

Surface-Water-Quality Assessment of the Lower Kansas River Basin, Kansas and Nebraska: Selected Metals, Arsenic, and Phosphorus in Streambed Sediments of First- and Second-Order Streams, 1987

By D.Q. TANNER and J.L. RYDER

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U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
GORDON P. EATON, Director

For additional information write to:

District Chief
U.S. Geological Survey
4821 Quail Crest Place
Lawrence, Kansas 66049-3839

Copies of this report can be
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CONVERSION FACTORS

Multiply	By	To obtain
mile	1.609	kilometer
square mile	2.590	square kilometer

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Abstract

The occurrence and geographic distribution of major metals and trace elements was assessed in the lower Kansas River Basin of Kansas and Nebraska by studying the concentrations of metals and nonmetallic elements in the less-than 63-micrometer-sized fraction of streambed-sediment samples from 422 sites on first- and second-order streams. Median concentrations were the same order of magnitude as the geometric mean concentrations in soils of the western United States. Either threshold concentrations or upper percentile classes (greater than 50 percent of concentrations) were determined for 14 metals, arsenic, and phosphorus. Threshold concentrations were determined as the point that the slope of a normal-probability plot increases, indicating data from two different populations. Samples with a concentration greater than the threshold concentration indicated possible enrichment with respect to that particular element. Concentrations of the transition metals, which included chromium, cobalt, copper, manganese, nickel, and vanadium, generally were larger in the southeastern part of the study unit where Permian and Pennsylvanian shale and limestone predominate.

The largest concentrations of the alkali metals, potassium and sodium, mainly were in the northwestern part of the study unit, which is an area of Quaternary loess deposits irrigated with ground water. Large concentrations of the alkaline-earth metal, barium, also were in the

northwestern part of the study unit. Concentrations of the other alkaline-earth metals, calcium, magnesium, and strontium, were larger in the southern part of the basin, which is underlain by Permian and Pennsylvanian shale and limestone. The largest concentrations of arsenic and lead were mainly in the southeastern part of the study unit, an area of Permian and Pennsylvanian shale. Large concentrations of phosphorus in the northwestern part of the study unit probably were due to runoff from irrigated agricultural lands.

INTRODUCTION

During the past two decades, public awareness of the importance of water-quality issues has increased substantially. Along with this increased awareness have come commitments by local, State, and Federal governments and industries for the assessment and protection of water quality. In 1986, the Congress appropriated funds for the U.S. Geological Survey to test and refine a National Water-Quality Assessment (NAWQA) program (Hirsch and others, 1988). The long-term goals of the NAWQA program are to: (1) provide a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources; (2) define long-term trends (or lack of trends) in water quality; and (3) identify, describe, and explain the major factors that affect observed water-quality conditions and trends.

The NAWQA program began with a pilot phase to test and modify assessment concepts and approaches. Seven pilot projects (four surface-water

projects and three ground-water projects) were initiated. The lower Kansas River Basin in Kansas and Nebraska is one of the four surface-water pilot projects (see cover). The lower Kansas River Basin was selected as a pilot project because it is typical of the very productive Midwestern grain belt that includes irrigated and nonirrigated cropland and nonirrigated pasture and rangeland.

Metals, arsenic, and phosphorus are important water-quality components of the lower Kansas River Basin surface-water system. Many of the metallic elements are beneficial or essential micronutrients for plants and animals in small concentrations, yet are toxic in large concentrations. Metals, arsenic, and phosphorus form the matrix of, or are adsorbed to, sediment particles that can be deposited on the bed of a stream. They can become re-suspended or dissolved at a later time.

Purpose and Scope

The purpose of this report is to describe the spatial distribution of concentrations of selected metals, arsenic, and phosphorus in streambed sediments of the lower Kansas River Basin and to relate these concentrations to geologic and human sources to the extent possible. The spatial distributions of large concentrations of 16 elements in 422 streambed-sediment samples collected from first- and second-order streams during September and October 1987 are examined, and these distributions are compared to surficial geology and land use.

Description of Study Unit

The lower Kansas River Basin (fig. 1) drains about 15,300 square miles and coincides with the area defined by the U.S. Water Resources Council as hydrologic subregion 1027 (Seaber and others, 1984). Although 7.5 square miles of this subregion lie within Missouri, drainage from the small area does not affect the quality of water used in the study unit and is not included in the study. The study unit includes the Big Blue River Basin in Nebraska and Kansas, as well as basins of smaller tributaries to the 170-mile Kansas River from Junction City to Kansas City, Kansas.

The Kansas River is formed by the confluence of the Smoky Hill and Republican Rivers at Junction City, Kansas. Three large reservoirs, Tuttle Creek Lake, Perry Lake, and Clinton Lake, lie within the

Kansas part of the study unit. The lower Kansas River Basin has been described in detail by Stamer and others (1987).

The surficial geology of the lower Kansas River Basin is depicted on plate 1. Several of the geologic units on plate 1 have been generalized to the least-specific geologic-age category from the component source maps. The northwest part of the study unit is composed primarily of Quaternary loess deposits, whereas the northeast part is composed primarily of Quaternary glacial drift. A relatively small area in the west-central part of the study unit is composed of Cretaceous sandstone and limestone. The southern part of the study unit consists of Permian and Pennsylvanian shale and limestone. Quaternary alluvium fills the major stream valleys throughout the study unit.

Land use in the lower Kansas River Basin (fig. 2) is predominantly agricultural. Corn, grain sorghum, wheat, and soybeans are the principal crops. The most intensely cultivated and irrigated land is in the northwestern part of the study unit. A 1987 inventory of land use estimates that more than 55 percent of the cropland in the northwestern part of the basin is irrigated (U.S. Soil Conservation Service, written commun., data tables, 1990). Estimates from the same inventory indicate that about 3 percent of the entire study unit is covered by woodlands, whereas nearly 10 percent of the southeastern part of the basin is wooded. Less than 3 percent of the study unit consists of urban or industrial areas. The principal urban developments include part of the Kansas City metropolitan area, Topeka, and Lawrence, Kansas. The large area of rangeland in the south-western part of the study unit accounts for most of the pasture and rangeland that together cover about 25 percent of the basin.

