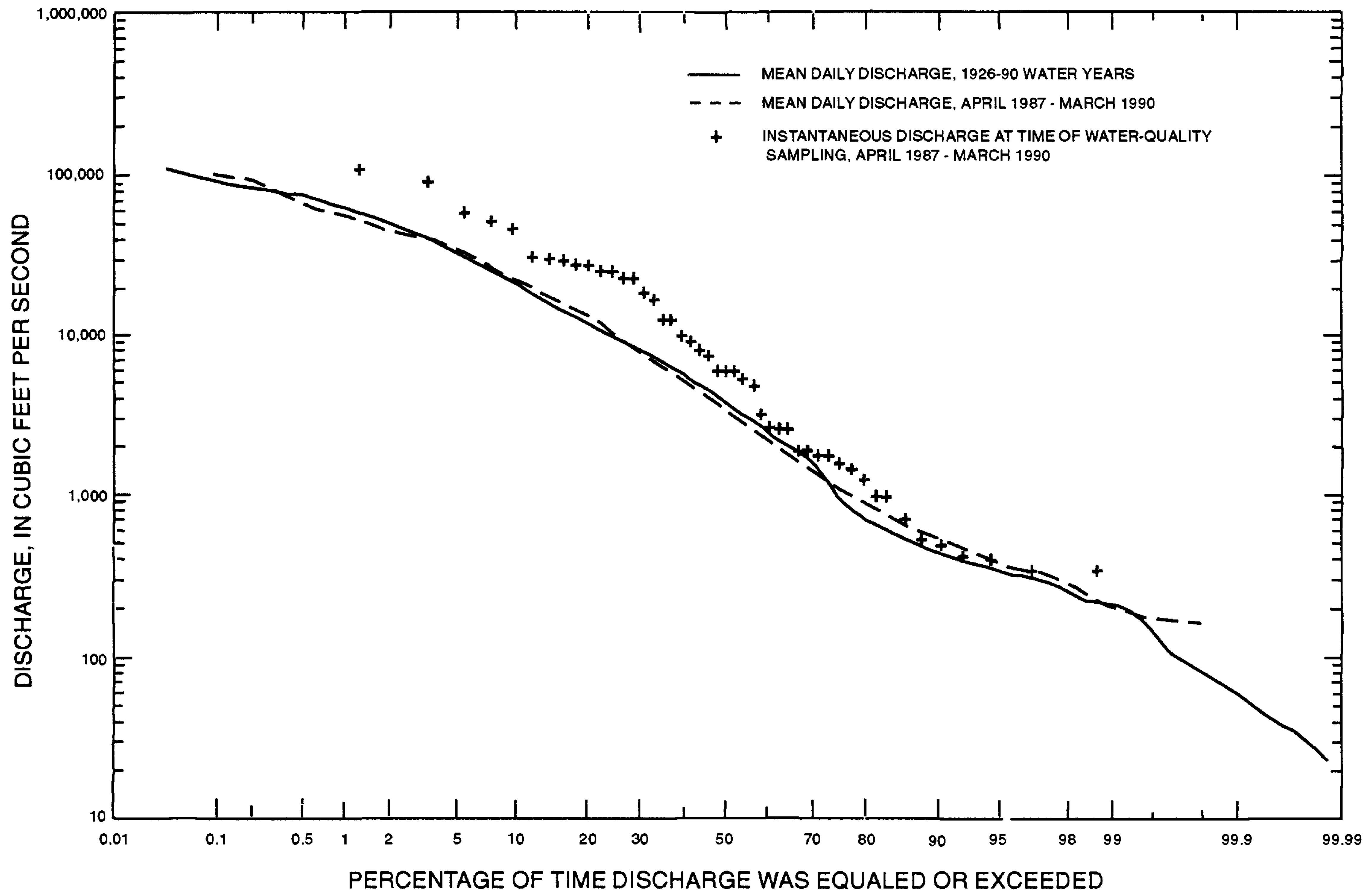

Figure 4. Flow-duration curves of discharge of the Kentucky River at Lock 2 (Kentucky River mile 31).

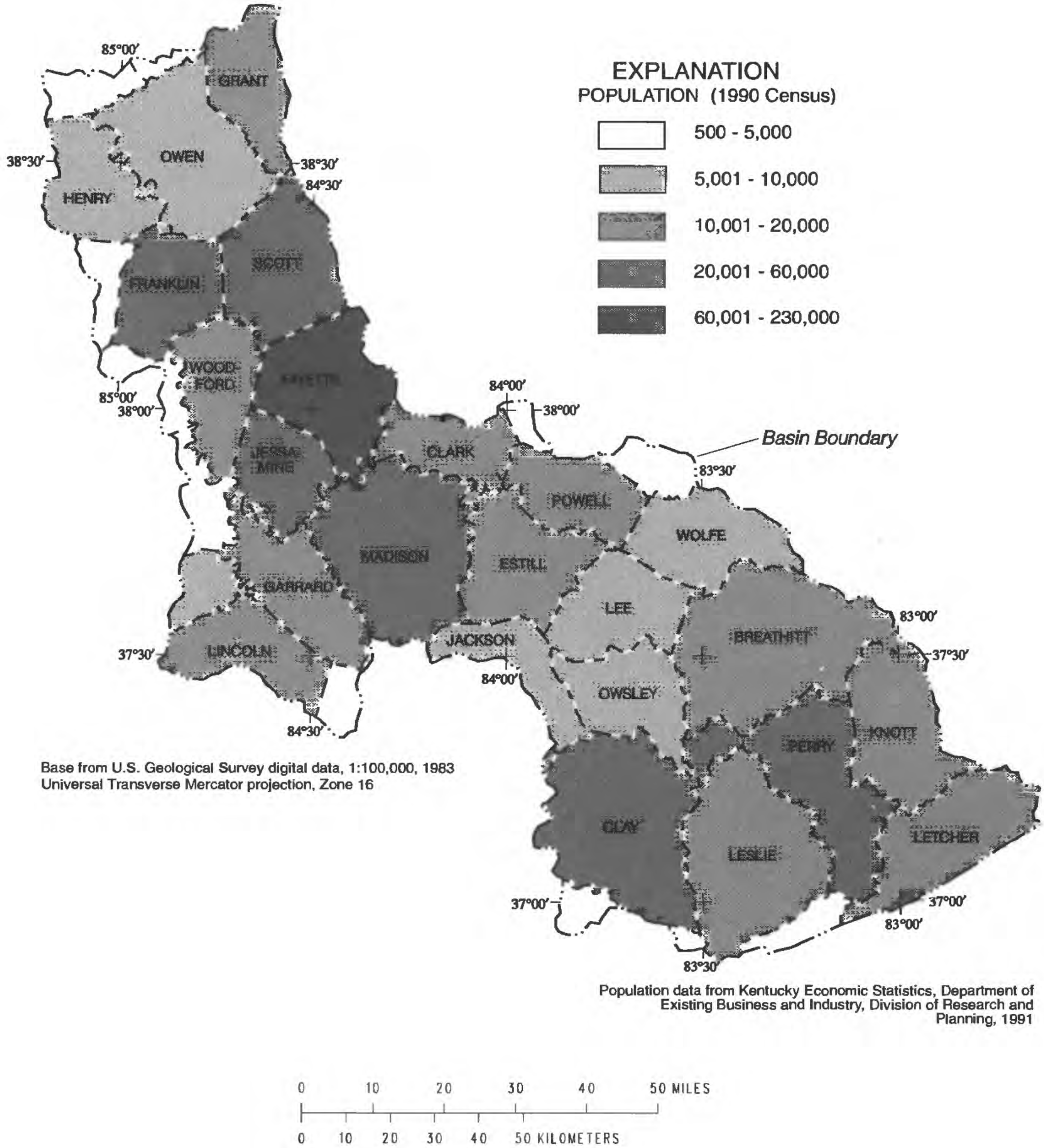

Figure 5. Population, by county, in the Kentucky River Basin, 1990.

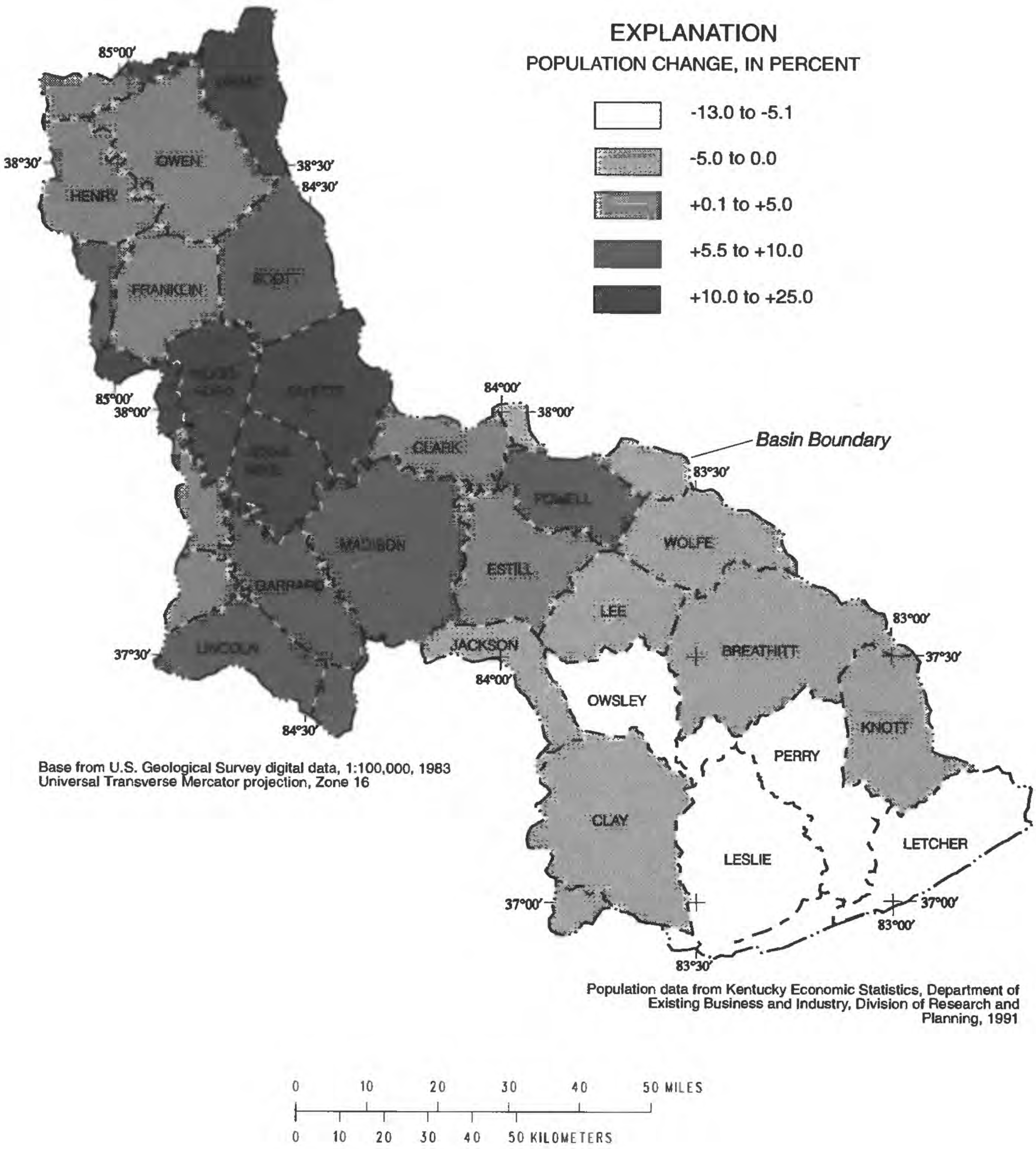

Figure 6. Changes in population in counties in the Kentucky River Basin from 1980 to 1990.

Major land uses include forestry, agriculture, coal mining, and oil and gas production; the amount of urban land also is substantial (Smoot and others, 1991). Forests make up more than 50 percent of the basin land area, although they are concentrated principally in the Eastern Coal Field Region. More than 90 percent of the timber volume is hardwood species, principally hickory and poplar; the remainder consists of pines and eastern red cedar. Approximately 40 percent of the basin is devoted to agriculture, primarily in the Inner and Outer Bluegrass Regions. Corn, soybeans, wheat, and tobacco are the dominant crops, and livestock includes horses, dairy and beef cattle, poultry, sheep, and goats. Bituminous coal is mined in the Eastern Coal Field Region and about 25 percent of the State's coal production is from the Kentucky River Basin. Oil and gas production are confined to the Knobs Region. Principal municipalities include Carrollton, Frankfort, Georgetown, Lexington, Danville, Richmond, and Hazard.

Water Use

In the Kentucky River Basin, water withdrawal differs considerably among subbasins, ranging from 1.66 Mgal/d in the Middle Fork Kentucky River to 70.04 Mgal/d in the lower Kentucky River. In all subbasins, the principal use of water withdrawn from surface supplies is for potable water supply. Surface water provides 95 percent of the public water supply basinwide. The largest municipalities supplying water are Lexington, Frankfort, and Richmond. Other water uses include industrial supply, recreation, commercial navigation, and propagation of fish and wildlife. The demand for water in the Bluegrass Region increased almost 20 percent between 1982 (64 Mgal/d) and 1987 (76 Mgal/d) (Don Hassall, Bluegrass Area Development District, written commun., 1992).

A total of 11 municipal wastewater-treatment facilities discharge more than 1 Mgal/d of effluent into the Kentucky River Basin. In addition, 30 small municipal wastewater-treatment plants each discharge wastewater quantities of less than 1 Mgal/d. Approximately 250 small nonmunicipal wastewater-treatment facilities are permitted to operate within the Kentucky River Basin. At least 29 industrial facilities discharge more than 1 Mgal/d of wastewater to surface waters in the Kentucky River Basin.

CONSTITUENT SOURCES AND EFFECTS ON SURFACE-WATER QUALITY

Nutrients, sediments, and pesticides were identified as high-priority water-quality issues in the NAWQA program by the USGS in conjunction with Federal, state, and local agencies and with the input of the NAWQA advisory council. A brief description of these constituents and a general summary of their occurrence and behavior in aquatic ecosystems are provided in this section.

Nutrients

Nutrients are essential to the ecological functioning of all ecosystems. Aquatic ecosystems depend on the conversion of solar energy into energy-rich organic molecules by primary producers such as algae and higher plants. Primary producers, in turn, are consumed by herbivores and omnivores, which transform and transfer energy through the system. The sustained growth of freshwater algae and higher plants requires a supply of nutrients (Smith, 1979, 1983), principally phosphorus and nitrogen, which are derived from precipitation and runoff from the land surface. Various biogeochemical processes serve to recycle nutrients and other minerals throughout the aquatic ecosystem.

Phosphorus is most often the limiting nutrient for growth of aquatic algae and other primary producers in aquatic systems. Inorganic phosphorus or orthophosphate--present primarily as fluorapatite, $Fl_3Ca_5(PO_4)$--is abundant in soils that originate from phosphatic limestone. Inorganic fertilizer applied to agricultural and domestic crops is another significant source of inorganic phosphorus. Organic phosphates, known as metaphosphates or polyphosphates, are derived principally from human and animal wastes that include decaying plant and animal material, sewage effluent, and septic-tank leachate. Dissolved phosphorus is readily taken up by photosynthetic organisms in surface waters, so concentrations in pristine waters seldom exceed a few tenths of a milligram per liter (Hem, 1985). Excess phosphorus can result in algal blooms, which are aesthetically unappealing and may cause taste and odor problems in waters serving as drinking-water sources. Decomposition of algal blooms causes depletion of dissolved oxygen, to the detriment of associated aquatic biota.

Nitrogen is the other principal nutrient essential for plant growth. Nitrogen is available to algae and higher plants in several forms in aquatic systems, including ammonia, nitrite, and nitrate. Interconversion of these forms is usually mediated by biota, principally microorganisms. Among the major human sources of nitrogen are municipal and industrial wastewater, feedlot runoff, inorganic fertilizers, leachate from landfills, and atmospheric deposition. Natural sources of nitrogen include fixation of atmospheric nitrogen by blue-green algae and the Rhizobium group of bacteria. Nitrogen concentrations in pristine waters are typically less than 1 mg/L (Hem, 1985). Excess nitrogen results in overabundance of algae, which can cause taste and odor problems as well as depletion of dissolved oxygen. Excessive nitrate concentrations in drinking water also pose a threat to human health.

Sediments

Fluvial sediment is defined as fragmentary material that originates primarily from weathering of rocks and is transported by, suspended in, or deposited from water (Federal Interagency Sedimentation Project, 1963). Fluvial sediment includes chemical and biological precipitates, as well as decomposed organic material (Edwards and Glysson, 1988). Sheet and channel erosion are the principal processes by which sediment particles enter into surface waters. Erosion is a function of land cover, surface slope, soil erodibility, and precipitation intensity. Fine sediments such as silt and clay move downstream at roughly the same velocity as the water and are kept in suspension by turbulence, whereas the coarser sediments are transported only occasionally during high flows.

Aquatic biota can be dislodged by scour and smothered by sediment transported and deposited by flowing water. Elevated suspended-sediment concentrations can render water aesthetically unsatisfactory for recreational use. The ability of suspended-sediment particles to adsorb nutrients and pesticides and other manmade organic compounds can lead to accelerated dispersal and accumulation of these constituents in streams (Smith and others, 1988; Adams and others, 1992). Alternatively, if toxic substances remain sorbed to fine-grained sediments and are less available to biota for accumulation and transfer up the food chain, then sorption to sediments may be beneficial. The fate of contaminated sediments is not well understood, however, and long-term changes in resuspension, mobilization, and dissolution are uncertain (American Society of Civil Engineers, Task Committee on Sediment Transport and Aquatic Habitats, Sedimentation Committee, 1992).

Pesticides

Herbicides are the most widely used agricultural pesticides in the United States and are also applied in urban settings. More than 120 chemicals are registered for herbicide use, and many formulations include numerous additives, adjuvants, and associated compounds. The postapplication residual life of herbicides ranges from a few days to more than a year, depending on the compound, soil type, and environmental conditions. A number of the triazines, which are nitrogen-containing herbicides, sorb readily to the soil and leach slowly in soils with more than 1 percent organic matter. Atrazine is the most commonly used herbicide in this class, which also includes simazine and metribuzin. Numerous other herbicides are widely used in agricultural settings, among them 2,4-D, alachlor, metolachlor, and dicamba.

Many insecticides are used in agricultural and residential settings. The fate of these compounds is affected by several environmentally dependent processes such as solubilization, runoff, leaching, bioaccumulation, and degradation (Biggar and Seiber, 1987). Principal classes of insecticides are chlorinated hydrocarbons, organophosphates, carbamates, and pyrethroids. Chlorinated hydrocarbons such as DDT, DDD, and methoxychlor are persistent in the environment and tend to accumulate in tissues and sediments because of their hydrophobic nature.

ASSESSMENT APPROACH

Water-quality data for the Kentucky River Basin NAWQA pilot study were collected and analyzed to determine (1) the spatial, temporal, and streamflow-related variability of constituents throughout the basin; (2) the effects of point-source discharges such as municipal and industrial effluents, on water quality; and (3) the effects of runoff from nonpoint sources, such as agricultural operations, on water-quality conditions. The target variables selected were constituents that are relevant to local, regional, or national water-quality issues, including nutrient enrichment, sedimentation, chemical contamination, and overall acceptability of water for use (Hirsch and others, 1988).

Design of Field Investigations

The Kentucky River Basin assessment of nutrients focused on point- and nonpoint-source contamination that may significantly affect relatively long reaches of principal streams of the basin. Constituents of interest included nitrate, nitrite, and ammonia nitrogen, as well as orthophosphate and phosphorus (Griffin and others, 1994). Fixed-station sampling and two synoptic studies were done to assess spatial and temporal distribution of these constituents.

Seven fixed stations were located within the basin (fig. 7; table 1). These stations were selected after consideration of variations in geographic and hydrographic resolution, major tributaries, land use, water use, and the availability of historic water-quality or streamflow data. Special consideration was given to locations upstream from major public-water-supply intakes, below urban or industrial areas, and in relatively homogenous subbasins. Fixed stations were sampled monthly for specific target constituents over a 3-year period from April 1987 through March 1990. Additional high-flow sampling was also done at these stations, generally at times when streamflow exceeded a flow duration of 10 percent. These high-flow data were required to improve the accuracy of constituent-load estimates because constituent-load transport often is greatest during high-flow periods (Griffin and others, 1994). A detailed description of station locations, sample collection, WATSTORE codes and detection levels for constituents at the fixed-station network in the Kentucky River Basin has been compiled by Griffin and others (1994).

Synoptic studies (studies that involve nearly simultaneous measurements at multiple sites) were done to evaluate water quality for a brief period of time over a broad geographical area. Single samples were taken at many sites to provide information on the occurrence and distribution of selected nutrients during stable, low-flow conditions when the effects of point-source discharges predominate. A total of 74 sites were sampled during August 24-28, 1987; and 74 sites were sampled during August 8-12, 1988. Sites were selected on the basis of physiography, land use, point-source discharges, and separations from one another of no more than 25 river miles (table 2, fig. 8). Nutrient samples from the fixed stations and synoptic sites were analyzed for concentrations of total phosphorus, dissolved phosphorus, ammonia nitrogen plus total organic nitrogen, ammonia nitrogen plus dissolved organic nitrogen, dissolved ammonia nitrogen, dissolved nitrate plus nitrate nitrogen, and dissolved nitrate nitrogen.

Relations among nutrients and algae in the Kentucky River Basin were assessed by collecting monthly phytoplankton samples from October 1987 through August 1988 at the seven fixed stations. Water samples were collected concurrently with algal samples and analyzed to determine pH and dissolved-oxygen concentration. The majority of the algae and associated water samples collected at the fixed stations (322 of 357) were collected between 8:00 a.m. and 4:30 p.m., but it was not possible to collect the samples at a consistent time of day during the 3-year study. Algae samples at the fixed stations were supplemented with algae samples collected during the synoptic surveys in August 1987 and August 1988. These algae samples and associated water samples were also generally collected between 8:00 a.m. and 4:30 p.m.

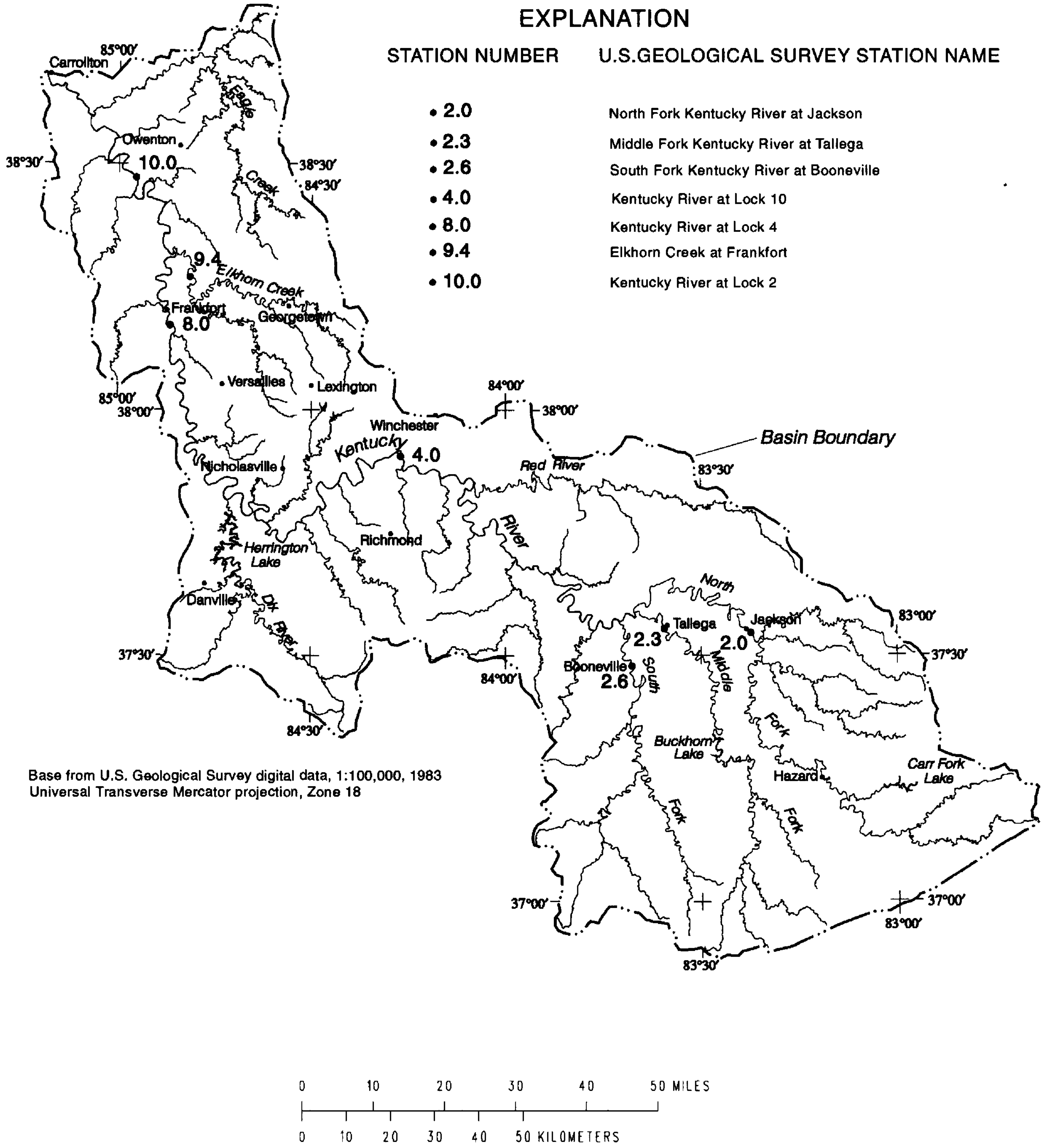

Figure 7. Location of fixed stations in the Kentucky River Basin.

Table 1. Characterization of the seven fixed stations in the Kentucky River Basin

[mi^2, square miles; ft^3/s, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile; data from Melcher and Ruhl, 1984]

Station name (Station number)	Drainage area (mi^2)	Average discharge (ft^3/s)	7-day 10-year low flow (ft^3/s)	Average specific discharge [$(ft^3/s)/mi^2$]
North Fork Kentucky River at Jackson (2.0)	1,101	1,360	3.1	1.24
Middle Fork Kentucky River at Tallega (2.3)	537	730	.6	1.36
South Fork Kentucky River at Booneville (2.6)	722	1,060	1.1	1.47
Kentucky River at Lock 10, near Winchester (4.0)	3,955	5,271	42.0	1.33
Kentucky River at Lock 4, near Frankfort (8.0)	5,410	7,110	175.0	1.31
Elkhorn Creek at Frankfort (9.4)	473	609	6.5	1.29
Kentucky River at Lock 2, near Lockport (10.0)	6,180	8,320	206.0	1.35

Tabla 2. Location of synoptic sites in the Kentucky River Basin

["Synoptic site code" corresponds to sempling sites shown in figure 8; "site number" refers to U.S. Geological Survey downstream-order number]

Site number	Site neme	Synoptic site code	Drainage area, in square miles	Latitude[1]	Longitude[1]
03277305	N Fk Ky R at Ice	AA	85	370632	825149
03277360	Rockhouse Cr nr Letcher	AB	51.5	370910	825628
03277410	Leatherwood Cr at Cornettsville	AC	49.7	370735	830505
03277470	Carr Fork at Scuddy	AD	79.7	371209	830513
03277550	N Fk Ky R at Combs	BA	480	371558	831303
03277690	N Fk Ky R at Chavies	CA	575	372052	832112
03277835	Troublesome Cr At Dwarf	CB	59.9	372030	830707
03279005	Troublesome Cr nr Clayhole	CC	195	372802	831647
03279400	Quicksand Cr at Lunah	CD	101	373331	831104
03279700	Quicksand Cr at Quicksand	CE	203	373211	832055
03280000	N Fk Ky R at Jackson	DA	1,101	373246	832221
03280120	N Fk Ky R at Frozen Creek	EA	1,134	373534	832523
03280500	N Fk Ky R nr Airdale	FA	1,294	373700	833800
03280551	M Fk Ky R at Asher	FB	70.6	370310	832400
03280600	M Fk Ky R nr Hyden	FC	202	370813	832217
03280700	Cutshin Cr at Wooton	FD	61.3	370954	831829
03280900	M Fk Ky R at Buckhorn	FE	420	372045	832807
03280940	M Fk Ky R nr Shoulderblade	FF	475	372914	832850
03281000	M Fk Ky R at Tallega	FG	537	373318	833538
03281017	Red Bird R nr Spring Creek	FH	53	370253	833239
03281040	Red Bird R nr Big Creek	FI	155	371043	833535
03281100	Goose Cr at Manchester	FJ	163	370907	834537
03281200	S Fk Ky R at Oneida	FK	486	371623	833850
03281351	Sexton Cr nr Taft	FL	71.6	372133	834059
03281500	S Fk Ky R at Booneville	FM	722	372845	834038
03282000	Ky R at Lock 14, Heidelberg	GA	2,657	373319	834606
03282048	Sturgeon Cr nr Ida May	GB	110	373215	834658
03282075	Big Sinking Cr nr Crystal	GC	23.4	373822	834705
03282100	Furnace Fk nr Crystal	GD	9.94	374121	835127
03282170	Station Camp Cr at Wagersville	GE	116	373715	835734
03282190	Redlick Cr nr Station Camp	GF	69.5	373801	835901
03282250	Ky R at Irvine	HA	3,138	374155	835832
03282500	Red R nr Hazel Green	HB	65.8	374844	832750
03283200	Red R at Highway 77	HC	184	375000	833936
03283320	M Fk Red R nr Slade	HD	25.4	374814	834233
03283370	Cat Cr nr Stanton	HE	8.30	374955	834841
03283500	Red R at Clay City	HF	362	375153	835601
03283815	Ky R nr Doylesville	IA	3,771	375140	840940
03283820	Muddy Cr at Elliston	IB	37.0	374427	840922

Table 2. Location of synoptic sites in the Kentucky River Basin--Continued

["Synoptic site code" corresponds to sampling sites shown in figure 8; "site number" refers to U.S. Geological Survey downstream-order number]

Site number	Site name	Synoptic site code	Drainage area, in square miles	Latitude[1]	Longitude[1]
03283830	Muddy Cr at Doylesville	IC	63.8	375048	840945
03283990	Otter Cr at Redhouse	ID	22.7	374947	841622
03284000	Ky R at Lock 10, Winchester	JA	3,955	375341	841544
03284210	Tate Cr at Million	JB	14.4	374646	842312
03284225	Ky R nr Valley View	KA	4,100	375049	842608
03284315	Silver Cr at Silver Creek	KB	68.2	373933	842146
03284560	Hickman Cr nr Mills	KC	64.2	375332	843053
03284600	Ky R at Camp Nelson	LA	4,528	374610	843703
03284630	Town Fk nr Nicholasville	LB	6.7	375049	843512
03284800	Dix R nr Stanford	LC	160	373318	843610
03285000	Dix R nr Danville	LD	318	373831	844444
03285200	Clarks Run nr Danville	LE	14.9	373820	844316
03286500	Ky R at Lock 7, Highbridge	MA	5,031	374945	844326
03286510	Ky R nr Highbrigde	NA	5,036	375138	844207
03287000	Ky R at Lock 6, Salvisa	OA	5,102	375532	844917
03287130	Clear Cr nr Mortonsville	OB	61.6	375637	844553
03287248	Ky R nr Tyrone	PA	5,222	380227	845047
03287300	Glenns Cr nr Versailles	PB	19.5	380548	844802
03287500	Ky R at Lock 4, Frankfort	QA	5,304	381206	845254
03287545	Benson Cr nr Frankfort	QB	101	381229	845614
03287575	Ky R nr Elkhorn Creek	RA	5,441	381857	845113
03288000	N Elkhorn Cr nr Georgetown	RB	119	381220	843049
03288150	N Elkhorn Cr at Great Crossing	RC	155	381256	843621
03288460	N Elkhorn Cr nr Frankfort	RD	276	381259	844751
03289000	S Elkhorn Cr at Fort Spring	RE	24	380235	843735
03289195	Town Branch nr Lexington	RF	30	380429	843253
03289300	S Elkhorn Cr nr Midway	RG	105	380827	843843
03289470	S Elkhorn Cr nr Frankfort	RH	187	381254	844756
03289500	Elkhorn Cr at Frankfort	RI	473	381607	844853
03290500	Ky R at Lock 2, Lockport	SA	6,180	382620	845748
03290600	Drennon Cr at Delville	SB	62	382839	850550
03291130	Eagle Cr at Lusbys Mill	SC	174	383153	844309
03291300	Eagle Cr at Donningsville	SD	293	383831	844246
03291310	Clarks Cr nr Stewartsville	SE	9.2	383754	843730
03291510	Eagle Cr nr Sanders	SF	468	383900	845648
03291600	Ky R at Carrollton	TA	6,956	384048	851117

[1] Degree, minute, and second symbols are omitted.

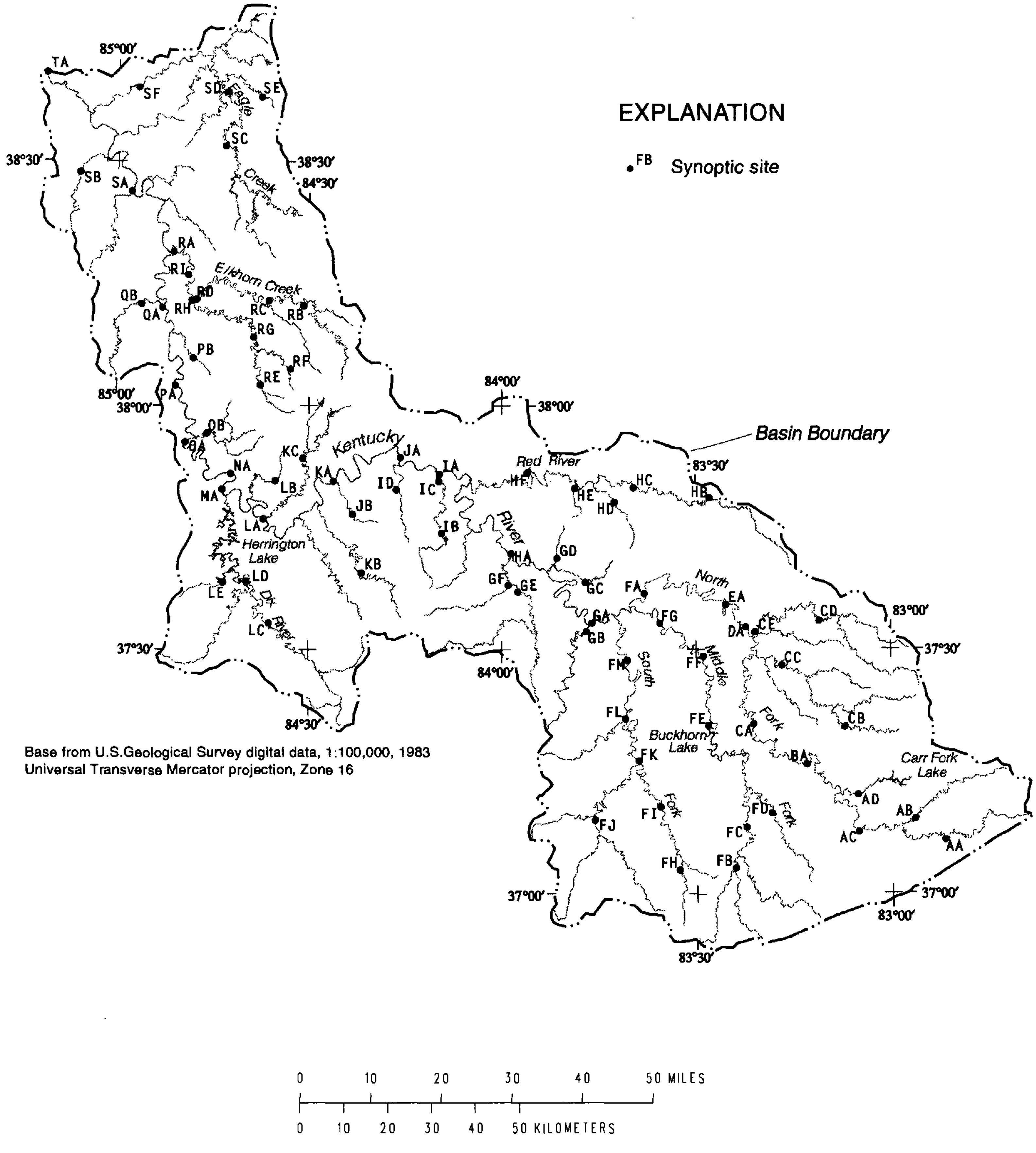

Figure 8. Location of synoptic sites in the Kentucky River Basin sampled during August 24-28, 1987, and August 8-12, 1988.

Samples for phytoplankton analyses were collected by the equal-discharge-increment/equal-width-increment (EDI/EWI) method described by Ward and Harr (1990). Subsamples for phytoplankton were withdrawn from the same water sample collected for nutrient determinations. Phytoplankton samples were processed in the field as described by Britton and Greeson (1989) and transported to the University of Louisville Biology Department for analyses of chlorophyll a content and phytoplankton-community composition. Chlorophyll a concentration was determined by the fluorometric method, as described by Weber (1973) and Clesceri and others (1989). Phytoplankton-community composition was determined by identifying and enumerating a minimum of 500 algal cells from each sample.

Suspended sediment was collected monthly at the seven fixed stations for the 3-year study period. Sediment samples were also collected during multiple high-flow events because of the demonstrated effect of high flows on annual load estimates (Singh and Durgunoglu, 1992). In addition, suspended-sediment data were collected during each of the nutrient synoptic surveys in 1987 and 1988.

The pesticide assessment included multiple components. During the water years 1988-89, selected sampling for hydrophilic pesticides was done at 14 sites in the basin. Sampling for chlorophenoxy acid and triazine herbicides and organophosphorus insecticides was done during runoff events to identify and quantify specific compounds and classes of compounds in surface waters. During runoff events in the summer to early fall of 1990, nine sites were sampled for chlorophenoxy acid and triazine herbicides and for organophosphorus and carbamate insecticides. A fixed-station, fixed-interval (every 2 months) sampling network was maintained during water year 1991 at four sites in the basin; the samples were analyzed for chlorophenoxy acid herbicides, dicamba, picloram, and triazine herbicides. A low-flow synoptic survey was done in November 1988 to determine the occurrence and distribution of organochlorine compounds in streambed sediments at 26 locations in the basin.

Methods of Sample Collection and Processing

Water samples for nutrients and suspended sediment were collected by use of a USGS D-77 or DH-81 sediment sampler and a cross-section-integrated sampling method. The sediment samplers are designed to collect a sample that represents the width and depth of a stream cross section. The cross-section-integrated sampling method is described as an equal-width-increment (EWI) method (Guy and Norman, 1970; Ward and Harr, 1990). At least seven verticals were sampled at each station during this study, except during high flows, when four to five verticals were sufficient. Additional details can be found in Griffin and others (1994).

At each cross section, water samples from all verticals were composited into a 14 L churn splitter for processing. Composited samples to be analyzed for total concentrations of nutrients, suspended sediments, and pesticides were transferred directly from the churn splitter to their respective containers. Samples for the analysis of dissolved constituents were passed through a 0.45 μm polycarbonate filter by use of a peristaltic pump.

Additional details of sample collection and processing can be found in Ward and Harr (1990).

Composited surficial streambed-sediment samples were collected from small and large streams during the low-flow synoptic study in the fall of 1987. The fine-fraction (<63 μm) sediments submitted for chemical analyses were collected by dry sieving at sites on small streams and by wet sieving at sites on large streams (S.D. Porter, U.S. Geological Survey, written commun., 1993).

Methods of Laboratory Analyses

U.S. Geological Survey laboratory methods for nutrient and suspended-sediment analyses are described in Fishman and Friedman (1989). Methods for analysis of pesticides are described by Wershaw and others (1987). All chemical analyses on water and water-sediment mixtures were done in the USGS National Water Quality Laboratory in Arvada, Colo. The size distribution of the sand and finer fraction of suspended sediment was analyzed by the USGS sediment laboratory in Louisville, Ky.

Methods of Data Analysis and Storage

Censored data (individual measurements "less than" analytical limits of detection) were set to the indicated detection limit or fit to a log-normal distribution depending on the type of analysis to be done (Helsel, 1991). Statistical analyses were done by use of System for Statistics (SYSTAT)[1] (Wilkinson, 1989). The use of the term "significant" in this report indicates that the probability of Type I statistical error was less than 5 percent ($p < 0.05$). Statistical correlations are discussed only if the absolute value of the correlation coefficient (r) exceeded 0.75 ($r > 0.75$).

Boxplots (Tukey, 1977) were constructed to provide graphical displays of the median, interquartile range, quartile skew, and extreme data values for selected constituents. A boxplot was not constructed if fewer than 10 observations for a site were available. Boxplots consist of a box drawn from the 25th percentile to the 75th percentile (the interquartile range). A horizontal line is drawn across the box at the median, and the two box parts 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.

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[1]Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Relations among nutrients and chlorophyll a concentrations and the effects of phytoplankton processes on other water-quality conditions were evaluated by pairwise correlations with nutrient chemistry, DO concentration, and pH. Data were log transformed where necessary to normalize the data and meet the assumptions of statistical tests. The net rate of oxygen production (NROP) by algae was estimated by measuring the DO concentration before sunrise (minimum), subtracting this value from a second DO measurement made during midmorning to late morning, and dividing the result by the amount of time that had elapsed between measurements, as follows:

$$NROP = DO/\Delta t, \qquad (1)$$

where NROP is the rate of oxygen production, in milligrams of dissolved oxygen per liter per hour;
DO is the change in dissolved oxygen concentration; and,
Δt is the time interval, in hours.

This calculation provides an estimate of net primary productivity but does not account for rates of oxygen diffusion, which are a function of water temperature and the difference in oxygen saturation between water and air (Odum, 1956).

Water-quality data collected during the study were stored in files of the USGS National Water Storage and Retrieval System (WATSTORE) and the National Water Information System--85.1 (NWIS) data bases (Hutchinson, 1975; Edwards and others, 1986).

Quality Assurance

The guidelines for quality assurance and quality control (QA/QC) in the NAWQA program are outlined in Mattraw and others (1989). Specific QA/QC procedures in practice during the Kentucky River Basin pilot study are described by Griffin and others (1994). Sample duplicates were collected for nutrient and suspended-sediment analysis at the fixed sites to assess sample-collection variability. Results are reported by Griffin and others (1994). Analytical laboratory QA/QC practices are detailed by Friedman and Erdmann (1983) and Fishman and Friedman (1989). The USGS National Water Quality Laboratory quality-assurance practices are described by Jones (1987).

Compilation and Analysis of Ancillary Data

Ancillary data were collected from a variety of sources to identify the factors affecting surface-water quality in the Kentucky River Basin. A small amount of data on the pH and chemistry of precipitation near the Kentucky River Basin was collected at four sites by the National Atmospheric Deposition Program in 1990 (National Atmospheric Deposition Program, 1991). For purposes of this report, values reported for sites in Letcher, Rowan, and Washington Counties (the latter two counties are located near but not in the Kentucky River Basin) were considered in calculating ranges of annual mean concentrations of ammonia and nitrate in precipitation and dry fall (L.J. Puckett, U.S. Geological Survey, written commun., 1992).

The KDOW has compiled an extensive data base on water quality. KDOW data cited or used in this report were collected during 1975-86 (Smoot and others, 1991) at the following locations: North Fork of the Kentucky River at Jackson; Middle Fork Kentucky River at Tallega; South Fork Kentucky River at Booneville; and in the main stem of the Kentucky River at Lock 4 at Frankfort. These stations are hereafter referred to as "paired stations." The KDOW routinely collects water-quality data by surface-grab sampling, whereby samples are collected in an open container from a single point at or near the stream surface. Detailed information on collection methods and quality assurance have been published (Kentucky Natural Resources and Environmental Protection Cabinet, 1988a). Surface-grab samples would not be expected to be an accurate representation of nonuniform water-quality conditions in a stream cross section, particularly with respect to suspended-sediment and sediment-associated constituents. Therefore, concentrations of water-quality constituents reported by the KDOW typically will be different than concentrations of water-quality constituents collected from paired stations by means of the cross-sectionally integrated, flow-weighted composite sampling used by the USGS (Martin and others, 1993).

Data characterizing the effluent water quality from individual WWTP's were summarized from Discharge Monitoring Reports (DMR) required for point-source discharges by the KDOW under the Kentucky Pollution Discharge Elimination System (KPDES) program. The DMR data used to estimate instantaneous discharge and instantaneous ammonia nitrogen loads in this report were those collected in 1991 during the month closest to the synoptic surveys in August 1987 and 1988, because DMR data for 1987 and 1988 were not available. The percentage of stream discharge and stream nitrogen load attributable to WWTP effluent in 1987 and 1988 was then estimated in subbasins of the Kentucky River Basin based on the available DMR data. The instantaneous nitrogen load from WWTP effluent was conservatively estimated and was assumed to be equal to the instantaneous effluent load of ammonia as reported in DMR. These estimates may underestimate the actual effluent load of ammonia as reported in DMR if WWTP's treat effluent ammonia prior to discharge; however, data on the extent of ammonia treatment were not available.

