National Water-Quality Assessment (NAWQA) Program Black River Synoptic Study, Southeastern Missouri, 1993 and 1995

By Suzanne R. Femmer

Chapter 5 of

Hydrologic Investigations Concerning Lead Mining Issues in Southeastern Missouri

Edited by Michael J. Kleeschulte

Scientific Investigations Report 2008–5140

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

Contents

Figures

Tables

National Water-Quality Assessment (NAWQA) Program Black River Synoptic Study, Southeastern Missouri, 1993 and 1995

By Suzanne R. Femmer

Abstract

Water chemistry, streambed sediment, fish tissue, and invertebrate samples were collected from 14 sites to evaluate the effects of lead and zinc mining and related activities on streams in the Viburnum Trend Subdistrict (Viburnum Trend). All samples were collected during August to September 1995, except for streambed sediment and fish tissue collected at Black River near Lesterville during October 1993. The metal-sulfide deposits in the Viburnum Trend are known as Mississippi Valley Type deposits and include the trace-elements (all metals) arsenic, cadmium, cobalt, copper, lead, nickel, and zinc. The sampled sites were grouped according to their proximity to mining activity: non-mining sites, sites upstream from mining activity or mine tailings, or sites where no mining activity is present in the basin; near-mining sites, mining activity or mine tailings ponds within 7.5 miles upstream from the site; and distal-mining sites, mining activity greater than 7.5 miles upstream from the site.

The water-quality samples from non-mining sites had small concentrations of Mississippi Valley Type-related metals, but at the near-mining sites, all of these metals were detected above the method reporting level. Only dissolved copper, nickel, and zinc were detected above the method reporting level at distal-mining sites. Dissolved lead, nickel, and zinc concentrations were substantially larger at the near-mining sites than at the non-mining or distal-mining sites. The Mississippi Valley Type-related metals detected at near-mining sites decreased in concentration downstream at the distal-mining sites.

In streambed-sediment and fish-tissue samples, the largest concentrations for each of the Mississippi Valley Type-related metals, except arsenic and copper, were detected at near-mining sites. The largest mean concentration for the Mississippi Valley Type-related metals, except for copper, occurred at the near-mining sites, followed by the distal-mining sites; the smallest mean concentrations were for the non-mining sites. Arsenic and cobalt concentrations gradually increased and cadmium, lead, and zinc decreased as the distance downstream from mining activity increased.

Invertebrate samples were collected at 13 sites for community structure analysis. These data indicated that there were disturbances in invertebrate community structure near mining activities. Quantitative and qualitative samples were collected at each site. The results of multiple metrics applied to the invertebrate community data consistently indicated effects to the community near mining activities. There was apparent recovery in community structure metrics as the distance downstream from mining activities increased.

The commonality through all the water chemistry, streambed sediment, fish tissue, and invertebrate data is that where mining activity is occurring in the vicinity of sampling sites, these stream reaches exhibit characteristics of an affected stream. The data also support the lessening effect of these mining activities as the distance downstream from the mining activity increased.

Introduction

During 1993 and 1995, water chemistry, streambed sediment, fish tissue, and invertebrate data were collected from streams in southeastern Missouri for the National Water-Quality Assessment (NAWQA) program (for more information access *http://water.usgs.gov/nawqa/*). This synoptic sampling was performed as part of a reconnaissance investigation to evaluate, by using these multiple lines of evidence, the effects of lead and zinc mining and related activities on area streams in the Viburnum Trend Subdistrict (Viburnum Trend).

Study Area Description

The Black River synoptic study was located in an area of well-developed karst terrain in southeastern Missouri. This study area is in the Salem Plateau physiographic region and has deep narrow valleys with steep-sided ridges. Relief can be as much as 300 feet (ft) (Fenneman, 1938). The study lies entirely within the Ozark Highlands ecoregion as designated by Omernik and Gallant (1987). In the Ozark Highlands, land use typically is forested (oak-hickory) with occasional stands of pine. Typically, less than one-quarter of the land use is cropland or pasture; the cropland and pasture available is located mainly in river valleys.

Purpose and Scope

The purpose of this chapter is to present data collected as part of the NAWQA program Black River synoptic study with emphasis on trace elements, although other constituents were analyzed. Sampling efforts were concentrated in the northern part of the upper Black River Basin where several lead and zinc mining operations are located (fig. 1). The metal-sulfide deposits in the Viburnum Trend subdistrict are a class known as Mississippi Valley Type (MVT) deposits and include the trace elements (all metals) arsenic, cadmium, cobalt, copper, lead, nickel, and zinc.

Methodology

Eleven sites in the Black River Basin and three sites outside of the basin (fig. 1) were selected for this analysis and grouped according to their proximity-to-mining activity. Non-mining sites include sampling sites upstream from mining activity or mine tailings or sites in basins where no mining activity is present. Non-mining sites outside of the basin were represented by Jacks Fork at Alley Spring (site N-1), Paddy Creek above Slabtown Spring (site N-2), and Big Creek near Rat (site N-3) and were selected because of similar geology, basin size, and land use (except for mining activity) to selected sites in the Black River Basin. Non-mining sites in the Black River Basin included West Fork Black River near Greeley (site N-4) and Middle Fork Black River at Redmondville (site N-5). Near-mining sites are those where mining activity or mine tailings ponds are within 7.5 miles (mi) upstream from the site. Near-mining sites are represented by the West Fork Black River at West Fork (site NR-1), Strother Creek near Oates (site NR-2), Neals Creek near Goodland (site NR-3), and Strother Creek near Redmondville (site NR-4). Distal-mining sites are those where mining activity is more than 7.5 mi upstream from the site. These sites are represented by the West Fork Black River near Centerville (site D-1), West Fork Black River at Centerville (site D-2), Middle Fork Black River at Black (site D-3), and the Black River near Lesterville (site D-4). Water-chemistry data from the Black River near Annapolis (site D-5, 8 mi downstream from Lesterville) was used as a supplement to data from the Black River near Lesterville. Water-quality data were not collected at the Lesterville site because of limited access during high flows.

All 14 sites were sampled during August or September, 1995. Streambed sediment and fish tissue were collected at the Black River near Lesterville (site D-4) during October 1993 (table 1). Collection and processing methods for all samples were performed according to protocols developed for the NAWQA program (U.S. Geological Survey, 2003). Water properties determined at each location included discharge, dissolved oxygen concentration, pH, specific conductance, water and air temperature, barometric pressure, alkalinity, and fecal indicator bacteria density [*Escherichia coli* (*E. coli*), fecal coliform, and fecal streptococci]. Water samples were sent to the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado, to be analyzed for major ions, nutrients, organic carbon content, and trace elements using the methods described in Fishman (1993) and in Fishman and Friedman, (1989). Suspended-sediment samples were sent to the USGS sediment laboratory in Rolla, Missouri, for sediment concentration analysis using standard methods (M.N. Barr, U.S. Geological Survey, written commun., 2007). Quality-control samples were collected for quality assurance. Duplicate or split samples were collected at 10 percent of the sites. All duplicate or split samples were comparable to original samples. No quality-assurance data were collected for the fish tissue or bed sediment samples in 1993 or 1995.

Streambed-sediment samples were collected at 10 sites, 8 of which are in the Black River system (fig. 1). Depositional areas of fine sediment were targeted for sampling at these sites, because the targeted analytes have an affinity for silt- and clay-sized particles (Rickert and others, 1977; Wilber and Hunter, 1979). The fine fraction [less than 63-micrometer (μm)] of the sediment was used for analysis. Streambed-sediment samples were collected by compositing subsamples at each site so as to obtain a representative sample of available material. Individual subsamples were obtained from a 1.5-inch (in.) Teflon cup hand sampler. The sampling cup was used to collect sediment from the top 0.6 in. of the streambed and the collected material was deposited into a glass container. The composited sample was sieved to obtain at least 10 grams (g) dry weight of the fine fraction. After the sample had settled, excess water was decanted. The samples were chilled and then shipped to the NWQL for analysis. Total elemental abundances of samples were analyzed using inductively coupled plasma-atomic emission spectrometry (ICP-AES) (Garbarino and Struzeski, 1998).