In a previous analysis of available data, Jordan and Stamer (1991) analyzed streambed-sediment data for the lower Kansas River Basin that were collected for the U.S. Department of Energy, National Uranium Resource Evaluation (NURE) Program during 1978 and 1979. They found that barium, sodium, and strontium had median concentrations larger than the geometric means of the corresponding elemental concentrations in soils and surficial materials of the conterminous United States (Shacklette and Boerngen, 1984). Large concentrations of barium were clustered in the northwestern part of the study unit and appeared to be related to the loess deposits there (Jordan and Stamer, 1991).

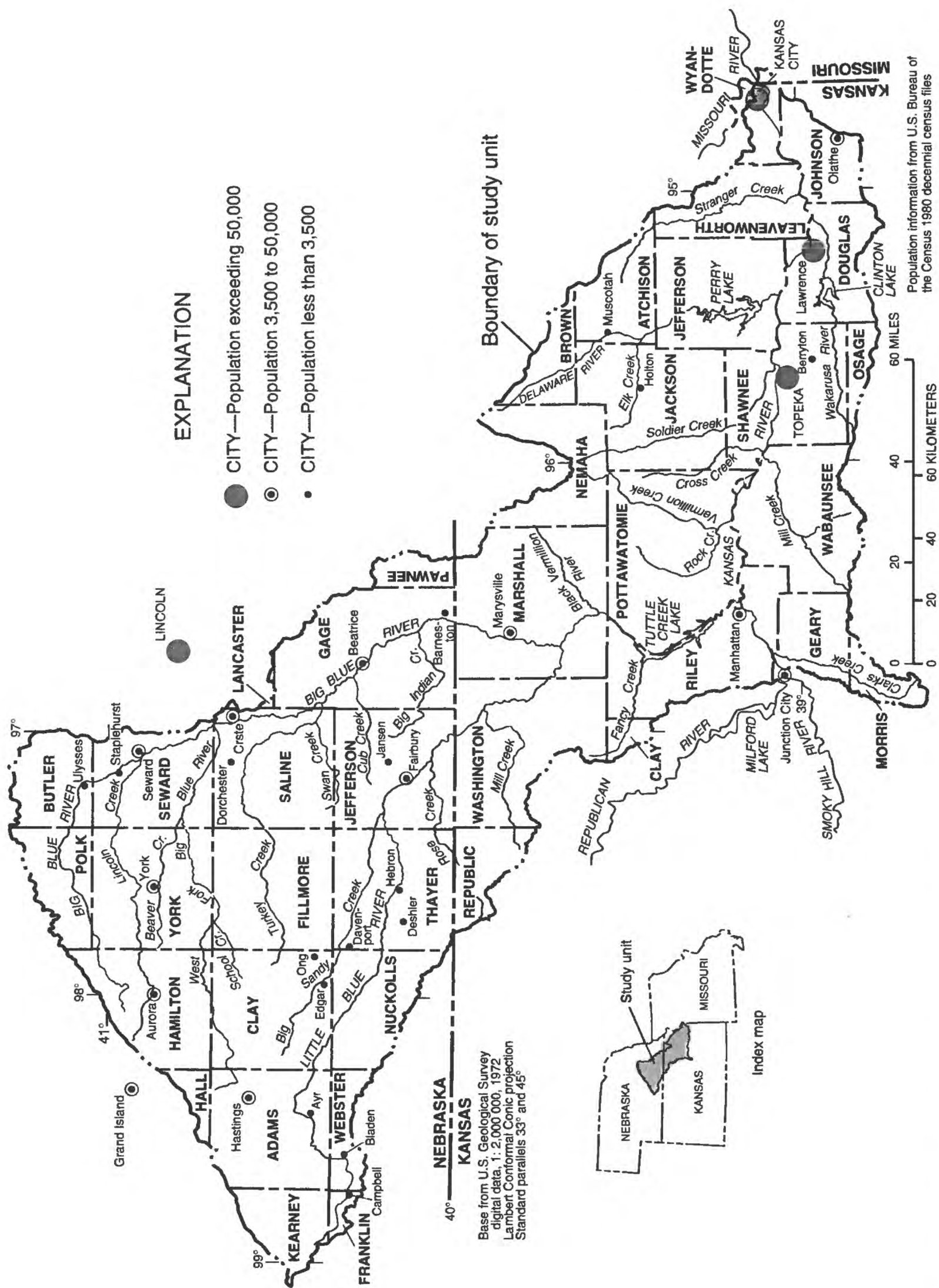


Figure 1. Major streams, surface-water impoundments, cities, and other geographical features in and near lower Kansas River Basin, Kansas and Nebraska (modified from Jordan and Stamer, 1991).