The sources of the land use data in this report are the 1983 National Atmospheric and Space Administration high-altitude aerial photographs and National High-Altitude Photography program photographs digitized at a scale of 1:250,000 (U.S. Geological Survey, 1986). These data were used to assign a dominant land use type for the subbasins upstream of each fixed station, and also for each subbasin upstream of each of the synoptic sites. Although the land-use data base lacked sufficient resolution for some types of analyses, it provided the best data available at the time of the study.

In correlation analyses involving land use in subbasins upstream from the synoptic sites, a weighting factor was used to assign the dominant land use. Land use was labeled "forest" in a subbasin if the proportion of forested land was greater then 50 percent. Land use was labeled "agriculture" if the proportion of agricultural land was greater than 50 percent and the proportion of urban land was less than 13 percent. Land use was labeled "urban" if the proportion of urban land use was greater than 13 percent.

Estimates of crop acreage and livestock numbers in the Kentucky River Basin are based on data collected by the U.S. Department of Agriculture (USDA) 1982 Census of Agriculture. This information has been updated with information available in the "Kentucky Agricultural Statistics 1990-1991" handbook (Kentucky Agricultural Statistics Service, 1991).

The Environmental Resources Branch (ERB) of the Office of Policy Analysis, U.S. Environmental Protection Agency (USEPA), has developed a data base of commercial fertilizer sales information, at the county level, for the period June 1986-July 1987. The data for Kentucky, which include nitrogen, phosphorus, and potash, were provided by the National Fertilizer Development Center of the Tennessee Valley Authority. The data set contains fertilizer sales by the season of sale; namely, spring (January through June) and fall (July through December). Amounts of the various forms of nitrogen fertilizer, including ammonium nitrate, anhydrous ammonia, nitrogen solutions, urea, and miscellaneous other forms, also are identified.

The Cooperative Extension Service of the University of Kentucky College of Agriculture has compiled data on pesticide use by Kentucky certified applicators. The Kentucky Division of Pesticides has developed a "LAWN" data base that contains information on agrichemicals applied by lawn-care companies that serve urban residential and commercial customers. The file contains application-rate data by county for calender year 1990.

Resources for the Future (RFF), Renewable Resources Division, has developed estimates for pesticide use in the Kentucky River Basin (Gianessi, 1986). These estimates are drawn from the RFF National Pesticide Usage Inventory. The inventory consists of 184 pesticides, in terms of their active ingredients, applied to 76 cropland types and 2 noncropland uses (nurseries and urban applicators) for the year 1982. Data are available by county and by hydrologic unit.

ASSESSMENT OF NUTRIENTS, SEDIMENTS, AND PESTICIDES IN STREAMS

Nutrients

The spatial distribution and temporal variability of nutrients in streams of the Kentucky River Basin was assessed by collecting water samples monthly at 7 fixed stations during the entire study period and at 74 synoptic sites during low-flow periods in August 1987 and August 1988. Ancillary data on the potential sources of nutrients in the basin also were compiled and analyzed.

Basin-Scale Distribution

The basin-scale distribution of phosphorus and nitrogen forms was assessed by collecting data at the seven fixed stations during 1987-90. Comparable data for these constituents collected by the KDOW during 1986-89 are included for purposes of discussion.

Spatial and temporal distribution

Average concentrations of dissolved orthophosphorus ranged from a minimum of less than 0.01 mg/L at several of the upstream fixed stations to a high of 2.3 mg/L in Elkhorn Creek (table 3). Concentrations found in Elkhorn Creek were significantly higher than concentrations at any of the other fixed stations. Concentrations of total phosphorus ranged from less than 0.01 mg/L at stations upstream from Lock 4 to a maximum of 5.7 mg/L in Elkhorn Creek at Frankfort. Median concentrations ranged from 0.02 to 0.72 mg/L; again, the concentrations were significantly higher at Elkhorn Creek than at the other six fixed stations. Concentrations of total phosphorus reported by the KDOW were slightly lower at virtually all paired stations, presumably because of differences in collection methods (as discussed in an earlier section of this report).

Median concentrations of dissolved ammonia nitrogen (table 3) ranged from 0.02 to 0.04 mg/L. Concentrations in Elkhorn Creek were significantly higher than those in the North Fork Kentucky River at Jackson, the Middle Fork Kentucky River at Tallega, and the South Fork Kentucky River at Booneville; however, differences were not significant among concentrations in the Kentucky River at Lock 10, Lock 4, and Lock 2. Concentrations of total ammonia plus organic nitrogen ranged from 0.30 to 0.90 mg/L, and concentrations were significantly higher in Elkhorn Creek at Frankfort than at any of the other fixed stations. Concentrations for each of these constituents reported by the KDOW are slightly lower at paired stations. Median concentrations of dissolved nitrite plus nitrate nitrogen ranged from 0.2 mg/L in the Middle Fork Kentucky River at Tallega to 3.5 mg/L in Elkhorn Creek at Frankfort. The maximum concentration of total nitrite plus nitrate (13.0 mg/L) during the period of this study occurred in South Elkhorn Creek near Midway, according to data collected by KDOW. Concentrations of dissolved nitrite plus nitrate in Elkhorn Creek at Frankfort were significantly higher than at any of the other stations. Concentrations in the Kentucky River at Lock 2 were not significantly different from those at Lock 4, but they were higher than those at all the other fixed stations except Elkhorn Creek at Frankfort.

Nutrient concentrations varied little at most of the fixed stations among years for the duration of the study. Concentrations of total phosphorus and nitrogen (fig. 9), as well as concentrations of the other nutrient forms, were similar during 1987-90 in the Kentucky River at Lock 2 (fig. 9) and at the other sites on the main stem of the Kentucky River (data not shown in fig. 9). At Elkhorn Creek (fig. 9), however, concentrations of total phosphorus and total nitrogen appeared to be higher in 1987 than in the other years.

Estimation of nutrient loads and yields

Transport estimates, expressed as mean annual loads, for dissolved orthophosphorus (table 4) ranged from 236 tons in Elkhorn Creek at Frankfort to 618 tons in the Kentucky River at Lock 2. Transport estimates for total phosphorus at the seven fixed stations were fairly low in the upper end of the basin, ranging from 32.6 tons in the Middle Fork Kentucky River at Tallega to 94.2 tons in the North Fork Kentucky River at Jackson (table 4). Loads were an order of magnitude higher in the Kentucky River main stem, where mean

Table 3. Statistical summary of nutrient concentrations at selected stations in the Kentucky River Basin

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

Station number	Station name	Period of record	N	N less than DL	Maximum DL, in milligrams per liter	MIN	Concentration at indicated percentile, in milligrams per liter: 10	25	50 (median)	75	90	MAX
Phosphorus, dissolved, as phosphorus												
10.0	Ky R at Lock 2	4/87-3/90	19	0	NA	0.02	--	0.03	0.07	0.09	--	0.24
Phosphorus, ortho, dissolved, as phosphorus												
2.0	N Fk Ky R at Jackson	4/87-3/90	47	42	0.01	<.01	*<.01	*<.01	*<.01	*.01	0.01	.02
2.3	M Fk Ky R at Tallega	4/87-3/90	47	41	.01	<.01	*<.01	*<.01	*<.01	*.01	.01	.02
2.6	S Fk Ky R at Booneville	4/87-3/90	45	40	.01	<.01	*<.01	*<.01	*<.01	*.01	.01	.03
4.0	Ky R at Lock 10	4/87-3/90	48	28	.01	<.01	*<.01	*<.01	*.01	.02	.02	.08
8.0	Ky R at Lock 4	4/87-3/90	47	4	.01	<.01	*0.01	.02	.03	.05	.11	.27
9.4	Elkhorn Cr at Frankfort	4/87-3/90	45	0	NA	.20	.26	.29	.42	.95	1.5	2.3
10.0	Ky R at Lock 2	4/87-3/90	48	0	NA	.01	.02	.04	.05	.08	.17	.32
Phosphorus, total, as phosphorus												
2.0	N Fk Ky R at Jackson	4/87-3/90	47	4	.01	<0.01	*.01	.02	.02	.04	.12	.44
2.3	M Fk Ky R at Tallega	4/87-3/90	47	5	.01	<.01	*.01	.02	.02	.04	.08	.15
2.6	S Fk Ky R at Booneville	4/87-3/90	46	4	.01	<.01	*.01	.01	.02	.04	.17	.36
4.0	Ky R at Lock 10	4/87-3/90	48	3	.01	<.01	.01	.03	.04	.05	.19	.93
8.0	Ky R at Lock 4	4/87-3/90	47	0	NA	.03	.04	.06	.09	.17	.47	1.0
9.4	Elkhorn Cr at Frankfort	4/87-3/90	45	0	NA	.03	.38	.50	.72	1.2	1.9	5.7
10.0	Ky R at Lock 2	4/87-3/90	48	0	NA	.03	.05	.09	.14	.21	.44	1.0
Phosphorus, total, as phosphorus (KDOW)												
2.0	N Fk Ky R at Jackson	10/86-9/89	42	2	.01	<.01	.01	.01	.02	.03	.07	.20
2.3	M Fk Ky R at Tallega	10/86-9/89	44	1	.01	<.01	.01	.01	.01	.02	.04	.12
2.6	S Fk Ky R at Booneville	10/86-9/89	44	2	.01	<.01	*<.01	.01	.01	.02	.04	.11
3.0	Ky R at Lock 14	10/86-9/89	44	0	NA	.01	.01	.01	.02	.02	.05	.17
3.1	Red R near Hazel Green	10/86-9/89	44	2	.01	<.01	.01	.01	.02	.05	.10	.53
3.3	Red R at Clay City	10/86-9/89	43	1	.01	<.01	.02	.02	.04	.06	.08	.16
5.0	Ky R at Camp Nelson	10/86-9/89	44	0	NA	.01	.03	.04	.06	.13	.39	.84
5.2	Dix R near Danville	10/86-9/89	44	0	NA	.01	.03	.05	.07	.12	.22	.96
8.0	Ky R at Lock 4	10/86-9/89	45	0	NA	.01	.03	.05	.07	.11	.33	1.0
9.3	S Elkhorn Cr near Midway	10/86-9/89	44	0	NA	.02	.68	1.1	1.7	2.5	3.6	4.8
10.1	Eagle Cr at Glencoe	10/86-9/89	38	0	NA	.01	.02	.04	.06	.10	.35	.71

Table 3. Statistical summary of nutrient concentrations at selected stations in the Kentucky River Basin--Continued

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

Station number	Station name	Period of record	N	N less than DL	Maximum DL, in milligrams per liter	MIN	Concentration at indicated percentile, in milligrams per liter: 10	25	50 (median)	75	90	MAX
Nitrogen, ammonia, dissolved, as nitrogen												
2.0	N Fk Ky R at Jackson	4/87-3/90	47	4	0.01	<0.01	*0.01	0.02	0.03	0.05	0.08	0.15
2.3	M Fk Ky R at Tallega	4/87-3/90	47	7	.01	<.01	*.01	.01	.02	.04	.06	.50
2.6	S Fk Ky R at Booneville	4/87-3/90	45	5	.01	<.01	*.01	.01	.03	.04	.09	.14
4.0	Ky R at Lock 10	4/87-3/90	48	4	.01	<.01	*.01	.02	.03	.04	.07	.26
8.0	Ky R at Lock 4	4/87-3/90	47	1	.01	<.01	.01	.02	.03	.06	.12	.14
9.4	Elkhorn Cr at Frankfort	4/87-3/90	45	1	.01	<.01	.02	.03	.04	.05	.10	.84
10.0	Ky R at Lock 2	4/87-3/90	48	3	.01	<.01	.01	.02	.03	.05	.09	.18
Nitrogen, ammonia plus organic, total, as nitrogen												
2.0	N Fk Ky R at Jackson	4/87-3/90	47	5	.20	<.20	*.18	.30	.40	.60	.80	2.60
2.3	M Fk Ky R at Tallega	4/87-3/90	47	3	.20	<.20	.20	.20	.30	.50	.62	1.10
2.6	S Fk Ky R at Booneville	4/87-3/90	46	10	.20	<.20	*.14	.20	.30	.50	.73	1.00
4.0	Ky R at Lock 10	4/87-3/90	48	3	.20	<.20	.20	.30	.40	.70	1.10	2.10
8.0	Ky R at Lock 4	4/87-3/90	47	5	.20	<.20	*.20	.30	.50	.80	1.02	2.50
9.4	Elkhorn Cr at Frankfort	4/87-3/90	44	0	NA	.30	.45	.70	.90	1.30	1.65	3.40
10.0	Ky R at Lock 2	4/87-3/90	48	3	.20	<.20	.20	.32	.50	.87	1.21	2.10
Nitrogen, ammonia plus organic, total, as nitrogen (KDOW)												
2.0	N Fk Ky R at Jackson	10/86-9/89	44	1	.05	<.05	.14	.18	.25	.39	.53	.89
2.3	M Fk Ky R at Tallega	10/86-9/89	44	1	.05	<.05	.11	.13	.19	.27	.38	.70
2.6	S Fk Ky R at Booneville	10/86-9/89	44	5	.05	<.05	*.06	.11	.19	.33	.39	.56
3.0	Ky R at Lock 14	10/86-9/89	45	1	.05	<.05	.16	.18	.27	.40	.49	.86
3.1	Red R near Hazel Green	10/86-9/89	44	3	.05	<.05	.07	.13	.27	.45	.54	1.3
3.3	Red R at Clay City	10/86-9/89	43	1	.05	<.05	.12	.19	.27	.44	.63	.74
5.0	Ky R at Camp Nelson	10/86-9/89	45	0	NA	.08	.14	.20	.33	.49	.86	1.6
5.2	Dix R near Danville	10/86-9/89	45	0	NA	.14	.17	.30	.49	.67	.82	2.5
8.0	Ky R at Lock 4	10/86-9/89	46	0	NA	.15	.19	.24	.39	.57	.84	1.1
9.3	S Elkhorn Cr near Midway	10/86-9/89	42	0	NA	.25	.70	.94	1.5	6.7	11	28
10.1	Eagle Cr at Glencoe	10/86-9/89	38	0	NA	.20	.30	.47	.58	.78	1.2	1.3
Nitrogen, ammonia, total, as nitrogen												
10.0	Ky R at Lock 2	4/87-3/90	19	0	NA	.01	--	.03	.04	.06	--	.21

Table 3. Statistical summary of nutrient concentrations at selected stations in the Kentucky River Basin--Continued

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

Station number	Station name	Period of record	N	N less than DL	Maximum DL, in milligrams per liter	MIN	Concentration at indicated percentile, in milligrams per liter: 10	25	50 (median)	75	90	MAX
Nitrogen, ammonia, total, as nitrogen (KDOW)												
2.0	N Fk Ky R at Jackson	10/86-9/89	44	39	0.05	<0.05	*<.01	*0.01	*0.01	*0.03	0.06	0.12
2.3	M Fk Ky R at Tallega	10/86-9/89	44	40	.05	<.05	<0.05	<.05	<.05	<.05	<.05	.08
2.6	S Fk Ky R at Booneville	10/86-9/89	44	42	.05	<.05	<.05	<.05	<.05	<.05	<.05	.09
3.0	Ky R at Lock 14	10/86-9/89	44	37	.05	<.05	*.01	*.01	*.02	*.04	.06	.12
3.1	Red R near Hazel Green	10/86-9/89	44	39	.05	<.05	*.01	*.01	*.02	*.03	.05	.14
3.3	Red R at Clay City	10/86-9/89	43	32	.05	<.05	*.01	*.02	*.03	.05	.09	.17
5.0	Ky R at Camp Nelson	10/86-9/89	45	40	.05	<.05	*.01	*.02	*.03	*.04	.05	.09
5.2	Dix R near Danville	10/86-9/89	45	37	.05	<.05	*.02	*.02	*.03	*.04	.06	.09
8.0	Ky R at Lock 4	10/86-9/89	45	37	.05	<.05	*.01	*.02	*.03	*.04	.06	.15
9.3	S Elkhorn Cr near Midway	10/86-9/89	45	4	.05	<.05	*.06	.11	1.6	6.1	9.1	14
10.1	Eagle Cr at Glencoe	10/86-9/89	38	33	.05	<.05	*.02	*.02	*.03	*.04	.06	.08
Nitrogen, nitrite, dissolved, as nitrogen												
2.0	N Fk Ky R at Jackson	4/87-3/90	47	34	.01	<.01	*<.01	*<.01	*.01	.01	.01	.03
2.3	M Fk Ky R at Tallega	4/87-3/90	47	41	.01	<.01	*<.01	*<.01	*<.01	*.01	.01	.03
2.6	S Fk Ky R at Booneville	4/87-3/90	45	38	.01	<.01	*<.01	*<.01	*.01	*.01	.01	.02
4.0	Ky R at Lock 10	4/87-3/90	48	27	.01	<.01	*<.01	*.01	*.01	.02	.03	.04
8.0	Ky R at Lock 4	4/87-3/90	47	26	.01	<.01	*<.01	*<.01	*.01	.01	.02	.15
9.4	Elkhorn Cr at Frankfort	4/87-3/90	45	10	.01	<.01	*.01	.01	.01	.02	.03	.05
10.0	Ky R at Lock 2	4/87-3/90	48	17	.01	<.01	*<.01	*.01	.01	.02	.04	.06
Nitrogen, nitrite plus nitrate, as nitrogen												
2.0	N Fk Ky R at Jackson	4/87-3/90	47	3	.10	<.10	.12	.26	.35	.52	.57	.69
2.3	M Fk Ky R at Tallega	4/87-3/90	47	3	.10	<.10	.12	.16	.20	.28	.34	.45
2.6	S Fk Ky R at Booneville	4/87-3/90	45	4	.10	<.10	*.10	.13	.22	.33	.42	.60
4.0	Ky R at Lock 10	4/87-3/90	48	5	.10	<.10	*.13	.21	.30	.40	.53	.80
8.0	Ky R at Lock 4	4/87-3/90	47	4	.10	<.10	*.18	.36	.53	.90	1.2	1.6
9.4	Elkhorn Cr at Frankfort	4/87-3/90	45	0	NA	1.2	2.1	2.6	3.5	5.3	6.4	8.5
10.0	Ky R at Lock 2	4/87-3/90	48	0	NA	.10	.25	.45	.68	1.5	1.6	2.2

Table 3. Statistical summary of nutrient concentrations at selected stations in the Kentucky River Basin--Continued

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

Station number	Station name	Period of record	N	N less than DL	Maximum DL, in milligrams per liter	MIN	Concentration at indicated percentile, in milligrams per liter: 10	25	50 (median)	75	90	MAX
Nitrogen, nitrite plus nitrate, as nitrogen, (KDOW)												
2.0	N Fk Ky R at Jackson	10/86-9/89	42	0	NA	0.04	0.09	0.25	0.49	0.59	0.62	0.67
2.3	M Fk Ky R at Tallega	10/86-9/89	43	0	NA	.02	.09	.13	.18	.30	.36	.49
2.6	S Fk Ky R at Booneville	10/86-9/89	43	0	NA	.02	.04	.08	.26	.40	.46	.65
3.0	Ky R at Lock 14	10/86-9/89	44	0	NA	.03	.07	.17	.34	.46	.55	.78
3.1	Red R near Hazel Green	10/86-9/89	44	0	NA	.04	.05	.11	.26	.42	.55	.89
3.3	Red R at Clay City	10/86-9/89	43	0	NA	.07	.09	.19	.29	.38	.62	.84
5.0	Ky R at Camp Nelson	10/86-9/89	45	0	NA	.06	.13	.33	.49	.73	.92	1.6
5.2	Dix R near Danville	10/86-9/89	44	0	NA	.01	.03	.30	.89	1.6	2.4	3.2
8.0	Ky R at Lock 4	10/86-9/89	44	0	NA	.01	.10	.38	.64	.99	1.2	2.1
9.3	S Elkhorn Cr near Midway	10/86-9/89	43	0	NA	.32	1.6	2.8	4.7	6.4	10	13
10.1	Eagle Cr at Glencoe	10/86-9/89	38	0	NA	.01	.02	.03	.34	.61	1.3	1.6

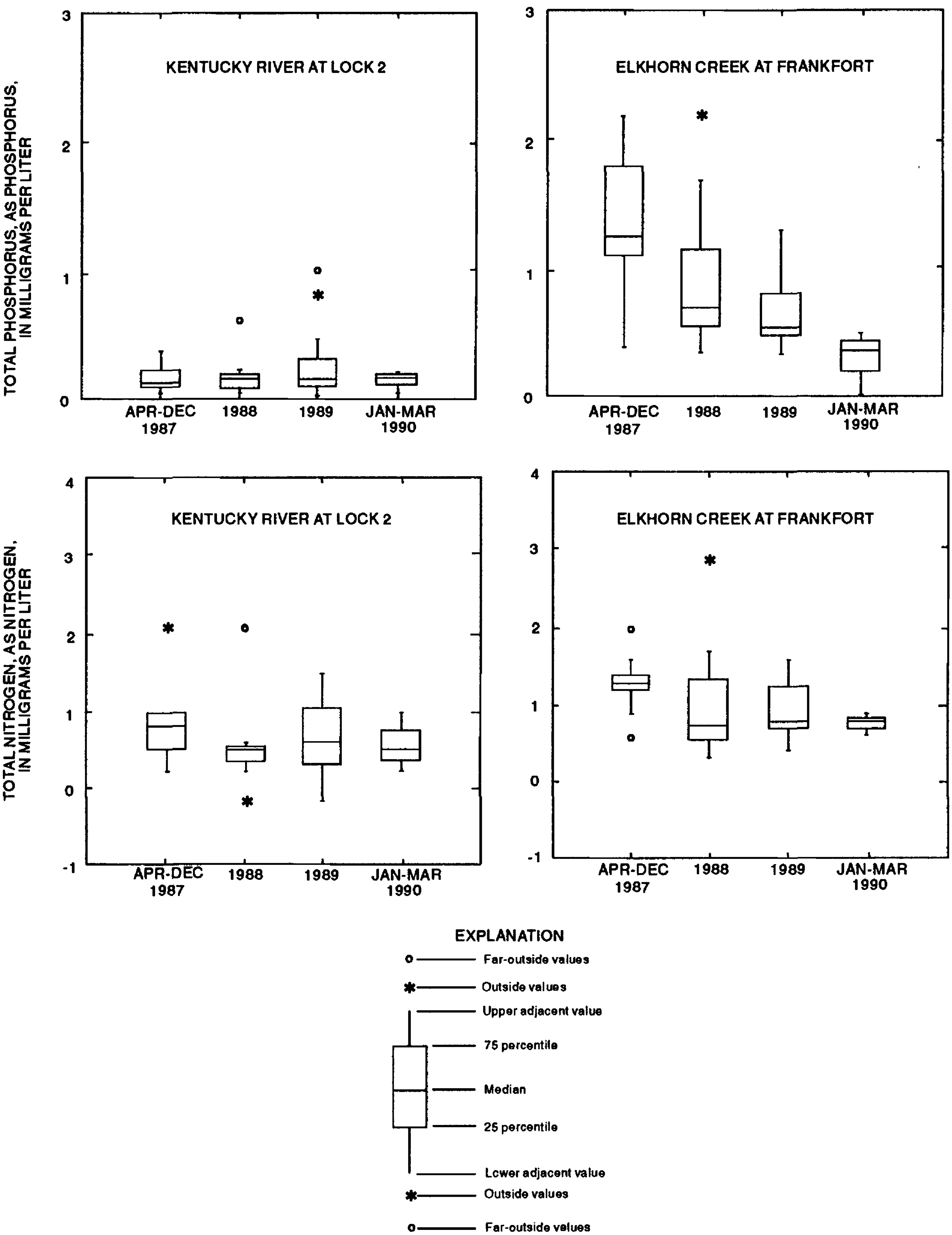

Figure 9. Annual summary of total phosphorus and total nitrogen concentrations in the Kentucky River at Lock 2 and in Elkhorn Creek at Frankfort, Ky., April 1987-March 1990.

Table 4. Nutrient-transport summary at selected stations in the Kentucky River Basin

[N, number of observations; DL, detection limit; KDOW, Kentucky Division of Water data. The table includes only those stations with 10 or more observations]

					Transport estimates		Uncertainty factors, in percent		
Station number	Station name	Period of record	N	N less than DL	Mean annual load, in tons	Mean annual yield, in tons per square mile	Standard error of regression	Flow duration of greatest sampled discharge	Proportion of load estimated beyond range of sampled discharge
Phosphorus, dissolved, as phosphorus									
10.0	Ky R at Lock 2	4/87-3/90	20	0	440	0.071	66.5	99.0	7.10
Phosphorus, ortho, dissolved, as phosphorus									
8.0	Ky R at Lock 4	4/87-3/90	47	4	419	.077	93.5	100	0
9.4	Elkhorn Cr at Frankfort	4/88-3/90	45	0	236	.498	29.1	99.7	3.23
10.0	Ky R at Lock 2	4/87-3/90	49	0	618	.100	72.2	100	0
Phosphorus, total, as phosphorus									
2.0	N Fk Ky R at Jackson	4/87-3/90	47	4	94.2	.086	88.6	100	0
2.3	M Fk Ky R at Tallega	4/87-3/90	47	5	32.6	.061	90.7	99.8	1.85
2.6	S Fk Ky R at Booneville	4/87-3/90	46	4	72.1	.100	100	99.7	17.1
4.0	Ky R at Lock 10	4/87-3/90	48	3	517	.131	12.2	100	0
8.0	Ky R at Lock 4	4/87-3/90	47	0	1,440	.266	78.9	100	0
9.4	Elkhorn Cr at Frankfort	4/88-3/90	45	0	423	.895	67.8	99.7	7.08
10.0	Ky R at Lock 2	4/87-3/90	49	0	1,920	.310	67.8	100	0
Phosphorus, total, as phosphorus (KDOW)									
2.0	N Fk Ky R at Jackson	10/86-9/89	42	2	40.5	.037	82.9	97.4	43.3
2.3	M Fk Ky R at Tallega	10/86-9/89	44	1	23.0	.043	55.6	93.9	42.1
2.6	S Fk Ky R at Booneville	10/86-9/89	44	2	20.4	.028	75.3	98.3	35.4
3.0	Ky R at Lock 14	10/86-9/89	44	0	156	.058	55.5	96.8	38.0
3.1	Red R near Hazel Green	10/86-9/89	44	2	3.11	.047	125	99.6	9.57
3.3	Red R at Clay City	10/86-9/89	43	1	26.3	.073	63.4	100	0
5.0	Ky R at Camp Nelson	10/86-9/89	44	0	1,040	.236	115	99.7	3.82
5.2	Dix R near Danville	10/86-9/89	44	0	74.5	.234	93.0	100	0
8.0	Ky R at Lock 4	10/86-9/89	45	0	1,450	.273	97.2	99.8	3.63
9.3	S Elkhorn Cr near Midway	10/86-9/89	44	0	209	1.99	82.1	99.9	.913
10.1	Eagle Cr at Glencoe	10/86-9/89	38	0	22.6	.052	105	99.2	34.3

Table 4. Nutrient-transport summary at selected stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; KDOW, Kentucky Division of Water data. The table includes only those stations with 10 or more observations]

Station number	Station name	Period of record	N	N less than DL	Transport estimates: Mean annual load, in tons	Transport estimates: Mean annual yield, in tons per square mile	Uncertainty factors, in percent: Standard error of regression	Uncertainty factors, in percent: Flow duration of greatest sampled discharge	Uncertainty factors, in percent: Proportion of load estimated beyond range of sampled discharge
Nitrogen, ammonia, dissolved, as nitrogen									
2.0	N Fk Ky R at Jackson	4/87-3/90	47	4	45.3	0.041	94.8	100	0
2.3	M Fk Ky R at Tallega	4/87-3/90	47	7	19.3	.036	110	99.8	1.06
2.6	S Fk Ky R at Booneville	4/87-3/90	45	5	26.5	.037	93.0	99.7	4.06
4.0	Ky R at Lock 10	4/87-3/90	48	4	233	.059	90.0	100	0
8.0	Ky R at Lock 4	4/87-3/90	47	1	243	.045	81.3	100	0
9.4	Elkhorn Cr at Frankfort	4/88-3/90	45	1	59.4	.126	109	99.7	12.4
10.0	Ky R at Lock 2	4/87-3/90	49	3	355	.057	95.7	100	0
Nitrogen, ammonia plus organic, total, as nitrogen									
2.0	N Fk Ky R at Jackson	4/87-3/90	47	5	713	.648	60.6	100	0
2.3	M Fk Ky R at Tallega	4/87-3/90	47	3	343	.638	48.9	99.8	1.59
2.6	S Fk Ky R at Booneville	4/87-3/90	46	10	414	.574	64.6	99.7	9.70
4.0	Ky R at Lock 10	4/87-3/90	48	3	3,260	.823	69.2	100	0
8.0	Ky R at Lock 4	4/87-3/90	47	5	4,490	.829	69.1	100	0
9.4	Elkhorn Cr at Frankfort	4/88-3/90	44	0	724	1.53	51.9	99.7	10.0
10.0	Ky R at Lock 2	4/87-3/90	49	3	5,770	.933	58.1	100	0
Nitrogen, ammonia plus organic, total, as nitrogen (KDOW)									
2.0	N Fk Ky R at Jackson	10/86-9/89	44	1	496	.451	55.0	97.4	35.1
2.3	M Fk Ky R at Tallega	10/86-9/89	44	1	189	.351	52.7	93.9	34.6
2.6	S Fk Ky R at Booneville	10/86-9/89	44	5	154	.213	93.1	98.3	21.7
3.0	Ky R at Lock 14	10/86-9/89	45	1	1,180	.446	60.8	96.8	25.8
3.1	Red R near Hazel Green	10/86-9/89	44	3	24.8	.376	98.4	99.6	7.10
3.3	Red R at Clay City	10/86-9/89	43	1	216	.597	64.5	100	0
5.0	Ky R at Camp Nelson	10/86-9/89	45	0	3,430	.774	67.2	99.7	3.70
5.2	Dix R near Danville	10/86-9/89	45	0	242	.761	59.6	100	0
8.0	Ky R at Lock 4	10/86-9/89	46	0	3,890	.736	52.7	99.8	2.68
9.3	S Elkhorn Cr near Midway	10/86-9/89	42	0	192	1.83	70.1	99.9	1.20
10.1	Eagle Cr at Glencoe	10/86-9/89	38	0	210	.482	45.6	99.2	25.7

Table 4. Nutrient-transport summary at selected stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; KDOW, Kentucky Division of Water data. The table includes only those stations with 10 or more observations]

					Transport estimates		Uncertainty factors, in percent		
Station number	Station name	Period of record	N	N less than DL	Mean annual load, in tons	Mean annual yield, in tons per square mile	Standard error of regression	Flow duration of greatest sampled discharge	Proportion of load estimated beyond range of sampled discharge
Nitrogen, ammonia, total, as nitrogen									
10.0	Ky R at Lock 2	4/87-3/90	20	0	473	0.076	78.8	99.0	9.99
Nitrogen, ammonia, total, as nitrogen (KDOW)									
9.3	S Elkhorn Cr near Midway	10/86-9/89	45	4	83.4	.794	162	99.9	.34
Nitrogen, nitrite, dissolved, as nitrogen									
9.4	Elkhorn Cr at Frankfort	4/88-3/90	45	10	11.3	.024	77.3	99.7	9.92
10.0	Ky R at Lock 2	4/87-3/90	49	17	102	.016	82.2	100	0
Nitrogen, nitrite plus nitrate, dissolved, as nitrogen									
2.0	N Fk Ky R at Jackson	4/87-3/90	47	3	618	.562	67.6	100	0
2.3	M Fk Ky R at Tallega	4/87-3/90	47	3	192	.357	44.4	99.8	1.82
2.6	S Fk Ky R at Booneville	4/87-3/90	45	4	292	.404	65.0	99.7	6.01
4.0	Ky R at Lock 10	4/87-3/90	48	5	2,360	.596	69.6	100	0
8.0	Ky R at Lock 4	4/87-3/90	47	4	6,570	1.21	82.2	100	0
9.4	Elkhorn Cr at Frankfort	4/88-3/90	45	0	2,520	5.32	37.2	99.7	5.95
10.0	Ky R at Lock 2	4/87-3/90	49	0	9,170	1.48	50.1	100	0
Nitrogen, nitrite plus nitrate, dissolved, as nitrogen (KDOW)									
2.0	N Fk Ky R at Jackson	10/86-9/89	42	0	1,300	1.18	66.8	96.6	48.9
2.3	M Fk Ky R at Tallega	10/86-9/89	43	0	215	.401	67.2	93.9	34.7
2.6	S Fk Ky R at Booneville	10/86-9/89	43	0	546	.756	99.6	98.3	33.2
3.0	Ky R at Lock 14	10/86-9/90	44	0	2,180	.820	72.6	96.8	32.9
3.1	Red R near Hazel Green	10/86-9/89	44	0	33.0	.502	72.7	99.6	12.7
3.3	Red R at Clay City	10/86-9/89	43	0	152	.419	63.2	100	0
5.0	Ky R at Camp Nelson	10/86-9/89	45	0	4,660	1.05	62.1	99.7	4.24
5.2	Dix R near Danville	10/86-9/89	44	0	2,520	7.94	131	100	0
8.0	Ky R at Lock 4	10/86-9/89	44	0	12,800	2.43	87.8	99.8	4.74
9.3	S Elkhorn Cr near Midway	10/86-9/89	43	0	1,070	10.2	78.3	99.9	3.31
10.1	Eagle Cr at Glencoe	10/86-9/89	38	0	284	.650	186	99.2	38.6

annual loads for total phosphorus were 1,440 tons at Lock 4 and 1,920 tons at Lock 2. Total phosphorus loads at the KDOW stations were lower in the upstream end of the basin, presumably because of differences in sample-collection methods and less frequent KDOW sampling during high flow.

Mean annual loads of dissolved ammonia nitrogen (table 4) were lowest in the Middle Fork Kentucky River at Tallega (19.3 tons) and highest in the Kentucky River at Lock 2 (355 tons). Annual load estimates of ammonia plus organic nitrogen ranged from 343 tons in the Middle Fork Kentucky River at Tallega to a high of 5,770 tons in the Kentucky River main stem at Lock 2. Estimated loads reported by the KDOW from paired stations were consistently lower. Transport estimates (mean annual loads) for dissolved nitrite plus nitrate nitrogen ranged from 192 tons to 9,170 tons at the seven fixed stations. Mean annual loads of nitrite plus nitrate at KDOW paired stations were nearly double, with the exception of the Middle Fork Kentucky River at Tallega.

Yield estimates for phosphorus, like load estimates, are relatively low at the upstream sites in the Kentucky River but are progressively higher downstream. Mean annual yield estimates for dissolved orthophosphorus were much higher in Elkhorn Creek (0.498 ton/mi^2) than at stations on the main stem (0.077 to 0.100 ton/mi^2). Mean annual yield estimates for total phosphorus were also highest in Elkhorn Creek (0.895 ton/mi^2) compared to the other fixed sites (0.061 to 0.31 ton/mi^2). Yield estimates of total phosphorus reported by the KDOW were lower than NAWQA estimates at paired stations; however, data collected by KDOW indicate that the highest yield in the Kentucky River Basin for total phosphorus was at South Elkhorn Creek near Midway (1.99 ton/mi^2).

Mean annual yields of dissolved ammonia were lowest in the Middle Fork Kentucky River at Tallega (0.036 ton/mi^2) and highest in Elkhorn Creek at Frankfort (0.126 ton/mi^2). Mean annual yield estimates for ammonia plus organic nitrogen ranged from 0.574 to 1.53 ton/mi^2 at the NAWQA fixed stations and from 0.213 to 0.736 ton/mi^2 at KDOW paired stations. Mean annual yields of nitrite plus nitrate nitrogen were again lowest in the Middle Fork Kentucky River at Tallega (0.357 ton/mi^2) and highest in Elkhorn Creek at Frankfort (5.32 ton/mi^2). A similar pattern of yield estimates is seen in KDOW data, but yields were higher at KDOW paired stations.

Relation of nutrients to discharge, other constituents, season, and atmospheric deposition

The concentration and distribution of nutrients in the Kentucky River Basin is related to stream discharge, other water-quality constituents, season, and atmospheric deposition.

Discharge and other constituents.--No significant correlations between nutrient concentrations and discharge were found at any of the fixed stations, with the exception of Elkhorn Creek at Frankfort, where a significant negative correlation ($r = -0.937$) between discharge and orthophosphate was found. However, patterns were found between some forms of nutrients and discharge. High concentrations of phosphorus occurred at high discharges in the North

Fork of the Kentucky River at Jackson (fig. 10) and at the other fixed stations, with the exception of Elkhorn Creek. In the Kentucky River at Lock 2, concentrations of total nitrogen appeared to be higher at low and high discharges than at intermediate discharges (fig. 11).

One approach to an analysis of nutrients in the Kentucky River Basin is to examine the relation between flow duration and nutrient concentrations. The flow-duration curve (fig. 5) is a method of showing the percentage of time when specified discharges are equaled or exceeded in a selected period of time (Searcy, 1969). When total phosphorus was plotted along the flow-duration curve (fig. 12), similar patterns were found for four upstream sites: the highest concentrations were at high flow (flow duration less than 20 percent). Total phosphorus averaged only about 0.1 mg/L at these sites. A similar pattern was found for the Kentucky River at Lock 4 and Lock 2, but total phosphorus concentrations were much higher, possibly because of inputs from WWTP's. Total phosphorus concentrations were highest in Elkhorn Creek, and the relation between total phosphorus concentrations and flow duration was different from that found for the four upstream stations. Phosphorus concentrations exceeded 1.2 mg/L at low flow (flow duration greater than 80 percent) and declined at higher flows (flow duration less than 30 percent). The pattern probably resulted from the predominance of WWTP effluent during low flow. The higher concentrations of total phosphorus at highest flows is most likely attributable to overland runoff during precipitation. Bypass of untreated wastewater by WWTP's during storms also may contribute to high nutrient loadings.

No clear differences were seen between the fixed stations when ammonia nitrogen concentrations were plotted along the flow-duration curve; however, differences between stations were evident for nitrate concentrations (fig. 13). With the exception of Elkhorn Creek, nitrate nitrogen concentrations were lowest at low flows (flow duration greater than 70 percent) and increased to a maximum at highest flows (flow duration less than 50 percent), presumably because of the increase in surface runoff. In Elkhorn Creek, the opposite was found: concentrations declined as flow increased because of the predominance of WWTP effluent during low flow. Moreover, concentrations of nitrate nitrogen were much higher in Elkhorn Creek at all points on the flow-duration curve than at any of the other fixed stations. Concentrations of total nitrogen were lowest at intermediate flows (fig. 14), when dilution of point sources is maximal and surface runoff is moderate. Concentrations of total nitrogen were almost always highest in Elkhorn Creek at any specified flow duration than at the other fixed stations.

At the fixed stations, concentrations of total nitrogen and dissolved nitrite plus nitrate were significantly correlated with concentrations of dissolved and total phosphorus. With few exceptions, no significant correlations were found among these nutrients and other water-quality constituents.

On the basis of data from the synoptic sites in 1987, correlations were significant between nitrite plus nitrate nitrogen and dissolved phosphorus, dissolved orthophosphorus, and total phosphorus. In 1988, dissolved ammonia nitrogen and dissolved organic carbon were significantly correlated. When

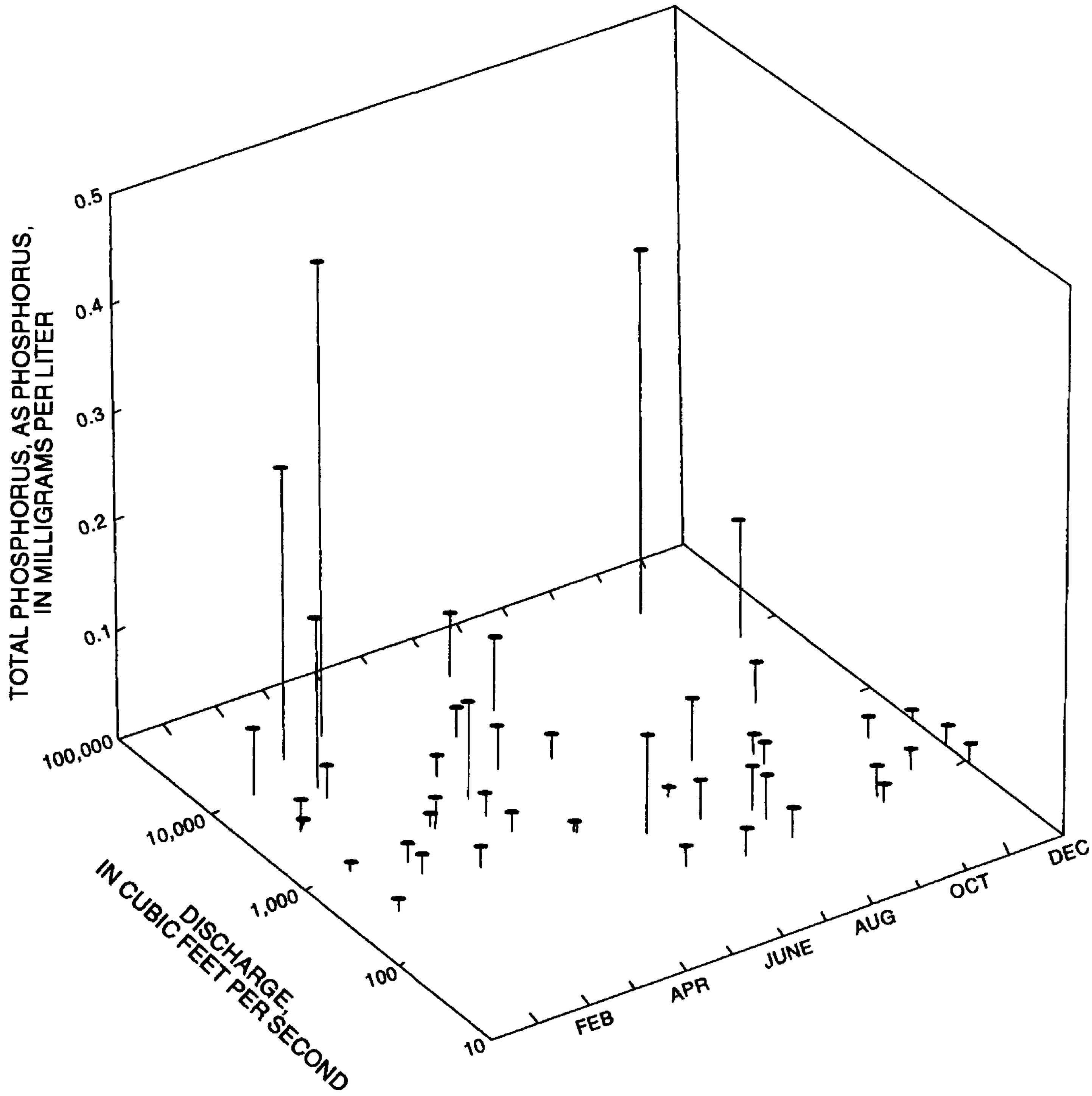

Figure 10. Variations in mean monthly discharge and mean monthly total phosphorus concentration in the North Fork Kentucky River at Jackson, 1987-90.

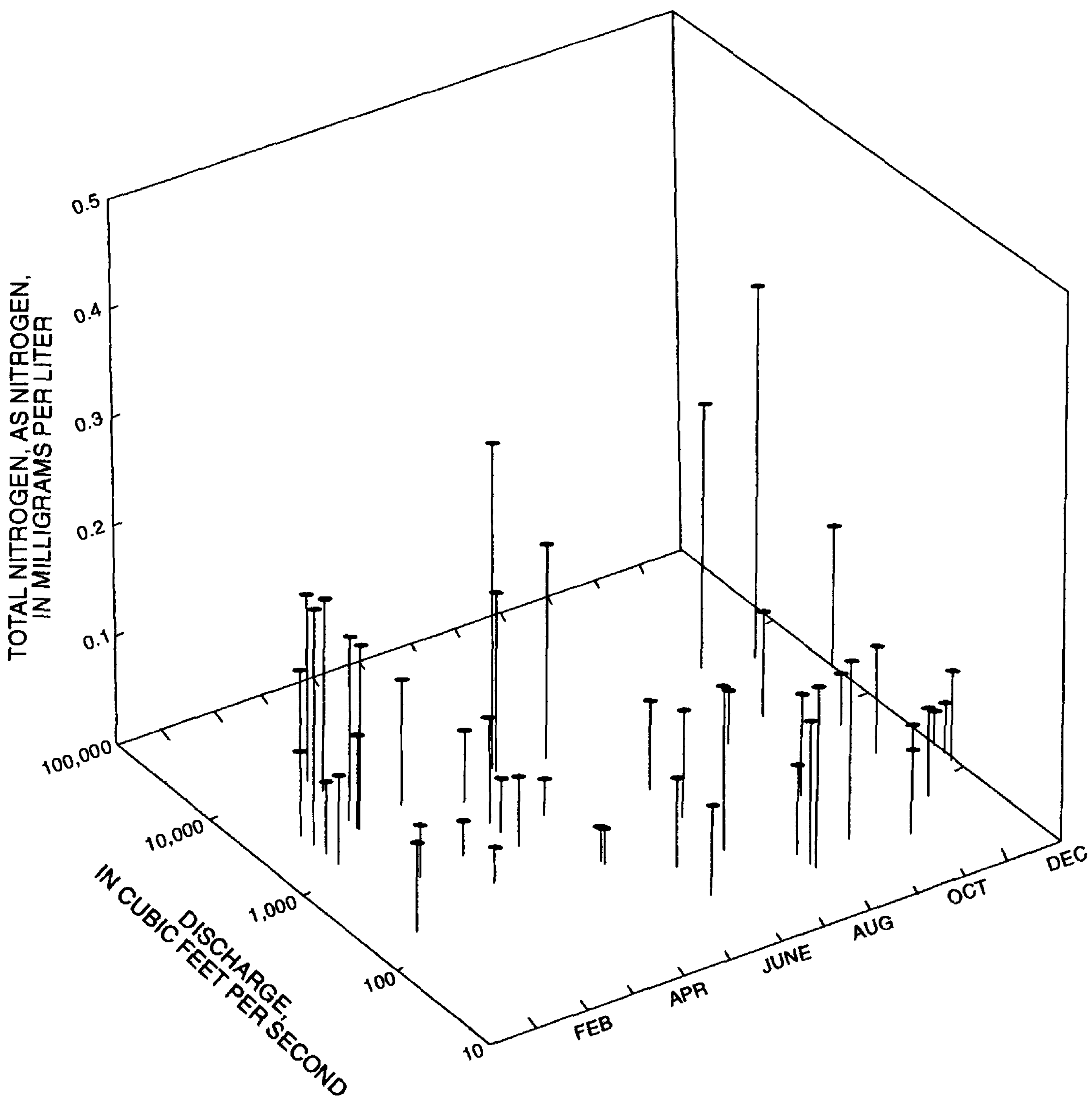

Figure 11. Variations in mean monthly discharge and mean monthly total nitrogen concentration in the Kentucky River at Lock 2, 1987-90.