Fish tissue (livers) samples were collected at eight sites, six of which are in the Black River Basin (fig. 1). An attempt was made to target the same fish species at each site to eliminate species variability, but this was not possible. Centrachids (sunfish) were collected at all sites except for Strother Creek near Redmondville (site NR-4) where the hogsucker, *Hypentelium nigricans,* was collected. The hogsucker is a bottom dwelling fish, unlike the centrarchids, and may have greater exposure to trace-metal laden sediment. The long-eared sunfish, *Lepomis megalotis*, was collected at four sites [Jacks Fork River at Alley Spring (site N-1), West Fork Black River near Centerville (site D-1), West Fork Black River at Centerville (site D-2), and the Black River near Lesterville (site D-4)]. The small mouth bass, *Micropterus dolomieu*, was collected at the West Fork Black River near Greeley (N-4) and West Fork Black River at West Fork (NR-1). The hogsucker, *Hypentelium nigricans*, was collected at Strother Creek near Redmondville (site NR-4), and the shadow bass, *Ambloplites ariommus*, was collected at Paddy Creek above Slabtown Spring (site

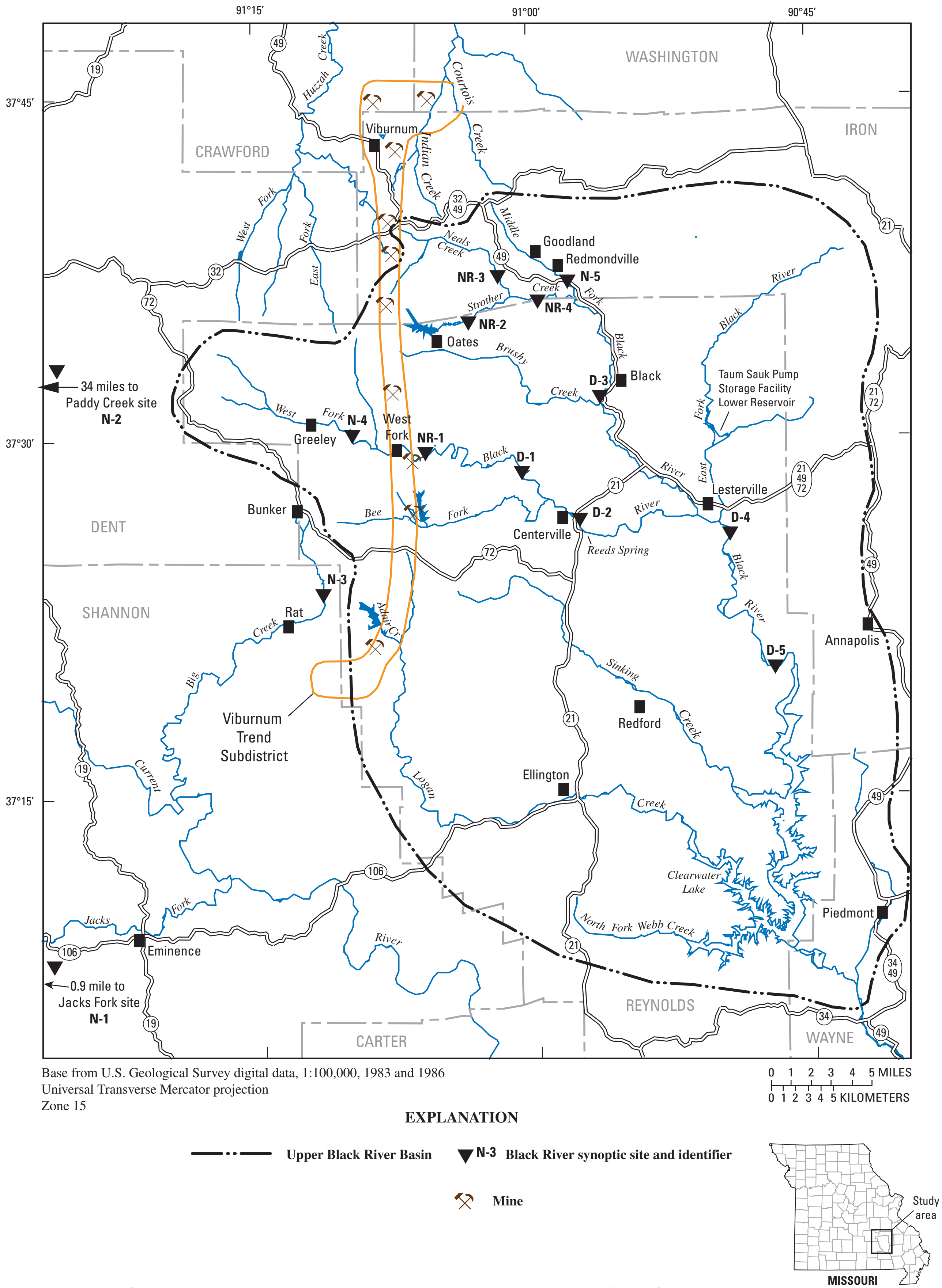


Figure 1. Study area and sampling sites on streams draining the Viburnum Trend Subdistrict.

Table 1. Black River synoptic site information.

[X, collected; NC, not collected]

Site name and identifier	Sampling date	Samples collected			
		Water quality	Streambed sediment	Fish tissue	Invertebrates
Non-mining sites					
Jacks Fork River at Alley Spring (N-1)	08/09/1995	X	X	X	X
Paddy Creek above Slabtown Spring (N-2)	08/11/1995	X	X	X	X
Big Creek near Rat (N-3)	09/11/1995	X	NC	NC	X
West Fork Black River near Greeley (N-4)	09/12/1995	X	X	X	X
Middle Fork Black River at Redmondville (N-5)	09/14/1995	X	X	NC	X
Near-mining sites					
West Fork Black River at West Fork (NR-1)	09/11/1995	X	X	X	X
Strother Creek near Oates (NR-2)	09/19/1995	X	NC	NC	X
Neals Creek near Goodland (NR-3)	09/19/1995	X	NC	NC	X
Strother Creek near Redmondville (NR-4)	09/18/1995	X	X	X	X
Distal-mining sites					
West Fork Black River near Centerville (D-1)	09/13/1995	X	X	X	X
West Fork Black River at Centerville (D-2)	09/13/1995	X	X	X	X
Middle Fork Black River at Black (D-3)	09/14/1995	X	X	NC	X
Black River near Lesterville (D-4)	10/26/1993	NC	X	X	NC
Black River near Lesterville (D-4)	08/22/1995	NC	NC	NC	X
Black River below Annapolis (D-5)	09/15/1995	X	NC	NC	NC

N-2). Livers were removed from fish at each sampled site and composited until a total mass of 5 g (ranged from 4 to 12 fish) was attained. Each composited sample was sent to the NWQL for analysis.

Quantitative and qualitative invertebrate community samples were collected at 13 sites. For the quantitative sample, five sampling points were selected at each site in the riffle habitat, which is the most likely to produce the richest community of invertebrates (U.S. Geological Survey, 2003). The samples collected at the five sampling points were combined into one composite sample for analysis at the NWQL. The qualitative invertebrate sample was collected by sampling every available habitat at the sites for 30 minutes. This method is used in an attempt to collect a sample of all present taxa at the site.

Black River Synoptic Study

Water chemistry, streambed sediment, fish tissue, and invertebrate data were collected at 14 sites in the Salem Plateau physiographic region. These data were analyzed in order to compare and assess mining, non-mining, and near-mining activities on biotic conditions.

Water Chemistry

Physical properties were determined onsite at 13 sampling locations (table 2, at the end of this chapter). During time of sampling, discharge ranged from 1.5 to 174 cubic feet per second (ft^3/s); dissolved oxygen ranged from 4.2 to 9.6 milligrams per liter (mg/L); pH ranged from 7.6 to 8.2 standard pH units; specific conductance ranged from 109 to 729 microsiemens per centimeter at 25 degrees Celsius (μS/cm); and water temperature ranged from 16.3 to 25.4 degrees Celsius (^{o}C), which tended to be related to air temperature at the time of sampling. *E. coli* and fecal coliform densities generally were larger at the non-mining sites than at the near-mining or distal-mining sites. Fecal streptococci densities generally were larger at the near-mining sites.

Nutrient analyses included several dissolved and total nitrogen and phosphorus species. Most nutrient concentrations were less than the method reporting level (MRL). The largest concentrations of nitrogen species were detected at the near-mining sites. Dissolved nitrate plus nitrite concentrations ranged from less than 0.05 to 0.25 mg/L as nitrogen at the non-mining sites, from 0.07 to 0.74 mg/L at the near-mining sites, and from 0.06 to 0.10 mg/L at the distal-mining sites. The concentrations above the MRL for dissolved phosphorus were at near-mining or distal-mining sites and for total phosphorus were at non-mining sites (table 2). Although nutrient concentrations varied throughout the study area, no concentrations were at levels of concern by state or national standards [Missouri Department of Natural Resources (2005), U.S. Environmental Protection Agency (2004)]. No substantial differences were noted in dissolved or particulate organic carbon concentrations among the sites.