EXPLANATION

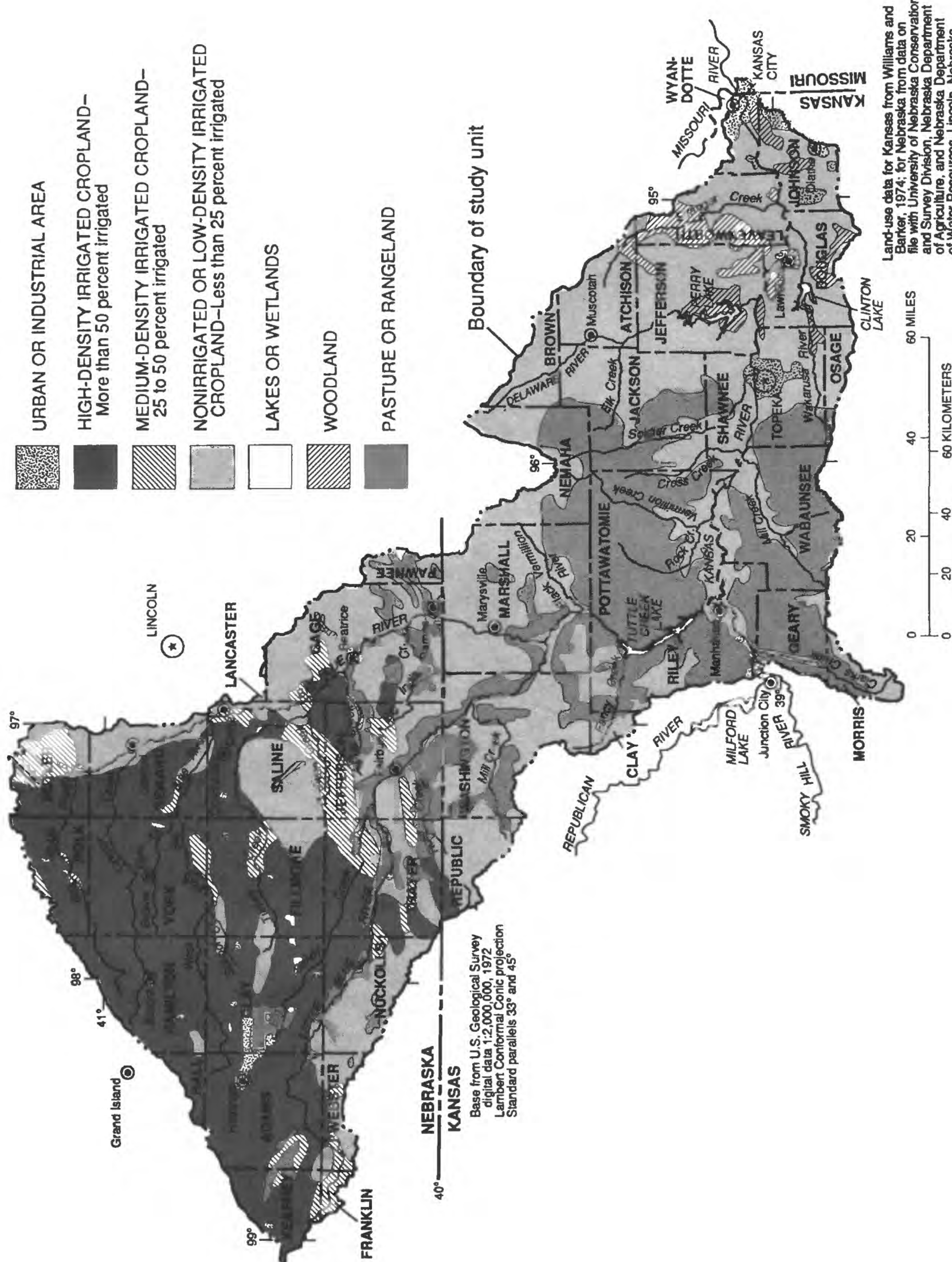
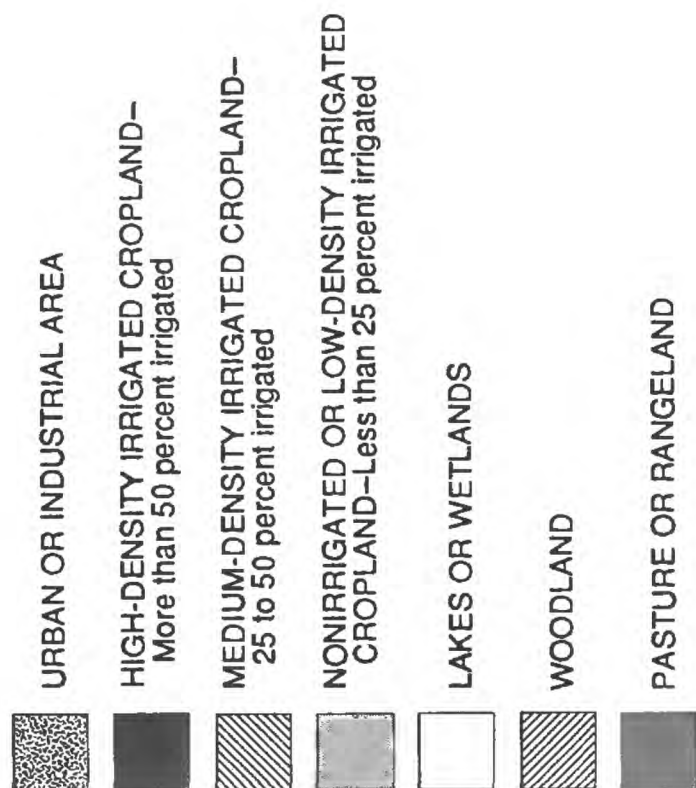


Figure 2. Land use in lower Kansas River Basin (modified from Jordan and Stamer, 1991).

METHODS OF DATA COLLECTION AND ANALYSIS

During September and October of 1987, 422 samples of streambed sediments were collected from first- and second-order streams in the lower Kansas River Basin (plate 1). The sites were selected using an areally stratified-random sampling design. The strata used were 6.21- by 6.21-mile grid cells. First-order streams were determined as those having no tributaries on a 1:24,000-scale U.S. Geological Survey topographic quadrangle. Second-order streams were those that had only first-order streams as tributaries. Forty-seven constituents were analyzed, for the fraction of streambed sediments having a particle diameter less than 63 micrometers, by the U.S. Geological Survey, Branch of Geochemistry Laboratories in Denver, Colorado. The 47 constituents included major and minor elements. Methods of sampling design and sample collection and analysis, along with all original data, are described by Tanner and others (1990).

Quality-assurance protocols for sample-handling procedures, sample preparation, analytical methods, use of instrumentation, and written documentation to be followed in the laboratory are described in Arbogast (1990). In addition to this quality-assurance program, a quality-control program was established for the four surface-water pilot projects in the NAWQA program. Documentation of the quality-control procedures, including results for the reference materials used for the quality-control program, is presented in Sanzolone and Ryder (1989).