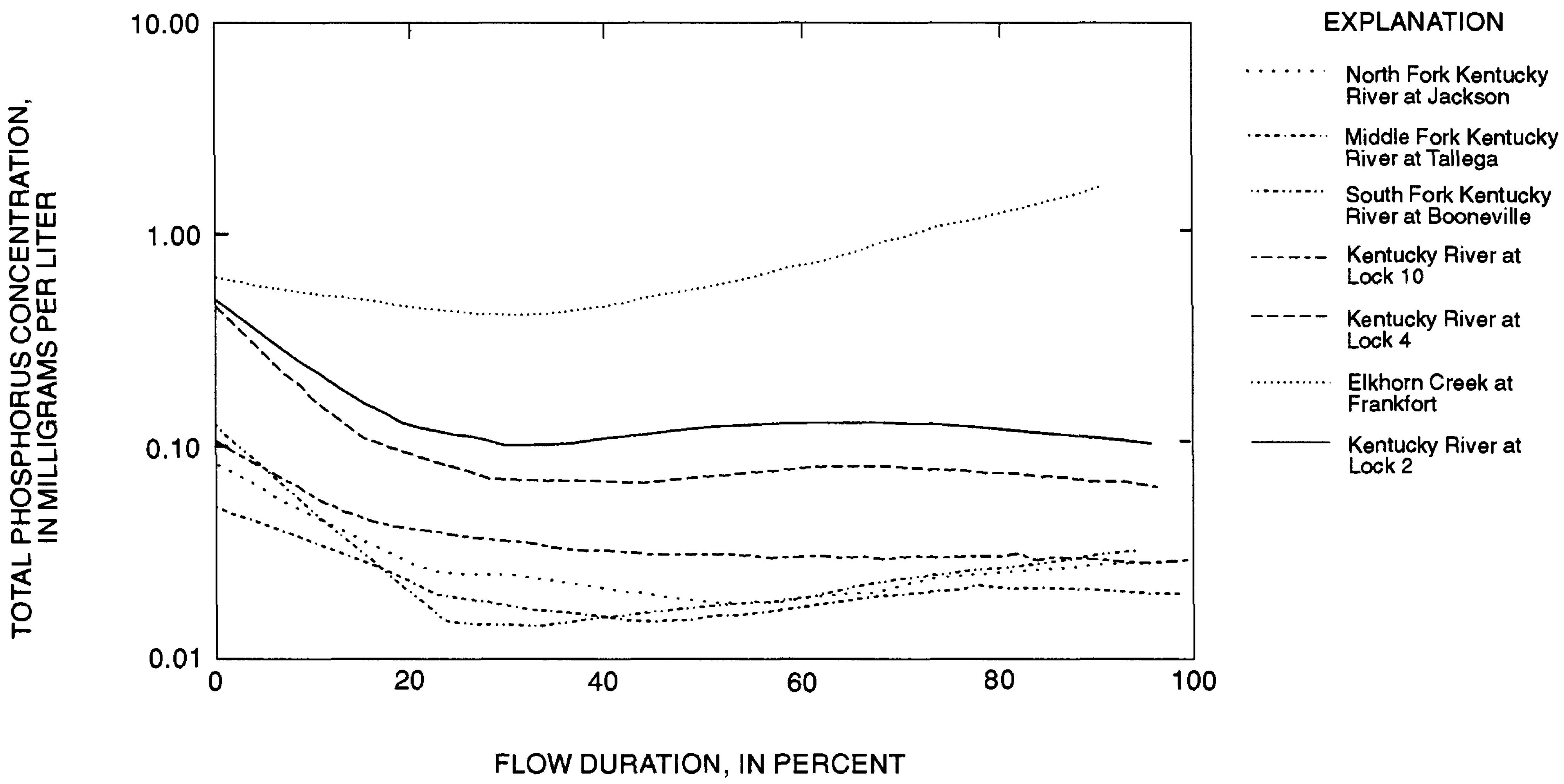

Figure 12. Relation between flow duration and total phosphorus concentration at the fixed stations in the Kentucky River Basin, 1987-90.

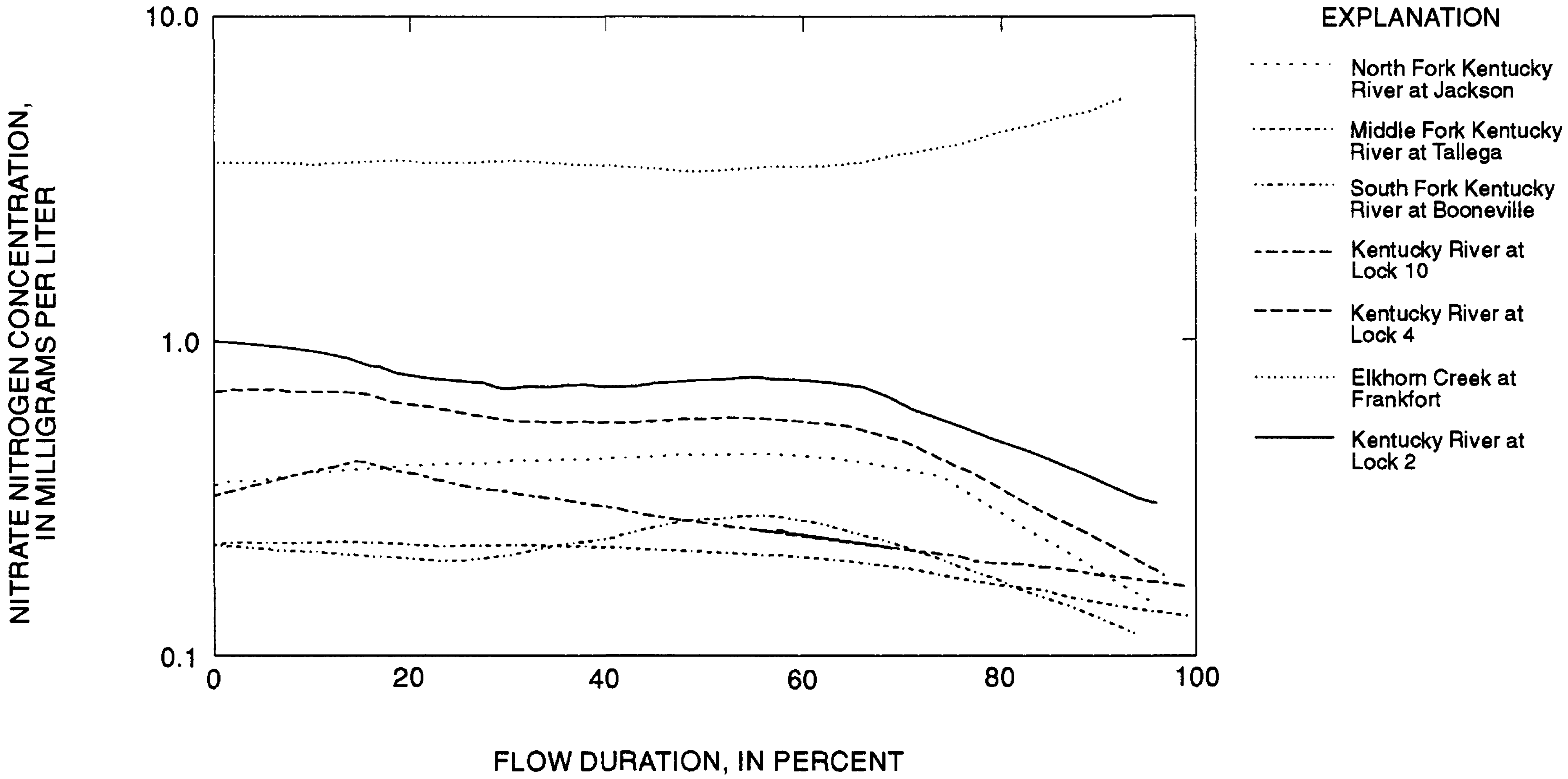

Figure 13. Relation between flow duration and nitrate nitrogen concentration at the fixed stations in the Kentucky River Basin, 1987-90.

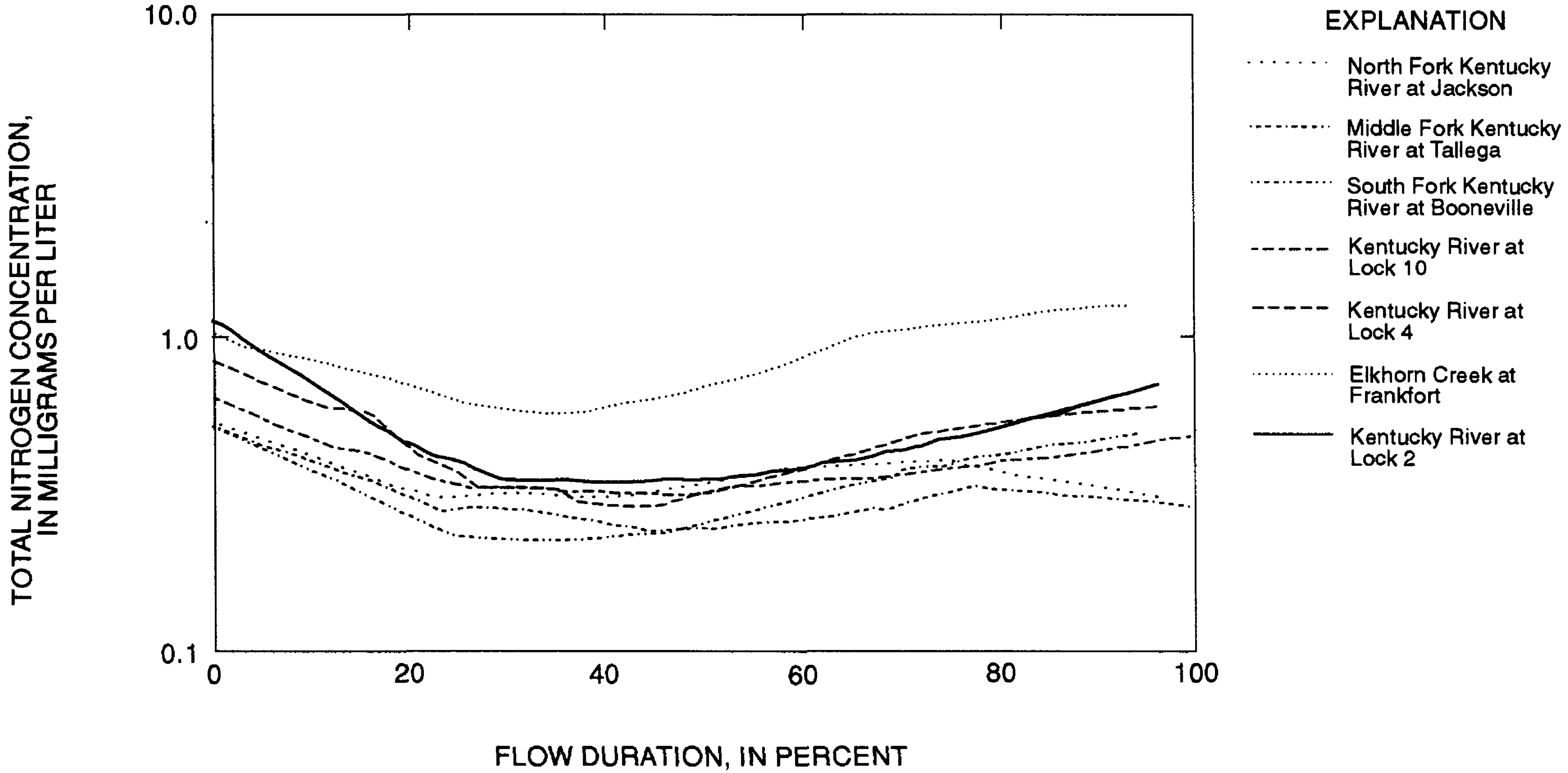

Figure 14. Relation between flow duration and total nitrogen concentration at the fixed stations in the Kentucky River Basin, 1987-90.

data from both water years were combined, correlations were significant among total suspended sediment, total phosphorus, and dissolved nitrite plus nitrate nitrogen.

Season.--The relation between season and total phosphorus concentrations is significant in Elkhorn Creek and in the Kentucky River at Lock 2 but not at any of the other fixed stations. In Elkhorn Creek, total phosphorus concentrations were higher in summer and fall (low flow) than in winter and spring (high flow) because of reduced dilution of WWTP sources of phosphorus. In the Kentucky River at Lock 2, total phosphorus concentrations were significantly higher in fall and winter than in spring and summer. Seasonal differences in orthophosphorus were significant for Elkhorn Creek as well as for two other fixed stations. Orthophosphorus concentrations were significantly lower in summer than in any other season at Lock 4, possibly because of uptake by algae, and were significantly higher in winter at Lock 2 than during other seasons of the year.

No significant differences in ammonia nitrogen concentrations with respect to season were found for any of the fixed stations other than Lock 4, where concentrations were significantly higher in summer. No significant differences in nitrate nitrogen or total nitrogen were attributable to season at any of the fixed sites. However, seasonal patterns were seen in nitrite plus nitrate nitrogen concentrations. At Lock 10, Lock 4, and Lock 2, nitrite plus nitrate nitrogen concentrations were lowest in spring and summer, whereas at the Middle Fork at Tallega, concentrations were highest in winter.

Atmospheric deposition.--Atmospheric deposition is an important nonpoint source of nitrogen in streams (Puckett, 1994). Estimates have been developed for the contribution of ammonia and nitrate nitrogen from precipitation in the Kentucky River Basin (L.J. Puckett, U.S. Geological Survey, written commun., 1992). These estimates are based on wet- and dry-precipitation data collected during 1984-90 at sites in Letcher, Rowan, and Washington Counties. An estimated 14,124 tons of total nitrogen are deposited in the Kentucky River Basin annually. This mass of nitrogen in the form of atmospheric deposition is equivalent to the total estimated amount of nitrogen applied as fertilizer in the Kentucky River Basin (14,046 tons).

The relative contributions of nitrogen from atmospheric deposition and fertilizers in the Kentucky River Basin differ from those in the other NAWQA pilot project study units (Wilber and Davis, 1993). In the Yakima River Basin, the total annual application of nitrogen fertilizer was approximately 19,650 tons, whereas estimated atmospheric deposition of nitrogen was 3,911 tons. In the upper Illinois River Basin, an estimated 174,920 tons of nitrogen fertilizer was applied annually, compared to 7,500 tons of nitrogen that fell as atmospheric deposition. In the Kansas River Basin, total nitrogen fertilizer applied was approximately 213,760 tons annually, whereas the estimated annual nitrogen deposition from precipitation was 25,745 tons. These comparisons indicate that dominant nitrogen sources vary among watersheds and that atmospheric deposition of nitrogen remains a factor to be considered in watershed studies (Puckett, 1994).

Subbasin-Scale Distribution

The distribution of nutrients in subbasins throughout the Kentucky River Basin was assessed by collecting data at the synoptic sites in August 1987 and August 1988. Data characterizing the effluent water quality from individual WWTP's were summarized from Discharge Monitoring Reports required under the Kentucky Pollution Discharge Elimination System (KPDES) program. Figures presented in this section show the results from 1987. With few exceptions, which are mentioned, data for 1988 corroborate results for 1987.

Relation of nutrients to point-source discharges

In eight subbasins of the Kentucky River Basin, no WWTP discharges occurred immediately upstream from the synoptic sites sampled in 1987 and 1988 (table 5). These subbasins are in the upper part of the Kentucky River Basin along the North, Middle, and South Forks, where population density is low and the principal land use is forest. Concentrations of dissolved orthophosphorus were all at or below the detection limit, as were many of the reported concentrations of dissolved nitrite plus nitrate nitrogen. The high concentration of total nitrogen at Redlick Creek near Station Camp and of dissolved nitrite plus nitrate nitrogen in Quicksand Creek at Lunah may have been related to untreated residential wastewater effluent or partially treated residential wastewater from sources such as septic tanks. Given that the samples were collected in both years during low flow, only small contributions to instream nutrient concentrations would be expected from nonpoint sources such as agricultural runoff. Concentrations of all forms of phosphorus and nitrogen were relatively low when compared to sites in the basin receiving WWTP effluent (table 6).

The distribution of wastewater-treatment plants in the Kentucky River Basin (fig. 15) and their instantaneous ammonia nitrogen loads (fig. 16) reflects population distribution; the largest discharges are near the municipalities of Lexington, Frankfort, Danville, Richmond, and Hazard. Analyses of nutrient concentrations in receiving streams indicate significant effects of WWTP's throughout the basin, particularly downstream from urban areas. Concentrations of total phosphorus were greater than 0.5 mg/L (fig. 17) at numerous synoptic sites in the Bluegrass and Knobs Regions in August 1987, principally downstream from the urban areas listed above. Concentrations of ammonia nitrogen exceeded 0.1 mg/L at many sites in the Kentucky River Basin in August 1987 (fig. 18) and August 1988 (data not shown in fig. 18). These include several sites in the upstream part of the basin. Concentrations of nitrite plus nitrate nitrogen (fig. 19, table 6) exceeded 10.0 mg/L at two synoptic sites: Hickman Creek near Mills (KC) (14 mg/L in 1987 and 25 mg/L in 1988) and Clarks Creek near Stewartsville (SE) (11 mg/L in 1987 and 16 mg/L in 1988). In August 1988 Town Branch near Lexington (RF) had a concentration of nitrite plus nitrate nitrogen of 11 mg/L. Numerous sites in both years had concentrations of nitrite plus nitrate nitrogen between 1.0 and 10.0 mg/L.

The percentage of instantaneous stream discharge (fig. 20) and instantaneous stream nitrogen load (fig. 21) attributable to WWTP effluent during low flow was estimated in subbasins of the Kentucky River Basin. The

Table 5. Water-quality constituents at synoptic sites in the Kentucky River Basin in subbasins unaffected by wastewater-treatment-plant discharges, August 1987 and August 1988

[mg/L, milligrams per liter; <, less than; --, no data available]

Site name (Site number)	Synoptic site code[1]	Phosphorus, total, as P (mg/L)	Phosphorus, orthophosphate, dissolved as P (mg/L)	Phosphorus, dissolved, as P (mg/L)	Suspended, sediment, total (mg/L)	Nitrogen, total, as N (mg/L)	Nitrogen, nitrite plus nitrate, dissolved, as N (mg/L)	Nitrogen, dissolved, as N (mg/L)	Nitrogen, ammonia, total, as N (mg/L)	Drainage area (square miles)	Principal land use
Quicksand Cr at Lunah	CD	0.04	<0.01	0.02	28	0.40	0.22	0.30	0.07	101.0	Forest
(3279400)		.15	<.01	.01	98	.80	1.00	.40	.05		
M FK KY R at Asher	FB	.04	.01	.02	--	.20	.10	.20	.02	70.6	Forest
(3280551)		.10	.01	.06	29	1.0	.34	1.0	.04		
Sexton Cr nr Taft	FL	.02	<.01	.02	14	.20	.17	.20	.04	71.6	Forest
(3281351)		.02	<.01	.03	2	.40	<.10	.60	.01		
Sturgeon Cr nr Ida May	GB	.02	<.01	.02	13	.30	.13	.20	.04	110.0	Forest
(3282048)		.03	<.01	.01	16	.80	.10	.60	.03		
Big Sinking Cr nr Crystal	GC	.01	<.01	.01	2	.60	<.10	.50	.04	23.4	Forest
(3282075)		.03	<.01	--	9	.30	<.10	--	--		
Station Camp Cr at	GE	.03	<.01	.01	8	.90	<.10	.70	.03	116.0	Forest
Wagersville (3282170)		.03	<.01	.03	6	.80	<.10	.50	.06		
Redlick Cr nr Station Camp	GF	.02	<.01	.01	5	.80	<.10	1.00	.27	69.5	Forest
(3282190)		.03	<.01	.01	52	1.20	.53	1.10	.07		
Cat Cr nr Stanton	HE	.01	<.01	.01	2	.30	.11	.40	.01	8.3	Forest
(3283370)		.02	<.01	--	12	.70	.14	--	--		

[1] Refer to figure 8 for synoptic site location.

Table 6. Water-quality constituents at synoptic sites in the Kentucky River Basin and estimated effluent loads of suspended solids and ammonia nitrogen from upstream wastewater-traatment plants

[mg/L, milligrams per liter; mg/sec, milligrams per second; --, no data available; <, less than; first row of data associated with each station number is from August 1987 and second row of data is from August 1988; values for suspended-sediment and ammonia nitrogen loads are summed for the entire drainage upstream from the indicated synoptic sites]

		Constituent concentrations at synoptic sites in the Kentucky River Basin										Estimated instantaneous effluent loads from upstream wastewater-treatment plants	
Site number[1]	Site code[2]	Phosphorus, total, as P (mg/L)	Phosphorus, orthophosphate, dissolved, as P (mg/L)	Phosphorus, dissolved, as P (mg/L)	Suspended sediment, total (mg/L)	Nitrogen, total, as N (mg/L)	Nitrogen nitrite plus nitrate, dissolved, as N (mg/L)	Nitrogen, dissolved, as N (mg/L)	Nitrogen, ammonia, total, as N (mg/L)	Drainage area, in square miles	Principal land use	Suspended solids (mg/sec)	Ammonia nitrogen (mg/sec)
3277305	AA	0.04	0.02	0.03	73	0.60	0.68	0.50	0.08	85.0	Forest	383	3
		.14	.03	.10	63	1.1	.36	.70	.32				
3277360	AB	.32	.01	.01	30	.40	.27	.60	.04	51.5	Forest	41	11
		.12	.01	.07	173	.90	.43	.60	.03				
3277410	AC	.03	.01	.02	94	1.0	.43	1.0	.05	49.7	Forest	157	14
		.03	.01	.05	15	.70	.10	.80	.01				
3277470	AD	.03	.03	.04	8	.20	.29	.20	.01	79.7	Forest	100	12
		.15	.01	.04	107	.50	2.8	.80	.05				
3277550	BA	.11	.05	.06	11	.30	.13	.30	.30	480.0	Forest	7,658	430
		.21	.07	.10	70	1.3	.37	1.1	.29				
3277690	CA	.01	.01	.01	8	.30	.28	.30	.04	575.0	Forest	7,710	447
		.03	.01	.06	9	.70	.25	.60	.04				
3277835	CB	.16	.02	.05	257	.80	.96	.30	.15	59.9	Forest	106	78
		.18	.01	.03	146	1.2	.41	1.2	.06				
3279005	CC	.01	.01	.01	39	.40	.43	.30	.06	195.0	Forest	142	99
		.04	.01	.06	48	1.4	.30	.50	.05				
3279700	CE	.03	.01	.02	68	.30	.34	.20	.04	203.0	Forest	6	1
		.03	.01	.02	20	.40	.16	--	.01				
3280000	DA	.04	.01	--	29	.70	.56	--	--	1,101.0	Forest	9,287	1,011
		.04	.01	.01	24	.80	.15	.60	.05				

Table 6. Water-quality constituents at synoptic sites in the Kentucky River Basin and estimated effluent loads of suspended solids and ammonia nitrogen from upstream wastewater-treatment plants--Continued

[mg/L, milligrams per liter; mg/sec, milligrams per second; --, no data available; <, less than; first row of data associated with each station number is from August 1987 and second row of data is from August 1988; values for suspended-sediment and ammonia nitrogen loads are summed for the entire drainage upstream from the indicated synoptic sites]

		Constituent concentrations at synoptic sites in the Kentucky River Basin										Estimated instantaneous effluent loads from upstream wastewater-treatment plants	
Site number[1]	Site code[2]	Phosphorus, total, as P (mg/L)	Phosphorus, orthophosphate, dissolved, as P (mg/L)	Phosphorus, dissolved, as P (mg/L)	Suspended sediment, total (mg/L)	Nitrogen, total, as N (mg/L)	Nitrogen nitrite plus nitrate, dissolved, as N (mg/L)	Nitrogen, dissolved, as N (mg/L)	Nitrogen, ammonia, total, as N (mg/L)	Drainage area, in square miles	Principal land use	Suspended solids (mg/sec)	Ammonia nitrogen (mg/sec)
3280120	EA	0.03	0.01	0.03	17	1.0	0.32	0.40	0.08	1,134.0	Forest	9,287	1,011
		.05	.01	.01	20	.60	.43	.80	.13				
3280500	FA	.02	.01	.02	12	.50	.10	.50	.07	1,294.0	Forest	9,293	1,012
		.03	.01	.01	29	.50	.15	.60	.09				
3280600	FC	.02	.01	.02	12	.20	.10	.20	.02	202.0	Forest	4	1
		.03	.01	.06	16	.70	.10	.30	.01				
3280700	FD	.06	.01	.02	53	.20	.10	.20	.05	61.3	Forest	6	2
		.07	.01	.06	50	1.0	.10	.60	.02				
3280900	FE	.01	.01	.01	27	.60	.10	.30	.17	420.0	Forest	373	109
		.02	.01	.01	10	3.5	.10	.60	.13				
3280940	FF	.02	.01	.01	11	.50	.10	.20	.01	475.0	Forest	373	109
		.03	.01	.02	11	.30	.10	.30	.03				
3281000	FG	.02	.01	--	9	.30	.15	--	--	537.0	Forest	373	109
		.02	.01	.01	10	.40	.19	.50	.04				
3281017	FH	.01	.01	.01	4	.60	.10	.60	.02	53.0	Forest	6	4
		.05	.01	.01	36	.50	.10	.70	.04				
3281040	FI	.02	.01	.01	2	.50	.10	.40	.03	155.0	Forest	8	5
		.05	.01	.03	9	.60	.10	.60	.05				
3281100	FJ	.03	.01	.01	12	.70	.15	.70	.02	163.0	Forest	266	101
		.06	.01	.02	9	.40	.12	.70	.02				

Table 6. Water-quality constituents at synoptic sites in the Kentucky River Basin and estimated effluent loads of suspended solids and ammonia nitrogen from upstream wastewater-treatment plants--Continued

[mg/L, milligrams per liter; mg/sec, milligrams per second; --, no data available; <, less than; first row of data associated with each station number is from August 1987 and second row of data is from August 1988; values for suspended-sediment and ammonia nitrogen loads are summed for the entire drainage upstream from the indicated synoptic sites]

		Constituent concentrations at synoptic sites in the Kentucky River Basin										Estimated instantaneous effluent loads from upstream wastewater-treatment plants	
Site number[1]	Site code[2]	Phosphorus, total, as P (mg/L)	Phosphorus, orthophosphate, dissolved, as P (mg/L)	Phosphorus, dissolved, as P (mg/L)	Suspended sediment, total (mg/L)	Nitrogen, total, as N (mg/L)	Nitrogen nitrite plus nitrate, dissolved, as N (mg/L)	Nitrogen, dissolved, as N (mg/L)	Nitrogen, ammonia, total, as N (mg/L)	Drainage area, in square miles	Principal land use	Suspended solids (mg/sec)	Ammonia nitrogen (mg/sec)
3281200	FK	0.02	0.01	0.02	11	0.40	0.10	0.40	0.05	486.0	Forest	367	127
		.03	.01	.01	13	.50	.10	.70	.12				
3281500	FM	.04	.01	--	12	.70	.10	--	--	722.0	Forest	392	133
		.05	.01	.02	20	.80	.10	.70	.07				
3282000	GA	.03	.01	.01	21	.60	.10	.50	.05	2,657.0	Forest	10,280	1,285
		.06	.01	.03	31	1.2	.16	.20	.17				
3282100	GD	.01	.01	.01	11	.40	.10	.30	.04	9.9	Forest	<1	<1
		.02	.03	--	9	.40	.10	--	--				
3282250	HA	.02	.01	.01	6	.50	.10	.30	.01	3,138.0	Forest	11,080	1,320
		.02	.02	.01	19	.70	.10	.40	.04				
3282500	HB	.04	.01	.01	12	.80	.10	.60	.01	65.8	Forest	10	1
		.07	.01	.01	35	.60	.17	1.5	.06				
3283200	HC	.01	.01	.01	8	.80	.10	.50	.02	184.0	Forest	139	14
		.04	.01	.01	18	.40	.30	.30	.03				
3283320	HD	.03	.01	.01	14	.30	.10	.50	.02	25.4	Forest	35	10
		.03	.01	.02	9	1.0	.20	.50	.05				
3283500	HF	.04	.01	.02	55	.80	.45	.80	.08	362.0	Forest	507	35
		.24	.01	.02	22	.60	.33	.40	.09				
3283815	IA	.04	.01	.02	12	.80	.16	.40	.03	3,771.0	Forest	11,680	1,402
		.05	.01	.01	9	1.1	.10	.50	.04				

Table 6. Water-quality constituents at synoptic sites in the Kentucky River Basin and estimated effluent loads of suspended solids and ammonia nitrogen from upstream wastewater-treatment plants--Continued

[mg/L, milligrams per liter; mg/sec, milligrams per second; --, no data available; <, less than; first row of dsta associated with each station number is from August 1987 and second row of data is from August 1988; valuas for suspended-sediment and ammonia nitrogen loads are summed for the entira drainaga upstream from the indicated synoptic sites]

		Constituent concentrations at synoptic sites in the Kentucky River Basin										Estimated instantaneous affluent loads from upstream wastewater-treatment plants	
Site number[1]	Site code[2]	Phosphorus, total, as P (mg/L)	Phosphorus, orthophosphate, dissolved, as P (mg/L)	Phosphorus, dissolved, as P (mg/L)	Suspended sediment, total (mg/L)	Nitrogen, total, as N (mg/L)	Nitrogen nitrite plus nitrate, dissolved, as N (mg/L)	Nitrogen, dissolved, as N (mg/L)	Nitrogen, ammonia, total, as N (mg/L)	Drainaga araa, in square miles	Principal land use	Suspended solids (mg/sec)	Ammonia nitrogen (mg/sec)
3283820	IB	0.04 .04	0.01 .04	0.04 .03	5 27	0.80 .70	0.10 .22	0.70 .30	-- 0.02	37.0	Agriculture	19	6
3283830	IC	.05 .06	.01 .01	.02 .01	17 12	.80 1.1	.13 .10	.20 1.0	.03 .05	63.8	Agriculture	19	6
3283990	ID	1.4 4.7	1.2 3.2	1.3 3.2	8 9	1.2 1.7	3.7 7.0	.90 1.3	.05 .08	22.7	Agriculture	1,100	32
3284000	JA	.03 .05	.01 .01	.01 .03	8 12	.60 .80	.10 .15	.40 .80	.05 .01	3,955.0	Forast	12,780	1,434
3284210	JB	1.9 4.2	1.7 .01	1.8 3.7	14 11	1.9 1.8	7.1 8.6	1.0 1.7	.06 .05	14.4	Agricultura	601	67
3284225	KA	.03 .03	.01 .01	.02 .02	5 5	.50 .60	.10 .10	.30 .30	.01 .04	4,100.0	Forest	13,460	1,554
3284315	KB	.14 .52	.08 .30	.10 .33	5 13	1.1 .90	.24 .32	.50 .70	.07 .06	68.2	Agriculture	61	24
3284560	KC	4.0 8.5	3.4 6.8	3.6 7.8	25 19	1.6 3.0	14 25	1.6 2.4	.06 .16	64.2	Agriculture	3,145	139
3284600	LA	.18 .19	.14 .12	.15 .15	9 179	.60 .80	.85 .38	.40 .20	.01 .01	4,528.0	Forest	16,720	1,764
3284630	LB	4.3 12	3.6 8.7	4.1 10	10 6	3.9 2.8	8.3 9.5	3.5 2.7	.32 .19	6.7	Agricultura	576	37

Table 6. Water-quality constituents at synoptic sites in the Kentucky River Basin and estimated effluent loads of suspended solids and ammonia nitrogen from upstream wastewater-treatment plants--Continued

[mg/L, milligrams per liter; mg/sec, milligrams per second; --, no data available; <, less than; first row of data associated with each station number is from August 1987 and second row of data is from August 1988; values for suspended-sediment and ammonia nitrogen loads are summed for the entire drainage upstream from the indicated synoptic sites]

		Constituent concentrations at synoptic sites in the Kentucky River Basin										Estimated instantaneous effluent loads from upstream wastewater-treatment plants	
Site number[1]	Site code[2]	Phosphorus, total, as P (mg/L)	Phosphorus, orthophosphate, dissolved, as P (mg/L)	Phosphorus, dissolved, as P (mg/L)	Suspended sediment, total (mg/L)	Nitrogen, total, as N (mg/L)	Nitrogen nitrite plus nitrate, dissolved, as N (mg/L)	Nitrogen, dissolved, as N (mg/L)	Nitrogen, ammonia, total, as N (mg/L)	Drainage area, in square miles	Principal land use	Suspended solids (mg/sec)	Ammonia nitrogen (mg/sec)
3284800	LC	0.09	0.01	0.03	18	0.80	0.19	1.1	0.04	160.0	Agriculture	1,663	74
		.21	.03	.04	51	1.3	.10	.70	.16				
3285000	LD	.06	.01	.03	10	1.1	.10	.20	.02	318.0	Agriculture	3,579	283
		.10	.05	.07	8	1.0	.21	1.0	.03				
3285200	LE	4.5	2.8	3.2	10	1.5	1.0	1.1	.05	14.9	Agriculture	921	73
		8.0	1.6	2.2	11	1.3	3.7	1.1	.13				
3286500	MA	--	--	--	--	--	--	--	--	5,031.0	Forest	--	--
		.25	.16	.18	4	1.1	.79	.50	.01			21,900	2,226
3286510	NA	.07	.03	.04	18	.60	.31	.40	.04	5,036.0	Forest	21,900	2,226
		.10	.03	.03	8	.90	.40	.50	.01				
3287000	OA	.05	.01	.01	8	.90	.38	.20	.04	5,102.0	Forest	22,120	2,304
		.05	.02	.02	6	.80	.22	.50	.01				
3287130	OB	.24	.19	.21	6	.50	1.2	.50	.04	61.6	Agriculture	<1	<1
		.29	.15	.22	6	.60	.10	.60	.06				
3287248	PA	.05	.01	.04	4	.60	.13	.80	.04	5,222.0	Forest	22,160	2,311
		.06	.01	.02	10	.50	.55	.30	.01				
3287300	PB	.61	.2	.26	45	1.4	1.0	1.1	.13	19.5	Agriculture	343	26
		1.7	1.2	1.2	13	1.0	3.9	1.3	.04				
3287500	QA	.06	.01	.03	11	.80	.10	.70	.11	5,304.0	Forest	22,640	2,339
		.10	.02	--	11	.70	.56	--	--				

Table 6. Water-quality constituents at synoptic sites in the Kentucky River Basin and estimated effluent loads of suspended solids and ammonia nitrogen from upstream wastewater-treatment plants--Continued

[mg/L, milligrams per liter; mg/sec, milligrams per second; --, no data available; <, less than; first row of data associated with each station number is from August 1987 and second row of data is from August 1988; values for suspended-sediment and ammonia nitrogen loads are summed for the entire drainage upstream from the indicated synoptic sites]

		Constituent concentrations at synoptic sites in the Kentucky River Basin										Estimated instantaneous effluent loads from upstream wastewater-treatment plants	
Site number[1]	Site code[2]	Phosphorus, total, as P (mg/L)	Phosphorus, orthophosphate, dissolved, as P (mg/L)	Phosphorus, dissolved, as P (mg/L)	Suspended sediment, total (mg/L)	Nitrogen, total, as N (mg/L)	Nitrogen nitrite plus nitrate, dissolved, as N (mg/L)	Nitrogen, dissolved, as N (mg/L)	Nitrogen, ammonia, total, as N (mg/L)	Drainage area, in square miles	Principal land use	Suspended solids (mg/sec)	Ammonia nitrogen (mg/sec)
3287545	QB	0.20	0.07	0.08	12	0.80	0.12	0.60	0.04	101.0	Agriculture	100	22
		.40	.02	.03	18	4.9	.10	1.6	.01				
3287575	RA	.19	.11	.13	6	.90	.82	.90	.06	5,441.0	Forest	34,690	10,890
		.24	.11	.20	7	.90	.61	.60	.04				
3288000	RB	.20	.15	.17	4	2.9	.12	2.4	.06	119.0	Agriculture	139	<1
		.25	.11	.12	18	1.4	.15	1.4	.04				
3288150	RC	.68	.58	.57	6	1.3	1.1	1.1	.02	155.0	Agriculture	893	162
		.99	.87	1.0	3	2.8	.48	.80	.31				
3288460	RD	.30	.21	.26	5	.70	.10	.90	.04	276.0	Agriculture	1,306	240
		.30	.21	.26	3	1.2	.10	1.0	.01				
3289000	RE	1.2	1.0	.98	31	1.6	1.9	.30	.06	24.0	Agriculture	282	307
		1.7	1.5	1.8	4	.90	2.6	.60	.04				
3289195	RF	2.8	1.2	1.7	7	25	.52	21	19	30.0	Urban	8,537	7,910
		3.4	3.1	3.2	10	2.0	11	1.3	.24				
3289300	RG	1.5	1.3	1.5	13	.80	7.2	.60	.04	105.0	Agriculture	8,987	8,228
		4.0	2.7	3.4	11	13	1.4	12	11				
3289470	RH	1.2	1.0	1.1	13	.40	2.1	.30	.01	187.0	Agriculture	9,139	8,233
		2.0	1.4	1.6	2	1.8	6.2	1.1	.04				
3289500	RI	.91	.83	--	10	.70	1.2	--	--	473.0	Agriculture	10,530	8,479
		1.8	1.3	1.5	7	1.6	4.5	0.80	0.03				

Table 6. Water-quality constituents at synoptic sites in the Kentucky River Basin and estimated effluent loads of suspended solids and ammonia nitrogen from upstream wastewater-treatment plants--Continued

[mg/L, milligrams per liter; mg/sec, milligrams per second; --, no data available; <, less than; first row of data associated with each station number is from August 1987 and second row of data is from August 1988; values for suspended-sediment and ammonia nitrogen loads are summed for the entire drainage upstream from the indicated synoptic sites]

		Constituent concentrations at synoptic sites in the Kentucky River Basin										Estimated instantaneous effluent loads from upstream wastewater-treatment plants	
Site number[1]	Site code[2]	Phosphorus, total, as P (mg/L)	Phosphorus, orthophosphate, dissolved, as P (mg/L)	Phosphorus, dissolved, as P (mg/L)	Suspended sediment, total (mg/L)	Nitrogen, total, as N (mg/L)	Nitrogen nitrite plus nitrate, dissolved, as N (mg/L)	Nitrogen, dissolved, as N (mg/L)	Nitrogen, ammonia, total, as N (mg/L)	Drainage area, in square miles	Principal land use	Suspended solids (mg/sec)	Ammonia nitrogen (mg/sec)
3290500	SA	0.05	0.02	0.03	5	0.50	0.14	--	0.05	6,180.0	Forest	34,800	10,900
		.11	.04	.09	11	1.0	.22	.60	.05				
3290600	SB	.08	.03	.07	12	1.1	.10	.70	.06	62.0	Agriculture	47	<1
		.10	.08	.09	12	.30	.10	.30	.01				
3291130	SC	.04	.05	.03	13	2.9	.10	2.30	.01	174.0	Agriculture	132	4
		.08	.01	.04	3	1.2	.10	1.20	.08				
3291300	SD	.11	.04	.07	23	1.3	.20	.30	.08	293.0	Agriculture	360	73
		--	--	--	--	--	--	--	--			--	--
3291310	SE	5.4	5.2	5.1	11	2.9	11	2.40	.03	9.2	Agriculture	87	17
		8.8	6.4	7.4	25	1.9	16	2.00	.05				
3291510	SF	.06	.01	.03	25	1.0	.10	.60	.01	468.0	Agriculture	550	119
		.06	.01	.03	14	1.0	.10	1.00	.04				
3291600	TA	.04	.02	.03	8	.50	.10	.20	.01	6,956.0	Forest	35,490	11,180
		.08	.03	.06	10	.50	.71	.80	.04				

[1]Refer to table 2 for complete site name associated with each site number.

[2]Refer to figure 8 for synoptic site location.

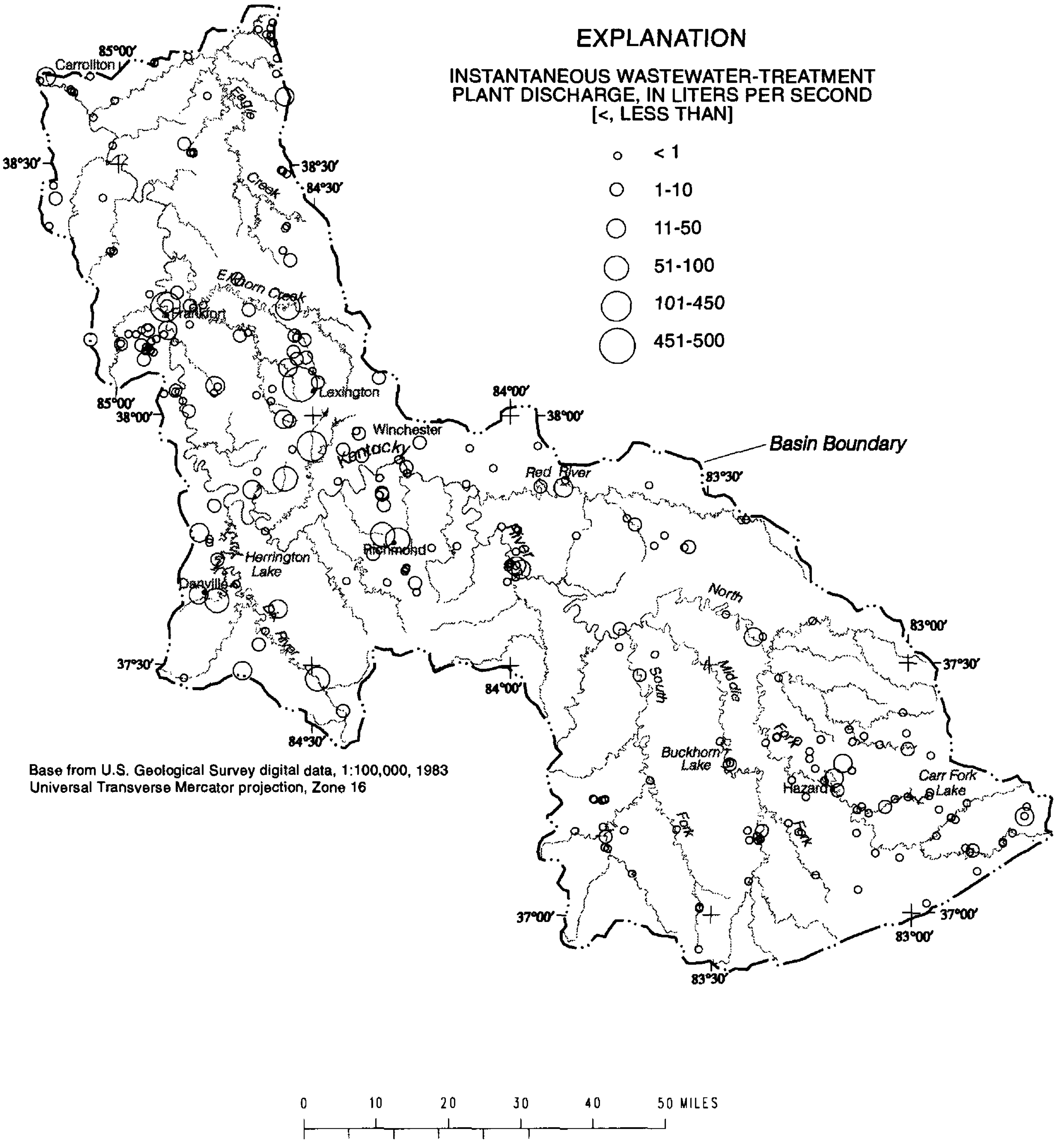

Figure 15. Instantaneous discharge from wastewater-treatment plants in the Kentucky River Basin, August, 1991.