Trace-element analyses included those metals associated with MVT ore deposits and local mining activities. Of the MVT-related metals, only nickel and zinc were detected at concentrations above MRL at the non-mining sites, but at near-mining sites, all seven metals were detected above the MRL at one or more sites. Dissolved copper, nickel, and zinc were detected above the MRL at one or more distal-mining sites. Dissolved lead, nickel, and zinc concentrations were substantially larger at some of the near-mining sites than at the non-mining or distal-mining sites. The MVT-related metals detected at near-mining sites decreased in concentration downstream from the mining activities (distal-mining sites).

Analyses of the non-MVT related elements indicated dissolved aluminum and barium concentrations were detected above the MRL at all sites. Dissolved manganese concentrations were detected at substantially larger concentrations at two near-mining sites NR-1 [141 micrograms per liter (µg/L)] and NR-2 (57 µg/L) than at non-mining or distal-mining sites.

Streambed Sediment

Streambed-sediment samples were collected at 10 sites, 8 of which are in the Black River Basin, during this synoptic study (fig. 1; table 3). The following discussion emphasizes the MVT-related metals (arsenic, cadmium, cobalt, copper, lead, nickel, and zinc) data. The results for the complete suite of analyzed elements are in chapter 3 of this report.

A couple of trends were observed after grouping the streambed-sediment data into the three proximity-to-mining related categories. The largest concentrations for each of the seven MVT-related metals, except arsenic and copper, were detected at near-mining sites when compared to the non-mining and distal-mining sites (table 3). The largest arsenic and copper concentrations were at the distal-mining Middle Fork Black River at Black (D-3) site, which is downstream from several tributaries with mining activities. The more obvious differences in concentrations at near-mining sites when compared to the other two groups were for cobalt [Strother Creek near Redmondville (site NR-4); 150 milligrams per kilogram (mg/kg)], lead [West Fork Black River at West Fork (site NR-1); 950 mg/kg], nickel [Strother Creek near Redmondville (site NR-4); 160 mg/kg], and zinc [Strother Creek near Redmondville (site NR-4); 1,200 mg/kg]. The largest mean concentration for each of the seven MVT-related metals occurred at the near-mining sites, followed by the distal-mining sites. The smallest mean concentration was for the non-mining sites.

Although the sample set was small, data from streambed-sediment samples collected downstream from the West Fork Black River at West Fork (site NR-1) exhibited a continual decrease in cadmium, lead, and zinc concentrations as the distance downstream from mining activity increased (fig. 2). However, arsenic and cobalt concentrations reversed this trend and the concentrations gradually increased as the distance downstream from mining activity increased, possibly because of tributary contributions.

Sediment-quality guidelines were exceeded several times (MacDonald and others, 2000). These guidelines are used to predict concentrations that can cause probable harm to sediment-dwelling organisms in freshwater ecosystems. These guidelines include threshold effect concentrations (TEC) and probable effects concentrations (PEC). TECs are concentrations below which harmful effects are not expected and PECs are concentrations above which harmful effects are expected. For arsenic, cadmium, and copper, no concentrations were above the PEC and most all were below the TEC (table 3). None of the non-mining sites had arsenic, cadmium,

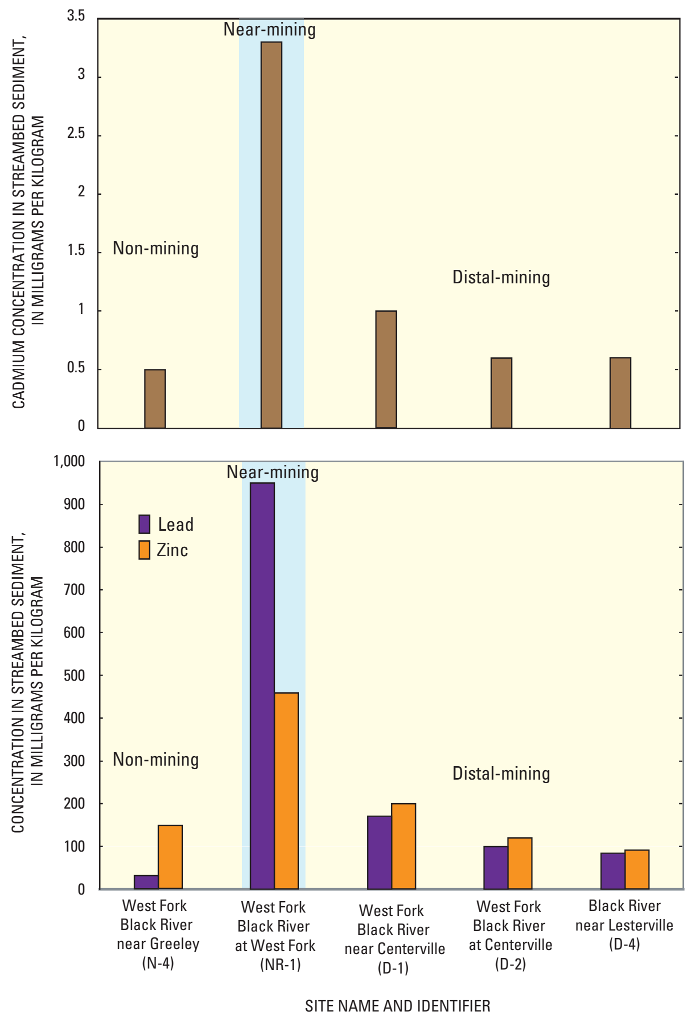


Figure 2. Cadmium, lead, and zinc concentrations in streambed sediment at West Fork Black River sites and downstream.

Table 3. Streambed sediment and fish tissue data from the National Water-Quality Assessment Program Black River synoptic study.

[mg/kg, milligram per kilogram; (N), non-mining site; (NR), near-mining site; (D), distal-mining site; NA, not available; µg/g, microgram per gram; <, less than]

Site name and identifier (fig. 1)	Streambed sediment (mg/kg)						
	Arsenic	Cadmium	Cobalt	Copper	Lead	Nickel	Zinc
Non-mining sites							
Jacks Fork at Alley Spring (N-1)	8.4	0.4	16	19	24	30	64
Paddy Creek above Slabtown Spring (N-2)	4.1	.2	9	15	27	23	54
West Fork Black River near Greeley (N-4)	4.9	.5	16	17	33	21	150
Middle Fork Black River at Redmondville (N-5)	6.9	.8	15	26	80	28	180
Near-mining sites							
West Fork Black River at West Fork (NR-1)	10	3.3	43	36	950	73	460
Strother Creek near Redmondville (NR-4)	7.2	2.2	150	31	200	160	1,200
Distal-mining sites							
West Fork Black River near Centerville (D-1)	5.5	1.0	18	22	170	31	200
West Fork Black River at Centerville (D-2)	6.1	.6	20	29	100	39	120
Middle Fork Black River at Black (D-3)	14	.8	31	37	100	50	210
Black River near Lesterville (D-4)	7.6	.6	25	21	84	29	91
Probable effects concentration (PEC)	33	4.98	NA	149	128	48.6	459
Threshold effects concentration (TEC)	9.79	.99	NA	31.6	35.8	22.7	121
Site name and identifier (fig. 1)	**Fish tissue (µg/g)**						
	Arsenic	**Cadmium**	**Cobalt**	**Copper**	**Lead**	**Nickel**	**Zinc**
Non-mining sites							
Jacks Fork at Alley Spring (N-1)	0.5	2.2	0.8	7.2	<0.2	0.3	71
Paddy Creek above Slabtown Spring (N-2)	.4	.5	.5	17	<.2	.2	71
West Fork Black River near Greeley (N-4)	.4	1.0	1.2	8.9	<.2	<.2	70
Near-mining sites							
West Fork Black River at West Fork (NR-1)	0.9	6.7	3.0	25	8.3	2.6	86
Strother Creek near Redmondville (NR-4)	.8	1.4	3.8	56	.7	1.2	140
Distal-mining sites							
West Fork Black River near Centerville (D-1)	1.2	6.1	1.5	150	0.9	1.1	110
West Fork Black River at Centerville (D-2)	.6	1.6	1.0	9.5	.5	<.2	70
Black River near Lesterville (D-4)	.3	2.4	.9	8.6	<.3	.4	77

and copper concentrations above the TEC. Most non-mining sites had concentrations above the TEC for lead, nickel, and zinc, especially for nickel. The Middle Fork Black River at Redmondville (site N-5) had above the TEC concentrations for lead, nickel, and zinc, although the concentrations were well below the PEC concentrations. All of the near-mining sites had concentrations of lead, nickel, and zinc above the PEC. All of the distal-mining sites had concentrations above the TEC and several concentrations were above the PEC.

