UNITED STATES DEPARTMENT OF INTERIOR
U.S. GEOLOGICAL SURVEY

Source, Transport, and Partitioning of Metals between Water, Colloids, and Bed Sediments of the Animas River, Colorado

by

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EXECUTIVE SUMMARY

- Reconnaissance geochemical data for water, colloid, and bed sediment samples, collected primarily during low flow in 1995, provide a synoptic view of the sources, movement and partitioning of metals in the Animas River watershed. The source of most of the iron, aluminum, copper, lead, zinc, arsenic, and cadmium in the Animas River is in the Animas River drainage basin upstream from site A-72 at Silverton, Colo.

- In the Animas River watershed upstream from Silverton, Cement Creek has the lowest pH (3.89) at low flow and carries most of its metal load in the aqueous phase. Mineral Creek has a pH of 6.35 at low flow and carries most of its metal load in the colloidal phase. Most of the metals in the Animas River above the confluence with Cement Creek reside in the colloidal component of the bed sediments. Downstream from the Animas River-Cement Creek confluence in the mixing zone, most metals from the dissolved load of Cement Creek are partitioned to the colloidal phase. Along upper Mineral Creek, and upstream from the Animas River-Cement Creek confluence, colloids aggregate, settle, and become an integral component of the bed sediments where they are stored until high-flow (snowmelt) runoff.

- At site A-72 during low flow, dissolved zinc and aluminum concentrations exceed the acute aquatic-life standard whereas the concentrations of the other metals do not exceed the chronic aquatic-life standard. Dissolved manganese concentrations are just below the chronic aquatic-life standard.

- Colloidal concentrations of copper, iron, zinc, and aluminum, if bioavailable upon ingestion as suggested by recent research, could exceed one or both of the aquatic-life standards at site A-72. There is a substantial loss of iron and aluminum colloids and their sorbed metal loads to the bed sediments in the Animas Canyon reach between Silverton and Bakers Bridge during low flow.

- More than 50 percent of the zinc in the bed sediments from Mineral Creek, 75 percent of the zinc in the bed sediments from Cement Creek, and 50 percent of the zinc in the bed sediments above the Animas River-Cement Creek confluence is in the form of sphalerite. Zinc concentrations in sphalerite from the bed sediments of the Animas River above the confluence with Cement Creek are about 1,000 ppm, from Cement Creek about 800 ppm, and from Mineral Creek about 400 ppm.

- Three water and colloid samples collected at high flow during snowmelt runoff (high flow) indicate that dissolved zinc concentrations far exceed the acute aquatic-life standard at site A-72 and are still twice that level as far downstream as Bondad. Metals stored in the colloidal phase of the bed load are moved downstream during high flow as is indicated by the high colloidal iron, aluminum, copper, lead, and zinc concentrations. Any remedial action that removes acidic metal-bearing discharges into Mineral and Cement Creeks and the upper Animas River or its tributaries will likely lessen the cumulative effect of metal toxicity on aquatic life.

- Lead-isotopic data from bed-sediment samples collected at low flow indicate that Mineral Creek contributes five to 10 percent of the total mass of metals in the bed sediments, Cement Creek contributes up to 40 percent of the metals in the bed sediments, and the bed sediments upstream from the Animas River-Cement Creek confluence contribute 50 to 60 percent of the metals at site A-72.

- Lead-isotopic data from bed-sediment samples collected downstream from site A-72 document the dilution of the metals derived from the Animas River Basin above Silverton by metal contributions from the tributaries. At Durango 75 km downstream, about 80 percent of the metals in the colloidal component of the bed sediments were derived from the Animas River watershed above Silverton whereas at Aztec, New Mexico, 57 percent of the metals were derived from this upstream source.

- No measurable contamination from the La Plata mining district at the headwaters of Junction Creek was found in the Animas River.

- Selenium concentrations in the bed sediments of the Animas River are elevated near the confluence of Lightner Creek in Durango, Colo. These elevated concentrations are related directly to the outcrop pattern of the Mancos Shale.

- Modeling of the sediment transport using the lead-isotopic data and the normalized labile copper, lead, and zinc data from bed sediments of the Animas River indicates some differential transport of the colloidal phase of the bed sediments. The chemical data from the waters and colloids indicate sorption of dissolved metals as a function of pH which changes with downstream distance where it is stored until remobilized during high-flow events. This colloidal component of the bed sediments dominates the bed sediment chemistry.

- Aggregation and transport of the colloidal component to the bed sediments reduces pore space between detrital grains in the bed, introduces toxic levels of metals into the food chain habitat for aquatic invertebrates, and if bioavailable to fish when ingested as suggested by recent research, may be a major cause of the deterioration of fish habitats in the stream bed.

- From lead-isotopic data, we have identified five or more discrete mineralization styles in the Animas River watershed above Silverton. Using these data, we can calculate the relative contribution of metals from each of these mineralization styles and the mines that exploited them to Mineral and Cement Creeks and the Animas River above its confluence with Cement Creek. The dominant lead-isotopic signature in the bed sediments of both Cement Creek and the upper Animas River is from the vein-type ore mineralization characteristic of the Eureka graben.

- Lead-isotopic data from stream sediments from Browns Gulch on the west side of the Mineral Creek drainage matches the vein-type ore in the Eureka district. These data suggest that vein-type ore from the Eureka district extends to the west of Cement Creek. The surface expression of this structure may be obscured by the hydrothermal alteration associated with Red Mountain No. 3.

INTRODUCTION

The U.S. Geological Survey Abandoned Mine Lands Initiative (USGS-AML) is focused on the evaluation of the effect of past mining practices on the water quality and the riparian and aquatic habitats of impacted stream reaches downstream from historic mining districts located primarily on federal lands. This problem is manifest in the eleven western states (i.e., west of 102°) where the majority of hardrock mines having past production are located on federal lands. Ferderer (1996) has developed a prioritization ranking of watersheds affected by historic mining activities on the basis of the number of past-producing metal mines per watershed. Using this mine census data as a first filter on the density of past-producing hardrock mines, he found that 18 watersheds contain more than 300 hardrock mines having past production, 20 watersheds contain 201-300 past producing hardrock mines, and 74 watersheds contain 101-200 past producing hardrock mines. In areas of temperate climate and moderate to heavy precipitation, the effect of rapid chemical and physical weathering of sulfides exposed on mine waste dumps and drainage from mines has resulted in elevated metal concentrations in the streams and bed sediments. The result of these processes is an unquantified impact on the quality of the water and the aquatic and riparian habitats that may limit their recreational resource value. One of the confounding factors in these studies is the determination of the component of metals derived from the hydrothermally altered but unmined portions of these drainage basins (Runnells and others, 1992). Several of these watersheds have been or are being actively studied to evaluate the effects of acid mine drainage (AMD) and acid rock drainage (ARD) on the near surface environment. The Animas River watershed in southwestern Colorado (fig. 1) contains a large number (>300) of past-producing metal mines that have affected the watershed. Beginning in October 1997, the USGS began a collaborative study of these impacts under the USGS-AML Initiative (Buxton and others, 1997).

The initial environmental characterization of the main tributary drainages in the Animas River watershed upstream from Silverton began in 1991 under the auspices of the Colorado Dept. of Public Health and Environment (J.R. Owen, written commun., 1997). These initial studies showed both seasonal and regional variability in surface water chemistry, and noted that, upstream from Silverton, many streams are generally acidic although pH is quite variable, depending on the geologic setting, precipitation, and amount of material that mining has exposed. Rocks in many tributary streams are coated with aluminum- and iron-hydroxides indicating the movement of metals under acidic conditions. Aquatic habitats in the Animas River above Bakers Bridge are known to be impaired.

The present study was funded under a cooperative program between the U.S. Geological Survey, the Bureau of Reclamation, the City of Durango, the Southern Ute Indian Tribe, and the Southwest Water Conservation District in October 1995. The Animas River Stakeholders Group (ARSG), a group of local concerned citizens in the basin from Silverton and Durango, the Colorado Dept. of Public Health and Environment, and the U.S. Environmental Protection Agency (EPA) have cooperated in providing data, consultation, and advice on local conditions within the watershed. Sunnyside Gold allowed access to their property to collect samples as did several property owners downstream from the Animas Canyon. The Southern Ute Indian Tribe provided guided access to our sampling sites on the Southern Ute Indian Reservation. This work was greatly enhanced by consultations with our colleagues on the project and individual members of the ARSG. W.G. Wright was particularly helpful in arranging field access and assisting S.E. Church in the field during October 1995.

Summary of Acid-Mine Drainage Studies in other Areas

Acidic metal-rich waters from mine drainage, waste rock, and mill tailings from inactive and abandoned mines, and naturally acidic waters from hydrothermally altered areas often enter stream reaches in upland watersheds and impact water quality. When these waters mix with less-acidic water and bed sediments from unmineralized areas, the physical and chemical conditions change during downstream transport. Metals are partitioned between water, colloids, and bed sediments through processes such as sorption, mineral precipitation, photoreduction, and biological interaction. Through these processes, all or portions of the metals are separated from water and are carried as suspended colloids or sediments, which ultimately settle to become a part of the bed sediment or become entrapped by microbes (algae). Thus, these metals may become available to aquatic organisms and larger forms of aquatic life in the food chain during transport downstream.

Figure 1. Index map of southwestern Colorado showing the area of the Animas River watershed. The state and county boundaries are from USGS (1989); watershed boundaries are from USGS (1982); and the towns, railroads, and roads are from ESRI (1992).

ANIMAS RIVER WATERSHED STUDY
SOUTHWESTERN COLORADO

COUNTY AND WATERSHED INDEX

One of the most important geochemical processes as mine drainage waters mix with water downstream is the dilution and neutralization of the acid, and subsequent formation of iron colloids (Runnells and Rampe, 1989, Kimball and others, 1995). The iron colloids precipitate in the water where they form larger aggregates and settle from the water to the bed sediment, coating the rocks in the stream. Ochre-colored stream beds are characteristic of many mine-affected streams as well as mineralized areas that have not been disturbed by mining (Runnells and others, 1992). These iron colloids are solids with effective diameters from less than one nanometer (10^{-9} meters) when they first precipitate to greater than a few microns (10^{-6} meters) after they aggregate (Ranville and others, 1989; van Olphen, 1977). Hydrous iron-oxide colloids have extensive surface areas that sorb and enhance the partitioning of toxic metals (Jenne, 1977; Morel and Gschwend, 1987; Stumm and Morgan, 1996). The sub-micron particles have a strong tendency to aggregate which creates a continuum of particle sizes from less than 0.001 micrometers (µm) to greater than one µm (Buffle and Leppard, 1995a; 1995b). These particles may be carried downstream as suspended colloidal particles. They also may precipitate on or bind to the surfaces of rocks and sand grains in the stream bed where they form a chemical sediment component of the bed sediments.

Study Objectives

The objectives of this study in the Animas River watershed are:

1) to identify the source areas of large metal loads in the Animas River watershed,
2) to determine the extent and time frames of metal movement downstream in the Animas River basin,
3) to measure the dispersion of metals in the river sediments downstream from these major metal sources,
4) to determine the partitioning of metals among water, colloids, and bed sediments, and
5) to document the fractionation of the metals between the dissolved phase, a suspended colloidal phase, and bed sediment and coatings.

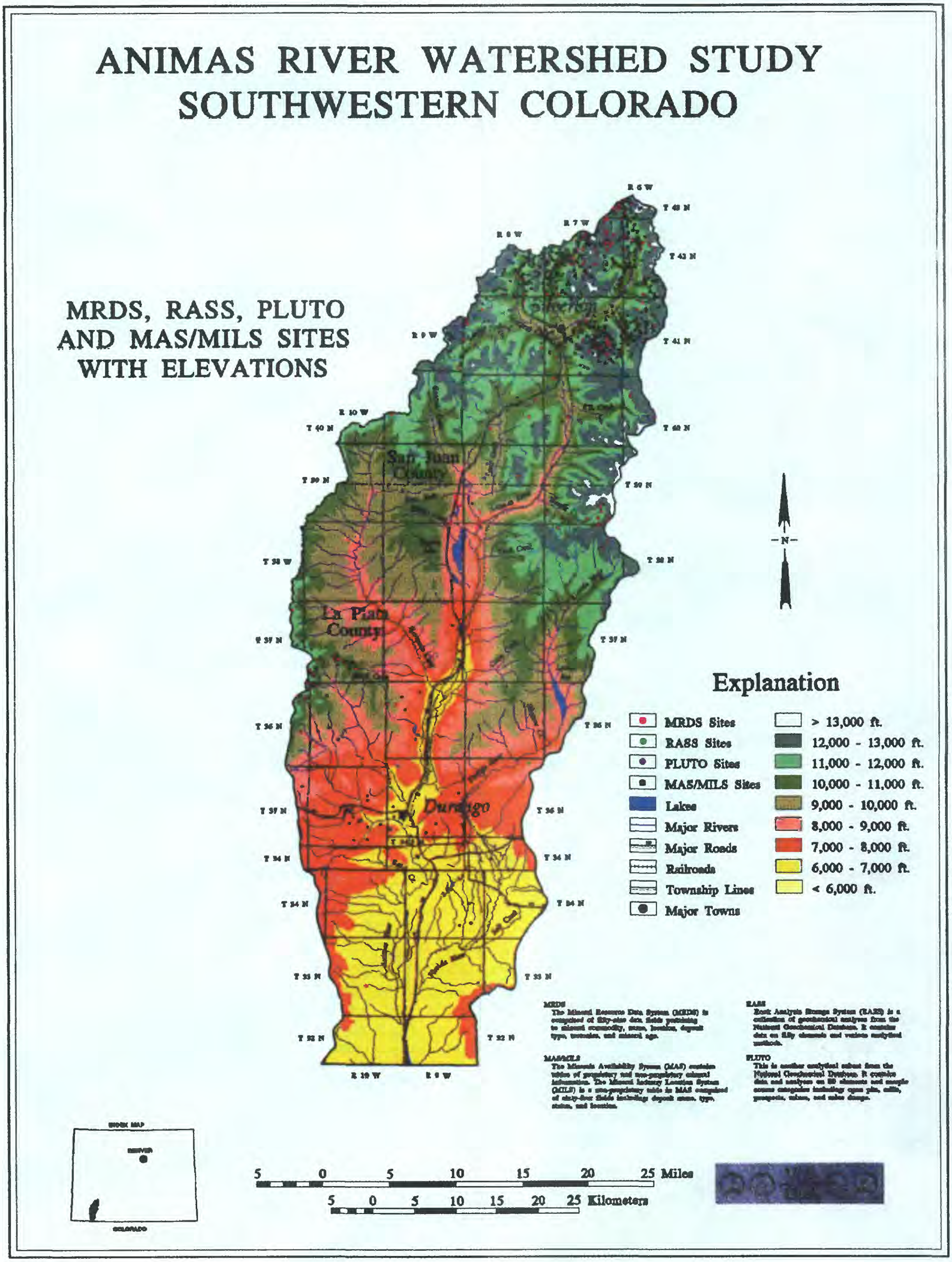
THE ANIMAS RIVER WATERSHED

The Animas River drainage basin (fig. 1) has its headwaters in the mountainous terrain above Silverton, Colo. and drains south into the San Juan River in northern New Mexico. Elevations range from more than 14,000 ft. at the headwaters to less than 6,000 ft. at the confluence with the San Juan River near Aztec, New Mexico (fig. 2). The major population center in the basin is the city of Durango, Colo. The geology exposed at the surface and underlying the basin is varied. Precambrian rocks crop out in the eastern part of the drainage basin in the Animas Canyon area south of Silverton (fig. 3) forming the high rugged mountainous area of the Animas Canyon. Paleozoic and Mesozoic sedimentary rocks crop out in the southern part of the drainage basin. The headwaters of the Animas River watershed are underlain by the Tertiary igneous intrusive and volcanic rocks that formed as a result of a late Tertiary age episode of andesitic to dacitic volcanism followed by a later episode of ash-flows, lava flows and intrusions of dacitic to rhyolitic composition (Lipman and others, 1976). During this later episode of volcanism, the Silverton caldera formed. Pervasive and intense hydrothermal alteration and mineralization events postdate the formation of the Silverton caldera by several million years (Casadevall and Ohmoto, 1977). This area of the Animas River watershed above Silverton has been extensively fractured, hydrothermally altered, and mineralized by Miocene hydrothermal activity.