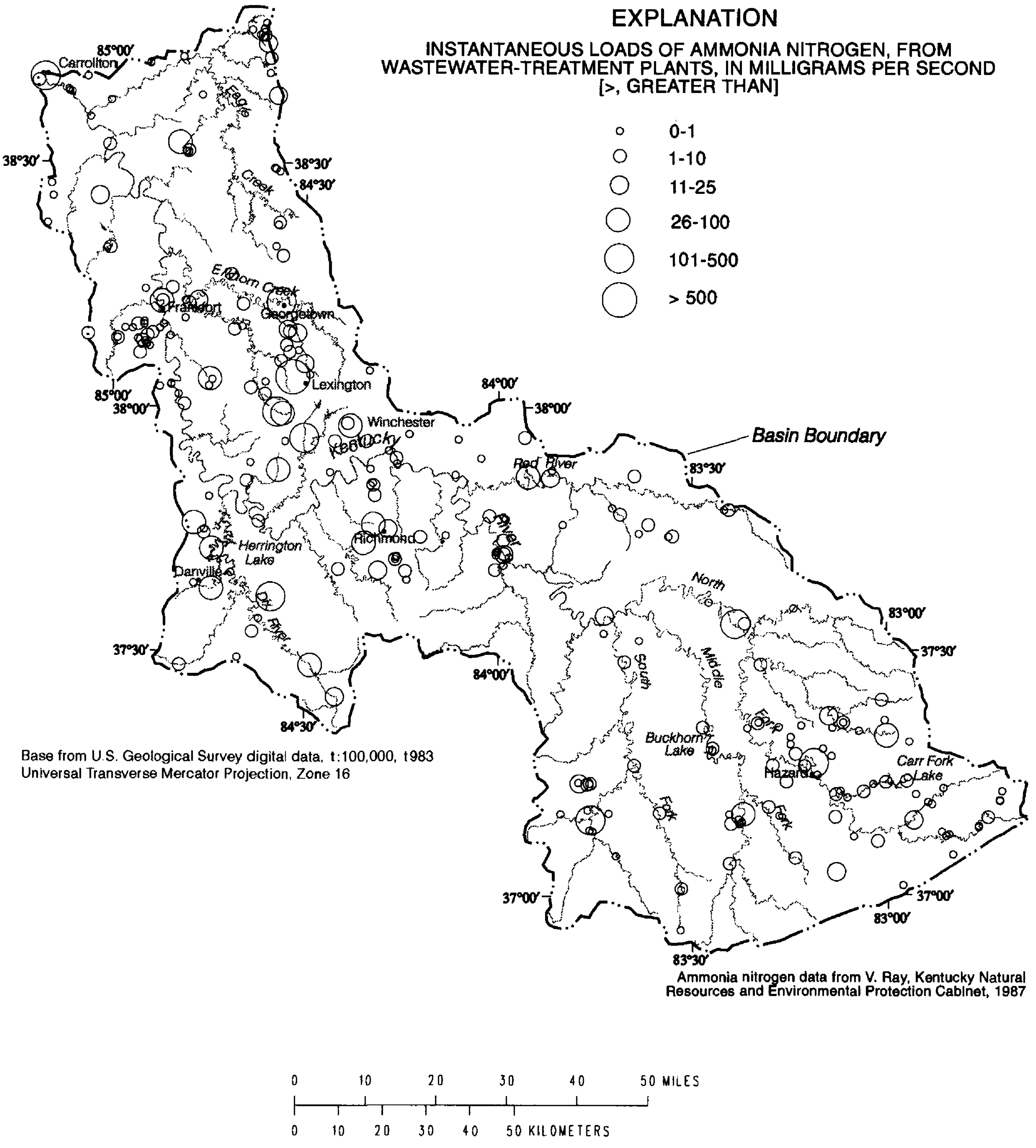

Figure 16. Instantaneous loads of ammonia nitrogen from wastewater-treatment plants in the Kentucky River Basin, August, 1991.

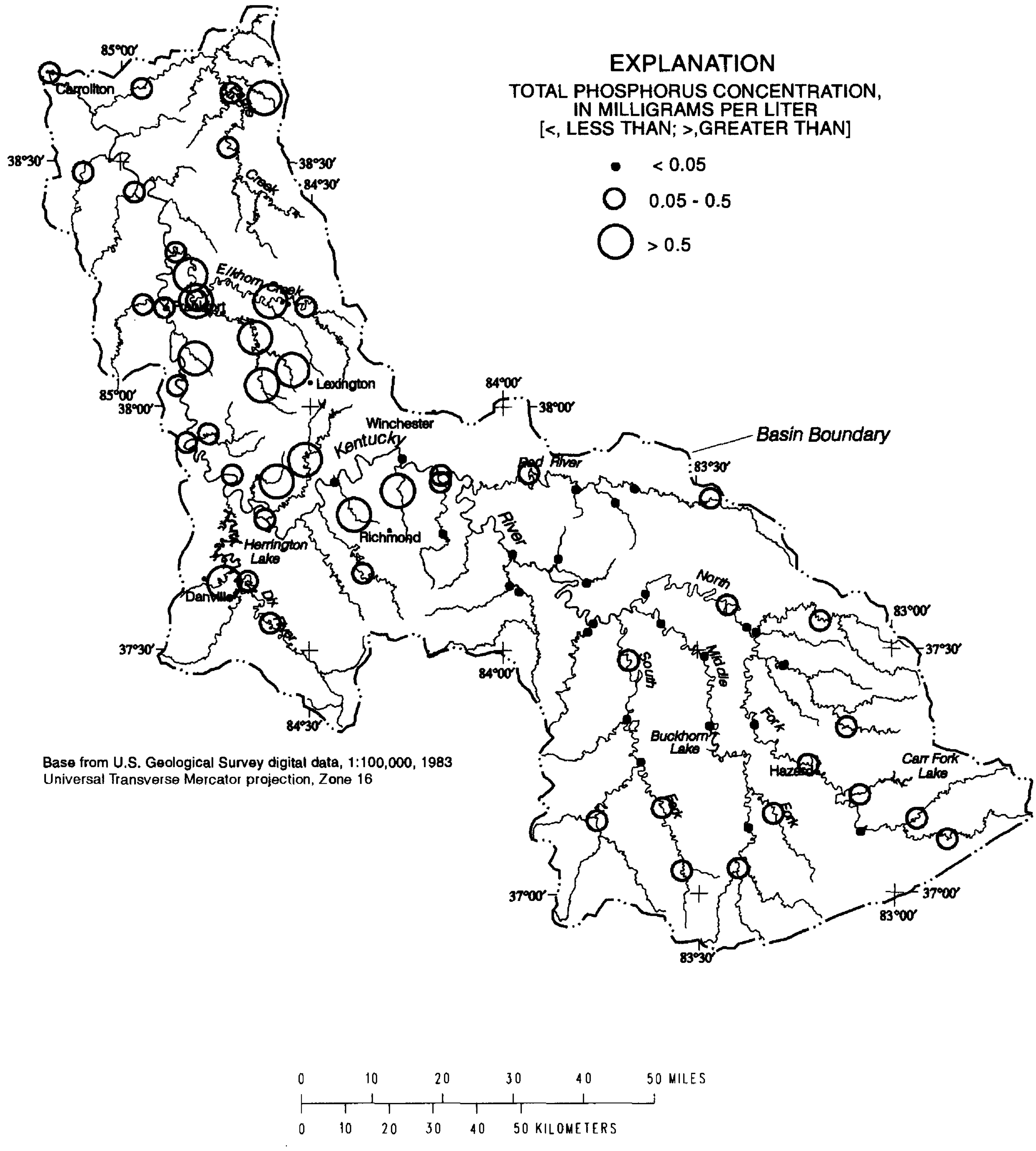

Figure 17. Concentrations of total phosphorus at synoptic sites in the Kentucky River Basin, August 8-12, 1987.

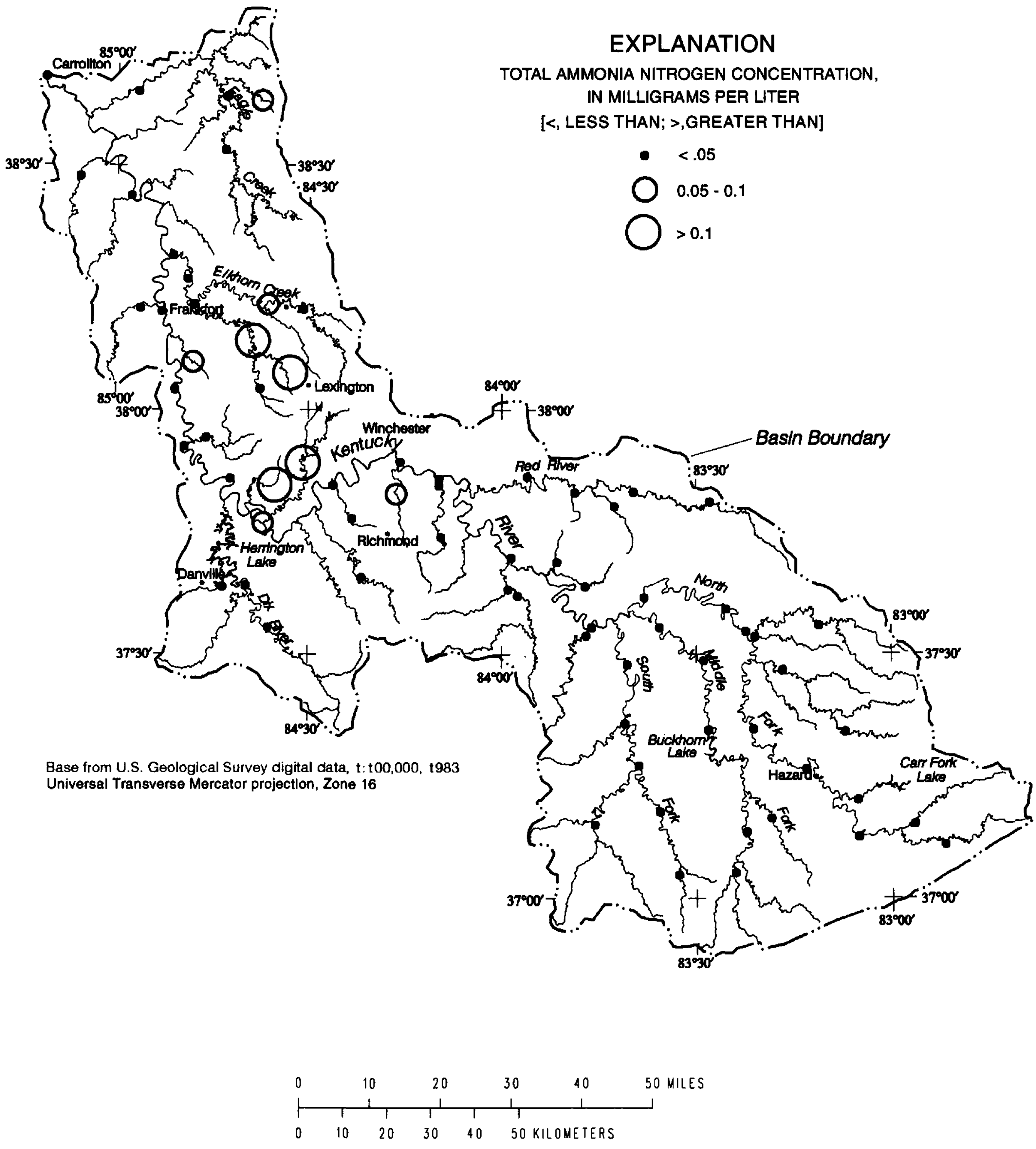

Figure 18. Concentrations of total ammonia nitrogen at synoptic sites in the Kentucky River Basin, August 8-12, 1987.

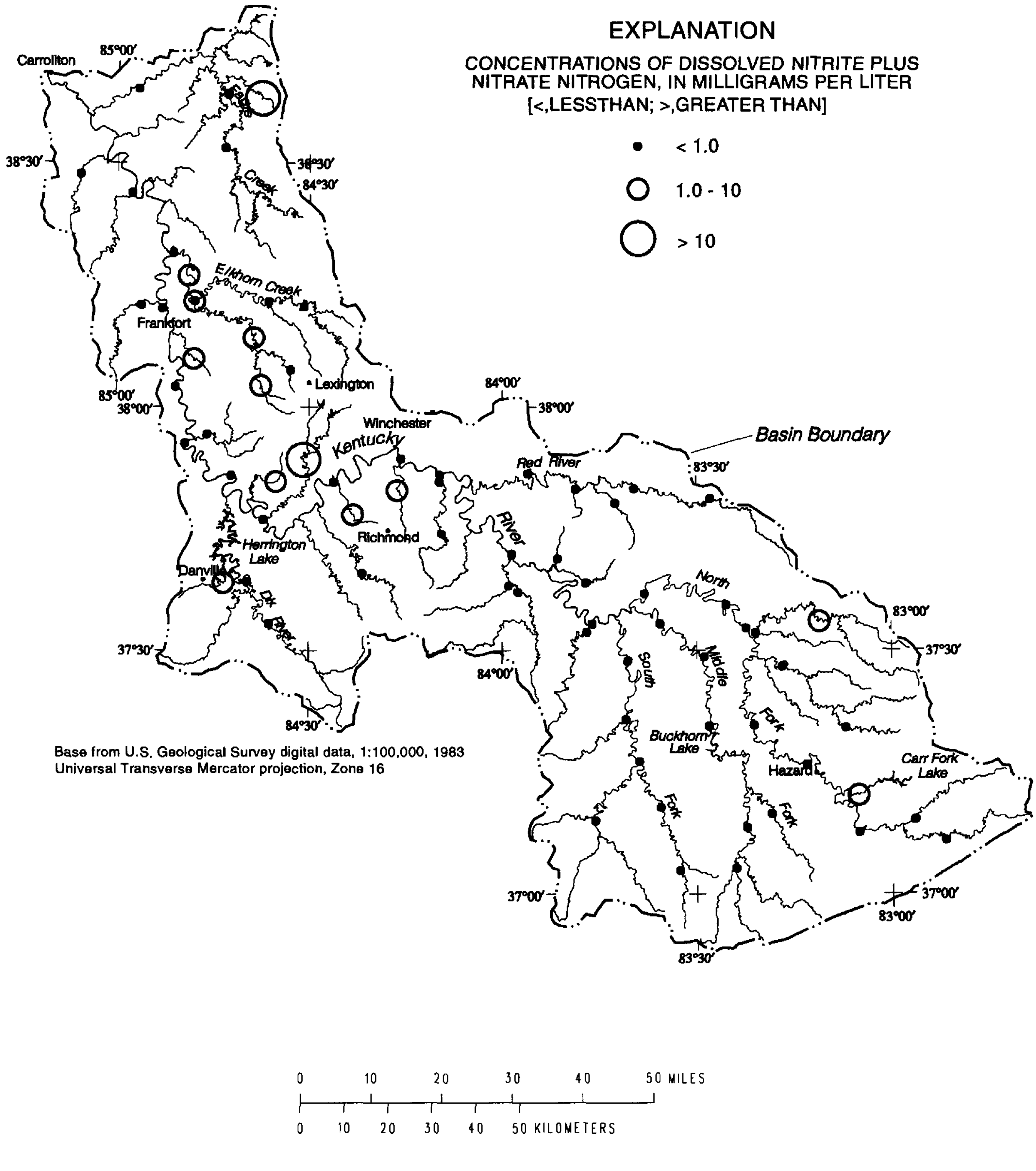

Figure 19. Concentrations of dissolved nitrite plus nitrate nitrogen at synoptic sites in the Kentucky River Basin, August 8-12, 1987.

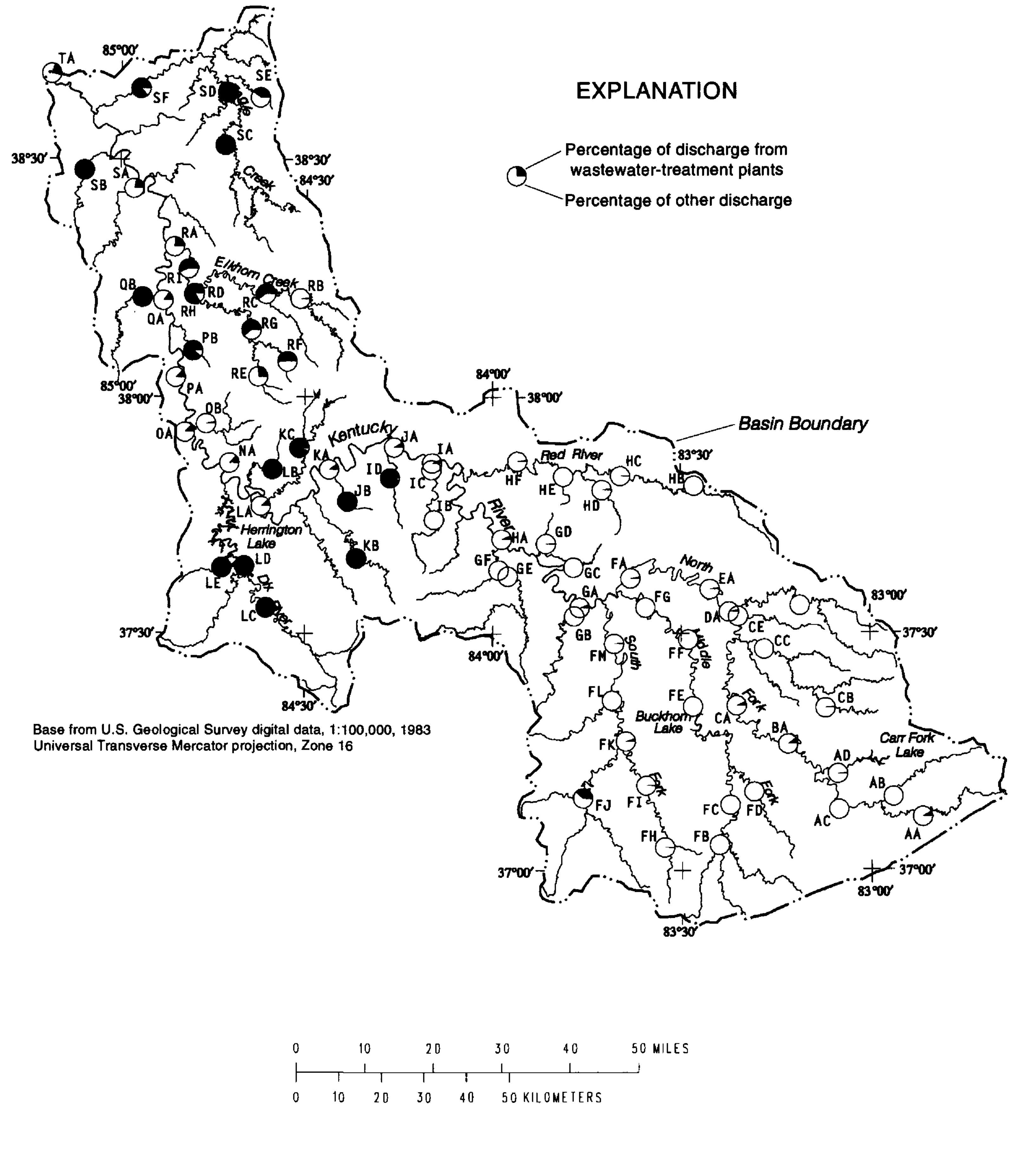

Figure 20. Percentage of total stream discharge attributable to wastewater-treatment-plant discharge in subbasins of the the Kentucky River Basin, August 1987.

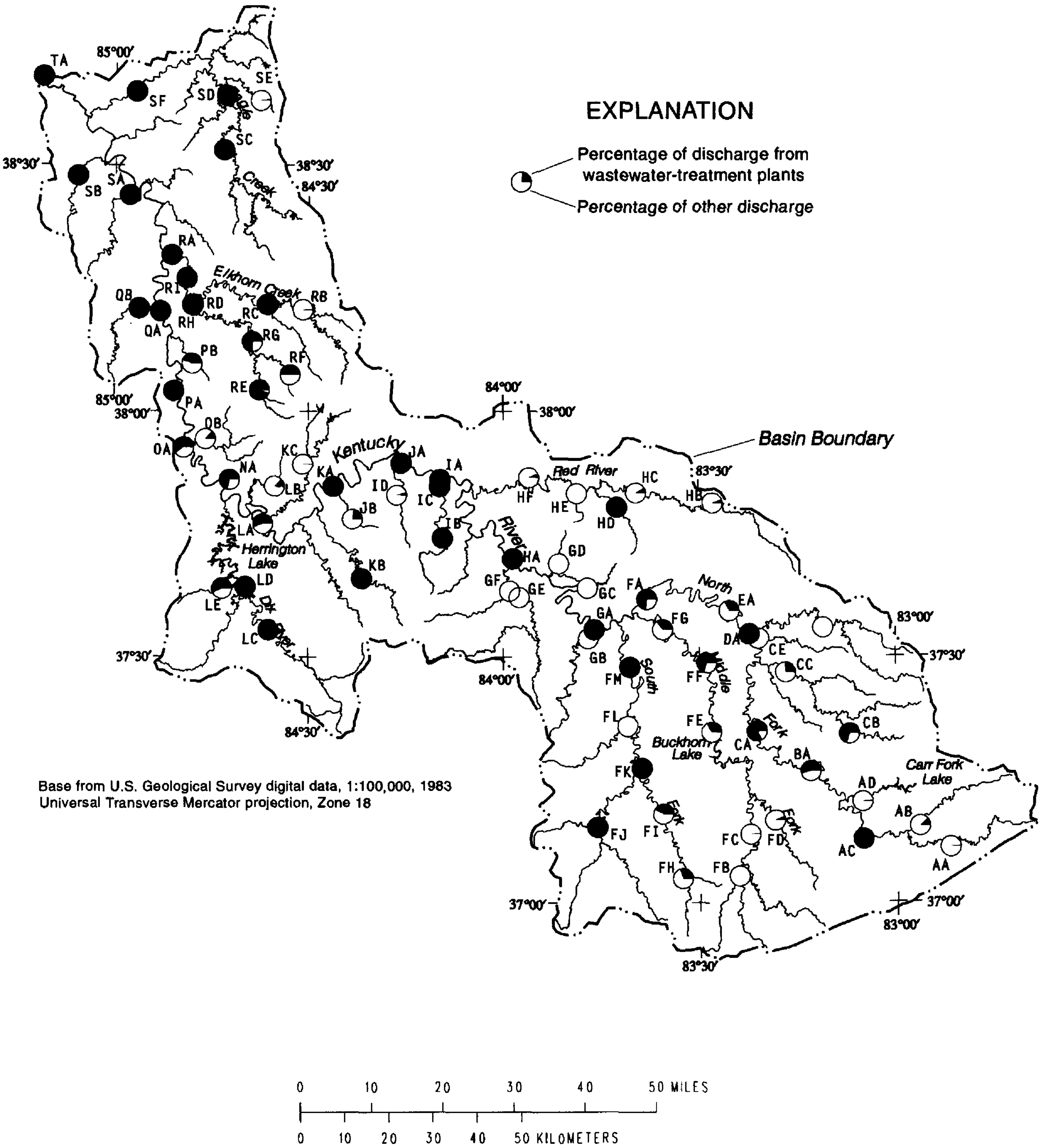

Figure 21. Percentage of total nitrogen load attributable to wastewater-treatment-plant discharge in the Kentucky River Basin, August 1987.

instantaneous nitrogen load from WWTP effluent was conservatively estimated and was assumed to be equal to the instantaneous ammonia loads reported in table 6.

In the upper part of the basin, WWTP effluent rarely makes up more than 10 percent of total stream discharge (fig. 20). One exception is at Goose Creek at Manchester (synoptic site FJ), where WWTP effluent accounted for about 39 percent of streamflow in 1987. Stream concentrations of total nitrogen (0.4 and 0.7 mg/L) and total phosphorus (0.03 and 0.06 mg/L) were relatively low at site FJ in 1987 and 1988 (table 6). At this site, however, most of the estimated instantaneous stream nitrogen load was attributable to WWTP effluent. Similarly, in the South Fork Kentucky River at Oneida (FK) and at Booneville (FM) and in Leatherwood Creek at Cornettsville (AC) and the North Fork Kentucky River at Jackson (DA), most of the instantaneous stream load of nitrogen was attributable to WWTP effluent during low flow, although less than 1 percent of the total stream discharge was attributable to WWTP effluent.

In the Red River Subbasin, effluent from WWTP's contributed less than 5 percent of total stream discharge (fig. 20). Likewise, the contribution to the instantaneous stream nitrogen load from WWTP effluent was less than 10 percent, with one exception: on the Middle Fork Red River near Slade (HD), most of the instantaneous stream nitrogen load was attributable to WWTP effluent (fig. 21). At this site (HD), the concentration of total phosphorus was 0.03 mg/L and the concentrations of total nitrogen were 0.03 and 1.0 mg/L (table 6).

In the main stem of the Kentucky River downstream from the confluence with the Red River, there are several sites where most of the instantaneous stream nitrogen load is attributable to WWTP effluent, including the site near Doylesville (IA), the site at Lock 10 (JA), and the site near Valley View (KA). Concentrations of stream total nitrogen at these sites ranged from 0.60 to 1.1 mg/L, and total phosphorus ranged from 0.03 to 0.05 mg/L (table 6). In the Kentucky River at Camp Nelson (LA), the proportion of stream nitrogen coming from WWTP effluent was about 56 percent. This proportion increased gradually downstream to 71 percent at the site near Highbridge (NA), and exceeded 90 percent from the site near Tyrone (PA) to the confluence of the Kentucky River with the Ohio River at Carrollton (TA), with the exception of Glenns Creek near Versailles (PB). At all of these main-stem sites, the proportion of total stream discharge attributable to WWTP effluent was always less than 20 percent (fig. 20). Total nitrogen concentrations at these sites ranged from 0.50 to 0.90 mg/L, and concentrations of total phosphorus ranged from 0.04 to 0.24 mg/L (table 6).

In August 1987, WWTP effluent accounted for nearly 100 percent of the stream discharge under low-flow conditions at several sites in the Dix River Basin. On the main stem of the Dix River (sites LC and LD), almost all of the instantaneous stream nitrogen load was from WWTP effluent. In Clarks Run near Danville (LE), however, only 58 percent of the instantaneous stream nitrogen load was from this source.

In the Elkhorn Creek Subbasin, with the exception of sites RB, RF, and RG, almost all of the instantaneous load of nitrogen was attributable to WWTP effluent even though, on average, only 50 percent of total stream discharge was from WWTP's. Concentrations of total nitrogen were very high at some of these sites, including Town Branch at Lexington (RF; 25 mg/L) and South Elkhorn Creek near Midway (RG; 13 mg/L). Sites in this subbasin had the highest instantaneous effluent nitrogen loads in the basin (table 6). Most total nitrogen concentrations in this subbasin exceeded 1.0 mg/L, and concentrations of total phosphorus were as high as 4.0 mg/L.

Relation of nutrients to land use and soils

Nonpoint sources of nutrients in the Kentucky River Basin include urban and agricultural inputs. Urban centers are most numerous in the Bluegrass Regions and include Lexington, Frankfort, Richmond, Danville, Georgetown, and Carrollton (fig. 1). Farm acreage exceeds 150,000 acres in Clark, Fayette, Henry, Owen, and Scott Counties and is as great as 250,000 acres in Madison County (fig. 22) (Kentucky Agricultural Statistics Service, 1991).

Beef cattle are the dominant livestock. However, many horses are raised in the Inner Bluegrass counties of Fayette, Jessamine, Scott, and Woodford. In Kentucky, beef cattle and horses are not typically kept in confined areas. Thus, the manure is widely distributed, and inputs to surface waters are not pulsed or concentrated (University of Kentucky, 1993a). In 1988, beef cattle numbered 50,000 to 60,000 in Madison and Lincoln Counties and 30,000 to 50,000 in Clark, Garrard, Scott, and Woodford Counties (fig. 23) (Kentucky Agricultural Statistics Service, 1991).

Dairy cattle, hogs, and poultry in Kentucky are commonly raised in confined-animal enterprises, but most of this type of animal production is outside the Kentucky River Basin. In 1988, numbers of dairy cattle were highest in Madison and Garrard Counties (>5,000 head), typically much less than 1,000 head in counties of the Bluegrass and Knobs Regions, and less than 100 head per county in the remainder of the basin. Hog production ranged from 2,000 to 5,000 head per county in most of the Bluegrass Region. Poultry production was highest in Madison and Breathitt Counties (10,000 to 20,000 birds) and ranged from 1,000 to 10,000 birds in many of the other counties in the basin (Kentucky Agricultural Statistics Service, 1991).

One major source of nitrogen and phosphorus is inorganic fertilizers applied to croplands. Statewide, more than 180,000 tons of fertilizer are applied annually, principally to corn, soybeans, and tobacco, and to a lesser extent to grass hay and pastures (University of Kentucky, 1993a). In the Kentucky River Basin in 1988, corn production was highest in Clark, Fayette, Madison, and Scott Counties, whereas soybean and tobacco production was widespread in all the counties of the Inner and Outer Bluegrass Region. Tobacco production (fig. 24) was highest in Fayette and Madison Counties (>3,500 acres). In the Kentucky River Basin, counties ranking highest in tons of fertilizer sold (501 to 1,500 tons) were Fayette, Madison, Lincoln, and Henry. Counties that ranked highest in nitrogen fertilizer sales were these four, as well as Scott and Woodford (fig. 25). Counties that ranked relatively high (101 to 500 tons) in phosphorus fertilizer sales were Garrard, Scott, and Owen, in addition to these four (fig. 26). An estimated

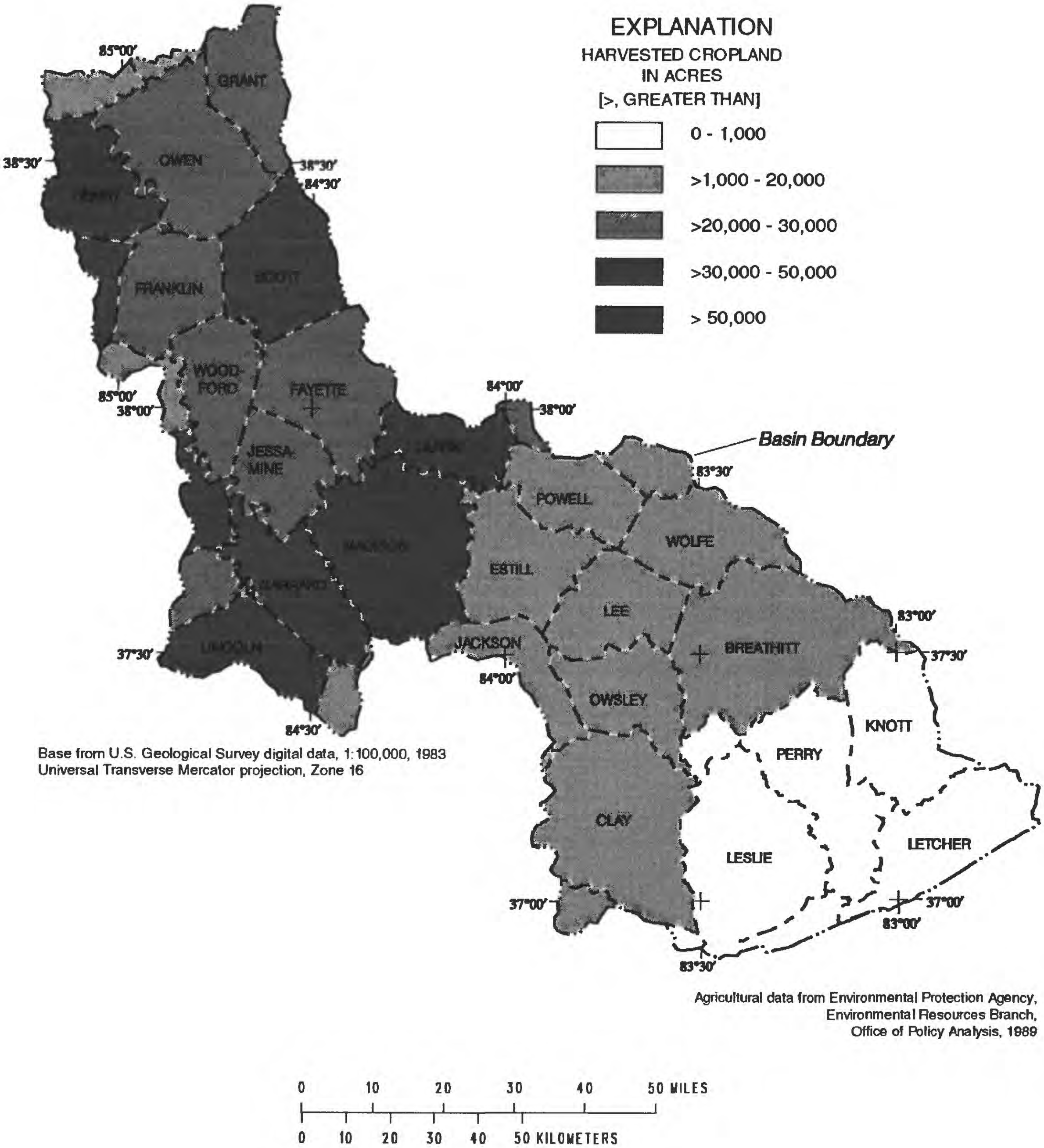

Figure 22. Harvested cropland by county in the Kentucky River Basin, 1988.

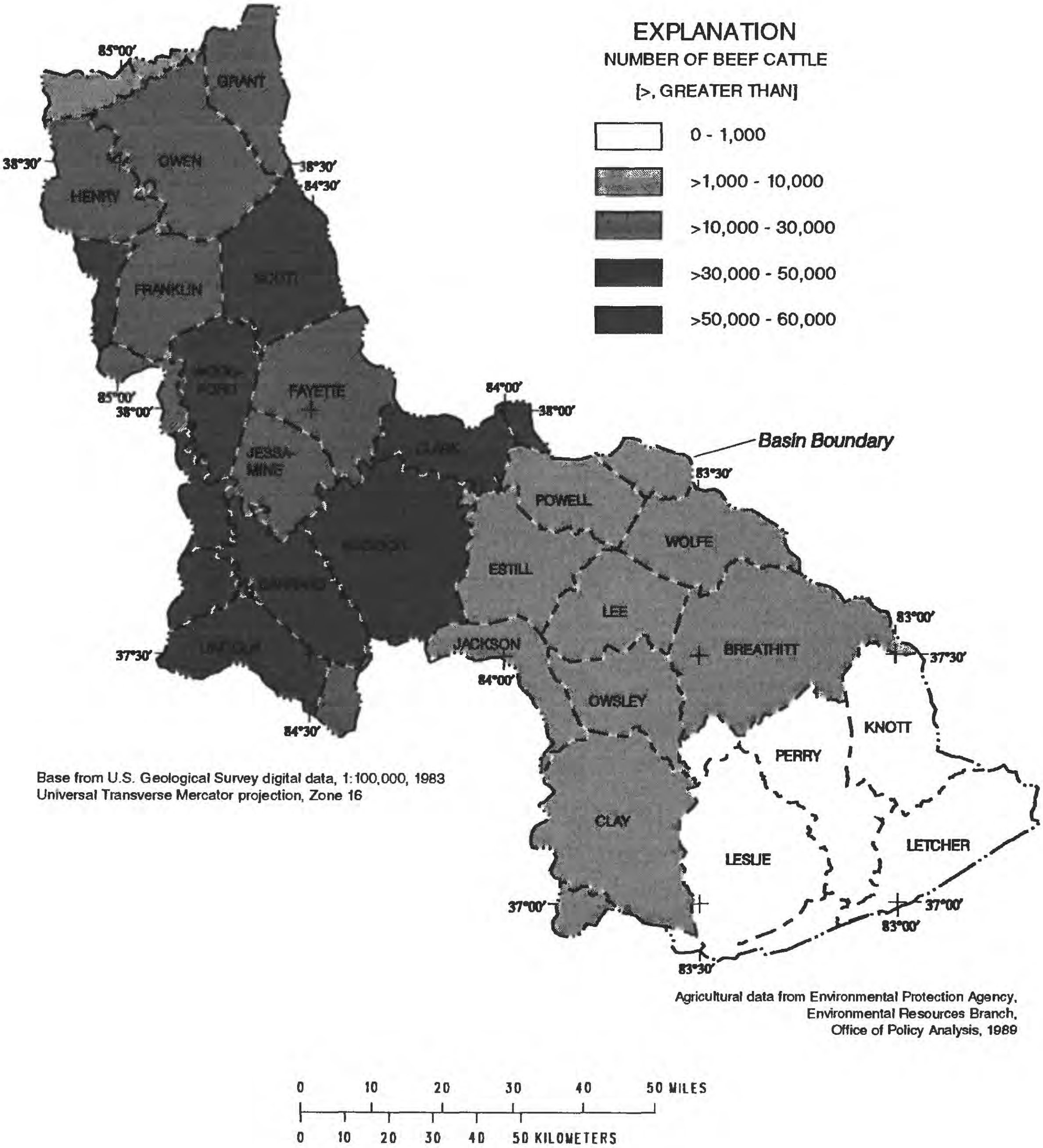

Figure 23. Numbers of beef cattle, by county, in the Kentucky River Basin, 1988.

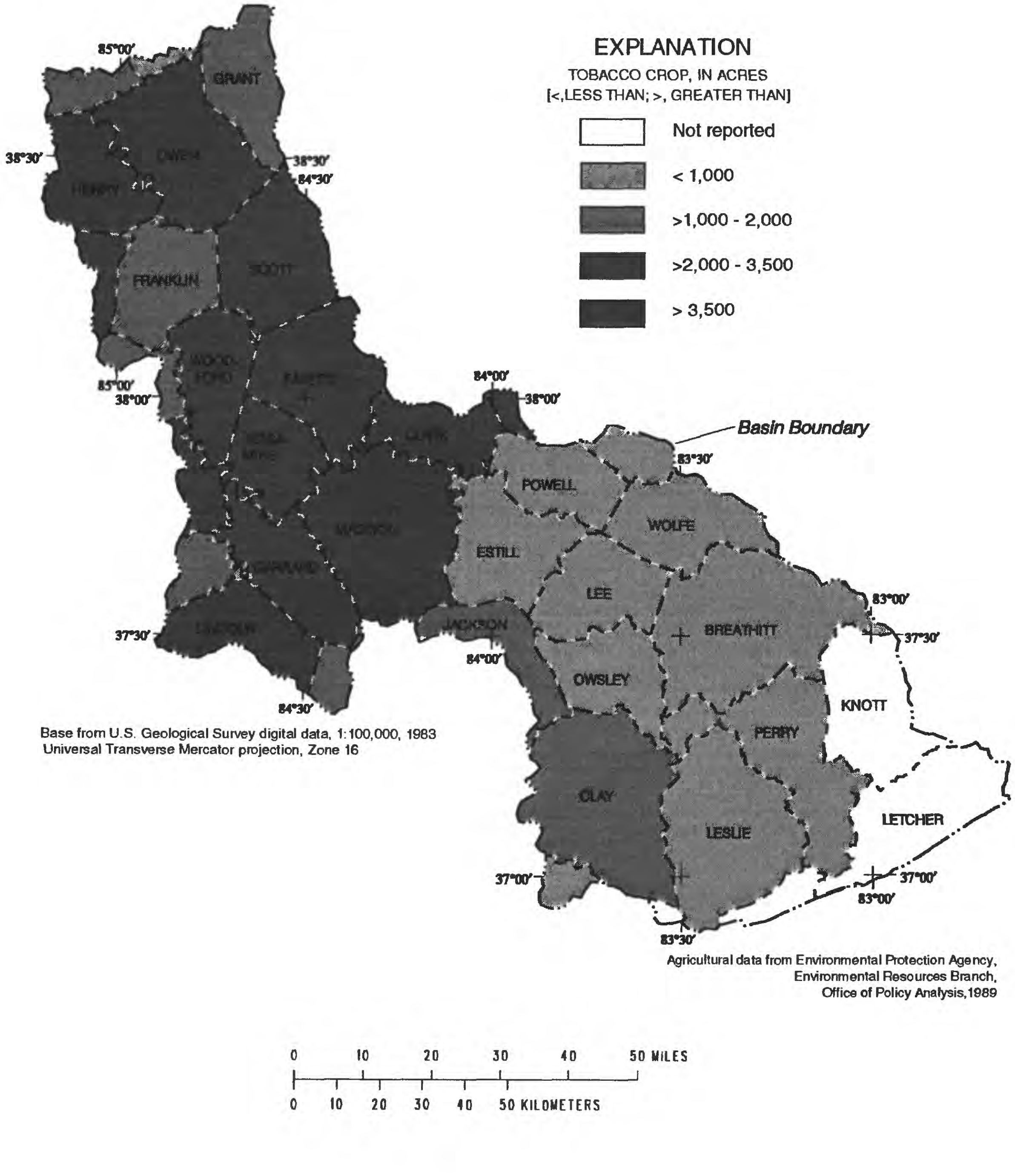

Figure 24. Tobacco production, by county, in the Kentucky River Basin, 1988.

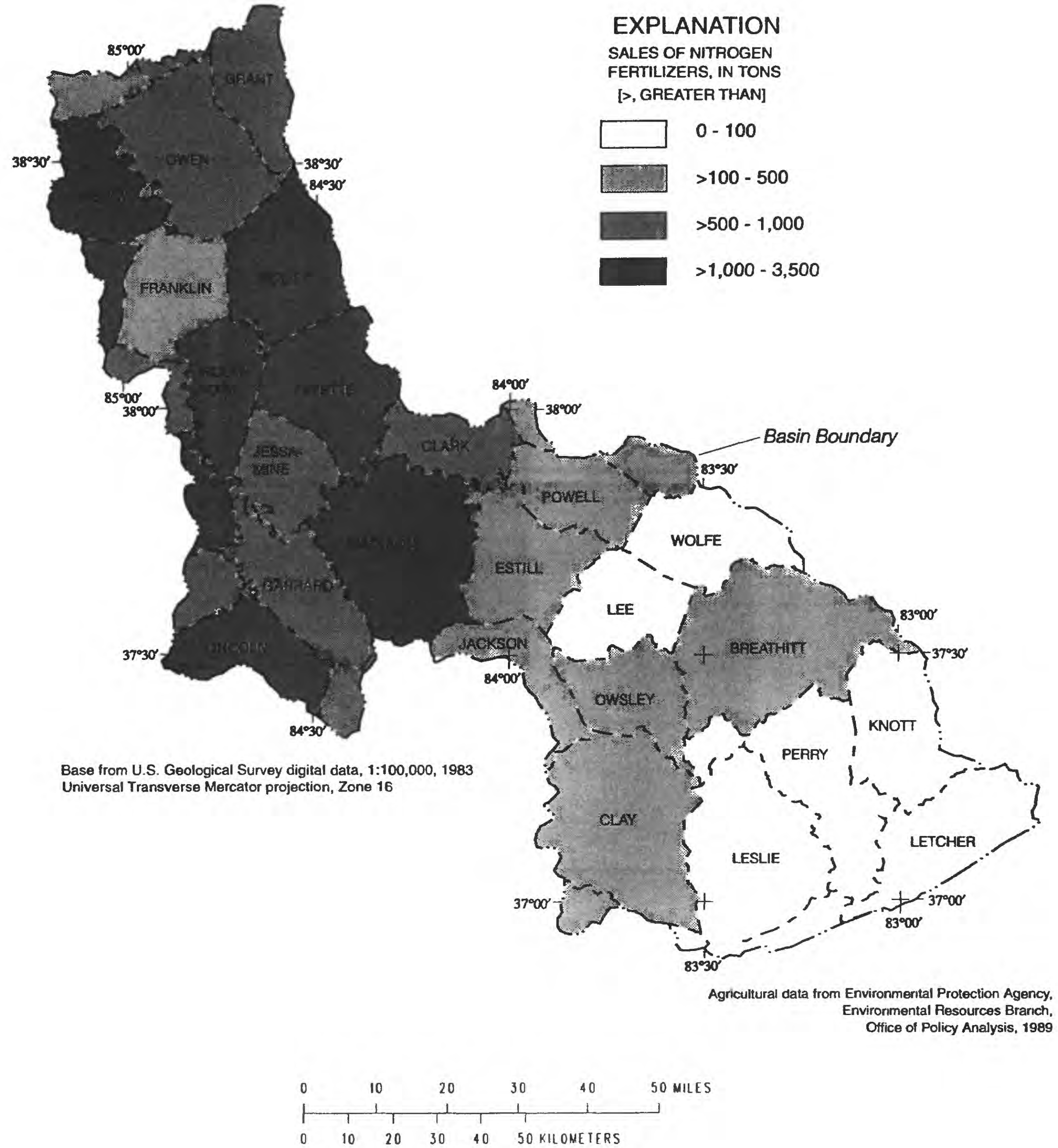

Figure 25. Sales of nitrogen fertilizers, by county, in the Kentucky River Basin, 1988.