Fish Tissue

Fish tissue samples (livers) were collected at eight sites, six of which are in the Black River Basin (fig. 1). In this chapter, emphasis is placed only on the analyses for the MVT-related metals (arsenic, cadmium, cobalt, copper, lead, nickel, and zinc). The results for the complete suite of analyzed elements can be accessed on the internet at (*http://waterdata.usgs.gov/nwis*).

The results of the fish tissue sampling were similar to those of the streambed sediment in that the largest concentrations for each of the seven MVT-related metals, except arsenic and copper, were detected at near-mining sites (table 3). In general, the largest mean concentration for each of the seven metals, except for copper, was at the near-mining sites, followed by the distal-mining sites; the smallest mean value was for the non-mining sites.

Whereas there appears to be a general trend that cadmium, lead, and zinc concentrations in fish tissue decrease as the stream distance from mining activity increases (fig. 3), the trend is more obscure than the streambed-sediment data. The data from West Fork Black River sites (NR-1, D-1, and D-2) and the Black River near Lesterville site (D-4) indicate cadmium, cobalt, lead, and nickel concentrations were less at the distal-mining sites than at the upstream near-mining sites. However, cadmium and nickel concentrations did not decrease continually downstream from mining activity. In addition, larger arsenic, copper, and zinc concentrations were detected downstream at a distal-mining site (D-1) than at the upstream near-mining site (NR-1).

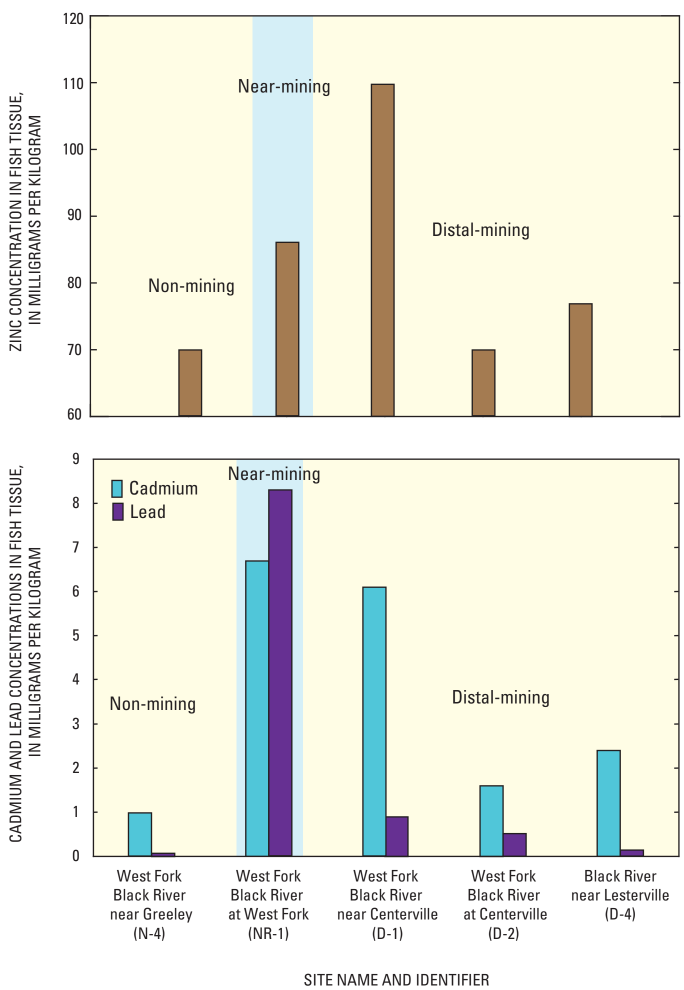


Figure 3. Cadmium, lead, and zinc concentrations in fish tissue at West Fork Black River sites and downstream.

Invertebrate Communities

Invertebrate samples were collected at 13 sites for community structure analysis. Quantitative and qualitative collections were made (data can be found at *http://infotrek.er.usgs.gov/traverse/f?p=NAWQA:HOME:3152244205107217*). A series of metrics were applied to the data to determine community similarities and differences (table 4) (Plafkin and others, 1989; Kerans and Karr, 1994). The metrics applied to the quantitative data include percent EPT (Ephemeroptera, Plecoptera, and Tricoptera) index, taxa richness, family taxa richness, percent dominant taxa, abundance, percent intolerant taxa, and percent sensitive EPT. A taxa richness metric also was applied to the qualitative data (table 4). With the exception of taxa richness, data at the family taxonomic level were used.

The percent EPT index metric, commonly used for stream assessment, is the percentage of the sample that is composed of the invertebrates of these three taxonomic groups [Ephemeroptera, Plecoptera, and Tricoptera (Bode and Novak, 1995)]. Generally, these three taxonomic groups are relatively intolerant of contaminants, so a large EPT score for a sample is an indicator of good stream condition. The percent EPT index metric for this study ranged from 21 (poor score) at Strother Creek near Redmondville (site NR-4) to 71 (better score) at the West Fork Black River near Greeley (site N-4). The mean percent EPT index metric score for this data set was 55 for non-mining sites, 28 for near-mining sites, and 58 for distal-mining sites. A definite reduction of the intolerant species at sites near mining activities existed.

Taxa richness is the number of invertebrate genera that were in each sample. In general, the larger the number of genera, or species diversity, in a sample, the better the stream conditions at the site. The taxa richness ranged from 27 at Strother Creek near Oates (site NR-2) to 72 at Big Creek near Rat (site N-3). The mean taxa richness score was 59 at non-mining sites, 43 at near-mining sites, and 54 at distal-mining sites. The number of invertebrate genera notably decreased at the near-mining sites when compared to the other site categories.

Family taxa richness is similar to taxa richness except that the invertebrates are identified only to the family level. The family taxa richness supported the taxa richness data and verified that species diversity was lower at the sites near mining activities, with recovery occurring downstream.

The percent dominant taxa metric indicates the percent of the most common or dominant taxa of the invertebrate population. It is an indication of imbalance if a single type of invertebrate dominates the community. The percent dominant taxa ranged from 12 at the West Fork Black River at Centerville (site D-2) to 56 at Strother Creek near Redmondville (site NR-4). The mean score was 19 (median of 19) for non-mining sites, 32 (median of 28) for near-mining sites, and 17 (median of 15) for distal-mining sites.

The abundance score is the number of individuals present in each sample. In general, the more individuals, the better the

Table 4. Selected metrics applied to invertebrate data collected for the National Water-Quality Assessment Program Black River synoptic study.

[EPT, Ephemeroptera, Plecoptera, and Trichoptera; (N), non-mining site; NA, not available; (NR), near-mining site; (D), distal-mining site]

Site name and identifier (fig. 1)	Percent EPT index	Taxa richness	Family taxa richness	Percent dominant taxa	Abundance	Percent intolerant taxa	Percent sensitive EPT	Qualitative taxa richness
Non-mining sites								
Jacks Fork River at Alley Spring (N-1)	59	60	32	15	8,681	11	13	NA
Paddy Creek above Slabtown Spring (N-2)	34	57	33	23	8,319	32	29	NA
Big Creek near Rat (N-3)	52	72	32	13	9,740	7	12	76
West Fork Black River near Greeley (N-4)	71	62	29	19	9,976	18	19	65
Middle Fork Black River at Redmondville (N-5)	58	42	24	25	19,277	30	28	53
Near-mining sites								
West Fork Black River at West Fork (NR-1)	40	51	25	24	1,900	10	5	49
Strother Creek near Oates (NR-2)	25	27	16	32	3,510	1	16	26
Neals Creek near Goodland (NR-3)	28	43	22	19	9,106	11	10	53
Strother Creek near Redmondville (NR-4)	21	51	23	56	20,075	9	12	62
Distal-mining sites								
West Fork Black River near Centerville (D-1)	50	65	33	16	16,901	13	15	66
West Fork Black River at Centerville (D-2)	52	60	27	12	18,372	11	11	84
Middle Fork Black River at Black (D-3)	67	52	30	14	31,483	12	13	79
Black River near Lesterville (D-4)	62	40	19	26	7,477	28	27	87

stream conditions, although at some sites, an imbalance in the invertebrate population can lead to an excessive number of a single taxa, which skews the metric. In this study, the abundance ranged from 1,900 individuals at West Fork Black River at West Fork (site NR-1) to 31,483 individuals at the Middle Fork Black River at Black (site D-3). The mean abundance score was 11,199 (median of 9,740) at non-mining sites, 8,648 (median of 6,308) at near-mining sites, and 18,558 (median of 17,636) at distal-mining sites.

