Prepared in cooperation with the
U.S. FISH AND WILDLIFE SERVICE and the
KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT

Assessment of Contaminated Streambed Sediment in the Kansas Part of the Historic Tri-State Lead and Zinc Mining District, Cherokee County, 2004

Scientific Investigations Report 2005–5251

U.S. Department of the Interior
U.S. Geological Survey

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U.S. Department of the Interior
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Front cover: Miners having lunch in Muncie Mine, Cherokee County, southeast Kansas, circa 1930 (photograph courtsey of Baxter Springs Heritage Center and Museum, Baxter Springs, Kansas).

Back cover: Top, Sonny Boy mine near Baxter Springs, Kansas. Bottom, Mule being lowered down mine shaft (photographs courtsey of Baxter Springs Heritage Center and Museum, Baxter Springs, Kansas).

Prepared by the U.S. Geological Survey in Lawrence, Kansas (http://ks.water.usgs.gov/)

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Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
millimeter (mm)	0.03937	inch (in.)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
gram (g)	0.03527	ounce (oz)
milligram per kilogram	0.000016	ounce per pound (oz/lb)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	megagram (Mg)
	Chemical constituents	
microgram per liter (µg/L)	1.0	part per billion (ppb)
milligram per liter (mg/L)	1.0	part per million (ppm)

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

°F = (1.8 x °C) + 32.

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

°C = (°F - 32) / 1.8.

Horizontal coordinate information is referenced to the *North American Datum of 1983 (NAD 83)*.

Assessment of Contaminated Streambed Sediment in the Kansas Part of the Historic Tri-State Lead and Zinc Mining District, Cherokee County, 2004

By Larry M. Pope

Abstract

The Tri-State Mining District in parts of southeast Kansas, southwest Missouri, and northeast Oklahoma was the primary source of lead and zinc ore in the world for much of its 120-year history. Commercial mining in the Kansas part of the Tri-State Mining District began in the mid-1870s and lasted until 1970. The environmental degradation caused by 100 years of mining resulted in the U.S. Environmental Protection Agency listing the Cherokee County, Kansas, part of the Tri-State Mining District on its National Priority List as a superfund hazardous waste site in 1983.

To assist in the injury determination and quantification step of the natural resource damage assessment for Cherokee County, Kansas, the U.S. Geological Survey in cooperation with the U.S. Fish and Wildlife Service and the Kansas Department of Health and Environment conducted a two-phase study of the occurrence and distribution of contaminated streambed and lake-bottom sediment. Phase I of this study determined concentrations of 28 trace elements and nutrients in streambed sediment at 87 sampling sites in the Spring River and Tar Creek watersheds in Kansas. Phase II determined bottom-sediment concentrations and mass accumulation and historic transport of trace elements into Empire Lake, an impoundment of the Spring River. The purpose of this report is to present the results of phase I of this study.

Streambed-sediment samples (98 composite samples) were collected from the upper 0.8 inch of sediment deposition, and the less than 0.063-millimeter (silt- and clay-size particles) fraction was analyzed for selected trace element and nutrient concentrations. Restricting analyses to the silt/clay fraction reduced particle-size induced variability between sampling sites and permitted direct site-to-site concentration comparisons.

Concentrations of cadmium, lead, and zinc had much greater ranges in concentrations than any other elements analyzed. Ranges in concentrations were 0.6 to 460 mg/kg (milligrams per kilogram) for cadmium, 22 to 7,400 mg/kg for lead, and 100 to 45,000 mg/kg for zinc, with median concentrations of 13, 180, and 1,800 mg/kg, respectively. Concentrations were largest at sampling sites in the Short, Tar, and Spring Branch Creek watersheds containing the most intensively mine-affected streams. Concentrations of cadmium, lead, and zinc in streambed sediment from sampling sites on the Spring River increased about 18, 7, and 17 times, respectively, within its 22-mile length in the study area. This finding may explain a downward trend in mussel diversity and density over the same length of stream as determined by the Kansas Department of Health and Environment.

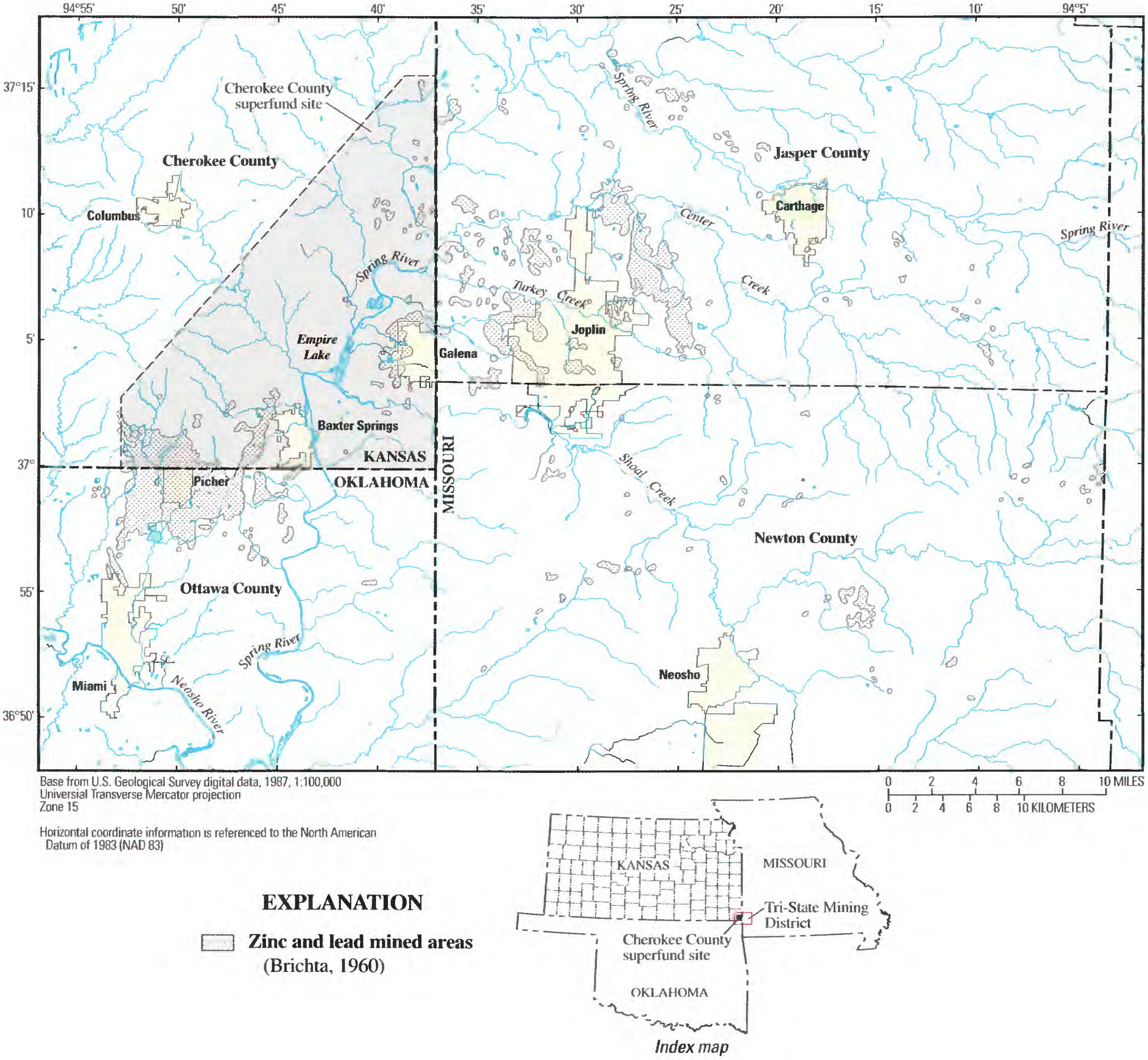
Concentrations of cadmium, lead, and zinc exceeded selected probable effects sediment-quality guidelines (4.98, 128, and 459 mg/kg, respectively) in 64, 56, and 75 percent of samples, respectively, from the 87 sampling sites. These guideline values are not regulatory criteria. Concentrations larger than probable effects guidelines frequently cause toxicological effects to some aquatic-life forms. Generally, 100 percent of sampling sites in the most mine-affected individual watersheds had concentrations of cadmium, lead, and zinc that exceeded probable effects guidelines.

Estimates of background (pre-mining) concentrations of cadmium, lead, and zinc in streambed sediment for streams in the study area were 0.6, 20, and 100 mg/kg, respectively. However, much of the study area may be contaminated with these trace elements from wind distribution of contaminated dust that was generated during ore milling, processing, smelting, and storage of waste material. On the basis of mollusk species diversity and abundance at sites with cadmium, lead, and zinc concentrations similar to background concentrations, it appears there is only a minimal biological effect.

Introduction

Problem and Background

The mining of metals such as lead and zinc may have environmental consequences (Ripley and others, 1996; National Research Council, 1997). These consequences can range from detrimental effects on terrestrial (Kimmerer, 1989; Mbila and Thompson, 2004) and aquatic (Giddings and others, 2001; Maret and others, 2003) ecosystems to adverse health effects on wildlife populations (Heinz and others, 1999; Sileo and others,



Base from U.S. Geological Survey digital data, 1987, 1:100,000
Universal Transverse Mercator projection
Zone 15

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83)

EXPLANATION

▨ **Zinc and lead mined areas** (Brichta, 1960)

Figure 1. Lead and zinc mined areas in the Tri-State Mining District, Kansas, Missouri, and Oklahoma, and location of Cherokee County superfund site.

2001; Sileo and others, 2004) and humans (Xintaras, 1992; Neuberger and others, 1990; Murgueytio and others, 1998). Land mined for lead and zinc typically is characterized by disturbed surface areas, piles of processed ore-bearing waste rock (chat), subsidences, and contaminated streams and surface-water impoundments (lakes and tailings ponds). One such area is the Tri-State Lead and Zinc Mining District (hereinafter referred to as the Tri-State District) located in parts of southeast Kansas, southwest Missouri, and northeast Oklahoma (fig. 1).

The Tri-State District produced lead and zinc from about 1850 to 1970 when the last mines closed. During much of this time, the Tri-State District was the primary source of lead and zinc ore in the world (Brosius and Sawin, 2001) and until 1945 was the world's largest producer of lead and zinc concentrates, which equated to 10 percent of the lead and 50 percent of the zinc produced in the United States (Gibson, 1972). Mining in the Kansas part of the Tri-State District began in the 1870s and continued for about a century (Clark, 1970; Brosius and Sawin, 2001). This long history of mining has left a legacy of streams contaminated with lead and zinc throughout the Tri-State District (Barks, 1977; Spruill, 1987; Davis and Schumacher, 1992; U.S. Fish and Wildlife Service, 1992) and may affect the occurrence and distribution of some aquatic life (Wildhaber and others, 1998, 1999) in the Spring River Basin (fig. 1). Aquatic species of particular concern include those on the Federal or State list of threatened or endangered species such as the Neosho madtom (*Noturus placidus*).

The Neosho madtom is a small catfish, less than 3 in. long, that lives among rocks and loosely packed gravel in riffles of the Spring River in the Tri-State District (Missouri Department of Conservation, 1997). The madtom was listed by the U.S. Fish and Wildlife Service (1990) as threatened under provisions of the Endangered Species Act of 1973 (U.S. Code Title 16, Chapter 35). While still found in the Spring River downstream from Empire Lake (fig. 1) and upstream in Missouri, the madtom apparently has been eliminated from the Spring River upstream from Empire Lake in Kansas (John Miesner, U.S. Fish and Wildlife Service, oral commun., 2003). The absence of the madtom may be the result of habitat degradation or toxicological effects caused by the accumulation of lead- and zinc-contaminated sediment from past mining activities (Wildhaber and others, 1998, 1999). In addition to the Federally listed madtom, several other resident fish and mussel species are listed by the Kansas Department of Wildlife and Parks (2001) as either threatened or endangered. Threatened species include the Arkansas darter (*Etheostoma cragini*), Redspot chub (*Nocomis asper*), Flutedshell mussel (*Lasmigona costata*), and Ouachita kidneyshell mussel (*Ptychobranchus occidentalis*). Endangered mussel species include the Elktoe (*Alasmidonta marginata*), Ellipse (*Venustaconcha ellipsiformis*), Neosho mucket (*Lampsilis rafinesqueana*), Rabbitsfoot (*Quadrula cylindrica cylindrica*), and Western fanshell (*Cyprogenia aberti*).

The environmental degradation caused by 100 years of lead and zinc mining in the southeast part of Cherokee County, Kansas (fig. 1), resulted in the U.S. Environmental Protection Agency (USEPA) listing the area on its National Priority List as a superfund hazardous waste site (fig. 2) in 1983 (U.S. Environmental Protection Agency, 2004a). Authority for establishment of superfund sites is given to USEPA through provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA; U.S. Code Title 42, Chapter 103). The provisions of this act provide a means to assess injured public natural resources through the direction and oversight of natural resource trustees. Trustees for natural resources in Kansas are the U.S. Department of the Interior, as represented by the U.S. Fish and Wildlife Service (USFWS), and the State of Kansas as represented by the Kansas Department of Health and Environment (KDHE) (Cherokee County Trustee Council, 2004). The process by which the trustees assess injured resources is known as natural resource damage assessment and restoration (NRDAR).

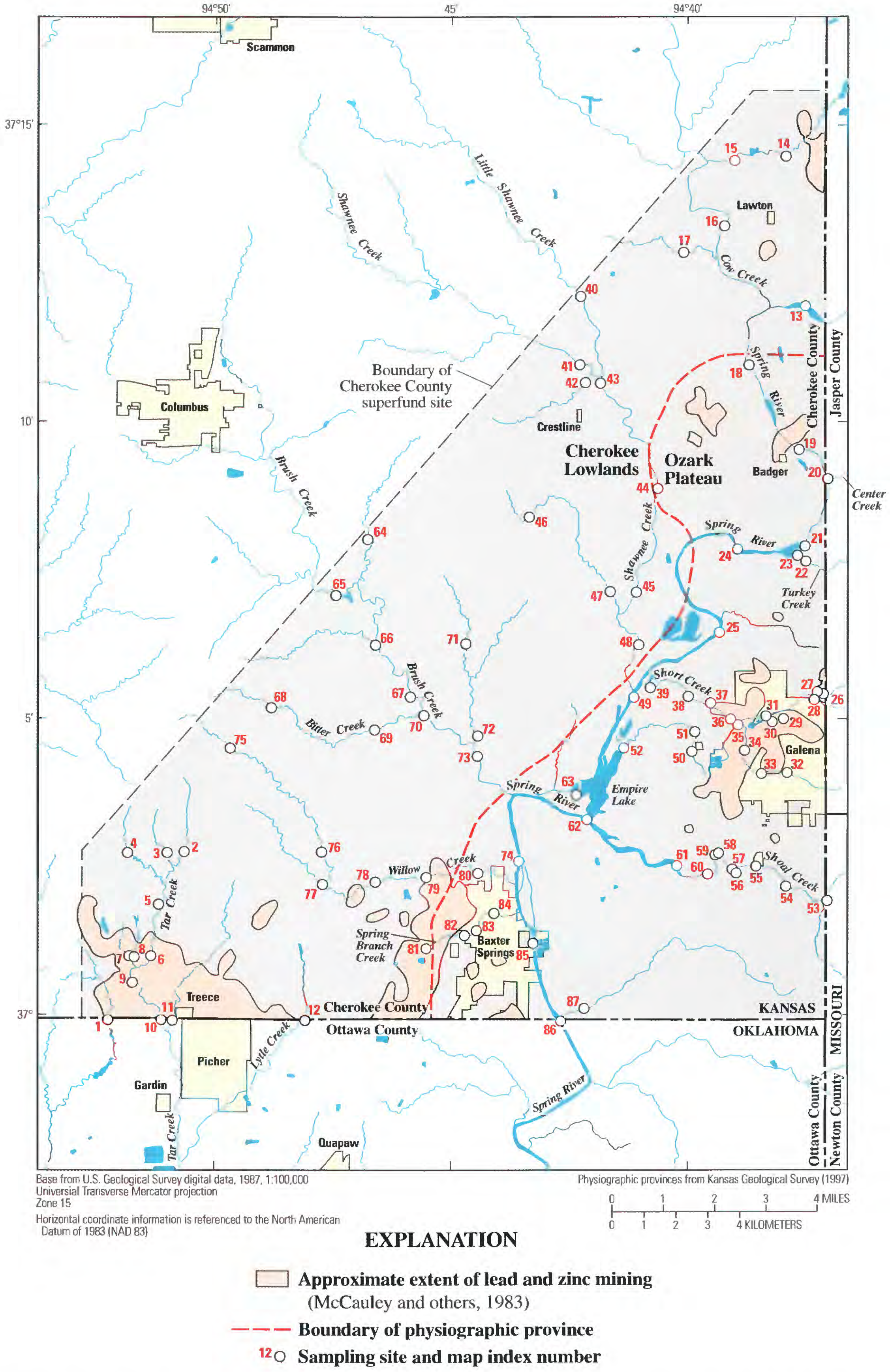
CERCLA required the promulgation of regulations for NRDARs, and the responsibility for rule making was delegated to the U.S. Department of the Interior (DOI) by Presidential Executive Order 12580 (January 23, 1987). DOI regulations and processes for conducting a NRDAR are set forth in Code of Federal Regulations Title 43, Part 11, which outlines four process phases with five major steps: (1) preassessment screen, (2) assessment planning, (3) injury determination and quantification, (4) pathway determination, and (5) damage determination and restoration (U.S. Department of Interior, 2002).

Previous studies in the Tri-State District have focused on the geology, mining activities, or environmental degradation caused by those activities (see "Previous Studies" section of this report). Several studies have assessed various aspects of the water resources of the area or examined individual components such as mine- or surface-water quality or conditions within specific watersheds. None to date (2005), however, have conducted a comprehensive assessment of streambed-sediment quality or its relation to sediment-quality guidelines to the degree necessary to meet the needs of the injury determination and quantification step of the Cherokee County, Kansas, superfund site NRDAR. To assist trustees with the injury determination and quantification step of the Cherokee County, Kansas, superfund site NRDAR, the U.S. Geological Survey (USGS), in cooperation with USFWS and KDHE, conducted a study of the occurrence and distribution of contaminated streambed and lake-bottom sediment as may be related to past mining activities.

The sediment study conducted by USGS was divided into two phases. The first phase determined occurrence and concentrations of selected trace elements in streambed sediment from sites in the Spring River and Tar Creek systems within the boundary of the Cherokee County, Kansas, superfund site (fig. 2). This included locations on the main stem of both the Spring River and Tar Creek and on major tributaries. The second phase determined the historic accumulation of sediment in Empire Lake and associated concentrations and mass of selected trace elements. Spatial distributions and temporal trends in concentrations of selected trace elements and nutrients in Empire Lake also were determined.

Purpose and Scope

The purpose of this report is to provide that comprehensive assessment of sediment quality in selected streams of the Spring River and Tar Creek systems of the Cherokee County, Kansas, superfund site (phase I). Streambed-sediment samples from 87 sites were collected during October through December 2004 and analyzed for 28 selected trace elements and nutrient constituents. The spatial distribution of these constituents are presented, and 2004 streambed-sediment concentrations are discussed relative to selected sediment-quality guidelines, estimated background (pre-mining) concentrations, and in association with historic mining activities.



Base from U.S. Geological Survey digital data, 1987, 1:100,000
Universal Transverse Mercator projection
Zone 15

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83)

Physiographic provinces from Kansas Geological Survey (1997)

Figure 2. Location of superfund site in Cherokee County, Kansas, approximate extent of lead and zinc mining, physiographic provinces, and streambed-sediment sampling sites.

Physiography, Geology, and Mineralogy

The geologic history of Kansas is defined by alternating depositional and erosional periods that occurred over hundreds of millions of years. The landscape of Kansas, as sculptured by these processes, can be divided into regions on the basis of physical geology (physiography). The area investigated and discussed in this report lies within the Cherokee Lowlands and Ozark Plateau physiographic provinces (fig. 2; Kansas Geological Survey, 1997).

The Cherokee Lowlands includes most of Cherokee County, generally west of the Spring River (fig. 2). The region is topographically subdued and characterized by gentle slopes and shallow stream valleys. Soils tend to be deep and fertile, and cropland is common. Timber is restricted to isolated limestone hills and to the riparian areas of streams (McCauley and others, 1983). Surficial rocks (fig. 3) in this region are of Pennsylvanian age and were deposited about 300 million years ago. Outcropping Pennsylvanian rock is chiefly shale with interbedded sandstone and limestone (table 1) and in the northern part of Cherokee County, commercially mined coal seams are associated with these deposits (Siebenthal, 1916).

The Ozark Plateau generally occurs east of the Spring River (fig. 2) with surficial rocks (fig. 3) of Mississippian age (about 350 million years old). The region has greater topographic relief than the Cherokee Lowlands, stream valleys are steep with rock and gravel streambeds, soils are thin and often mantled with cherty gravel, and hillsides are timbered and cropland restricted to the valley floors of the Spring River and Shoal Creek (McCauley and others, 1983). The Mississippian rocks are the oldest exposed rocks in Kansas and consist of limestone, chert, and shale (table 1). The lead and zinc deposits mined in the Tri-State District occur in the Mississippian rocks. West of the Spring River the Mississippian rocks underlie rocks of Pennsylvanian age. Regional dip of these formations is to the west and northwest (Haworth and others, 1904).

The lead and zinc ores in Mississippian rocks of the Tri-State District were deposited as precipitates from water of either artesian or magmatic origin. Siebenthal (1916) concluded that Ozark artesian circulation of alkaline-saline sulfurous water from Cambrian and Ordovician rocks ascending into the overlaying Mississippian rocks was the agent for primary deposition of lead and zinc minerals in brecciated, fractured, and erosional (dissolved) openings in the Mississippian rocks. Although a magmatic source of lead and zinc in the Tri-State District was possible, the ratio of zinc to lead in mined ore, and that in Cambrian and Ordovician limestone, is almost identical; the deep-lying deposits of lead and zinc could have been reached only by water having artesian circulation, and the occurrence of ore at the base of the Pennsylvanian rocks in places not cut through by erosion implies deposition by ascending artesian water (Siebenthal, 1916).

More recent analyses, on the other hand, by USGS (McKnight and Fischer, 1970) and the Kansas Geological Survey (Brosius and Sawin, 2001) support the hypothesis of a magmatic (hydrothermal) source for lead and zinc deposition in the Tri-State District. Under this hypothesis, hot, metal-bearing solutions that originate deep within the Earth rose along major faults and fractures until reaching the Mississippian rocks where the solutions were forced laterally into broken beds of chert and limestone by overlying, impermeable Pennsylvanian rock. This lateral migration deposited the minerals that ultimately formed the economic basis of the Tri-State District.

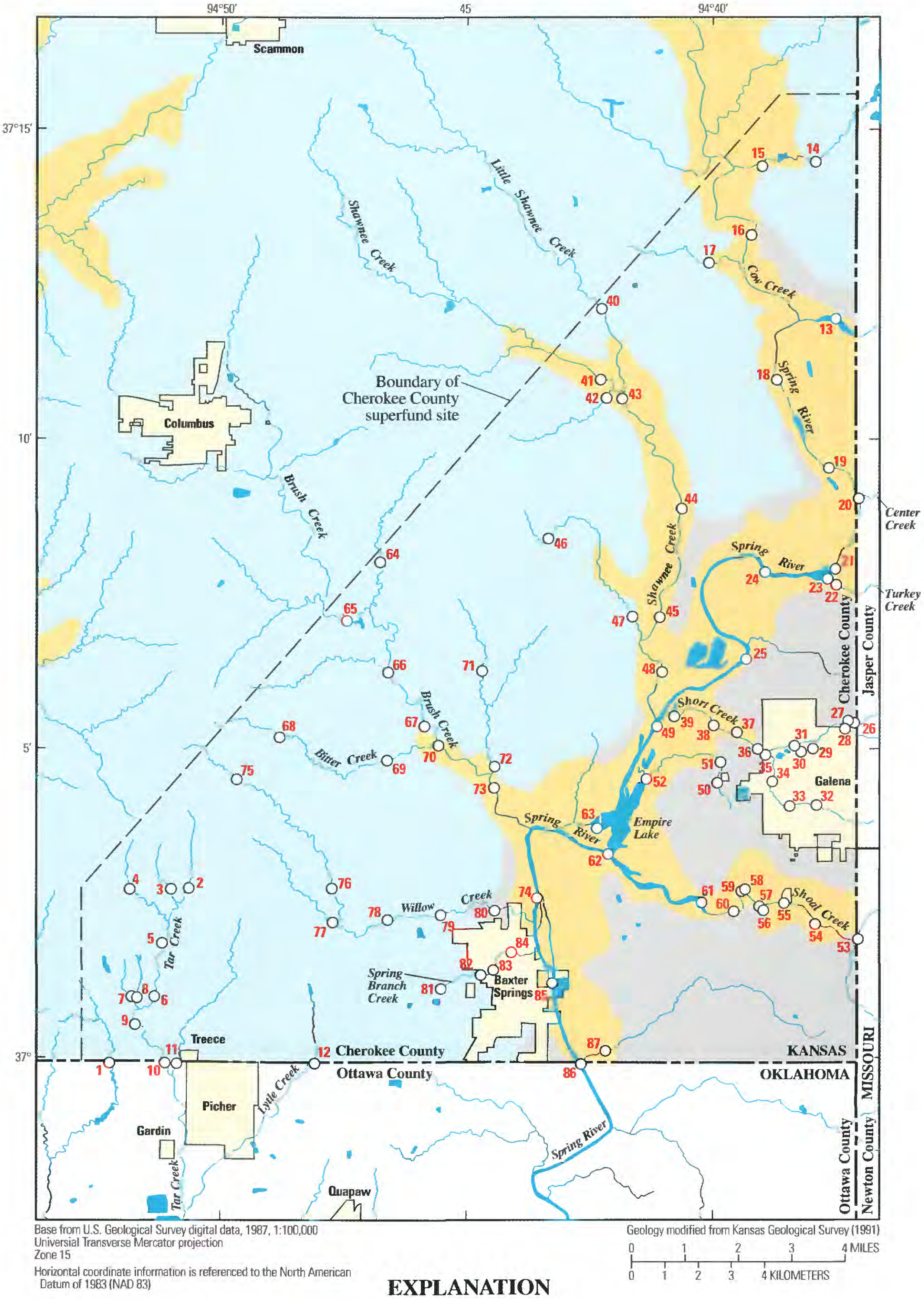
About 40 minerals have been identified in the Tri-State District. Of these, however, only about 11 (table 2) commonly occurred throughout the district, and fewer yet were of economic importance (Ritchie, 1986). Galena and sphalerite (fig. 4) were the most common and economically important sources of lead and zinc, respectively, in the Tri-State District even though other chemical compositions did occur and were mined along with the sulfide minerals.