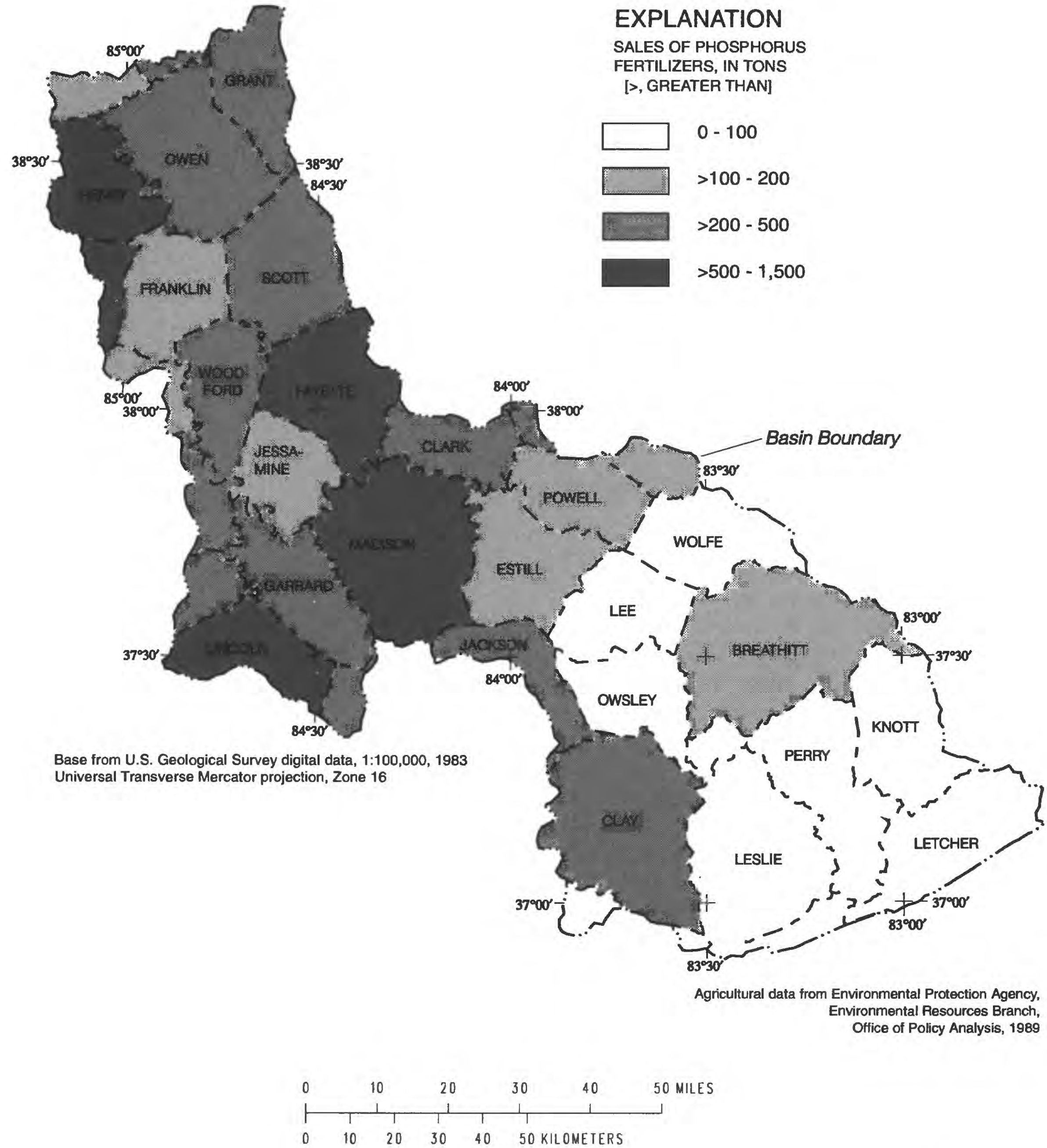

Figure 26. Sales of phosphorus fertilizers, by county, in the Kentucky River Basin, 1988.

14,058 tons of total nitrogen and 6,330 tons of total phosphorus were sold as fertilizer in the Kentucky River Basin annually from July 1986 through June 1987 (table 7).

The data base also includes information on seasonal sales patterns of fertilizer. In the Kentucky River Basin, most fertilizer is sold (and is presumed to be applied) in the spring (table 7). The implications for surface-water quality are that large concentrations of nutrients could be flushed from cropland and transported in surface waters in response to late spring and early summer rainfall (Thurman and others, 1992).

No significant correlations between land use and total phosphorus, total nitrogen, nitrate nitrogen, nitrite nitrogen, or ammonia were found when all data from the fixed stations were combined. Concentrations of dissolved phosphorus and orthophosphorus were significantly and positively correlated with urban land use and agricultural land use, and were significantly but negatively correlated with forest and mining land use. Although patterns were similar at the synoptic sites, correlations were not significant between these nutrient and land-use variables. A finer resolution of land use type including related factors such as soil type, crop type, and land-management practices would facilitate more conclusive analyses of the relations between land-use type and fertilizer-derived nutrients in streams (Beaulac and Reckhow, 1982).

The phosphorus content of soils in the Inner and Outer Bluegrass Regions affects the concentrations of nutrients in surface water (fig. 27). Soils with highest concentrations of phosphorus (>150 ppm) are in Fayette, Franklin, Jessamine, Scott, and Woodford Counties. These counties contain many of the synoptic sites within the Kentucky River Basin where phosphorus concentrations were elevated.

Relation of nutrients to ground-water sources of constituents

Collection of data on ground-water quality was not a part of the Kentucky River NAWQA pilot study design, but historical ground-water-quality data for some nutrient forms are available in files of the USGS office in Louisville (Faust and others, 1980). Data were collected between 1950 and 1987 in a few of the counties in the Kentucky River Basin (table 8). Average concentrations of dissolved nitrite ranged from 0.02 mg/L as nitrogen in Powell County to 0.32 mg/L as nitrogen in Jessamine County. Average concentrations of dissolved nitrate ranged from 0.28 mg/L in Leslie County to 2.50 mg/L as nitrogen in Jessamine County. Average concentrations of total nitrate ranged from 0.02 mg/L as nitrogen in three counties to 2.48 mg/L as nitrogen in Madison County.

Studies are ongoing in Kentucky to assess the quality of ground water and the extent of nitrate contamination. A reconnaissance of ground-water resources in the Kentucky River Basin is presented by Currens and others (1991). Preliminary data collected by the Kentucky Department of Agriculture during 1990-91 (University of Kentucky, 1993a) in Woodford and Jessamine Counties indicate average concentrations of 2.41 mg/L nitrate nitrogen in ground water. Less than 5 percent of the water withdrawn in the basin is from

Table 7. Annual and seasonal fertilizer sales, by county, in the Kentucky River Basin, July 1986-June 1987

[Amounts are in tons. Data from U.S. Environmental Protection Agency, Office of Policy Analysis, Environmental Resources Branch, 1989]

	Nitrogen fertilizers, total sales			Phosphorus fertilizers, total sales		
County	Annual	Spring	Fall	Annual	Spring	Fall
Anderson	154.29	150.81	3.48	44.62	43.93	0.68
Bell	2.40	2.18	.21	3.23	2.90	.32
Boone	16.28	11.46	4.82	8.92	7.08	1.84
Boyle	285.01	220.40	64.60	109.56	90.96	18.59
Breathitt	172.55	168.92	3.62	128.20	122.72	5.48
Carroll	134.97	121.62	13.34	64.97	63.95	1.02
Clark	493.74	435.79	57.94	205.02	189.18	15.84
Clay	268.00	235.14	32.85	233.78	178.77	55.00
Estill	165.51	156.21	9.30	126.09	120.10	5.99
Fayette	1,629.28	1,234.25	395.03	550.22	475.50	74.71
Franklin	386.76	365.14	21.61	119.62	111.40	8.22
Gallatin	142.94	127.30	15.64	73.67	67.22	6.44
Garrard	875.21	719.24	155.96	343.63	315.59	28.04
Grant	469.08	448.94	20.14	218.77	210.37	8.40
Harlan	3.56	3.22	.33	3.74	3.69	.04
Henry	1,064.08	964.62	99.45	413.56	388.84	24.71
Jackson	178.03	171.46	6.57	119.98	113.36	6.62
Jessamine	565.12	489.81	75.30	159.13	149.19	9.94
Knott	12.43	12.01	.41	12.11	11.69	.41
Knox	16.83	15.52	1.30	12.82	10.73	2.09
Lee	55.74	50.52	5.21	46.05	39.80	6.24
Leslie	28.30	25.40	2.90	37.10	30.21	6.88
Letcher	39.32	36.36	2.95	50.56	45.90	4.65
Lincoln	1,073.37	891.87	181.50	620.15	560.95	59.19
Madison	1,593.71	1,385.35	208.36	1,059.62	1,010.05	49.56
Menifee	48.48	47.43	1.04	42.48	40.38	2.10
Mercer	267.70	219.15	48.54	68.27	52.75	15.52
Montgomery	42.41	40.00	2.41	31.07	29.41	1.66
Owen	733.95	645.37	88.58	312.65	280.07	32.58
Owsley	141.46	134.02	7.43	87.69	83.42	4.26
Perry	29.21	24.74	4.47	22.06	21.18	.87
Powell	108.31	101.60	6.71	114.20	105.90	8.29
Rockcastle	117.37	109.22	8.15	108.97	100.87	8.10
Scott	1,260.82	856.73	404.08	341.96	265.49	76.46
Shelby	396.60	271.58	125.01	150.09	124.41	25.67
Wolfe	77.63	68.51	9.12	60.01	55.16	4.85
Woodford	1,007.82	794.78	213.03	225.74	122.48	103.25
TOTAL[1]	14,058	11,757	2,301	6,330	5,646	685

[1] Columns may not add to totals because of independent rounding.

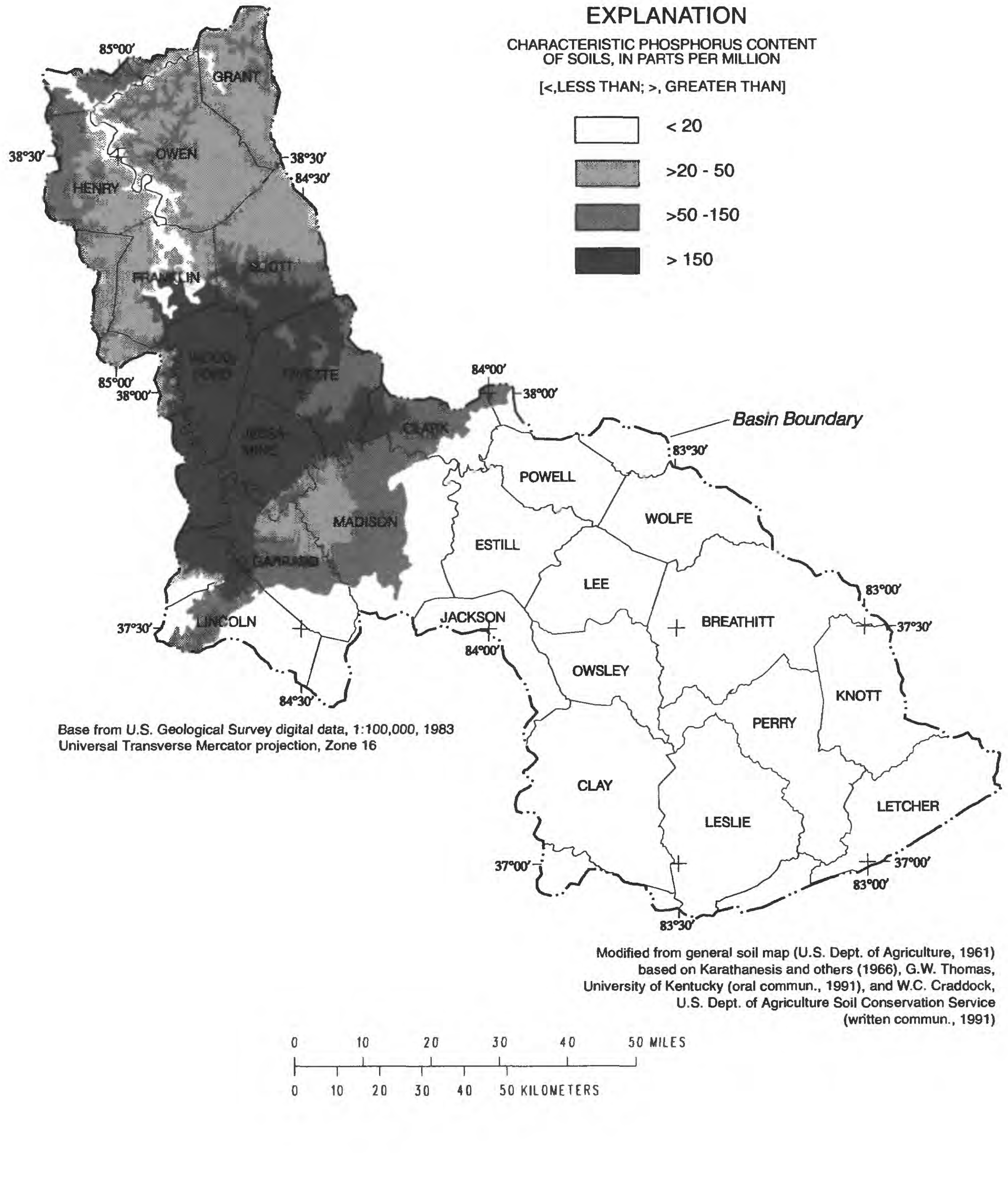

Figure 27. Characteristic phosphorus content of soils in the Kentucky River Basin.

Table 8. Average concentrations of nitrite and nitrate in ground water, by county, in the Kentucky River Basin, 1950-87

[N, number of observations per site; mg/L, milligrams per liter; --, no data]

County	N	Nitrite, dissolved, as nitrogen in mg/L	Nitrate total, as nitrogen, in mg/L	Nitrate, dissolved, as nitrogen, in mg/L
Breathitt	6	--	0.14	0.46
Estill	6	--	--	1.70
Jessamine	1	0.32	.02	--
	24	--	--	2.50
Lee	5	--	--	.47
Leslie	1	--	.02	--
	7	--	--	.28
Madison	7	--	2.48	--
Owsley	1	--	.02	--
	6	--	--	.64
Powell	1	.02	--	--
	3	--	.14	--
	8	--	--	.35
	1	.02	--	--

ground-water sources, and ground water is primarily used for rural-domestic and stock purposes. However, in karst areas of the Bluegrass Region, where ground-water and surface-water exchange is high, the concentration of nitrogen in ground water may be important to surface-water quality. Based on the historical data, the counties with the highest concentrations of nitrogen in ground water are Madison and Jessamine (both in the Bluegrass Region). Other studies of karst aquifers in the Bluegrass Region support this conclusion (Kiesler and others, 1986).

Relation of nutrients to phytoplankton populations in the main stem

Phytoplankton chlorophyll a concentrations during low flow in the Kentucky River main stem correlated positively with concentrations of total phosphorus and total ammonia plus organic nitrogen. Concentrations of nitrite plus nitrate nitrogen in the Kentucky River correlated positively with phosphorus concentrations but did not correlate with chlorophyll a.

Concentrations of nutrients and chlorophyll a were lowest in the main stem around Lock 14 at river mile 249 (figs. 28 and 29) and highest downstream from Lock and Dam 6 (river mile 96). Sources of nutrients upstream from Lock 14 (fig. 30) include WWTP discharges from the towns of Beattyville and Booneville. Although WWTP discharges from the towns of Jackson, Hazard, and Whitesburg contribute nutrients to the North Fork Kentucky River upstream from river mile 303, phytoplankton chlorophyll a concentrations were relatively small, probably because loads of suspended sediment from sources associated with coal-mining activities increase water turbidity (fig. 31), thereby reducing light availability for algal photosynthesis and growth. Increases in nutrient and chlorophyll a concentrations in the Kentucky River between river miles 180 and 120 (figs. 28 and 29) probably were associated with WWTP discharges from the cities of Richmond, Berea, Lexington, Nicholasville, and Wilmore to tributary streams of the Kentucky River in the Bluegrass Region. The positive correlation of chlorophyll a with total ammonia plus organic nitrogen in the Kentucky River probably indicates that a considerable proportion of total (suspended) nitrogen was transported as algal biomass during periods of low flow.

Although nutrient concentrations were largest in tributary streams that receive WWTP effluent, phytoplankton chlorophyll a concentrations and algal cell density were generally highest in the Kentucky River main stem. This might be expected because as is true in many stream systems (Hynes, 1970), nutrients were not limiting in streams of the Kentucky River Basin. Compared to tributary streams, the lower turbulence and lower stream velocity in the main stem allow longer retention times for algae and the possibility for reproduction. During stable, low-flow conditions, phytoplankton communities in the Kentucky River main stem were dominated by species that are typical of reservoirs and lakes (euplankton), whereas phytoplankton assemblages in smaller, tributary streams in the Kentucky River Basin were frequently dominated by dislodged periphyton (tychoplankton) species (Stevenson and White, 1995). Phytoplankton communities in the Kentucky River upstream from river mile 185 (near Doylesville) were dominated by green algae and flagellates, and algal cell density was less than 1,600 cells per milliliter (cells/mL). In contrast, blue-green algae (cyanobacteria) were predominant

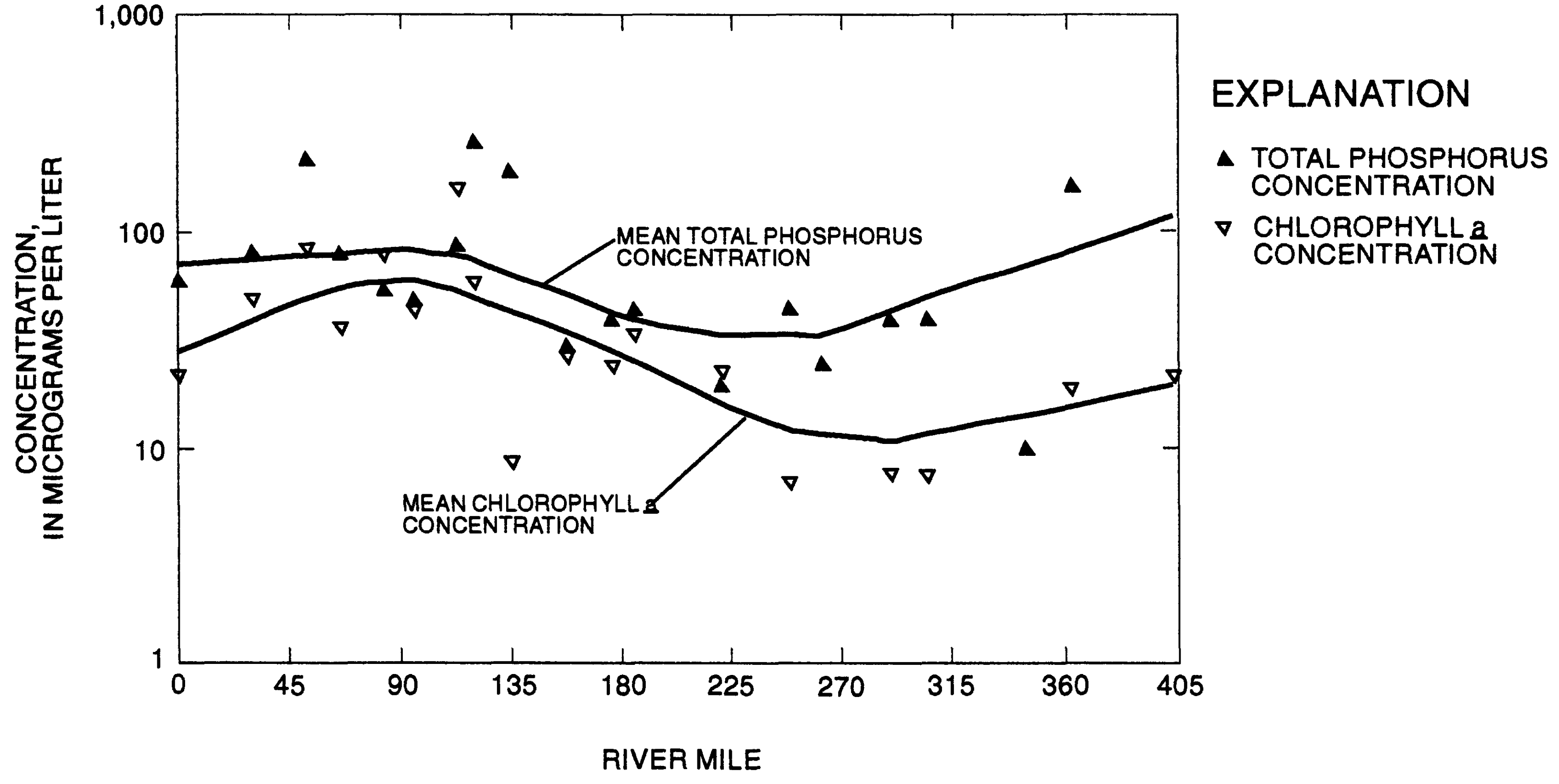

Figure 28. Smoothed mean chlorophyll a and total phosphorus concentrations in the Kentucky River. Data points are mean of values for August 1987 and August 1988.

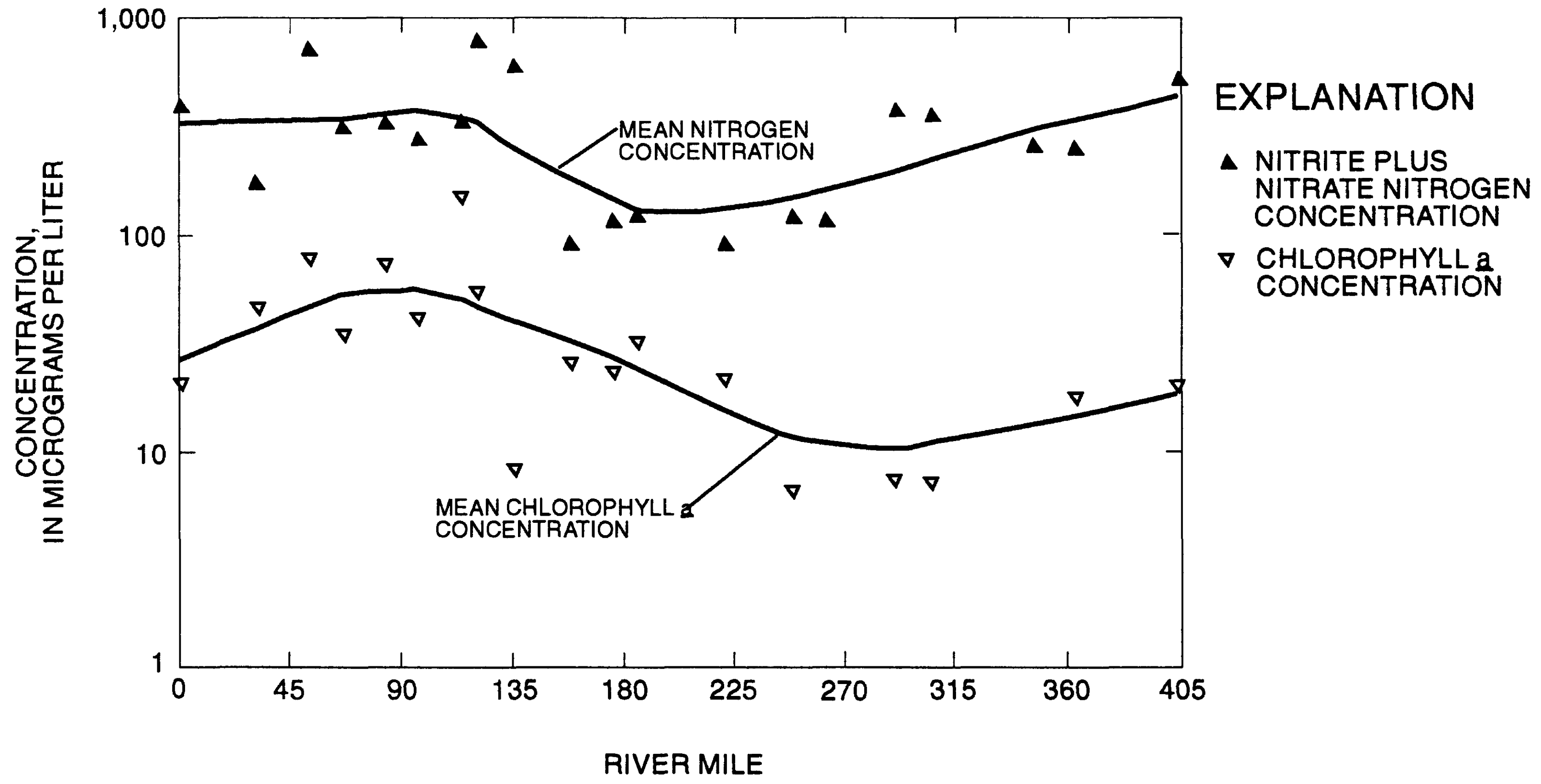

Figure 29. Smoothed mean chlorophyll a and nitrite plus nitrate nitrogen concentrations in the Kentucky River. Data points are means of values for August 1987 and August 1988.

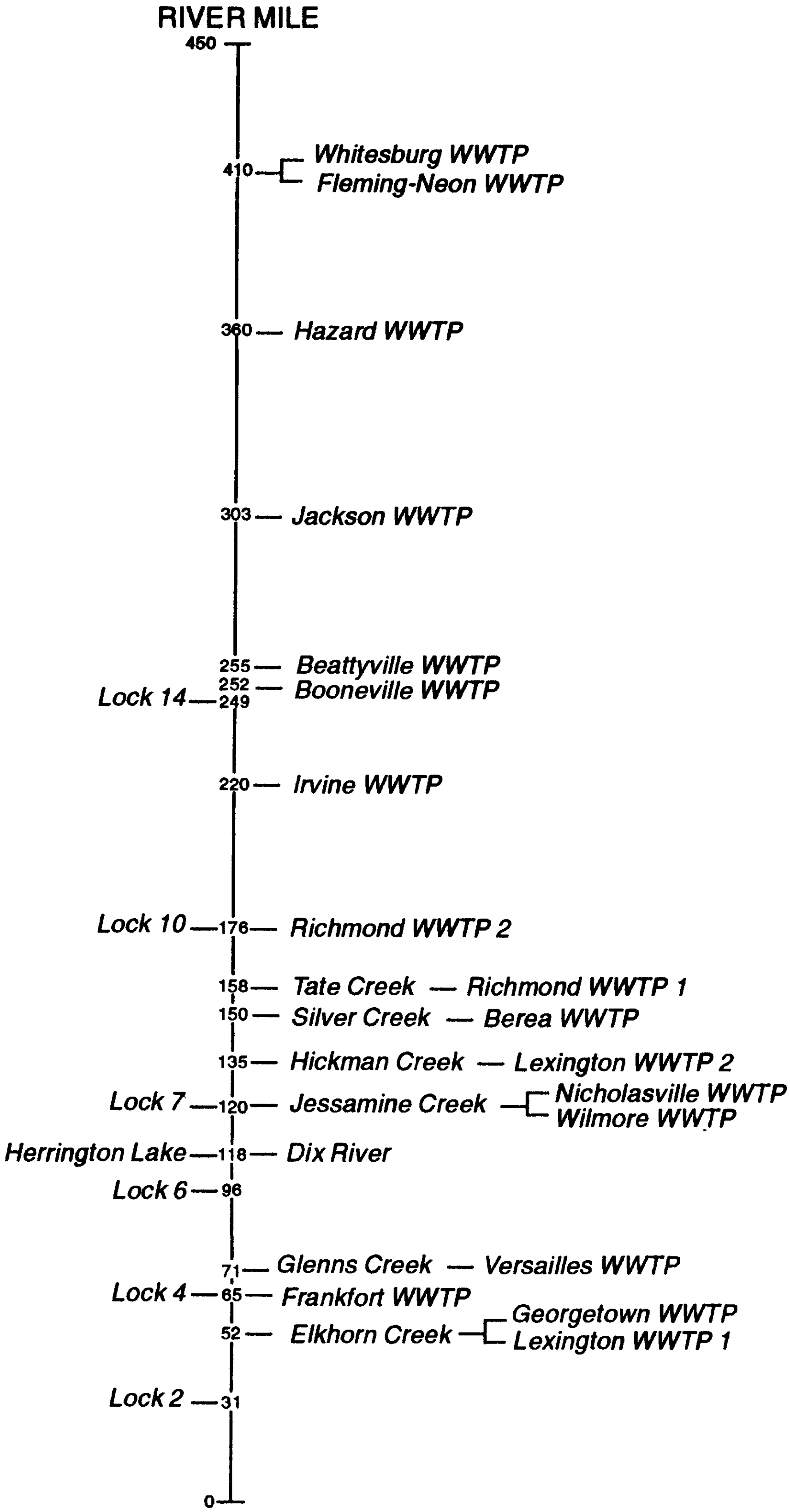

Figure 30. Location of major tributaries, navigation locks, and municipal wastewater-treatment plants (WWTP) with respect to the main stem of the Kentucky River.

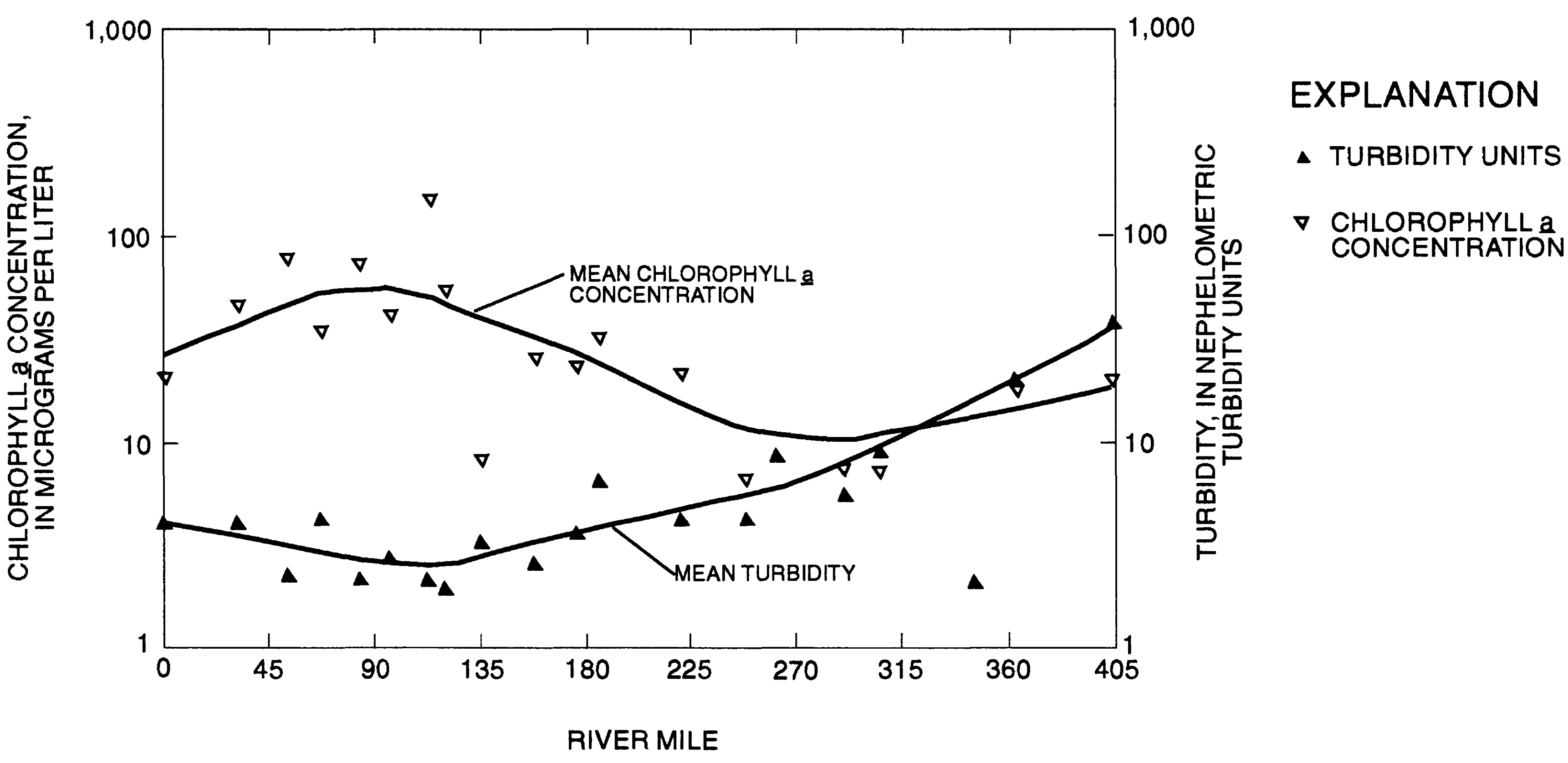

Figure 31. Smoothed mean chlorophyll a concentration and mean turbidity in the Kentucky River. Data points are means of values for August 1987 and August 1988.

from river mile 158 (near Tate Creek) downstream to near the mouth of the Kentucky River. Large blue-green algal populations have been associated with "musty" tastes and odors in public water supplies (Mallevialle and Suffet, 1987).

The increase of phytoplankton cell density (fig. 32), from 3,600 cells/mL at river mile 158 to 34,000 cells/mL at river mile 113, may result in increased water-treatment costs to water utilities at several locations in the pools above Locks 8 and 9 of the Kentucky River. Downstream from river mile 113, algal-cell density remained relatively constant (fig. 32), ranging from about 12,000 cells/mL at river mile 83 to 11,000 cells/mL at river mile 31 and decreasing to 5,600 cells/mL at river mile 1. Algal-cell density in the Kentucky River correlated significantly with chlorophyll a concentrations ($r = 0.69$; $p = 0.009$; $n = 13$). Chlorophyll-biomass-nutrient relations in the Kentucky River are similar to those reported for lakes and reservoirs elsewhere (Canfield and others, 1985).

Nutrients indirectly affect concentrations of dissolved oxygen (DO) and pH in the Kentucky River by stimulating the growth and photosynthetic processes of phytoplankton. Rates of these processes may vary seasonally and by time of day. However, this study did not address seasonal or diel variability in chlorophyll a. Consequently, the relation between dissolved oxygen, chlorophyll a, and time of day could not be established. Dissolved oxygen does exhibit diel variability (G.L. Jarrett, U.S. Geological Survey, written commun., 1994) but this cannot be statistically related to chlorophyll a and primary production in this study. Although the concentration and saturation of DO did not correlate with chlorophyll a concentrations, changes in average DO saturation and chlorophyll a concentration during low flow in the Kentucky River main stem followed a similar pattern (fig. 33). Dissolved-oxygen saturation exceeded 100 percent from approximately river mile 120 (Lock 7 pool) downstream to river mile 52 (Lock 3 pool near Elkhorn Creek), which corresponded with the distribution of highest cell density of phytoplankton in the Kentucky River (fig. 32). Downstream from river mile 52 and upstream from about river mile 221, DO saturation decreased to about 50 percent (fig. 33), and early-morning DO concentrations were near 5 mg/L.

Variations in pH were associated with variations in phytoplankton cell density. Values of pH were highest (8.0-9.0) between river miles 113-120 (near Lock 7) and decreased as chlorophyll a concentrations decreased downstream to river mile 52. Some pH measurements met but did not exceed the water-quality criterion of 9.0 (U.S. Environmental Protection Agency, 1992). All pH measurements were made before noon and it is likely that this criterion was temporarily exceeded during the afternoon hours as a result of photosynthesis in waters with large phytoplankton populations.

The net rate of oxygen production (NROP) in the Kentucky River main stem generally increased with chlorophyll a and nutrient concentrations, from river mile 249 downstream to about river mile 66 (fig. 34). The lower than expected NROP between river mile 176 and river mile 135 may have been associated with the relatively high chemical oxygen demand (COD) that occurred in this 40-mi segment of the Kentucky River (fig. 35). The reason for the high COD may be

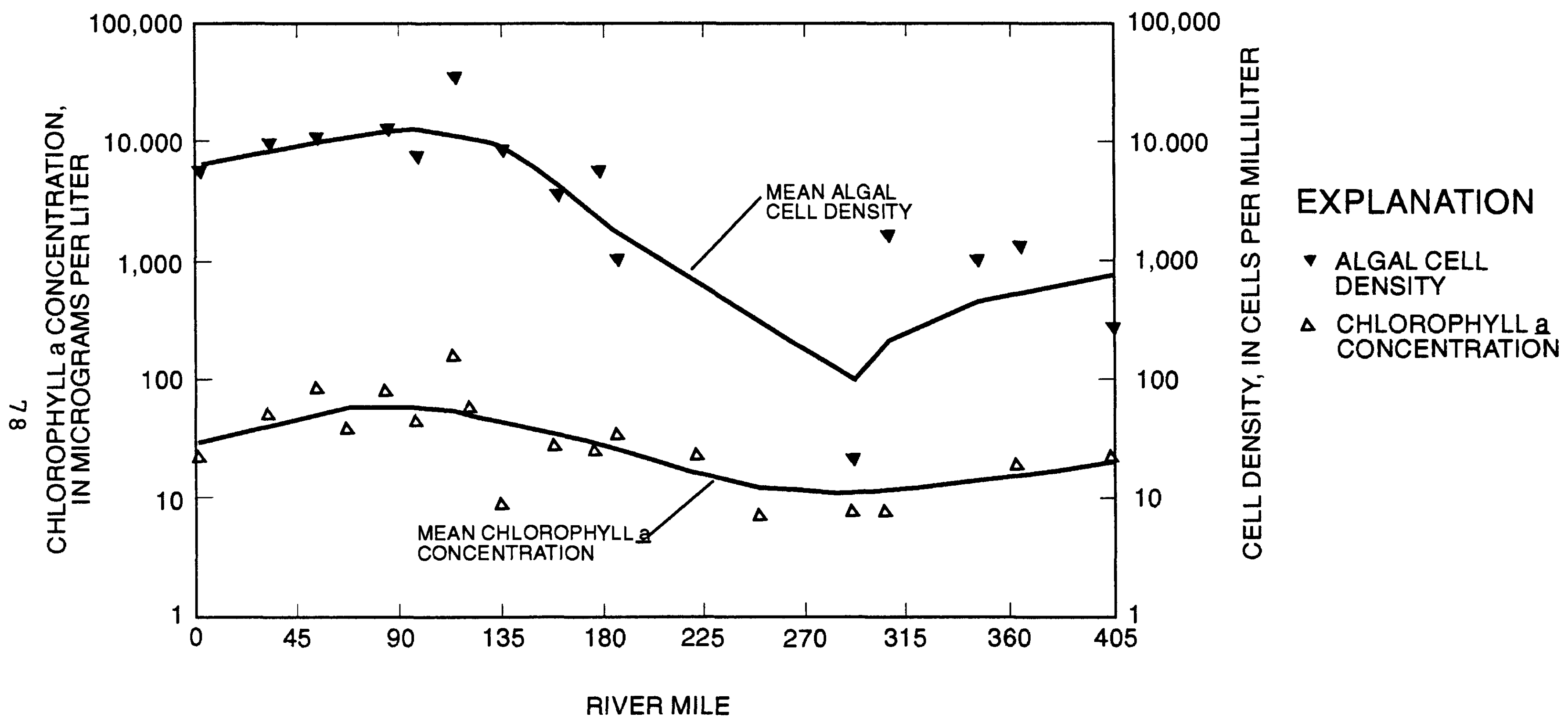

Figure 32. Smoothed mean algal cell density and mean chlorophyll *a* concentration in the Kentucky River. Data points are means of values for August 1987 and August 1988.

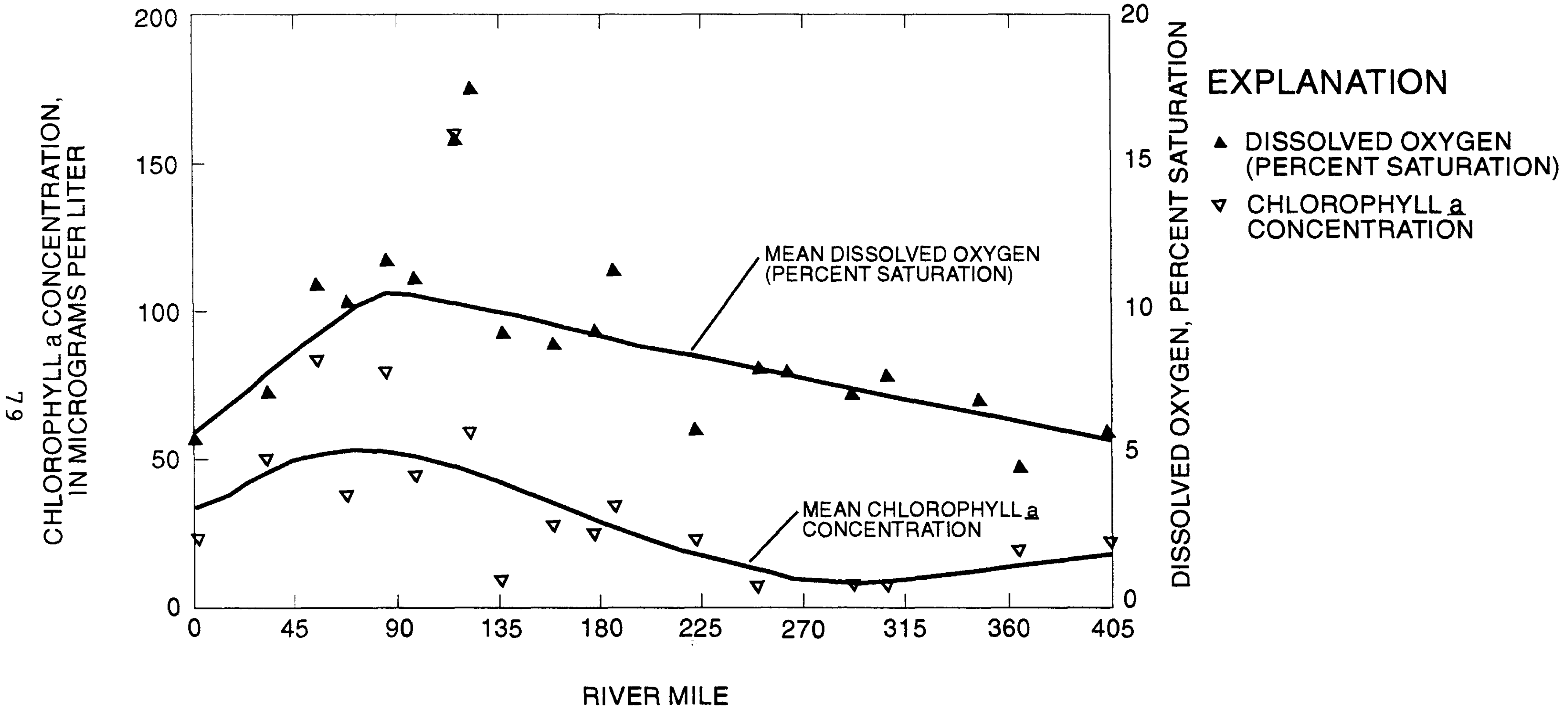

Figure 33. Smoothed chlorophyll a concentration and percent saturation of dissolved oxygen in the Kentucky River. Data points are means of values for August 1987 and August 1988.

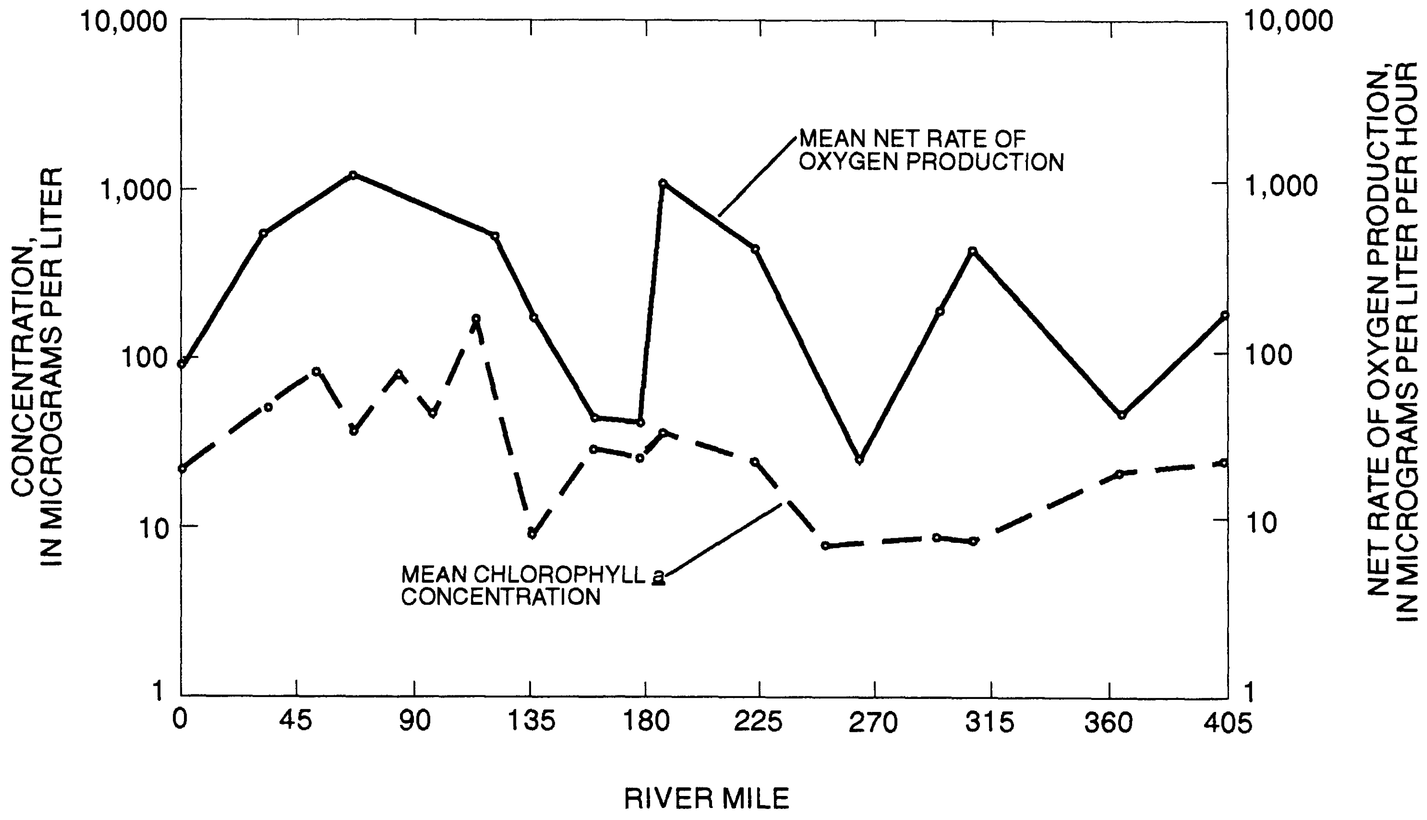

Figure 34. Mean chlorophyll a concentration and net rate of oxygen production in the Kentucky River. Data points are means of values for August 1987 and August 1988.