Fourteen metals, arsenic, and phosphorus were selected for statistical and graphical analysis (table 1). The 16 elements were selected on the basis of the following factors: (1) having a majority of concentrations greater than the lower level of detection and (2) having an apparent nonrandom spatial pattern among the largest concentrations. Total concentrations of these elements were determined by inductively coupled plasma-atomic emission spectrometry, except for arsenic, which was determined by atomic absorption spectrometry after hydride generation.

For each of the 16 elements, either a threshold concentration or the upper percentile classes (greater than 50 percent) were determined. A sample with a concentration larger than the threshold value could indicate enrichment of the sample from natural or human sources with respect to that particular

element. To determine the threshold concentration, the cumulative probability distribution (or normal-probability plot) of the concentration was inspected to determine if there was an increase in slope (fig. 3). An increase in the slope of a normal-probability plot indicated deviation from a normal distribution and suggested that the data were from two distinct populations. A computer program was used to determine the beginning point of this increase in slope by iteratively performing a linear regression calculation for concentration versus cumulative frequency. The iterations involved gradually increasing an index value, above which concentrations were not included in the regression calculation. The procedure was repeated until the coefficient of determination (r^2) began to decrease. This threshold concentration, although somewhat arbitrary, could be interpreted as the point differentiating the "background" population from the "enriched" population. The location of sites with concentrations equal to or larger than the threshold value was plotted to indicate areas of possible enrichment.

If there was no increase in the slope of the normal-probability plot (fig. 4), the data probably belong to a single population. In this case, even though the data cannot be divided statistically into "enriched" and "background" components, the relatively large concentrations may occur principally in one or more geographic areas. To determine this, the following arbitrary percentile classes were determined: (1) greater than 50th to 75th percentile, (2) greater than 75th to 90th percentile, and (3) greater than 90th to 100th percentile. The location of sites with concentrations included in the upper percentile classes then was plotted.

There are no Federal or State guidelines for interpreting the environmental importance of concentrations of metals, arsenic, and phosphorus in streambed sediments. Although the sampling techniques and geochemical environment for streambed sediments are different from those of soils, it is helpful to consider the concentrations of these elements in soils. Shacklette and Boerngen (1984) summarized the concentrations of 34 elements in soils at 778 sites in the western conterminous United States. Geometric means of concentrations are given in table 1 for those elements described in this report. (Geometric means are used to represent the central tendency of positively skewed frequency distributions.) The abundance of each of the 16 elements in selected rock types also is

Table 1. Median concentrations of selected elements in streambed sediments of first- and second-order streams, lower Kansas River Basin, Kansas and Nebraska, 1987, geometric mean concentrations in soils of the western United States, and abundance in selected rock types

[All values are expressed as total elemental concentrations; $\mu\text{g/g}$, micrograms per gram; g/kg , grams per kilogram. Order of elements corresponds to the order shown on plates 2-4]

Element	Median concentration, in lower Kansas River Basin	Geometric mean concentration in soils of the western United States ¹	Abundance in selected rock types ²		
			Shale	Sand- stone	Carbonate rocks
Transition metals (plate 2)					
Chromium, µg/g	45	41	90	35	11
Cobalt, µg/g	11	7.1	19	.3	.1
Copper, µg/g	15	21	45	1–9	4
Manganese, µg/g	550	380	850	10–90	1,100
Nickel, µg/g	18	15	68	2	20
Vanadium, µg/g	71	70	130	20	20
Alkali and alkaline-earth metals (plate 3)					
Potassium, g/kg	18	³ 18	26.6	10.7	2.7
Sodium, g/kg	8.6	9.7	9.6	3.3	.4
Barium, µg/g	690	580	580	10–90	10
Calcium, g/kg	8.6	18	22.1	39.1	302
Magnesium, g/kg	5.3	7.4	15	7	47
Strontium, µg/g	160	200	300	20	610
Other metals and constituents (plate 4)					
Lead, µg/g	20	17	20	7	9
Zinc, µg/g	56	55	95	16	20
Arsenic, µg/g	6.4	5.5	13	1	1
Phosphorus, µg/g	500	320	700	170	400

¹R.C. Severson, U.S. Geological Survey, written commun., 1987, based on data in Shacklette and Boerngen (1984).

²Parker (1967).

³Mean is arithmetic, not geometric.

shown in table 1. In the sections that follow, selected characteristics are described for each element based on information from Hem (1985) and the U.S. Environmental Protection Agency (1976).

SELECTED METALS IN STREAMBED SEDIMENTS

The location of sites with concentrations equal to or larger than the threshold concentration or concen-

trations in the upper percentile classes (greater than 50 percent) is mapped (plates 2-4) for the following 14 metals: chromium, cobalt, copper, manganese, nickel, and vanadium (plate 2); potassium, sodium, barium, calcium, magnesium, and strontium (plate 3); and lead and zinc (plate 4). Median concentrations of the 14 metals in streambed sediments of the lower Kansas River Basin generally approximated the geometric mean concentrations in soils of the western United States (table 1).