Tolerance scores have been developed to rank species by the degree of tolerance of the taxon to contaminants. Most of these tolerance scores have been developed specifically for organic contaminants. The tolerance scores used in this study are modified from Hilsenhoff (1987) and data from other streams have been taken into account (Plafkin and others, 1989; Bode and others, 1996; and Mackie, 2001). The tolerance values used in this study have not been specifically developed for the stream conditions in the Black River and are used only for a general comparison. Using these scores, the percent of the sampled taxa that are intolerant to contaminants in the system can be determined. The scores of 0 to 2 were used as intolerant metrics for this study. The type of invertebrates with these low tolerance scores are able to live in contaminated streams. Large scores for the percent intolerant taxa metric indicate better stream conditions. The percent intolerant scores ranged from 1 at Strother Creek near Oates (site NR-2) to 32 at Paddy Creek above Slabtown Spring (site N-2). The largest mean percent intolerant score was for non-mining sites (20), followed by distal-mining sites (16), and the lowest score was for near-mining sites (8). The percent intolerant index scores indicate recovery as the distance downstream from mining increases.

The percent sensitive EPT metric is the percentage of these three taxon with tolerance scores of 0 to 3. These genera are the most contaminant sensitive species of the EPT community. As with the other metrics, the percent sensitive EPT metric has a smaller mean score at near-mining sites (11) and slightly larger scores for the non-mining (20) and distal-mining sites (16). There also is the trend of recovery as the distance downstream from mining activity increases.

The qualitative taxa richness is the number of taxa present in each sample. Because multiple habitats are sampled for a qualitative sample, a greater number of taxa would be expected than in the quantitative sample (taxa richness) where only one type of habitat is sampled. A greater number of qualitative taxa than quantitative taxa (taxa richness) were found at 9 of the 11 sites with available data. Qualitative taxa richness scores ranged from 26 at Strother Creek near Oates (NR-2) to 87 at Black River near Lesterville (D-4). As with the quantitative taxa richness data, the near-mining sites have a smaller mean score (48) than the non-mining (65) and distal-mining sites (79).

The invertebrate community relative abundance data for these sites are illustrated in figure 4. Each part of the

Non-mining sites

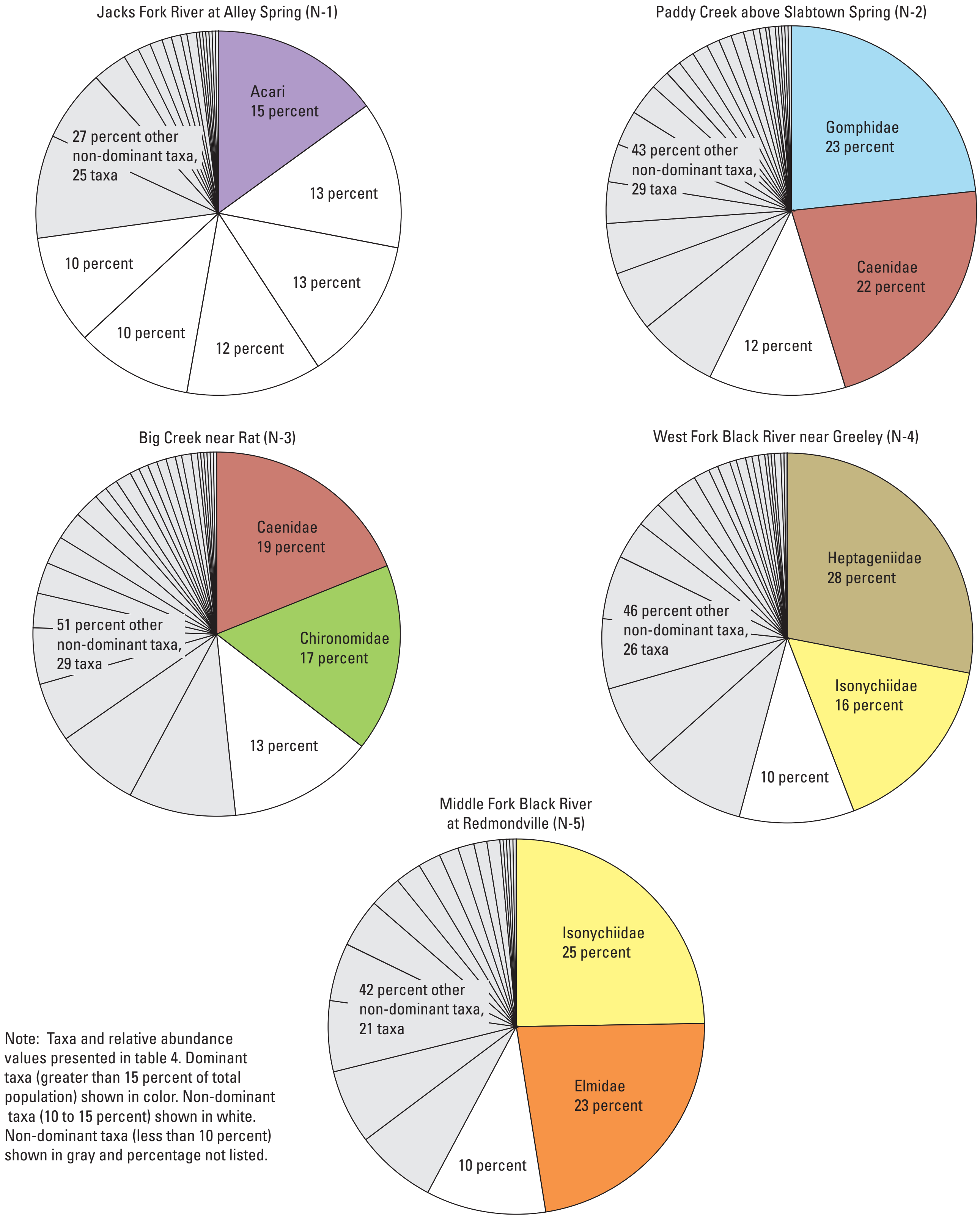
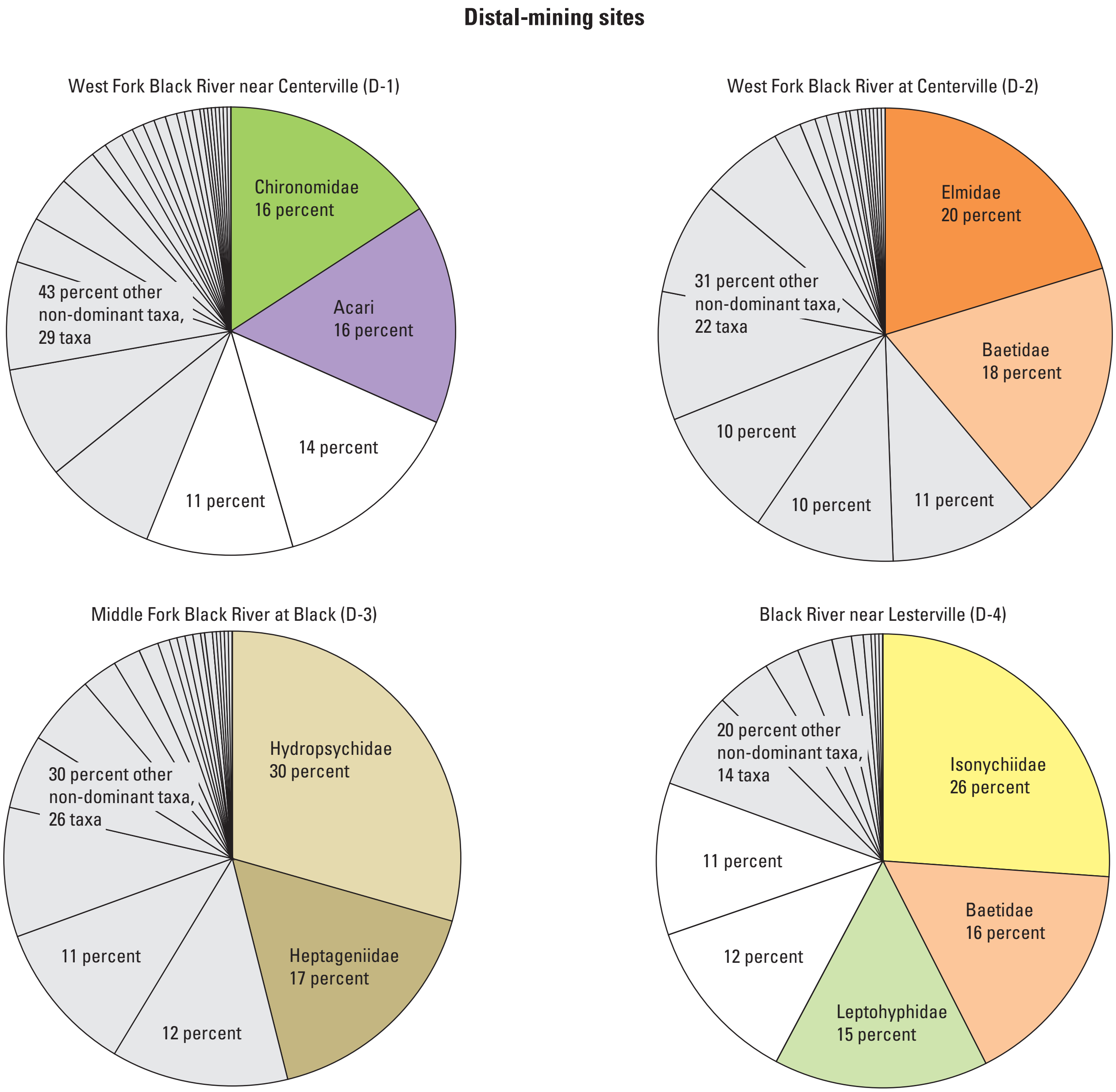
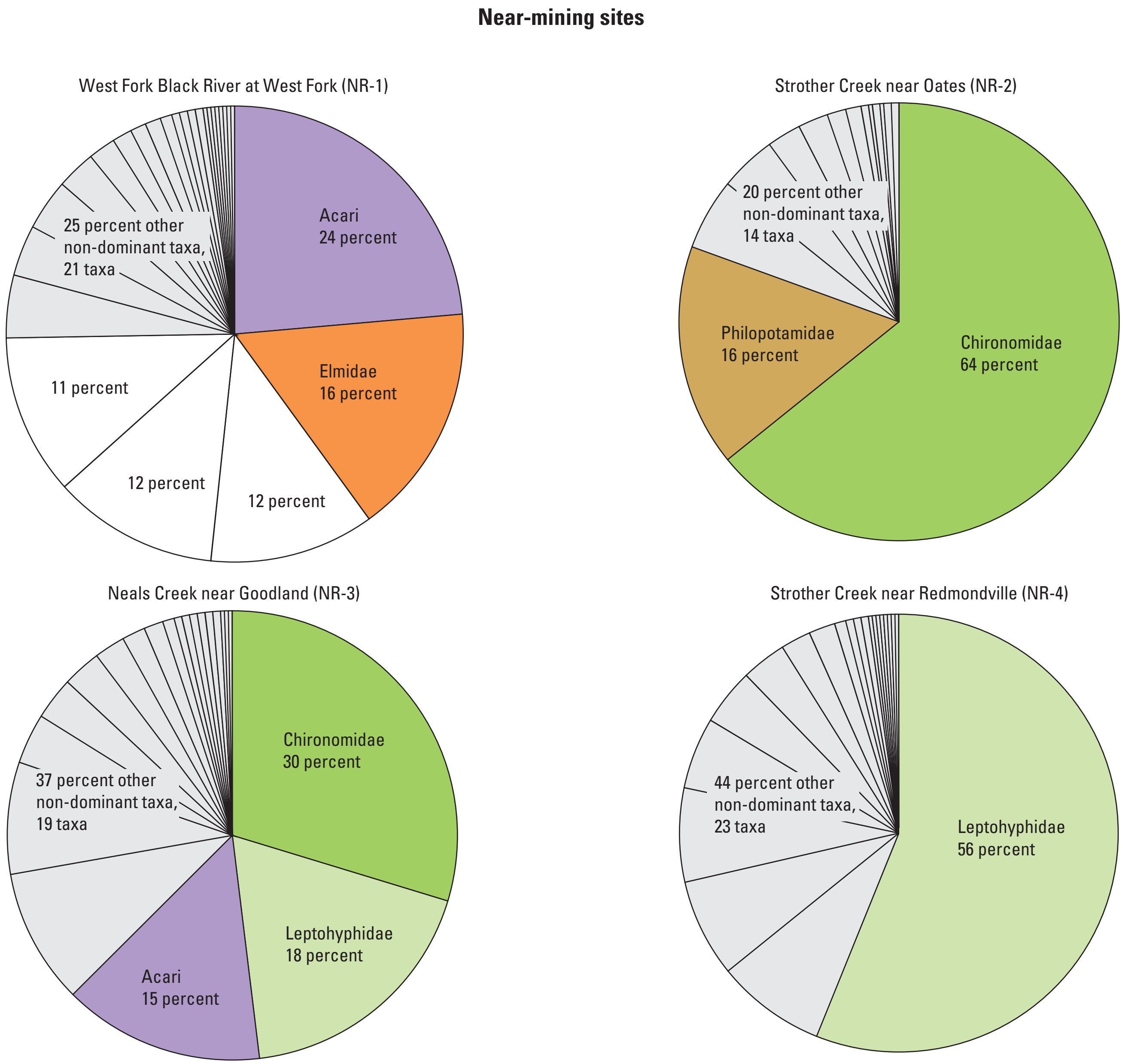