Zinc ores of the Tri-State District contained economically recoverable amounts of other minerals and elements. The cadmium sulfide mineral greenockite was found in a few locations in the district, but most cadmium occurred as a thin greenish-yellow coating on sphalerite and smithsonite and as an impurity in zinc sulfide minerals. As an impurity, cadmium replaced zinc atoms in the structure of sphalerite or wurtzite crystals (Ritchie, 1986). Gallium and germanium also occurred as impurities in zinc sulfide minerals. Late in the history of mining the Tri-State District, gallium and germanium were recovered commercially during zinc ore smelting and refining. As percentages of zinc concentrates, cadmium, gallium, and germanium were recovered at rates of 0.2, 0.005, and 0.05 percent, respectively (Ritchie, 1986). Other minerals of lesser or no economic importance during the mining period in the Tri-State District included minerals of calcium (fluorite, CaF_2); copper (chalcanthite, $CuSO_4.5H_2O$; chalcopyrite, $CuFeS_2$; covellite, CuS; cuprite, Cu_2O; malachite, $Cu_2CO_3(OH)_2$), iron (hematite, Fe_2O_3; pyrite, FeS_2), and manganese (pyrolusite, MnO_2). Although many of the minerals and elements listed herein were not exploited commercially, their environmental dispersal during milling, smelting, and onsite storage of contaminated residual rock (chat) established the possibility for contamination of aquatic environments.

History and Legacy of the Tri-State Mining District

The Tri-State District (fig. 1) covers an area of about 2,500 mi^2 and has a history of mining that predates the Civil War. Surface deposits of lead were mined, smelted, and molded into bullets by transient trappers and explorers as early as 1820, but commercial mining of lead did not begin until about 1850 near Joplin, Missouri. Although zinc ore was more abundant than lead ore in the Tri-State District (at about a 5:1 ratio), little value was placed on zinc production because of difficulty in smelting and low price for the concentrate (Gibson, 1972).

The first 20 years of commercial mining in the Tri-State District was a period of increasing activity in shallow (soft ground) mining, but several factors kept the district from reaching the production capabilities achieved in later years.



Base from U.S. Geological Survey digital data, 1987, 1:100,000
Universal Transverse Mercator projection
Zone 15

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83)

Geology modified from Kansas Geological Survey (1991)

EXPLANATION

Surficial geology

- 🟨 Alluvium
- 🟦 Pennsylvanian rocks
- ⬜ Mississippian rocks

12○ **Sampling site and map index number**

Figure 3. Surficial geology of Tri-State Mining District, Cherokee County, Kansas.

Table 1. Generalized geologic section of surficial rocks in the Kansas part of the Tri-State Mining District.

[Modified from McCauley and others (1983). Stratigraphic terms are those of the U.S. Geological Survey and may differ somewhat from those used by the Kansas Geological Survey]

System	Series	Provincial series	Stratigraphic unit	Average thickness (feet)	Physical characteristics
Pennsylvanian	Middle Pennsylvanian	Des Moinesian	Krebs Formation	225	Shale, sandstone, and limestone with beds of coal.
Mississippian	Upper Mississippian	Chesterian	Undifferentiated rocks of Chesterian age	120	Limestone, shale, and siltstone.
		Meramecian	Warsaw Limestone	120	Crinoidal limestone with chert. Contains deposits of lead and zinc of commercial value.
	Lower Mississippian	Osagean	Keokuk Limestone	130	Medium to coarse crystalline limestone with chert. Contains deposits of lead and zinc of commercial value.
			Fern Glen Limestone	170	Dolomitic limestone in lower strata and limestone with abundant chert in upper strata. Contains deposits of lead and zinc of commercial value.

Table 2. Major minerals of the Tri-State Mining District of southeast Kansas, southwest Missouri, and northeast Oklahoma.

[Modified from Ritchie (1986)]

Mineral name	Chemical composition	Chemical formula
Anglesite	Lead sulfate	$PbSO_4$
Calcite	Calcium carbonate	$CaCO_3$
Cerussite	Lead carbonate	$PbCO_3$
Chert	Silicon dioxide	SiO_2 amorphous
Dolomite	Calcium magnesium carbonate	$CaMg(CO_3)_2$
Galena	Lead sulfide	PbS
Hemimorphite	Zinc silicate hydrate	$Zn_4Si_2O_7(OH)_2.H_2O$
Marcasite	Iron sulfide	FeS_2
Quartz	Silicon dioxide	SiO_2
Smithsonite	Zinc carbonate	$ZnCO_3$
Sphalerite	Zinc sulfide	ZnS

Figure 4. Specimen of lead and zinc ores. Photograph taken at Tri-State Mineral Museum (Joplin, Missouri), February 18, 2005.

Transportation options prior to and during the Civil War restricted production development. The main transportation mode during this period was horse- or oxen-drawn wagon to one of the navigable rivers in the area where the smelted ore was loaded onto flatboats for transport to New Orleans or St. Louis. Wagon transport to eastern Missouri railroad terminals also was an option. The Civil War limited commercial development of the district when the area was occupied at various times by both Union and Confederate forces and suffered through attacks by western Missouri guerrilla forces, most notably those led by William Quantrill. The lack of heavy machinery restricted mining activities to the shallow ore deposits common in the Missouri part of the district. Individual mines in this period tended to be small and operated by just a few miners (Gibson, 1972).

The peace following the Civil War brought renewed interest and investment in lead and, subsequently, zinc production. Railroads extended lines into the Tri-State District by the 1870s and with them came the steam-powered equipment needed to operate the drills, hoists, and pumps necessary for the rapid expansion of mining operations into both deeper levels of the fields and other areas of the district. By 1876, mines were opened in the Galena, Kansas, area (fig. 2) (Ritchie, 1986).

With the discovery of lead ore in the Kansas part of the Tri-State District in 1876, thousands of people migrated into the area to take advantage of the relatively shallow (to about 100 ft) deposits. Within months, the Galena area had a population of about 10,000 people (Blackmar, 1912). Lead production during

Figure 5. Example of a mine room circa 1950 (photograph courtesy of Baxter Springs Heritage Center and Museum, Baxter Springs, Kansas).

the first 18 months of mining in Kansas totalled about 6 million lb (Cutler, 1883). Additional mining camps were established at Baxter Springs and Treece, Kansas (fig. 2), within a few years of the discoveries at Galena. Smaller, isolated, and relatively short-lived camps also were established near Badger, Crestline, and Lawton in the northern part of the study area (fig. 2).

Most mining operations in Kansas consisted of a shaft developed to the ore-bearing level where room-and-pillar methods were used to mine the ore veins. These rooms were as much as 100 ft in height (fig. 5) with the ceilings supported by massive rock pillars left during the mining process (Brichta, 1960). Some surface mining was done near Galena, but generally, mine depths increased in a westerly direction and were greatest in the Baxter Springs and Treece areas. The deepest mine in the Tri-State District was located north of Treece and had a 480-ft shaft (McCauley and others, 1983).

The period 1880–1900 was one of technological advances for lead and zinc mining in Kansas. Local ore-processing mills and smelters were constructed. Improvements in drilling, hoisting, pumping, blasting equipment, and transportation brought more efficient prospecting methods, allowed for the development of deeper mines, and reduced labor and transportation costs. Consolidation of mining operations began during this period. Production from the shallow mines operated by a few miners gradually declined and, subsequently, were bought out by the larger mining companies that had the capital required to exploit the deeper ore reserves (Gibson, 1972).

The milling (separation of lead and zinc minerals from waste rock) had a long evolutionary history in the Tri-State District. The earliest systematic milling process consisted of hand crushing lead and zinc ore and separating the lead and zinc minerals from the waste rock in a wood sluice (Gibson, 1972). Later developments included the construction of a wood- or steel-framed mill at the mine shaft to process the ore-bearing material as it was removed from the mine. These mills typically consisted of a series of rock crushing, jigging, and tabling operations to size, separate, and concentrate the lead and zinc minerals. About 1916, flotation separation was added to the milling process to increase the percentage of mineral recovery (Gibson, 1972). The flotation process produced a higher grade of mineral concentrate. The process was conducted on the fine-graded (sand-size) ore that escaped the other milling steps. Large tanks of air agitated water/ore slurries, and various organic oils and chemicals were used to differentially float sulfide minerals. Initially, the process would float lead sulfide minerals that were skimmed off after which the remaining slurry was pumped to a second tank where the zinc sulfide minerals were floated and skimmed (Ritchie, 1986).

Each milling operation produced tailings (waste rock) that usually were stored on site. Because lead and zinc minerals averaged only about 4 percent of the ore processed in the Tri-State District, large volumes of tailings were generated in milling (Ritchie, 1986). The jigging process produced about 80 percent of mill tailings (chat). Chat ranged in size from about 0.016 to 0.375 in. (U.S. Environmental Protection Agency, 1997) and was stacked in large piles by elevators and conveyor belts. Tabling operations produced smaller sized tailing particles that represented about 12 percent of the waste rock. These tailings often were stacked separately from the chat piles and possibly sold for roofing aggregate or abrasive material. Flotation tailings were the smallest sized waste rock particles (less than about 0.003 in. in diameter) and represented about 8 percent of the waste rock. Flotation tailings were stored in large ponds near the mill (Ritchie, 1986). The milling process, however, was never totally efficient, and residual concentrations of lead and zinc minerals remained in all chat and tailings and were a potential source of environmental contamination through either water or wind distribution. Average concentrations of lead and zinc in chat ranged from about 360 to 1,500 mg/kg and about 6,000 to 13,000 mg/kg, respectively. Concentrations were about five times larger in flotation tailings (U.S. Environmental Protection Agency, 1997).

Smelting (extraction of metallic lead and zinc) of ore in the Tri-State District evolved from simple wood-fired furnaces used by individual miners to smelt lead ore to centralized coal or natural-gas fired zinc smelters of large mining companies. Both coal and natural gas were found in southeast Kansas, and smelters were built near these resources or the coal and gas was transported to existing smelters within the mining district. Early lead and zinc smelters were inefficient in metal recovery. Part of this inefficiency was due to metal vaporization or particulate loss to the atmosphere during the firing process (Gibson, 1972). Over the years, the release of contaminants from smelting operations in and near the Tri-State District has contributed to an increase in soil lead and zinc concentrations particularly evident in residential areas of Galena, Kansas (U.S. Environmental Protection Agency, 2000).

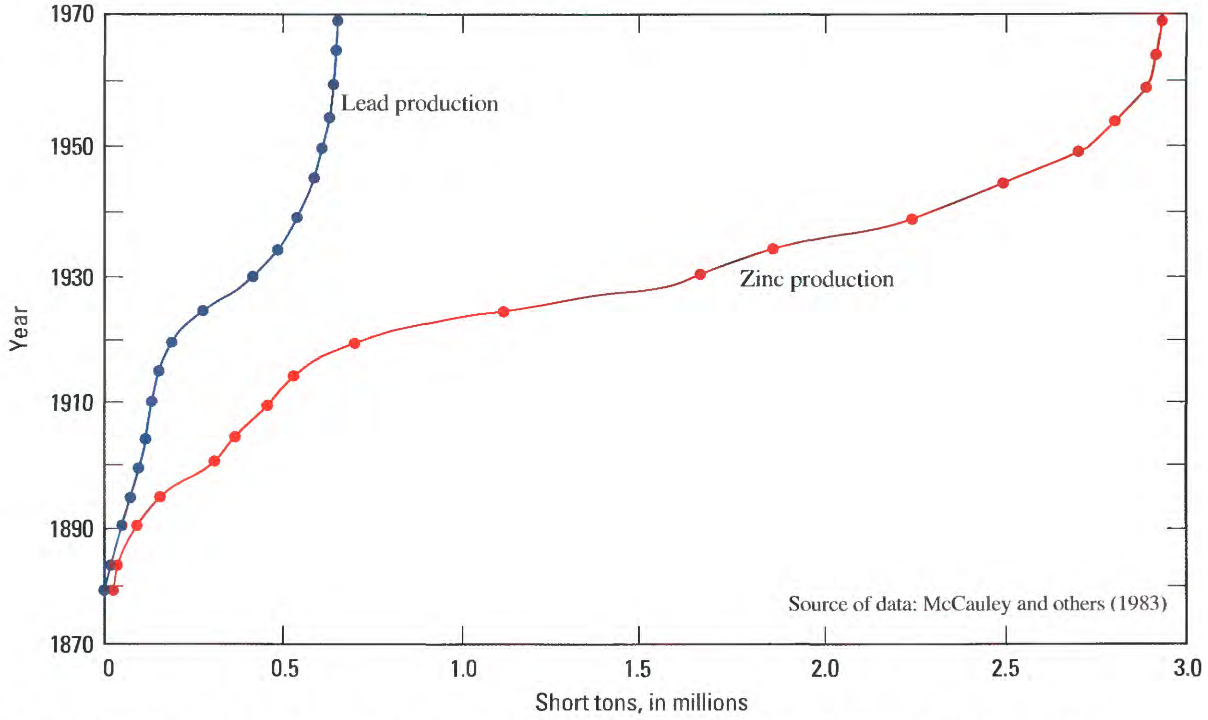
Production of lead and zinc in Kansas continued to increase into the early part of the 20th century when economic and national and international political events caused metal production to rise and fall until the mid-1940s (fig. 6). Mine output generally peaked in the mid-to-late 1920s and began a gradual decline after World War II. Depletion of the economically recoverable ore reserve, competition from foreign imports, and increasing costs of production forced the closure of many mines until the last Tri-State District mine was closed near Baxter Springs in 1970.

Total production from the nearly 100-year history of mining in Kansas was estimated at 650 thousand tons of lead and 2.9 million tons of zinc (McCauley and others, 1983) processed from about 111 million tons of unprocessed ore (1.4 billion ft^3 of rock) (Spruill, 1987). By volume, that was enough rock to build a 1-ft thick wall 220 ft high around the State of Kansas. The mining, milling, and smelting of this large volume of ore and rock left a degraded environmental legacy for southeast Cherokee County, Kansas.

McCauley and others (1983) conducted a survey of mine-disturbed areas in the Kansas part of the Tri-State District and identified about 2,300 acres of surface area covered by mine and mill waste (chat piles, tailing ponds, and shaft and mine development rock) (fig. 7). This area was associated with about 2,200 acres of underground mining. Physical hazards surveyed included 315 open pits and surface collapses and about 3,500 mine shafts of which about 900 were considered physically hazardous.

The mined area in and around Galena was affected by mine wastes (fig. 8). Mining activities in this area were so extensive and environmentally destructive that, locally, the area was referred to as "Hell's Half Acre" (Kansas Geological Survey, 2003). In the early 1990s, USEPA began remediation of the Galena area by sealing shaft openings, filling open pits and surface collapses, and revegetating with native grasses. Remediation efforts also included the removal or regrading of some chat and rock piles throughout the superfund site (fig. 2).

As prevously mentioned in the "Introduction" section of this report, lead, zinc, and other associated trace elements have been widely dispersed throughout the area during active mining. This dispersal originated from milling and smelting operations and, possibly, by wind distribution from chat piles or roads on which chat was used as a gravel overlay. Chat and tailings have been shown to contain large concentrations of lead, zinc, and other trace elements such as cadmium associated with fine sand and silt/clay-size particles (U.S. Environmental Protection Agency, 1997; Datin and Cates, 2002). Runoff from chat piles, residual mining materials scattered about the land surface, and



Source of data: McCauley and others (1983)

Figure 6. Cumulative lead-and-zinc production in the Kansas part of the Tri-State Mining District, 1876–1970.

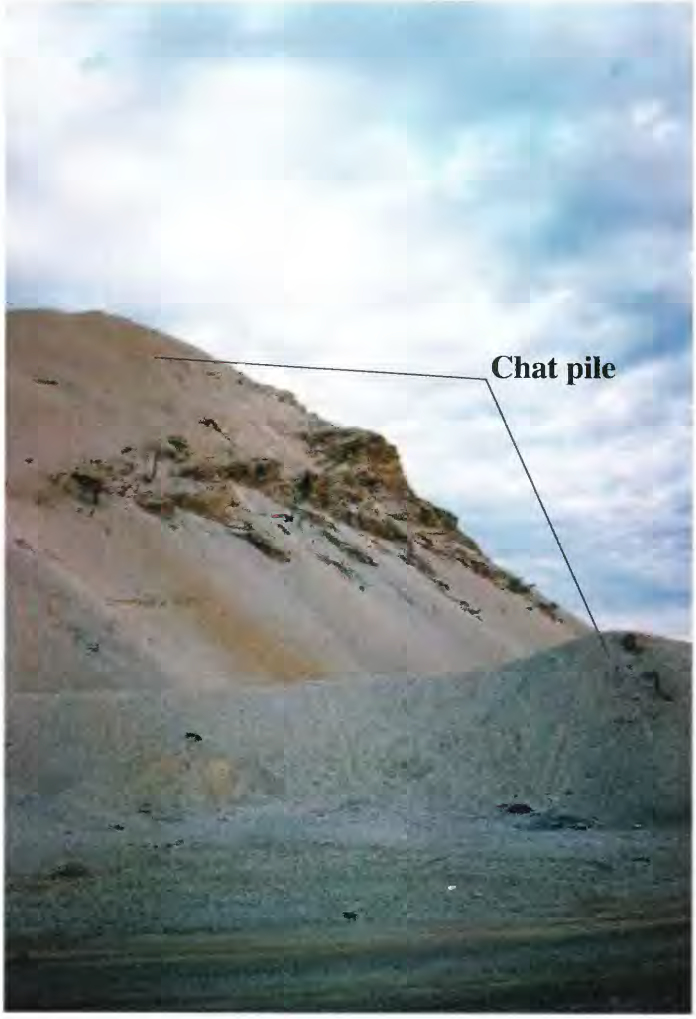


Figure 7. Chat piles near Baxter Springs, Kansas (photograph courtesy of Kansas Geological Survey).

roads and out of tailings ponds contaminated receiving streams and affected the health of aquatic ecosystems in the Tri-State District (Barks, 1977; Spruill, 1987).

During active mining in the Tri-State District, it was necessary to continually dewater the mines. Most "hard ground" mining was done in water-bearing geologic formations, and water from these formations had to be removed to facilitate mine development and operation (DeHay, 2003). Dewatering was accomplished by steam-, electric-, or gasoline-powered pumps. Some of this water was used in the ore-milling process or as boiler water if of suitable quality. Acidic mine water destroyed pumping machinery and boiler plate and piping (Gibson, 1972). Acidic water was formed by the oxidation of sulfide minerals and released sulfuric acid. Poor quality water often was discharged into local streams where it damaged aquatic ecosystems (Gibson, 1972). With cessation of mining and dewatering operations, mines filled with water and subsequently began discharging it at the surface through unsealed bore holes, mainly in the Tar Creek watershed (fig. 2) (Spruill, 1987). Because of the historically acidic nature of some mine water, it may have contained large concentrations of trace elements such as cadmium, copper, lead, manganese, nickel, and zinc (Christenson and others, 1994). The discharge of these elements into streams and potential sorption onto streambed-sediment particles may have had detrimental effects on aquatic organisms.

Previous Studies

Literally hundreds of books, reports, articles, pamphlets, circulars, and abstracts have been published about various aspects of the Tri-State District since commercial mining began over 150 years ago. One of the first formal geological studies of the Tri-State District was presented by Schmidt and Leonhard (1874) and included descriptions of ore and minerals, rock associations, ore deposits, and mining and smelting operations. Later geological studies included those of Haworth and others (1904), Bain (1905), Siebenthal (1916), Netzband (1928), Jakosky and others (1942), Ruhl and others (1949), and McKnight and Fischer (1970). Of particular geologic interest (if only for academic reasons) was the origin of lead and zinc deposits in the Tri-State District, which was discussed and debated at great lengths (Bain, 1902; Haworth and others, 1904; Siebenthal, 1916; Ridge, 1936; Roy, 1937; Hagni and Grawe, 1964). Of greater economic interest to the district was the abundant detailing of the occurrence and distribution of commercially exploitable ore deposits and reserves in publications typified by Smith (1903), Clerc (1907), Brittain (1907; 1908), Bain (1916), Ellis (1926), Spurr (1927), Fowler and Lyden (1932), Sales (1933), Ruhl (1946), and Ruhl and others (1949).

More germane, perhaps, to the study described in this report are previous studies describing or assessing the environmental consequences of nearly 150 years of mining in the Tri-State District. An awareness of the environmental degradation caused by mining in the Tri-State District and particularly in Kansas is not a recent concern. As early as 1905, stream-water samples indicated the effects of mining. The concentration of zinc in a water sample from Short Creek (fig. 2) about 0.5 mi upstream from its confluence with the Spring River was 732 mg/L on April 1, 1905 (Bailey, 1911) at a flow rate described as "slightly above the ordinary stage." Bailey (1911) did not describe sample collection or analytical procedures or whether the analysis was performed on a filtered or whole-water sample, so it is unknown what quality-assurance protocols were used to mitigate sample contamination during collection and analysis. The sulfate concentration in this sample was 1,625 mg/L with a total solids (Bailey's nomenclature) concentration of 3,833 mg/L. Zinc concentrations in water samples from other stream sites for the same period (March 30 to April 1, 1905) ranged from 0.3 mg/L in a sample from Center Creek to 47.3 mg/L in a sample from Turkey Creek, both near the Kansas-Missouri State line. Concentrations of zinc in water samples collected at three sites on the Spring River were less than 20 mg/L. However, all of these zinc concentrations were

Figure 8. Lead- and zinc-mined area near Galena, Kansas, 1980 (photograph courtesy of Kansas Geological Survey).

far greater than the current (2005) 0.12-mg/L criterion for protection of freshwater aquatic life, and the concentrations in samples from Turkey and Short Creeks were substantially greater than the 26-mg/L criterion for human consumption of aquatic organisms (U.S. Environmental Protection Agency, 2004b). Although no freshwater criterion currently (2005) exists for sulfate, a 250-mg/L national Secondary Drinking-Water Regulation has been recommended (U.S. Environmental Protection Agency, 2005a) as well as a 1,000-mg/L livestock water standard (Kansas Department of Health and Environment, 2004).

The reason for these large stream concentrations of zinc and sulfate probably can be traced to mine dewatering and its subsequent discharge into local streams. Bailey (1911) also presented analyses of mine and sludge-mill water samples collected between March 30 and April 1, 1905. Concentrations of zinc in 11 samples from the mines in the Galena, Kansas, area (fig. 2) ranged from about 680 to 1,800 mg/L. Sulfate concentrations ranged from about 310 to 5,500 mg/L. Lead concentrations (5.7 and 37.0 mg/L) were detected in water from two mines. The pH of these samples was not determined, but it is assumed that much of the mine water was very acidic to support these large concentrations provided the samples were not contaminated during sampling and analysis. Bailey (1911) presented anecdotal evidence of acidic water when he mentioned that iron pipes at the mines corroded so rapidly that wood-lined pipes with brass fittings and valves were used. The discharge of mine water into local streams created the potential for trace elements to either precipitate out or sorb to and accumulate on streambed sediment. Clearly, by the beginning of the 20th century, water quality in some streams of the Tri-State District was severely affected by mining, and aquatic ecosystems may have been degraded.

Many previous water-quality studies conducted after cessation of mining in the Tri-State District attempted to assess the environmental legacy of historic mining operations. These included studies by Feder and others (1969), Board (1970), Howland (1974), Stewart (1980), and Parkhurst (1987; 1988). Of particular relevance are the studies of Barks (1977), Spruill (1987), Angelo and others (2005), and Stiles (2005).

Barks (1977) examined water from mines, wells, and streams, as well as runoff from tailings piles. He determined that dissolved zinc concentrations averaged 9.4 mg/L in water from flooded mines and 16.0 mg/L in runoff from tailing piles. A water sample collected from Short Creek (fig. 2) near the Kansas-Missouri State line had a dissolved zinc concentration of 1.6 mg/L at a flow rate of 37 ft^3/s (about six times the average). However, he also referenced a water sample collected by the Missouri Clean Water Commission in July 1969 that had a dissolved zinc concentration of 32.0 mg/L at a flow rate of 0.7 ft^3/s. He also determined that past mining activities had produced a 10-fold increase in dissolved zinc and a 25-fold increase in lead and zinc in streambed sediment in Center and Turkey Creeks. These increases were relative to estimated background (pre-mining) concentrations of 0.04 mg/L dissolved zinc in water and 20 mg/kg lead and 100 mg/kg zinc in streambed sediment. Streambed sediment samples collected by Barks (1977) were not sieved to any particular particle size, and subsequent analyses represented the "whole sediment sample" that consisted mainly of very fine to very coarse sand-sized particles collected from the upper 2 in. of the streambed. Background concentrations estimated on the less than 0.063-mm fraction of streambed sediment probably would have been larger than those reported by Barks (1977).

Spruill (1987) evaluated water-resource problems related to abandoned lead and zinc mines in Cherokee County, Kansas, and adjacent areas in Missouri and Oklahoma. This evaluation included ground water (mines and wells) and surface water (streams and seepage from tailing piles). Collection and analyses of water samples from these sources indicated larger median concentrations of lead (0.24 mg/L) and zinc (37.6 mg/L) in mine water from the eastern part (Ozark Plateau) of the study area compared to the western part (Cherokee Lowlands), less than 0.01 and 3.2 mg/L, respectively. The largest stream-water concentration of zinc (25 mg/L) was in a sample collected from Short Creek (fig. 2) in August 1981 during low flow. Spruill (1987) concluded that contaminants in Short Creek during periods of low flow were due primarily to inflow of ground water from the breccia, to natural mine discharge, and to seepage from chat piles in the Short Creek Basin. Tar Creek (fig. 2) had the largest concentrations of zinc (5.8 mg/L) of any stream in the western part of the study area. Spruill (1987) also concluded that drainage from chat piles during wet weather contained large concentrations of sulfate, cadmium, and zinc. Spruill's study was conducted prior to extensive, large-scale efforts to remediate the environmental degradation from nearly 100 years of mining in the Kansas part of the Tri-State District.

Angelo and others (2005) examined the effects of historical lead and zinc mining on mussel populations in the Spring River Basin. Mussel diversity (number of species), densities, and concentrations of cadmium, lead, and zinc in streambed sediment and mussel soft tissue were determined at selected sites on the Spring River and tributary streams. Sampling sites 13 and 18 (fig. 2) on the Spring River supported 20 to 23 species of mussels, but only 9 species were identified at sampling site 85, downstream from most mined areas in the Kansas part of the Tri-State District. Additionally, mussel diversity and density were substantially reduced in the Spring River downstream from Center and Turkey Creeks. The downstream reaches of Center, Short, Turkey, and Willow Creeks were seemingly devoid of mussel species. On the basis of these data, Angelo and others (2005) concluded that historical lead and zinc mining activities continue to degrade the aquatic environment and impede the recovery or establishment of viable mussel populations in much of the Spring River Basin in Kansas.

Stiles (2005) reported information concerning water-quality impaired streams in the Kansas part of the Tri-State District as identified by the 303(d) process of the Federal Water Pollution Control Act (Public Law 92-500), commonly referred to as the Clean Water Act (U.S. Environmental Protection Agency, 1972). Aquatic-life use of segments of the Spring River and Brush, Little Shawnee, Shoal, Short, and Turkey Creeks (fig. 2) was listed as impaired for water concentrations of one or more of cadmium, copper, lead, or zinc (Kansas Department of Health and Environment, 2005). Total maximum daily loads (TMDLs) developed for the Spring River Basin indicate that larger concentrations of these trace elements occur during high streamflows (runoff) thereby potentially increasing toxicological conditions requiring more extensive load reductions at higher streamflows. TMDL is a calculation of the maximum amount of a contaminant that a water body can receive and still meet water-quality standards and an allocation of that amount to the contaminant's sources (U.S. Environmental Protection Agency, 2005b). Stiles (2005) concluded that removal of metal-laden sediments in stream channels and from Empire Lake may be necessary to mitigate the effects of historic lead and zinc mining on aquatic life in the Spring River Basin.