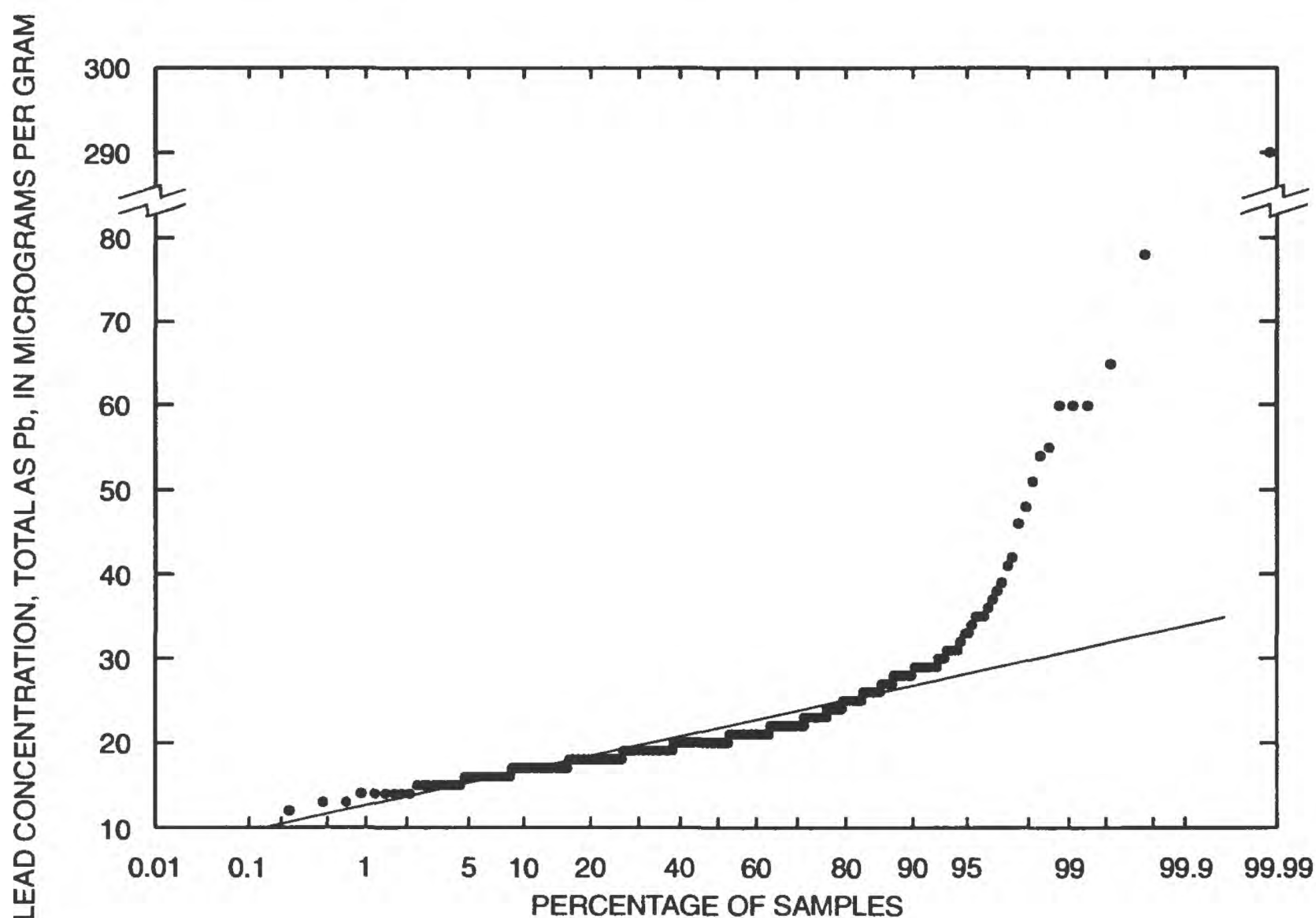


Figure 3. Example of a normal-probability plot with an increase in slope.

Transition Metals

Transition metals are those elements with the atomic numbers 21–29, 39–47, and 72–79 in the periodic table (Mortimer, 1971, p. 647). This group includes chromium, cobalt, copper, manganese, nickel, and vanadium. Their unique characteristics include distinct metallic properties, the occurrence of more than one oxidation state in water, and a tendency to form anionic complexes. The location of sites having concentrations of transition metals equal to or larger than the threshold value or concentrations in the upper percentile classes (greater than 50 percent) is shown on plate 2.

Chromium is a relatively abundant transition metal. It is used in electroplating, paints and dyes, and leather tanning. Although chromium is a trace element essential to humans, its hexavalent form causes

deterioration of mucous membranes (U.S. Environmental Protection Agency, 1976). There was no increase in slope of the normal-probability plot for chromium concentrations; therefore, sites in the upper percentile classes (greater than 50 percent of concentrations) were plotted on plate 2A. The largest concentrations of chromium were prevalent in the southeastern part of the study unit where chromium may occur as a component of shale, which contains a relatively large amount of chromium (table 1).

Cobalt is a rare transition metal. Natural water contains only a few micrograms per liter of cobalt. It is essential for the nutrition of ruminant animals and is required for the fixation of atmospheric nitrogen by the bacteria in legume root nodules. There was no increase in the slope of the normal-probability plot for cobalt concentrations; therefore, the upper percentile classes (greater than 50 percent of concentrations)