Figure 4. Invertebrate community relative abundance data,1995, showing dominant taxa at each site in relation to community structure.



Note: Taxa and relative abundance values presented in table 4. Dominant taxa (greater than 15 percent of total population) shown in color. Non-dominant taxa (10 to 15 percent) shown in white. Non-dominant taxa (less than 10 percent) shown in gray and percentage not listed.

Figure 4 Invertebrate community relative abundance data,1995, showing dominant taxa at each site in relation to community structure.—Continued



Note: Taxa and relative abundance values presented in table 4. Dominant taxa (greater than 15 percent of total population) shown in color. Non-dominant taxa (10 to 15 percent) shown in white. Non-dominant taxa (less than 10 percent) shown in gray and percentage not listed.

Figure 4 Invertebrate community relative abundance data,1995, showing dominant taxa at each site in relation to community structure.—Continued pie-shaped graph represents the percentage of the population of each family collected. For instance, a wedge equaling 25 percent of the pie represents a family that comprised 25 percent of the sampled population. The two near-mining Strother Creek sites (NR-2 and NR-4) have a single family that dominates the community structure. These families also are invertebrates that are tolerant of contaminants in their habitats. The distal-mining and non-mining sites generally did not have an overwhelmingly dominant family present and had a more heterogeneous population.

Summary and Conclusions

Water chemistry, streambed sediment, fish tissue, and invertebrate data were collected to evaluate the effects of lead and zinc mining and related activities on area streams in the Viburnum Trend Subdistrict. All samples were collected during August to September 1995, except for streambed sediment and fish tissue collected at Black River near Lesterville during October 1993. The metal-sulfide deposits in the Viburnum Trend Subdistrict are a class known as Mississippi Valley Type deposits and include the trace elements (all metals) arsenic, cadmium, cobalt, copper, lead, nickel, and zinc. Eleven sites in the Black River Basin and three sites outside of the basin were grouped according to their proximity to mining activity: non-mining sites, sites upstream from mining activity or mine tailings, or sites where no mining activity is present in the basin; near-mining sites, mining activity or mine tailings ponds within 7.5 miles upstream from the site; and distal-mining sites, mining activity greater than 7.5 miles upstream from the site.

The water-quality samples from non-mining sites had small concentrations of Mississippi Valley Type-related metals. With the exception of zinc, the Mississippi Valley Type-related metal concentrations typically were less than the method reporting levels at the non-mining sites. At near-mining sites, Mississippi Valley Type-related metal concentrations frequently were larger than the method reporting levels; however, only dissolved copper, nickel, and zinc were detected at concentrations larger than the method reporting levels at distal-mining sites. Dissolved lead, nickel, and zinc concentrations were substantially larger at the near-mining sites than at the non-mining or distal-mining sites. The Mississippi Valley Type-related metals detected at near-mining sites decreased in concentration downstream from the mining activities (distal-mining sites).