The concentrations of lead and zinc in mine- and surface-water samples reported by Barks (1977) and Spruill (1987) were small relative to more historical analyses (Bailey, 1911). For example, the smallest mine-water concentration of zinc (680 mg/L) reported in Bailey (1911) was 72 times larger than the average concentration (9.4 mg/L) reported in Barks (1977) and at least 18 times larger than the median concentrations (3.2 and 37.6 mg/L) reported in Spruill (1987). The largest concentration of zinc in mine water reported in Spruill (1987) was 79.0 mg/L. A comparison of zinc concentrations in Short Creek indicated similar differences. A sample collected from Short Creek by Bailey (1911) had a zinc concentration of 732 mg/L compared to 32.0 mg/L reported in Barks (1977) and 25.0 mg/L reported in Spruill (1987).

The large mine- and stream-water sample concentrations reported by Bailey (1911) indicate that environmental degradation may have been more extreme during the active-mining phase in the Tri-State District than has been determined in the post-mining phase (since about 1970). These early 20th century degradation effects probably would have included larger stream-water concentrations and transport of trace elements, greater acidity (lower pH) and turbidity in stream water, larger concentrations of trace elements in streambed sediment, severe depletion of stream aquatic life, and detrimental effects on predatory wildlife that relied on clean water and aquatic organisms for survival.

Study Methods

Sampling Site Selection

The selection of streambed-sampling sites (fig. 2; table 3) for the study described in this report was affected by several factors. First and foremost, the sampling network was a targeted design. The areas most intensively mined for lead and zinc in Cherokee County, Kansas, were known and, as such, more streambed-sampling sites were located on streams in those areas. Detailed evaluations in mined areas would determine the extent and magnitude of selected trace element and nutrient contamination for potential prioritization of stream segments most in need of remediation efforts. Other streambed-sampling sites were selected to define spatial variability in selected trace element and nutrient concentrations throughout the superfund site, to estimate background (pre-mining) concentrations of trace elements and nutrients in streambed sediment, and to correspond with sites sampled in the previous water-quality study by Spruill (1987) or in the current (2005) study of historical mining effects on mussel populations in the Spring River Basin conducted by KDHE (table 3). Eighty-seven streambed-sampling sites were selected throughout the study area for collection of streambed-sediment samples and assessed for concentrations of selected trace elements and nutrients.

Sample Collection, Handling, and Processing

Streambed-sediment samples were collected from the upper 0.8 in. of sediment deposition with a white plastic scoop to obtain only the most recently deposited material. Sampling the upper 0.8 in. of deposition follows protocols of the USGS National Water-Quality Assessment Program (Shelton and Capel, 1994). The targeted sediment particle size for the investigation described in this report was less than 0.063 mm (silt- and clay-size particles). Concentrations of associated trace elements and nutrients can vary substantially between particle-size classes and, generally, are largest within the silt/clay fraction (Forstner and Wittman, 1983; Horowitz, 1991; Grosbois and others, 2002). Restricting trace element and nutrient analyses to the silt/clay fraction reduced particle-size variability between sampling sites and permitted direct site-to-site comparisons.

At each streambed-sediment sampling site (fig. 2), multiple subsamples of the upper 0.8 in. of deposition were collected. If possible, 5 to 10 subsamples were collected from depositional zones along the sides and center of the stream. These subsamples were composited in a polyethylene zip-lock bag. The bag was sealed with a chain-of-custody sticker, placed in a second

Table 3. Streambed-sediment sampling sites in the Kansas part of the Tri-State Mining District, 2004.

[USGS, U.S. Geological Survey; KDHE, Kansas Department of Health and Environment; OK, Oklahoma; KS, Kansas; MO, Missouri; --, not applicable; NRDAR, natural resource damage assessment and restoration]

Map index number (fig. 2)	USGS site identification number	Site name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	USGS 7.5-minute quadrangle (Kansas unless otherwise indicated)	KDHE mussel site identifier[1]
1	365956094521400	Elm Creek tributary at Kansas-Oklahoma State line near Treece	36°59' 55.8"	94°52' 14.5"	Picher, OK-KS	--
2	370245094503800	Tar Creek tributary 1 at Greenlawn Road near Treece	37°02' 45.4"	94°50' 38.2"	Neutral	--
3	370245094510000	Tar Creek at Greenlawn Road and SW 10th Street near Treece	37°02' 45.2"	94°50' 59.6"	Neutral	--
4	370245094515000	Tar Creek tributary 2 at Greenlawn Road near Treece	37°02' 45.3"	94°51' 49.9"	Neutral	--
5	370153094511100	Tar Creek at U.S. 166 Highway near Treece	37°01' 53.0"	94°51' 10.9"	Neutral	--
6	370100094512100	Tar Creek at Star Road near Treece	37°01' 00.1"	94°51' 21.1"	Neutral	--
7	370101094514800	Tar Creek tributary 3 at Star Road near Treece	37°01' 00.6"	94°51' 47.7"	Neutral	--
8	370100094514300	Tar Creek tributary 4 at Star Road near Treece	37°01' 00.2"	94°51' 42.7"	Neutral	--
9	370034094514400	Tar Creek near center of section 11, 1 mile northwest of Treece	37°00' 33.6"	94°51' 43.6"	Neutral	--
10	365956094510800	Tar Creek upstream of Treece Road near Treece	36°59' 56.0"	94°51' 07.6"	Picher, OK-KS	--
11	365955094505400	Tar Creek tributary at Kansas-Oklahoma State line near Treece	36°59' 55.4"	94°50' 53.7"	Picher, OK-KS	--
12	365956094480500	Lytle Creek at Kansas-Oklahoma State line near Treece	36°59' 55.8"	94°48' 05.1"	Picher, OK-KS	--
13	371158094373000	Spring River near Lawton	37°11' 58.2"	94°37' 30.4"	Carl Junction, MO-KS	SPRNG2
14	371429094375500	Cow Creek tributary at 110th Street near Lawton	37°14' 29.4"	94°37' 54.6"	Crestline	--
15	371425094390100	Cow Creek tributary at 100th Street near Lawton	37°14' 25.4"	94°39' 00.7"	Crestline	--
16	371319094391400	Cow Creek at Lawton Road near Lawton	37°13' 19.2"	94°39' 13.6"	Crestline	COW1
17	371253094400600	Cow Creek tributary at 90th Street near Lawton	37°12' 52.6"	94°40' 05.5"	Crestline	--
18	371059094384200	Spring River upstream of K-96 Highway near Lawton	37°10' 58.7"	94°38' 42.3"	Crestline	SPRNG3
19	370934094373800	Spring River near Kansas-Missouri State line	37°09' 33.7"	94°37' 38.0"	Crestline	--

Table 3. Streambed-sediment sampling sites in the Kansas part of the Tri-State Mining District, 2004.—Continued

[USGS, U.S. Geological Survey; KDHE, Kansas Department of Health and Environment; OK, Oklahoma; KS, Kansas; MO, Missouri; --, not applicable; NRDAR, natural resource damage assessment and restoration]

Map index number (fig. 2)	USGS site identification number	Site name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	USGS 7.5-minute quadrangle (Kansas unless otherwise indicated)	KDHE mussel site identifier[1]
20	370904094370100	Spring River at confluence with Center Creek near Smithfield, MO (Jasper County)	37°09' 03.9"	94°37' 01.4"	Carl Junction, MO-KS	--
21	370756094373100	Spring River at 110th Street near Galena	37°07' 55.7"	94°37' 30.9"	Carl Junction, MO-KS	SPRNG4
22	370740094373000	Turkey Creek at 110th Street near Galena	37°07' 40.5"	94°37' 29.5"	Carl Junction, MO-KS	--
23	370746094374000	Spring River at confluence with Turkey Creek near Galena	37°07' 46.4"	94°37' 40.3"	Crestline	--
24	370753094385600	Spring River 1 mile south of Messer School near Galena	37°07' 53.3"	94°38' 55.8"	Baxter Springs	SPRNG5
25	370628094392000	Spring River at Lostine Road near Galena	37°06' 28.4"	94°39' 20.3"	Baxter Springs	--
26	370526094370800	Short Creek near Galena	37°05' 25.9"	94°37' 08.0"	Joplin West MO-KS	--
27	370528094371500	Short Creek tributary north of Short Creek near Galena	37°05' 28.4"	94°37' 15.3"	Joplin West MO-KS	--
28	370522094371900	Spring Branch tributary to Short Creek near Galena	37°05' 21.5"	94°37' 19.0"	Joplin West MO-KS	--
29	370501094375800	Short Creek tributary near Galena	37°05' 01.4"	94°37' 58.3"	Baxter Springs	--
30	370459094381200	Short Creek tributary at Galena	37°04' 59.2"	94°38' 12.5"	Baxter Springs	--
31	370504094382000	Short Creek at Main Street at Galena	37°05' 03.7"	94°38' 20.2"	Baxter Springs	--
32	370406094375400	Short Creek tributary at Wood Street at Galena	37°04' 06.4"	94°37' 53.6"	Baxter Springs	--
33	370405094382600	Short Creek tributary at K-26 Highway at Galena	37°04' 05.4"	94°38' 26.4"	Baxter Springs	--
34	370429094384800	Short Creek tributary at K-66 Highway near Galena	37°04' 29.2"	94°38' 47.9"	Baxter Springs	--
35	370455094385600	Short Creek tributary near confluence with Short Creek near Galena	37°04' 55.4"	94°38' 55.5"	Baxter Springs	--
36	370501094390500	Short Creek 0.6 mile north of K-66 Highway near Galena	37°05' 01.3"	94°39' 04.8"	Baxter Springs	--
37	370520094393200	Short Creek tributary at Vine Street near Galena	37°05' 19.9"	94°39' 31.7"	Baxter Springs	--
38	370524094395900	Short Creek at Vine Street near Galena	37°05' 24.1"	94°39' 59.2"	Baxter Springs	SHORT1
39	370533094404700	Short Creek near confluence with Spring River near Riverton	37°05' 32.8"	94°40' 46.9"	Baxter Springs	--

Table 3. Streambed-sediment sampling sites in the Kansas part of the Tri-State Mining District, 2004.—Continued

[USGS, U.S. Geological Survey; KDHE, Kansas Department of Health and Environment; OK, Oklahoma; KS, Kansas; MO, Missouri; --, not applicable; NRDAR, natural resource damage assessment and restoration]

Map index number (fig. 2)	USGS site identification number	Site name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	USGS 7.5-minute quadrangle (Kansas unless otherwise indicated)	KDHE mussel site identifier[1]
40	371208094421700	Little Shawnee Creek at U.S. 69 Highway near Crestline	37°12' 07.7"	94°42' 16.8"	Crestline	--
41	371059094421700	Shawnee Creek at U.S. 69 Highway near Crestline	37°10' 59.2"	94°42' 16.6"	Crestline	--
42	371041094421000	Shawnee Creek tributary at K-96 Highway near Crestline	37°10' 41.0"	94°42' 10.0"	Crestline	--
43	371040094415100	Shawnee Creek at K-96 Highway near Crestline	37°10' 40.4"	94°41' 50.9"	Crestline	--
44	370855094403800	Shawnee Creek at Messer Road near Crestline	37°08' 54.8"	94°40' 38.2"	Crestline	--
45	370709094410500	Shawnee Creek at Boston Mills Road near Riverton	37°07' 09.1"	94°41' 05.0"	Baxter Springs	SHWN1
46	370825094432100	Shawnee Creek tributary at 60th Street near Crestline	37°08' 25.3"	94°43' 20.9"	Crestline	--
47	370709094413800	Shawnee Creek tributary at Boston Mills Road near Riverton	37°07' 09.3"	94°41' 38.2"	Baxter Springs	--
48	370616094410200	Shawnee Creek at Lostine Road near Riverton	37°06' 16.1"	94°41' 02.3"	Baxter Springs	--
49	370523094410800	Spring River near confluence of Shawnee Creek near Riverton	37°05' 22.8"	94°41' 07.8"	Baxter Springs	--
50	370428094395400	Spring River tributary at K-66 Highway near Riverton	37°04' 28.5"	94°39' 54.2"	Baxter Springs	--
51	370448094395000	Spring River tributary at Chico Road near Galena	37°04' 48.5"	94°39' 50.3"	Baxter Springs	--
52	370432094412100	Spring River tributary near Riverton	37°04' 32.4"	94°41' 21.3"	Baxter Springs	--
53	370156094370900	Shoal Creek at Kansas-Missouri State line	37°01' 55.8"	94°37' 09.2"	Joplin West MO-KS	--
54	370211094375500	Shoal Creek 0.5 mile east of K-26 Highway near Galena	37°02' 11.5"	94°37' 54.8"	Baxter Springs	--
55	370232094383300	Shoal Creek at Schermerhorn Park on K-26 Highway near Galena	37°02' 31.7"	94°38' 33.1"	Baxter Springs	SHL3
56	370224094385900	Shoal Creek tributary 0.3 mile west of K-26 Highway near Galena	37°02' 23.7"	94°38' 59.1"	Baxter Springs	--
57	370228094390300	Shoal Creek near K-26 Highway near Galena	37°02' 28.3"	94°39' 02.6"	Baxter Springs	--
58	370244094392100	Shoal Creek tributary 0.75 mile west of K-26 Highway near Galena	37°02' 44.5"	94°39' 21.2"	Baxter Springs	--

Table 3. Streambed-sediment sampling sites in the Kansas part of the Tri-State Mining District, 2004.—Continued

[USGS, U.S. Geological Survey; KDHE, Kansas Department of Health and Environment; OK, Oklahoma; KS, Kansas; MO, Missouri; --, not applicable; NRDAR, natural resource damage assessment and restoration]

Map index number (fig. 2)	USGS site identification number	Site name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	USGS 7.5-minute quadrangle (Kansas unless otherwise indicated)	KDHE mussel site identifier[1]
59	370243094392400	Shoal Creek tributary 0.87 mile west of K-26 Highway near Galena	37°02' 42.8"	94°39' 24.2"	Baxter Springs	--
60	370223094393500	Shoal Creek 0.90 mile west of K-26 Highway near Galena	37°02' 23.2”	94°39'34.8”	Baxter Springs	
61	370232094401400	Shoal Creek near Lowell	37°02' 32.1"	94°40' 13.6"	Baxter Springs	--
62	370319094420800	Spring River below Empire Lake near Lowell	37°03' 18.6"	94°42' 08.1"	Baxter Springs	--
63	370344094422100	Spring River below Empire Lake Dam near Riverton	37°03' 44.5"	94°42' 21.1"	Baxter Springs	--
64	370803094464600	Brush Creek tributary at Clem Road near Neutral	37°08' 02.7"	94°46' 46.2"	Columbus	--
65	370706094472600	Brush Creek at 22nd Street near Neutral	37°07' 05.8"	94°47' 26.4"	Neutral	--
66	370616094463600	Brush Creek at Lostine Road near Riverton	37°06' 15.8"	94°46' 36.3"	Neutral	BRSH1
67	370523094455100	Brush Creek at Quaker Road near Riverton	37°05' 23.4"	94°45' 51.4"	Neutral	--
68	370512094484800	Bitter Creek at SE 10th Street near Treece	37°05' 12.5"	94°48' 47.9"	Neutral	--
69	370451094463700	Bitter Creek at SE 30th Street near Treece	37°04' 50.7"	94°46' 37.3"	Neutral	--
70	370505094453500	Brush Creek at SE 40th Street near Riverton	37°05' 04.9"	94°45' 34.9"	Neutral	--
71	370617094444200	Brush Creek tributary at Lostine Road near Riverton	37°06' 17.3"	94°44' 41.6"	Baxter Springs	--
72	370444094442600	Brush Creek tributary at SE 50th Street near Riverton	37°04' 44.1"	94°44' 26.2"	Baxter Springs	--
73	370424094442700	Brush Creek at Old U.S. 66 Highway near Riverton	37°04' 23.5"	94°44' 26.6"	Baxter Springs	--
74	370237094433400	Spring River near Lowell	37°02' 36.6"	94°43' 34.2"	Baxter Springs	--
75	370432094494000	Willow Creek at Beasley Road near Neutral	37°04' 31.6"	94°49' 40.0"	Neutral	--
76	370245094474400	Willow Creek at SE 20th Street and Greenlawn Road near Baxter Springs	37°02' 45.3"	94°47' 44.2"	Neutral	--
77	370213094474200	Willow Creek tributary at SE 20th Street near Baxter Springs	37°02 13.0"	94°47' 42.2"	Neutral	--
78	370215094463600	Willow Creek at Swalley Avenue near Baxter Springs	37°02' 15.2"	94°46' 36.4"	Neutral	--

Table 3. Streambed-sediment sampling sites in the Kansas part of the Tri-State Mining District, 2004.—Continued

[USGS, U.S. Geological Survey; KDHE, Kansas Department of Health and Environment; OK, Oklahoma; KS, Kansas; MO, Missouri; --, not applicable; NRDAR, natural resource damage assessment and restoration]

Map index number (fig. 2)	USGS site identification number	Site name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	USGS 7.5-minute quadrangle (Kansas unless otherwise indicated)	KDHE mussel site identifier[1]
79	370220094453100	Willow Creek at Ballard Road near Baxter Springs	37°02' 20.0"	94°45' 31.3"	Neutral	--
80	370224094442600	Willow Creek at old U.S. 66 Highway at Baxter Springs	37°02' 24.2"	94°44' 25.5"	Baxter Springs	WLW1
81	370109094453100	Spring Branch Creek at SE 40th Street near Baxter Springs	37°01' 08.7"	94°45' 31.1"	Neutral	--
82	370121094444200	Spring Branch Creek at Kansas Avenue, Baxter Springs	37°01' 21.4"	94°44' 42.4"	Baxter Springs	--
83	370127094442800	Spring Branch Creek at 12th Street, Baxter Springs	37°01' 26.6"	94°44' 27.7"	Baxter Springs	--
84	370144094440500	Spring Branch Creek at Military Avenue, Baxter Springs	37°01' 44.1"	94°44' 05.2"	Baxter Springs	SBSRG1
85	370114094431600	Spring River at Baxter Springs	37°01' 14.0"	94°43' 16.5"	Baxter Springs	SPRNG6
86	365955094424100	Spring River at Kansas-Oklahoma State line	36°59' 54.7"	94°42' 40.8"	Peoria, OK-KS	--
87	370007094421100	Spring River tributary at Five Mile Avenue near Baxter Springs	37°00' 07.3"	94°42' 10.9"	Baxter Springs	--

[1] Part of current (2005) study of mussel populations in the Spring River Basin.

bag, sealed with a chain-of-custody sticker, and placed in a third bag and stored on ice in a secured area until shipped to the USGS sediment trace element laboratory in Atlanta, Georgia. Exceptions to this protocol were sites on the Spring River where samples generally were collected from depositional zones only along one side of the channel because swift or turbulent flows and the rock and cobble streambed limited boat or personnel access to only one side of the stream. A total of 98 composite samples were collected.

The quantity and distribution of silt/clay streambed particles varied among streams in the area of investigation. Many streams were armored with limestone and chert cobbles from the weathering of Mississippian rocks (fig. 9). Generally, these streams were east of the Spring River (Ozark Plateau province) where stream gradients were steeper and flows swifter than the area west of the Spring River. These swift, rocky streams limited the collection of samples to depositional zones where silt/clay particles collected around and under rocks or along the sides of streams where flows were slower. Streams west of the Spring River (Cherokee Lowlands province) had streambeds composed of sand, silt, and clay (fig. 10), and streambed samples from these streams generally had larger percentages of silt/clay particles than samples from streams in the Ozark Plateau province (table 11 in the "Supplemental Information" section at the back of this report).

Figure 9. Example of streams in the Ozark Plateau physiographic province of Cherokee County, Kansas (Shoal Creek, map index number 54, fig. 2), with streambed armored with limestone and chert cobbles.

Figure 10. Example of streams in the Cherokee Lowlands physiographic province of Cherokee County, Kansas (Brush Creek, map index number 67, fig. 2), with streambed composed of sand, silt, and clay.

Table 4. Trace elements and nutrients analyzed in the less than 0.063-millimeter fraction of streambed sediment collected from selected sampling sites in the Kansas part of the Tri-State Mining District, 2004.

[mm, millimeter]

Trace element or nutrient			
Aluminum	Carbon, total	Manganese	Silver
Antimony	Chromium	Mercury	Strontium
Arsenic	Cobalt	Molybdenum	Thallium
Barium	Copper	Nickel	Titanium
Beryllium	Iron	Nitrogen, total	Vanadium
Cadmium	Lead	Phosphorus	Uranium
Carbon, organic, total	Lithium	Selenium	Zinc

Upon receipt at the USGS sediment trace element laboratory in Atlantic, Georgia, the streambed-sediment samples were freeze dried and placed in secure storage until pre-analytical processing. Chain-of-custody procedures were followed during sample storage, processing, and analysis. Prior to analysis, the samples were sieved through a 2-mm polyester screen to remove large material such as wood and leaf debris and gravel. The less than 2-mm sample was mechanically homogenized, and a less than 0.063-mm fraction was obtained by sieving a representative aliquot of the homogenized sample through a 0.063-mm polyester screen held in a polycarbonate frame. Screens were replaced between samples.

Sample Analysis

The less than 0.063-mm fractions of streambed-sediment samples were analyzed for selected trace elements (table 4) generally using procedures presented in Fishman (1993) and modified by Horowitz and others (1989). Basically, the procedures involved digestion of 0.5-g homogenized aliquots of the less than 0.063-mm fractions using a strong-acid combination (hydrochloric, hydrofluoric, perchloric, and nitric acids) in Teflon beakers at 210 °C for all constituents except mercury, total carbon, total inorganic carbon, total nitrogen, and total phosphorus. This strong-acid digestion breaks apart the mineral matrix, and subsequent analyses provide total trace element concentrations and represent something greater than 95 percent or greater of the element that was sorbed to and (or) bound in the mineral matrix (Maloney, 2004). The salts from the digestion procedure were solubilized with 5 percent HCl and analyzed by inductively coupled plasma-atomic emission spectroscopy, flame atomic absorption spectroscopy (AAS), or hydride generation AAS. Mercury was determined using cold vapor AAS (Grosbois and others, 2001). Carbon, nitrogen, and phosphorus were determined by procedures in Fishman (1993).

Preliminary quality assurance (QA) of results of sample analyses (table 11 in the "Supplemental Information" section at the back of this report) was performed at the sediment trace element laboratory before transmittal to the USGS office in Lawrence, Kansas. Additional QA evaluations were performed on sample results at the Lawrence office.

Quality Assurance

Quality-assurance samples were collected to test precision and bias in sediment sample collection, processing, and analyses. Quality-assurance samples included concurrently, sequentially, and temporally collected replicate environmental samples, laboratory split-replicate samples (table 11 in the "Supplemental Information" section at the back of this report), and standard-reference soil/sediment samples (table 12 in the "Supplemental Information" section at the back of this report). A target goal for variability among analyses of concurrent-, sequential-, and split-replicate samples was a relative percentage difference of ±20 percent except when constituent concentrations were at or near analytical detection limits. Relative percentage difference (RPD) was calculated as the difference in replicate analyses divided by the mean and expressed as a percentage. A target goal for acceptable results of analysis of reference samples was within published limits (table 12) for each constituent for each standard or ±10 percent of the most probable value (MPV) for the constituent (whichever was greater), except when constituent concentrations were at or near analytical detection limits.

Concurrent-replicate samples consisted of alternately collected subsamples (from same subsampling site) composited into two sample-collection bags. Analysis of concurrent-replicate samples measures the variability of sample-collection methods. Eight pairs of concurrent-replicate streambed-sediment samples were collected during the study described in this report (table 11). RPDs between paired constituent concentrations were calculated and summarized (table 5) if

Table 5. Statistical summary of absolute relative percentage differences between total trace element and nutrient analyses of concurrent and sequentially collected replicate samples and laboratory split-replicate samples of the less than 0.063-millimeter fraction of streambed sediment from selected sampling sites in the Kansas part of the Tri-State Mining District, 2004.

[N, number of replicate pairs; Min, minimum percentage; Med, median percentage; Max, maximum percentage; --, not determined]

Trace element or nutrient	Concurrent-replicate samples					Sequential-replicate samples					Temporal-replicate samples (N=1)	Laboratory split-replicate samples[1]				
	N[2]	Min	Med	Mean	Max	N[2]	Min	Med	Mean	Max		N[2]	Min	Med	Mean	Max
Aluminum	8	1.0	2.3	3.6	9.5	2	11.8	31.0	31.0	50.3	21.6	15	0	3.5	4.5	14.5
Antimony	8	0	3.4	6.2	15.4	2	0	4.8	4.8	9.5	13.3	15	0	10.5	8.6	22.2
Arsenic	8	0	2.9	4.5	10.5	2	6.7	16.4	16.4	26.1	30.0	15	0	2.4	4.7	18.2
Barium	8	0	1.5	2.3	7.1	2	5.1	30.7	30.7	56.3	4.4	15	0	2.7	4.6	12.5
Beryllium	8	0	4.3	3.4	8.0	2	6.9	32.7	32.7	58.5	0	15	0	8.0	7.2	17.5
Cadmium	8	0	7.1	7.7	18.2	2	0	77.9	77.9	156	17.1	15	0	0	5.0	22.2
Carbon, organic, total	8	0	3.9	4.8	15.4	2	0	5.3	5.3	10.5	47.9	13	0	6.1	5.7	13.3
Carbon, total	8	0	3.6	3.2	8.7	2	0	34.7	34.7	69.5	48.2	13	0	0	2.2	6.5
Chromium	8	0	2.5	2.8	7.1	2	6.2	10.0	10.0	13.8	3.4	15	2.0	7.1	6.6	12.9
Cobalt	8	0	6.0	6.1	15.4	2	12.5	29.6	29.6	46.7	34.3	15	0	7.7	7.9	16.2
Copper	8	0	6.2	11.8	51.2	2	12.1	33.8	33.8	55.6	31.6	15	0	5.1	6.1	15.4
Iron	8	0	3.7	4.4	11.1	2	4.7	20.9	20.9	37.2	24.0	15	0	4.7	4.6	13.3
Lead	8	0	3.1	4.4	11.8	2	11.8	44.8	44.8	77.9	0	15	0	5.5	6.2	41.9
Lithium	8	0	4.4	3.9	7.2	2	7.4	14.0	14.0	20.5	29.8	15	0	7.6	10.0	41.9
Manganese	8	0	10.1	8.5	18.2	2	11.5	25.5	25.5	39.5	4.6	15	0	5.0	5.1	11.5
Mercury	7	4.9	16.5	8.5	22.4	2	24.3	58.3	58.3	92.4	5.7	11	0	15.4	17.0	46.9
Molybdenum	0	--	--	--	--	1	45.6	--	--	45.6	0	10	0	16.2	13.8	28.6
Nickel	8	1.7	4.1	6.3	15.4	2	14.3	20.2	20.2	26.1	38.7	15	0	4.7	6.0	15.4
Nitrogen, total	8	4.7	7.8	10.0	26.9	2	0	2.2	2.2	4.4	24.4	13	0	4.3	7.5	26.1
Phosphorus	8	0	6.1	5.1	8.5	2	9.5	26.9	26.9	44.3	16.5	15	0	3.6	5.3	15.4
Selenium	8	0	5.9	9.9	33.3	2	16.2	17.2	17.2	18.2	38.6	15	0	10.5	14.1	35.3
Silver	1	0	--	--	0	1	31.6	--	--	31.6	23.3	0	--	--	--	--
Strontium	8	0	3.0	3.7	8.1	2	2.9	37.0	37.0	71.0	10.5	15	0	4.9	4.8	13.5
Thallium	0	--	--	--	--	0	--	--	--	--	--	0	--	--	--	--
Titanium	8	0	2.1	2.0	4.1	2	5.1	17.8	17.8	30.6	3.8	15	0	4.5	4.5	9.3
Vanadium	8	0	4.1	4.1	8.7	2	9.7	29.9	29.9	50.2	1.6	15	0	3.6	4.7	10.2
Uranium	0	--	--	--	--	0	--	--	--	--	--	0	--	--	--	--
Zinc	8	0	8.3	7.7	14.3	2	11.5	74.5	74.5	137	4.1	15	0	2.2	3.6	10.0

[1] Includes requested laboratory reanalyses.