Gold deposits were first discovered in 1871 on Arrastra Creek above Silverton by following the occurrence of placer gold upstream. Following the signing of a treaty with the Ute Indians in 1873, between 1,000 and 1,500 mining claims were staked in the Animas River watershed upstream from Silverton. Mining activity spread rapidly throughout the area. The chimney deposits (mineralized breccia pipes, see fig. 4) at the head of Mineral Creek were discovered in 1881. The railroad was brought up from Durango in 1882 providing cheap transportation to the smelters in Durango (Sloan and Skowronski, 1975). Mining continued in the Animas River watershed at various levels of activity until 1991 when the Sunnyside Mine was closed.

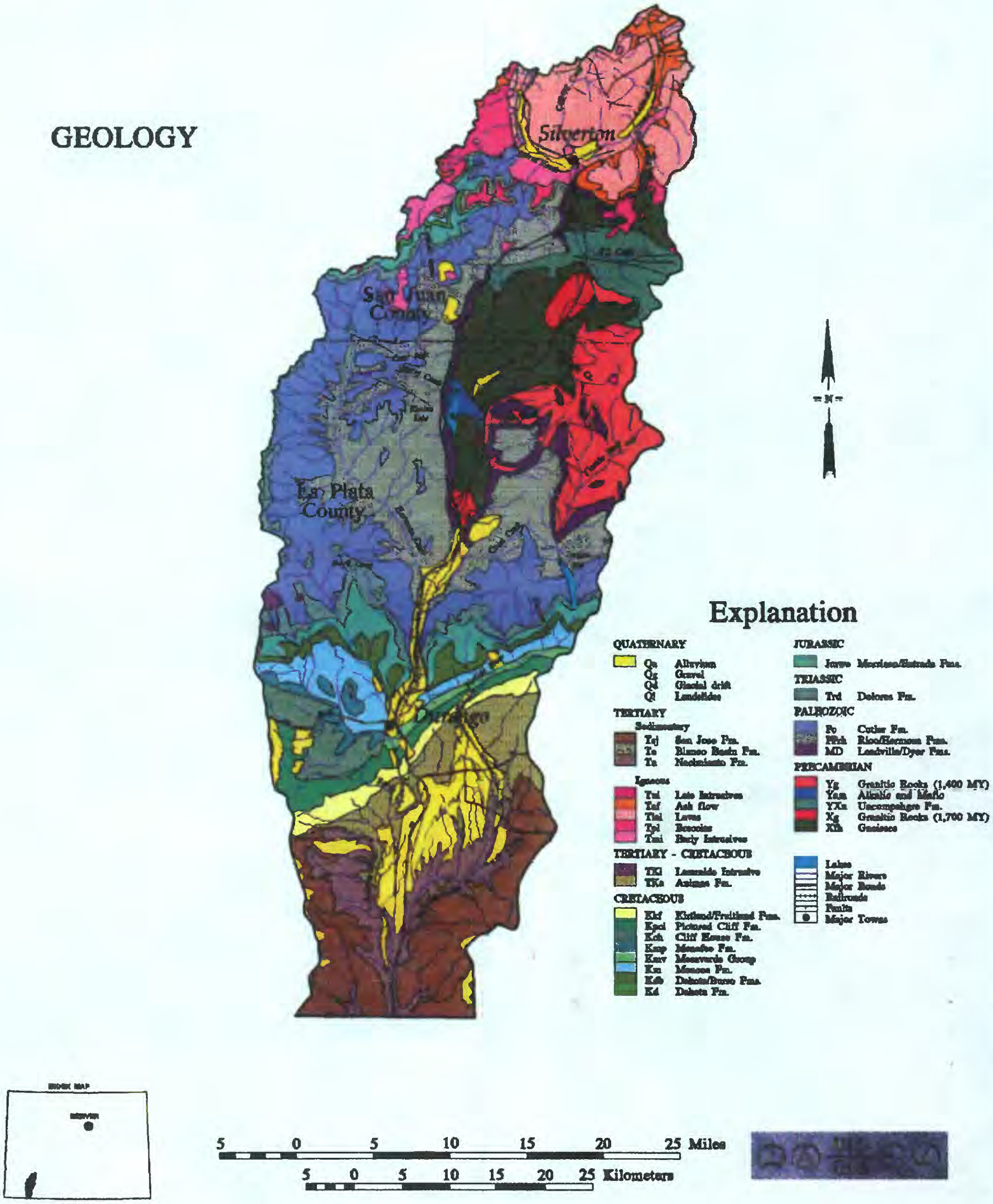
Figure 2. Map of the Animas River watershed showing elevation and locations of mines and prospects in the USGS MRDS, RASS, and PLUTO data bases (Ryder, 1994) and the USBM MAS data base (Babitzke and others, 1982). The digital elevation model data are from USGS (1990), towns, railroads, and roads are from ESRI (1992), and the hydrology data are from USGS (1989).

Figure 3. Geologic map of the Animas River watershed area (after Tweto, 1979) The digital geology is from Green (1992); hydrology data are from USGS (1989); and the towns, railroads, and roads are from ESRI (1992).


ANIMAS RIVER WATERSHED STUDY
SOUTHWESTERN COLORADO
MRDS, RASS, PLUTO
AND MAS/MILS SITES
WITH ELEVATIONS
San Juan County
La Plata County
Durango
N
Explanation
MRDS Sites
RASS Sites
PLUTO Sites
MAS/MILS Sites
Lakes
Major Rivers
Major Roads
Railroads
Township Lines
Major Towns
> 13,000 ft.
12,000 - 13,000 ft.
11,000 - 12,000 ft.
10,000 - 11,000 ft.
9,000 - 10,000 ft.
8,000 - 9,000 ft.
7,000 - 8,000 ft.
6,000 - 7,000 ft.
< 6,000 ft.
5 0 5 10 15 20 25 Miles
5 0 5 10 15 20 25 Kilometers

ANIMAS RIVER WATERSHED STUDY
SOUTHWESTERN COLORADO

GEOLOGY



The extent of mining activity within various portions of the Animas River watershed can be estimated from the distribution of mining claims and Minerals Availability System (MAS) records (Babitzke and others, 1982) within the basin. In figure 2, plots of the geochemical data from the USGS mines data bases (Ryder, 1994) are indicative of the density of mines and prospects in the Animas River drainage basin above Silverton, Colo. Mineral deposits in several major mining districts have recorded production. Deposits in the Red Mountain district in the northwestern part of the Silverton caldera, the Eureka district in the Eureka graben within the Silverton caldera, and the South Silverton district along the southern margin of the Silverton caldera east of the town of Silverton (see fig. 4; Burbank and Luedke, 1968; Leedy, 1971; Casadevall and Ohmoto, 1977) comprised the majority of the mineral production. There are also several porphyry molybdenum deposits discovered by drilling in the Mineral Creek area (oral commun., Tom Casadevall, 1996). Some of the porphyry molybdenum deposits are surrounded by large iron bogs at the surface. Iron bogs are found elsewhere within the basin associated with springs flowing from mineralized fractures, some of which have been studied recently by W.G. Wright (written commun., 1996).

PREVIOUS GEOCHEMICAL WORK

Surface water quality studies in the Animas River drainage basin above Silverton were undertaken beginning in 1991 under the auspices of the CDPHE (J.R. Owen, written commun., 1997). Many streams in the region upstream from Silverton are acidic although the pH is quite variable and zinc is derived from multiple sources within the basin. The iron and aluminum concentrations in these acidic waters is great enough to exceed the solubility product of the various iron and aluminum hydroxides (or aluminum hydroxysulfates, W.G. Wright, written commun., 1997). Precipitation of the iron hydroxide occurs when the pH of the waters is greater than 3.5 and precipitation of aluminum hydroxides occurs when the pH of the waters is greater than 5.5 (Broshears and others, 1996). The rocks in many streams are coated with aluminum- and iron-hydroxides and many of these stream reaches do not support aquatic life (J.R. Owen, written commun., 1997).

Previous reconnaissance exploration stream-sediment geochemical sampling of the watershed had been done in the mid-1970's under the National Uranium Resource Evaluation (NURE) program (Shannon, 1980; Warren and others, 1981). These data were used to evaluate the sources of metals in the small tributary drainage basin (areas of 2-10 km^2 or more). These data were of adequate sample density and analytical quality to characterize the geochemical landscape of the Animas River watershed. Geochemical data from small tributary streams from the USGS National Geochemical Data Base (Hoffman and Buttleman, 1994) were used to prepare regional geochemical maps of the Animas River watershed following the procedure outlined by Smith (1994). The details of the computational methods are in appendix I. The preliminary geochemical maps were refined using some of the data presented in this report. Some data points where eliminated from the original data set because the geochemical anomalies that could not be verified. In addition, samples collected along the irrigation ditches were also eliminated because these samples were contaminated by colloidal particles from the Animas River water being used for irrigation. Geochemical maps of four elements, calcium, copper, lead, and zinc, (figs. 5-8, respectively) clearly show how the geology of the Animas River watershed controls the geochemistry of the bed sediments in the Animas River. The map of calcium shows that the volcanic rocks hosting the mineralization in the Silverton area are calcium poor, indicating a lack of carbonate present in the basin. Carbonate species buffer the acid generated by weathering of pyrite in hydrothermally altered zones, mineral deposits, and waste rock piles exposed in the headwaters of the basin. In contrast, streams draining the area underlain by Paleozoic sedimentary rocks (fig. 3) have high calcium concentrations and substantial buffering capability as evidenced by the water chemistry below Cascade Creek as discussed below.

Maps of copper, lead, and zinc show high elemental concentrations in stream sediments collected from the Animas River watershed upstream from Silverton. These maps display the geochemical baseline when the samples were collected in the mid-1970s. The value that geochemists refer to as the crustal abundance value (CAV; Fortescue, 1992) in stream sediments is shown in gray on these three maps. Metal concentra-

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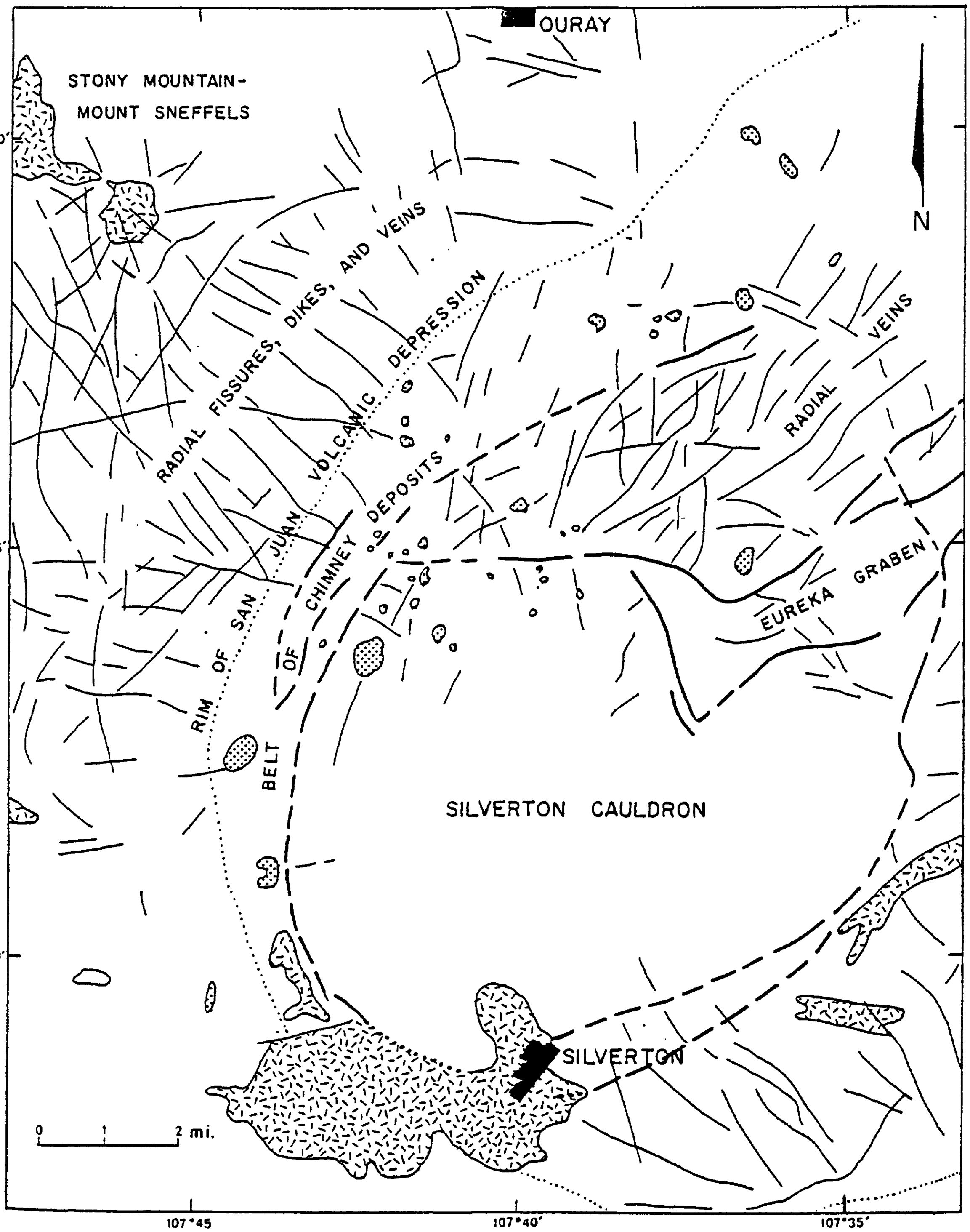
Figure 4. Simplified structural map showing the belt of chimney deposits in the Red Mountain district, the Eureka graben in the Eureka mining district, and the South Silverton mining district east of Silverton Colorado (from Leedy, 1971). Stippled areas are outcrops of small rhyolite to quartz latite intrusives. The large hachured mass at the bottom of the figure is the outcrop pattern of the Sultan Mountain quartz monzonite pluton.


OURAY
STONY MOUNTAIN-
MOUNT SNEFFELS
N
RADIAL FISSURES, DIKES, AND VEINS
RIM OF SAN JUAN VOLCANIC DEPRESSION
BELT OF CHIMNEY DEPOSITS
RADIAL VEINS
EUREKA GRABEN
SILVERTON CAULDRON
SILVERTON
0 1 2 mi.
38°00′
37°55′
37°50′
107°45
107°40′
107°35′

tions exceed 20 times crustal abundance values in stream sediments above Silverton. Thus, these maps include any effect that mining might have had on the stream reaches within the mining districts. These maps do not give an indication of the premining background levels of metals in the bed-sediments prior to mining in the vicinity of Silverton.

FIELD SAMPLING

In order to meet the objectives of the study outlined above, new samples were collected for water, colloid, and bed-sediment chemistry in the larger tributaries of Cement and Mineral Creeks and the Animas River to evaluate stream reaches where major sources of metal loading might be expected. This suite of samples was also used to supplement and validate the previous geochemical data set. The initial stream sediment and water sampling was conducted during the week of Oct. 16-20, 1995 during low-flow conditions. Supplementary sampling of the stream sediments was done during the weeks of Aug. 25, 1996, and Oct. 24, 1996, to evaluate annual and seasonal variability. Additional supplementary water sampling was done during snowmelt runoff the weeks of May 9, May 20, and June 20, 1996, to evaluate the dissolved and colloid metal loads under high-flow conditions. A hydrograph showing the stream flow discharge for the period from July 1994 to Oct. 1996 is shown in figure 9. The periods during which water sampling were done are indicated on the hydrograph.