Streambed-sediment samples were collected at 10 sites, 8 of which are in the Black River Basin, during this synoptic study. The largest concentrations for each of the seven Mississippi Valley Type-related metals, except arsenic and copper, were detected at near-mining sites. The largest mean concentration for the Mississippi Valley Type-related metals occurred at the near-mining sites, followed by the distal-mining sites; the smallest mean concentration was for the non-mining sites. Generally, arsenic and cobalt concentrations gradually increased as the distance downstream from mining activity increased. Cadmium, lead, and zinc concentrations decreased as the distance downstream from mining activities increased.

Fish tissue samples (livers) were collected at eight sites, six of which are in the Black River Basin. Results were similar to those of the streambed sediment in that the largest concentrations for each of the seven Mississippi Valley Type-related metals, except arsenic and copper, were detected at near-mining sites. The largest mean concentration for each of the seven metals, except for copper, is at the near-mining sites, followed by the distal-mining sites, and the smallest mean value is for the non-mining sites.

Invertebrate samples were collected for community structure analysis. These data indicated a definite reduction of the intolerant species at sites near mining activities.

Invertebrate genera also decreased noticeably at the near-mining sites when compared to the other site categories. The family taxa richness supported these conclusions and verified that species diversity was lower at the sites near mining activities, with recovery occurring downstream. The percent dominant taxa metric had fewer individuals at the sites near mining activities, indicating an imbalance in the invertebrate community. The percent intolerant index scores indicated recovery as the distance downstream from mining increased. As with the other metrics, the percent Ephemeroptera, Plecoptera, and Tricoptera scores indicated a trend of recovery for these three taxonomic groups as the distance from the mining activity increased. The invertebrate community relative abundance data indicated the two near-mining Strother Creek sites have a single family that dominates the community structure. These families are invertebrates that are tolerant of contaminants in their habitats. The distal-mining and non-mining sites generally did not have an overwhelmingly dominant family present and had a more heterogeneous population.

The commonality through all the water chemistry, streambed sediment, fish tissue, and invertebrate data analyses is that where mining activity is occurring in the vicinity of sampling sites, the stream reaches exhibit characteristics of an affected stream. The data also support the lessening effects of these mining activities as the distance downstream from the mine increased.

References

Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B., 1999, Rapid bioassessment protocols for use in streams and wadeable rivers—Periphyton, benthic macroinvertebrates and fish (2d ed.): Washington, D.C., U.S. Environmental Protection Agency, Office of Water, EPA 841–B–99–002, 339 p.

Bode, R.W., and Novak, M.A., 1995, Development and application of biological impairment criteria for rivers and streams in New York State, *in* Davis, W.S. and Simon, T.P., eds., Biological assessment and criteria—Tools for water resources planning and decision making: Lewis Publishers, chap. 8, p. 97–107.

Bode, R.W., Novak, M.A., and Abele, L.E., 1996, Quality assurance work plan for biological stream monitoring in New York State: New York State Department of Environmental Conservation, 89 p.

Fenneman, N.M., 1938, Physiography of eastern United States: New York, McGraw-Hill Book Co., 689 p.

Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93–125, 217 p.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Garbarino, J.R., and Struzeski, T.M., 1998, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of elements in whole-water digests using inductively coupled plasma-optical emission spectrometry and inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 98–165, 101 p.

Hilsenhoff, W.L., 1987, An improved biotic index of organic stream pollution: Great Lakes Entomology, v. 20, p. 31–39.

Kerans, B.L., and Karr, J.R., 1994, A benthic index of integrity (B–IBI) for rivers of the Tennessee Valley: Ecological Applications, v. 4, no. 4, p. 768–785.

MacDonald, D.D., Ingersoll, T.A., and Berger, T.A., 2000, Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems, Archives of Environmental Contamination and Toxicology, v. 39, p. 20–31.

Mackie, G.L., 2001, Applied aquatic ecosystem concepts: Dubuque, Iowa, Kendall/Hunt Publishing Co., 744 p.

Missouri Department of Natural Resources, 2005, Missouri water quality standards—Chapter 7, Water quality: Jefferson City, Mo., Clean Water Commission, 136 p.

Omernik, J.M., and Gallant, A.L., 1987, Ecoregions of the south central United States: U.S. Environmental Protection Agency, scale 1:2,500,000.

Plafkin, J.L., Barbour, M.T., Porter, K.D., Gross, S.K., and Hughes, R.M., 1989, Rapid bioassessment protocols for use in streams and rivers—Benthic macroinvertebrates and fish: U.S. Environmental Protection Agency, EPA 440/4–4–89/001, 340 p.

Rickert, D.A., Kennedy, V.C., McKenzie, S.W., and Hines, W.G., 1977, A synoptic survey of trace metals in bottom sediments of the Willamette River, Oregon: U.S. Geological Survey Circular 715–F, 27 p.

U.S. Environmental Protection Agency, 2004, National recommended water quality criteria: Washington, D.C., Office of Water, Office of Science and Technology, EPA/4304T, 22 p.

U.S. Geological Survey, 2003, National Water-Quality Assessment (NAWQA) protocols, accessed March 8, 2007, at URL *http://water.usgs.gov/nawqa/protocols/doc_list.html*

Wilber, W.G., and Hunter, J.V., 1979, The impact of urbanization on the distribution of heavy metals in bottom sediments of the Saddle River: Water Resources Bulletin, v. 15, no. 3, p. 790–800.

Table

Table 2. Water-quality data from the National Water-Quality Assessment Program Black River synoptic study, August and September 1995.

[ft^3/s, cubic feet per second; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °Celsius; °C, degree Celsius; mm, millimeters; Hg, mercury; (N), non-mining site; --, not available; (NR), near-mining site; (D), distal-mining site; N, nitrogen; <, less than; col/100 mL, colonies per 100 milliliters; mL, milliliter; E, estimated; µg/L, micrograms per liter]

Site name and identifier (fig. 1)	Sample date	Discharge (ft^3/s)	Dissolved oxygen (mg/L)	pH (standard units)	Specific conductance (µS/cm)	Temperature, water (°C)	Temperature, air (°C)	Barometric pressure (mm of Hg)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)
Non-mining sites										
Jacks Fork River at Alley Spring (N-1)	08/09/1995	124.0	8.1	8.2	306	25.4	33.0	770	32	20.0
Paddy Creek upstream from Slabtown (N-2)	08/11/1995	1.5	6.4	8.0	295	22.3	32.0	762	32	18.0
Big Creek near Rat (N-3)	09/11/1995	1.6	4.2	7.6	109	21.0	22.2	745	11	5.6
West Fork Black River near Greeley (N-4)	09/12/1995	10.0	8.9	8.1	343	17.3	--	761	37	22.0
Middle Fork Black River at Redmondville (N-5)	09/14/1995	5.1	9.6	8.2	319	17.7	17.5	767	35	20.0
Near-mining sites										
West Fork Black River at West Fork (NR-1)	09/11/1995	23.0	8.8	8.2	416	23.1	24.3	746	39	25.0
Strother Creek near Oates (NR-2)	09/19/1995	9.9	8.6	8.1	729	19.7	20.0	759	64	44.0
Neals Creek near Goodland (NR-3)	09/19/1995	4.1	8.4	8.1	407	16.3	14.5	761	43	27.0
Strother Creek near Redmondville (NR-4)	09/18/1995	18.0	9.4	8.0	558	18.6	16.0	766	51	34.0
Distal-mining sites										
West Fork Black River near Centerville (D-1)	09/13/1995	33.0	8.8	8.2	365	18.2	20.5	766	36	22.0
West Fork Black River at Centerville (D-2)	09/13/1995	54.0	8.2	8.2	345	20.5	21.1	750	34	21.0
Middle Fork Black River at Black (D-3)	09/14/1995	33.0	7.8	7.9	403	21.2	20.3	752	39	24.0
Black River near Annapolis (D-5)	09/15/1995	174.0	9.3	8.0	295	21.3	22.8	757	30	18.0