[2] Number of replicate pairs with both values reported as noncensored data (greater than laboratory method reporting limit).

both analyses had concentrations greater than laboratory method reporting limits (noncensored data). No RPDs were available for molybdenum, thallium, and uranium. Both median and mean RPDs for all summarized constituents were substantially less than the target quality goal of ±20 percent RPD. The maximum RPD exceeded this goal for only four constituents (copper, mercury, nitrogen, and selenium). Generally, the largest RPDs were calculated from paired analyses with relatively small concentrations. However, overall results of concurrently collected replicate samples of streambed sediment indicated that variability in sampling methods was small for the sites assessed during the study described in this report and within the acceptable quality-assurance goals of ±20 percent.

Sequential-replicate samples consisted of two independently collected (different subsampling sites) samples acquired at the same sampling site. Analysis of sequential-replicate samples measures the effects of sampling-site (within site) variability and the degree to which data accurately and precisely represent a characteristic of a population at a sampling site. Results of analyses of sequentially collected replicate streambed-sediment samples indicated greater variability than evidenced in the collection of concurrent-replicate samples (table 5). Sequential-replicate samples were collected at only two streambed sampling sites (sites 23 and 46; fig. 2; table 11) so definitive conclusions that can be drawn from this data set are limited. Site 23 (Spring River, table 3) generally had acceptable agreement in analytical results of sequential-replicate samples as indicated by most of the minimum RPDs listed in table 5, whereas results for samples from site 46 (Shawnee Creek tributary; table 3) had large RPDs as indicated by the maximum RPDs listed in table 5 (except for antimony, chromium, and selenium that had larger RPDs at sampling site 23). Analytical reanalysis of the sample from site 46 (table 11) verified the large RPDs. The relatively large RPDs at site 46 may be an anomaly, an indication of pervasive conditions among the sampling sites, or evidence that stream size (associated drainage area) is a contributing factor in sediment-quality variability. Site 46 represented one of the smallest stream segments (fig. 2) of all 87 sampling sites. Sediment-quality variability in small, pool-and-riffle streams may be a natural condition not evident in larger streams such as the Spring River. Clearly, no conclusion can be substantiated with the available data, but it does indicate that sequential-replicate sampling should be a larger part of quality-assurance protocols for future work in the Tri-State District.

Sampling site 31 (Short Creek, fig. 2) was sampled twice (about 1 month apart, table 11) to determine short-term (temporal) sediment-quality variability. Although data from one site does not provide a comprehensive evaluation of temporal variability for the 87 sites sampled during the study described in this report, it does provide some information about temporal variability relative to other variability factors. For example, 69 percent (18 of 26 constituents) of RPDs between temporal replicates were less than or within the range of corresponding sequential-replicate RPDs, and 50 percent (13 of 26 constituents) were within the range of corresponding concurrent-replicate samples. Temporal-replicate RPDs for lead and zinc were less than mean or median lead and zinc RPDs for either concurrent- or sequential-replicate RPDs, and in fact, the temporal-replicate RPD for lead (0 percent) equalled the minimum concurrent-replicate RPD. Overall, temporal-replicate RPDs ranged from 0 percent (beryllium, lead, and molybdenum) to about 48 percent for organic and total carbon with a median of 16.8 percent and a mean of 18.4 percent. Therefore, short-term, temporal factors do not seem to be a substantial source of variability in sediment-quality data for many of the assessed constituents, at least relative to sample-collection methods as evaluated by concurrent-replicate samples or to within-site variability as evaluated by sequential-replicate samples.

Laboratory split-replicate samples consisted of two subsamples of a homogeneously prepared environmental sample that were randomly selected at the time of sample analysis. Analysis of split-replicate samples measures the precision (reproducibility) among replicate measurements of the same property and represents the ability of laboratory methods to reproduce the same or nearly the same concentration of selected constituents in a natural environmental matrix. Fifteen laboratory split-replicate samples were analyzed to evaluate precision in laboratory methods (table 5). Of the 25 constituents with noncensored data, none had median or mean RPDs greater than the target goal of ±20 percent, and only eight of those had maximum RPDs that exceeded ±20 percent. Therefore, laboratory precision, as evaluated with this data set, was acceptable and not a source of substantial variability in constituent concentrations for samples collected during the study described in this report.

Standard-reference soil/sediment samples were obtained from sources indicated in table 12. Analysis of reference samples provides a measure of the accuracy of laboratory methods to produce the true value of a measured constituent and essentially represents the bias in methodology (instrumentation and procedures). As many as 30 reference-sample analyses were performed for the sediment-quality constituents evaluated in the study described in this report (table 6). Of the 651 constituent analyses performed on reference samples, 87 percent met quality goals as previously defined. Censored results (106 constituent analyses) were not used in comparison to reference limits or MPVs. Individually, the percentage of acceptable reference sample analyses ranged from 25 percent for uranium to 100 percent for several constituents. Median and mean percentage differences from MPVs generally were less than 10 percent. Many of the results that did not meet quality goals were from samples with small concentrations, relative to other reference samples and (or) environmental sample concentrations (table 11), such as antimony, cadmium, cobalt, copper, mercury, molybdenum, selenium, silver, titanium, and vanadium. Generally, however, laboratory accuracy was of acceptable quality, and the analytical results from environmental samples were considered representative of the samples submitted for analysis.

Table 6. Summary of trace element and nutrient analyses of standard-reference soil/sediment samples.

[MPV, most probable value; --, not determined]

Trace element or nutrient	Number of reference analyses[1]	Range of MPVs[2]	Percentage difference from MPV (absolute values)				Percentage of reference analyses within established quality criteria[3]
			Minimum	Median	Mean	Maximum	
Aluminum	30	2.30–9.73	0.1	1.2	1.5	6.5	100
Antimony	27	0.3–19.4	0	3.8	6.4	19.0	89
Arsenic	27	3.5–105	0	4.8	6.4	31.4	100
Barium	30	210–1,370	0	4.0	7.7	49.6	90
Beryllium	22	1.06–9.6	3.0	7.6	8.7	18.2	81
Cadmium	22	0.14–41.7	0	25.0	21.6	50.0	50
Carbon, organic, total	4	3.3–25.0	3.0	6.0	5.8	8.0	100
Carbon, total	19	1.2–28.0	0	5.0	7.3	23.5	80
Chromium	30	3.2–352	0	6.6	9.4	34.4	93
Cobalt	29	0.9–46.8	1.0	4.5	6.6	44.4	90
Copper	30	4.6–117.7	0	5.6	8.7	56.5	87
Iron	30	2.00–7.91	0	2.7	2.6	5.7	100
Lead	30	12.0–1,162	0	6.8	7.3	17.6	80
Lithium	24	17.0–147	0	4.0	6.6	21.9	88
Manganese	30	234–1,757	0	2.9	3.8	13.9	97
Mercury	28	0.01–6.25	0	13.6	171	3,900	50
Molybdenum	27	1.37–134	0	11.5	13.5	50.0	67
Nickel	30	3.0–99.5	0	5.5	11.1	60.3	100
Nitrogen, total	3	.35	5.7	11.4	10.5	14.3	67
Phosphorus	30	270–1,552	0	4.2	5.1	16.1	100
Selenium	19	0.19–4.95	0	5.3	8.6	47.4	68
Silver	7	0.08–4.63	.6	22.0	105	520	43
Strontium	30	68.0–700	0	4.0	4.2	10.5	100
Thallium	0	--	--	--	--	--	--
Titanium	30	0.081–0.884	0	3.8	4.3	11.1	90
Vanadium	30	8.7–357.6	0	6.2	10.4	65.5	97
Uranium	4	9.06–48.8	10.7	31.8	58.6	160	25
Zinc	30	49.0–485.3	0	3.3	4.0	10.8	100

[1] Does not include analyses reported as less than the laboratory method reporting limit.

[2] In milligrams per kilogram except for aluminum, carbon, iron, nitrogen, and titanium, which are in percent dry weight.

[3] Acceptable variability among analyses of standard-reference samples is within the published limits for each constituent for each standard or ±10 percent of the MPV, whichever is greater.

Assessment of Contaminated Streambed Sediment

Streambed sediment is a natural accumulator of many trace elements. Analysis of streambed sediment can provide useful information about stream and watershed contamination sources, extent, and magnitude. Samples of streambed sediment were collected at 87 sampling sites throughout the Cherokee County superfund site (fig. 2) and analyzed for trace element and nutrient content. Results of these analyses were tabulated (table 11 in the "Supplemental Information" section at the back of this report), summarized, and assessed. The assessment of these data included the identification of past or present trace element and nutrient contamination, the extent and magnitude of that contamination, and the potential for the contaminated sediment to adversely affect aquatic life relative to recommended sediment-quality guidelines. Quality-assurance samples were collected at many sampling sites in addition to primary environmental samples (table 11). For sampling sites with both primary and concurrent-, sequential-, temporal-, or laboratory split-replicate samples or reanalyses, analytical results of these primary and quality-assurance samples were averaged prior to statistical summary and assessment.

Statistical Summary and Spatial Variability

Trace element and nutrient concentrations in streambed sediment from all 87 sampling sites (table 11) were summarized statistically and selected percentiles calculated (table 7). Large ranges in concentrations were determined for several trace elements. Most notable were those for cadmium, lead, and zinc that had factor increases (maximum divided by minimum concentrations) of about 770, 340, and 450 times, respectively. These contrast with factor increases of less than 10 times for the majority of constituents (aluminum, arsenic, barium, beryllium, carbon-organic, carbon-total, chromium, iron, lithium, nickel, nitrogen, strontium, titanium, and vanadium). Factor increases of 50 times or greater were calculated for antimony (55), copper (59), and phosphorus (50), whereas factor increases of 25 times or less were calculated for cobalt (18), manganese (25), and selenium (13). Because of censored data for either the minimum or maximum concentration, factor increases were not calculated for mercury, molybdenum, silver, thallium, or uranium.

The large ranges in concentrations of cadmium (0.6 to 460 mg/kg), lead (22 to 7,400 mg/kg), and zinc (100 to 45,000 mg/kg) in streambed sediment are almost certainly the result of mining and mining related effects on some streams. A comparison of mean and median concentrations for selected trace elements and nutrients indicate that the central tendency of the data populations is skewed by several large concentrations. For example, the median (50 percentile) of lead concentrations from all 87 sampling sites was 180 mg/kg, but because of relatively large concentrations from about 10 percent of the sampling sites, the mean was 650 mg/kg (3.6 times larger). Similar examples were evident for the median and means of cadmium (median of 13 and mean of 42 mg/kg) and zinc (median of 1,800 and mean of 5,600 mg/kg).

The ranges in antimony (0.4 to 22 mg/kg) and phosphorus (400 to 20,000 mg/kg) were the result of large concentrations at a few sampling sites (table 11). The maximum concentration of antimony was determined at sampling site 31 on Short Creek (fig. 2; table 3). The second largest concentration also was determined at a Short Creek sampling site (site 38) but at a much smaller concentration of 6.7 mg/kg. The factor increase would have been about 17 times using the second largest concentration. It is not known if the enrichment of antimony in streambed sediment of Short Creek is related to lead and zinc mining, but it is possible that it may be of industrial origin. Antimony is used as a hardening agent for lead in the production of lead-acid storage batteries and electrical cable sheathing (Mineral Information Institute, 2005). Antimony may have been used in the lead smelting and refining process at a smelter located near Short Creek at Galena, Kansas, with subsequent environmental release or discharge. Lead and zinc ores of the Tri-State District were mostly free of antimony (Haworth and others, 1904).

The large phosphorus range among the 87 sampling sites was the result of a large concentration (20,000 mg/kg) determined at Short Creek sampling site 26 (fig. 2; table 3). Other sampling sites (31, 38, and 39) on Short Creek also had relatively large phosphorus concentrations (4,200, 5,500, and 13,000 mg/kg, respectively). It is believed that these large concentrations of phosphorus in streambed-sediment samples from Short Creek are related to a fertilizer manufacturing facility located in the Short Creek watershed. Phosphorus concentrations from all other streambed-sediment sampling sites did not exceed 1,700 mg/kg (table 11).

The range in copper concentrations (11 to 650 mg/kg) in streambed-sediment samples, although substantially smaller (on the basis of factor increases) than that determined for cadmium, lead, or zinc, was large relative to most other trace elements and also may be related to lead and zinc mining. As previously mentioned, several copper minerals occur in association with the lead and zinc ores in the Tri-State District and, although not commercially recovered, their environmental distribution during the milling, processing, and smelting of the lead and zinc ores was likely.

Large spatial variability was determined for streambed-sediment concentrations of cadmium (fig. 11), lead (fig. 12), and zinc (fig. 13) throughout the study area; however, the spatial distributional pattern was similar for all three trace elements. Sampling sites in the most intensively mine-affected areas had the largest concentrations of these trace elements. The largest streambed-sediment concentrations of cadmium, lead, and zinc were determined at sampling sites in the Short Creek watershed in and near Galena, Kansas. For example, concentrations of cadmium at sampling sites on the main stem of Short Creek (sites 26, 31, 36, 38, and 39; table 3) ranged from 110 (site 36) to 460 mg/kg (site 39) (table 11). Lead concentrations ranged from 280 (site 26) to 7,400 (site 31). The lead

Table 7. Statistical summary of sediment particle size and selected trace element and nutrient concentrations of streambed sediment collected from 87 sampling sites in the Kansas part of the Tri-State Mining District, 2004.

[Values may represent an average of primary and replicate samples presented in table 11. Values are given in milligrams per kilogram unless otherwise indicated. mm, millimeter; pdw, percent dry weight; --, not determined; <, less than]

Constituent	Particle size or concentration										Factor increase[1] (minimum to maximum)
	Mean	Minimum	Percentile							Maximum	
			5	10	25	50 (median)	75	90	95		
Sediment, <0.063 mm, pdw	27	6	9	11	18	23	36	49	55	59	--
Trace element or nutrient concentration in less than 0.063-mm fraction											
Aluminum, pdw	4.7	2.8	3.3	3.6	3.8	4.5	5.3	6.0	7.1	8.3	3.0
Antimony	1.3	.4	.6	.7	.8	.9	1.1	1.6	2.1	22	55
Arsenic	11	3.9	4.4	6.0	7.6	9.7	14	17	21	32	8.2
Barium	450	160	350	370	430	450	490	510	520	780	4.9
Beryllium	1.8	1.2	1.2	1.3	1.4	1.8	2.1	2.5	2.7	3.6	3.0
Cadmium	42	.6	.9	1.0	2.4	13	52	110	210	460	770
Carbon, organic, total, pdw	2.4	.6	1.4	1.5	1.8	2.1	2.9	4.1	5.1	5.5	9.2
Carbon, total, pdw	2.8	.8	1.6	1.7	2.1	2.5	3.5	4.8	5.8	6.7	8.4
Chromium	62	39	44	46	50	59	68	83	99	160	4.1
Cobalt	20	6.7	9.0	10	12	16	23	37	49	120	18
Copper	56	11	15	16	19	23	40	100	190	650	59
Iron, pdw	2.8	1.4	1.6	1.8	2.0	2.5	3.4	4.2	5.0	8.7	6.2
Lead	650	22	33	39	58	180	520	1,600	3,400	7,400	340
Lithium	35	17	20	21	24	29	42	58	64	82	4.8
Manganese	990	150	400	500	660	870	1,200	1,600	1,900	3,700	25
Mercury	--[2]	<.01	.02	.03	.05	.09	.16	.40	1.0	1.9	--
Molybdenum	--[2]	<1	<1	<1	<1	1	2	2	2	4	--
Nickel	31	14	17	20	23	27	36	46	55	89	6.4
Nitrogen, total, pdw	.23	.07	.12	.13	.16	.20	.29	.38	.44	.60	8.6
Phosphorus	1,300	400	460	550	670	800	1,000	1,500	1,700	20,000	50
Selenium	1.1	.3	.6	.7	.8	.9	1.2	1.9	2.1	4.0	13
Silver	--[2]	<.5	<.5	<.5	<.5	<.5	<1.0	1.0	1.1	2.2	--
Strontium	82	45	58	60	64	73	97	120	130	200	4.4
Thallium	--[2]	<50	<50	<50	<50	<50	<100	<100	<100	<100	--
Titanium, pdw	.45	.24	.30	.39	.44	.46	.50	.53	.53	.55	2.3
Vanadium	74	42	49	53	60	70	85	99	120	130	3.1
Uranium	--[2]	<50	<50	<50	<50	<50	<100	<100	<100	<100	--
Zinc	5,600	100	170	200	450	1,800	5,800	16,000	26,000	45,000	450

[1] Not calculated if the minimum was a censored value.

[2] Data set contained censored (less than) values. Mean not calculated.

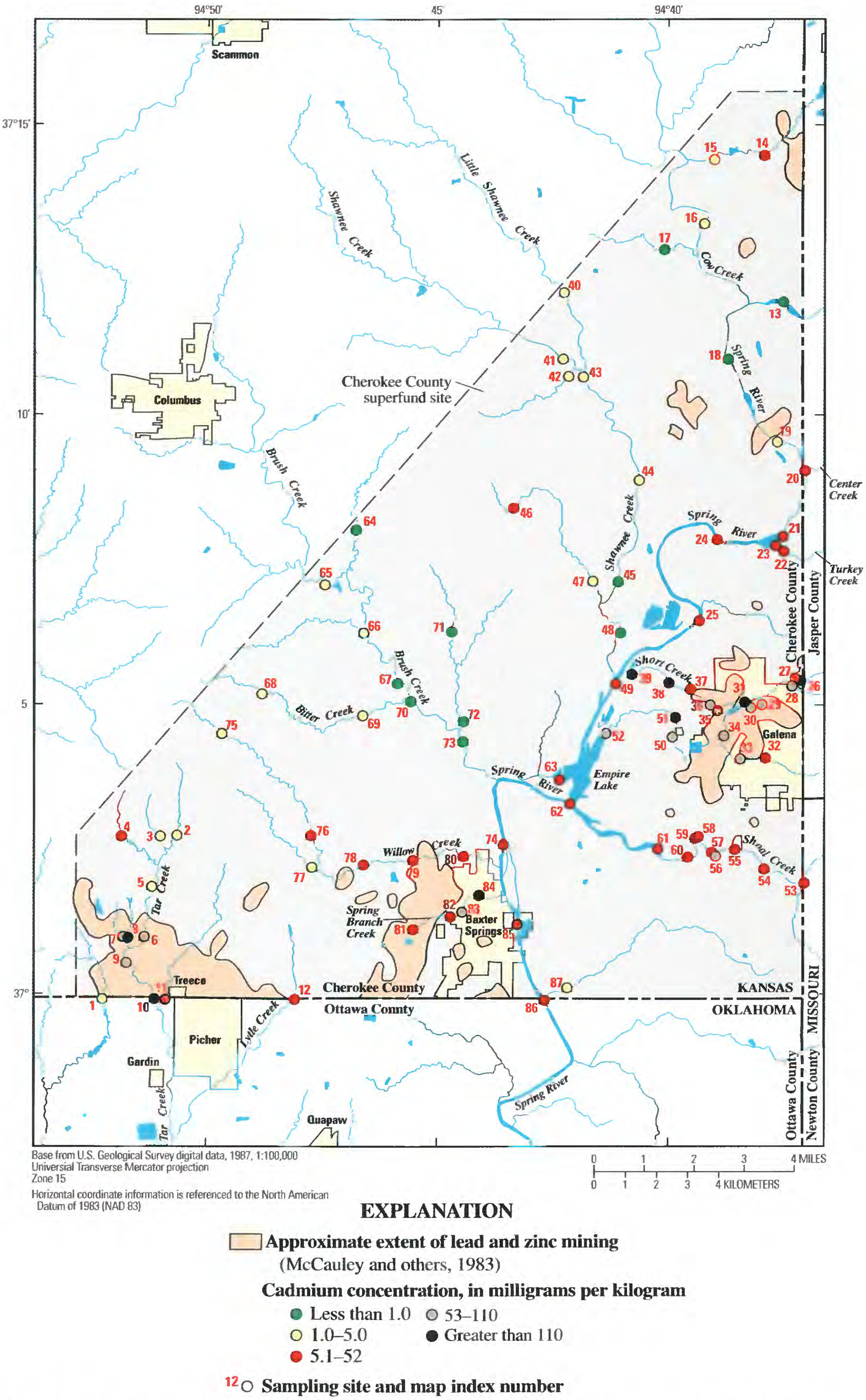


Figure 11. Distribution of cadmium concentrations in the less than 0.063-millimeter fraction of streambed-sediment samples from the Kansas part of the Tri-State Mining District, 2004.

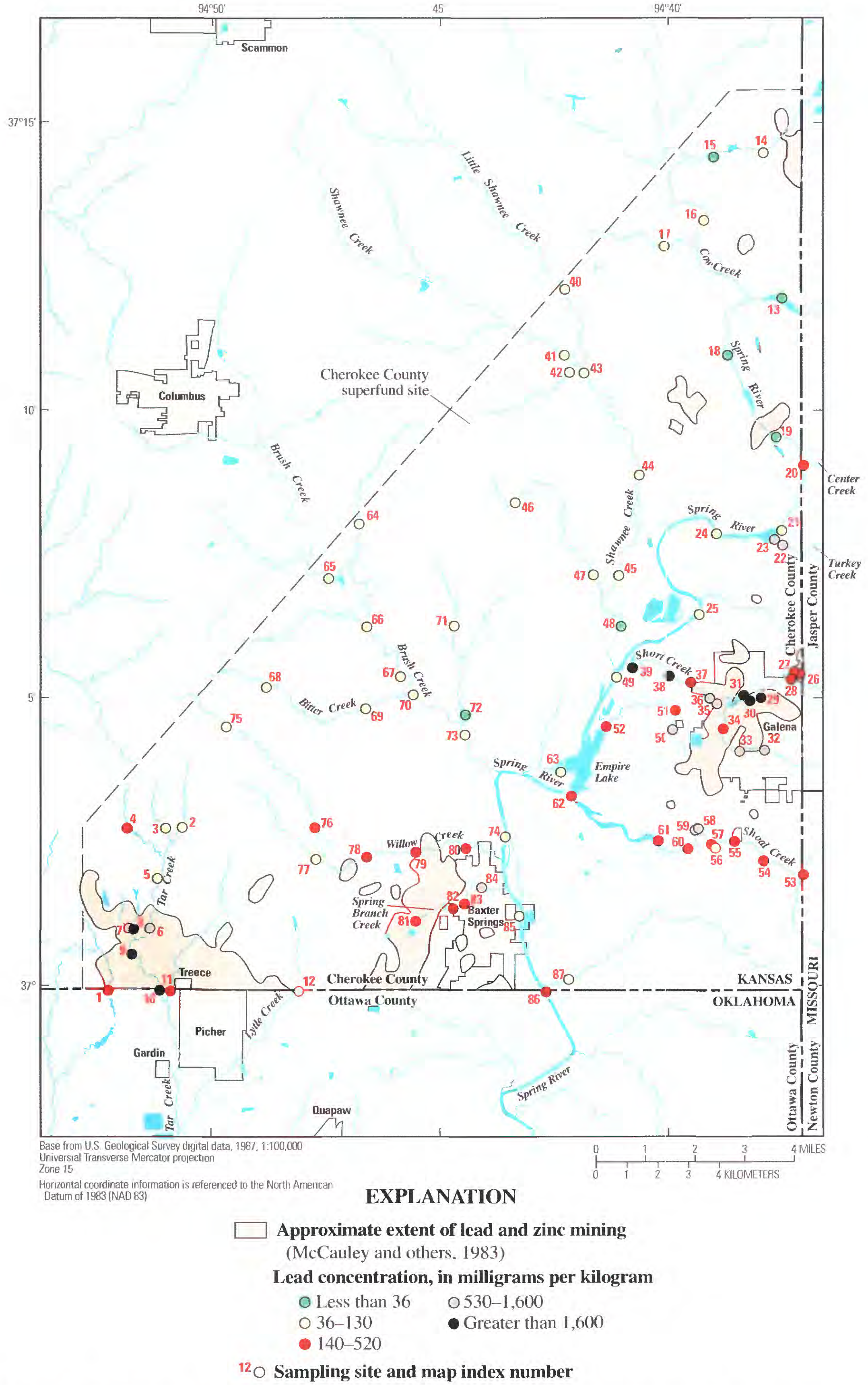
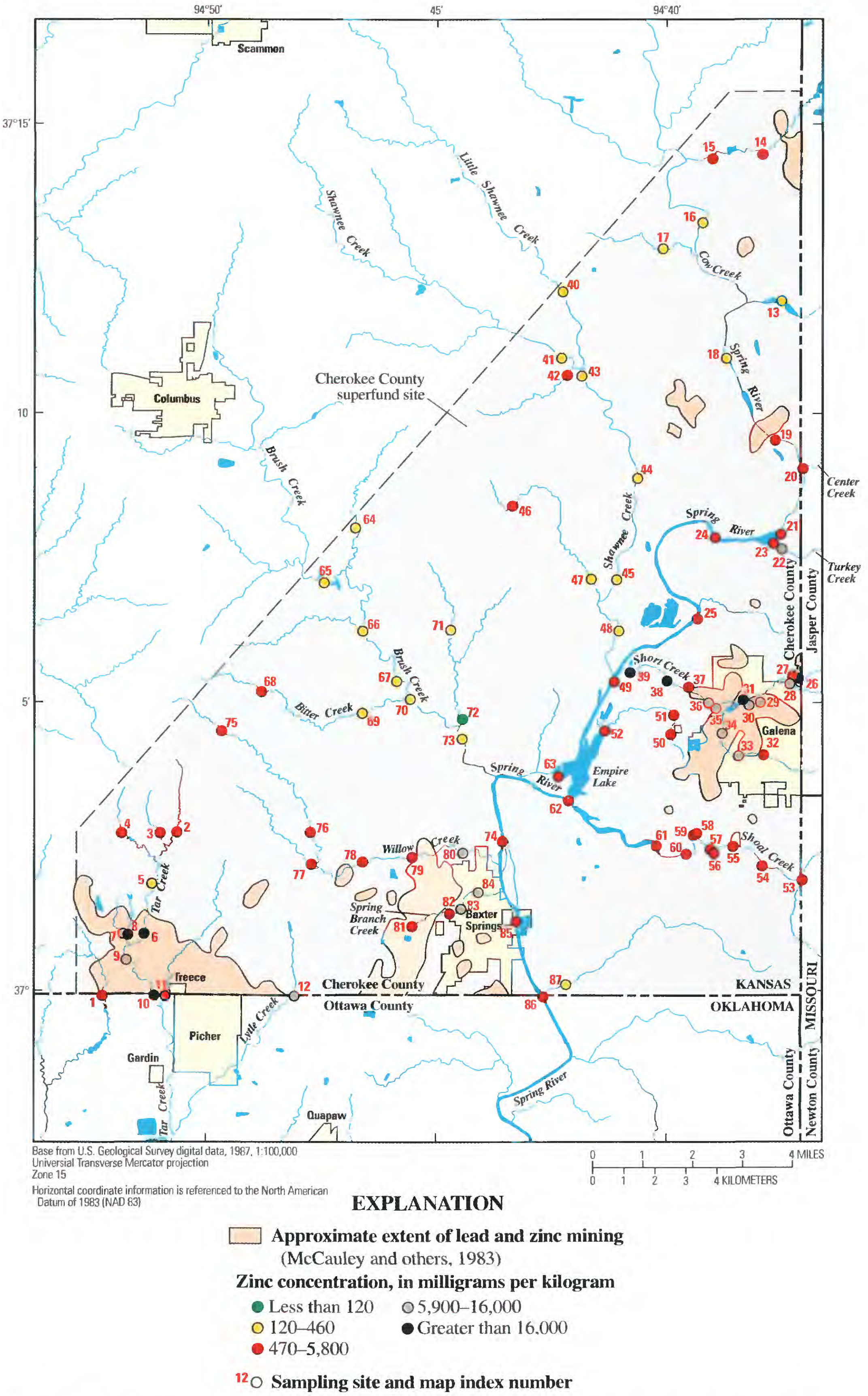


Figure 12. Distribution of lead concentrations in the less than 0.063-millimeter fraction of streambed-sediment samples from the Kansas part of the Tri-State Mining District, 2004.