Water and Colloids

The study in the Animas River basin involved the measurement of selected metals in water, colloids, and bed-sediment samples from the mainstem of the river and from the major tributaries (fig.10). The sampling included six sites near Silverton, Colorado, and fourteen sites downstream between Bakers Bridge and Aztec, New Mexico. Stream flow discharge was measured at the time of sample collection, and samples were collected by equal-width integration across the channel (Ward and Harr, 1990). Ultrafiltration was used to separate the "dissolved" metals from the colloidal phase. Analytical procedures are in appendix II and the analytical results are in appendices III-IV.

Figure 5. Geochemical map for calcium (Ca) of the Animas River watershed. Data from the National Geochemical Data Base was supplemented by samples from the major tributary streams during the 1995 sampling to evaluate the contributions of metals from the major tributary drainages in the Animas River watershed. Important tributary streams are labeled for reference; hydrology data are from USGS (1989); and the towns, railroads, and roads are from ESRI (1992).

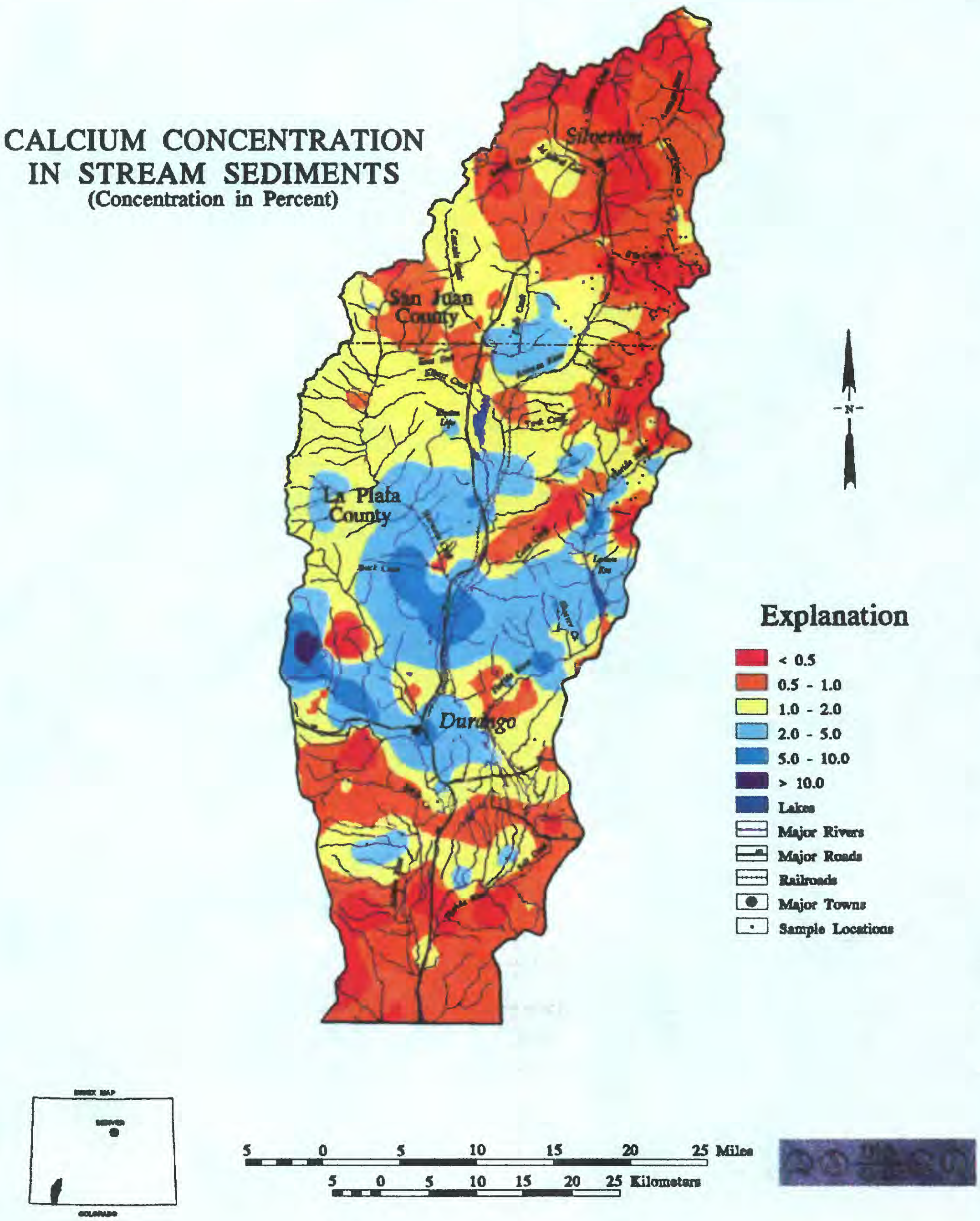
Figure 6. Geochemical map for copper (Cu) of the Animas River watershed. Data from the National Geochemical Data Base (Hoffman and Buttleman, 1994) was supplemented by samples from the major tributary streams during the 1995 sampling to evaluate the contributions of metals from the major tributary drainages in the Animas River watershed. Important tributary streams are labeled for reference; hydrology data are from USGS (1989); and the towns, railroads, and roads are from ESRI (1992).

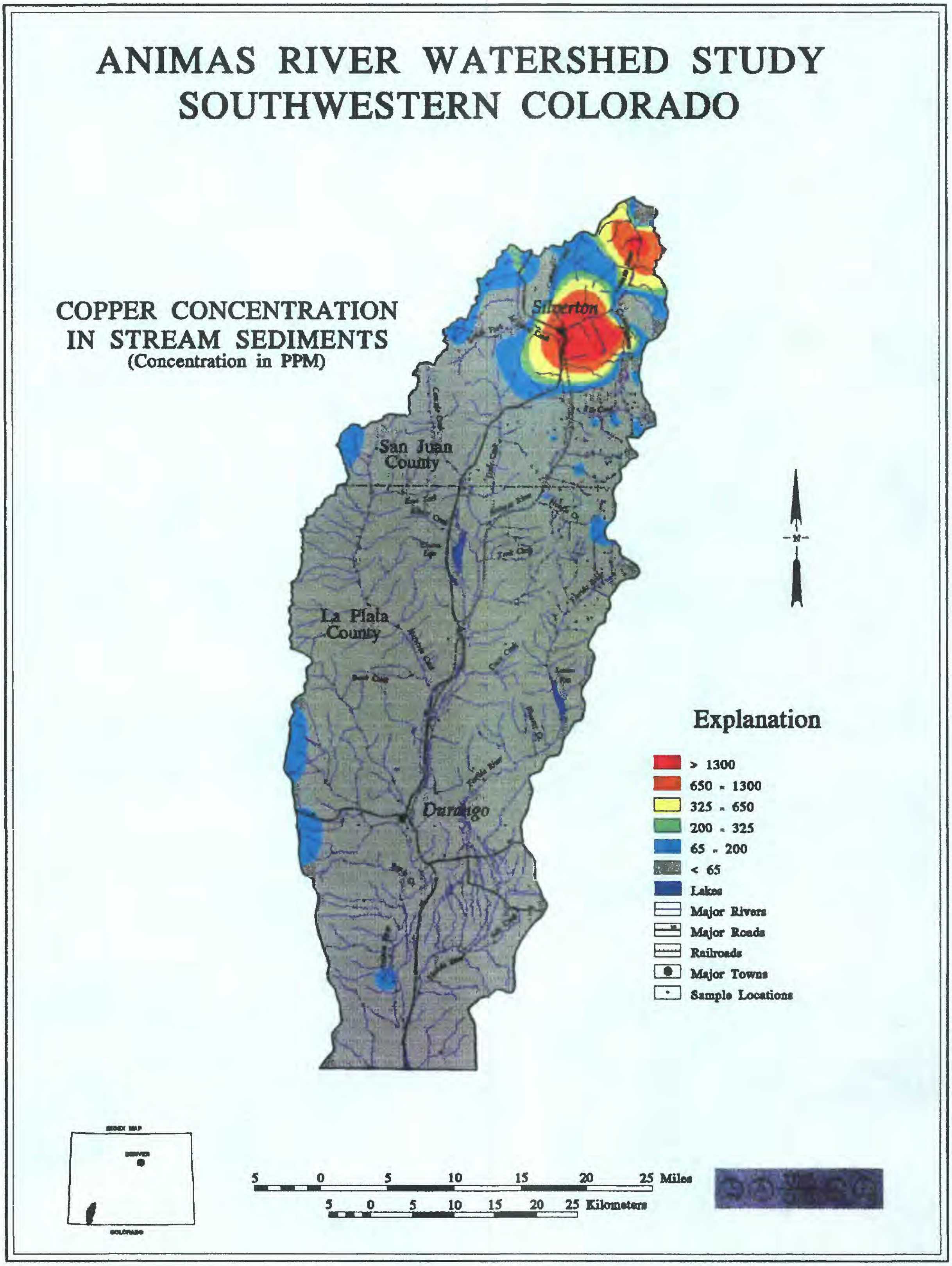
Figure 7. Geochemical map for lead (Pb) of the Animas River watershed. Data from the National Geochemical Data Base (Hoffman and Buttleman, 1994) was supplemented by samples from the major tributary streams during the 1995 sampling to evaluate the contributions of metals from the major tributary drainages in the Animas River watershed. Important tributary streams are labeled for reference; hydrology data are from USGS (1989); and the towns, railroads, and roads are from ESRI (1992).

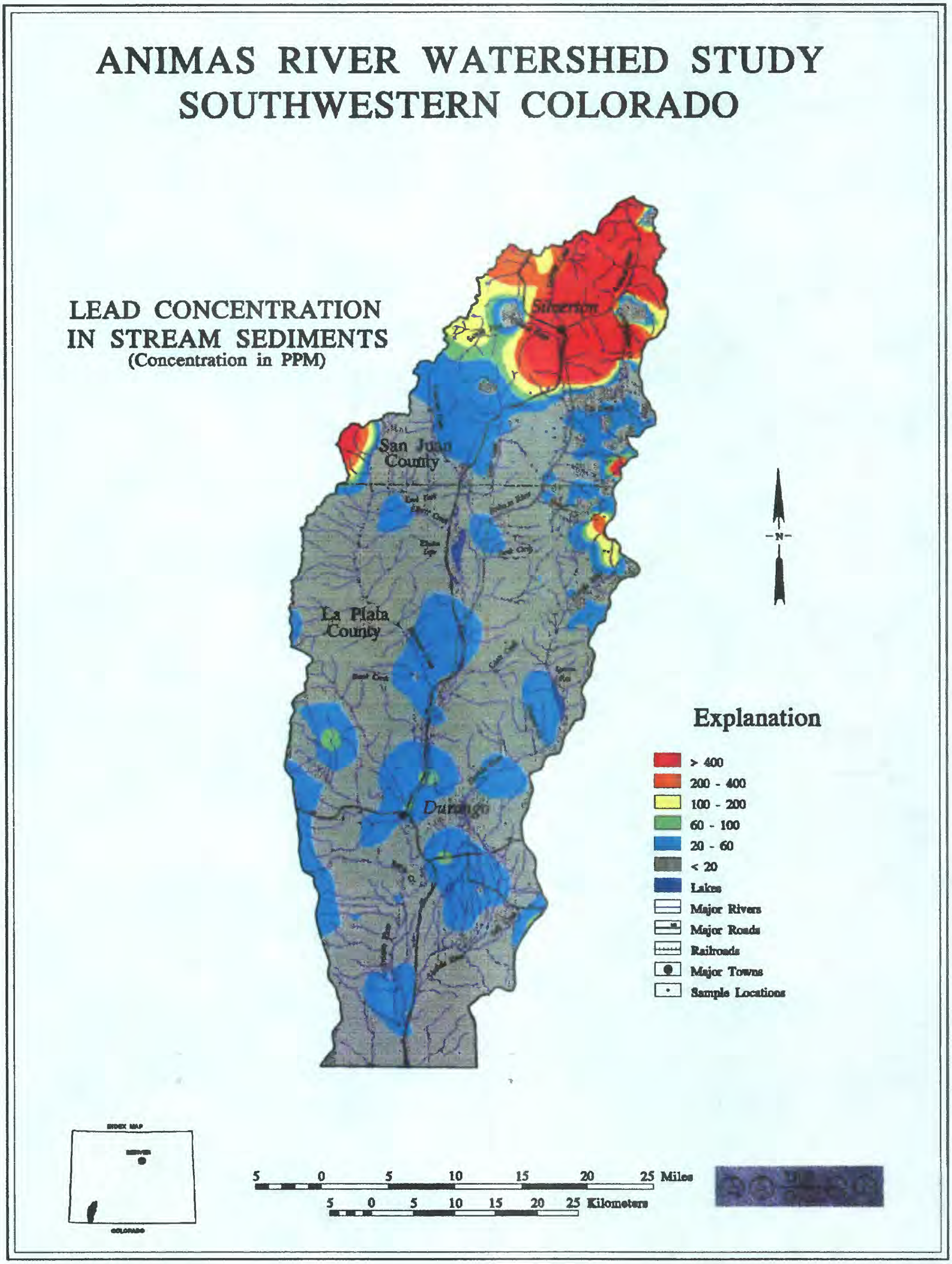
Figure 8. Geochemical map for zinc (Zn) of the Animas River watershed. Data from the National Geochemical Data Base (Hoffman and Buttleman, 1994) was supplemented by samples from the major tributary streams during the 1995 sampling to evaluate the contributions of metals from the major tributary drainages in the Animas River watershed. Important tributary streams are labeled for reference; hydrology data are from USGS (1989); and the towns, railroads, and roads are from ESRI (1992).