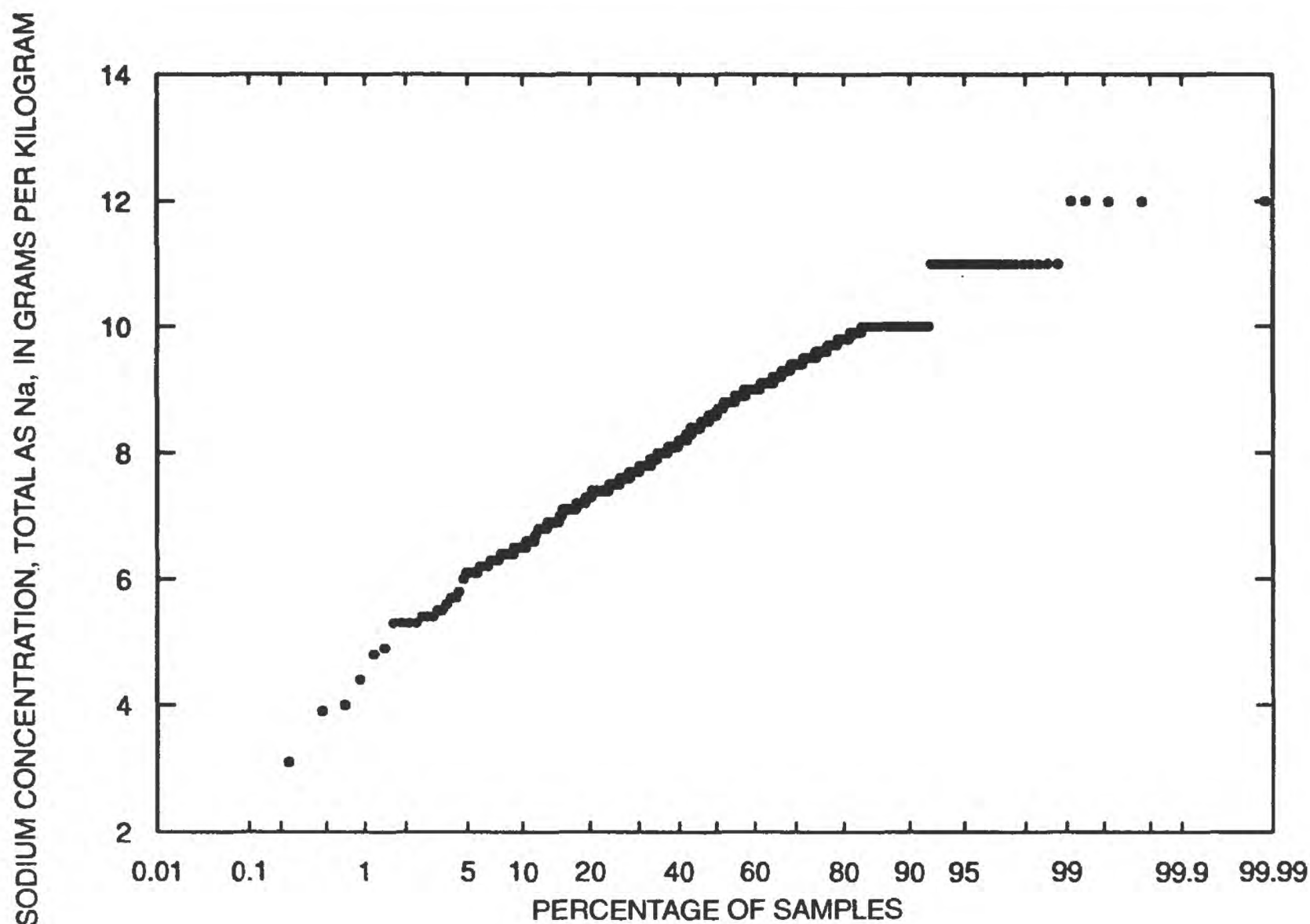


Figure 4. Example of a normal-probability plot with no increase in slope.

were plotted on plate 2B. As with chromium, the largest concentrations of cobalt were prevalent in the southeastern part of the study unit where cobalt also may occur as a component of shale (table 1).

Copper is a relatively abundant transition metal, which occurs both as a native metal and combined with other elements. Copper sulfate is used extensively as an algacide in water-supply reservoirs. Copper is used in electrical products, metal plating, alloys, and fungicides. Although trace amounts of copper are essential to animals and plants, large amounts can be toxic to fish. There was an increase in slope of the normal-probability plot for copper, indicating possible enrichment at concentrations larger than 21 $\mu\text{g/g}$. Most of the concentrations of copper equal to or larger than this threshold value occurred in the southeastern part of the study unit (plate 2C) where

copper may occur in shale, which generally contains a relatively large amount of copper (table 1).

Manganese is a relatively abundant transition metal. It is an essential trace element for both animals and plants, but it can be undesirable in water supplies due to disagreeable taste and laundry staining. Manganese is used in the manufacture of metal alloys, fertilizers, and paint. There was no increase in the slope of the normal-probability plot for manganese concentrations. The upper percentile classes (greater than 50 percent) of manganese concentrations were distributed throughout most of the study unit (plate 2D); however, the largest concentrations generally were in the southeastern part of the basin where manganese may occur as a relatively abundant component of shale and limestone (a carbonate rock) (table 1).

Nickel is a transition metal that rarely occurs in the elemental state. It is used extensively in the manufacture of stainless steel and other alloys. Nickel salts are used in fabric dyeing and in the manufacture of ceramic colors. Nickel is relatively nontoxic to humans, but it can be toxic to aquatic life. There was an increase in the slope of the normal-probability plot for nickel, indicating possible enrichment at concentrations larger than 24 $\mu\text{g/g}$. The largest concentrations of nickel occurred mostly in the southeastern part of the basin (plate 2E) where nickel may be a relatively abundant component of shale and limestone (table 1).

Vanadium is a transition element, the ore of which often is associated with uranium ore. Vanadium is a constituent of coal and petroleum and may be released to the atmosphere during combustion. Some metal alloys are made from vanadium. There was no increase in slope of the normal-probability plot for vanadium concentrations. The uppermost percentile class (greater than 90 percent of concentrations) was slightly more prevalent in the southeastern part of the basin (plate 2F) where vanadium may be present as a relatively abundant component of shale (table 1).

Alkali and Alkaline-Earth Metals

The elements in Group I-A of the periodic table are referred to as alkali metals because they form hydroxides that are strongly basic (Mortimer, 1971, p. 640). This group includes potassium and sodium. Alkali metals are highly metallic; they have a silvery luster, are good conductors of heat and electricity, and are ductile and malleable. Alkali metals are very reactive and do not occur naturally in elemental form.

Alkaline-earth metals are in Group II-A of the periodic chart (Mortimer, 1971, p. 641). This group includes barium, calcium, magnesium, and strontium. Alkaline-earth metals are more dense and have higher melting points than alkali metals. Alkaline-earth metals are not found in their elemental form in nature; they are divalent under natural conditions. The location of sites having concentrations of selected alkali and alkaline-earth metals equal to or larger than threshold values or concentrations in the upper percentile classes (greater than 50 percent) is shown on plate 3.