Base from U.S. Geological Survey digital data, 1987, 1:100,000
Universal Transverse Mercator projection
Zone 15

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83)

Figure 13. Distribution of zinc concentrations in the less than 0.063-millimeter fraction of streambed-sediment samples from the Kansas part of the Tri-State Mining District, 2004.

concentration at the downstream-most Short Creek sampling site (site 39), about 0.5 mi upstream from the confluence with the Spring River, was 3,800 mg/kg. Zinc concentrations ranged from 14,000 (site 36) to 45,000 mg/kg (site 39).

Streambed-sediment sampling sites in the Tar Creek watershed had large concentrations of cadmium, lead, and zinc relative to most sampling sites but were secondary in magnitude to concentrations in the Short Creek watershed. However, the range in concentrations in the Tar Creek watershed was greater than in Short Creek. Concentrations of cadmium at Tar Creek main-stem sampling sites (sites 3, 5, 6, 9, and 10; table 3) ranged from 1.2 (site 5) to 270 mg/kg (site 10) (table 11). Concentrations of lead for these same main-stem sites ranged from 58 (site 5) to 3,400 mg/kg (site 10), and concentrations of zinc ranged from 250 (site 5) to 32,000 mg/kg (site 10). Concentrations of cadmium, lead, and zinc in the Tar Creek watershed clearly show the effects of mined areas on a stream as it flows from relatively unaffected areas into the intensively mined part of the watershed. These mining effects may include surface discharge of mine water, seepage from chat piles, discharge or runoff from tailings ponds, intentional use of chat on roads, and windblown distribution of mine-waste material.

Other streams in the study area with enriched concentrations of cadmium, lead, and zinc in streambed sediment included the Shoal Creek watershed south of Galena, Kansas, and Spring Branch Creek and the downstream segment of Willow Creek at or near Baxter Springs, Kansas (figs. 11–13). In contrast, most sampling sites in the Brush, Cow, and Shawnee Creek watersheds had relatively small streambed-sediment concentrations of cadmium (less than 5 mg/kg), lead (less than 130 mg/kg), and zinc (less than 460 mg/kg).

Contaminated streambed sediment in several tributaries of the Spring River in Kansas had enriched concentrations of cadmium, lead, and zinc in streambed sediment of the Spring River. Concentrations of cadmium, lead, and zinc in Spring River streambed sediment generally increased in a downstream direction and had spatially restricted concentration spikes in the immediate reach downstream from some tributary streams (fig. 14). For example, Spring River sampling site 20 had concentrations (table 11) of cadmium (41 mg/kg), lead (510 mg/kg), and zinc (5,400 mg/kg) that were about 10 to 15 times larger than concentrations at the next upstream (0.8 mi) sampling site (site 19; fig. 14). The sample from site 20 was collected about 100 ft downstream and on the same side of the river at the confluence of Center Creek. Because the complete length of Center Creek is outside the study area, a sample was not collected from it; however, results of the Spring River samples at sites 19 and 20 provide presumptive evidence of the quality of streambed sediment in Center Creek. A similar close-proximity sample was collected from the Spring River (site 23) immediately downstream from the confluence of Turkey Creek. This sample also had elevated concentrations of cadmium (40 mg/kg), lead (640 mg/kg), and zinc (5,200 mg/kg). The sample collected from Turkey Creek (site 22) had concentrations of cadmium (52 mg/kg), lead (1,000 mg/kg), and zinc (6,900 mg/kg) that probably are responsible for the elevated Spring River results immediately downstream from Turkey Creek. In both comparisons, concentrations of cadmium, lead, and zinc decreased substantially at the next downstream (within about 1.4 mi) sampling site (sites 21 and 24).

Concentrations of cadmium, lead, and zinc in the Spring River near where it enters the study area (site 13, near the Kansas-Missouri State line; fig. 2) were 0.9, 26, and 150 mg/kg, respectively, and were 16, 180, and 2,500 mg/kg, respectively, near where the river exits the study area (site 86, near the Kansas-Oklahoma State line). These concentrations represent increases in cadmium, lead, and zinc in streambed sediment of the Spring River of about 18, 7, and 17 times, respectively, within its 22-mi length in Kansas. However, because the drainage areas of some tributary streams (Center, Turkey, Short, and Shoal Creeks) also are affected by mined areas in Missouri (fig. 1), documented problems in the Spring River in Kansas or its watershed may not be attributable entirely to conditions in either State.

Lakes and reservoirs may be effective traps or sinks for the fluvial transport of some sediment-associated trace elements and nutrients (Juracek and Mau, 2002; Juracek 2003, 2004). A small lake on a tributary to Cow Creek was bracketed by streambed-sediment sampling sites 14 (upstream) and 15 (downstream) (fig. 2). The drainage area of this tributary includes lead and zinc mined areas upstream from sampling site 14. Concentrations of cadmium, lead, and zinc in streambed sediment were smaller at sampling site 15 (3.7, 31, and 730 mg/kg, respectively; table 11) than at site 14 (18, 92, and 2,800 mg/kg, respectively). These concentration differences may indicate that a large part of the transported load of these trace elements was deposited as bottom sediment in the lake.

A similar analogy for Empire Lake (fig. 2) on the Spring River may not be as evident. Concentrations of cadmium, lead, and zinc in streambed sediment were larger at downstream sampling site 62 (18, 190, and 2,400 mg/kg) than at upstream sampling site 49 (16, 130, and 1,800 mg/kg). In contrast, concentrations at downstream sampling site 63 (11, 120, and 1,400 mg/kg) were slightly smaller than those at sampling site 49. Concentrations at sampling site 61 (19, 180, and 1,900 mg/kg, respectively) were similar to those at sampling site 62. Sampling site 61 was on Shoal Creek, a major tributary to Empire Lake. These somewhat mixed results for concentrations upstream and downstream from Empire Lake may indicate that the trapping efficiency for some trace elements in Empire Lake is not as great as other impoundments in the Spring River system and that a substantial part of the transported trace element load into Empire Lake may migrate through the lake and downstream to other impoundments. This possibility could have detrimental environmental consequences for downstream impoundments with trapping efficiencies greater than that of Empire Lake. Phase II of the Spring River/Empire Lake system NRDAR study will examine the historical effects of Empire Lake on transported loads.

The concentrations of cadmium, lead, and zinc in streambed sediment of the Spring River (table 11; fig. 14) may be harmful to aquatic life. Qualitative and quantitative surveys of

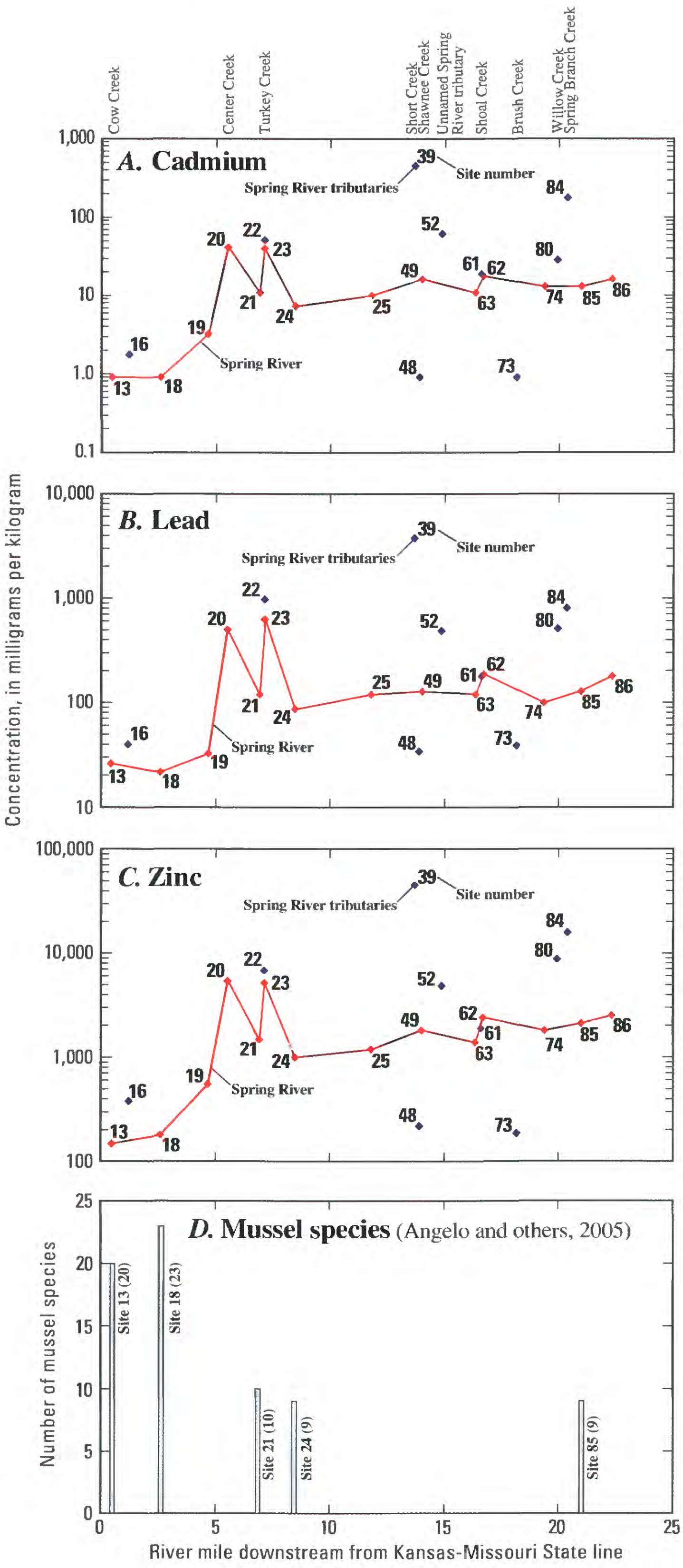


Figure 14. Distribution of *(A)* cadmium, *(B)* lead, and *(C)* zinc concentrations in the less than 0.063-millimeter fraction of streambed sediment from selected sampling sites on the Spring River and tributary streams in the Kansas part of the Tri-State Mining District, 2004. Location of sampling sites shown in figures 11–13.

mussel and Asian clam (*Corbicula fluminea*) populations in the Spring River by KDHE have indicated that mussel diversity and density decline in a downstream direction in the Spring River (Angelo and others, 2005). Streambed-sampling sites 13 and 18 (fig. 2) on the Spring River supported at least 20 and 23 species of mussels, respectively, but only 9 species were identified at Spring River site 85 (fig. 14D). Mussel diversity and density declined sharply in the river downstream from Center and Turkey Creeks. The downstream reaches of Center, Turkey, Short, Spring Branch, and Willow Creeks were seemingly devoid of live mussels or other aquatic mollusks (Angelo and others, 2005). Angelo and others (2005) concluded that mining effects degrade river quality and impede the recovery of mussel communities in a large part of the Spring River Basin. The conclusions of Angelo and others (2005) are supported by the results of the study described in this report that identified a general upward trend in cadmium, lead, and zinc concentrations in streambed sediment of the Spring River in a downstream direction and spatially restricted spikes in concentrations downstream from the confluences of Center and Turkey Creeks (fig. 14). Because of these and other potential effects on aquatic ecosystems, streambed-sediment concentrations of trace elements were evaluated relative to recommended sediment-quality guidelines.

Relation to Sediment-Quality Guidelines

USEPA (1998) has recommended sediment-quality guidelines in the form of level-of-concern concentrations for several trace elements (table 8). These level-of-concern concentrations were derived from biological-effects correlations made on the basis of paired field and laboratory data to relate the incidence of adverse biological effects to dry-weight sediment concentrations. Two such level-of-concern concentrations presented by USEPA (1998) are referred to as the threshold effects level (TEL) and the probable effects level (PEL). The smaller of the two guidelines (TEL) is assumed to represent the concentration below which toxic effects rarely occur. In the range of concentrations between TEL and PEL, adverse effects occasionally occur. Toxic effects usually or frequently occur at concentrations above the larger guideline (PEL).

USEPA (1998) cautions that TEL and PEL are guidelines used as screening tools for possible hazardous levels of chemicals and are not intended as regulatory criteria. This cautionary statement is made because, although biological-effects correlation identifies level-of-concern concentrations associated with the likelihood of adverse organism response, the procedure may not demonstrate that a particular chemical is solely responsible. In fact, biological-effects correlation may not indicate direct cause-and-effect relations because sampling sites may contain a mixture of chemicals that contribute to the adverse effects to some degree. Therefore, for any given site, these guidelines may be over- or underprotective.

Table 8. Sediment-quality guidelines for selected trace elements.

[Values in milligrams per kilogram. Shading represents guidelines to which environmental concentrations were compared. USEPA, U.S. Environmental Protection Agency; TEL, threshold effects level; PEL, probable effects level; TEC, threshold effects concentration; PEC, probable effects concentration; --, not determined]

Trace element	USEPA (1998)		MacDonald and others (2000)	
	TEL	PEL	TEC	PEC
Arsenic	7.24	41.6	9.79	33.0
Cadmium	.676	4.21	.99	4.98
Chromium	52.3	160	43.4	111
Copper	18.7	108	31.6	149
Lead	30.2	112	35.8	128
Mercury	.13	.696	.18	1.06
Nickel	15.9	42.8	22.7	48.6
Zinc	124	271	121	459

Consensus-based sediment-quality guidelines were developed by MacDonald and others (2000) for selected trace elements in freshwater sediments (table 8). Consensus-based guidelines were an attempt to incorporate the limitations and advantages of previously published numerical guidelines and to focus on the agreement between them. These previously published guidelines were used to develop a threshold effects concentration (TEC) and a probable effects concentration (PEC) that were analogous to TEL and PEL established by USEPA (1998). Consensus-based TECs identified concentrations of selected trace elements in freshwater sediment below which effects on sediment-dwelling organisms are not expected to occur (MacDonald and others, 2000). Consensus-based PECs defined concentrations of sediment trace elements above which adverse effects on sediment-dwelling organisms are likely to occur. Concentrations above TECs but below PECs may produce adverse biological effects.

Both the sediment-quality guidelines presented by USEPA (1998) and MacDonald and others (2000) were considered for the biological-effects assessment of data collected for the study described in this report. Because of potential variability in the development of sediment-quality guidelines, the possibility of different guideline values exists. Generally, however, the differences between USEPA (1998) and MacDonald and others (2000) guidelines were small (table 8). The USEPA (1998) presented guidelines for silver but because most reported concentrations of silver were less than analytical method reporting limits (table 11), silver was not assessed relative to quality guidelines in this report.

The largest differences between the quality guidelines presented by USEPA (1998) and MacDonald and others (2000) were for zinc PEL and PEC values, respectively. The PEC value (459 mg/kg) was about 69 percent larger than the PEL value (271 mg/kg). The sediment-quality guidelines used for assessment in this report (table 8) were selected to produce a conservative (less-stringent) assessment. Therefore, for each trace element and quality level (threshold effects and probable effects), the larger of the two options was selected with which to compare results of analyses of streambed-sediment samples from 87 sampling sites (fig. 2) in the Kansas part of the Tri-State District.

Numbers and percentages of streambed-sediment sampling sites with concentrations of selected trace elements that exceeded sediment-quality guidelines varied among the trace elements (table 9). Twenty-three percent of the 87 sampling sites had mercury concentrations that exceeded the threshold effects guideline (0.18 mg/kg), whereas 99 percent had zinc concentrations that exceeded the threshold effects guideline (124 mg/kg). Only cadmium, lead, and zinc had large percentages (64, 56, and 75, respectively) of sampling sites with concentrations that exceeded selected probable effects guidelines (4.98, 128, and 459 mg/kg, respectively). The next largest percentage of sampling sites that exceeded a probable effects guideline was 8 percent for nickel. Clearly, much of the study area has elevated concentrations of cadmium, lead, and zinc to an extent that adverse effects on biological communities may be common.

Watersheds in the study area varied with respect to concentrations of assessed trace elements determined at streambed-sediment sampling sites contained within those watersheds and the relation of the concentrations to sediment-quality guidelines (fig. 15*A–H*). Plotted concentrations in figure 15 may represent results from more than one sampling site. Concentrations of mining-related trace elements (cadmium, lead, and zinc) were largest at sampling sites in the tributary watersheds of the Spring River most affected by mining activities (Shoal, Short, Spring Branch, Tar, and Turkey Creeks, and the unnamed Spring River tributary near Galena, Kansas, sampling sites 50–52; fig. 2). Large percentages of sampling sites had streambed-sediment concentrations of arsenic, chromium, copper, mercury, and nickel that exceeded threshold effects guidelines for some watersheds, but few of these concentrations also exceeded probable effects guidelines (table 10).

In contrast, many of the locations that had concentrations of cadmium, lead, and zinc that exceeded threshold effects guidelines also exceeded probable effects guidelines (fig. 16). In 7 of the 11 watersheds, group of unnamed tributaries, or main stem of the Spring River, 100 percent of the sampling sites had concentrations of cadmium and lead that exceeded threshold effects guidelines (0.99 and 35.8 mg/kg, respectively). Many of these concentrations also exceeded probable effects guidelines (4.98 and 128 mg/kg, respectively). Ten of these 11 groupings had 100 percent of sampling sites with concentrations of zinc that exceeded the threshold effects guideline of 124 mg/kg, and most of these concentrations also exceeded the probable effects guideline of 459 mg/kg. These results indicate that not only is cadmium, lead, and zinc contamination pervasive throughout the study area but also that concentrations are frequently at levels that may harm sediment-dwelling organisms and probably explain the degraded biological results from studies such as that of Angelo and others (2005).

Estimation of Background Concentrations

One of the objectives of the study described in this report was an estimation of local background concentrations of selected trace elements in streambed sediment. Background (pre-mining) information would provide a standard with which to compare or assess the magnitude of contamination from mining-related activities. However, the underlying assumption

Table 9. Number and percentage of 87 streambed-sediment sampling sites with concentrations of selected trace elements in the less than 0.063-millimeter fraction of sediment that exceeded threshold effects and probable effects sediment-quality guidelines in the Kansas part of the Tri-State Mining District, 2004.

[Guideline values in milligrams per kilogram, dry weight]

Trace element	Threshold effects guidelines			Probable effects guidelines		
	Guideline value	Number of sites exceeding guideline	Percentage of sites exceeding guideline	Guideline value	Number of sites exceeding guideline	Percentage of sites exceeding guideline
Arsenic	[1]9.79	42	48	[2]41.6	0	0
Cadmium	[1].99	76	87	[1]4.98	56	64
Chromium	[2]52.3	55	63	[2]160	0	0
Copper	[1]31.6	29	33	[1]149	6	7
Lead	[1]35.8	81	93	[1]128	49	56
Mercury	[1].18	20	23	[1]1.06	2	2
Nickel	[1]22.7	63	72	[1]48.6	7	8
Zinc	[2]124	86	99	[1]459	65	75

[1] MacDonald and others (2000).

[2] U.S. Environmental Protection Agency (1998).

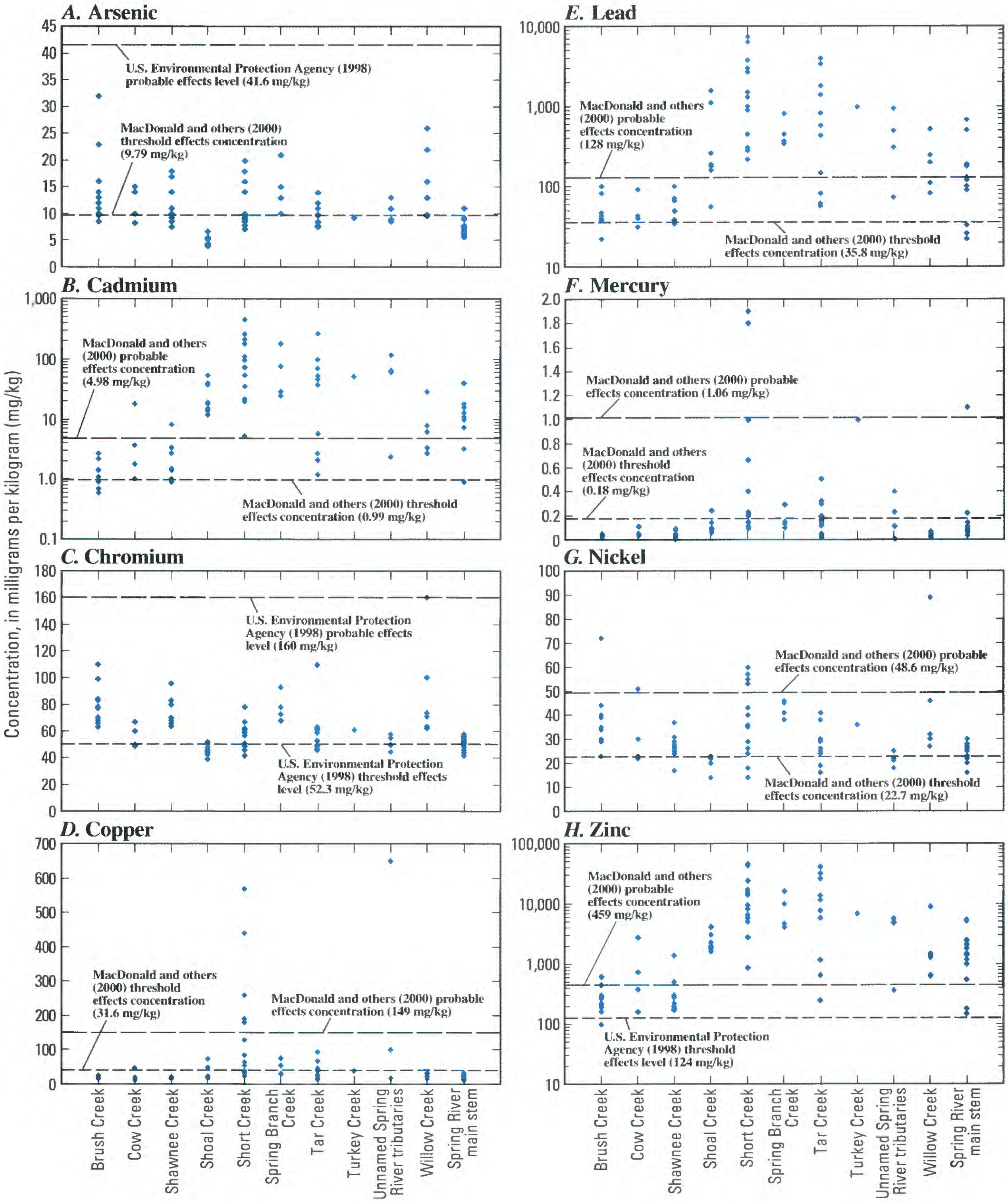


Figure 15*A*–*H*. Distribution of concentrations of selected trace elements in the less than 0.063-millimeter fraction of streambed sediment from sampling sites in major watersheds or stream segments of the Spring River Basin and relation to sediment-quality guidelines in the Kansas part of the Tri-State Mining District, 2004.

Table 10. Percentage of streambed-sediment sampling sites in major watersheds or stream segments of the Spring River Basin with concentrations of selected trace elements in the less than 0.063-millimeter fraction of sediment that exceeded threshold effects (TEL[1] or TEC[2]) and probable effects (PEL[1] or PEC[2]) sediment-quality guidelines in the Kansas part of the Tri-State Mining District, 2004.

[Guideline values () in milligrams per kilogram, dry weight. TEL, threshold effects level; TEC, threshold effect concentration; PEL, probable effects level; PEC, probable effects concentration]

Watershed or stream segments (map index number, fig. 2)	Percentage of streambed-sampling sites exceeding sediment-quality guidelines (values in parentheses)															
	Arsenic		Cadmium		Chromium		Copper		Lead		Mercury		Nickel		Zinc	
	TEC (9.79)	PEL (41.6)	TEC (0.99)	PEC (4.98)	TEL (52.3)	PEL (160)	TEC (31.6)	PEC (149)	TEC (35.8)	PEC (128)	TEC (0.18)	PEC (1.06)	TEC (22.7)	PEC (48.6)	TEL (124)	PEC (459)
Brush Creek (64–73)	80	0	40	0	100	0	0	0	90	0	0	0	100	10	90	10
Cow Creek (14–17)	75	0	75	25	50	0	25	0	75	0	0	0	75	25	100	50
Shawnee Creek (40–48)	67	0	78	11	100	0	0	0	89	0	0	0	89	0	100	22
Shoal Creek (53–61)	0	0	100	100	0	0	22	0	100	89	11	0	11	0	100	100
Short Creek (26–39)	50	0	100	100	57	0	86	36	100	100	57	14	86	29	100	100
Spring Branch Creek	100	0	100	100	100	0	50	0	100	100	25	0	100	0	100	100
Tar Creek (2–12)	45	0	100	73	55	0	55	0	100	73	45	0	73	0	100	91
Turkey Creek (22)	0	0	100	100	100	0	100	0	100	100	100	0	100	0	100	100
Unnamed Spring River tributaries (50–52, 87)	50	0	100	75	50	0	75	25	100	75	50	0	25	0	100	75
Willow Creek (75–80)	83	0	100	67	100	0	17	0	100	67	0	0	100	17	100	100
Spring River, main stem (13, 18–21, 23–25, 49, 62, 63,	7	0	86	79	43	0	7	0	79	64	14	0	57	0	100	86

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[1] U.S. Environmental Protection Agency (1998).

[2] MacDonald and others (2000).