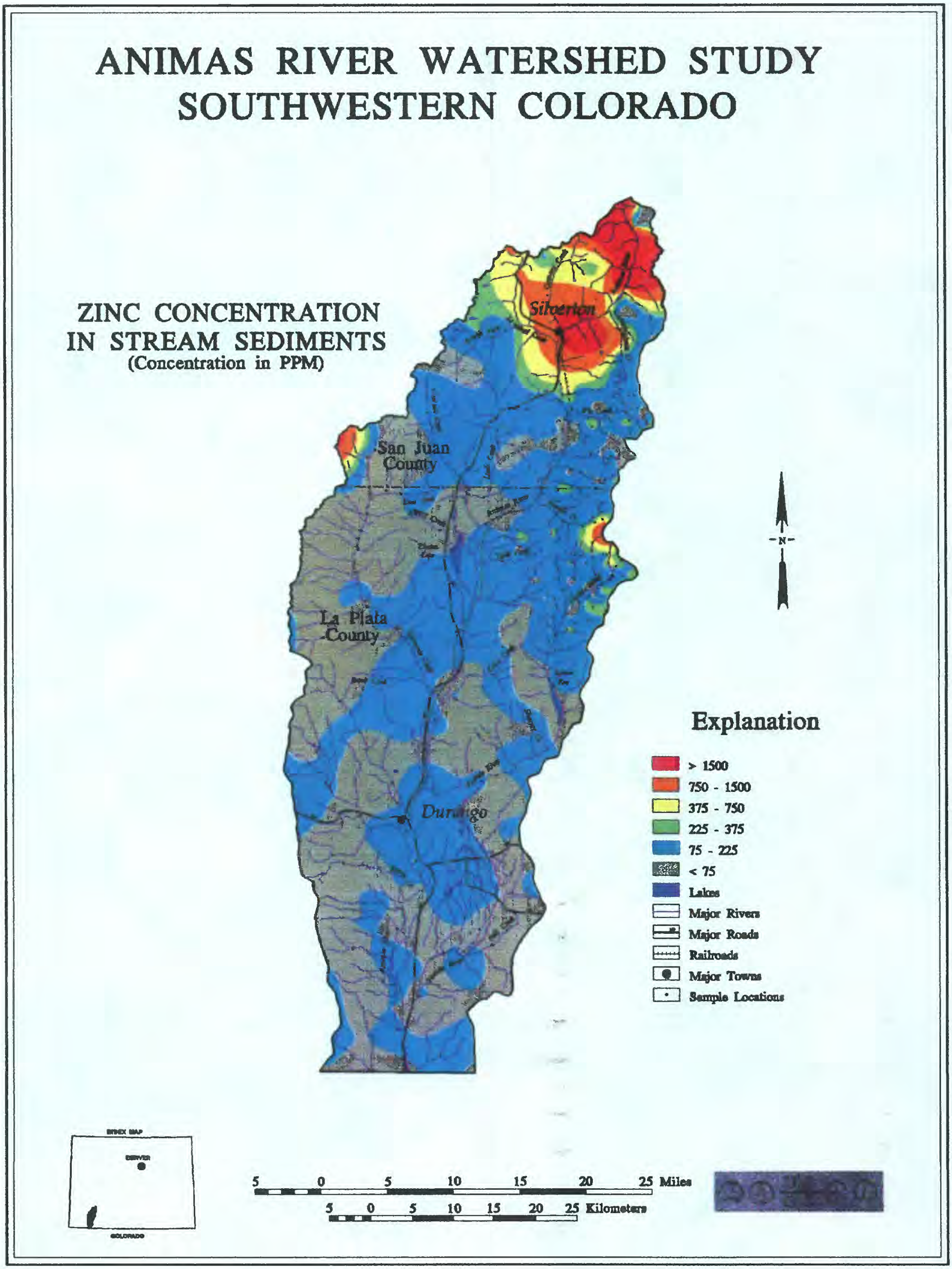
Figure 9. Hydrograph of the Animas River showing stream flow discharge from data collected at the gaging station below Silverton (A-72) between Oct. 1, 1994 to Oct. 1, 1996.

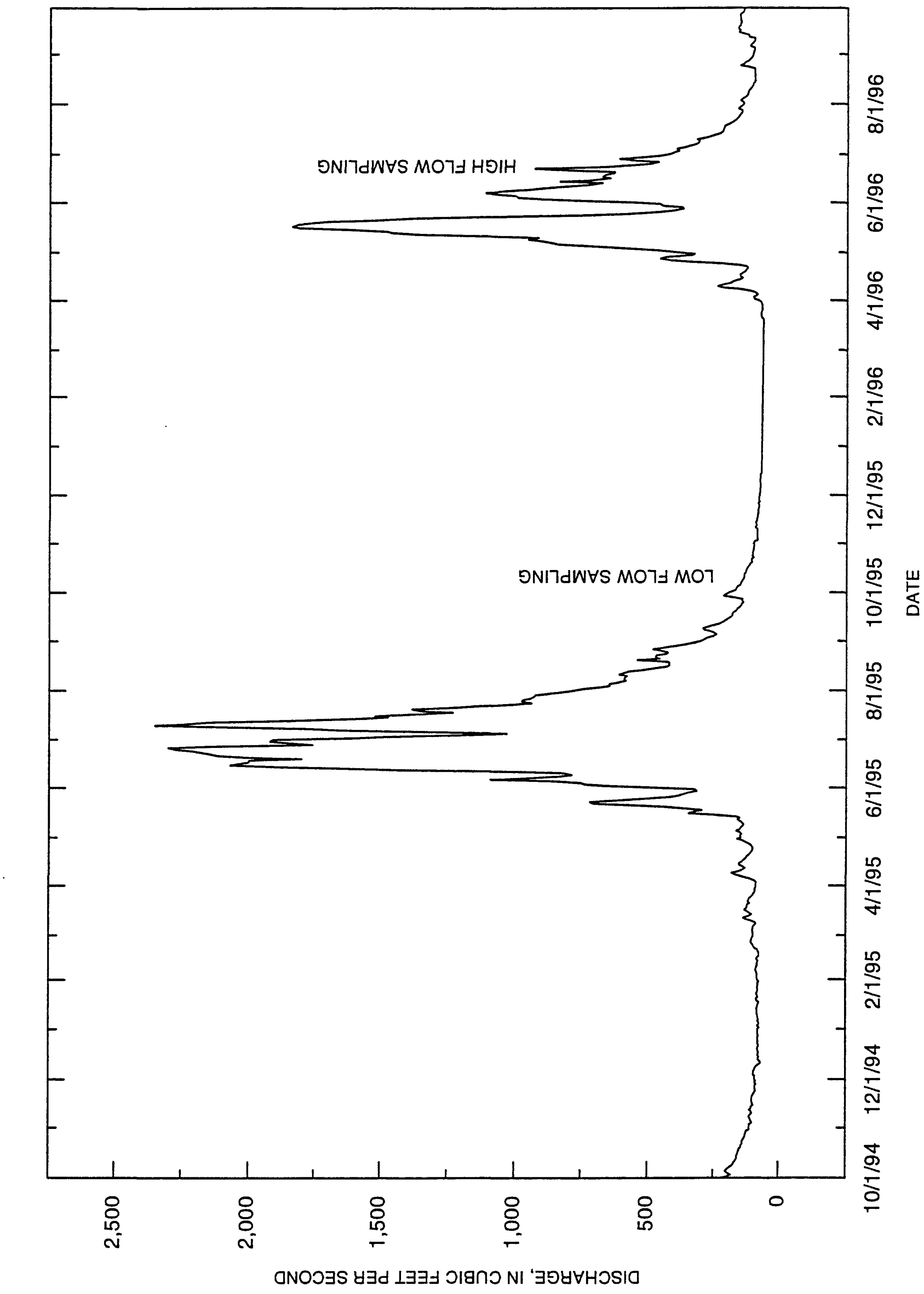
ANIMAS RIVER WATERSHED STUDY
SOUTHWESTERN COLORADO




ANIMAS RIVER WATERSHED STUDY
SOUTHWESTERN COLORADO
COPPER CONCENTRATION
IN STREAM SEDIMENTS
(Concentration in PPM)
Silverton
San Juan County
La Plata County
Durango
Explanation
> 1300
650 - 1300
325 - 650
200 - 325
65 - 200
< 65
Lakes
Major Rivers
Major Roads
Railroads
Major Towns
Sample Locations
5 0 5 10 15 20 25 Miles
5 0 5 10 15 20 25 Kilometers


ANIMAS RIVER WATERSHED STUDY
SOUTHWESTERN COLORADO
LEAD CONCENTRATION
IN STREAM SEDIMENTS
(Concentration in PPM)
Silverton
San Juan County
La Plata County
Durango
N
Explanation
> 400
200 - 400
100 - 200
60 - 100
20 - 60
< 20
Lakes
Major Rivers
Major Roads
Railroads
Major Towns
Sample Locations
5 0 5 10 15 20 25 Miles
5 0 5 10 15 20 25 Kilometers


ANIMAS RIVER WATERSHED STUDY
SOUTHWESTERN COLORADO
ZINC CONCENTRATION
IN STREAM SEDIMENTS
(Concentration in PPM)
Silverton
San Juan
County
La Plata
County
Durango
N
Explanation
> 1500
750 - 1500
375 - 750
225 - 375
75 - 225
< 75
Lakes
Major Rivers
Major Roads
Railroads
Major Towns
Sample Locations
5 0 5 10 15 20 25 Miles
5 0 5 10 15 20 25 Kilometers



DISCHARGE, IN CUBIC FEET PER SECOND
2,500
2,000
1,500
1,000
500
0
DATE
10/1/94
12/1/94
2/1/95
4/1/95
6/1/95
8/1/95
10/1/95
12/1/95
2/1/96
4/1/96
6/1/96
8/1/96
LOW FLOW SAMPLING
HIGH FLOW SAMPLING

Stream Sediments

Stream-sediment samples were collected from sites within selected stream reaches to characterize the reach as well as to supplement previous sampling. At individual sites, a sample was composited along 50-100 feet of the stream from several localities on both sides of the stream below the active water line. This composite sample was sieved through a minus-10-mesh stainless steel sieve (2 mm) into a plastic gold pan and 1-2 kg sample of fine-grained sediment was transported to the laboratory. The sample was dried at room temperature (about 20°C) and then sieved to collect the minus-100-mesh (minus-149-µm) grain-size fraction. This minus-100-mesh sample was used for all chemical and lead-isotopic work. Sample localities from Mineral Creek, Cement Creek, and the Animas River are in figure 11. For further details on the sample handling, see appendix I in Church and others (1993). Chemical procedures, analytical precision, and reproducibility are discussed in appendix II and the analytical results are in appendices V-VII.

Additional samples of overbank sediments, composed of fine-grained sand and silt sediments deposited at high water, were collected in the same manner from the sides of the stream channel to evaluate the effect of wetting and drying of these sediments on the availability of water-soluble metals. These samples were dry-sieved in the field. Some water-soluble efflorescent salts and mill tailings were also collected from along the stream reaches. These special samples are identified and briefly described in the data tables (appendices V and VI).

RESULTS FROM THE WATER AND COLLOID DATA

Analytical data in this report provided the basis for interpretation of the loading, partitioning, and transport of metals from source areas upstream from Silverton, Colo. to Aztec, New Mexico under low-flow conditions. The synoptic sampling reported in this section took place at low flow in October, when bed sediments were not being transported; thus, the focus of transport in this report is on the dissolved and colloidal loads. It is important to realize that at high flow, during storms, or snowmelt runoff, there will be large amounts of metal transported with movement of the bed sediments. On an annual basis, the amount of metals transported with the bed sediments could greatly exceed the annual fluxes measured for the dissolved and colloidal loads.

Synoptic Sampling of Water and Colloids, October 1995

Site identifications, field measurements, and major ion chemistry of samples collected for water and colloids are in appendix III. Results of chemical determinations for dissolved and colloidal metal concentrations are in appendix IV. In both appendices, data are sorted in downstream order in for the Animas River (mainstem) and tributaries (Mineral and Cement Creeks) to emphasize the changes downstream. These analyses were compared to water-quality standards for aquatic life for Colorado given in table 1 (CDPHE, written commun., 1997).

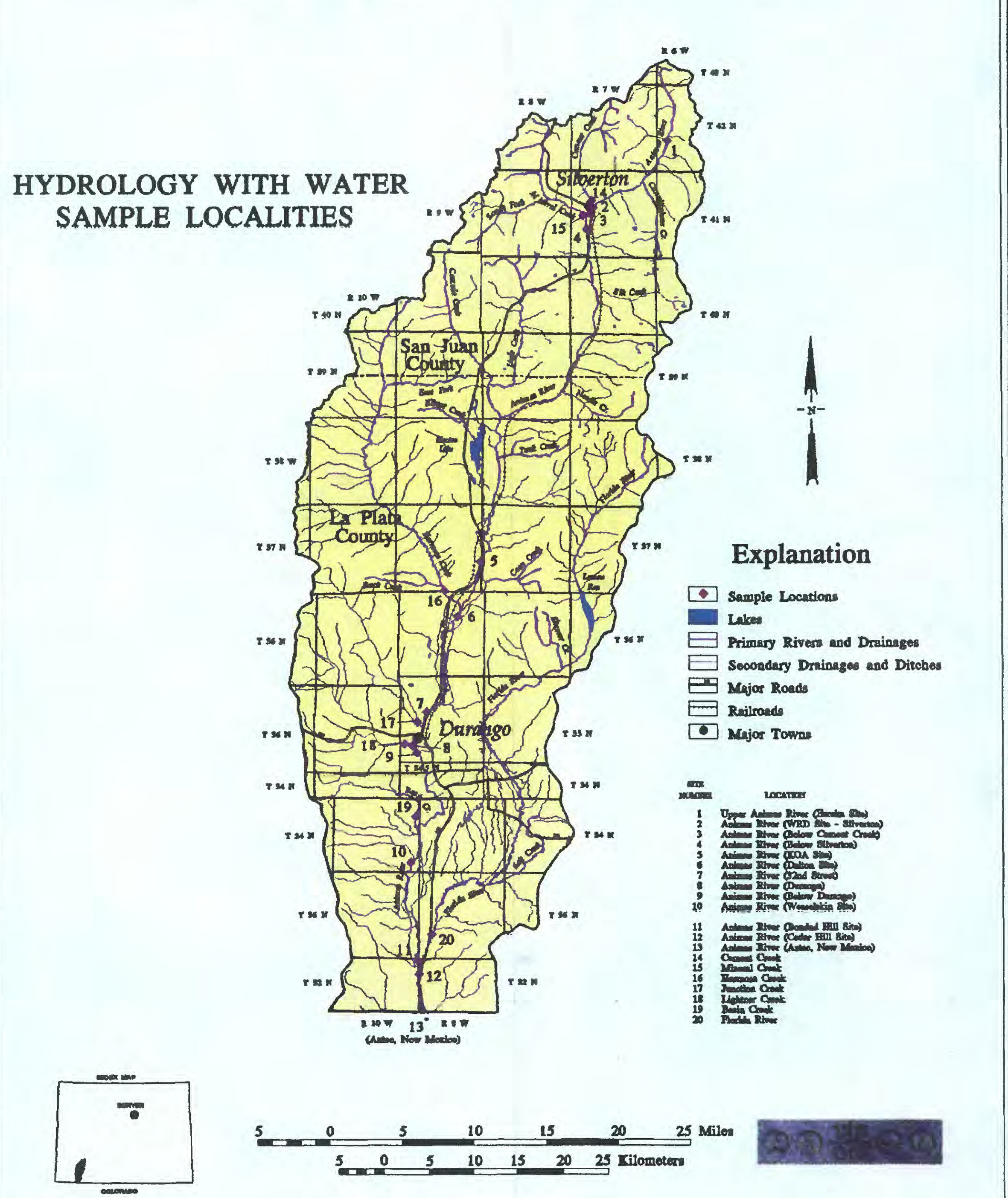
Aluminum

In the headwater stream reaches upstream from Silverton, aluminum coatings (chalk-white precipitates) seen on the rocks on the sides of the stream channel indicate that aluminum is partially removed from the streams before entering the Animas Canyon. Concentrations of dissolved aluminum ranged from a high of 0.42 mg/L at site A-72, downstream from Silverton, to an average of 0.09 mg/L downstream from the Animas Canyon. Thus, not all the aluminum was removed as coatings before entering the Animas River. The dissolved aluminum concentrations in the Silverton area are in excess of the water quality standard for aquatic life, but below this standard downstream from the Animas Canyon. However, much of the aluminum in the Animas River downstream from Mineral Creek is colloidal (appendix IV). Recent work has noted that colloidal aluminum may be toxic to fish whereas dissolved aluminum may not be (Witters and others, 1996). In fact, Witters and others (1996) found that freshly formed aluminum-hydroxide precipitates may be most toxic to trout. This would be the dominant form of aluminum in the waters within the Animas Canyon reach.

Figure 10. Map of the Animas River watershed showing localities for water and colloid samples collected in Oct., 1995. The hydrology data are from USGS (1989); and the towns, railroads, and roads are from ESRI (1992).