Potassium is an abundant alkali metal. Although the common salts of potassium are soluble, potassium has a tendency to be reincorporated into stable aluminosilicate clay. Potassium enters surface water from agricultural fertilizers and by the leaching

of plant residues from crops and natural vegetation. Potassium is essential to animals and is one of the three major nutrients required by plants. There was no increase in slope of the normal-probability plot for potassium. The larger concentrations (percentile classes greater than 50 percent) mostly were in the northwestern part of the study unit (plate 3A), which is an area of Quaternary loess deposits irrigated with ground water. In this area, potassium from agricultural fertilizers may have been adsorbed to streambed sediments. The loess particles themselves also may be a source of potassium because relatively young soils, such as loess, generally have more available nutrients (Brady, 1974, p. 300). Because the streambed-sediment samples were digested completely before chemical analysis, it was not possible to differentiate between these two potential sources. Partial digestions of streambed sediments would be needed to make further conclusions about the sources of potassium.

Sodium is another abundant alkali metal. Sodium salts are very soluble; once dissolved, they tend to remain in solution even at large concentrations. Sodium can enter streams from salts used to de-ice roadways. The reuse of irrigation water commonly concentrates sodium on agricultural lands. As with potassium, there was no increase in the slope of the normal-probability plot for sodium, and the larger concentrations of sodium (percentile classes greater than 50 percent) mostly were in the northwestern part of the study unit where loess deposits are common (plate 3B).

Barium is an alkaline-earth metal. The solubility of barium in natural water probably is controlled by barite (BaSO_4), which is nearly insoluble. Barium compounds are used for metallurgical, industrial, and medicinal purposes. There was no change in the slope of the normal-probability plot for barium. Many of the sites with relatively large concentrations of barium (percentile classes greater than 50 percent) were located in the northwestern part of the study unit where loess deposits are common (plate 3C).

Calcium is an abundant alkaline-earth metal. The distribution of calcium in aqueous systems is controlled by the solubility of solids, such as calcium carbonate, and by the carbonate equilibrium system, which includes gaseous carbon dioxide. Calcium is widely distributed in calcareous rock formations such as limestone and is essential to plants and animals. There was an increase in slope of the normal-

probability plot for calcium, indicating enrichment at concentrations larger than 11 g/kg (grams per kilogram). The location of sites with concentrations of calcium equal to or larger than the threshold value (plate 3D) generally corresponds with the areas of shale and limestone in the southern part of the basin. Calcium occurs in larger concentrations in carbonate rocks than in other selected rock types (table 1).

Magnesium is an abundant alkaline-earth metal that occurs in large amounts in most limestone. Magnesium has many industrial and chemical uses, including the fabrication of light metal alloys. It is essential to both plant and animal nutrition. There was an increase in the slope of the normal-probability plot for magnesium larger than a concentration of 7.3 g/kg. Areas of shale and limestone in the southern part of the basin contain streambed sediments with larger concentrations of magnesium as compared to areas of Quaternary loess deposits in the northern part of the study unit (plate 3E).

Strontium is an alkaline-earth metal. The solubility of strontium in natural water is thought to be controlled by the minerals strontianite or celestite. Strontium 90, a radioactive isotope, is a common product of uranium-235 fission. Salts of strontium are used to make fireworks and flares. At strontium concentrations larger than 230 µg/g, there was an increase in the slope of the normal-probability plot. As with calcium and magnesium, areas of shale and limestone in the southern part of the basin contained concentrations equal to or larger than the threshold value (plate 3F). Strontium occurs in greater abundance in carbonate rocks than in other selected rock types (table 1).

Other Metals

In addition to the transition, alkali, and alkaline-earth metals, the metals lead and zinc are of interest. The location of sites having concentrations of lead or zinc larger than the respective threshold values is shown on plate 4.

Lead is released to the environment from mining and smelting activities, from the manufacture of storage batteries, and from lead-bearing paint and plumbing fixtures. Airborne lead can originate from lead-arsenate pesticides and from the combustion of fossil fuels containing lead as an additive. Lead is a cumulative toxin to animal life. The normal-probability plot indicated that lead concentrations

possibly were enriched at concentrations larger than 26 µg/g. Concentrations equal to or larger than this commonly occurred in the southeastern part of the study unit (plate 4A). A possible source of lead is shale, which contains a relatively large amount of lead (table 1).

Zinc is a moderately abundant metal. It is used for galvanizing iron and steel, for the manufacture of metal alloys, and in insecticides. Zinc oxide is a constituent of certain dyes and pigments. Small concentrations of zinc are essential to plants and animals, but in large concentrations it can be toxic to plants and aquatic organisms. Zinc causes a bitter taste in water, making it undesirable in water supplies. The normal-probability plot for zinc showed an increase in slope at a concentration larger than 72 µg/g.

ARSENIC AND PHOSPHORUS IN STREAMBED SEDIMENTS

Median concentrations of arsenic and phosphorus in streambed sediments of the lower Kansas River Basin were approximately the same as the geometric mean concentrations in soils of the western United States (table 1). Arsenic is a nonmetallic element, compounds of which are released into the environment by a variety of industrial and manufacturing processes. Prior to 1968, inorganic forms of arsenic were used as insecticides, herbicides, and fungicides. Organic arsenicals have since replaced inorganic forms in pesticides (Page, 1982, p. 386). There was an increase in the slope of the normal-probability plot for arsenic, indicating possible enrichment at concentrations larger than 8.9 µg/g. Concentrations of arsenic equal to or larger than this threshold value occurred mostly in the southeastern part of the study unit (plate 4C), corresponding to areas of shale. Arsenic generally is more abundant in shale than in some other rock types (table 1).

Phosphorus is a common nonmetal. Due to the small solubility of phosphorus compounds, most phosphorus in streams is associated with suspended sediment. Soil erosion from agricultural lands fertilized with phosphates can increase the concentrations of phosphate suspended in streams. A shortage of phosphate can limit plant growth, and large amounts of phosphate can contribute to algal blooms and eutrophication. The normal-probability plot for phosphorus had a slope increase at 800 µg/g. Most of the sites with phosphorus concentrations equal to or larger than

this threshold value occurred in the northwestern part of the basin (plate 4D), probably as a result of runoff from irrigated agricultural land. Phosphorus fertilizer application rates generally have been largest in the northwestern part of the study unit (fig. 5) where high-density irrigated cropland is present (fig. 2).