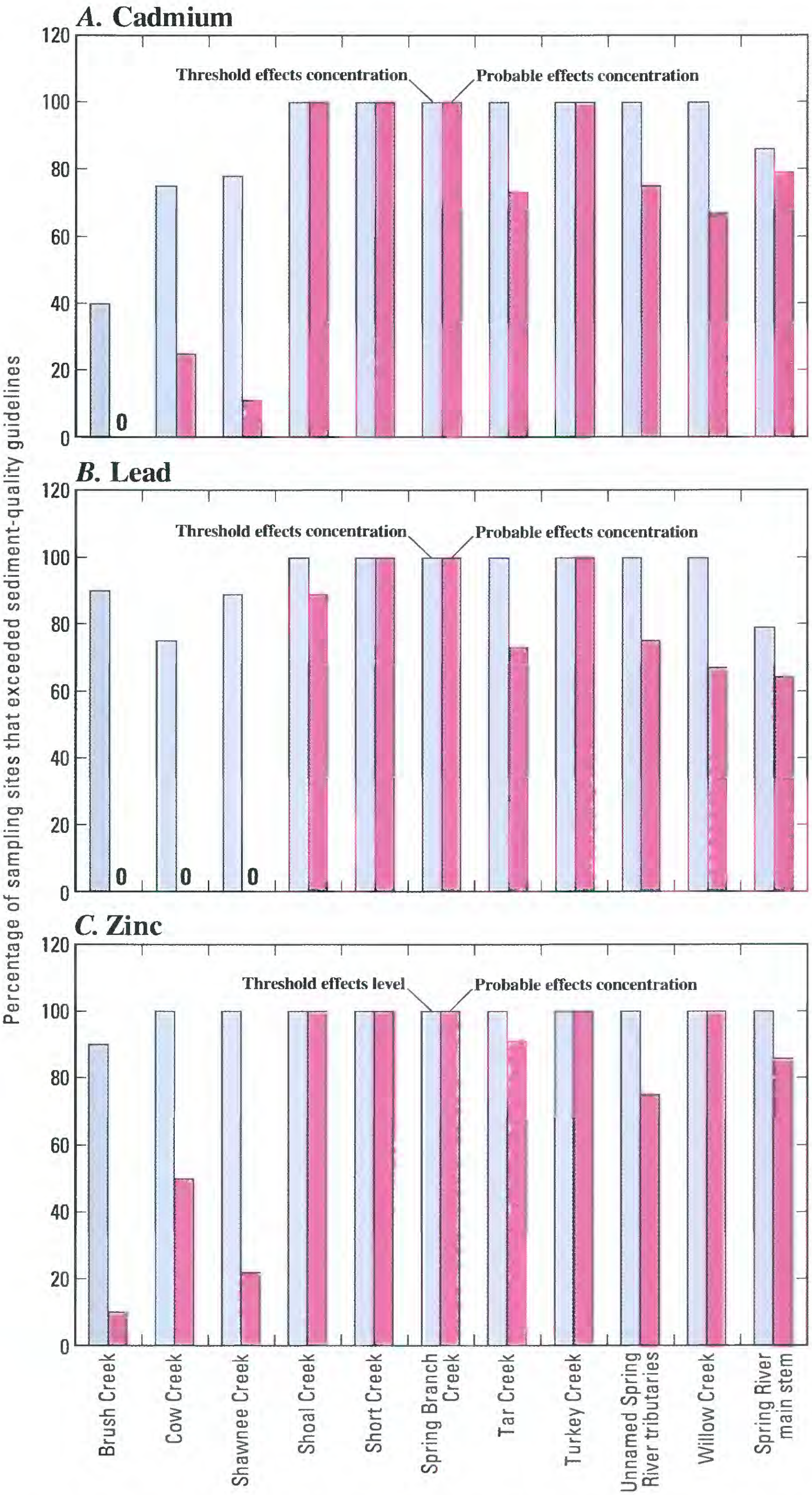

Figure 16. Percentage of streambed-sediment sampling sites in major watersheds or stream segments of the Spring River Basin with concentrations of cadmium, lead, and zinc in the less than 0.063-millimeter fraction of sediment that exceeded selected threshold effects and probable effects sediment-quality guidelines in the Kansas part of the Tri-State Mining District, 2004. Sediment-quality guidelines from U.S. Environmental Protection Agency (1998) and MacDonald and others (2000).

in determining background (pre-mining) concentrations is that areas selected as representative of background conditions be free of contamination. Contamination-free areas may be rare in the study area.

Much of the lead and zinc mining in the study area was done in the southern one-half of the area around the cities of Galena, Baxter Springs, and Treece, Kansas (fig. 2). Prevailing southerly winds could distribute airborne mining waste over much of the same area. Mining waste would include dust from the milling and processing of lead and zinc ore, from chat piles, and from chat moved and disturbed for industrial applications such as aggregate in concrete and asphalt and as gravel on rural roads. The smelting of lead and zinc ore also could be a source of atmospherically distributed particulate-associated cadmium, lead, and zinc.

Evidence of possible area-wide cadmium, lead, and zinc contamination may be indicated in the concentration distribution and watershed comparisons presented in figure 15*B*, *E*, and *H*. Sediment samples from few of the sampling sites had cadmium, lead, or zinc concentrations that were less than threshold effects guidelines. Eleven sampling sites (table 11 in the "Supplemental Information" section at the back of this report) had cadmium concentrations in streambed sediment less than the threshold effects guideline of 0.99 mg/kg (plotted concentrations in figure 15 may represent results from more than one sampling site). Six sampling sites had lead concentrations less than the threshold effects guideline of 35.8 mg/kg, and only one sampling site had a zinc concentration less than the threshold effects guideline of 124 mg/kg.

In a study of bottom sediment from 10 small reservoirs in eastern Kansas (Juracek, 2004), median concentrations of cadmium, lead, and zinc in the less than 0.063-mm fraction of bottom-sediment core samples exceeded the threshold effects guidelines used in this report in only zero, three, and five reservoirs, respectively. In contrast, cadmium and lead concentrations in streambed-sediment samples from at least 97 percent and concentrations of zinc in samples from 99 percent of sampling sites in the study described in this report exceeded their respective threshold effects guidelines. Therefore, contamination by mining-related trace elements such as cadmium, lead, and zinc appears to be pervasive, if not to the same magnitude, throughout the study area, and background estimates made on the basis of information from contaminated areas may not be representative of natural pre-mined conditions.

Estimates of background concentrations of cadmium, lead, and zinc in streambed sediment, however, could be made on the basis of smallest determined concentrations for these trace elements—cadmium at 0.6 mg/kg (table 11) at sampling sites 64 and 72 (fig. 2), lead at 22 mg/kg at sampling sites 18 and 72, and zinc at 100 mg/kg at sampling site 72. Barks (1977) estimated similar background concentrations for lead and zinc (20 and 100 mg/kg, respectively) although on the basis of larger particle-size streambed-sediment samples. Estimates of background concentrations for cadmium, lead, and zinc in the study area described in this report, therefore, could be generalized at 0.6, 20, and 100 mg/kg, respectively. These estimates are similar to estimates of national background concentrations of 23 mg/kg for lead and 88 mg/kg for zinc (Horowitz and others, 1991).

Summary and Conclusions

The Tri-State Mining District in parts of southeast Kansas, southwest Missouri, and northeast Oklahoma was the primary source of lead and zinc ore in the world for much of its 120-year history. Commercial mining in the Kansas part of the Tri-State District began in the mid-1870s and lasted until 1970. During this period, total production in Kansas was about 650 thousand tons of lead and 2.9 million tons of zinc. This long history of lead and zinc production left a degraded environmental legacy for southeast Cherokee County, Kansas. A survey of mine-disturbed areas in Kansas identified 2,300 acres of surface area covered by mine and mill waste (chat piles, tailings ponds, and shaft and mine development rock) in association with 2,200 acres of underground mining. Physical hazards included 315 open pits and surface collapses and about 3,500 mine shafts of which about 900 were considered physically hazardous. The environmental degradation caused by 100 years of mining resulted in the U.S. Environmental Protection Agency listing the Cherokee County area on its National Priority List as a superfund hazardous waste site in 1983. Remediation of this site began in the early 1990s by sealing shaft openings, filling open pits and surface collapses, and revegetating with native grasses. Remediation efforts also included the removal or regrading of some chat and rock piles throughout the superfund site.

During the active mining period in the Tri-State District, lead, zinc, and other associated trace elements (such as cadmium) were widely dispersed throughout the area as a result of the milling, processing, and smelting of lead and zinc ores. Discharge of trace element laden mine water and runoff from chat piles and out of tailings ponds has contaminated receiving streams and streambed sediment and affected the health of sediment-dwelling organisms and other aquatic life such as the Neosho madtom (*Noturus placidus*), a small catfish on the Federal endangered species list.

To assist in the injury determination and quantification step of the Cherokee County, Kansas, superfund site national resource damage assessment, the U.S. Geological Survey in cooperation with the U.S. Fish and Wildlife Service and the Kansas Department of Health and Environment conducted a two-phase study of the occurrence and distribution of contaminated streambed and lake-bottom sediment. Phase I of the study determined concentrations of 28 trace elements and nutrients in streambed sediment at 87 sampling sites in the Spring River and Tar Creek watersheds in Kansas. Phase II determined bottom-sediment concentrations, mass accumulations, and estimates of historic transport levels of trace elements and nutrients into Empire Lake, an impoundment of the Spring River. The purpose of this report was to present the results of streambed-sediment sampling in the historic Tri-State Lead and Zinc Mining District.

Streambed-sediment samples were collected from the upper 0.8 in. of sediment deposition. The targeted sediment particle size for this study was less than 0.063 mm (silt- and clay-size particles). Restricting trace element and nutrient analyses to the silt/clay fraction reduced particle-size variability between sampling sites and permitted direct site-to-site concentration comparisons. If possible, each streambed-sediment sample consisted of 5 to 10 subsamples collected at silt/clay depositional areas along the sides and center of streams and composited for analysis. A total of 98 composite samples were collected. Chain-of-custody protocols were followed during sample handling, storage, transport, and analysis. Sample analysis included a total (strong acid) digestion that destroyed the mineral matrix and provided a total trace element analysis that represented greater than 95 percent of the elements sorbed to or bound within the mineral matrix.

Cadmium, lead, and zinc were the trace elements most enriched in streambed sediment. These trace elements had much larger concentration ranges than any other element determined. For example, the factor increases between minimum and maximum concentrations for all 87 streambed-sampling sites were about 770, 340, and 450 times, respectively. These contrast to factor increases of less than 10 times for the majority of the other trace elements. Copper had the next largest factor increase at 59. Ranges in concentrations were 0.6 to 460 mg/kg for cadmium, 22 to 7,400 mg/kg for lead, and 100 to 45,000 mg/kg for zinc. Median concentrations of cadmium, lead, and zinc for all 87 sampling sites were 13, 180, and 1,800 mg/kg, respectively. Mean concentrations were much larger (42, 650, and 5,600 mg/kg, respectively), which indicated that mean calculations were affected by several extremely large concentrations.

Large spatial variability was determined for streambed-sediment associated concentrations of cadmium, lead, and zinc throughout the study area. Sampling sites in the most intensively mine-affected areas had the largest concentrations. Sampling sites on the main stem of Short Creek at or near Galena, Kansas, had the largest concentrations of cadmium (110 to 460 mg/kg), lead (280 to 7,400 mg/kg), and zinc (14,000 to 45,000 mg/kg) of any stream in the study area. Concentrations at main-stem Tar Creek sampling sites were secondary in magnitude only to those in Short Creek.

Concentration ranges for Tar Creek sampling sites were 1.2 to 270 mg/kg for cadmium, 58 to 3,400 mg/kg for lead, and 250 to 32,000 mg/kg for zinc. Concentrations at Tar Creek sampling sites indicated the transition from upstream unmined areas to intensively mined downstream areas. The smallest concentrations of cadmium, lead, and zinc were in streambed sediment collected at upstream main-stem sampling sites.

Other streams in the study area with enriched concentrations of cadmium, lead, and zinc in streambed sediment included the Shoal Creek watershed south of Galena, Kansas, and Spring Branch Creek and the downstream segment of Willow Creek at or near Baxter Springs, Kansas. In contrast, most sampling sites in the Brush, Cow, and Shawnee Creek watersheds had relatively small streambed-sediment concentrations of cadmium (less than 5 mg/kg), lead (less than 130 mg/kg), and zinc (less than 460 mg/kg).

Concentrations of cadmium, lead, and zinc in the Spring River near where it enters the study area (near the Kansas-Missouri State line) were 0.9, 26, and 150 mg/kg, respectively, and were 16, 180, and 2,500 mg/kg, respectively, near where it exits the study area (near the Kansas-Oklahoma State line). These concentrations represent increases in cadmium, lead, and zinc in streambed sediment of the Spring River of about 18, 7, and 17 times, respectively, within its 22-mi length in Kansas. However, because the drainage areas of some tributary streams (Center, Turkey, Short, and Shoal Creeks) also are affected by mined areas in Missouri, documented problems in the Spring River in Kansas or its watershed may not be attributable entirely to conditions in either State.

Trace element concentrations in streambed sediment at Spring River sampling sites provide supporting causal evidence of a general downward trend in mussel diversity and density in a downstream direction on the Spring River. This trend in mussel populations was identified by the Kansas Department of Health and Environment and included spatially restricted areas of sharply decreased mussel populations. These areas corresponded to areas of sharply increased concentrations of cadmium, lead, and zinc (identified in the study described in this report) immediately downstream from the major Spring River tributaries, Center and Turkey Creeks.

Concentrations of selected trace elements in streambed sediment were compared to sediment-quality guidelines. However, only cadmium, lead, and zinc had large percentages (64, 56, and 75, respectively) of the 87 sampling sites with concentrations that exceeded selected probable effects guidelines (4.98, 128, and 459 mg/kg, respectively). Concentrations larger than the probable effects guideline are frequently expected to have toxicological effects on some aquatic-life forms. The next largest percentage of sampling sites that exceeded a probable effects guideline was 8 percent for nickel. Much of the study area has been contaminated with cadmium, lead, and zinc to an extent that adverse effects on the biological community may be common. The most mine-affected individual watersheds had the largest percentage of sampling sites with concentrations of cadmium, lead, and zinc that exceeded probable effects guidelines. Generally, this percentage was 100 percent for these trace elements.

Preliminary background (pre-mining) concentrations of cadmium, lead, and zinc in streambed sediment in the study area were estimated at 0.6, 20, and 100 mg/kg, respectively. The validity of these estimates was tempered with the conclusion that much of the study area may be contaminated with these trace elements from wind distribution of contaminated dust generated during ore milling, processing, and smelting, as well as from the storage of waste material and its use in commercial or industrial applications such as gravel on rural roads. Therefore, estimates made on the basis of information from contaminated areas may not be representative of natural, pre-mine conditions.

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Supplemental Information

Table 11. Results of physical and total trace element and nutrient analyses of primary and replicate streambed-sediment samples (less than 0.063-millimeter particle-size fraction) from selected sampling sites in the Kansas part of the Tri-State Mining District, 2004.

[mm, millimeter; mg/kg, milligrams per kilogram; P, primary; LR, laboratory replicate; CR, concurrent replicate; SR, sequential replicate; AR, analytical rerun; TR, temporal replicate; <, less than; --, not determined]

Map index number (fig. 2)	Date of sample collection (month/ day/year)	Time (24-hour)	Sample type	Sediment, <0.063 mm (percent dry weight)	Aluminum (percent dry weight)	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Cadmium (mg/kg)	Carbon, organic, total (percent dry weight)	Carbon, total (percent dry weight)
1	10/20/04	0910	P	52	4.1	0.9	10	430	1.7	3.2	1.4	1.5
2	10/20/04	1045	P	22	4.2	1.5	7.5	470	1.5	2.1	1.5	1.6
3	10/20/04	1020	P	20	5.2	.9	9.9	510	2.0	2.7	2.0	2.2
4	10/20/04	1035	P	12	3.8	.8	9.7	370	1.7	5.9	4.4	4.8
5	10/20/04	1005	P	59	4.3	.8	7.7	440	1.5	1.2	1.2	1.3
6	10/20/04	0950	P	49	3.9	1.0	7.9	150	1.2	100	3.8	4.2
		0951	LR	49	3.8	.9	7.8	170	1.1	100	3.8	4.2
7	10/20/04	0930	P	40	5.2	1.0	11	460	1.5	71	2.8	3.5
8	10/20/04	0940	P	23	4.3	1.2	8.5	200	1.4	270	3.9	4.0
9	10/20/04	1340	P	18	4.9	1.0	12	370	1.8	53	3.4	4.1
10	10/20/04	1310	P	44	3.2	.8	8.4	220	1.2	270	4.1	5.1
11	10/20/04	0830	P	17	5.3	.9	14	510	1.6	38	1.5	1.6
12	10/20/04	0805	P	18	5.5	1.1	11	440	2.1	49	3.6	3.8
		0810	CR	19	5.4	1.1	11	440	2.0	44	3.5	3.7
13	11/09/04	1245	P	10	3.6	.6	5.6	430	1.2	.9	1.8	2.1
14	10/22/04	1030	P	53	3.6	.9	8.2	380	1.3	18	1.4	1.8
		1031	LR	53	3.6	.8	8.4	370	1.2	18	1.3	1.9
15	10/22/04	1000	P	19	3.6	.8	10	350	1.3	3.7	1.5	1.7
16	10/22/04	0930	P	10	4.8	1.2	15	480	2.0	1.8	2.9	3.4
17	12/15/04	1025	P	19	5.9	.9	14	430	2.1	.8	3.3	3.6
		1026	LR	19	5.6	.9	13	420	2.0	.8	3.0	3.6
18	11/09/04	1145	P	18	4.0	.7	6.0	440	1.3	.9	2.2	2.6
19	11/09/04	1040	P	6	3.8	.7	7.5	440	1.5	3.3	2.1	2.6
20	12/15/04	1530	P	29	4.2	.8	7.1	450	1.5	41	1.8	2.1
21	11/09/04	0950	P	37	4.2	.7	6.4	480	1.4	11	2.1	2.5
22	10/21/04	1645	P	23	3.7	1.3	9.3	390	1.4	52	2.6	3.6
23	12/15/04	1435	P	13	4.0	1.0	8.7	380	1.4	40	2.4	3.4
		1445	SR	23	4.5	1.1	9.3	400	1.5	40	2.4	3.4
24	11/09/04	0855	P	25	4.0	.7	6.3	440	1.3	7.1	1.9	2.2
		0900	CR	25	3.7	.6	5.7	410	1.2	7.5	1.9	2.1
25	11/09/04	1440	P	52	4.5	1.4	6.4	480	1.4	10	2.2	2.7
		1441	LR	52	4.2	1.3	6.4	450	1.2	11	2.3	2.7

Table 11. Results of physical and total trace element and nutrient analyses of primary and replicate streambed-sediment samples (less than 0.063-millimeter particle-size fraction) from selected sampling sites in the Kansas part of the Tri-State Mining District, 2004.—Continued

[mm, millimeter; mg/kg, milligrams per kilogram; P, primary; LR, laboratory replicate; CR, concurrent replicate; SR, sequential replicate; AR, analytical rerun; TR, temporal replicate; <, less than; --, not determined]

Map index number (fig. 2)	Date of sample collection (month/day/year)	Time (24-hour)	Sample type	Sediment, <0.063 mm (percent dry weight)	Aluminum (percent dry weight)	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Cadmium (mg/kg)	Carbon, organic, total (percent dry weight)	Carbon, total (percent dry weight)
26	10/21/04	0915	P	18	5.1	0.5	10	760	2.6	200	3.9	4.4
	Requested rerun		AR	18	5.9	.4	9.5	800	3.1	220	--	--
27	10/21/04	0940	P	18	5.2	1.0	7.8	580	1.9	36	1.4	1.6
28	10/21/04	0835	P	21	4.9	1.6	10	480	2.1	73	3.5	3.8
29	10/20/04	1715	P	8	4.5	1.8	8.5	350	1.6	98	5.1	5.9
30	10/21/04	0810	P	31	3.3	2.0	9.2	360	1.4	74	1.9	2.3
31	10/19/04	0815	P	8	4.1	21	17	440	1.9	160	3.7	4.3
	11/18/04	1330	TR	6	3.3	24	23	460	1.9	190	6.0	7.0
32	10/19/04	1110	P	36	3.6	.8	7.1	440	1.2	5.2	2.1	2.2
33	10/19/04	1040	P	22	4.5	1.3	14	390	1.9	75	5.5	6.5
34	10/19/04	1620	P	25	5.3	.8	9.7	460	1.9	55	1.3	1.6
35	10/21/04	1030	P	19	4.3	.8	9.7	510	3.0	22	1.5	1.8
36	10/21/04	1045	P	28	4.5	2.8	9.0	440	3.2	110	2.5	2.7
		1046	LR	28	4.5	2.5	8.8	450	3.2	110	2.5	2.6
37	10/19/04	0905	P	8	4.5	2.1	16	430	1.5	20	1.4	1.7
38	10/19/04	0930	P	9	3.2	6.7	16	410	1.9	260	5.1	5.8
39	10/20/04	1610	P	13	2.9	4.2	18	490	2.2	440	5.5	6.0
	Requested rerun		AR	13	2.8	4.7	17	530	2.6	480	--	--
40	10/22/04	0820	P	38	5.0	.9	11	460	1.8	1.4	1.7	2.1
	10/22/04	0825	CR	42	5.5	.8	9.9	490	1.9	1.4	1.8	2.1
41	10/22/04	0845	P	35	5.0	.8	8.6	470	1.9	3.4	1.6	1.9
42	12/15/04	1055	P	16	7.1	.9	18	500	2.5	2.7	1.8	2.0
43	10/22/04	0900	P	27	5.3	1.0	14	500	2.3	1.0	2.2	2.5
		0901	LR	27	5.1	.9	14	490	2.2	1.0	2.4	2.6
44	10/21/04	1600	P	13	5.9	.9	14	470	2.5	1.5	1.9	2.3
45	10/21/04	1520	P	20	5.2	.8	9.3	450	2.0	.9	1.9	2.2
46	12/15/04	1120	P	10	4.8	1.0	20	450	2.1	1.8	1.4	1.5
	Requested rerun		AR	10	4.9	1.0	19	460	2.1	1.8	1.3	1.6
		1130	SR	9	2.8	1.0	15	250	1.1	14	1.4	3.1
	Requested rerun		AR	9	3.0	1.0	15	260	1.2	15	1.6	3.3
47	10/21/04	1540	P	27	5.5	1.0	11	530	2.2	1.0	2.5	2.9

Table 11. Results of physical and total trace element and nutrient analyses of primary and replicate streambed-sediment samples (less than 0.063-millimeter particle-size fraction) from selected sampling sites in the Kansas part of the Tri-State Mining District, 2004.—Continued

[mm, millimeter; mg/kg, milligrams per kilogram; P, primary; LR, laboratory replicate; CR, concurrent replicate; SR, sequential replicate; AR, analytical rerun; TR, temporal replicate; <, less than; --, not determined]

Map index number (fig. 2)	Date of sample collection (month/ day/year)	Time (24-hour)	Sample type	Sediment, <0.063 mm (percent dry weight)	Aluminum (percent dry weight)	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Cadmium (mg/kg)	Carbon, organic, total (percent dry weight)	Carbon, total (percent dry weight)
48	10/21/04	1455	P	34	5.0	0.7	7.5	480	1.8	0.9	2.0	2.6
49	11/09/04	1520	P	58	4.7	.8	7.8	480	1.5	16	2.5	2.9
50	10/19/04	1545	P	55	4.5	.7	8.5	430	2.1	65	2.3	2.8
51	10/19/04	1600	P	42	3.9	1.4	11	450	1.4	120	3.0	3.5
52	10/20/04	1540	P	34	3.3	1.1	13	450	1.4	62	2.2	2.6
53	11/18/04	1230	P	25	3.7	.6	4.2	430	1.2	14	2.6	3.1
54	11/19/04	1115	P	33	3.7	.7	5.3	460	1.3	12	1.9	2.3
		1120	CR	35	3.8	.6	5.1	460	1.3	11	1.9	2.2
55	10/19/04	1010	P	25	4.0	.8	4.0	430	1.4	18	3.4	3.8
56	11/10/04	1125	P	27	4.2	.8	6.7	460	1.4	54	1.9	2.1
57	11/10/04	1100	P	55	3.6	.7	4.1	440	1.2	15	2.8	3.2
		1101	LR	55	3.5	.6	4.6	450	1.2	15	2.7	3.2
58	11/10/04	1035	P	20	3.0	.7	5.5	400	1.8	40	1.5	1.7
59	11/10/04	1000	P	45	3.5	.6	5.2	440	1.8	38	2.1	2.3
60	11/10/04	0910	P	41	3.6	.7	4.5	460	1.3	18	2.7	3.3
		0911	LR	41	3.3	.6	4.0	420	1.2	18	2.5	3.2
61	11/10/04	0840	P	56	3.5	.5	3.9	440	1.2	19	2.3	2.7
62	11/10/04	1300	P	51	3.7	.8	12	460	1.2	18	2.8	3.3
		1301	LR	51	3.8	.7	10	470	1.2	18	2.8	3.3
		1305	CR	52	3.7	.7	11	460	1.2	19	3.0	3.6
63	11/10/04	1340	P	11	4.4	.8	9.2	400	1.6	11	1.8	2.2
64	12/15/04	1150	P	29	5.6	.9	16	430	2.0	.6	1.5	1.6
65	12/15/04	1210	P	26	5.9	.7	11	460	2.0	1.1	2.1	2.3
66	10/21/04	1335	P	20	5.7	.7	10	470	2.2	1.4	2.1	2.4
67	10/21/04	1315	P	13	6.0	.9	23	500	2.5	.9	1.8	2.1
68	10/21/04	1420	P	42	5.1	.7	8.5	460	2.0	2.7	1.6	1.8
69	10/21/04	1400	P	18	6.5	.7	12	510	2.4	2.2	1.4	1.7
70	10/21/04	1250	P	13	6.2	.8	13	500	2.4	.9	1.7	2.1
71	12/15/04	1305	P	38	8.3	1.0	32	490	3.6	.7	1.1	1.0
72	10/21/04	1215	P	16	7.3	.7	14	500	2.6	.5	.6	.8
		1220	CR	19	7.5	.7	14	510	2.7	.6	.7	.8
73	10/19/04	1135	P	22	5.2	.7	9.1	470	2.0	1.0	1.6	1.9
		1140	CR	20	5.2	.7	10	480	1.9	.8	1.6	1.8
		1141	LR	20	5.3	.7	10	480	2.1	1.0	1.7	1.8

Table 11. Results of physical and total trace element and nutrient analyses of primary and replicate streambed-sediment samples (less than 0.063-millimeter particle-size fraction) from selected sampling sites in the Kansas part of the Tri-State Mining District, 2004.—Continued

[mm, millimeter; mg/kg, milligrams per kilogram; P, primary; LR, laboratory replicate; CR, concurrent replicate; SR, sequential replicate; AR, analytical rerun; TR, temporal replicate; <, less than; --, not determined]