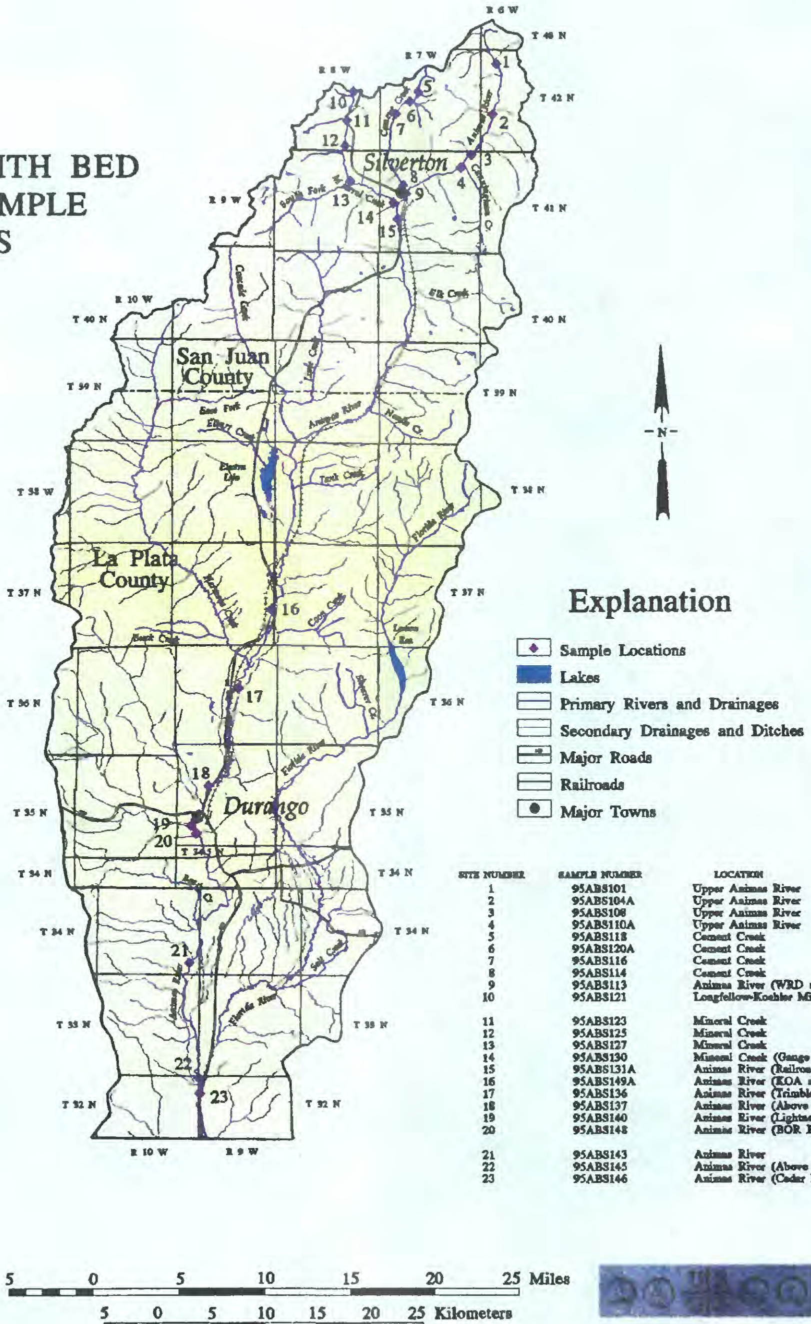
Figure 11. Map of the Animas River watershed showing localities for sediment samples collected from Mineral Creek, Cement Creek, and the Animas River in Oct., 1995. The hydrology data are from USGS (1989); and the towns, railroads, and roads are from ESRI (1992).

ANIMAS RIVER WATERSHED STUDY
SOUTHWESTERN COLORADO



ANIMAS RIVER WATERSHED STUDY SOUTHWESTERN COLORADO

HYDROLOGY WITH BED SEDIMENT SAMPLE LOCALITIES



SITE NUMBER	SAMPLE NUMBER	LOCATION
1	95ABS101	Upper Animas River
2	95ABS104A	Upper Animas River
3	95ABS108	Upper Animas River
4	95ABS110A	Upper Animas River
5	95ABS118	Cement Creek
6	95ABS120A	Cement Creek
7	95ABS116	Cement Creek
8	95ABS114	Cement Creek
9	95ABS113	Animas River (WRD site)
10	95ABS121	Longfellow-Koehler Mine
11	95ABS123	Mineral Creek
12	95ABS125	Mineral Creek
13	95ABS127	Mineral Creek
14	95ABS130	Mineral Creek (Gauge site)
15	95ABS131A	Animas River (Railroad site)
16	95ABS149A	Animas River (KOA site)
17	95ABS136	Animas River (Trimble site)
18	95ABS137	Animas River (Above 32nd)
19	95ABS140	Animas River (Lightner Creek)
20	95ABS148	Animas River (BOR Pump)
21	95ABS143	Animas River
22	95ABS145	Animas River (Above Bondad)
23	95ABS146	Animas River (Cedar Hill)

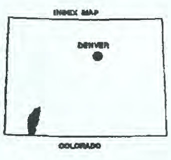


Table 1. Water Quality Standards for Metals, Colorado

Metal	Aquatic Life Standard[1] Acute	Chronic	Agricultural[2] Standard	Domestic [2] Standard
Aluminum	750	87		
Arsenic	360	150	100	50
Cadmium	$e^{(1.128[\ln(\text{hardness})] - 2.905)}$ Trout = $e^{(1.128[\ln(\text{hardnass})] - 3.828)}$	$e^{(0.7852[\ln(\text{hardness})] -3.490)}$	10	5
Chromium^{+3}	$e^{(0.818[\ln(\text{hardness})] - 3.688)}$	$e^{(0.818[\ln(\text{hardness})] - 1.561)}$	100	50
Chromium^{+5}	16	11	100	50
Copper	$1/2e^{(0.9422[\ln(\text{hardness})] - 0.7703)}$	$e^{(0.8545[\ln(\text{hardness})] - 1.465)}$	200	1,000
Iron		1,000 (total recovery)		300_{dis}
Lead	$1/2e^{(1.6148[\ln(\text{hardnass})] - 2.1805)}$	$e^{(1.417[\ln(\text{hardness})] - 5.167)}$	100	50
Manganese		1,000	200	50_{dis}
Mercury	2.4	0.1		2
Nickel	$1/2e^{(0.76[\ln(\text{hardness})] + 4.02)}$	$1/2e^{(0.76[\ln(\text{hardness})] + 1.06)}$	200	100
Selenium	20	5	20	50
Silver	$1/2e^{(1.72[\ln(\text{hardness})] - 6.52)}$	$1/2e^{(1.72[\ln(\text{hardness})] - 9.06)}$ Trout = $e^{(1.72[\ln(\text{hardness})] - 10.51)}$		100
Zinc	$e^{(0.8473[\ln(\text{hardness})] + 0.8604)}$	$e^{(0.8473[\ln(\text{hardness})] + 0.7614)}$	2,000	5,000

[1] Metals for aquatic life standards are dissolved; concentrations are given in µg/L. Water hardness to be used in equations are in mg/L expressed as calcium carbonate. Standards should not be exceed more than once every three years.

[2] Metals are expressed as total recoverable metals unless otherwise stated; $_{dis}$ is the dissolved form of the metal.

Data from CDPHE (written commun., 1997)

Cadmium

Concentrations of cadmium were below the limit of detection (<0.001 mg/L) in most of the water samples. Values downstream from Cement Creek and Mineral Creek were measurable where the pH was lower. Cadmium concentrations were not elevated in water or colloids from sites downstream from Silverton during low flow and, at these low concentrations, cadmium did not exceed any water-quality standards.

Copper

In samples from the upper Animas River, dissolved copper concentrations averaged 0.003 mg/L and colloidal copper concentrations averaged 0.006 mg/L. These values are near the lower detection limit for copper (<0.001 mg/L). The highest concentrations of dissolved copper were in Cement Creek and Mineral Creek. Due to a pH of 6.35 and a substantial source of copper in its headwaters, Mineral Creek had the highest concentration of colloidal copper at 0.055 mg/L. Cement Creek, on the other hand, had the highest concentration of dissolved copper at 0.06 mg/L. Sites downstream from the Animas River-Cement Creek confluence and the Animas River-Mineral Creek confluence had the highest colloidal concentrations of copper at 0.016 mg/L and 0.022 mg/L respectively. Downstream from the Animas Canyon at the KOA Campground site (72.5 km), there was a relatively high colloidal copper concentration of 0.006 mg/L, but all the remaining sites in the basin had concentrations less than 0.004 mg/L. Concentrations at the majority of sites were less than the concentration in the field equipment blank (appendices III and IV), so it is not possible to make distinctions among them. One relatively high concentration of dissolved copper, 0.008 mg/L, was observed at the 32nd Street Bridge in Durango. This must have been from some unidentified source near Durango. The acute water-quality standard for dissolved copper was exceeded only in Cement Creek. However, colloidal copper concentrations exceeded the water-quality standard for chronic toxicity at most other sites. It is not clear what aquatic-life standards are applicable to the colloids, but these copper concentrations could cause chronic toxicity if copper in the colloids were available to aquatic life.

Iron

Iron is the main component of the colloidal material that forms in the streams upstream from Silverton. Concentrations of colloidal iron were measured in all samples collected all the way downstream to Aztec. The pattern was similar to that observed downstream from mining sources in the Arkansas Basin (Kimball and others, 1995); both rivers show a large increase in the colloidal iron concentration immediately downstream from the source and then a gradual decrease downstream. In the Animas River, the highest concentrations of dissolved iron were 0.64 mg/L downstream from the confluence of Cement Creek and 0.68 mg/L downstream from the confluence of Mineral Creek. Downstream from the Animas Canyon, only a few dissolved iron concentrations were above the limit of detection (<0.001 mg/L), with the greatest concentration at the KOA Campground site (0.012 mg/L) just downstream from the Animas Canyon.

There is an aquatic life standard for total recoverable iron of 1 mg/L. The colloidal concentrations reported here from the sites downstream from Cement Creek and Mineral Creek exceed this water-quality standard. Although iron does not cause acute toxicity, it does influence habitat and chronic toxicity because of its deposition on the substrate of the stream bed and incorporation into the food chain. Witters and others (1996) suggest that colloidal iron may be dissolved in fish guts releasing the sorbed metals.

Manganese

As observed in many other streams (Kimball and others, 1995), manganese in the Animas River resided principally in the dissolved phase rather than the colloidal phase. The pattern of dissolved manganese was very similar to the pattern of iron; the highest concentrations were downstream from the confluences of Cement and Mineral Creeks, and then the concentrations decreased downstream. The highest tributary concentration of dissolved manganese was from Cement Creek, with 1.3 mg/L. The dissolved concentrations in the Silverton area were almost at the chronic water-quality standard for manganese; however, there is no manganese standard for acute toxicity.

Strontium

Although strontium is not a toxic metal, it is useful to contrast its distribution pattern with other metals. Almost all of the measured strontium was in solution rather than in the colloidal phase. Strontium concentrations were high in the Animas River near Silverton, decreased downstream and then increased again due to the high inflow concentrations downstream from the Animas Canyon. The highest tributary concentration was in Cement Creek, at 2.6 mg/L, which may reflect the leaching of carbonate minerals (calcite, $CaCO_3$, and rhodochrosite, $MnCO_3$) present in the Eureka graben vein-type ore. Strontium will substitute for manganese in the rhodochrosite structure. The pattern of concentration downstream differed from that of the mining-related metals because there were substantial sources of strontium downstream from the Cretaceous Picture Cliffs, Kirtland, and Fruitland Formations. The next highest inflow concentrations were from Basin, Hermosa, and Lightner Creeks near Durango. Thus, the strontium data illustrate the pattern of an element that does not originate from the headwaters near Silverton.

Zinc

Like manganese, zinc occurred principally in the dissolved phase. The highest dissolved concentrations were near Silverton. Cement Creek had a dissolved zinc concentration of 1.3 mg/L, the highest of any tributary, and the measured pH was 3.89. Unlike some other metals, the dissolved concentration of zinc at Eureka (pH 7.06), upstream from Silverton, was high at 0.46 mg/L. Downstream from Silverton, the concentrations of zinc consistently decreased as pH increased from 6.62 to 7.87 in the Animas Canyon reach.

Downstream from the Animas Canyon, the dissolved zinc concentration in the Animas River decreased substantially from that upstream but did not decrease to levels that were comparable to the colloidal zinc concentration until near Bondad Hill where the pH increased to about 8.6.

The concentrations of dissolved zinc exceeded water-quality standards for both chronic and acute toxicity at each of the sites upstream from the Animas Canyon (fig. 10). Concentrations of colloidal zinc in these reaches were below aquatic-life standards, but if sorbed zinc were released in the guts of fish as suggested by the work of Witters and others (1996), colloidal zinc could contribute to chronic zinc toxicity.

Arsenic, Mercury, and Selenium

Samples were analyzed for arsenic, mercury, and selenium to evaluate the dissolved and colloidal loads. None of the samples had concentrations of these metals above the detection limits. The detection limits were 1 microgram per liter (µg/L) for arsenic and selenium, and 0.1 µg/L for mercury. The lack of detection in water and colloids emphasizes the tendency of these elements to be associated with the bed sediments.

High-flow Sampling of Water and Colloids, Spring, 1996

A second set of samples was collected during the snowmelt runoff period between May and June 1996 to compare the metal loads in water and colloids between low- and high-flow conditions (fig. 9). Results of determinations from these samples are in appendices III and IV. Only three sites were sampled during high flow, so there only is an outline of spatial detail. The samples, however, permit some generalizations about the loading of metals under two different flow regimes.

In the absence of acid-mine drainage, concentrations of dissolved metals generally decrease as flow increases. At high flow from snowmelt runoff, one would expect water quality standards to be achieved. Concentrations of some metals, however, did increase with higher flow, mostly the colloidal concentrations, creating the opportunity to exceed toxicity levels for some organisms. Among the dissolved metals sampled, zinc was the only metal that exceeded the acute toxicity standard. Zinc concentrations far exceeded the acute toxicity standard at site A-72 below Silverton, and at the two downstream sites (Durango and Cedar Hill), it was about twice the acute toxicity standard. Other metal concentrations either exceeded the chronic toxicity standard or were very close to the standard. Concentrations of copper did not exceed the standard, but were only a few micrograms per liter below the standard. During high flow, colloidal iron was greater than 1 mg/L, the standard for "total recoverable" iron concentrations, at both downstream sites. The concentrations of dissolved lead were below detection (<0.01 mg/L).