CONCLUSIONS

Spatial distributions of concentrations of selected metals, arsenic, and phosphorus in streambed sediments in the lower Kansas River Basin were related largely to surficial geology. Transition metals in streambed sediments generally were more concentrated in the southeastern part of the study unit, which is underlain by Permian and Pennsylvanian shale and limestone. The normal-probability plots for the following elements showed no increase in slope: chromium, cobalt, manganese, and vanadium. These transition metals occur as components of shale and limestone. The normal-probability plots for copper and nickel showed increases in slope, probably indicating enrichment.

Concentrations of the alkali metals potassium and sodium in streambed sediments showed no slope increase in their normal-probability plots. Potassium and sodium were most concentrated in the northwestern part of the study unit, which is an area of Quaternary loess deposits irrigated with ground water. The alkaline-earth metal, barium, also was more concentrated in the northwestern part of the study unit. Concentrations of the other alkaline-earth metals, calcium, magnesium, and strontium, in streambed sediments showed slope increases in their normal-probability plots. The areas where concentrations of these elements were largest correspond to the presence of Permian and Pennsylvanian shale and limestone in the southern part of the basin.

Concentrations of lead and zinc showed increases in slope of their normal-probability plots. The largest concentrations of lead were mainly in the southeastern part of the study unit where Permian and Pennsylvanian shale is prevalent.

Concentrations of arsenic and phosphorus also showed increases in slope of their normal-probability plots. Large concentrations of arsenic occurred mostly in the southeastern part of the study unit, corresponding to areas of Permian and Pennsylvanian shale and limestone. Large concentrations of phosphorus in the

northwestern part of the study unit probably were due to runoff from irrigated agricultural lands.

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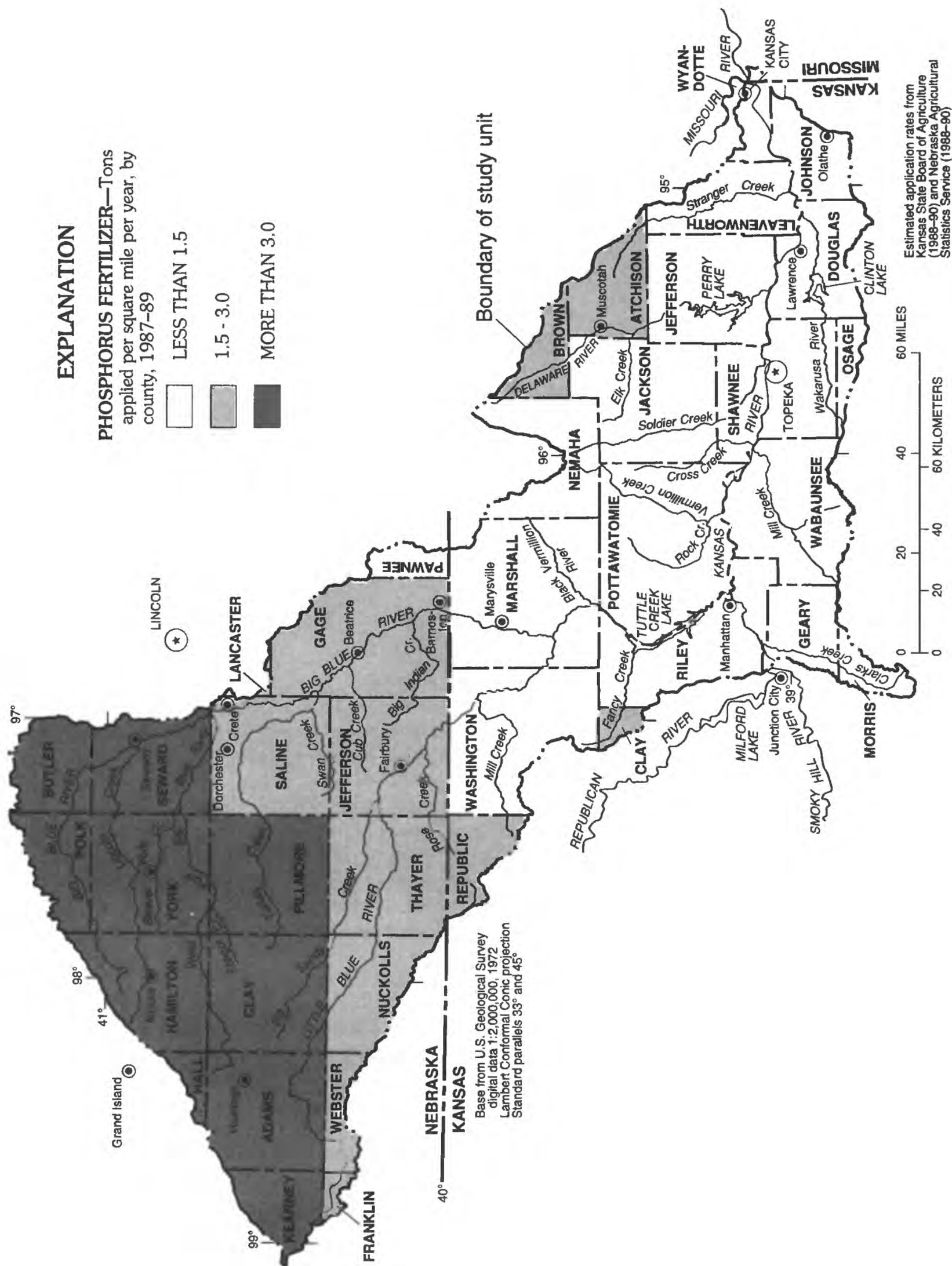


Figure 5. Estimated application rates of phosphorus fertilizer, lower Kansas River Basin, 1987-89.

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