Map index number (fig. 2)	Date of sample collection (month/ day/year)	Time (24-hour)	Sample type	Sediment, <0.063 mm (percent dry weight)	Aluminum (percent dry weight)	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Cadmium (mg/kg)	Carbon, organic, total (percent dry weight)	Carbon, total (percent dry weight)
74	11/08/04	1540	P	34	4.4	0.7	6.6	470	1.4	13	2.2	2.7
75	12/15/04	1240	P	15	4.7	1.2	22	500	2.3	2.7	2.2	2.5
76	10/20/04	1435	P	34	5.0	.8	10	450	1.9	7.8	2.2	2.6
		1440	CR	32	5.1	.8	9.8	450	2.0	7.6	2.1	2.6
77	10/20/04	1420	P	38	5.5	.8	9.5	500	2.0	3.4	2.3	2.4
78	10/20/04	1455	P	12	7.4	.9	16	550	2.7	7.8	1.7	2.1
79	10/19/04	1445	P	20	7.6	.9	13	480	2.6	6.2	1.8	2.2
80	10/19/04	1210	P	15	5.6	1.8	26	410	2.3	29	2.9	4.0
81	10/19/04	1430	P	34	5.7	.9	21	520	1.9	25	1.5	2.0
82	10/19/04	1410	P	15	7.0	1.1	15	520	2.2	29	1.8	2.0
83	10/19/04	1350	P	40	4.9	1.1	10	410	1.7	79	3.2	3.7
		1351	LR	40	4.6	1.1	10	380	1.6	72	3.4	3.7
84	10/19/04	1330	P	22	4.3	1.4	13	340	1.5	180	5.3	6.7
85	11/08/04	1420	P	48	3.6	1.1	6.7	440	1.3	13	1.8	2.1
86	11/08/04	1335	P	6	3.8	.7	7.6	450	1.4	16	2.1	2.6
87	11/08/04	1630	P	24	3.7	.9	8.9	460	1.6	2.4	4.6	5.3

Table 11. Results of physical and total trace element and nutrient analyses of primary and replicate streambed-sediment samples (less than 0.063-millimeter particle-size fraction) from selected sampling sites in the Kansas part of the Tri-State Mining District, 2004.—Continued

[mm, millimeter; mg/kg, milligrams per kilogram; P, primary; LR, laboratory replicate; CR, concurrent replicate; SR, sequential replicate; AR, analytical rerun; TR, temporal replicate; <, less than; --, not determined]

Map index number (fig. 2)	Date of sample collection (month/ day/year)	Time (24-hour)	Sample type	Chromium (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Iron (percent dry weight)	Lead (mg/kg)	Lithium (mg/kg)	Manganese (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)
1	10/20/04	0910	P	55	13	13	3.1	160	25	520	0.07	<1	25
2	10/20/04	1045	P	49	11	16	2.2	62	30	550	.02	<1	16
3	10/20/04	1020	P	59	18	18	3.4	82	40	870	.03	<1	24
4	10/20/04	1035	P	47	12	23	4.1	150	21	560	.05	<1	19
5	10/20/04	1005	P	50	9.2	13	2.1	58	29	380	.19	<1	16
6	10/20/04	0950	P	48	14	43	2.2	750	34	410	.16	1	25
		0951	LR	44	13	41	2.1	910	30	390	.13	1	24
7	10/20/04	0930	P	61	23	39	2.5	1,400	42	1,100	.16	2	26
8	10/20/04	0940	P	53	11	68	2.2	4,000	36	400	.51	1	25
9	10/20/04	1340	P	63	16	46	3.0	1,800	41	980	.30	1	41
10	10/20/04	1310	P	47	10	95	1.9	3,400	30	500	.32	1	29
11	10/20/04	0830	P	62	25	28	4.0	430	48	640	.12	1	38
12	10/20/04	0805	P	110	11	41	2.7	590	47	830	.20	1	31
		0810	CR	110	12	39	2.6	580	45	830	.21	<1	30
13	11/09/04	1245	P	44	11	11	1.6	26	22	870	.04	<2	16
14	10/22/04	1030	P	50	11	46	2.0	89	24	460	.11	2	22
		1031	LR	49	10	47	1.9	94	27	450	.11	2	21
15	10/22/04	1000	P	49	21	12	2.3	31	24	930	.05	1	23
16	10/22/04	0930	P	60	35	19	4.0	40	37	3,700	.04	2	51
17	12/15/04	1025	P	69	22	17	3.5	43	45	880	.04	2	31
		1026	LR	65	21	16	3.4	43	42	840	.04	<2	29
18	11/09/04	1145	P	48	13	13	1.9	22	25	930	.04	<2	20
19	11/09/04	1040	P	51	15	29	2.4	33	22	1,100	.06	<2	26
20	12/15/04	1530	P	53	13	24	2.1	510	25	970	.22	<1	22
21	11/09/04	0950	P	56	14	17	2.0	120	27	1,000	.10	<2	22
22	10/21/04	1645	P	61	17	39	2.1	1,000	24	840	1.0	<2	36
23	12/15/04	1435	P	54	15	31	2.1	640	26	980	.90	1	26
		1445	SR	62	17	35	2.2	720	28	1,100	1.2	<2	30
24	11/09/04	0855	P	47	14	14	1.9	91	22	920	.09	<2	21
		0900	CR	44	12	12	1.7	90	23	820	.11	<2	18
25	11/09/04	1440	P	56	14	18	2.1	120	25	1,100	.08	1	23
		1441	LR	52	12	16	1.9	130	25	980	.10	1	20

Table 11. Results of physical and total trace element and nutrient analyses of primary and replicate streambed-sediment samples (less than 0.063-millimeter particle-size fraction) from selected sampling sites in the Kansas part of the Tri-State Mining District, 2004.—Continued

[mm, millimeter; mg/kg, milligrams per kilogram; P, primary; LR, laboratory replicate; CR, concurrent replicate; SR, sequential replicate; AR, analytical rerun; TR, temporal replicate; <, less than; --, not determined]

Map index number (fig. 2)	Date of sample collection (month/ day/year)	Time (24-hour)	Sample type	Chromium (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Iron (percent dry weight)	Lead (mg/kg)	Lithium (mg/kg)	Manganese (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)
26	10/21/04	0915	P	58	75	36	2.7	300	25	2,200	0.21	1	54
	Requested rerun		AR	63	81	35	2.8	260	22	2,000	--	1	56
27	10/21/04	0940	P	59	11	31	1.9	220	27	190	.23	<2	35
28	10/21/04	0835	P	62	16	55	2.5	450	29	970	.15	1	29
29	10/20/04	1715	P	67	13	64	2.3	3,000	29	1,400	.40	2	24
30	10/21/04	0810	P	46	6.7	190	1.8	6,400	24	480	.66	2	18
31	10/19/04	0815	P	58	29	480	2.2	7,400	27	2,100	1.8	3	48
	11/18/04	1330	TR	60	41	660	2.8	7,400	20	2,200	1.7	3	71
32	10/19/04	1110	P	42	10	23	1.6	890	21	680	.09	1	14
33	10/19/04	1040	P	61	53	39	4.0	1,000	23	1,600	.15	2	35
34	10/19/04	1620	P	78	17	85	2.3	310	34	650	.11	2	40
35	10/21/04	1030	P	49	120	180	2.3	1,500	25	1,900	.14	<2	43
36	10/21/04	1045	P	50	54	130	1.9	1,300	28	1,200	.24	1	37
		1046	LR	52	54	130	1.9	1,300	28	1,200	.17	1	36
37	10/19/04	0905	P	57	29	35	3.0	300	25	840	.14	<2	26
38	10/19/04	0930	P	49	37	260	1.9	2,700	17	1,600	1.0	2	53
39	10/20/04	1610	P	49	21	440	2.0	3,600	19	1,100	1.9	3	59
	Requested rerun		AR	52	23	440	2.0	4,000	15	1,200	--	3	55
40	10/22/04	0820	P	67	15	17	2.7	48	43	550	.05	<1	24
	10/22/04	0825	CR	65	15	19	2.9	51	46	620	.04	<1	27
41	10/22/04	0845	P	64	18	15	2.9	36	42	910	.09	<1	25
42	12/15/04	1055	P	96	24	21	5.0	71	61	1,300	.05	2	37
43	10/22/04	0900	P	71	22	20	3.8	63	41	1,000	.03	1	28
		0901	LR	68	21	19	3.6	69	38	980	<.01	1	28
44	10/21/04	1600	P	83	20	20	4.3	49	43	1,000	.03	<1	31
45	10/21/04	1520	P	68	18	16	2.8	38	41	870	<.01	<1	29
46	12/15/04	1120	P	69	20	14	5.3	61	26	920	.03	2	21
	Requested rerun		AR	63	17	12	4.9	62	17	900	.05	2	18
		1130	SR	66	12	24	3.6	140	17	590	.12	1	15
	Requested rerun		AR	58	11	22	3.4	140	18	630	.10	1	15
47	10/21/04	1540	P	80	17	18	3.2	39	38	570	.02	<1	27

Table 11. Results of physical and total trace element and nutrient analyses of primary and replicate streambed-sediment samples (less than 0.063-millimeter particle-size fraction) from selected sampling sites in the Kansas part of the Tri-State Mining District, 2004.—Continued

[mm, millimeter; mg/kg, milligrams per kilogram; P, primary; LR, laboratory replicate; CR, concurrent replicate; SR, sequential replicate; AR, analytical rerun; TR, temporal replicate; <, less than; --, not determined]

Map index number (fig. 2)	Date of sample collection (month/ day/year)	Time (24-hour)	Sample type	Chromium (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Iron (percent dry weight)	Lead (mg/kg)	Lithium (mg/kg)	Manganese (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)
48	10/21/04	1455	P	66	13	17	2.5	34	38	400	0.02	<1	24
49	11/09/04	1520	P	42	14	19	2.1	130	29	1,200	.09	<2	23
50	10/19/04	1545	P	58	7.5	650	1.9	950	26	150	.40	<2	21
51	10/19/04	1600	P	55	11	100	1.9	310	36	950	.11	<2	18
52	10/20/04	1540	P	45	8.8	100	2.5	500	34	790	.23	<2	22
53	11/18/04	1230	P	45	9.3	17	1.5	160	20	840	.09	1	22
54	11/19/04	1115	P	45	9.8	18	1.6	270	22	850	.15	<1	20
		1120	CR	45	9.4	18	1.6	240	22	850	.12	1	21
55	10/19/04	1010	P	52	8.9	21	1.6	180	23	550	.09	<1	22
56	11/10/04	1125	P	52	11	24	1.8	55	21	750	.08	<2	23
57	11/10/04	1100	P	44	9.4	19	1.5	190	20	820	.10	<2	21
		1101	LR	45	9.2	19	1.5	190	20	840	.10	<2	22
58	11/10/04	1035	P	39	15	73	1.5	1,600	17	580	.24	1	14
59	11/10/04	1000	P	46	12	49	1.6	1,100	20	620	.14	1	22
60	11/10/04	0910	P	50	9.6	21	1.6	190	21	780	.06	<2	23
		0911	LR	45	9.0	18	1.4	180	19	710	.07	<2	21
61	11/10/04	0840	P	43	8.6	17	1.4	180	20	710	.08	<2	20
62	11/10/04	1300	P	53	11	25	1.6	190	21	1,100	.07	<2	26
		1301	LR	55	11	27	1.6	190	22	1,100	.07	1	26
		1305	CR	58	12	28	1.6	190	20	1,200	.09	<2	28
63	11/10/04	1340	P	54	18	21	2.5	120	28	1,000	.07	<2	28
64	12/15/04	1150	P	68	16	16	4.0	38	40	700	.04	1	23
65	12/15/04	1210	P	66	20	17	3.3	39	48	1,300	.05	1	29
66	10/21/04	1335	P	77	17	20	3.6	43	54	660	.05	<1	34
67	10/21/04	1315	P	78	17	20	5.1	47	55	1,000	.05	1	35
68	10/21/04	1420	P	63	19	18	2.7	100	40	1,100	.03	<1	30
69	10/21/04	1400	P	83	24	20	3.8	82	64	2,500	.03	<1	44
70	10/21/04	1250	P	84	23	19	4.1	38	58	1,400	.03	<1	39
71	12/15/04	1305	P	110	49	25	8.7	40	73	1,900	.02	1	72
72	10/21/04	1215	P	98	19	19	4.1	22	76	620	.03	<1	40
		1220	CR	100	20	19	4.2	23	74	710	.04	<1	41
73	10/19/04	1135	P	68	15	16	2.8	36	46	540	.04	<1	30
		1140	CR	68	13	28	2.9	38	45	550	.03	1	28
		1141	LR	73	15	26	3.1	42	46	580	<.01	<1	31

Table 11. Results of physical and total trace element and nutrient analyses of primary and replicate streambed-sediment samples (less than 0.063-millimeter particle-size fraction) from selected sampling sites in the Kansas part of the Tri-State Mining District, 2004.—Continued

[mm, millimeter; mg/kg, milligrams per kilogram; P, primary; LR, laboratory replicate; CR, concurrent replicate; SR, sequential replicate; AR, analytical rerun; TR, temporal replicate; <, less than; --, not determined]

Map index number (fig. 2)	Date of sample collection (month/ day/year)	Time (24-hour)	Sample type	Chromium (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Iron (percent dry weight)	Lead (mg/kg)	Lithium (mg/kg)	Manganese (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)
74	11/08/04	1540	P	51	15	19	2.1	100	27	1,200	0.08	<2	25
75	12/15/04	1240	P	64	30	15	5.7	110	31	1,700	.07	2	27
76	10/20/04	1435	P	62	18	23	2.7	200	42	1,200	.05	<1	30
		1440	CR	62	18	24	2.8	200	40	1,000	.05	<1	31
77	10/20/04	1420	P	71	19	22	3.1	83	51	850	.02	<1	32
78	10/20/04	1455	P	160	25	29	4.7	250	82	1,100	.07	4	46
79	10/19/04	1445	P	100	15	31	3.6	200	69	220	.04	<1	46
80	10/19/04	1210	P	74	38	33	6.0	520	47	860	.05	1	89
81	10/19/04	1430	P	78	26	29	4.1	340	59	1,300	.15	1	41
82	10/19/04	1410	P	93	42	31	3.5	370	61	1,800	.10	1	45
83	10/19/04	1350	P	71	25	56	2.3	430	41	600	.14	1	39
		1351	LR	66	22	54	2.2	470	37	560	.12	1	36
84	10/19/04	1330	P	73	39	75	3.0	810	35	1,500	.29	1	46
85	11/08/04	1420	P	52	13	22	1.8	130	25	930	.14	<2	23
86	11/08/04	1335	P	50	18	24	2.2	180	24	1,400	.11	<2	30
87	11/08/04	1630	P	50	15	18	1.9	73	23	1,100	<.02	<2	25

Table 11. Results of physical and total trace element and nutrient analyses of primary and replicate streambed-sediment samples (less than 0.063-millimeter particle-size fraction) from selected sampling sites in the Kansas part of the Tri-State Mining District, 2004.—Continued

[mm, millimeter; mg/kg, milligrams per kilogram; P, primary; LR, laboratory replicate; CR, concurrent replicate; SR, sequential replicate; AR, analytical rerun; TR, temporal replicate; <, less than]

Map index number (fig. 2)	Date of sample collection (month/day/year)	Time (24-hour)	Sample type	Nitrogen, total (percent dry weight)	Phosphorus (mg/kg)	Selenium (mg/kg)	Silver (mg/kg)	Strontium (mg/kg)	Thallium (mg/kg)	Titanium (percent dry weight)	Vanadium (mg/kg)	Uranium (mg/kg)	Zinc (mg/kg)
1	10/20/04	0910	P	0.14	530	0.8	<0.5	75	<50	0.50	72	<50	1,600
2	10/20/04	1045	P	.13	490	.8	<.5	83	<50	.49	69	<50	500
3	10/20/04	1020	P	.16	740	1.1	<.5	110	<50	.50	87	<50	650
4	10/20/04	1035	P	.33	1,400	1.2	<.5	97	<50	.40	68	<50	1,200
5	10/20/04	1005	P	.13	400	.7	<.5	85	<50	.48	68	<50	250
6	10/20/04	0950	P	.36	900	1.1	<.5	71	<50	.43	57	<50	26,000
		0951	LR	.34	910	1.0	<.5	69	<50	.45	55	<50	26,000
7	10/20/04	0930	P	.25	850	1.2	<.5	90	<50	.48	74	<50	12,000
8	10/20/04	0940	P	.38	1,200	1.6	<.5	62	<50	.41	66	<50	41,000
9	10/20/04	1340	P	.34	880	1.5	<.5	69	<50	.44	82	<50	14,000
10	10/20/04	1310	P	.37	930	1.5	<.5	45	<50	.28	53	<50	32,000
11	10/20/04	0830	P	.15	450	.9	<.5	68	<50	.49	78	<50	5,800
12	10/20/04	0805	P	.31	1,500	1.2	<.5	86	<50	.50	100	<50	7,900
		0810	CR	.34	1,600	1.2	<.5	83	<50	.49	96	<50	7,800
13	11/09/04	1245	P	.17	550	.5	<1.0	60	<100	.46	54	<100	150
14	10/22/04	1030	P	.12	470	1.0	<1.0	63	<100	.48	62	<100	2,800
		1031	LR	.12	440	.9	<.5	60	<50	.48	60	<50	2,900
15	10/22/04	1000	P	.13	510	.7	<.5	55	<50	.48	63	<50	730
16	10/22/04	0930	P	.27	1,500	1.1	<1.0	94	<100	.49	80	<100	380
17	12/15/04	1025	P	.30	950	.9	<.5	86	<50	.50	87	<50	170
		1026	LR	.29	930	.7	<1.0	83	<100	.47	85	<100	160
18	11/09/04	1145	P	.21	780	.7	<1.0	65	<100	.49	58	<100	180
19	11/09/04	1040	P	.20	740	.8	<1.0	66	<100	.45	60	<100	550
20	12/15/04	1530	P	.20	730	.5	<.5	63	<50	.42	60	<50	5,400
21	11/09/04	0950	P	.20	800	.4	<1.0	65	<100	.49	63	<100	1,500
22	10/21/04	1645	P	.29	1,200	1.4	<1.0	64	<100	.42	58	<100	6,900
23	12/15/04	1435	P	.30	1,000	1.0	.8	68	<50	.38	59	<50	4,900
		1445	SR	.30	1,100	1.2	1.1	70	<100	.40	65	<100	5,500
24	11/09/04	0855	P	.19	750	.5	<1.0	64	<100	.47	57	<100	1,100
		0900	CR	.18	700	.7	<1.0	59	<100	.46	53	<100	970
25	11/09/04	1440	P	.20	910	.5	<.5	71	<50	.47	63	<50	1,300
		1441	LR	.23	810	.7	.5	62	<50	.45	58	<50	1,200

Table 11. Results of physical and total trace element and nutrient analyses of primary and replicate streambed-sediment samples (less than 0.063-millimeter particle-size fraction) from selected sampling sites in the Kansas part of the Tri-State Mining District, 2004.—Continued

[mm, millimeter; mg/kg, milligrams per kilogram; P, primary; LR, laboratory replicate; CR, concurrent replicate; SR, sequential replicate; AR, analytical rerun; TR, temporal replicate; <, less than]

Map index number (fig. 2)	Date of sample collection (month/ day/year)	Time (24-hour)	Sample type	Nitrogen, total (percent dry weight)	Phosphorus (mg/kg)	Selenium (mg/kg)	Silver (mg/kg)	Strontium (mg/kg)	Thallium (mg/kg)	Titanium (percent dry weight)	Vanadium (mg/kg)	Uranium (mg/kg)	Zinc (mg/kg)
26	10/21/04	0915	P	0.44	20,000	2.2	<0.5	190	<50	0.29	67	<50	17,000
	Requested rerun		AR	--	21,000	2.1	<1.0	200	<100	.31	70	<100	17,000
27	10/21/04	0940	P	.11	400	.9	<1.0	81	<100	.44	75	<100	5,000
28	10/21/04	0835	P	.33	1,000	1.9	<.5	71	<50	.42	80	<50	5,900
29	10/20/04	1715	P	.59	1,600	2.0	<.5	79	<50	.34	72	<50	16,000
30	10/21/04	0810	P	.14	950	2.9	<.5	69	<50	.35	54	<50	15,000
31	10/19/04	0815	P	.36	3,900	3.4	1.9	90	<50	.27	62	<50	25,000
	11/18/04	1330	TR	.46	4,600	2.3	2.4	100	<100	.26	61	<100	24,000
32	10/19/04	1110	P	.19	570	.6	<.5	60	<50	.46	56	<50	860
33	10/19/04	1040	P	.56	1,000	1.6	<1.0	65	<100	.39	80	<100	6,500
34	10/19/04	1620	P	.14	510	1.1	<1.0	71	<100	.53	80	<100	8,200
35	10/21/04	1030	P	.13	650	.8	<1.0	62	<100	.44	61	<100	9,500
36	10/21/04	1045	P	.23	1,400	2.1	<.5	65	<50	.45	69	<50	14,000
		1046	LR	.24	1,400	2.0	<.5	65	<50	.46	70	<50	15,000
37	10/19/04	0905	P	.13	610	.6	<1.0	60	<100	.44	75	<100	2,800
38	10/19/04	0930	P	.60	5,500	1.6	<1.0	73	<100	.24	51	<100	44,000
39	10/20/04	1610	P	.56	12,000	3.8	1.3	77	<100	.28	51	<100	45,000
	Requested rerun		AR	--	14,000	4.2	<1.0	84	<100	.26	55	<100	45,000
40	10/22/04	0820	P	.17	700	.8	<.5	94	<50	.52	82	<50	260
	10/22/04	0825	CR	.15	750	.8	<.5	100	<50	.54	88	<50	300
41	10/22/04	0845	P	.16	600	.8	<.5	93	<50	.55	81	<50	170
42	12/15/04	1055	P	.20	820	1.1	<1.0	110	<100	.49	120	<100	500
43	10/22/04	0900	P	.18	840	1.0	<.5	99	<50	.51	93	<50	200
		0901	LR	.20	810	.9	<.5	99	<50	.48	91	<50	200
44	10/21/04	1600	P	.16	1,000	.9	<.5	100	<50	.52	100	<50	300
45	10/21/04	1520	P	.19	700	.9	<.5	86	<50	.53	87	<50	180
46	12/15/04	1120	P	.10	810	.7	<1.0	81	<100	.43	93	<100	450
	Requested rerun		AR	.13	790	1.0	<1.0	76	<100	.40	84	<100	440
		1130	SR	.10	530	.9	<.5	170	<50	.31	54	<50	2,300
	Requested rerun		AR	.12	490	1.1	1.0	160	<100	.30	52	<100	2,500
47	10/21/04	1540	P	.23	820	.9	.5	110	<50	.52	93	<50	180

Table 11. Results of physical and total trace element and nutrient analyses of primary and replicate streambed-sediment samples (less than 0.063-millimeter particle-size fraction) from selected sampling sites in the Kansas part of the Tri-State Mining District, 2004.—Continued

[mm, millimeter; mg/kg, milligrams per kilogram; P, primary; LR, laboratory replicate; CR, concurrent replicate; SR, sequential replicate; AR, analytical rerun; TR, temporal replicate; <, less than]

Map index number (fig. 2)	Date of sample collection (month/day/year)	Time (24-hour)	Sample type	Nitrogen, total (percent dry weight)	Phosphorus (mg/kg)	Selenium (mg/kg)	Silver (mg/kg)	Strontium (mg/kg)	Thallium (mg/kg)	Titanium (percent dry weight)	Vanadium (mg/kg)	Uranium (mg/kg)	Zinc (mg/kg)
48	10/21/04	1455	P	0.21	810	0.7	<0.5	88	<50	0.51	81	<50	220
49	11/09/04	1520	P	.27	1,000	.3	<1.0	68	<100	.51	66	<100	1,800
50	10/19/04	1545	P	.25	1,000	1.8	<1.0	68	<100	.46	70	<100	5,700
51	10/19/04	1600	P	.34	1,300	1.2	<1.0	60	<100	.45	63	<100	4,800
52	10/20/04	1540	P	.23	1,700	1.5	<1.0	60	<100	.43	61	<100	4,900
53	11/18/04	1230	P	.24	780	.8	1.0	61	<50	.43	49	<50	1,600
54	11/19/04	1115	P	.18	590	.8	.6	57	<50	.45	51	<50	1,900
		1120	CR	.19	610	.7	.6	57	<50	.44	51	<50	1,700
55	10/19/04	1010	P	.36	960	1.5	1.0	68	<50	.43	55	<50	2,300
56	11/10/04	1125	P	.16	560	.8	<1.0	69	<100	.45	63	<100	1,800
57	11/10/04	1100	P	.25	770	.8	<1.0	59	<100	.44	47	<100	1,800
		1101	LR	.24	780	.9	<1.0	57	<100	.44	48	<100	1,800
58	11/10/04	1035	P	.13	440	1.1	.5	57	<50	.39	42	<50	3,100
59	11/10/04	1000	P	.21	630	1.1	.5	61	<50	.43	49	<50	4,200
60	11/10/04	0910	P	.27	800	.9	<1.0	58	<100	.45	51	<100	2,100
		0911	LR	.25	750	.9	1.2	53	<100	.44	47	<100	1,900
61	11/10/04	0840	P	.24	720	.8	1.1	58	<100	.46	47	<100	1,900
62	11/10/04	1300	P	.27	960	.8	<1.0	63	<100	.45	48	<100	2,400
		1301	LR	.28	930	.8	.9	64	<50	.44	48	<50	2,400
		1305	CR	.30	1,000	.9	<1.0	62	<100	.44	48	<100	2,500
63	11/10/04	1340	P	.15	720	.7	<1.0	62	<100	.45	67	<100	1,400
64	12/15/04	1150	P	.20	700	.9	<.5	85	<50	.50	82	<50	160
65	12/15/04	1210	P	.30	1,100	.8	<.5	100	<50	.47	84	<50	270
66	10/21/04	1335	P	.17	880	.8	<.5	110	<50	.49	91	<50	290
67	10/21/04	1315	P	.17	910	1.0	<.5	110	<50	.52	99	<50	220
68	10/21/04	1420	P	.13	550	.8	<.5	99	<50	.52	81	<50	610
69	10/21/04	1400	P	.10	700	.9	<.5	120	<50	.53	99	<50	450
70	10/21/04	1250	P	.15	750	.9	<.5	110	<50	.53	100	<50	210
71	12/15/04	1305	P	.10	1,300	1.0	<1.0	140	<100	.46	130	<100	300
72	10/21/04	1215	P	.08	670	.6	<.5	130	<50	.53	110	<50	97
		1220	CR	.06	670	.6	<.5	140	<50	.53	120	<50	110
73	10/19/04	1135	P	.15	620	.8	.5	98	<50	.50	83	<50	180
		1140	CR	.14	670	.6	<.5	100	<50	.49	88	<50	190
		1141	LR	.14	680	.7	<.5	100	<50	.52	85	<50	190

Table 11. Results of physical and total trace element and nutrient analyses of primary and replicate streambed-sediment samples (less than 0.063-millimeter particle-size fraction) from selected sampling sites in the Kansas part of the Tri-State Mining District, 2004.—Continued

[mm, millimeter; mg/kg, milligrams per kilogram; P, primary; LR, laboratory replicate; CR, concurrent replicate; SR, sequential replicate; AR, analytical rerun; TR, temporal replicate; <, less than]

Map index number (fig. 2)	Date of sample collection (month/day/year)	Time (24-hour)	Sample type	Nitrogen, total (percent dry weight)	Phosphorus (mg/kg)	Selenium (mg/kg)	Silver (mg/kg)	Strontium (mg/kg)	Thallium (mg/kg)	Titanium (percent dry weight)	Vanadium (mg/kg)	Uranium (mg/kg)	Zinc (mg/kg)
74	11/08/04	1540	P	0.23	910	0.7	<1.0	68	<100	0.50	61	<100	1,800
75	12/15/04	1240	P	.20	910	.9	<1.0	81	<100	.42	95	<100	640
76	10/20/04	1435	P	.21	740	1.1	<.5	110	<50	.50	80	<50	1,300
		1440	CR	.22	720	1.1	<.5	110	<50	.48	81	<50	1,300
77	10/20/04	1420	P	.18	670	1.0	<.5	130	<50	.52	86	<50	660
78	10/20/04	1455	P	.17	820	1.3	<.5	130	<50	.50	120	<50	1,400
79	10/19/04	1445	P	.18	700	1.2	<.5	110	<50	.52	120	<50	1,500
80	10/19/04	1210	P	.30	1,600	2.0	<.5	83	<50	.52	88	<50	8,800
81	10/19/04	1430	P	.12	620	1.0	<.5	130	<50	.46	93	<50	4,600
82	10/19/04	1410	P	.15	660	.9	<.5	95	<50	.50	100	<50	4,200
83	10/19/04	1350	P	.26	790	1.1	<.5	76	<50	.45	75	<50	11,000
		1351	LR	.26	710	.9	<.5	71	<50	.41	68	<50	10,000
84	10/19/04	1330	P	.44	1,700	2.1	<.5	86	<50	.36	70	<50	16,000
85	11/08/04	1420	P	.19	820	.7	<1.0	63	<100	.47	55	<100	2,100
86	11/08/04	1335	P	.19	860	.8	<1.0	65	<100	.45	58	<100	2,500
87	11/08/04	1630	P	.38	630	.8	<1.0	58	<100	.45	64	<100	370

Table 12. Results of chemical analyses of soil reference samples and comparison to most probable values.