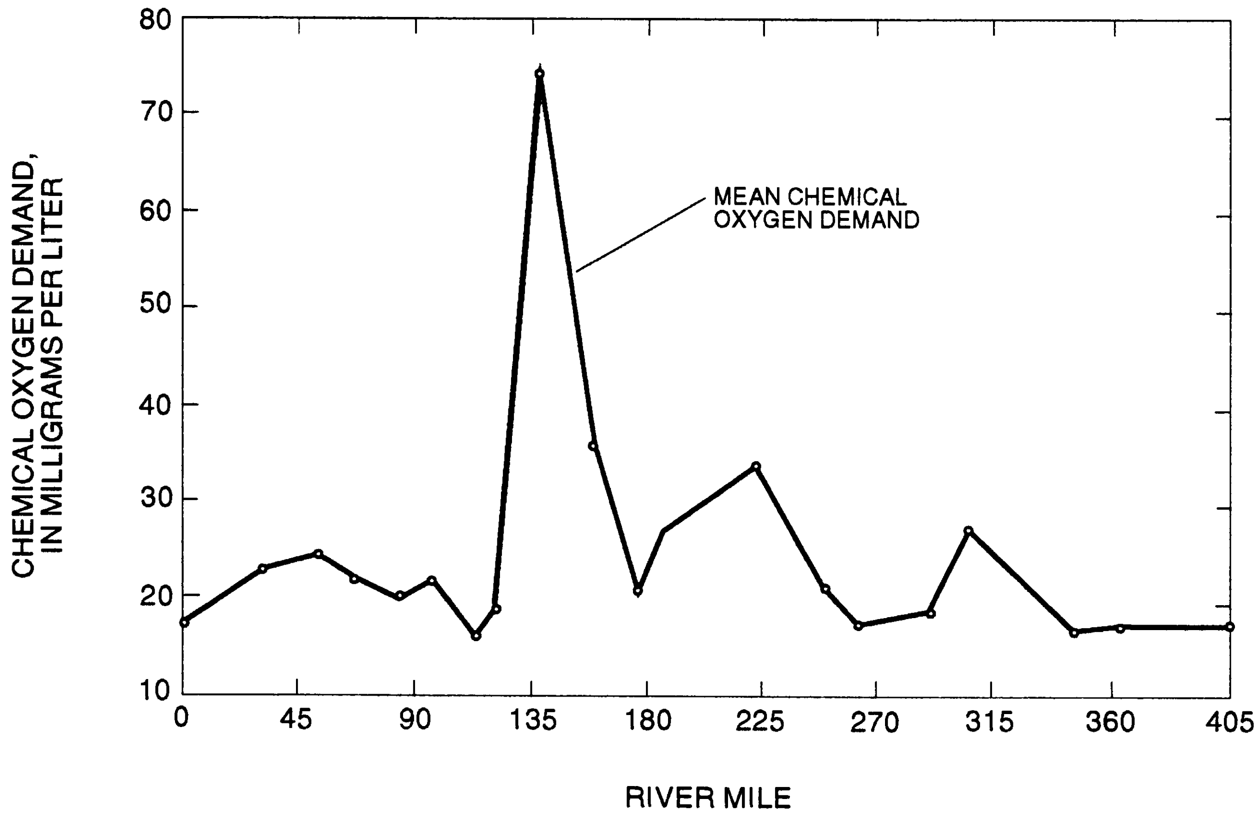

Figure 35. Mean chemical oxygen demand in the Kentucky River. Data points are means of values for August 1987 and August 1988.

the discharge of oxygen-demanding wastes from multiple WWTP's (fig. 30). The NROP is relatively high downstream from river mile 120, and it decreases with chlorophyll a concentrations downstream from river mile 66 (fig. 34).

Relation of nutrients to phytoplankton populations in tributary streams

Phytoplankton chlorophyll a concentrations in tributary streams of the Kentucky River correlated positively with concentrations of total phosphorus and total ammonia plus organic nitrogen. Although dissolved nitrite plus nitrate nitrogen concentrations did not significantly correlate with chlorophyll a concentrations, they did positively correlate with concentrations of total phosphorus, and ammonia nitrogen did positively correlate with total ammonia plus organic nitrogen concentrations. Maximum chlorophyll a concentrations during August 1987 were greater than 165 μg/L in three streams [Benson Creek (QB), Glenns Creek (PB), and Otter Creek (IO); fig. 8]. Mean concentrations of chlorophyll a were greater than 25 μg/L in North Elkhorn Creek near Georgetown (RB), South Elkhorn Creek (RG and RH), Hickman Creek (KC), Goose Creek (FJ), Silver Creek (KB), and Town Fork near Nicholasville (LB) (table 2, fig. 36), and in several other tributary streams. Algal-cell density in these streams generally exceeded 2,500 cells/mL, and phytoplankton samples were dominated by blue-green and green algae that are indicative of nutrient and organic enrichment. These streams receive nutrient loads from WWTP discharges.

In contrast, several other streams affected by nutrient enrichment from WWTP discharges contained relatively low concentrations of phytoplankton chlorophyll a, including Town Branch (RF), Tate Creek (JB), Clarks Creek (SE), and Clarks Run (LE). The relatively high NROP (greater than 800 μg/L per hour) in Tate Creek, Clarks Creek, and Clarks Run indicates high algal productivity but this was likely a product of the periphyton community rather than phytoplankton in those streams. High concentrations of metals in Town Branch near Lexington (S.D. Porter, U.S. Geological Survey, written commun., 1993) may have exerted a toxic effect on algal productivity at that site.

The relation between nutrients and phytoplankton differs among streams that drain agricultural, urban, surface-mined, and forested areas. Streams that are affected by agricultural sources of nutrients in the Kentucky River Basin contain relatively higher densities of phytoplankton than streams that drain forested subbasins; however, separation of agricultural sources of nutrients from those attributable to rural WWTP's can be difficult. Median chlorophyll a concentrations and algal cell density in agricultural streams were significantly higher than concentrations and densities in forested streams or streams affected by surface mining. However, concentrations of nutrients in many of these streams were relatively small. Perhaps dissolved concentrations of nitrogen and phosphorus are being rapidly removed from the water as a result of nutrient-uptake processes of algae and other microorganisms, and nutrients are being retained and transported as algal biomass during periods of low discharge.

Median concentrations of chlorophyll a and algal cell density in urban streams (9.5 μg/L and 2,600 cells/mL) were not statistically different from those found in agricultural streams (17.4 μg/L and 15,600 cells/mL).

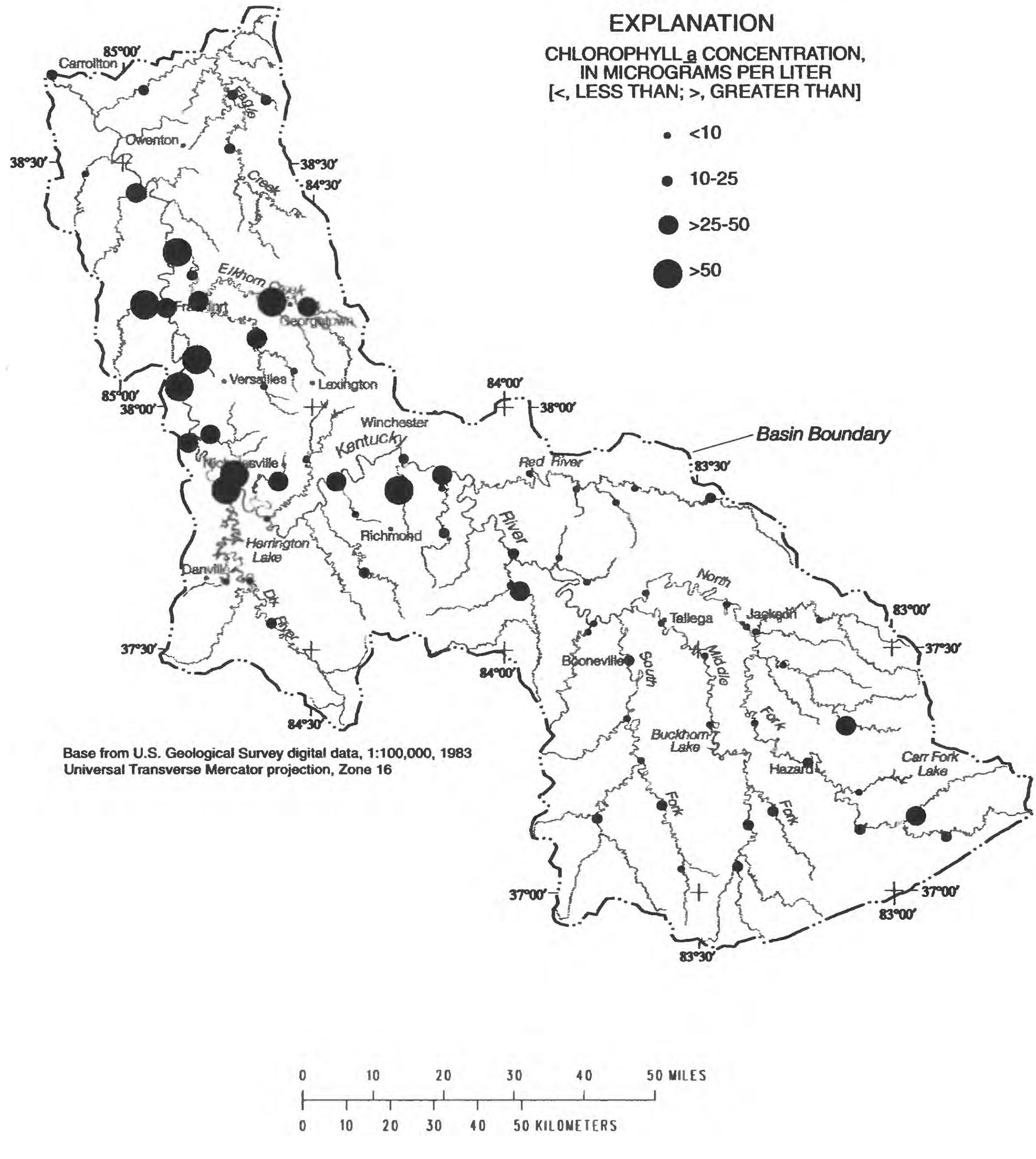

Figure 36. Chlorophyll a concentration in streams of the Kentucky River Basin, August 1987.

Moreover, algal community composition in agricultural streams was similar to that found in urban streams; that is, dominated by blue-green algae, small flagellates, and green algae. Phytoplankton species diversity, however, was lower in agricultural streams (Stevenson and White, 1995).

Median concentrations of chlorophyll a (4.1 μg/L) and algal cell density (930 cells/mL) were significantly lower in streams that drain forested or surface-mined areas in the Knobs and Eastern Coal Field Regions than in streams that drain agricultural and urban lands in the Inner and Outer Bluegrass Regions. Small chlorophyll a concentrations in streams affected by turbidity from surface-mining activities may have resulted from reduced light availability or toxicity associated with mine drainage. Although median concentrations of nutrients also are lower in these streams, higher concentrations of chlorophyll a in Rockhouse Creek and Quicksand Creek (fig. 36, table 2) are probably associated with nutrient loads from rural WWTP discharges. Algal communities in these streams were dominated by periphyton (benthic diatoms; Stevenson and White, 1995).

Seasonal nutrient-phytoplankton relations

Phytoplankton densities at fixed stations during 1987-90 correlated positively with water temperature, pH, alkalinity, and total ammonia plus organic nitrogen concentrations and correlated negatively with concentrations of dissolved oxygen, ammonia nitrogen, and suspended sediment (Stevenson and White, 1995). No correlation was found between total phytoplankton density and concentrations of nitrite plus nitrate nitrogen or total phosphorus. Average phytoplankton density at fixed stations was highest during summer and fall and lowest during winter. Algal communities were dominated by green algae during winter, diatoms during spring, and blue-green algae during summer. Phytoplankton diversity changed with water-quality and hydrologic conditions. Diversity generally decreased with nutrient enrichment, and increased with changes in water quality (water temperature, specific conductance, or concentrations of metals) that altered species composition or inhibited algal growth (Stevenson and White, 1995).

Temporal Trends in Nutrient Concentrations

Opportunities to discern temporal trends in phosphorus and nitrogen concentrations (table 9) in the Kentucky River main stem were limited by data requirements of Seasonal-Kendall trend tests. The period of record is not sufficient at most stations for such analyses. Results are available, however, for four stations where eight or more years of data were collected. A significant downward trend was detected in the North Fork Kentucky River at Jackson ($p < 0.075$) for total phosphorus. No significant trend was evident in the Kentucky River at Lock 2 on the basis of data for 1975-90. Data collected by the KDOW during 1980-90 indicate significant downward trends in total phosphorus in Eagle Creek at Glencoe. A significant ($p < 0.088$) upward trend in concentrations of dissolved nitrite plus nitrate was found in the Middle Fork Kentucky River at Tallega during 1982-90.

Table 9. Trend-test results for nutrients at selected stations in the Kentucky River Basin

[N, number of observations; P, probability; *, censored values used in analysis; NA, not applicable; **, censored values affect trend analysis; Down, downward trend. Trend-line slopes not significant at the 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	
Station number	Station name	Period of record (water years[3])	N	P level	Milligrams per liter, per year	Percent of median per year	P level	Milligrams per liter, per year	Percent of median per year
Nitrogen, ammonia, dissolved, as nitrogen									
2.0	N Fk Ky R at Jackson	1982-90	*64	0.670	NA	NA	NA	NA	NA
2.3	M Fk Ky R at Tallega	1982-90	*63	1.000	NA	NA	NA	NA	NA
2.6	S Fk Ky R at Booneville	1982-90	*64	.224	NA	NA	NA	NA	NA
4.0	Ky R at Lock 10	1987-90	*48	.291	NA	NA	NA	NA	NA
8.0	Ky R at Lock 4	1987-90	*47	.663	NA	NA	NA	NA	NA
9.4	Elkhorn Cr at Frankfort	1987-90	*45	1.000	NA	NA	NA	NA	NA
10.0	Ky R at Lock 2	1979-90	*96	.245	NA	NA	NA	NA	NA
Nitrogen, ammonia, total, as nitrogen									
2.0	N Fk Ky R at Jackson	1984-87	*28	1.000	NA	NA	NA	NA	NA
2.3	M Fk Ky R at Tallega	1984-87	*28	.540	NA	NA	NA	NA	NA
2.6	S Fk Ky R at Booneville	1984-87	*26	.540	NA	NA	NA	NA	NA
10.0	Ky R at Lock 2	1977-90	*67	.475	NA	NA	NA	NA	NA
Nitrogen, nitrite, as nitrogen									
2.0	N Fk Ky R at Jackson	1987-90	*46	1.000	NA	NA	NA	NA	NA
2.3	M Fk Ky R at Tallega	1987-90	*47	1.000	NA	NA	NA	NA	NA
2.6	S Fk Ky R at Booneville	1987-90	*45	1.000	NA	NA	NA	NA	NA
4.0	Ky R at Lock 10	1987-90	*48	1.000	NA	NA	NA	NA	NA
8.0	Ky R at Lock 4	1987-90	*47	1.000	NA	NA	NA	NA	NA
9.4	Elkhorn Cr at Frankfort	1987-90	*45	.834	NA	NA	NA	NA	NA
10.0	Ky R at Lock 2	1987-90	**49	.130	Down	Down	NA	NA	NA

Table 9. Trend-test results for nutrients at selected stations in the Kentucky River Basin--Continued

[N, number of observations; P, probability; *, censored values used in analysis; NA, not applicable; **, censored values affect trend analysis; Down, downward trend. Trend-line slopes not significant at the 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	
Station number	Station name	Period of record (water years[3])	N	P level	Milligrams per liter, per year	Percent of median per year	P level	Milligrams per liter, per year	Percent of median per year
Nitrogen, ammonia plus organic, as nitrogen									
2.0	N Fk Ky R at Jackson	1982-90	*91	0.420	NA	NA	NA	NA	NA
2.3	M Fk Ky R at Tallega	1982-90	**90	.191	0.020	6.667	NA	NA	NA
2.6	S Fk Ky R at Booneville	1982-90	*86	1.000	NA	NA	NA	NA	NA
4.0	Ky R at Lock 10	1987-90	*48	.488	NA	NA	NA	NA	NA
8.0	Ky R at Lock 4	1987-90	*47	.628	NA	NA	NA	NA	NA
9.4	Elkhorn Cr at Frankfort	1987-90	44	.291	NA	NA	0.488	NA	NA
10.0	Ky R at Lock 2	1975-90	**145	.168	.008	1.569	NA	NA	NA
Nitrogen, nitrite plus nitrate, dissolved, as nitrogen									
2.0	N Fk Ky R at Jackson	1982-90	*64	.897	NA	NA	NA	NA	NA
2.3	M Fk Ky R at Tallega	1982-90	**63	.088	<u>.008</u>	<u>4.706</u>	NA	NA	NA
2.6	S Fk Ky R at Booneville	1982-90	**61	.187	-.017	-7.328	NA	NA	NA
4.0	Ky R at Lock 10	1987-90	*48	.358	NA	NA	NA	NA	NA
8.0	Ky R at Lock 4	1987-90	*47	.540	NA	NA	NA	NA	NA
9.4	Elkhorn Cr at Frankfort	1987-90	45	.284	NA	NA	.540	NA	NA
10.0	Ky R at Lock 2	1979-90	*99	.324	NA	NA	NA	NA	NA
Phosphorus, total, as phosphorus									
2.0	N Fk Ky R at Jackson	1980-90	**92	.075	<u>-.002</u>	<u>-6.667</u>	NA	NA	NA
2.3	M Fk Ky R at Tallega	1980-90	*91	.415	NA	NA	NA	NA	NA
2.6	S Fk Ky R at Booneville	1980-90	*89	.601	NA	NA	NA	NA	NA
4.0	Ky R at Lock 10	1987-90	**48	.146	.006	17.143	NA	NA	NA
8.0	Ky R at Lock 4	1987-90	47	1.000	NA	NA	.230	NA	NA
9.4	Elkhorn Cr at Frankfort	1987-90	45	.044	<u>-.366</u>	<u>-52.137</u>	.149	-0.210	89.362
10.0	Ky R at Lock 2	1975-90	149	.720	NA	NA	.291	NA	NA

Table 9. Trand-test results for nutrients at selected stations in the Kentucky River Basin--Continued

[N, number of observations; P, probability; *, censored values used in analysis; NA, not applicable; **, censored values affect trend analysis; Down, downward trend. Trend-line slopes not significant at the 0.2 probability level ara not reported, and thosa 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	
Station number	Station name	Period of record (water years[3])	N	P level	Milligrams per liter, per year	Percent of median per year	P leval	Milligrams per liter, per year	Parcent of median per yaar
Phosphorus, dissolved, as phosphorus									
2.0	N Fk Ky R at Jackson	1982-87	*18	0.337	NA	NA	NA	NA	NA
2.3	M Fk Ky R at Tallega	1982-87	*17	1.000	NA	NA	NA	NA	NA
2.6	S Fk Ky R at Booneville	1982-87	*17	1.000	NA	NA	NA	NA	NA
10.0	Ky R at Lock 2	1978-90	91	.135	-0.003	-3.750	NA	NA	NA
Phosphorus, orthophosphate, as phosphorus									
2.0	N Fk Ky R at Jackson	1982-90	*91	1.000	NA	NA	NA	NA	NA
2.3	M Fk Ky R at Tallega	1983-90	*48	1.000	NA	NA	NA	NA	NA
2.6	S Fk Ky R at Booneville	1982-90	*60	1.000	NA	NA	NA	NA	NA
4.0	Ky R at Lock 10	1987-90	*48	1.000	NA	NA	NA	NA	NA
8.0	Ky R at Lock 4	1987-90	*47	.652	NA	NA	NA	NA	NA
9.4	Elkhorn Cr at Frankfort	1987-90	45	.052	<u>-.188</u>	<u>-33.571</u>	1.000	NA	NA
10.0	Ky R at Lock 2	1981-90	*73	.574	NA	NA	NA	NA	NA

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

[2]Flow-adjusted trends were not computed when (a) the relation batween 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]Water year is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which it ends.

Suspended Sediments

The presence of sediments in surface waters directly and indirectly affects various water-quality characteristics and the biotic community. Therefore, suspended-sediment samples were collected through time and at specified sites throughout the basin to provide information on spatial and temporal distribution.

Spatial and Temporal Distribution

The spatial and temporal distribution of sediments was assessed by analyzing samples collected during the 3-year study at the fixed stations (table 10). A summary of data collected by the KDOW is included for comparison. Median concentrations of suspended sediment collected at the NAWQA sites are higher than indicated by KDOW data at the four paired stations (North Fork Kentucky River at Jackson, Middle Fork Kentucky River at Tallega, South Fork Kentucky River at Booneville, and Kentucky River at Lock 4, Frankfort). As discussed in an earlier section, this discrepancy probably resulted from differences of sample-collection methodology. Because of correlative relations between concentrations of nutrients and concentrations of suspended sediment, the water-quality data and transport estimates from this study will differ from those from the KDOW.

Among the fixed stations, the median concentration of suspended sediment was lowest in Elkhorn Creek at Frankfort (10 mg/L; table 10). Median concentrations were highest in the North Fork Kentucky River at Jackson (30 mg/L) and in the Kentucky River at Lock 10 and Lock 2 (31 mg/L). A greater proportion of samples contained elevated concentrations of suspended sediment in the North Fork Kentucky River at Jackson, and this site had the highest maximum suspended-sediment concentration (1,780 mg/L) of all the fixed stations. The maximum suspended-sediment concentration was lowest in the Middle Fork Kentucky River at Tallega (302 mg/L), probably because of suspended-sediment retention by Buckhorn Lake upstream from this site.

Suspended-sediment particle size and surface area are significant factors controlling sediment chemistry. Finer-sized sediment particles have a higher capacity for sorption of organic compounds, because they tend to have higher organic matter content (Witkowski and others, 1987). The median concentration of suspended sediment classified as silt and clay (less than 63 μm) ranged from 74 percent (Middle Fork of Kentucky River at Tallega) to 89 percent (Kentucky River at Lock 2) at the fixed stations, excluding Elkhorn Creek (table 10). In Elkhorn Creek at Frankfort, the median concentration of fine-grained suspended-sediment particles was 68 percent.

Moreover, fine-grained sediments, because of their large surface areas, are the main sites for the collection and transport of inorganic constituents (Horowitz, 1991). The median estimated surface area of suspended sediment ranged from a low of 15.85 m^2/g (square meters per gram) in the North Fork Kentucky River at Jackson to a high of 21.52 m^2/g in the Kentucky River at Lock 10. Differences between sites were not statistically significant.

Table 10. Statistical summary of suspended-sediment concentrations at selected stations in the Kentucky River Basin

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; mg/L, milligrams per liter; NA, not applicable; KDOW, Kentucky Division of Water data obtained from STORET; <, less than]

Station number	Station name	Period of record	N	N less than DL	Minimum DL, in milligrams per liter	MIN	Concentration at indicated percentile, in milligrams per liter (or as indicated): 10	25	50 (median)	75	90	MAX
Suspended sediment (mg/L)												
2.0	N Fk Ky R at Jackson	4/87-3/90	48	0	NA	3	6	8	30	314	1,264	1,780
2.3	M Fk Ky R at Tallega	4/87-3/90	48	0	NA	2	5	9	26	116	250	302
2.6	S Fk Ky R at Booneville	4/87-3/90	46	0	NA	2	5	8	18	45	389	760
4.0	Ky R at Lock 10	4/87-3/90	48	0	NA	3	9	14	31	173	563	1,040
8.0	Ky R at Lock 4	4/87-3/90	47	0	NA	3	6	13	26	230	455	1,030
9.4	Elkhorn Cr at Frankfort	4/87-3/90	47	0	NA	1	3	6	10	56	173	800
10.0	Ky R at Lock 2	4/87-3/90	46	0	NA	3	8	13	31	176	397	818
Suspended sediment[1] (mg/L) (KDOW)												
2.0	N Fk Ky R at Jackson	10/86-9/89	43	1	1	<1	4	12	22	58	180	461
2.3	M Fk Ky R at Tallega	10/86-9/89	43	1	1	<1	2	6	10	32	94	182
2.6	S Fk Ky R at Booneville	10/86-9/89	43	1	1	<1	1	3	7	15	58	144
3.0	Ky R at Lock 14	10/86-9/89	44	0	NA	1	4	6	11	28	95	424
3.1	Red R near Hazel Green	10/86-9/89	41	0	NA	1	2	4	13	32	120	808
3.3	Red R at Clay City	10/86-9/89	41	0	NA	2	5	8	14	62	102	190
5.0	Ky R at Camp Nelson	10/86-9/89	45	1	1	<1	3	6	9	42	343	478
5.2	Dix R near Danville	10/86-9/89	45	1	1	<1	2	4	8	16	74	681
8.0	Ky R at Lock 4	10/86-9/89	45	0	NA	1	3	5	10	46	187	410
9.3	S Elkhorn Cr near Midway	10/86-9/89	44	0	NA	1	3	6	9	16	48	227
10.1	Eagle Cr at Glencoe	10/86-9/89	38	0	NA	2	5	8	14	32	107	744

Table 10. Statistical summary of suspended-sediment concentrations at selected stations in the Kentucky River Basin--Continued

[N, number of observations; DL, detection limit; MIN, minimum; MAX, maximum; mg/L, milligrams per liter; NA, not applicable; KDOW, Kentucky Division of Water data obtained from STORET; <, less than]

Station number	Station name	Period of record	N	N less than DL	Minimum DL, in milligrams per liter	Concentration at indicated percentile, in milligrams per liter (or as indicated): MIN	10	25	50 (median)	75	90	MAX
Suspended sediment, percent less than 62 micrometers												
2.0	N Fk Ky R at Jackson	4/87-3/90	47	0	NA	33	52	62	79	86	96	100
2.3	M Fk Ky R at Tallega	4/87-3/90	47	0	NA	11	45	59	74	85	92	100
2.6	S Fk Ky R at Booneville	4/87-3/90	45	0	NA	19	52	71	79	88	100	100
4.0	Ky R at Lock 10	4/87-3/90	47	0	NA	41	63	73	86	94	100	100
8.0	Ky R at Lock 4	4/87-3/90	46	0	NA	26	51	76	87	93	100	100
9.4	Elkhorn Cr at Frankfort	4/87-3/90	46	0	NA	20	38	48	68	87	94	100
10.0	Ky R at Lock 2	4/87-3/90	45	0	NA	50	62	79	89	94	95	100
Suspended sediment, surface area (square meters per gram)												
2.0	N Fk Ky R at Jackson	4/87-3/90	38	0	NA	11.70	12.60	13.10	15.85	17.71	20.57	23.60
2.3	M Fk Ky R at Tallega	4/87-3/90	41	0	NA	11.00	14.32	16.95	20.63	22.40	28.98	35.00
2.6	S Fk Ky R at Booneville	4/87-3/90	36	0	NA	4.08	11.52	14.15	16.80	21.43	26.22	34.10
4.0	Ky R at Lock 10	4/87-3/90	42	0	NA	10.11	14.98	19.10	21.52	24.74	28.79	37.87
8.0	Ky R at Lock 4	4/87-3/90	40	0	NA	9.80	16.11	18.09	20.55	23.17	27.66	39.00
9.4	Elkhorn Cr at Frankfort	4/87-3/90	37	0	NA	8.40	9.36	14.20	19.80	24.37	25.84	27.20
10.0	Ky R at Lock 2	4/87-3/90	42	0	NA	9.04	15.61	18.92	21.16	23.45	25.63	30.66

[1]Reported as "suspended solids."

In water years 1987 and 1988, a consistent downward trend in suspended-sediment concentrations (fig. 37) was detected in the Kentucky River main stem from the headwaters to the mouth. Concentrations declined rapidly from the headwaters to about river mile 270 on the main stem and then declined more gradually downstream to river mile 176 (Lock 10). From river mile 176 (Lock 10) downstream to the mouth, suspended-sediment concentrations remained relatively low.

Concentrations of suspended sediment were consistently higher in 1989 than in the two previous water years at all fixed stations. Data for the North Fork Kentucky River at Jackson and for the Kentucky River at Lock 2 are shown in figure 38. Moreover, the variation in sediment concentrations from month to month was also much greater in 1989 than at other times in the 3-year sampling period. Higher daily mean discharge in 1989 (fig. 4) was the likely cause of the high suspended sediment concentrations.

Estimation of Suspended-Sediment Loads and Yields

Estimates of mean annual suspended sediment loads (table 11) are much higher in the North Fork Kentucky River at Jackson (1,040,000 tons) than at the other two stations in the upper part of the basin (116,000 tons in the Middle Fork Kentucky River at Tallega; 212,000 tons in the South Fork Kentucky River at Booneville). This location receives drainage from surface-mining activities in the North Fork Kentucky River Subbasin, and a large part of the total sediment transport in the Kentucky River originates in the North Fork Kentucky River Subbasin. Estimates of the mean annual suspended-sediment load increase in the Kentucky River main stem downstream to 1,600,000 tons in the Kentucky River at Lock 2. Mean annual suspended-sediment-load estimates are much lower in Elkhorn Creek at Frankfort (139,000 tons). Singh and Durgunoglu (1992) reported a suspended-sediment load of 60,780 tons for Elkhorn Creek on the basis of a nonlinear rating curve; however, the source of the data for these estimates is not given.

A further understanding of sediment transport can be developed by examination of annual load estimates obtained from KDOW data (table 11). KDOW data indicate that (1) a considerable sediment mass of more than 7 million tons/yr is deposited upstream from Lock 14, and (2) sediment transport increases in the middle part of the Kentucky River Basin as a result of suspended-sediment contributions from the Red River and other tributary streams of the Knobs Region (fig. 3). Overall, about 40 percent of sediment mass transport in the middle reach of the Kentucky River (at the Lock 10 and Camp Nelson) originates in the Eastern Coal Field Region, and about 60 percent originates in the Knobs Region. The increase in the estimated suspended-sediment load in the Kentucky River between Lock 4 and Lock 2 seems to be related largely to the transport of sediment from agricultural and urban land-use activities in the Elkhorn Creek Subbasin.

Relation of Suspended-Sediment Concentrations to Discharge

Suspended-sediment concentrations averaged for the entire study period were highly correlated with discharge at the fixed stations (figs. 39-41),

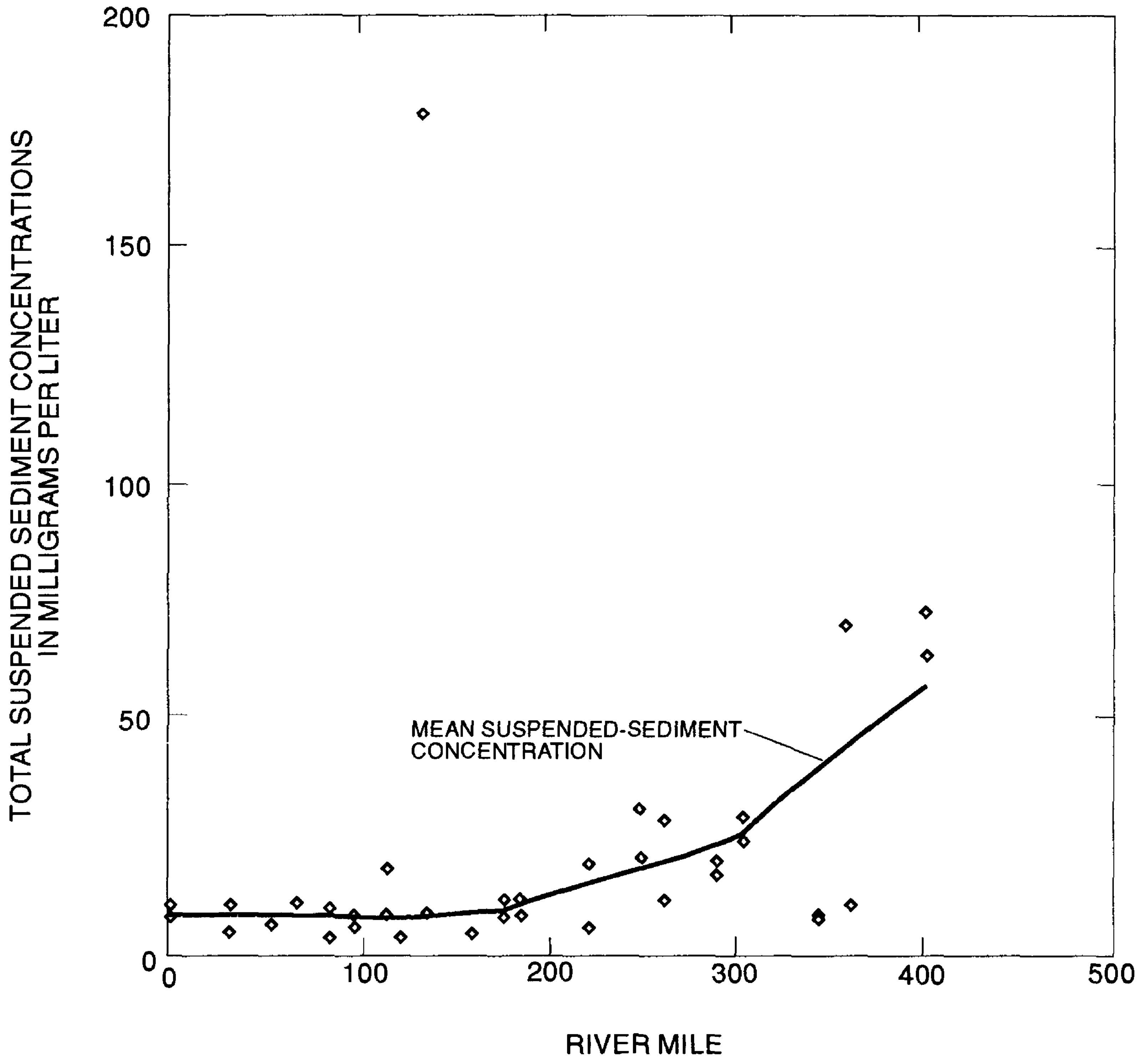

Figure 37. Smoothed mean suspended-sediment concentration in the Kentucky River, April 1987 - March 1990.

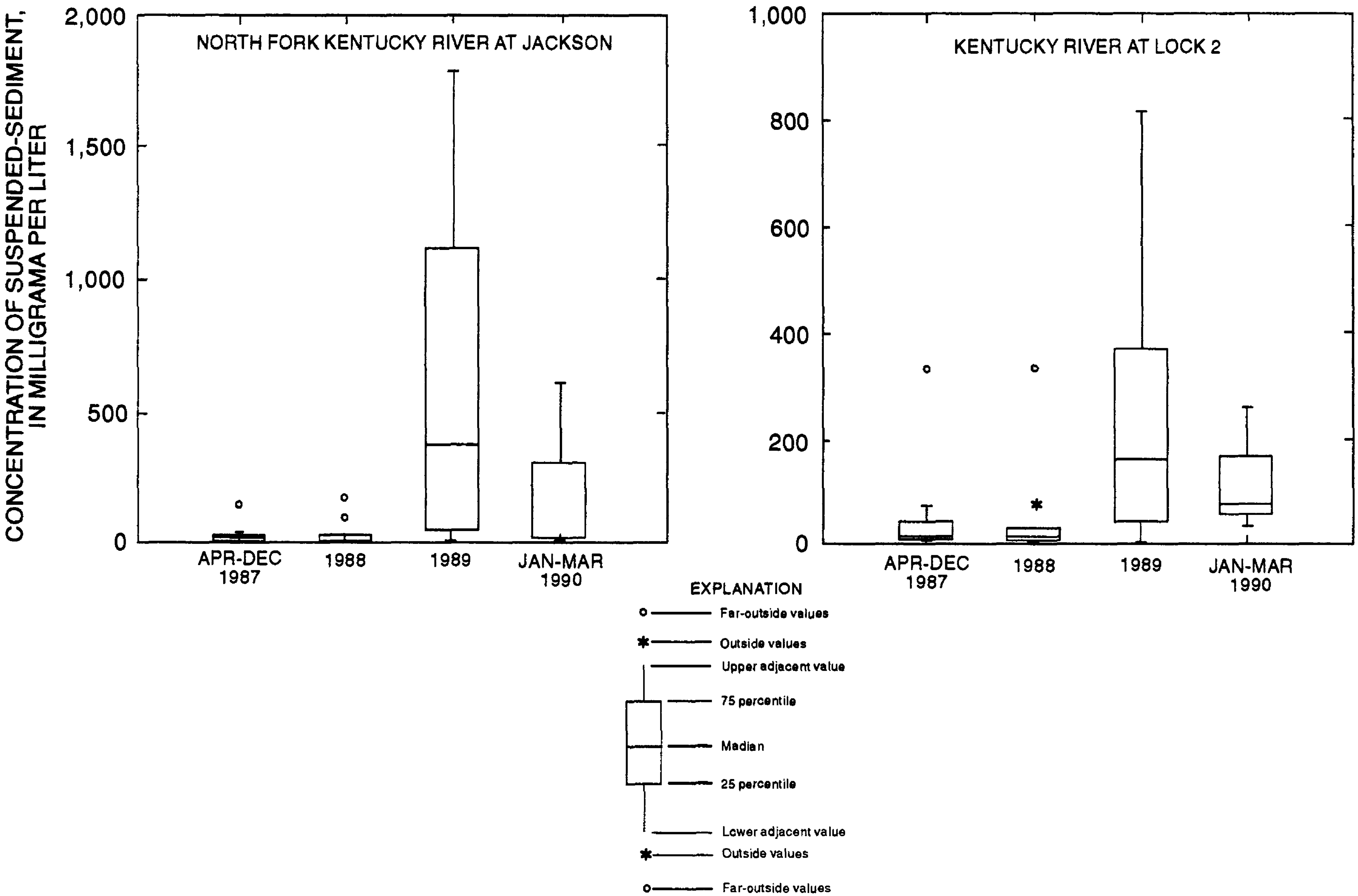

Figure 38. Summary of annual suspended-sediment concentrations in the North Fork Kentucky River at Jackson and in the Kentucky River at Lock 2, April 1987-March 1990.

Table 11. Summary of suspended-sediment transport at selected stations in the Kentucky River Basin

[N, number of observations; DL, detection limit]

Station number	Station name	Period of record	N	N less than DL	Transport estimates: Mean annual load (tons)	Transport estimates: Mean annual yield (tons per square mile)	Uncertainty factors, in percent: Standard error of regression	Uncertainty factors, in percent: Flow duration of greatest sampled discharge	Uncertainty factors, in percent: Proportion of load estimated beyond range of sampled discharge
Suspended sediment									
2.0	N Fk Ky R at Jackson	4/87-3/90	47	0	1,040,000	948	110	100	0
2.3	M Fk Ky R at Tallega	4/87-3/90	47	0	116,000	216	79.0	99.8	2.56
2.6	S Fk Ky R at Booneville	4/87-3/90	46	0	212,000	294	118	99.7	35.2
4.0	Ky R at Lock 10	4/87-3/90	48	0	1,140,000	287	73.7	100	0
8.0	Ky R at Lock 4	4/87-3/90	47	0	1,420,000	263	75.8	100	0
9.4	Elkhorn Cr at Frankfort	4/88-3/90	46	0	139,000	293	99.6	99.7	44.4
10.0	Ky R at Lock 2	4/87-3/90	47	0	1,600,000	259	64.1	100	0
Suspended solids (KDOW)									
2.0	N Fk Ky R at Jackson	10/86-9/89	43	1	561,000	510	116	97.4	78.4
2.3	M Fk Ky R at Tallega	10/86-9/89	43	1	89,500	167	92.1	93.9	57.1
2.6	S Fk Ky R at Booneville	10/86-9/89	43	1	62,400	86.4	91.6	98.3	58.5
3.0	Ky R at Lock 14	10/86-9/89	44	0	47,100	25.7	99.0	96.8	54.6
3.1	Red R near Hazel Green	10/86-9/89	41	0	4,600	70.0	188	99.6	12.8
3.3	Red R at Clay City	10/86-9/89	41	0	73,000	202	83.1	100	0
5.0	Ky R at Camp Nelson	10/86-9/89	45	1	1,390,000	314	109	99.7	10.4
5.2	Dix R near Danville	10/86-9/89	45	1	21,500	67.7	237	100	0
8.0	Ky R at Lock 4	10/86-9/89	45	0	848,000	160	104	99.8	7.8
9.3	S Elkhorn Cr near Midway	10/86-9/89	44	0	6,160	58.7	89.0	100	16.6
10.1	Eagle Cr at Glencoe	10/86-9/89	38	0	22,400	51.3	149	99.2	40.7

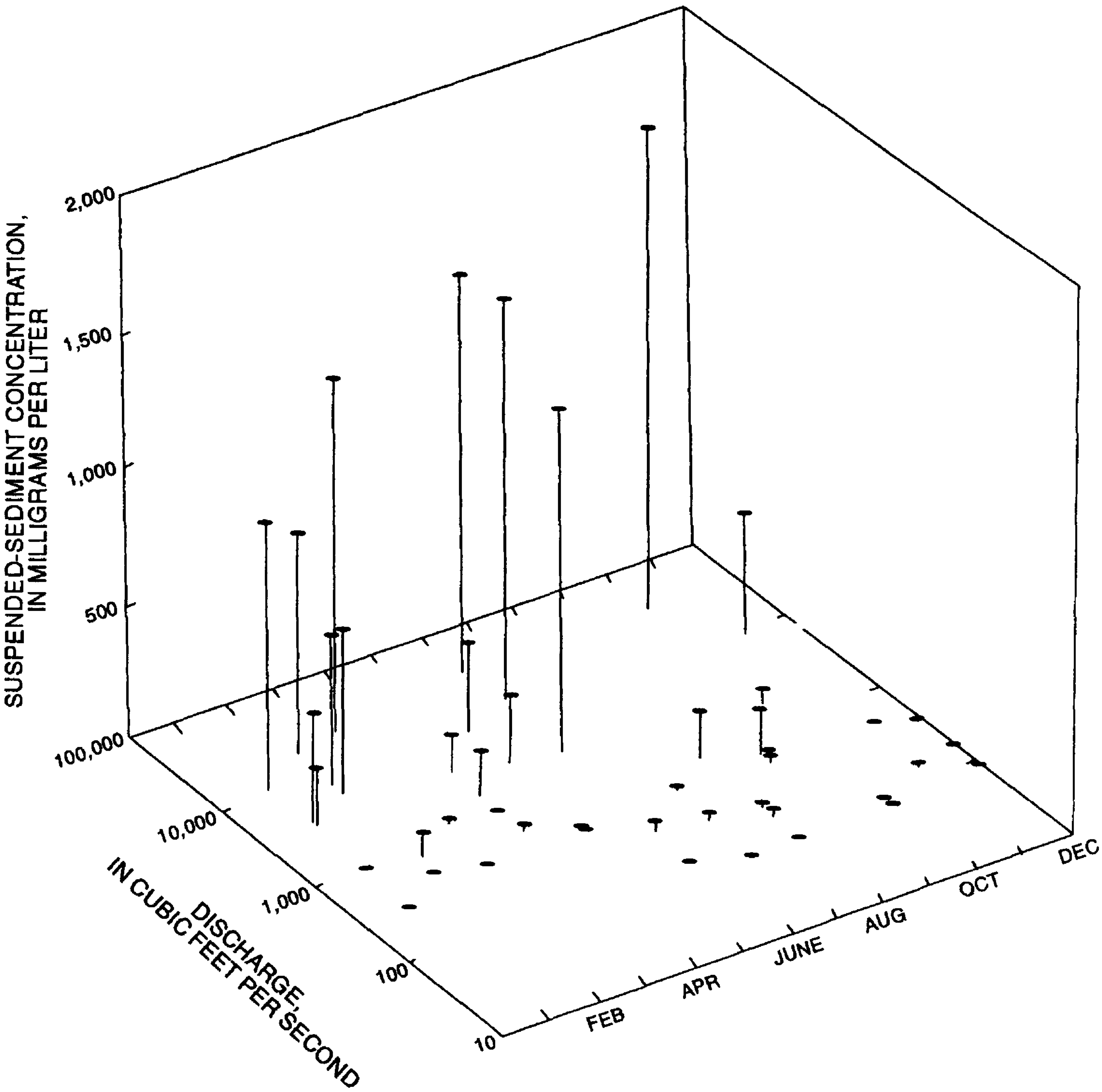

Figure 39. Variations in mean monthly suspended-sediment concentrations and discharge in the North Fork Kentucky River at Jackson, April 1987 - March 1990.