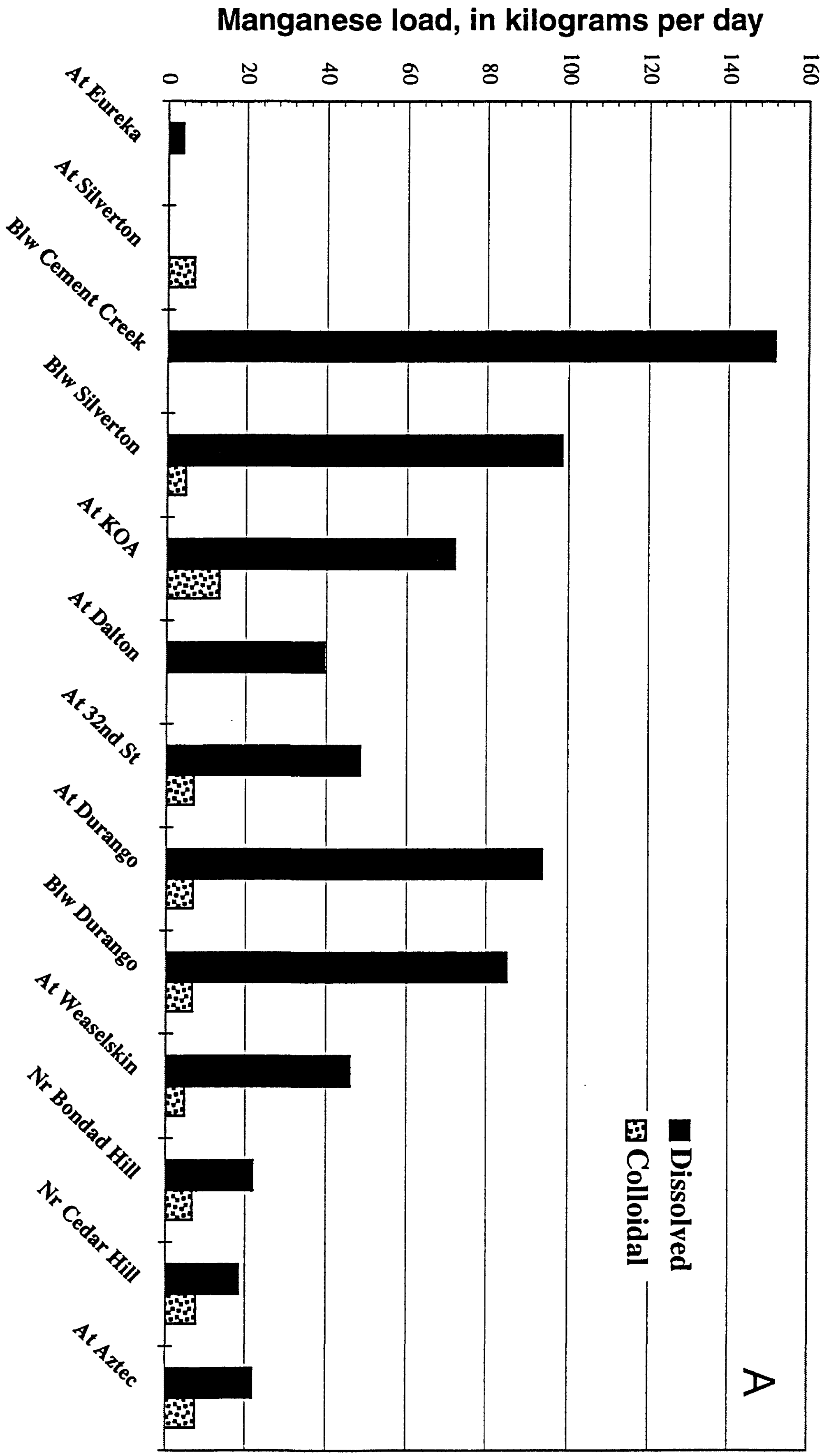
The samples collected at high flow contained some sand-sized particles that were screened out before measuring the metal concentrations in the colloids. This indicates that there was some unquantified metal transport associated with suspended particulate material (>62 µm) at high flow associated with these particles. Unfortunately, this component was not analyzed and has been discarded.

Dissolved Versus Colloidal Transport

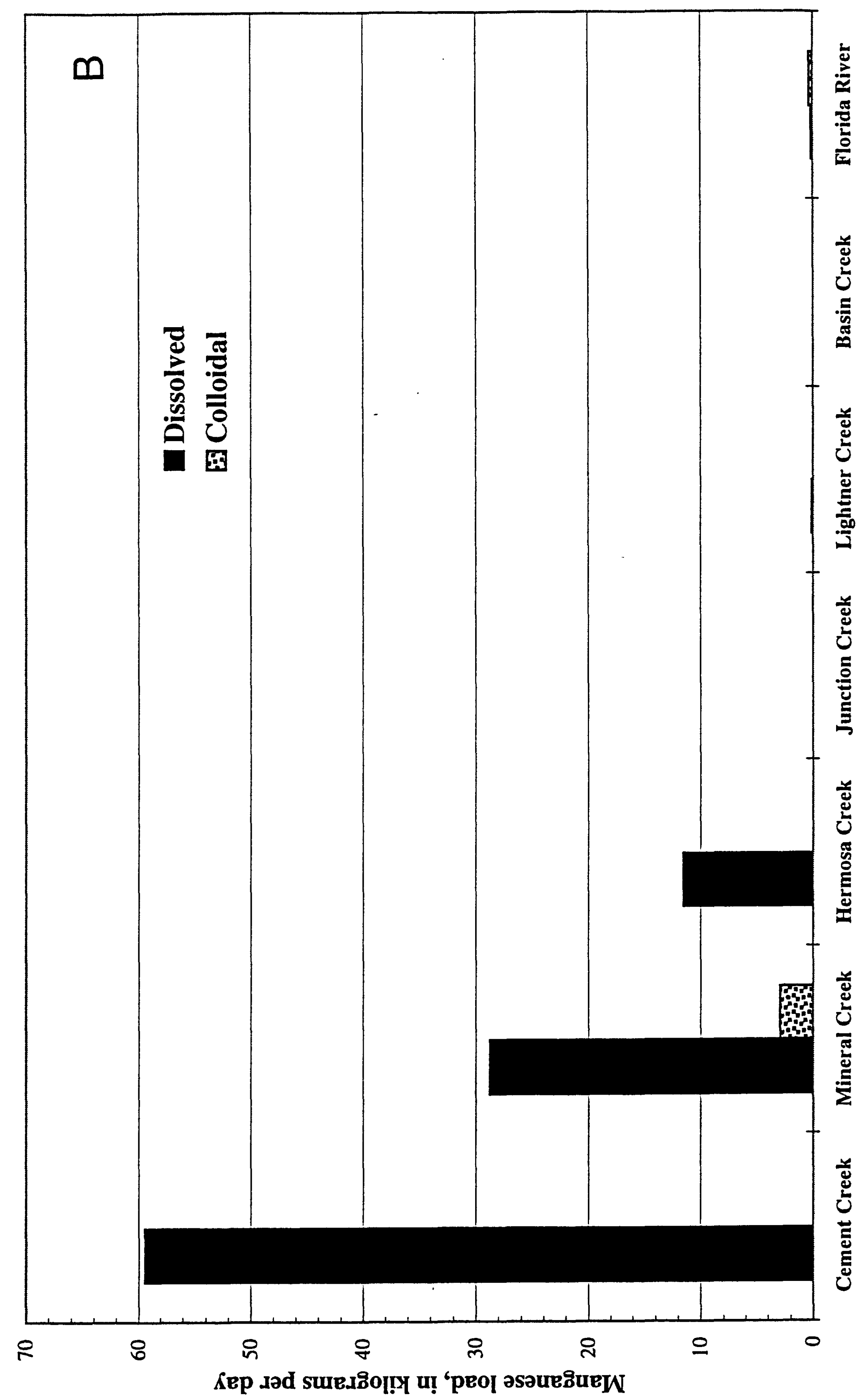
Measured stream flow discharge was multiplied by concentrations and converted to units of kilograms per day (kg/day) to evaluate the instantaneous synoptic metal load. There was a clear distinction between metals transported in the dissolved load and those transported in the colloidal load. Both dissolved and colloidal metals, however, had the same downstream profile of metal loading. The profile shows a sharp increase contributed by the inflows of Cement and Mineral Creeks near Silverton and then a gradual decrease during flow through the Animas Canyon and on downstream. The decrease, or attenuation, of the dissolved load resulted either from an increase of the colloidal load, or in sorption of metals onto material in the bed sediments. Attenuation of the colloidal load results from deposition of aggregated colloids to the stream bed and incorporation into the bed sediments.

Figure 12. Dissolved and colloidal manganese in (A) the Animas River and (B) major tributaries.

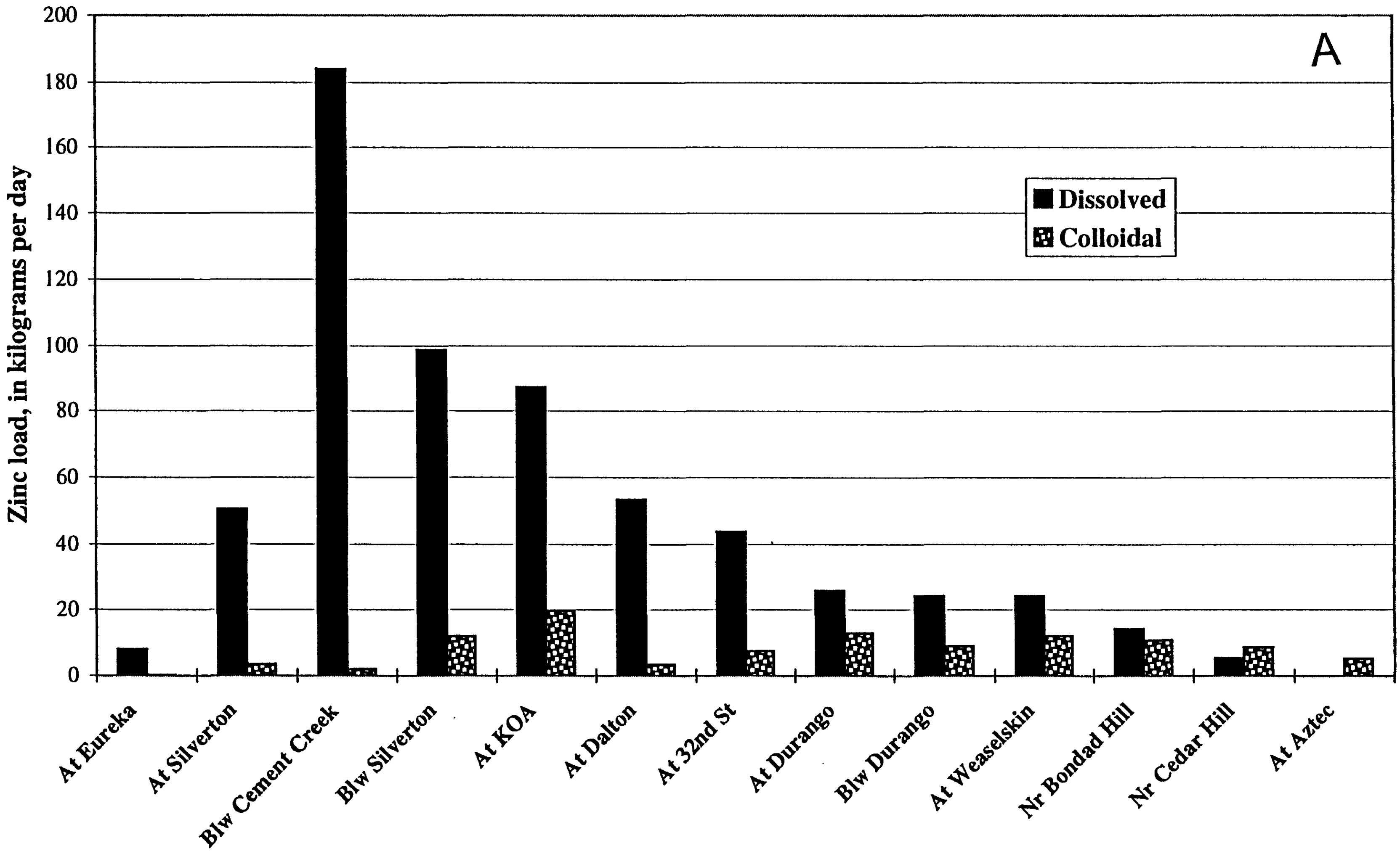
Figure 13. Dissolved and colloidal zinc in (A) the Animas River and (B) major tributaries.

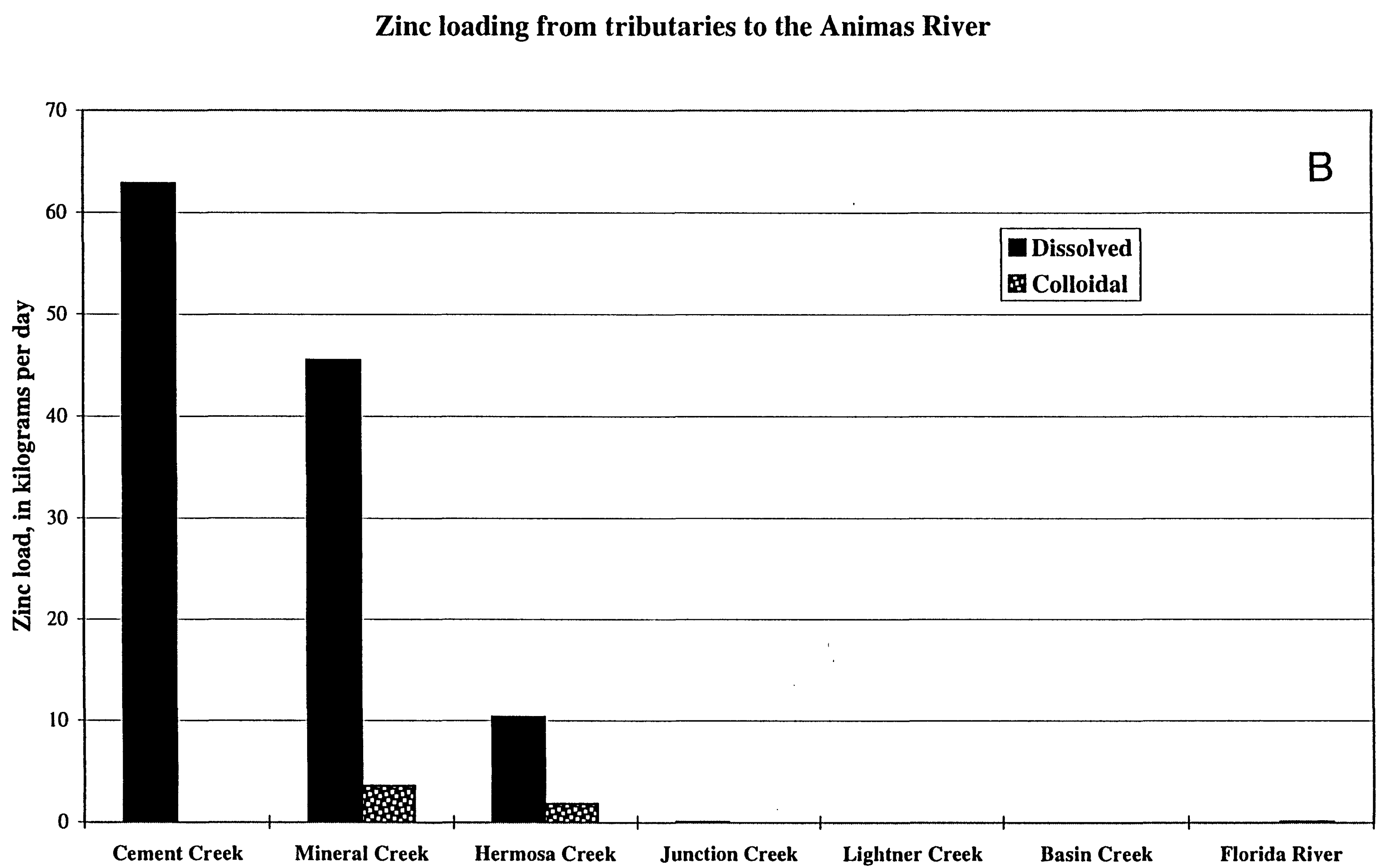


Manganese load, in kilograms per day
0
20
40
60
80
100
120
140
160
A
Dissolved
Colloidal
At Eureka
At Silverton
Blw Cement Creek
Blw Silverton
At KOA
At Dalton
At 32nd St
At Durango
Blw Durango
At Weaselskin
Nr Bondad Hill
Nr Cedar Hill
At Aztec


B
Dissolved
Colloidal
Manganese load, in kilograms per day
0
10
20
30
40
50
60
70
Cement Creek
Mineral Creek
Hermosa Creek
Junction Creek
Lightner Creek
Basin Creek
Florida River

Zinc loading in the Animas River




Zinc loading from tributaries to the Animas River
B
Dissolved
Colloidal
Zinc load, in kilograms per day
0
10
20
30
40
50
60
70
Cement Creek
Mineral Creek
Hermosa Creek
Junction Creek
Lightner Creek
Basin Creek
Florida River

Manganese

Manganese and zinc were transported mostly in the dissolved load of the Animas River (figs. 12A and 13A). The inflows from Cement and Mineral Creeks near Silverton were mostly as dissolved manganese and zinc (figs. 12B and 13B). In the mixing zone downstream from each creek, there was no partitioning of the dissolved metals to the colloidal phase, most likely because in the pH range between 6.5 and 7.5, and neither manganese nor zinc tended to sorb to or form colloids in this pH range. Although there was no partitioning to colloidal loads, both the dissolved loads of manganese and zinc decreased downstream indicating that these two metals were lost to the bed sediments. In the bed sediments, zinc, in particular, could increase the toxicity of sediments for aquatic organisms. In the Durango area, there was an increase in the dissolved manganese load, but not in the dissolved zinc load. The manganese may have been from urban sources, but more likely it is from sedimentary rocks that crop out in this section of the basins that are supplying detritus to the drainage.