[Shading indicates values outside of published limits for each soil-quality constituent or ±10 percent of the most probable value, whichever is greater. MPV, most probable value; mg/kg, milligrams per kilogram; NIST, National Institute of Standards and Technology; --, not determined; USGS, U.S. Geological Survey; ?, actual value in question; <, less than]

			Aluminum		Antimony		Arsenic		Barium	
Sample source	Sample code		Concentration (percent dry weight)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV
NIST	1646a	MPV	2.30±0.02	--	0.3	--	6.23±0.21	--	210	--
			2.4	4.3	.3	0	6.2	-0.5	220	4.8
			2.2	-4.3	.3	0	6.4	2.7	210	0
			2.2	-4.3	.3	0	6.5	4.3	200	-4.8
NIST	SRM 2702 marine sediment	MPV	8.41±0.22	--	5.60±0.24	--	45.3±1.8	--	397.4±3.2	--
			8.4	-.1	5.8	3.6	48	6.0	380	-4.4
NIST	2709	MPV	7.50±0.06	--	7.9±0.6	--	17.7±0.8	--	968±40	--
			7.4	-1.3	7.3	-7.6	18	1.7	980	1.2
			7.4	-1.3	7.6	-3.8	19	7.3	970	.2
			7.6	1.3	7.6	-3.8	19	7.3	980	1.2
NIST	2711 MT. soil	MPV	6.53±0.09	--	19.4±1.8	--	105±8	--	726±38	--
			6.6	1.1	20	3.1	100	-4.8	740	1.9
			6.4	-2.0	19	-2.1	110	4.8	720	-.8
			6.6	1.1	19	-2.1	110	4.8	740	1.9
USGS	GSP-2	MPV	7.88±0.11	--	--	--	--		1,340±44	
			7.9	.3	.5	--	2.8	--	1,300	-3.0
			7.9	.3	--	--	--	--	1,300	-3.0
USGS	MAG-1	MPV	8.66±0.16	--	0.96±0.10	--	9.2±1.2	--	479±41	--
			8.6	-.7	.9	-6.2	9.7	5.4	520	7.9
			8.7	.5	.9	-6.2	9.8	6.5	470	-1.9
			8.6	-.7	.8	-16.7	9.3	1.1	480	.2
USGS	QLO-1	MPV	8.56±0.10	--	2.1±0.4	--	3.5±1.8	--	1,370±80	--
			8.3	-3.0	1.7	-19.0	2.4	-31.4	1,400	2.1
			8.6	.5	1.8	-14.3	2.6	-25.7	1,400	2.1
			8.3	-3.0	--	--	--	--	1,300	-5.1
USGS	SCO-1	MPV	7.23±0.11	--	2.5±0.1	--	12.4±1.4	--	570±30	--
			7.2	-.5	2.5	0	13	4.8	600	5.2
			7.2	-.5	2.4	-4.0	13	4.8	540	-5.3
			7.2	-.5	2.3	-8.7	13	4.8	550	-3.5
USGS	SDO-1	MPV	6.49±0.14	--	4.45	--	68.5±8.6	--	397±38	--
			6.4	-1.4	4.5	1.1	67	-2.1	200	-49.6
			6.5	.2	4.5	1.1	73	6.6	280	-29.5
			6.5	.2	4.4	-1.1	71	3.6	210	-47.1
USGS	SGR-1	MPV	3.45±0.11	--	3.4±0.5	--	67±5	--	290±40	--
			3.4	-1.4	3.0	-11.8	63	-6.0	270	-6.9
			3.4	-1.4	3.9	14.7	68	1.5	270	-6.9
			3.4	-1.4	3.1	-8.8	61	-9.0	260	-10.3
USGS	STM-1	MPV	9.73±0.12	--	1.66±0.15	--	4.6±0.6	--	560±60	--
			9.6	-1.3	1.4	-15.7	4.2	-8.7	600	7.1
			9.1	-6.5	1.4	-15.7	4.8	4.3	570	1.8
			9.8	.7	1.7	2.4	5.0	8.7	620	10.7

Table 12. Results of chemical analyses of soil reference samples and comparison to most probable values.—Continued

[Shading indicates values outside of published limits for each soil-quality constituent or ±10 percent of the most probable value, whichever is greater. MPV, most probable value; mg/kg, milligrams per kilogram; NIST, National Institute of Standards and Technology; --, not determined; USGS, U.S. Geological Survey; ?, actual value in question; <, less than]

Sample source	Sample code		Beryllium		Cadmium		Carbon, organic, total		Carbon, total	
			Concentration (mg/kg)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV	Concentration (percent dry weight)	Percent different from MPV	Concentration (percent dry weight)	Percent different from MPV
NIST	1646a	MPV	<1.0	--	0.2	--	--	--	--	--
			1.0	--	.2	0	0.5	--	0.6	--
			.8	--	.1	-50.0	.5	--	.6	--
			.8	--	.1	-50.0	.5	--	.4	--
NIST	SRM 2702 marine sediment	MPV	3.0	--	0.82±0.01	--	3.3	--	3.4	--
			2.7	-10.0	.6	-26.8	3.2	-3.0	3.2	-6.2
NIST	2709	MPV	--	--	.4	--	--	--	1.2	--
			6.0	--	.3	-25.0	1.0	--	1.2	0
			5.3	--	.3	-25.0	1.1	--	1.1	-8.3
			5.4	--	.3	-25.0	1.1	--	1.0	-16.7
NIST	2711 MT. soil	MPV	--	--	41.70±0.25	--	--	--	2.0	--
			2.4	--	41	-1.7	1.7	--	1.9	-5.0
			2.0	--	41	-1.7	1.7	--	1.9	-5.0
			2.3	--	41	-1.7	1.8	--	1.7	-15.0
USGS	GSP-2	MPV	1.5±0.2		--	--	--	--	--	--
			1.3	-13.3	<.1	--	<.1	--	.2	--
			1.4	-6.7	.07	--	.2	--	<.1	--
USGS	MAG-1	MPV	3.2±0.4	--	0.2±0.1	--	--	--	2.15±0.40	--
			3.3	3.1	.3	50.0	2.3	--	2.3	7.0
			2.7	-15.6	.3	50.0	2.2	--	2.4	11.6
			2.9	-9.4	.2	0	2.2	--	2.2	2.3
USGS	QLO-1	MPV	1.89±0.17	--	.05?	--	--	--	<.01	--
			2.0	5.8	<.1	--	<.1	--	.06	--
			1.6	-15.3	<.1	--	<.1	--	<.10	--
			1.7	-10.1	<.1	--	.1	--	<.10	--
USGS	SCO-1	MPV	1.84±0.20	--	.14	--	--	--	0.81±0.12	--
			1.9	3.3	.10	-28.6	.9	--	1.0	23.5
			1.6	-13.0	.10	-28.6	.9	--	1.0	23.5
			1.7	-7.6	.10	-28.6	1.0	--	.9	11.1
USGS	SDO-1	MPV	3.3±0.6	--	--	--	--	--	9.95±0.44	--
			3.4	3.0	.10	--	9.8	--	9.9	-.5
			2.7	-18.2	.07	--	10	--	10	.5
			3.1	-6.1	.10	--	9.5	--	9.7	-2.5
USGS	SGR-1	MPV	1.06±0.16	--	0.93±0.05	--	25	--	28	--
			1.1	3.8	1.0	7.5	27	8.0	28	0
			.9	-15.1	1.1	18.3	27	8.0	28	0
			1.0	-5.7	1.0	7.5	26	4.0	28	0
USGS	STM-1	MPV	9.6±0.6	--	0.27±0.05	--	--	--	.01	--
			10	4.2	.3	11.1	<.1	--	<.10	--
			8.7	-9.4	.2	-25.9	<.1	--	<.10	--
			10	4.2	.3	11.1	<.1	--	<.10	--

Table 12. Results of chemical analyses of soil reference samples and comparison to most probable values.—Continued

[Shading indicates values outside of published limits for each soil-quality constituent or ±10 percent of the most probable value, whichever is greater. MPV, most probable value; mg/kg, milligrams per kilogram; NIST, National Institute of Standards and Technology; --, not determined; USGS, U.S. Geological Survey; ?, actual value in question; <, less than]

Sample source	Sample code		Chromium		Cobalt		Copper		Iron	
			Concentration (mg/kg)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV	Concentration (percent dry weight)	Percent different from MPV
NIST	1646a	MPV	41±2	--	5.0	--	10±0.34	--	2.00±0.04	--
			41	0	5.1	2.0	11	10.0	2.1	5.0
			39	-4.9	4.9	-2.0	9.6	-4.0	1.9	-5.0
			39	-4.9	4.7	-6.0	9.0	-10.0	1.9	-5.0
NIST	SRM 2702 marine sediment	MPV	352±22	--	27.8±0.6	--	117.7±5.8	--	7.91±0.24	--
			340	-3.4	26	-6.9	110	-6.5	7.9	-.1
NIST	2709	MPV	130±4	--	13.4±0.7	--	34.6±0.7	--	3.5±0.11	
			120	-7.7	13	-3.0	36	4.0	3.6	2.9
			110	-15.4	13	-3.0	34	-1.7	3.5	0
			120	-7.7	14	4.5	34	-1.7	3.6	2.9
NIST	2711 MT. soil	MPV	47	--	10	--	114±2	--	2.89±0.06	--
			46	-2.1	9.9	-1.0	120	5.3	2.9	.3
			45	-4.3	11	10.0	110	-3.5	2.8	-3.1
			44	-6.4	11	10.0	110	-3.5	2.9	.3
USGS	GSP-2	MPV	20±6	--	7±1	--	43±4	--	3.43±0.11	--
			15	-25.0	6.8	-2.9	44	2.3	3.4	-.9
			19	-5.0	7.1	1.4	41	-4.7	3.3	-3.8
USGS	MAG-1	MPV	97±8	--	20.4±1.6	--	30±3	--	4.75±0.21	--
			110	13.4	22	7.8	30	0	4.9	3.2
			92	-5.2	20	-2.0	24	-20.0	4.5	-5.3
			94	-3.1	21	2.9	27	-10.0	4.8	1.1
USGS	QLO-1	MPV	3.2±1.7	--	7.2±0.5	--	29±3	--	3.04±0.10	--
			2.1	-34.4	7.3	1.4	28	-3.4	3.0	-1.3
			4.0	25.0	6.8	-5.6	25	-13.8	3.0	-1.3
			3.0	-6.2	7.1	-1.4	26	-10.3	3.0	-1.3
USGS	SCO-1	MPV	68±5	--	10.5±0.8	--	28.7±1.9	--	3.59±0.13	--
			73	7.4	11	4.8	30	4.5	3.7	3.1
			63	-7.4	10	-4.8	25	-12.9	3.6	.3
			66	-2.9	11	4.8	27	-5.9	3.5	-2.5
USGS	SDO-1	MPV	66.4±7.6	--	46.8±6.3	--	60.2±9.6	--	6.53±0.15	--
			66	-.6	46	-1.7	58	-3.7	6.4	-2.0
			59	-11.1	43	-8.1	54	-10.3	6.5	-.5
			61	-8.1	46	-1.7	54	-10.3	6.3	-3.5
USGS	SGR-1	MPV	30±3	--	11.8±1.5	--	66±9	--	2.12±0.10	--
			32	6.7	12	1.7	65	-1.5	2.0	-5.7
			29	-3.3	10	-15.3	58	-12.1	2.0	-5.7
			30	0	11	-6.8	58	-12.1	2.0	-5.7
USGS	STM-1	MPV	4.3±2.6	--	0.90±0.15	--	4.6±2.0	--	3.65±0.07	--
			3.5	-18.6	1.1	22.2	4.1	-10.9	3.7	1.4
			3.5	-18.6	<1.0	--	2.0	-56.5	3.6	-1.4
			3.3	-23.3	1.3	44.4	4.4	-4.3	3.8	4.1

Table 12. Results of chemical analyses of soil reference samples and comparison to most probable values.—Continued

[Shading indicates values outside of published limits for each soil-quality constituent or ±10 percent of the most probable value, whichever is greater. MPV, most probable value; mg/kg, milligrams per kilogram; NIST, National Institute of Standards and Technology; --, not determined; USGS, U.S. Geological Survey; ?, actual value in question; <, less than]

			Lead		Lithium		Manganese		Mercury	
Sample source	Sample code		Concentration (mg/kg)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV
NIST	1646a	MPV	12±1	--	17	--	234±3	--	0.04	--
			12	0	17	0	240	2.6	.04	0
			12	0	15	-11.8	240	2.6	.04	0
			12	0	16	-5.9	240	2.6	.03	-25.0
NIST	SRM 2702 marine sediment	MPV	133±1	--	78	--	1,757±58	--	0.438±0.024	--
			130	-2.3	75	-3.8	1,700	-3.2	.44	.5
NIST	2709	MPV	18.9±0.5	--	--	--	538±17	--	1.40±0.08	--
			20	5.8	59	--	540	.4	1.4	0
			18	-4.8	49	--	560	4.1	1.4	0
			18	-4.8	56	--	530	-1.5	1.5	7.1
NIST	2711 MT soil	MPV	1,162±31	--	--	--	638±28	--	6.25±0.19	--
			1,200	3.3	25	--	640	.3	6.1	-2.4
			1,100	-5.3	22	--	660	3.4	6.4	2.4
			1,100	-5.3	27	--	620	-2.8	6.1	-2.4
USGS	GSP-2	MPV	42±3	--	36±1	--	320±20	--	--	--
			39	-7.1	34	-5.6	320	0	.01	--
			42	0	35	-2.8	320	0	.06	--
USGS	MAG-1	MPV	24±3	--	79±4	--	760±70	--	.02	--
			27	12.5	81	2.5	760	0	.06	200
			22	-8.3	77	-2.5	740	-2.6	.05	150
			28	16.7	80	1.3	690	-9.2	.05	150
USGS	QLO-1	MPV	20.4±0.8	--	25±2	--	721±49	--	.01	--
			21	2.9	26	4.0	690	-4.3	.40	3,900
			22	7.8	25	0	700	-2.9	.01	0
			23	12.7	24	-4.0	700	-2.9	.01	0
USGS	SCO-1	MPV	31±3	--	45±3	--	408±30	--	.05	--
			35	12.9	46	2.2	390	-4.4	.03	-40.0
			32	3.2	42	-6.7	410	.5	.08	60.0
			35	12.9	45	0	390	-4.4	.07	40.0
USGS	SDO-1	MPV	27.9±5.2	--	28.6±5.5	--	325±39	--	0.19±0.08	--
			26	-6.8	29	1.4	310	-4.6	.24	26.3
			26	-6.8	27	-5.6	310	-4.6	.20	5.3
			23	-17.6	30	4.9	300	-7.7	.20	5.3
USGS	SGR-1	MPV	38±4	--	147±26	---	267±34	--	.313	--
			42	10.5	130	-11.6	240	-10.1	.16	-48.9
			41	7.9	120	-18.4	300	12.4	.20	-36.1
			42	10.5	120	-18.4	230	-13.9	.19	-39.3
USGS	STM-1	MPV	17.7±1.8	--	32±8	--	1,700±120	--	.015	--
			18	1.7	38	18.8	1,600	-5.9	.011	-26.7
			15	-15.3	33	3.1	1,700	0	.012	-20.0
			20	13.0	39	21.9	1,700	0	.014	-6.7

Table 12. Results of chemical analyses of soil reference samples and comparison to most probable values.—Continued

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			Molybdenum		Nickel		Nitrogen, total		Phosphorus	
Sample source	Sample code		Concentration (mg/kg)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV	Concentration (percent dry weight)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV
NIST	1646a	MPV	1.8	--	23	--	--	--	270±10	--
			.9	-50.0	22	-4.3	0.07	--	290	7.4
			1.8	0	23	0	.07	--	260	-3.7
			1.5	-16.7	21	-8.7	.08	--	260	-3.7
NIST	SRM 2702 marine sediment	MPV	10.8±1.6	--	75.4±1.5	--	--	--	1,552±66	--
			8.6	-20.4	73	-3.2	.28	--	1,500	-3.4
NIST	2709	MPV	2.0	--	88±5	--	--	--	620±50	--
			1.5	-25.0	85	-3.4	.12	--	650	4.6
			2.0	0	86	-2.3	.10	--	620	0
			1.8	-10.0	89	1.1	.11	--	640	3.2
NIST	2711 MT. soil	MPV	1.6	--	20.6±1.1	--	--	--	860±70	--
			<1.0	--	20	-2.9	.15	--	870	1.2
			1.9	18.8	21	1.9	.15	--	800	-7.0
			1.4	-12.5	20	-2.9	.15	--	850	-1.2
USGS	GSP-2	MPV	2.1±0.6	--	17±2	--	--	--	1,300±100	--
			2.7	28.6	16	-5.9	.02	--	1,200	-7.7
			1.9	-9.5	15	-11.8	.04	--	1,300	0
USGS	MAG-1	MPV	1.6±0.6	--	53±8	--	--	--	710±90	--
			<1.0	--	49	-7.5	.27	--	760	7.0
			1.2	-25.0	51	-3.8	.27	--	680	-4.2
			1.3	-18.8	47	-11.3	.27	--	700	-1.4
USGS	QLO-1	MPV	2.6±0.3	--	5.8±3.6	--	--	--	1,110±70	--
			1.9	-26.9	2.3	-60.3	.02	--	1,200	8.1
			2.4	-7.7	3.0	-48.3	.02	--	1,000	-9.9
			2.3	-11.5	4.0	-31.0	.02	--	1,100	-.9
USGS	SCO-1	MPV	1.37±0.16	--	27±4	--	--	--	900±90	--
			<1.0	--	26	-3.7	.08	--	940	4.4
			1.2	-12.4	25	-7.4	.07	--	880	-2.2
			1.1	-19.7	24	-11.1	.08	--	820	-8.9
USGS	SDO-1	MPV	134±21	--	99.5±9.9	--	0.35±0.04	--	480±31	--
			150	11.9	94	-5.5	.37	5.7	480	0
			130	-3.0	94	-5.5	.31	-11.4	460	-4.2
			140	4.5	91	-8.5	.40	14.3	470	-2.1
USGS	SGR-1	MPV	35.1±0.9	--	29±5	--	--	--	1,430±290	--
			33	-6.0	28	-3.4	.82	--	1,300	-9.1
			33	-6.0	28	-3.4	.91	--	1,200	-16.1
			33	-6.0	26	-10.3	.99	--	1,200	-16.1
USGS	STM-1	MPV	5.2±0.9	--	3.0±1.6	--	--	--	690±60	--
			4.7	-9.6	2.2	-26.7	.03	--	720	4.3
			5.0	-3.8	3.0	0	.01	--	660	-4.3
			5.2	0	1.9	-36.7	.03	--	740	7.2

Table 12. Results of chemical analyses of soil reference samples and comparison to most probable values.—Continued

[Shading indicates values outside of published limits for each soil-quality constituent or ±10 percent of the most probable value, whichever is greater. MPV, most probable value; mg/kg, milligrams per kilogram; NIST, National Institute of Standards and Technology; --, not determined; USGS, U.S. Geological Survey; ?, actual value in question; <, less than]

Sample source	Sample code		Selenium		Silver		Strontium		Thallium	
			Concentration (mg/kg)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV
NIST	1646a	MPV	0.19±0.03	--	<0.3	--	68	--	<0.5	--
			.2	5.3	<.5	--	74	8.8	<50	--
			.2	5.3	<.5	--	71	4.4	<50	--
			.1	-47.4	<.5	--	71	4.4	<50	--
NIST	SRM 2702 marine sediment	MPV	4.95±0.46	--	0.62±0.08	--	120±3	--	0.827±0.006	--
			4.7	-5.1	.9	45.2	120	0	<50	--
NIST	2709	MPV	1.57±0.08	--	0.41±0.03	--	231±2	--	0.74±0.05	--
			1.6	1.9	.5	22.0	240	3.9	<50	--
			1.7	8.3	1.0	140.0	240	3.9	<50	--
			1.5	-4.5	<1.0	--	240	3.9	<100	--
NIST	2711 MT. soil	MPV	1.52±0.14	--	4.63±0.39	--	245.3±0.7	--	2.47±0.15	--
			1.4	-7.9	4.6	-.6	250	1.9	<50	--
			1.6	5.3	4.6	-.6	250	1.9	<50	--
			1.5	-1.3	4.3	-7.1	250	1.9	<100	--
USGS	GSP-2	MPV	--	--	--	--	240±10	--	1.1	--
			.1	--	<.5	--	230	-4.2	<50	--
			<.1	--	<1.0	--	240	0	<100	--
USGS	MAG-1	MPV	1.16±0.12	--	.08	--	146±15	--	0.590±?	--
			1.3	12.1	<.5	--	160	9.6	<50	--
			1.2	3.4	<.5	--	140	-4.1	<50	--
			1.3	12.1	<.5	--	150	2.7	<50	--
USGS	QLO-1	MPV	0.009±0.002	--	.06	--	336±12	--	0.220±0.040	--
			<.1	--	<.5	--	350	4.2	<50	--
			<.1	--	<.5	--	320	-4.8	<50	--
			<.1	--	<.5	--	330	-1.8	<50	--
USGS	SCO-1	MPV	0.89±0.06	--	.13	--	174±16	--	0.72±0.13	--
			1.1	23.6	<.5	--	190	9.2	<50	--
			.8	-10.1	<.5	--	160	-8.0	<50	--
			.9	1.1	<.5	--	170	-2.3	<50	--
USGS	SDO-1	MPV	1.9-6.8	--	0.1-0.2	--	75.1±11	--	8.3?	--
			1.9	--	<0.5	--	79	5.2	<50	--
			2.6	--	<0.5	--	75	-.1	<50	--
			1.6	--	<1.0	--	83	10.5	<100	--
USGS	SGR-1	MPV	3.5±0.28	--	0.01-0.20	--	420±30	--	0.330±?	--
			3.3	-5.7	<0.5	--	430	2.4	<50	--
			3.6	2.9	<0.5	--	390	-7.1	<50	--
			3.5	0	<1.0	--	390	-7.1	<100	--
USGS	STM-1	MPV	0.008±0.002	--	.08	--	700±30	--	0.260±0.050	--
			<.1	--	.5	520.0	700	0	<50	--
			<.1	--	<.5	--	690	-1.4	<50	--
			<.1	--	<.5	--	740	5.7	<50	--

Table 12. Results of chemical analyses of soil reference samples and comparison to most probable values.—Continued

[Shading indicates values outside of published limits for each soil-quality constituent or ±10 percent of the most probable value, whichever is greater. MPV, most probable value; mg/kg, milligrams per kilogram; NIST, National Institute of Standards and Technology; --, not determined; USGS, U.S. Geological Survey; ?, actual value in question; <, less than]

Sample source	Sample code		Titanium		Vanadium		Uranium		Zinc	
			Concentration (percent dry weight)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV	Concentration (mg/kg)	Percent different from MPV
NIST	1646a	MPV	0.46±0.02	--	45±1	--	2.0	--	49±2	--
			.48	4.3	47	4.4	<50	--	50	2.0
			.47	2.2	44	-2.2	<50	--	46	-6.1
			.44	-4.3	43	-4.4	<50	--	47	-4.1
NIST	SRM 2702 marine sediment	MPV	0.884±0.082	--	357.6±9.2	--	10.4	--	485.3±4.2	--
			.88	-.5	350	-2.1	<50	--	480	-1.1
NIST	2709	MPV	0.342±0.024	--	112±5	--	3.0	--	106±3	--
			.36	5.3	120	7.1	<50	--	110	3.8
			.34	-.6	110	-1.8	<50	--	100	-5.7
			.36	5.3	110	-1.8	<100	--	110	3.8
NIST	2711 MT. soil	MPV	0.306±0.023	--	81.6±2.9	--	2.6	--	350.4±4.8	--
			.31	1.3	85	4.2	<50	--	340	-3.0
			.31	1.3	79	-3.2	<50	--	340	-3.0
			.31	1.3	82	.5	<100	--	340	-3.0
USGS	GSP-2	MPV	0.40±0.01	--	52±4	--	2.4	--	120±10	--
			.40	0	48	-7.7	<50	--	110	-8.3
			.41	2.5	50	-3.8	<100	--	120	0
USGS	MAG-1	MPV	0.450±0.040	--	140±6	--	2.7±0.3	--	130±6	--
			.44	-2.2	150	7.1	<50	--	130	0
			.44	-2.2	130	-7.1	<50	--	120	-7.7
			.42	-6.7	130	-7.1	<50	--	130	0
USGS	QLO-1	MPV	0.374±0.020	--	54±6	--	1.94±0.12	--	61±3	--
			.37	-1.1	51	-5.6	<50	--	59	-3.3
			.38	1.6	48	-11.1	<50	--	59	-3.3
			.36	-3.7	49	-9.3	<50	--	59	-3.3
USGS	SCO-1	MPV	0.376±0.039	--	131±13	--	3.0±0.2	--	103±8	--
			.35	-6.9	140	6.9	<50	--	99	-3.9
			.35	-6.9	120	-8.4	<50	--	98	-4.9
			.35	-6.9	120	-8.4	<50	--	100	-2.9
USGS	SDO-1	MPV	0.426±0.019	--	160±21	--	48.8±6.5	--	64.1±6.9	--
			.41	-3.8	170	6.2	58	18.9	71	10.8
			.43	.9	140	-12.5	54	10.7	65	1.4
			.40	-6.1	160	0	<100	--	66	3.0
USGS	SGR-1	MPV	0.152±0.015	--	128±6	--	5.4±0.4	--	74±9	--
			.15	-1.3	120	-6.2	<50	--	69	-6.8
			.14	-7.9	120	-6.2	<50	--	70	-5.4
			.14	-7.9	120	-6.2	<100	--	68	-8.1
USGS	STM-1	MPV	0.081±0.007	--	8.7±5.2	--	9.06±0.13	--	235±22	--
			.09	11.1	4.0	-54.0	24	160	230	-2.1
			.09	11.1	3.0	-65.5	5.0	-44.8	230	-2.1
			.09	11.1	5.0	-42.5	<50	--	250	6.4

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