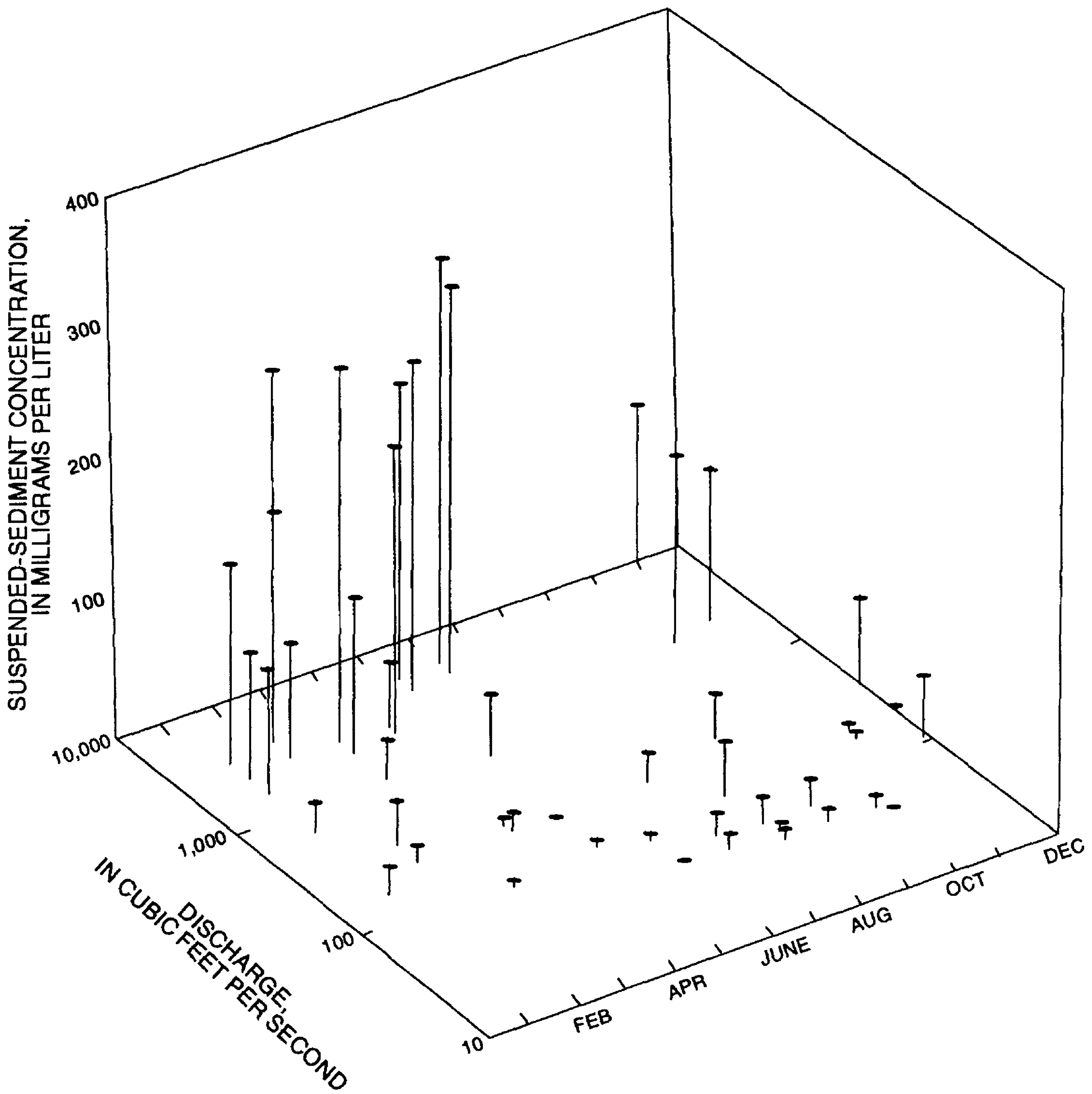

Figure 40. Variations in mean monthly suspended-sediment concentrations and discharge in the Middle Fork Kentucky River at Tallega, April 1987 - March 1990.

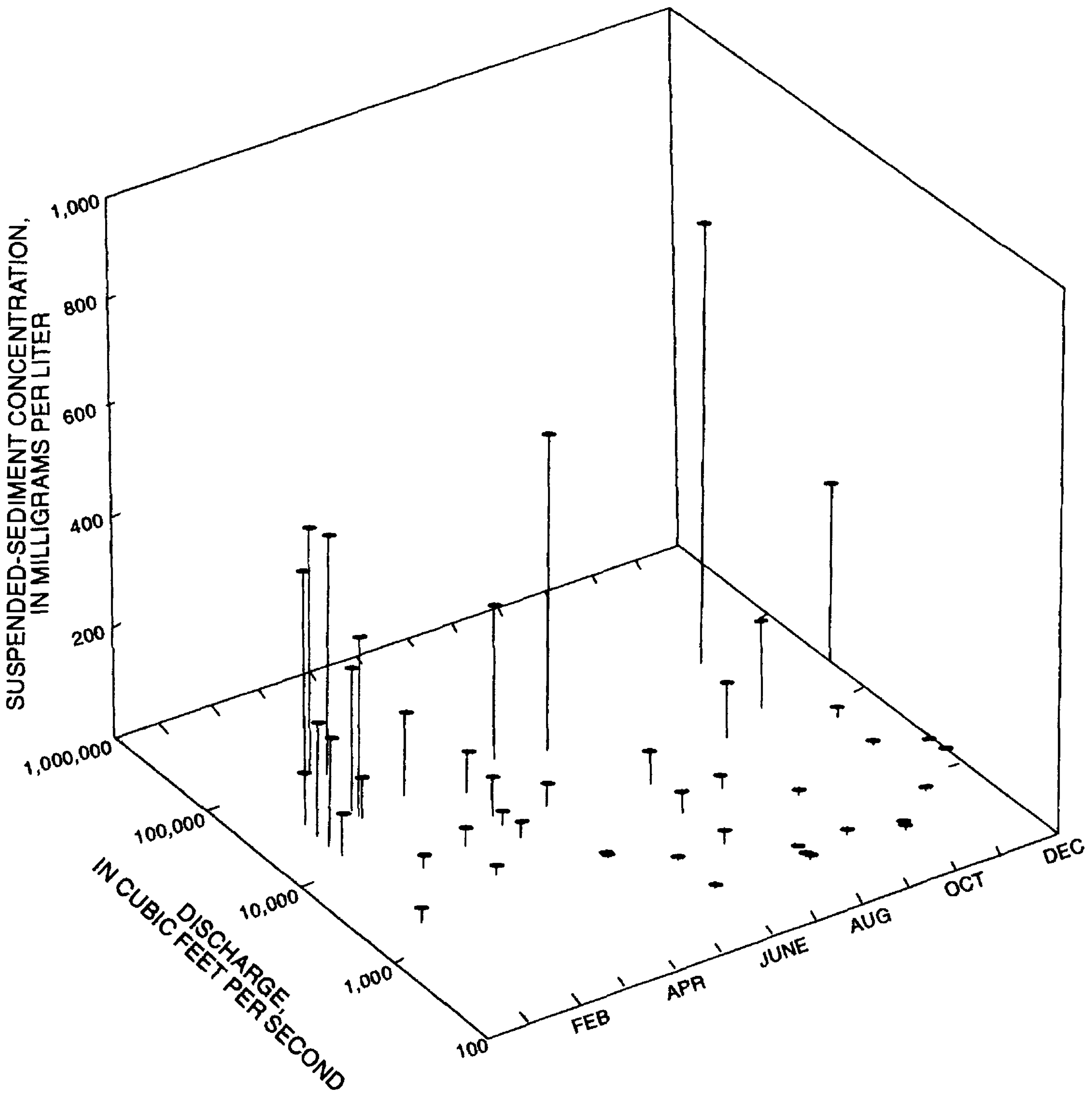

Figure 41. Variations in mean monthly suspended-sediment concentrations and discharge in the Kentucky River at Lock 2, April 1987 - March 1990.

with the exception of South Fork Kentucky River at Booneville and Elkhorn Creek at Frankfort (data not shown in figs. 39-41). The suspended-sediment concentrations were always lower during July-September, which is typically a low-flow period, than during any other months of the year.

Relation of Suspended-Sediment Concentrations to Other Constituents

The ability of suspended sediment to adsorb other constituents is well established. However, at the fixed stations in the Kentucky River Basin, significant correlations were not found between total suspended sediment and total concentrations of any of the nutrient forms studied in this basin. At the synoptic sites on the Kentucky River a significant relation was found between mean (August 1987 and August 1988) total phosphorus and suspended sediment above river mile 200 (fig. 42). The relation was weaker and was not significant further downstream where suspended-sediment concentrations were much lower.

Relation of Suspended-Sediment Concentrations During Low Flow to Land Use and Point Sources

Samples were collected for determination of suspended-sediment concentrations as part of the low-flow synoptic studies in August 1987 and August 1988. No significant correlations between total suspended-sediment concentrations and discharge were found among the synoptic samples in either year or when data from both years were combined, presumably because the range of discharge during this low-flow period was small. No correlations were found between land use and total suspended-sediment concentrations, although the level of resolution of land-use data was perhaps not adequate to reflect differences at the subbasin scale.

However, the correlation between point-source discharges, specifically WWTP's, and suspended-sediment concentrations in streams was significant. The instantaneous effluent loads of total suspended solids from WWTP's in the basin are shown in figure 43. It should be noted that as much as 65 percent of the material reported as total suspended solids in WWTP effluent may be volatile solids (McElroy and Bell, 1974).

Turbidity, which reflects the amount of suspended material in the water column, was measured in both synoptic surveys. Highest turbidities (>50 NTU) were measured in the upper part of the basin (fig. 44), principally in coal-mining areas. Turbidities in the range of 5.0 to 50 NTU were common in tributary streams throughout the basin for all land uses. Turbidities in the main stem of the Kentucky River tended to be below 5.0 NTU during both synoptic surveys, which were done during low-flow periods.

Temporal Trends in Suspended-Sediment Concentrations

Opportunities to discern temporal trends in suspended-sediment concentrations in the Kentucky River main stem were limited by data requirements of Seasonal-Kendall trend tests. The period of record is not

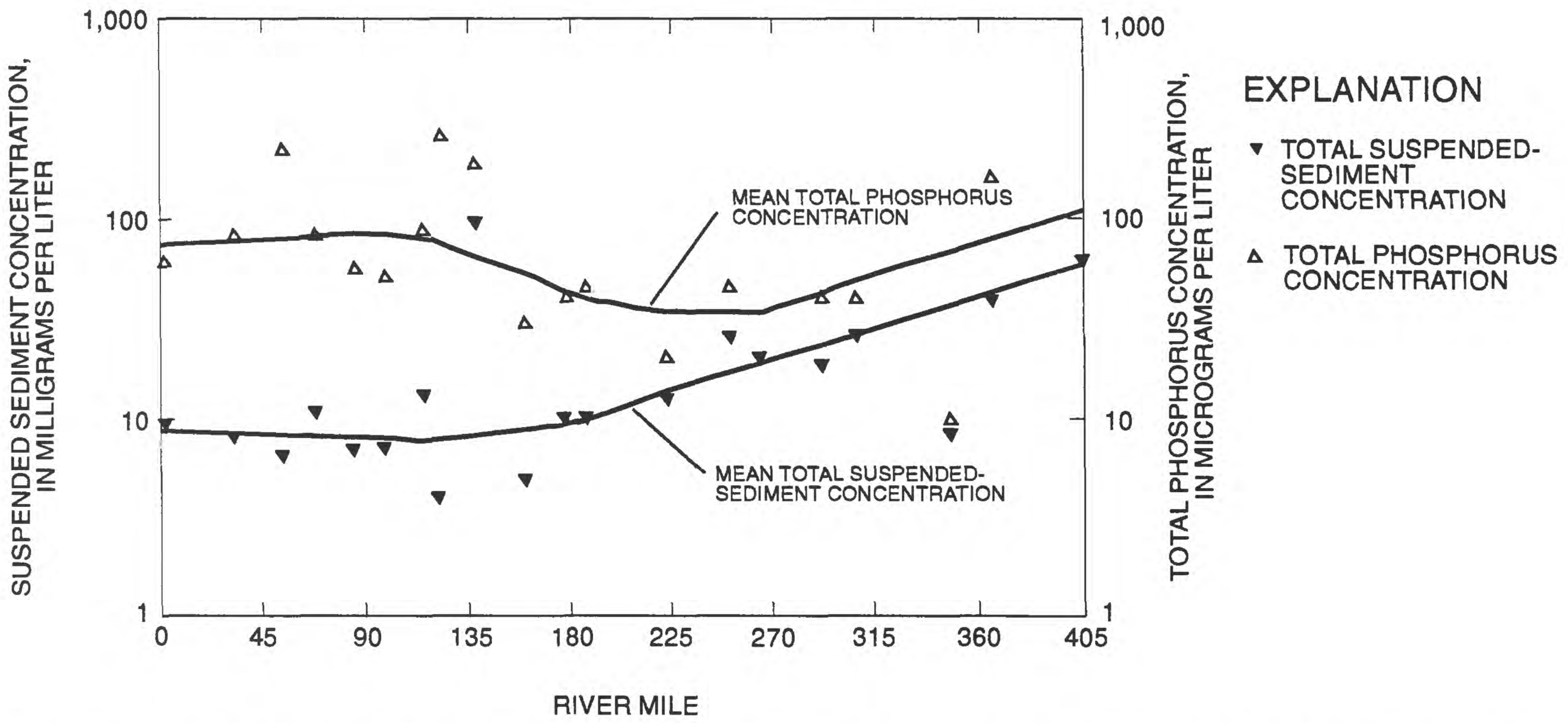

Figure 42. Smoothed mean suspended-sediment and mean total phosphorus concentrations in the Kentucky River. Data points are means of values for August 1987 and August 1988.

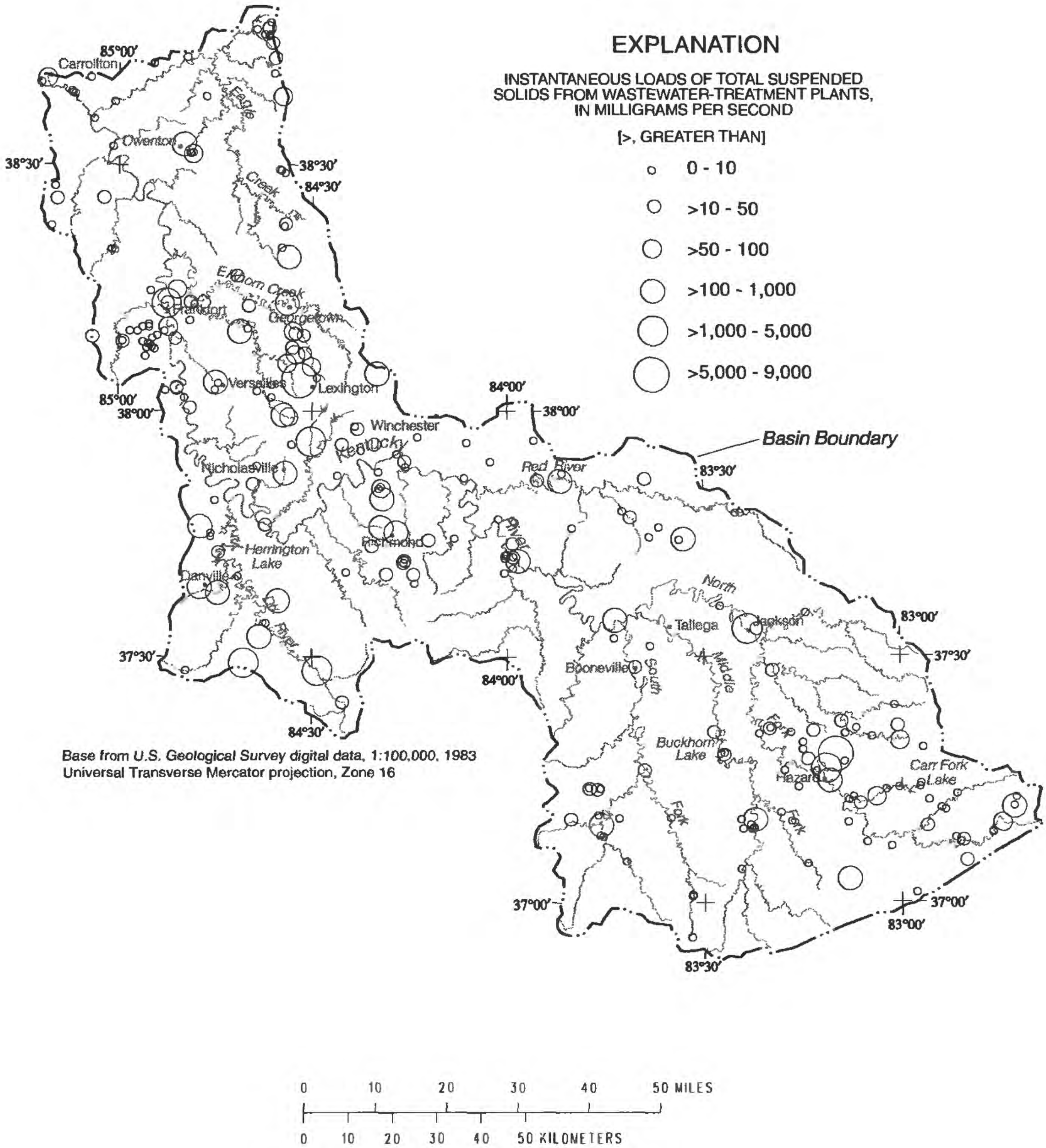

Figure 43. Instantaneous loads of total suspended solids from wastewater-treatment plants in the Kentucky River Basin, August 1991.

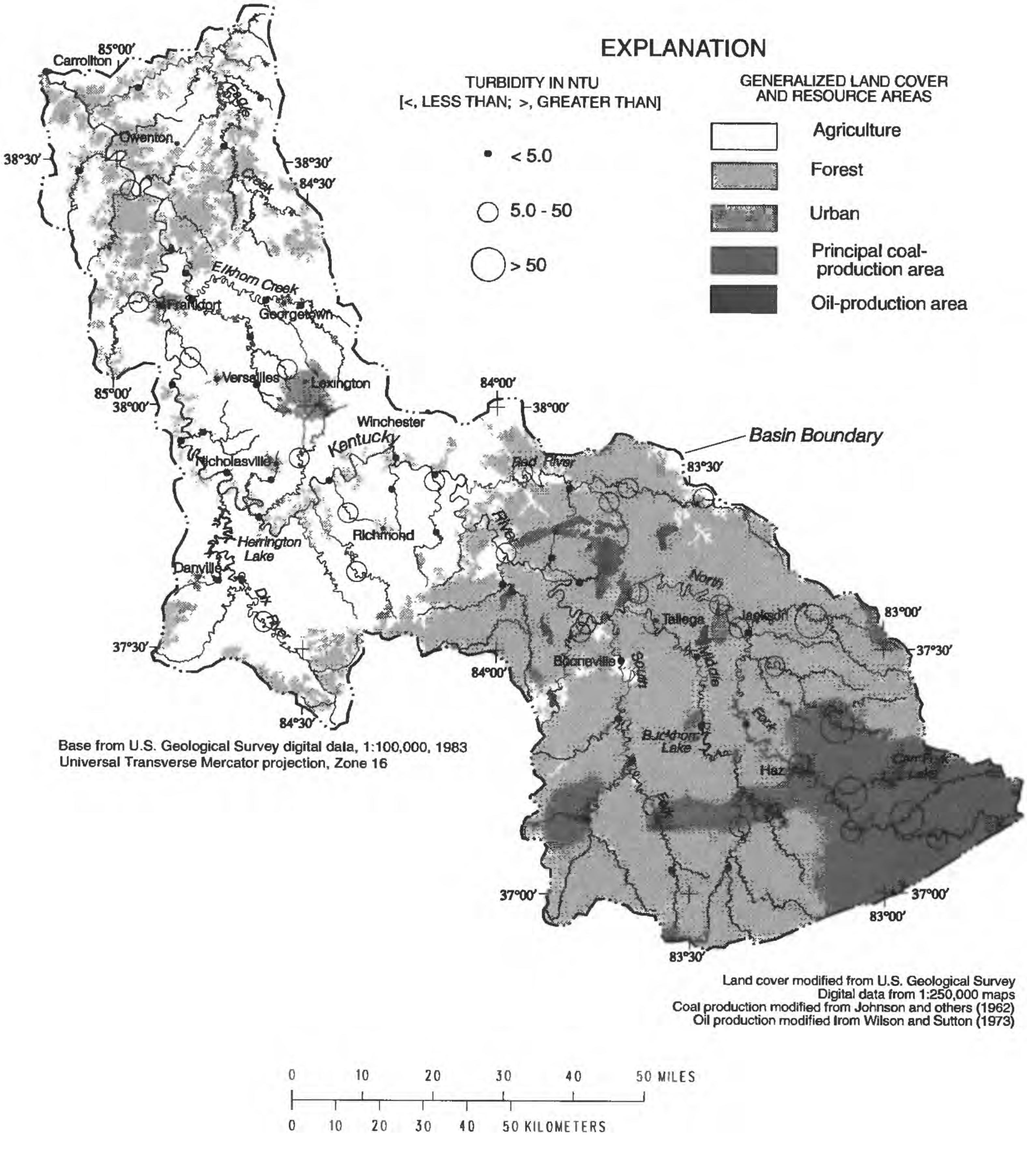

Figure 44. Turbidity in streams of the Kentucky River Basin, August 8-12, 1987.

sufficient for such analysis at most stations. Results are available, however, for 4 stations where 10 or more years of data were collected. A significant 15-year downward flow-adjusted trend for suspended-sediment concentrations is indicated for the Kentucky River at Lock 2. Similar results were found by use of data from KDOW at Lock 2. No other significant trends in suspended-sediment concentrations were found.

The downward trend at Lock 2 may have resulted from the implementation of best-management practices to reduce soil erosion from surface-mining and agricultural activities in the Kentucky River Basin. Hill (1991) suggests that the implementation of best-management practices in North Carolina may have reduced the sediment yield there by an order of magnitude. However, the suspension of routine lock and dam operations by the U.S. Army Corps of Engineers during the late 1970's and the consequent reduced use of lock facilities by commercial and recreational traffic upstream from Lock 4 may have resulted in increased deposition of sediment upstream from the navigational locks and dams on the Kentucky River and may have affected the observed concentrations over time.

Pesticides

Water and streambed-sediment samples were analyzed for pesticides at selected sites in the Kentucky River Basin during 1988-90. Results for most samples indicated insecticide (table 12) and herbicide (table 13) concentrations at or below reporting limits.

Spatial Distribution

The spatial distribution of selected pesticides was assessed by sampling surface-water runoff at 14 sites in 1988 and 1989. Some sites were sampled only once, whereas others were sampled on 3-10 different dates. Surface water was sampled every 2 months at four of those sites in 1990 (fig. 45). Additional sampling was done during low flows in 1988 to determine the occurrence of organochlorine compounds in streambed sediments at 26 sites in the basin (fig. 46).

Detection in water samples

Pesticides were detected in water samples in all three years of the study (tables 14 and 15; fig. 47). Diazinon, malathion, and parathion were the most frequently detected organophosphate insecticides, particularly in the Elkhorn Creek Subbasin. In 1988-89, diazinon was found at two sites. Concentrations of diazinon ranged from 0.03 μg/L in Elkhorn Creek at Frankfort to 0.40 μg/L in South Elkhorn Creek at Midway. In 1990, diazinon was detected not only in the Elkhorn Creek Subbasin but also in the Kentucky River at Lock 10 and Lock 2, in the Red River at Clay City, and in the Eagle Creek Subbasin (table 15). Diazinon is widely used for insect control on tobacco, fruits, vegetables, pasture, grasslands, and ornamentals. Diazinon has a moderately rapid rate of degradation when exposed to sunlight and low mobility in the soil (U.S. Environmental Protection Agency, 1991).

Table 12. Incidence of detection of insecticides in water and streambed-sediment samples in the Kentucky River Basin, 1988-90

[μg/kg, micrograms per kilogram; μg/L, micrograms per liter]

Common name	Reporting limit	Number of samples	Incidence of detection, in percent
Aldrin	2.5 μg/kg	25	16
Arochlor 1242	25.0 μg/kg	25	8
Arochlor 1260	25.0 μg/kg	25	4
BHC-Alpha isomer	2.5 μg/kg	25	4
Chlordane	.25 μg/kg	24	25
Chlorpyrifos	.01 μg/L	6	9
DDE	2.5 μg/kg	23	9
DDT	2.5 μg/kg	25	8
Diazinon	.01 μg/L	30	77
Dieldrin	2.5 μg/kg	25	4
Endosulfan	.5 μg/kg	25	8
Endrin	2.5 μg/kg	25	8
Heptachlor	2.5 μg/kg	25	16
Heptachlor epoxide	2.5 μg/kg	25	36
Lindane	2.5 μg/kg	24	4
Malathion	.01 μg/L	30	30
Parathion	.01 μg/L	30	13

Table 13. Incidence of detection of herbicides in water samples in the Kentucky River Basin, 1988-90

Common name	Reporting limit, in micrograms per liter	Number of samples	Incidence of detection, in percent
Alachlor	0.1	28	14
Atrazine	.1	27	44
Cyanazine	.1	28	7
2,4-D	20.0	29	45
Dicamba	.01	29	14
Metolachlor	.1	29	3
Metribuzin	.1	29	3
Picloram	.01	28	4
Prometon	.1	29	34
Simazine	.1	28	36

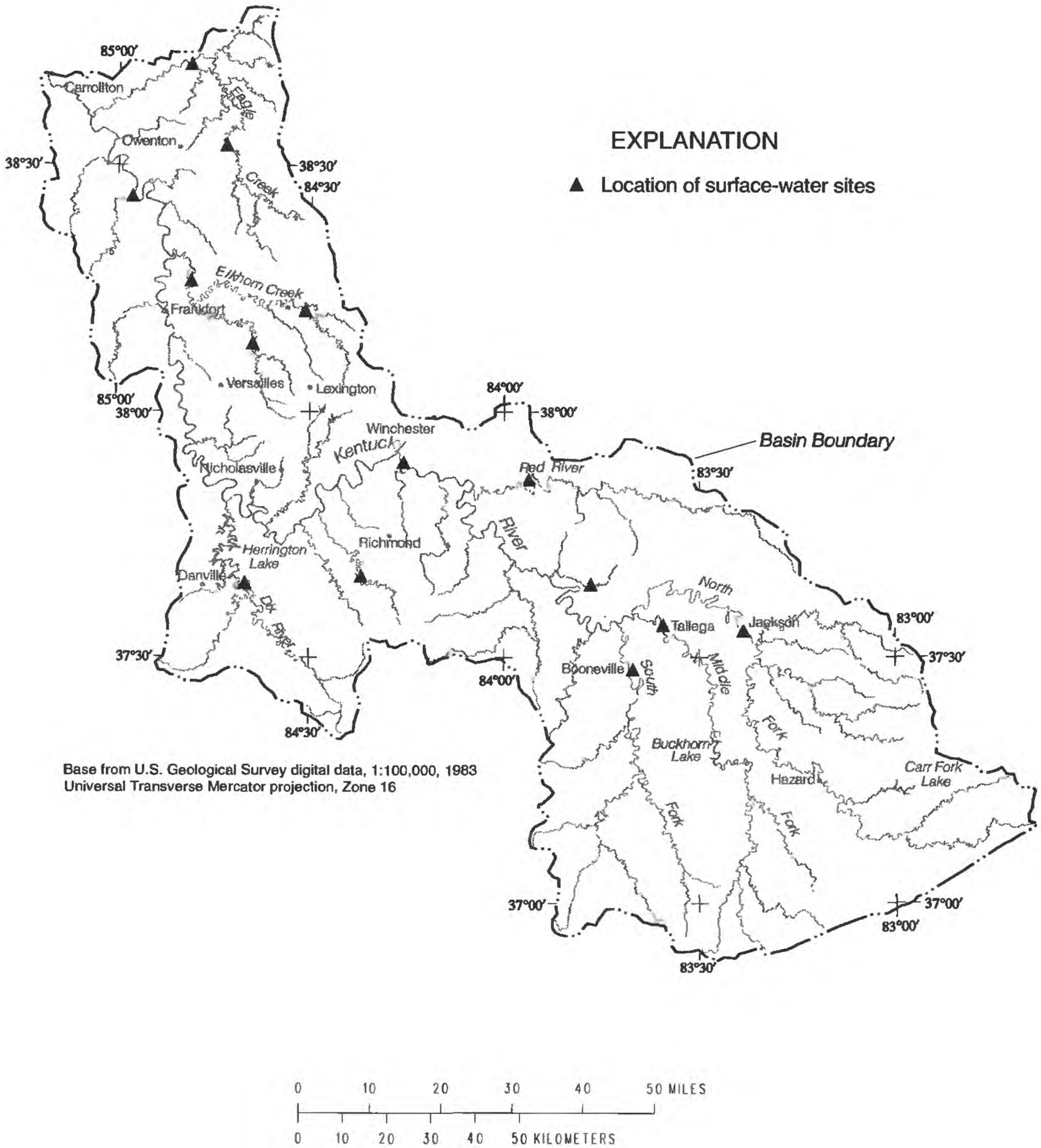

Figure 45. Surface-water sampling sites for pesticides in the Kentucky River Basin, 1988-90.

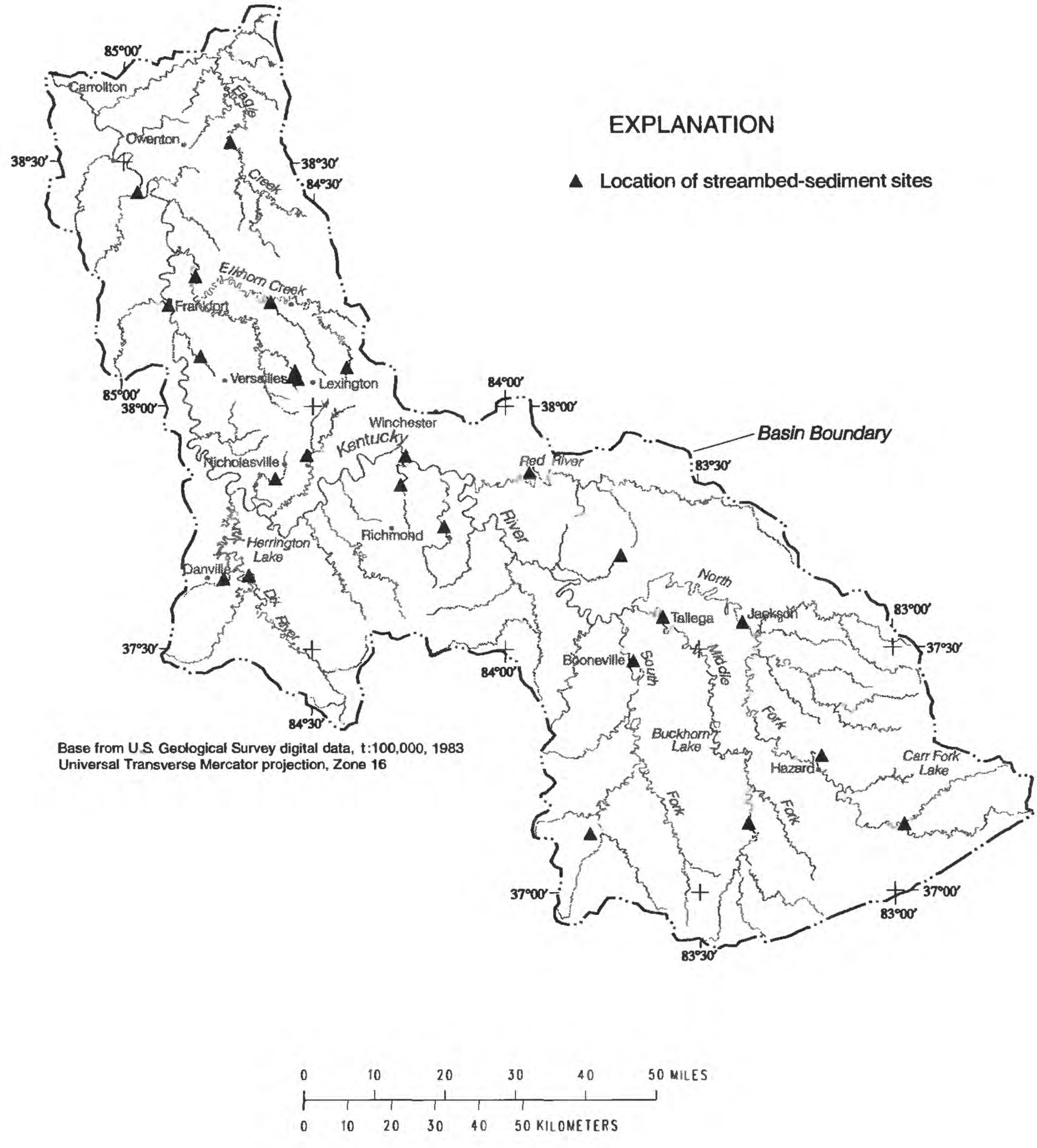

Figure 46. Streambed-sediment sampling sites for pesticides in the Kentucky River Basin, 1988-90.

Table 14. Concentrations of pesticides detected in water samples from streams in the Kentucky River Basin, 1988-89

Pesticide and sample site	Date	Concentration, in micrograms per liter
<u>Organophosphate insecticides</u>		
Diazinon		
South Elkhorn Creek near Midway	11/05/88	0.34
	02/13/89	.10
	06/06/89	.07
	09/12/89	.40
Elkhorn Creek at Frankfort	11/05/88	.12
	06/06/89	.03
Malathion		
South Elkhorn Creek near Midway	06/06/89	.01
	09/12/89	[a].14
Parathion		
South Elkhorn Creek near Midway	09/12/89	[a].11
<u>Herbicides</u>		
Alachlor		
North Elkhorn Creek near Georgetown	02/13/89	1.2
	02/15/89	.2
South Elkhorn Creek near Midway	06/06/89	.3
Eagle Creek at Glencoe	06/06/89	.1
Atrazine		
North Fork Kentucky River at Jackson	06/15/89	.1
Middle Fork Kentucky River at Tallega	06/16/89	.1
South Fork Kentucky River at Booneville	06/15/89	.1
Red River at Clay City	09/06/89	.3
Kentucky River at Lock 10	06/17/89	.2
North Elkhorn Creek near Georgetown	02/13/89	1.0
	06/06/89	[b]16.0
South Elkhorn Creek near Midway	06/06/89	.8
Elkhorn Creek at Frankfort	06/06/89	.3
Eagle Creek at Glencoe	06/06/89	.2
Cyanazine		
Red River at Clay City	09/06/89	.1
Elkhorn Creek at Frankfort	06/06/89	.2

Table 14. Concentrations of pesticides detected in water samples from streams in the Kentucky River Basin, 1988-89--Continued

Pesticide and sample site	Date	Concentration, in micrograms per liter
2,4-D		
North Elkhorn Creek near Georgetown	06/06/89	0.17
South Elkhorn Creek near Midway	06/06/89	.47
Elkhorn Creek at Frankfort	11/05/88	.02
	06/06/89	.44
Dicamba		
Big Sinking Creek near Crystal	02/15/89	.4
Elkhorn Creek at Frankfort	11/05/88	.02
Metolachlor		
North Elkhorn Creek near Georgetown	02/13/89	.9
Metribuzin		
North Elkhorn Creek near Georgetown	02/13/89	1.1
Picloram		
South Elkhorn Creek near Midway	11/05/88	.02
Prometon		
North Elkhorn Creek near Georgetown	11/05/88	.2
Elkhorn Creek at Frankfort	06/06/89	.1
South Elkhorn Creek near Midway	06/06/89	.1
	09/12/89	.1
Simazine		
South Fork Kentucky River at Booneville	06/15/89	.1
Red River at Clay City	06/09/89	.1
North Elkhorn Creek near Georgetown	02/13/89	.6
	06/06/89	4.5
South Elkhorn Creek near Midway	06/06/89	.2
Elkhorn Creek at Frankfort	06/06/89	.2
Eagle Creek at Glencoe	06/06/89	.1

[a]Concentrations exceed the Maximum Contaminant Levels for acute and (or) chronic aquatic life criteria (U.S. Environmental Protection Agency, 1992).

[b]Concentrations exceed the Maximum Contaminant Levels for drinking water (U.S. Environmental Protection Agency, 1991).

Table 15. Concentrations of pesticides detected in water samples from streams in the Kentucky River Basin, 1990

Pesticide and sample site	Date	Concentration, in micrograms per liter
<u>Organophosphate insecticides</u>		
Chlorpyrifos		
South Elkhorn Creek near Midway	08/29/90	0.02
Diazinon		
Red River at Clay City	07/12/90	.01
Kentucky River at Lock 10	07/12/90	.02
North Elkhorn Creek near Georgetown	01/04/90	.07
	08/29/90	.02
South Elkhorn Creek near Midway	01/04/90	.03
	08/29/90	.23
Elkhorn Creek at Frankfort	08/29/90	.06
Kentucky River at Lock 2	07/13/90	.01
Eagle Creek at Lusbys Mill	08/29/90	.01
Malathion		
North Elkhorn Creek near Georgetown	01/04/90	.03
	08/29/90	.03
South Elkhorn Creek near Midway	08/29/90	.01
Parathion		
North Elkhorn Creek near Georgetown	01/04/90	[a].08
<u>Herbicides</u>		
Atrazine		
Red River at Clay City	07/12/90	.4
Kentucky River at Lock 10	07/12/90	.3
North Elkhorn Creek near Georgetown	08/29/90	.1
Kentucky River at Lock 2	07/13/90	.3
2,4-D		
Red River at Clay City	07/12/90	.69
Kentucky River at Lock 10	07/12/90	.09
North Elkhorn Creek near Georgetown	08/29/90	.05
South Elkhorn Creek near Midway	08/29/90	.47
Elkhorn Creek at Frankfort	08/29/90	.13
Kentucky River at Lock 2	07/13/90	.05
Eagle Creek at Lusbys Mill	08/29/90	.03

Table 15. Concentrations of pesticides detected in water samples from streams in the Kentucky River Basin, 1990--Continued

Pesticide and sample site	Date	Concentration, in micrograms per liter
Dicamba		
South Elkhorn Creek near Midway	08/29/90	0.03
Prometon		
North Elkhorn Creek near Georgetown	08/29/90	.1
South Elkhorn Creek near Midway	01/04/90	.1
	08/29/90	.6
Elkhorn Creek at Frankfort	08/29/90	.2
Simazine		
Red River at Clay City	07/12/90	.1
Kentucky River at Lock 10	07/12/90	.2
Kentucky River at Lock 2	07/13/90	.1

[a]Concentrations exceed Maximum Contaminant Levels for acute and (or) chronic aquatic life criteria (U.S. Environmental Protection Agency, 1992).

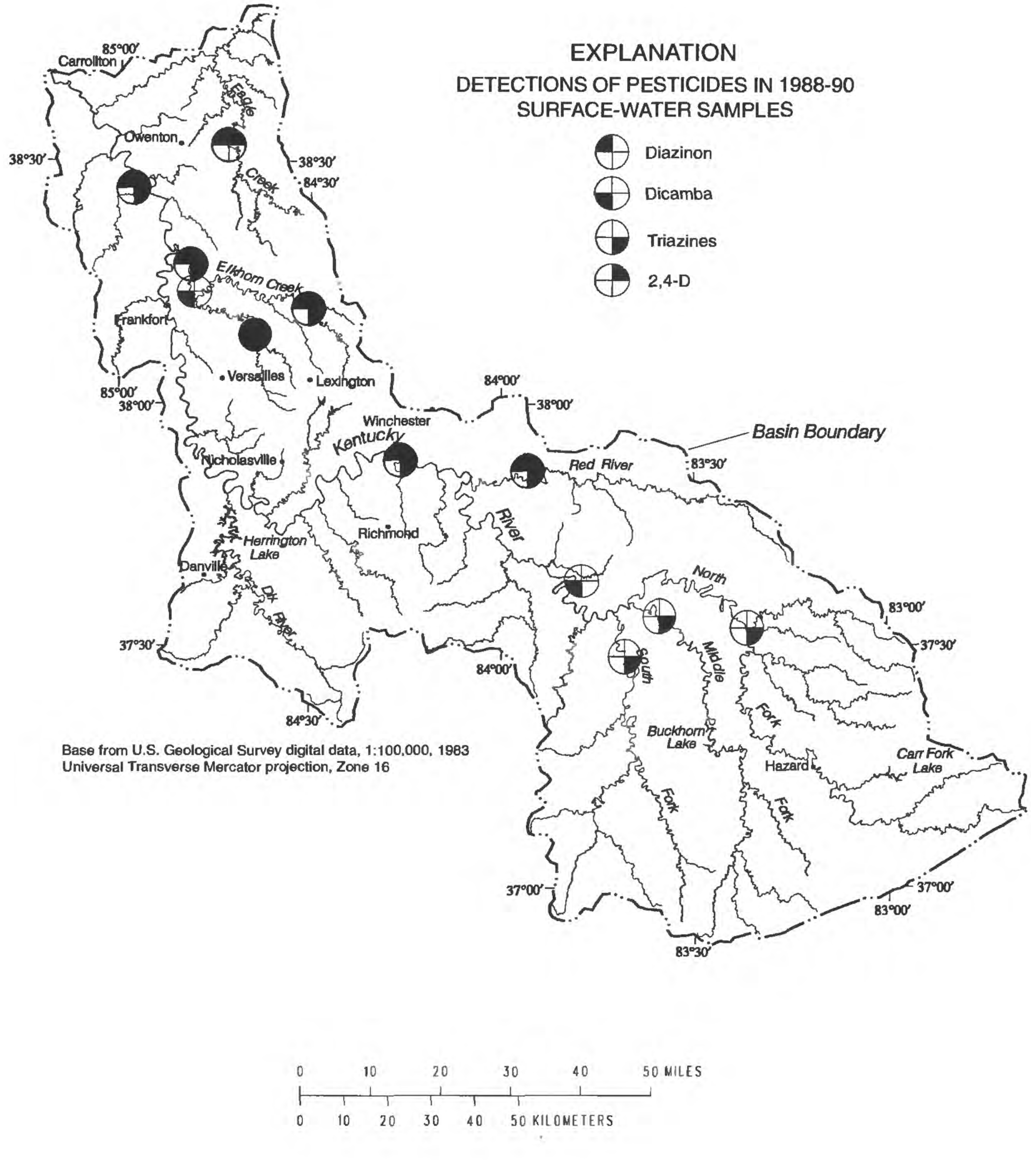

Figure 47. Detections of pesticides in surface-water samples in the Kentucky River Basin, 1988-90.

Malathion and parathion were often detected in the Elkhorn Creek Subbasin in all 3 years; concentrations ranged from 0.01 to 0.14 µg/L and 0.08 to 0.11 µg/L, respectively. These compounds are relatively short lived in the environment (Biggar and Seiber, 1987), but they are used widely in agriculture, home gardens, and mosquito-abatement programs. Chlorpyrifos, which is used for house parasites and some insects of crops (including corn and tobacco), was detected only in 1990 in South Elkhorn Creek at Midway (0.02 µg/L). Organochlorine insecticides were not detected in water samples in this study. The very low solubility of these compounds in water makes it unlikely that they would be present at levels above the reporting limits (Butler, 1987).

Several herbicides were detected in surface-water samples in the basin (fig. 47), principally in 1989 (tables 14 and 15). Among the triazine herbicides were atrazine, cyanizine, simazine, and metribuzin. Atrazine was found throughout the basin, including the North, Middle, and South Forks of the Kentucky River. Atrazine is the most heavily used herbicide in the United States and is extensively used in the Kentucky River Basin for selective weed control in corn production. Atrazine is moderately to highly mobile in soils ranging from clay to gravelly sand (D.A. Goolsby, U.S. Geological Survey, written commun., 1992), and frequent detections in surface-water samples would be expected, particularly after seasonal application to crops. Numerous detections of atrazine were recorded in the Elkhorn Creek Subbasin. Although concentrations rarely exceeded 0.5 µg/L, water samples collected in June 1989 from North Elkhorn Creek near Georgetown had unusually high concentrations of atrazine (16.0 µg/L) and simazine (4.5 µg/L). These high concentrations are similar to those found by Goolsby and others (1991) in the Mississippi River. Goolsby and others (1991) reported atrazine residues throughout the year; however, the highest atrazine concentrations occurred in May and June, presumably after postapplication rainfall flushing in late spring and early summer.

Prometon, another triazine herbicide approved for use on perennial broadleaf weeds and grasses, was found at several sites in the Elkhorn Creek Basin. Prometon is the only herbicide commonly used on tobacco that was detected in this study.

The herbicide 2,4-D was present in multiple samples collected in the Elkhorn Creek Subbasin, as well as in samples from the Red River, the Kentucky River at Locks 10 and 2, and in Eagle Creek at Lusbys Mill. Although 2,4-D is widely used to control broadleaf weeds in cereal crops, such as corn, wheat, alfalfa, and soybeans, it degrades within 1 to 4 weeks under field conditions (Howard, 1991).

Alachlor and metolachlor, which are significantly less persistent than atrazine (Perry, 1991; Thurman and others, 1992), were found in Elkhorn Creek and Eagle Creek in 1989. Alachor and metolachlor are used on corn and soybeans; the latter is mobile in soil and available in surface-water runoff (U.S. Environmental Protection Agency, 1991). Dicamba was found in the Elkhorn Creek Subbasin at low concentrations (0.02-0.03 µg/L), and in Big Sinking Creek at a higher concentration (0.4 µg/L). Dicamba is used to control broadleaf weeds in field and silage corn, as well as on noncrop areas such as fence rows, roadways, and wastelands. Picloram, a restricted-use herbicide used on grassland and rights-of-way for powerlines, was found at only one site, South Elkhorn Creek near Midway. Metribuzin, used on alfalfa and soybeans, was found in only one sample, from North Elkhorn Creek near Georgetown.