Iron and Aluminum

The profiles of colloidal loads of iron and aluminum were very similar (compare the data in figs. 14A and 15A), and the masses of colloidal iron and aluminum were nearly the same. The inflow of both metals from Cement Creek primarily was as a dissolved load, whereas the inflow from Mineral Creek was mostly as a colloidal load (figs. 14B and 15B). This difference in the chemical form of the load was the result of the different pH conditions in the two streams. In the mixing zone, downstream from the confluence with Cement Creek, the dissolved iron and aluminum loads from Cement Creek were partitioned almost completely to colloidal loads. This process occurred within tens of minutes as the water traveled 1 km from Cement Creek to Mineral Creek.

The contrast in the behavior of aluminum in Cement and Mineral Creeks illustrates the stronger influence of pH on the mode of aluminum transport. In Cement Creek, at a pH of 3.89, dissolved aluminum was 6.0 mg/L and colloidal aluminum was 0.1 mg/L. In Mineral Creek, at a pH of 6.35, dissolved aluminum was 0.09 mg/L, and colloidal aluminum was 3.6 mg/L. At sites along the Animas River between Cement Creek (24 km) and Dalton Ranch (81 km), most of the aluminum was colloidal, ranging from 1.72 mg/L (26 km) and 1.18 mg/L (24 km), to an average of 0.09 mg/L at sites beyond 81 km downstream. Downstream from 81 km, both dissolved and colloidal loads of aluminum were low.

The mass transfer or partitioning of aluminum from dissolved to colloidal loads quantifies the process influenced by differences in pH (fig. 16). Three sources of dissolved aluminum were represented: 10.4 kg/day from the upper Animas River above the confluence with Cement Creek, 283 kg/day from Cement Creek, and 12 kg/day from Mineral Creek. Adding the inputs from the upper Animas River and from Cement Creek should result in a dissolved aluminum load of 293 kg/day downstream from Cement Creek, but only 88 kg/day were measured. Thus, 205 kg/day of dissolved aluminum were lost, while 240 kg/day of colloidal aluminum was formed. This is a reasonable mass balance for the process of aluminum partitioning from the dissolved to the colloidal phase.

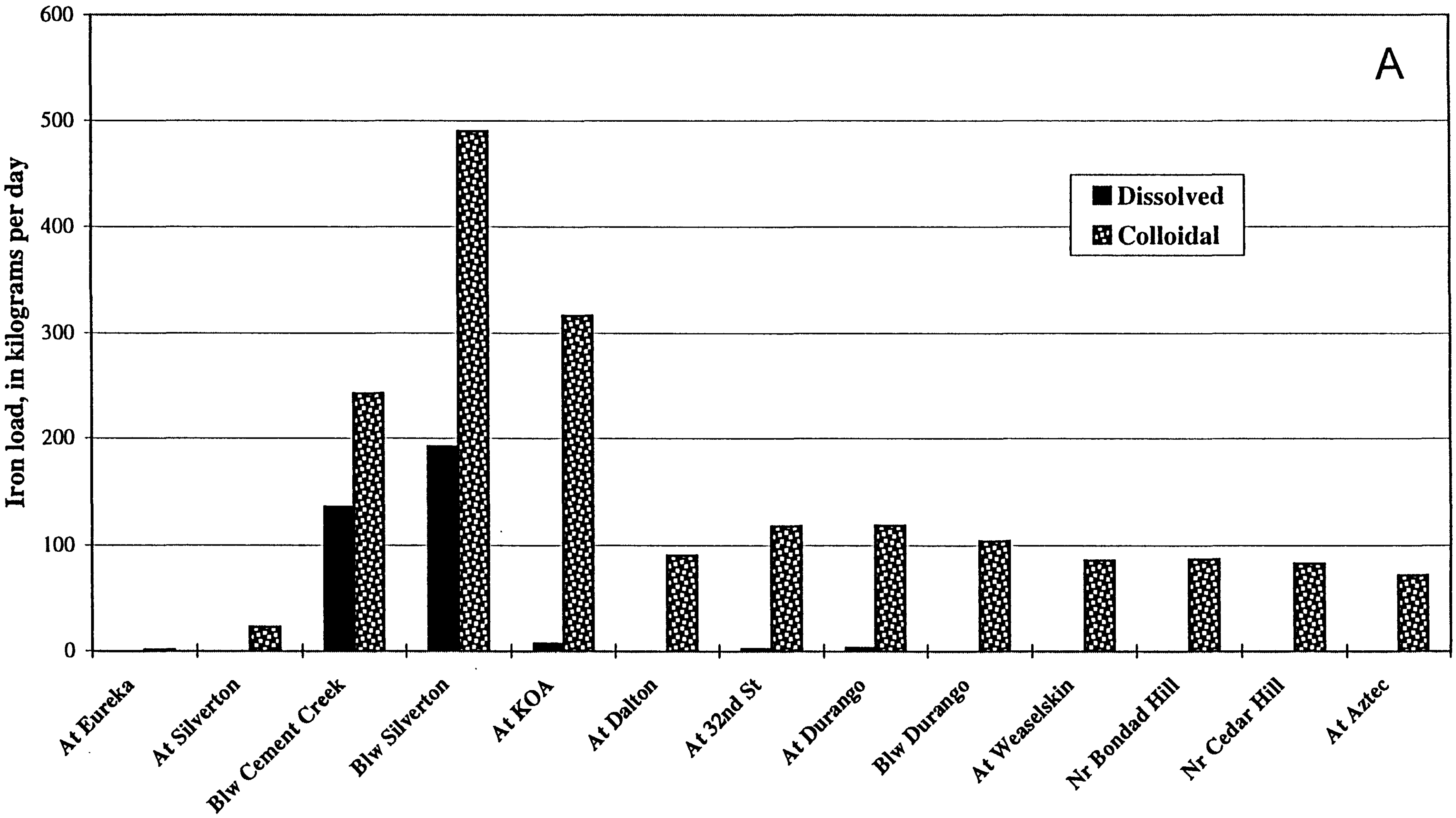
In the mixing zone downstream from the confluence with Mineral Creek, there was a net loss of dissolved and colloidal aluminum from the stream. The loss of dissolved aluminum in that mixing zone was 89 kg/day, but there also was a loss of 256 kg/day of colloidal aluminum. This indicates that there was not only a loss of dissolved aluminum to form colloidal aluminum, but also a net loss of colloidal aluminum to the stream bed. These data suggest that aluminum precipitation to form colloidal particles and their aggregation in the water column is rapid; it occurred just downstream from Cement Creek. The time required for settling or deposition of the colloidal aggregates to the stream bed sediments is longer; it did not occur until the water traveled downstream from Mineral Creek. This sequence is schematically illustrated in figure 16.

The same process occurs for iron and the mass of iron that is lost to the stream bed was very similar to aluminum (fig. 17). The gain in colloidal iron downstream from Cement Creek was comparable to the loss of dissolved load, and there was a net loss of colloidal iron downstream from Mineral Creek. This amount of colloidal iron and aluminum would substantially affect the habitat of the stream bed by filling up pore space normally occupied by benthic invertebrates.

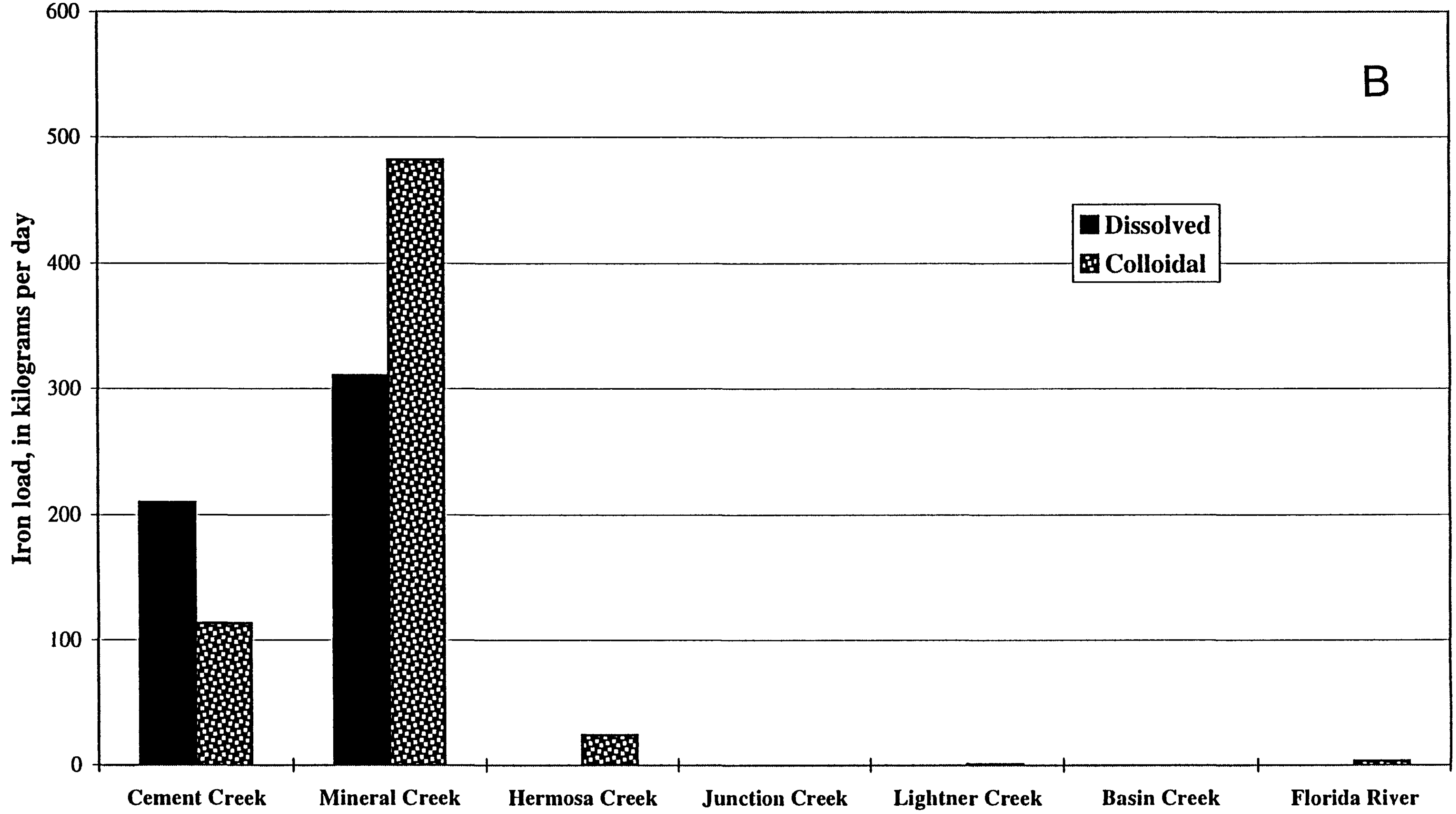
Figure 14. Dissolved and colloidal iron in (A) the Animas River and (B) major tributaries.

Figure 15. Dissolved and colloidal aluminum in (A) the Animas River and (B) major tributaries.