Site name and identifier (fig. 1)	Potassium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Alkalinity (mg/L)	Chloride dissolved (mg/L)	Fluoride dissolved (mg/L)	Silica, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Ammonia plus organics dissolved (mg/L as N)	Ammonia plus organics, total (mg/L as N)	Ammonia, dissolved (mg/L as N)
Non-mining sites										
Jacks Fork River at Alley Spring (N-1)	1.7	1.3	159	2.0	<0.1	9.4	2.4	<0.02	<0.02	<0.01
Paddy Creek upstream from Slabtown (N-2)	1.2	1.4	154	1.5	<.1	10.0	2.7	<.02	<.02	<.01
Big Creek near Rat (N-3)	1.3	1.4	46	1.5	.1	6.6	2.7	<.02	<.02	.05
West Fork Black River near Greeley (N-4)	0.8	1.5	185	1.8	<.1	8.0	2.0	<.02	<.02	<.01
Middle Fork Black River at Redmondville (N-5)	0.9	1.3	160	1.4	<.1	9.3	2.7	<.02	<.02	.02
Near-mining sites										
West Fork Black River at West Fork (NR-1)	1.9	8.2	160	10	0.2	7.9	38	<0.02	<0.02	0.05
Strother Creek near Oates (NR-2)	4.8	17.0	136	24	.2	6.2	200	<.02	.20	.04
Neals Creek near Goodland (NR-3)	1.0	1.9	197	1.9	<.1	8.0	14	<.02	<.02	<.01
Strother Creek near Redmondville (NR-4)	3.0	10.0	175	13	.1	7.0	120	<.02	<.02	.01
Distal-mining sites										
West Fork Black River near Centerville (D-1)	1.3	5.1	151	6.6	<0.1	7.2	23	<0.02	<0.02	<0.01
West Fork Black River at Centerville (D-2)	1.3	5.0	151	5.7	.1	7.3	20	<.02	<.02	<.01
Middle Fork Black River at Black (D-3)	1.9	5.2	137	7.3	<.1	8.1	58	<.02	<.02	<.01
Black River near Annapolis (D-5)	1.2	2.7	131	3.6	<.1	7.3	14	<.02	<.02	<.01

Table 2. Water-quality data from the National Water Quality Assessment program Black River synoptic study, August and September 1995.—Continued

[ft³/s, cubic feet per second; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °Celsius; °C, degree Celsius; mm, millimeters; Hg, mercury; (N), non-mining site; --, not available; (NR), near-mining site; (D), distal-mining site; N, nitrogen; <, less than; col/100 mL, colonies per 100 milliliters; mL, milliliter; E, estimated; µg/L, micrograms per liter]

Site name and identifier (fig. 1)	Nitrite plus nitrate dissolved (mg/L as N)	Nitrite, dissolved (mg/L as N)	Ortho-phosphate, dissolved (mg/L)	Phosphorus, dissolved (mg/L)	Phosphorus, total (mg/L)	Carbon, organic, dissolved (mg/L)	Carbon, organic, particulate, total (mg/L)	Escherichia coli (col/100 mL)	Fecal coliform (col/100 mL)	Fecal streptococci (col/100 mL)
Non-mining sites										
Jacks Fork River at Alley Spring (N-1)	0.17	<0.01	<0.01	<0.01	0.02	1.0	0.1	37	42	17
Paddy Creek upstream from Slabtown (N-2)	<.05	<.01	<.01	<.01	.02	.9	.1	27	20	41
Big Creek near Rat (N-3)	.25	<.01	<.01	<.01	<.01	.7	.1	120	86	37
West Fork Black River near Greeley (N-4)	<.05	<.01	<.01	<.01	.02	.4	.2	37	54	61
Middle Fork Black River at Redmondville (N-5)	.06	<.01	<.01	<.01	<.01	.5	.2	44	34	50
Near-mining sites										
West Fork Black River at West Fork (NR-1)	0.25	0.01	<0.01	<0.01	<0.01	0.5	0.2	8	7	22
Strother Creek near Oates (NR-2)	.74	.01	<.01	.02	<.01	1.1	.3	11	25	85
Neals Creek near Goodland (NR-3)	.07	<.01	<.01	<.01	<.01	.5	.1	18	14	120
Strother Creek near Redmondville (NR-4)	.17	.01	<.01	.01	<.01	<.5	<.1	<10	<14	E48
Distal-mining sites										
West Fork Black River near Centerville (D-1)	0.09	<0.01	<0.01	<0.01	<0.01	0.5	0.2	12	24	42
West Fork Black River at Centerville (D-2)	.08	<.01	<.01	.02	<.01	.4	.1	15	5	14
Middle Fork Black River at Black (D-3)	.10	<.01	<.01	<.01	<.01	.4	.1	10	9	22
Black River near Annapolis (D-5)	.06	<.01	<.01	<.01	<.01	.4	.1	E10	E4	77

Site name and identifier (fig. 1)	Antimony, dissolved (µg/L)	Aluminum, dissolved (µg/L)	Arsenic[a], dissolved (µg/L)	Barium, dissolved (µg/L)	Beryllium, dissolved (µg/L)	Cadmium[a], dissolved (µg/L)	Chromium, dissolved (µg/L)	Cobalt[a], dissolved (µg/L)	Copper[a] dissolved (µg/L)	Iron, dissolved (µg/L)
Non-mining sites										
Jacks Fork River at Alley Spring (N-1)	<1	6	<1	35	<1	<1	1	<1	<1	<3
Paddy Creek upstream from Slabtown (N-2)	<1	5	<1	54	<1	<1	1	<1	<1	7
Big Creek near Rat (N-3)	<1	12	<1	40	<1	<1	<1	<1	<1	10
West Fork Black River near Greeley (N-4)	<1	5	<1	40	<1	<1	2	<1	<1	<3
Middle Fork Black River at Redmondville (N-5)	<1	4	<1	43	<1	<1	1	<1	<1	<3
Near-mining sites										
West Fork Black River at West Fork (NR-1)	<1	8	3	41	<1	<1	2	6	1	28
Strother Creek near Oates (NR-2)	2	6	2	31	<1	<1	2	31	2	19
Neals Creek near Goodland (NR-3)	<1	5	<1	30	<1	<1	<1	<1	<1	<3
Strother Creek near Redmondville (NR-4)	<1	6	1	46	<1	1	<1	<1	<1	<3
Distal-mining sites										
West Fork Black River near Centerville (D-1)	<1	5	<1	39	<1	<1	1	<1	<1	<3
West Fork Black River at Centerville (D-2)	<1	5	<1	39	<1	<1	1	<1	1	<3
Middle Fork Black River at Black (D-3)	<1	5	<1	50	<1	<1	1	<1	1	<3
Black River near Annapolis (D-5)	<1	6	<1	39	<1	<1	2	<1	1	<3

Table 2. Water-quality data from the National Water Quality Assessment program Black River synoptic study, August and September 1995.—Continued

[ft³/s, cubic feet per second; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °Celsius; °C, degree Celsius; mm, millimeters; Hg, mercury; (N), non-mining site; --, not available; (NR), near-mining site; (D), distal-mining site; N, nitrogen; <, less than; col/100 mL, colonies per 100 milliliters; mL, milliliter; E, estimated; µg/L, micrograms per liter]

Site and identifier (fig. 1)	Lead[a], dissolved (µg/L)	Manganese, dissolved (µg/L)	Molybdenum, dissolved (µg/L)	Nickel[a], dissolved (µg/L)	Selenium, dissolved (µg/L)	Silver, dissolved (µg/L)	Uranium, dissolved (µg/L)	Zinc[a], dissolved (µg/L)	Suspended sediment (mg/L)
Non-mining sites									
Jacks Fork River at Alley Spring (N-1)	<1	2	<1	2	<1	<1	--	1	298
Paddy Creek upstream from Slabtown (N-2)	<1	8	<1	2	<1	<1	--	1	--
Big Creek near Rat (N-3)	<1	12	<1	<1	<1	<1	<1	8	15
West Fork Black River near Greeley (N-4)	<1	2	<1	<1	<1	<1	<1	13	29
Middle Fork Black River at Redmondville (N-5)	<1	2	<1	<1	<1	<1	<1	7	22
Near-mining sites									
West Fork Black River at West Fork (NR-1)	11	141	3	12	<1	<1	<1	33	20
Strother Creek near Oates (NR-2)	3	57	13	114	<1	<1	<1	148	51
Neals Creek near Goodland (NR-3)	<1	<1	1	7	<1	<1	<1	47	20
Strother Creek near Redmondville (NR-4)	1	<1	3	10	<1	1	1	33	42
Distal-mining sites									
West Fork Black River near Centerville (D-1)	<1	2	1	<1	<1	<1	<1	13	19
West Fork Black River at Centerville (D-2)	<1	2	1	<1	<1	<1	<1	2	36
Middle Fork Black River at Black (D-3)	<1	1	2	1	<1	<1	<1	3	40
Black River near Annapolis (D-5)	<1	3	<1	<1	<1	<1	<1	2	25

[a] Mississippi Valley Type-related metals.