The concentrations of pesticides seldom exceeded the established Maximum Contaminant Levels (MCL's) in the USEPA Drinking Water Health Advisory (U.S. Environmental Protection Agency, 1991) and acute and chronic Aquatic Life Criteria (U.S. Environmental Protection Agency, 1986) (tables 14 and 15). Malathion and parathion were found in South Elkhorn Creek near Midway at concentrations exceeding MCL's for aquatic life, whereas atrazine was found at concentrations exceeding MCL's for drinking water in North Elkhorn Creek near Georgetown. Concentrations of atrazine may periodically be sufficiently high to affect the biotic integrity of streams in the Kentucky River Basin, as indicated in studies of direct and indirect effects of this herbicide on stream biota (deNoyelles and others, 1982; Dewey, 1986; Veber and others, 1981).

<u>Accumulation in streambed sediments</u>

Many organic compounds have a low solubility in water and tend to adsorb to particulate matter. Streambed sediments in the Kentucky River Basin were analyzed for pesticides at 25 sites in November 1988 (table 16; fig. 48).

Organochlorine insecticides were detected in streambed sediments at numerous sites in the basin. These compounds account for less than 10 percent of all insecticides used in the United States, but they are highly persistent and tend to remain in the environment long after their initial application. The cyclodiene insecticides--including aldrin, chlordane, dieldrin, endrin, endosulfan, heptachlor, heptachlor epoxide, and lindane--were commonly detected, particularly in the lower end of the basin (fig. 48). Chlordane was found at concentrations from 59.4 to 269.0 μg/kg in Hickman Creek, Town Fork, Town Branch, Glenns Creek, and North Elkhorn Creek (table 16). Although chlordane is no longer used for termite control, it is highly persistent in the environment and is fairly common near residential or urban land use. Heptachlor was detected at eight sites, principally in the lower end of the basin. Concentrations of heptachlor, a restricted-use insecticide used principally for termite control, ranged from 1.1 to 33.8 μg/kg (table 16). Endosulfan was detected at only two sites in the basin in 1988; however, the agricultural use of endosulfan increased in the state by about 65 percent from 1990 to 1992 (University of Kentucky, 1993b), and detections in streambed-sediment samples in agricultural areas may also increase.

The occurrence of DDT in the Kentucky River Basin is notable because DDT has been banned in the United States since 1973. It was present in two streambed-sediment samples at concentrations ranging from 3.8 to 8.8 μg/kg (table 16). DDE, a degradation product of DDT, was found in four samples at concentrations ranging from 2.7 to 55.9 μg/kg. Both of these compounds are relatively insoluble in water and tend to associate with streambed sediments, where they can remain for years.

Table 16. Maximum concentrations of pesticides detected in streambed-sediment samples from streams in the Kentucky River Basin, 1988

Pesticide and sample site	Date	Concentration, in micrograms per kilogram
<u>Organochlorine insecticides</u>		
Aldrin		
North Fork Kentucky River at Jackson	11/15/88	3.3
South Fork Kentucky River at Booneville	11/15/88	2.0
Horse Creek near Hima	11/14/88	22.0
Eagle Creek at Lusbys Mill	11/16/88	3.5
Arochlor 1242		
South Fork Kentucky River at Booneville	11/15/88	46.2
Eagle Creek at Lusbys Mill	11/16/88	57.8
Arochlor 1260		
Hickman Creek near Mills	11/16/88	130.0
BHC-Alpha isomer		
South Fork Kentucky River at Booneville	11/15/88	.9
Chlordane		
Hickman Creek near Mills	11/16/88	59.4
Town Fork near Nicholasville	11/16/88	84.8
Glenns Creek near Versailles	11/16/88	96.6
North Elkhorn Creek at Bryan Station	11/15/88	269.0
Town Branch near Lexington	11/16/88	97.0
DDE		
Kentucky River at Lock 10	11/15/88	10.4
Town Branch near Lexington	11/16/88	55.9
Kentucky River at Lock 2	11/17/88	8.9
Eagle Creek at Lusbys Mill	11/16/88	2.7
DDT		
North Fork Kentucky River at Blackey	11/14/88	3.8
Horse Creek near Hima	11/14/88	8.8
Dieldrin		
Glenns Creek near Versailles	11/16/88	16.9
Endosulfan		
Horse Creek near Hima	11/14/88	3.8
Eagle Creek at Lusbys Mill	11/16/88	1.9

Table 16. Maximum concentrations of pesticides detected in streambed-sediment samples from streams in the Kentucky River Basin, 1988--Continued

Pesticide and sample site	Date	Concentration, in micrograms per kilogram
Endrin		
Kentucky River at Lock 10	11/15/88	12.7
Town Branch near Lexington	11/16/88	93.6
Heptachlor		
Lotts Creek near Darfork	11/14/88	1.1
Otter Creek at Redhouse	11/15/88	9.5
Hickman Creek near Mills	11/16/88	22.9
Town Fork near Nicholasville	11/16/88	14.6
Glenns Creek near Versailles	11/16/88	13.6
North Elkhorn Creek at Great Crossing	11/16/88	17.7
Town Branch near Lexington	11/16/88	33.8
Eagle Creek at Lusbys Mill	11/16/88	3.2
Heptachlor epoxide		
Town Branch near Lexington	11/16/88	28.1
Lindane		
South Fork Kentucky River at Booneville	11/15/88	1.2
Hickman Creek near Mills	11/16/88	3.2

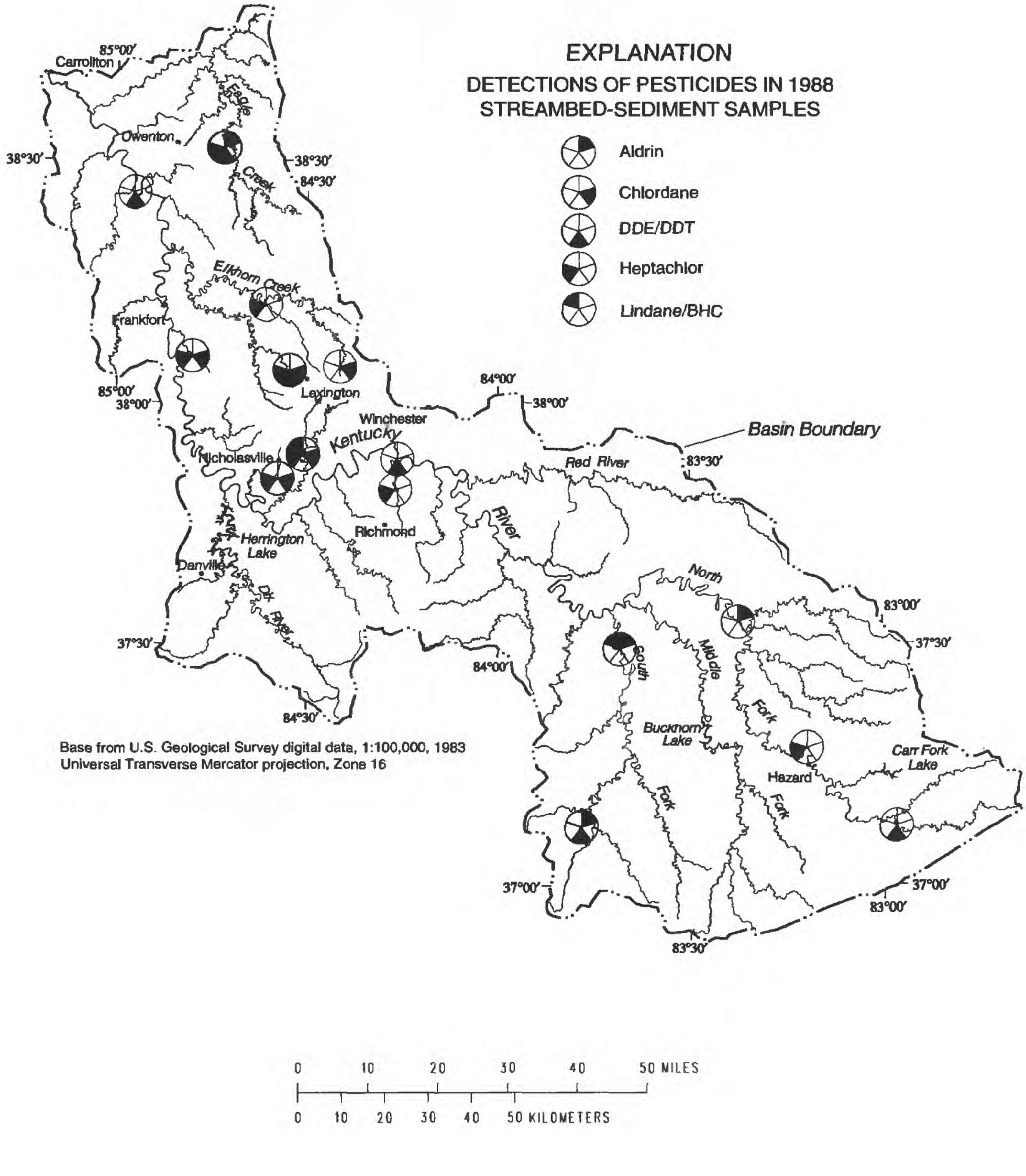

Figure 48. Detections of pesticides in streambed-sediment samples in the Kentucky River Basin, 1988.

Currently (1994), standards or criteria have not been established for pesticides in bottom material by USEPA. These compounds can and do solubilize, however, and may be chronically present in the water column at low levels. The presence of pesticides in the water column solubilized from bed sediments at levels below the detection limits can be of concern because of the tendency of pesticides to bioaccumulate in the fat and tissues of aquatic animals. Studies in the San Joaquin River and its tributaries reported measurable levels of DDD, DDE, and DDT in fine-grained bed sediments associated with undesirable levels in fish from the San Joaquin River (Gilliom and Clifton, 1987). Investigators in the San Joaquin River study estimated concentrations of selected organochlorine pesticides in water from measured concentrations in bed sediments. In the case of dieldrin, a measured concentration of 8.9 μg/kg resulted in an estimated water concentration of 0.004 μg/L, which exceeds the aquatic-life criterion for this compound (U.S. Environmental Protection Agency, 1986). A dieldrin concentration of 16.9 μg/kg was found in streambed sediments in Glenns Creek at Versailles, indicating possible concentrations in water that exceed aquatic-life criteria in the Kentucky River Basin. Concentrations of chlordane in surface water that exceed aquatic-life criteria might also be expected on the basis of concentrations in streambed sediments near Lexington.

Occurrence of Pesticides in Fish and Macroinvertebrate Tissue

Studies on the Mississippi River and some of its tributaries have indicated that numerous chlorinated pesticides and hydrocarbons can be found in fish tissue even though pesticide concentrations in the water are below detection limits (Leiker and others, 1991). Although the study design of the Kentucky River NAWQA project did not include tissue analyses, other studies in the basin indicate that certain pesticides are present and may affect the biota. Data collected by the KDOW illustrate the utility of multiple lines of evidence to determine the presence of pesticides. Sediment samples collected from eight sites in the Kentucky River below Bailey Run contained no detectable concentrations of pesticides, whereas fish tissue collected from the same sites contained detectable concentrations of chlordane, DDD, DDE, DDT, and dieldrin (Kentucky Natural Resources and Environmental Protection Cabinet, 1988b). Detectible concentrations of dieldrin, DDT, and chlordane were found in fish-tissue samples from the Red River near Hazel Green in 1986, whereas analyses of biological communities in this reach of the Red River generally indicated acceptable water quality (Bradfield and Porter, 1990).

Other examples of pesticides in tissues are available in the Kentucky River Basin. The KDOW reported chlordane residues of 320 μg/kg and 440 μg/kg in fish-tissue samples collected from the Kentucky River below Frankfort in 1984 (Kentucky Natural Resources and Environmental Protection Cabinet, 1986). These concentrations are slightly above U.S. Food and Drug Administration action levels of 300 μg/kg. Tissues of three species of fishes at two sites in South Elkhorn Creek contained detectable concentrations of chlordane, dieldrin, DDT, DDE, and DDD (Kentucky Natural Resources and Environmental Protection Cabinet, 1983). Fish tissue from Eagle Creek contained detectible concentrations of chlordane, PCB's, DDT, and methoxychlor (M.R. Mills, Kentucky Division of Water, written commun., 1988).

A small-scale sampling of the Asiatic clam *Corbicula fluminea* was done in this NAWQA study in Elkhorn Creek near Frankfort in April 1992 to gain an understanding of the accumulation of pesticides in macroinvertebrate tissue. Tissue samples were pooled, and seven subsamples were analyzed for organochlorine insecticides. DDE was present at a concentration of 5.15 μg/kg, and nonachlor at 9.89 μg/kg. Lindane (gamma HCH) was present at 4.67 μg/kg, and chlordane was detected at 9.66 μg/kg. Heptachlor epoxide, endrin, and DDD were detected at or below reporting levels. These compounds were all found in bed sediment at sites in the Kentucky River Basin in the course of the NAWQA project; however, none were found at the Elkhorn Creek at Frankfort site. These data illustrate the utility of tissue analyses as a compliment to bed-sediment analyses to ascertain the occurrence and distribution of hydrophobic pesticides.

Relation of Pesticides to Land Uses and Other Human Activities

Pesticides in surface water in the Kentucky River Basin can originate from many sources. These include, but are not limited to, application of herbicides and insecticides to agricultural cropland, use of herbicides on golf courses and other recreational turf, residential herbicide and pesticide use, and application of insecticides for urban mosquito control.

Agricultural land use

The use of agrichemicals can be inferred from an examination of the distribution of cropland in conjunction with an analysis of information on agricultural pesticide sales. The distribution of agricultural croplands in the Kentucky River Basin is shown in figure 22. These distributional patterns are noteworthy because they indicate probable patterns of pesticide application, based on common practice. Wide-scale use of agricultural chemicals is confined to production of corn, soybeans, tobacco, alfalfa, and wheat. Areas lying within the Inner and Outer Bluegrass Region are important agricultural areas--particularly for livestock and tobacco (figs. 23 and 24)--but most farms are general-purpose operations that raise a mix of forage crops, tobacco, and grains. For example, the ratio of row crops (corn, soybeans, wheat, alfalfa, and tobacco) to total agricultural acreage is relatively low in Henry County (15 percent), Fayette County (13 percent), Scott County (9 percent), Clark County (8 percent), and Madison County (6 percent) (University of Kentucky, 1993a). Therefore, the extensive acreages of single-row crops found elsewhere, which involve the use of large amounts of pesticides, would not be expected in the Kentucky River Basin.

Corn and other row crops are common in the upper part of the Kentucky River Basin, although agriculture is not the dominant land use. Row crops are commonly found along streams. Detections of pesticides such as atrazine and 2,4-D in streams in Breathitt, Lee, and Owsley Counties indicate that although the percentage of land use devoted to agriculture may be small, the possibility for contamination of streams does exist, particularly where agricultural land is adjacent to streams.

Agricultural sales data summarize the use of numerous pesticides in the counties within the basin. By assuming that the point of application is near the point of sale, one can infer patterns of agricultural application of these chemicals. The counties of Clark, Fayette, Madison, and Scott all had relatively high agricultural sales of several commonly used herbicides (figs. 49-51) and insecticides (figs. 52-53) in 1989. Many of the detections of pesticides in the Kentucky River Basin occurred in counties of the Bluegrass Region where agricultural land use is dominant. However, the limited frequency and distribution of our sample sites prohibits the definition of cause and effect relations between application patterns and occurrence in water and streambed sediments.

Urban land use

The use of certain pesticides can be linked to patterns of urban land use. The counties with the greatest population (>20,000) in the Kentucky River Basin include Clay, Fayette, Franklin, Jessamine, Letcher, Madison, Perry, and Scott (fig. 5). All these counties have at least one urban population center. As noted previously, population distribution has changed over the last 10 years, with density increasing in urban areas and decreasing in rural areas. When urbanization occurs, increased residential pesticide application can be expected not only from homeowners but also from certified pesticide applicators. A concomitant increase in pesticide use on golf courses, cemeteries, school grounds, public parks, and roadside turf is frequently observed. Turf-maintenance expenses in Kentucky in 1989 included expenditures on pesticides of $11,076,000 (Kentucky Agricultural Statistics Service, 1991), indicating the magnitude of pesticide application.

Statistical data on residential sales of pesticides by retail outlets are not available. Estimates of pesticide application by certified applicators employed by commercial lawn-care firms are available. The principal pesticides applied by lawn-care companies and found in water samples collected in the Kentucky River Basin in 1990 are summarized by county in table 17. In the counties of Fayette, Franklin, Jessamine, Scott, and Woodford, which are all relatively urbanized, sales of pesticides used by commercial lawn-care companies were considerable, and detection sites for herbicides and organophosphate insecticides were numerous. However, limitations in the number and distribution of sample sites preclude statistical analyses of these data.

The occurrence of DDT in sediment samples in the Kentucky River Basin may be linked in part to residential pesticide use. Although not approved for sale and use as a principal active ingredient, DDT is a component, or known impurity, of approved commercial products that contain other principal active ingredients. For example, DDT may constitute as much as 15 percent of Kelthane (dicofol) (Miller, 1988). In 1982, an estimated 1,166,099 lb active ingredient of dicofol were imported and used in the United States. According to the Kentucky Division of Pesticides (Ernest Collins, written commun., 1993), there were no agricultural sales of Kelthane in Kentucky during 1990-91; however, eight commercial applicators sold or applied Kelthane in lawn-care operations in 1991, and one of these operations was in Fayette County in the Kentucky River Basin.

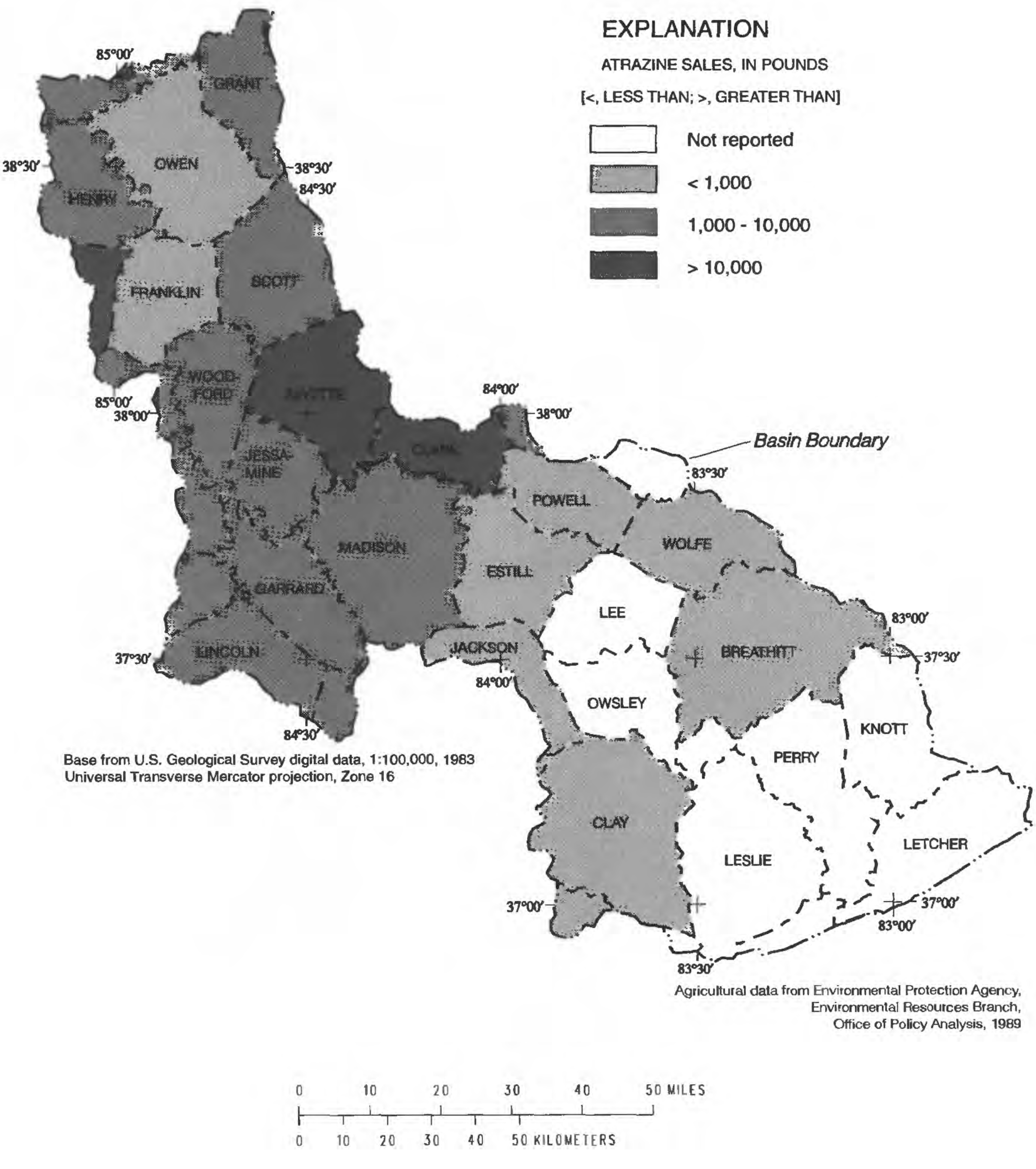

Figure 49. Agricultural sales of atrazine, by county, in the Kentucky River Basin, 1989.

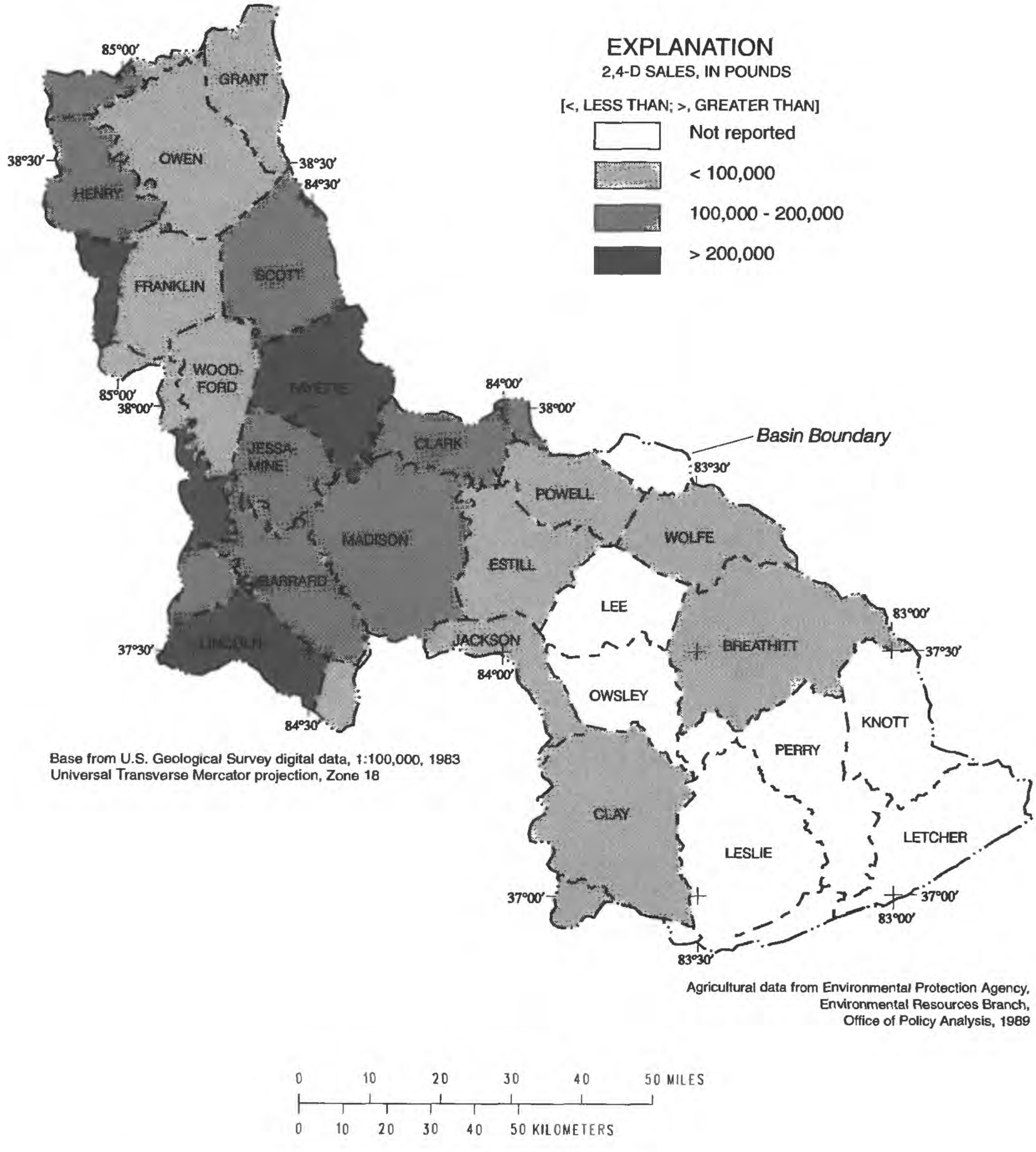

Figure 50. Agricultural sales of 2,4-D, by county, in the Kentucky River Basin, 1989.

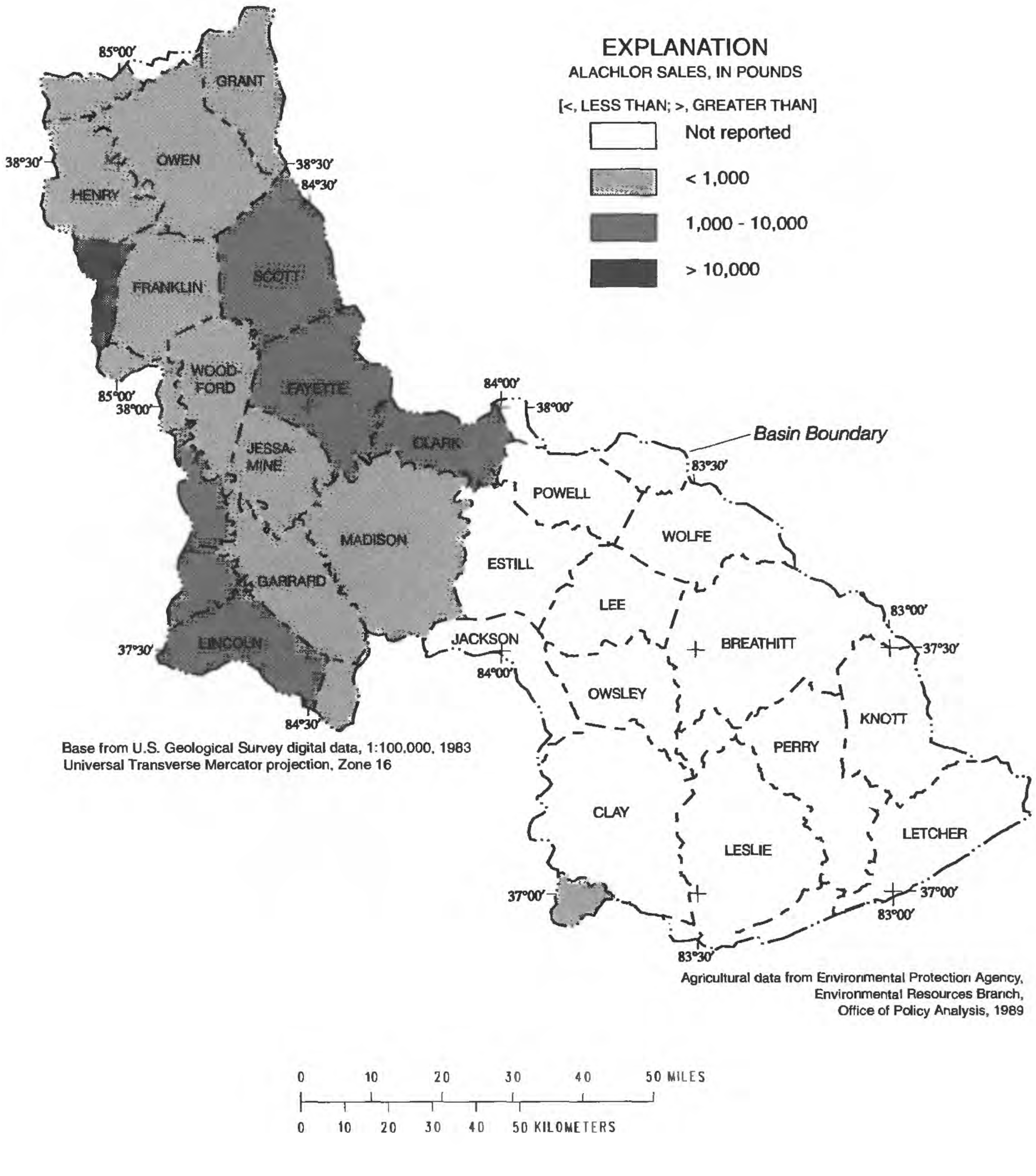

Figure 51. Agricultural sales of alachlor, by county, in the Kentucky River Basin, 1989.

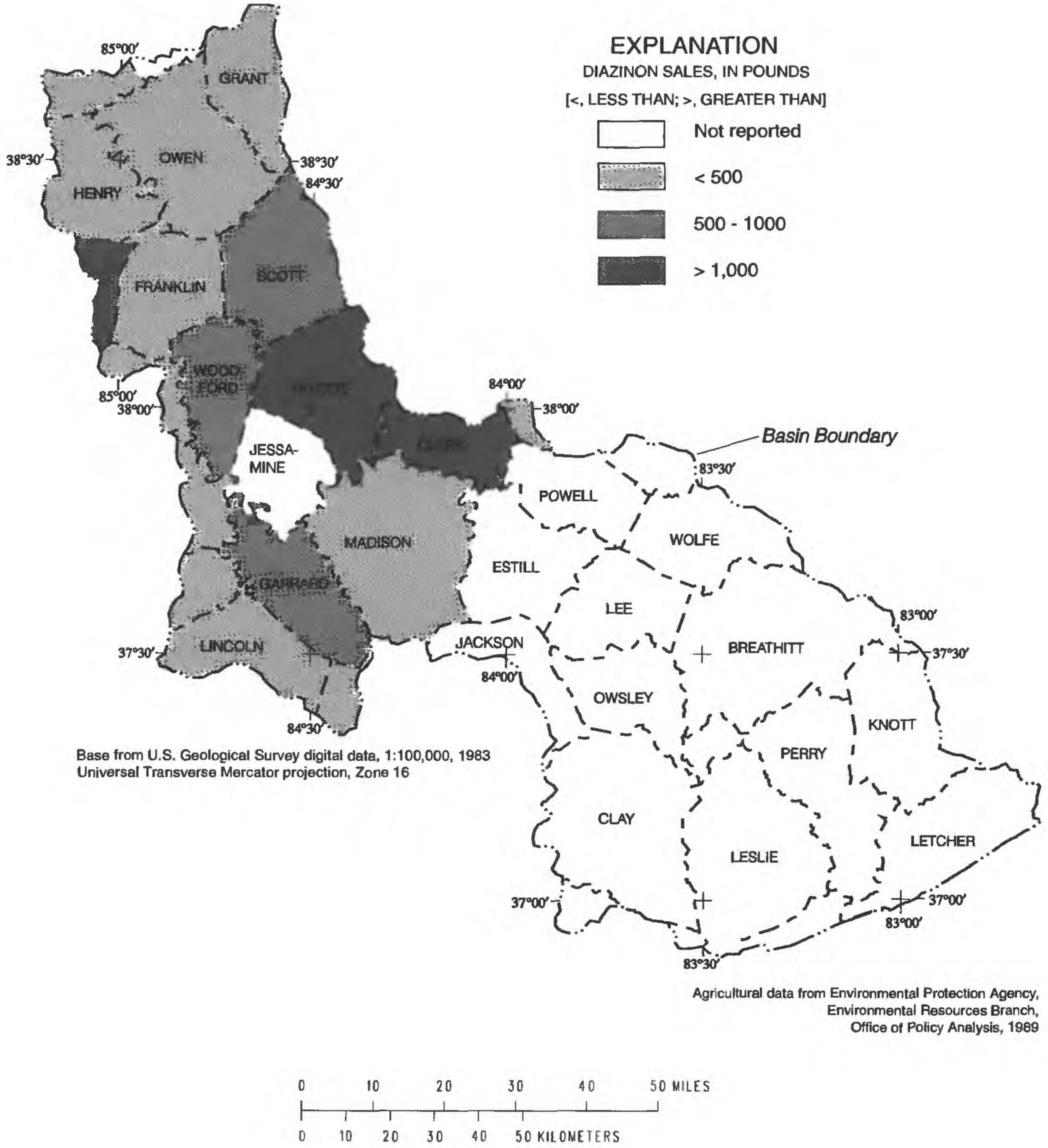

Figure 52. Agricultural sales of diazinon, by county, in the Kentucky River Basin, 1989.

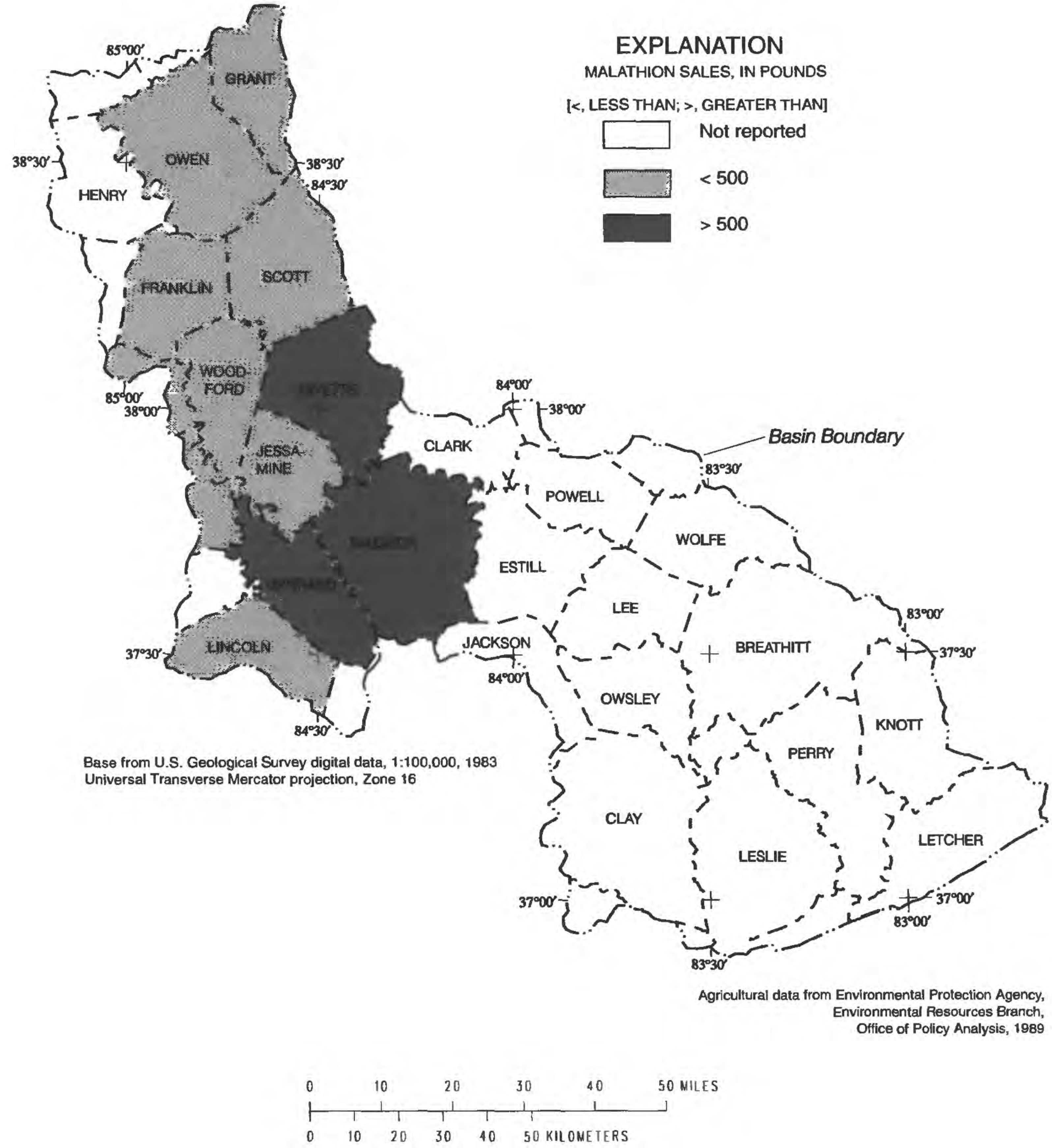

Figure 53. Agricultural sales of malathion, by county, in the Kentucky River Basin, 1989.

Table 17. Estimated use of selected herbicides and insecticides by lawn-care companies in counties of the Kentucky River Basin, 1990

[--, not used; Data from Kentucky Division of Pesticides, 1990, "LAWN" data base. Counties in the Kentucky River Basin not listed in the table had no lawn-care companies reporting pesticide-use data; active ingredients listed include only those for which analyses were done in the National Water Quality Assessment Program pesticide surveys]

County	Active ingredient, in pounds							
	2,4-D	2,4-DP	2,4-D amine	Dicamba	Prometon	Chlorpyrifos	Diazinon	Malathion
Boyle	--	--	18.0	7.6	--	--	--	--
Clark	--	--	76.5	32.3	--	--	5.0	--
Fayette	3,369	231	--	1,327	--	2,264	1,440	2.5
Franklin	1,319	--	--	125	--	--	22.5	--
Garrard	--	--	148	62.7	10.0	--	30.0	--
Henry	61.7	--	--	26.0	--	--	13.0	10.0
Jessamine	2,274	--	--	449	4.0	350	175	--
Madison	184	--	--	16.5	--	--	15.3	1.5
Scott	1,710	--	--	--	--	--	1,700	--
Woodford	557	--	--	21.0	--	--	28.5	--

SUMMARY AND CONCLUSIONS

The U.S. Geological Survey collected water and sediment samples from streams in the Kentucky River Basin, Kentucky, during April 1987-March 1990 as part of the National Water Quality Assessment Program. Seven fixed stations were sampled monthly during the study period. A total of 75 synoptic sites were sampled during low flow (August 1987 and August 1988), when the effects of point-source discharges were predominant. Samples from throughout the 7,000 mi^2 basin were analyzed for concentrations of nutrients, suspended sediment, and pesticides. Chlorophyll a concentrations and algal cell densities also were measured at several synoptic sites. Mean annual loads and yields of water-quality constituents were estimated at sites where at least 2 years of streamflow data had been collected. Efforts were made to identify factors affecting instream concentrations and loads of constituents.

Generally, nutrient concentrations at the fixed stations did not vary significantly from year to year. Concentrations of total ammonia and organic nitrogen ranged from less than 0.2 mg/L to 3.4 mg/L at these sites, whereas concentrations of dissolved nitrite plus nitrate nitrogen ranged from less than 0.01 mg/L to 8.5 mg/L. Total phosphorus concentrations ranged from less than 0.01 mg/L to 5.7 mg/L. At the Elkhorn Creek at Frankfort station, however, total phosphorus and total nitrogen concentrations appeared to be higher in 1987 than in the other years.

Estimates of mean annual total phosphorus loads at the fixed stations were relatively low in the upper end of the basin, ranging from 32.6 tons in the Middle Fork of the Kentucky River at Tallega to 94.2 tons in the North Fork of the Kentucky River at Jackson. Phosphorus loads were an order of magnitude higher (1,920 tons) at the most downstream site (Kentucky River at Lock 2). Estimates of the mean annual load of dissolved nitrite plus nitrate nitrogen ranged from 192 tons in the Middle Fork of the Kentucky River at Tallega to 9,170 tons in the Kentucky River at Lock 2. Mean annual yield estimates for total phosphorus and for nitrite plus nitrate nitrogen were highest in Elkhorn Creek at Frankfort (0.95 tons/mi^2 and 5.32 tons/mi^2, respectively), because of upstream discharges of wastewater-treatment-plant (WWTP) effluent.

Although no statistically significant correlations were found between nutrient concentrations and discharge, high concentrations of phosphorus were generally found at high discharges in rural (nonurban) areas where nonpoint-source runoff is dominant. High concentrations of total nitrogen were found at both the upper and lower extremes of discharge in the lower part of the basin near the mouth of the Kentucky River, reflecting the combined effects of point and nonpoint sources of constituents. Significant correlations were found between concentrations of total phosphorus and suspended sediment. At many sampling sites in urban areas, most of the stream nitrogen load was attributable to WWTP discharges, even when only a small proportion of the total stream discharge was composed of WWTP discharges. Instream nitrogen concentrations at synoptic sites downstream from WWTP's were among the highest measured in the Kentucky River Basin. For example, concentrations of nitrite plus nitrate nitrogen exceeded 10.0 mg/L in Hickman Creek near Mills and in Clarks Creek near Stewartsville in August 1987 and in Town Branch near Lexington in August 1988.

Significant correlations were not found between land-use type and concentrations of nitrogen forms at the fixed sites. Concentrations of phosphorus, however, were positively correlated with urban and agricultural land use and negatively correlated with forest and mining land use. The high phosphorus content of soils in the Inner and Outer Bluegrass Regions presumably contributes to concentrations of phosphorus in streams of these physiographic regions. No correlations between nutrients and land-use type were indicated at the synoptic sites, although high concentrations of phosphorus were also found in areas where urban or agricultural land use predominated.

Phytoplankton chlorophyll a concentrations in the main stem of the Kentucky River during low flows correlated positively with concentrations of total phosphorus and total ammonia plus organic nitrogen. The positive correlation of chlorophyll a with total ammonia plus organic nitrogen indicates that a considerable proportion of total nitrogen was transported as algal biomass during periods of low discharge. The highest algal cell densities and the highest concentrations of chlorophyll a were found in the lower Kentucky River, downstream from river mile 180. In tributary streams, phytoplankton chlorophyll a concentrations also correlated positively with concentrations of total phosphorus and total ammonia plus organic nitrogen. In August 1987 and August 1988, several streams affected by urban sources of nutrient enrichment contained relatively low concentrations of phytoplankton chlorophyll a, indicating that periphyton probably dominated the algal community in those streams. Streams affected by agricultural sources of nutrients contained higher densities of phytoplankton than streams that drained forested subbasins. Median concentrations of chlorophyll a and algal cell density were significantly lower in streams that drained surface-mined areas than in streams that drained agricultural and urban lands.

Median suspended-sediment concentrations ranged from 18 to 31 mg/L at the main-stem sites. The maximum suspended-sediment concentration in the study area was found in the North Fork of the Kentucky River at Jackson (1,780 mg/L), an area where mining activities are a predominant land use. The median concentration of suspended sediment in Elkhorn Creek at Frankfort (10 mg/L) was the lowest among the fixed stations. The trend in suspended-sediment concentrations during the study was a downstream decrease in the Kentucky River main stem from the headwaters to the mouth. Suspended-sediment concentrations were correlated with discharge at the fixed stations; concentrations were always lower in summer, which is typically a low-flow period, than in any other season of the year. No significant correlations were found between suspended-sediment concentrations and any nutrient forms in the Kentucky River Basin, with the exception of phosphorus. No correlations were found between land use and total suspended-sediment concentrations, although the level of resolution of land-use data may not have been adequate to reflect differences at the subbasin scale. A significant 15-year-long downward flow-adjusted trend in suspended-sediment concentrations was indicated for the Kentucky River at Lock 2. The downward trend may have resulted from the implementation of best management practices to reduce soil erosion from surface-mining and agricultural activities in the Kentucky River Basin.

Atrazine was found in water samples at sites throughout the Kentucky River Basin. Concentrations of triazine herbicides rarely exceeded 0.5 μg/L, but water samples collected in June 1989 from North Elkhorn Creek at Georgetown contained unusually high concentrations of atrazine (16.0 μg/L) and simazine (4.5 μg/L). Other herbicides frequently found were 2,4-D, alachlor, metolachlor, and dicamba. Diazinon, malathion, and parathion were the most frequently detected organophosphate insecticides in water samples, particularly in the Elkhorn Creek Basin. At two sites, concentrations of pesticides in water samples exceeded the USEPA Maximum Contaminant Levels (MCL's) for drinking water (atrazine in North Elkhorn Creek at Georgetown) and acute and chronic aquatic-life criteria (malathion and parathion in South Elkhorn Creek at Midway).

Analyses of streambed-sediment samples resulted in frequent detections of several organochlorine insecticides, including aldrin, chlordane, DDT, DDE, dieldrin, endrin, endosulfan, heptachlor, heptachlor epoxide, and lindane. Chlordane was found at concentrations ranging from 59.4 to 268.7 μg/kg in Hickman Creek, Town Fork, Town Branch, Glenns Creek, and North Elkhorn Creek. Many of the pesticides detected in the Kentucky River Basin were in counties of the Bluegrass Region, where agricultural land use is dominant. Data indicated that residential pesticide application in urban areas in the Bluegrass Region also might affect the distribution of pesticides such as 2,4-D and diazinon in streams.

In conclusion, the temporal and spatial variability of nutrients, suspended sediments, and pesticides in the Kentucky River Basin were affected by numerous factors, including land-use type, agricultural and urban runoff, WWTP discharges, and the distribution of algal populations. Nutrients in WWTP effluent had substantial effects on water quality during low flows in many tributary streams. The temporal variability of nutrients and dissolved oxygen was strongly affected by the presence of algal populations, particularly in the Kentucky River main stem. A large amount of suspended sediment originates in the Eastern Coal Field Region, but contributions of suspended sediment from the Red River and other tributary streams of the Knobs Region also are substantial. Water and streambed-sediment samples collected at sites throughout the basin contained numerous herbicides and insecticides, reflecting agricultural as well as residential pesticide-use patterns.

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