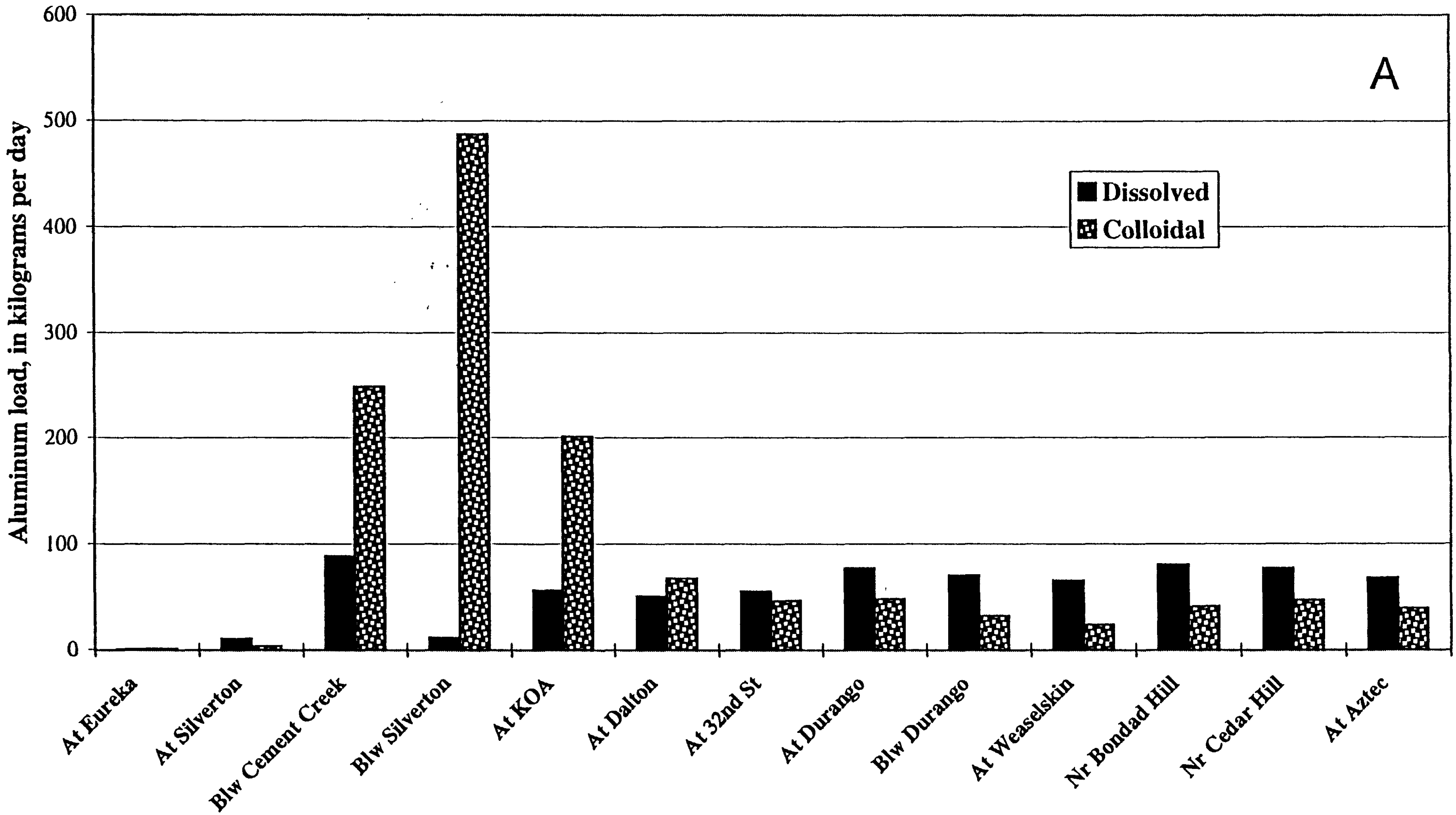
Iron loading in the Animas River



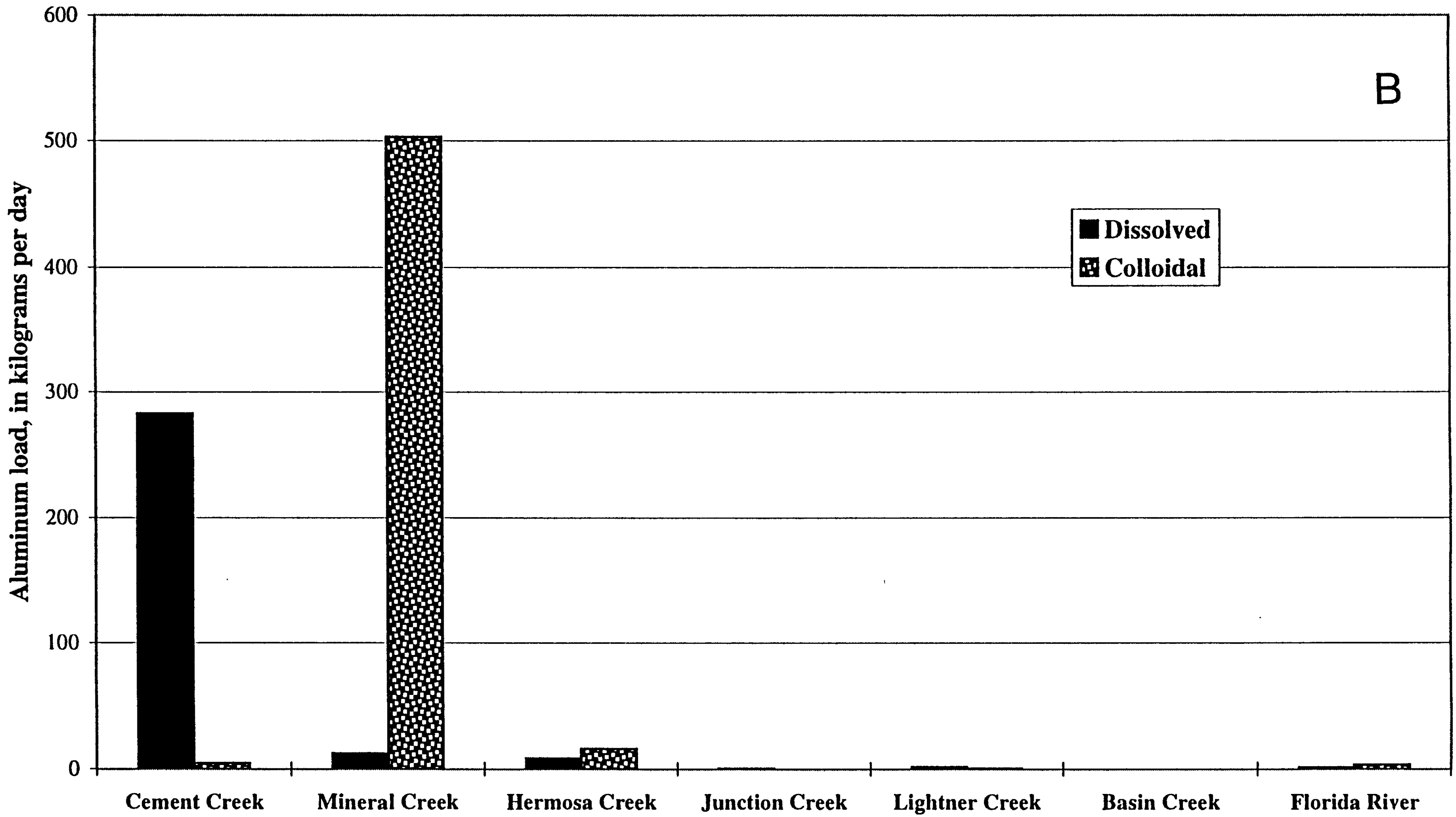
Iron loading from tributaries to the Animas River



Aluminum loading in the Animas River



Aluminum loading from tributaries to the Animas River



Copper

The dissolved copper concentration was below the limit of detection downstream from Cement Creek, even though the concentration entering from Cement Creek was near 6 μg/L. Copper was completely partitioned to the colloidal phase, probably as a result of sorption to colloids of iron and aluminum hydroxide, causing the colloidal concentration to increase to 13 μg/L downstream from Cement Creek. Sorption of copper continued downstream from Mineral Creek, and the colloidal concentration reached a maximum of 23 μg/L. The loss of colloidal copper load was about 5 kg/day downstream from Mineral Creek.

Zinc

Unlike aluminum and iron, only a small amount of zinc was partitioned from the dissolved to the colloidal phase. In the Animas River downstream from Cement Creek, the dissolved zinc load was 184 kg/day, which was greater than the sum of the individual sources of the upper Animas River and Cement Creek. This increased load may indicate a contribution of zinc from some nonpoint sources, perhaps from dispersed tailings in the alluvium.

In the Animas River downstream from Mineral Creek, the load of dissolved zinc was 99 kg/day, which represented a net loss of 131 kg/day of dissolved zinc. This net loss coincided with a gain of colloidal zinc of only 6 kg/day, so most of the dissolved zinc was not partitioned to the colloidal phase. Instead, a substantial loss of dissolved zinc to the stream bed occurred through sorption to the abundant aluminum and iron colloids that had previously settled to the stream bed.

These calculations not only demonstrate the substantial masses involved in the geochemical processes active in the streams, but also indicate the large quantity of colloidal material that becomes stored in the bed sediments. Once the colloids are part of the bed sediments, they influence the bed-sediment chemistry and affect the aquatic habitat. As described in the next section, much of the colloidal material is remobilized during high-flow periods.

Comparison of Metal Loads During Low-Flow and High-Flow Conditions

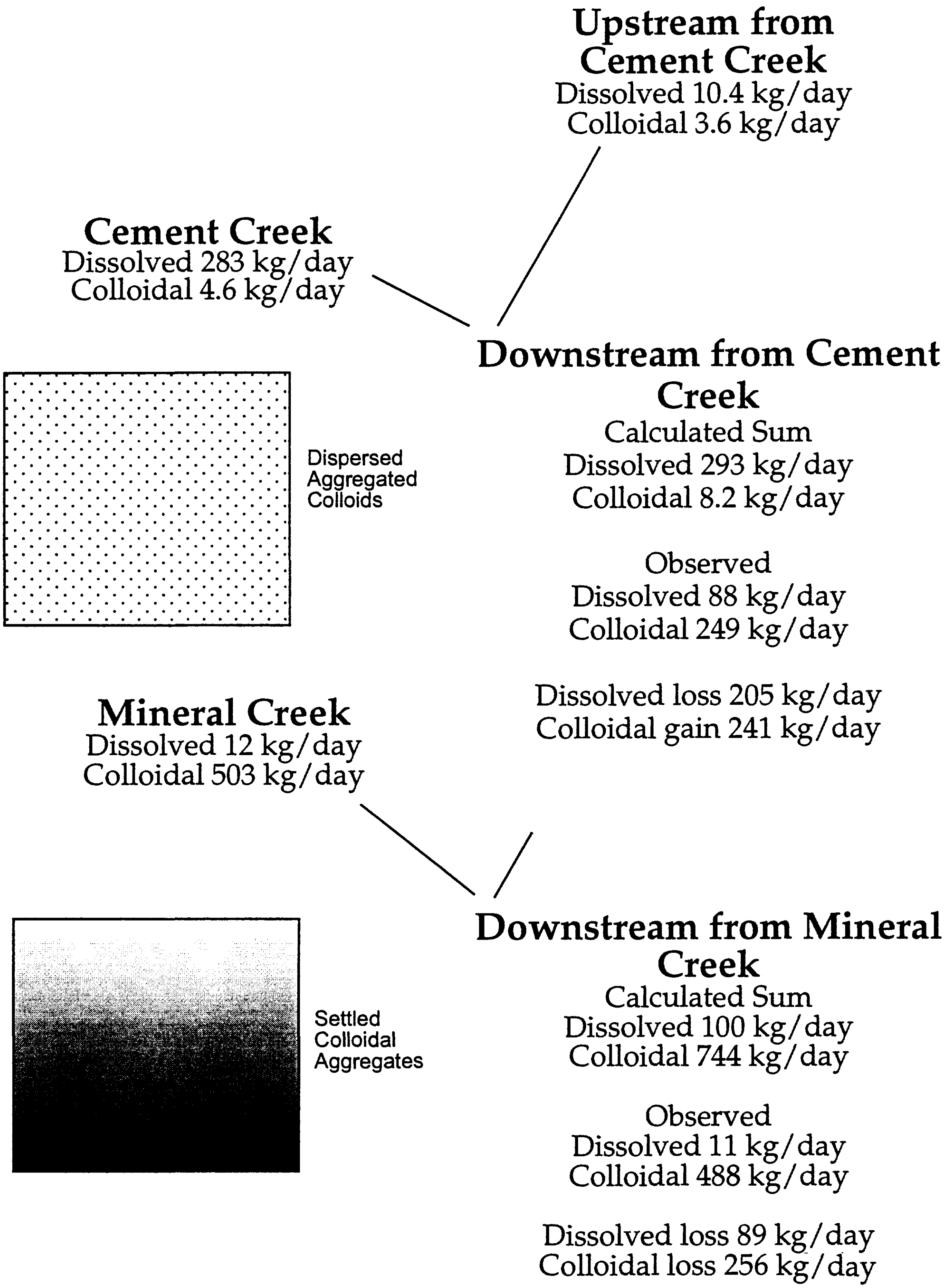
The samples that were collected during snowmelt runoff in 1996 indicated substantial differences in the transport of metals between low-flow and high-flow conditions. Ultrafiltration of the samples, as described in appendix II, provided the best possible measure of the dissolved and colloidal metal concentrations at both stages of discharge. The principal differences in transport patterns between low and high flow were the dominance of colloidal transport processes during high flow, and the greater mass of dissolved and colloidal material transported during high flow.

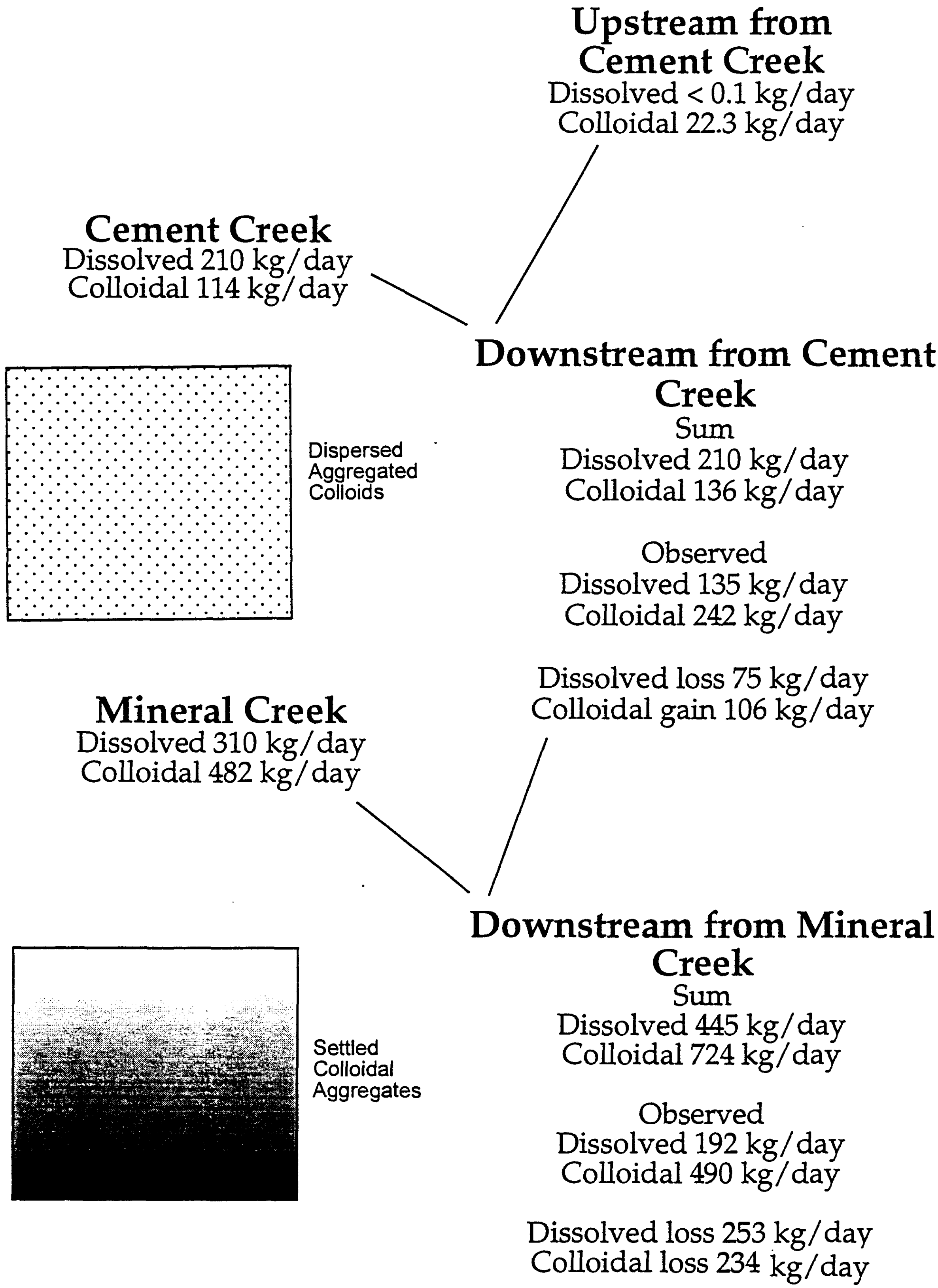
Dominance of the colloidal load was evident with the transport of aluminum (fig. 18A). At low flow, the colloidal load steadily decreased downstream from Silverton to the point where the dissolved load slightly exceeded the colloidal load at Durango (fig. 15). In contrast, the colloidal load increased continuously downstream during each of the three high-flow sampling trips. The colloidal load was about 10 times greater than the dissolved load during high flow. Dissolved and colloidal iron showed the same general pattern as aluminum (fig. 18B). In particular, the increase in the colloidal iron load from Silverton to Durango was very large compared to the low flow. However, dissolved and colloidal zinc varied from the iron and aluminum patterns because dissolved zinc transport was comparable to the colloidal transport at Silverton. Downstream at Durango and Cedar Hill, colloidal zinc transport was dominant (fig. 18C).

Cadmium, copper, and lead had the same seasonal pattern as aluminum, iron, and zinc. Concentrations of dissolved cadmium were near detection limits in all samples, but concentrations of colloidal cadmium were measurable. During high flow, the colloidal load of cadmium at Durango was 4.3 and 5.6 kg/day for the first two high-flow sampling trips, compared to 0.3 kg/day at low flow (fig. 18D). Colloidal copper loads increased even more between low and high flow, from 1.5 kg/day to greater than 133 kg/day during the May 1996 period (fig. 18E). The increase in the colloidal lead load at Durango was comparable to copper, from less than 3 kg/day to greater than 220 kg/day (fig. 18F). Thus, even though the loads of colloidal cadmium, copper, and lead were small in comparison to loads of aluminum, iron and zinc, these loads increased greatly during high flow and could have effects on toxicity if the metals entered the food chain or became bioavailable in some way.

Figure 16. Summary of mass transfer of aluminum in mixing zones downstream from Cement and Mineral Creeks.

Figure 17. Summary of mass transfer of iron in mixing zones downstream from Cement and Mineral Creeks.


Upstream from Cement Creek
Dissolved 10.4 kg/day
Colloidal 3.6 kg/day
Cement Creek
Dissolved 283 kg/day
Colloidal 4.6 kg/day
Downstream from Cement Creek
Calculated Sum
Dissolved 293 kg/day
Colloidal 8.2 kg/day
Observed
Dissolved 88 kg/day
Colloidal 249 kg/day
Dissolved loss 205 kg/day
Colloidal gain 241 kg/day
Dispersed Aggregated Colloids
Mineral Creek
Dissolved 12 kg/day
Colloidal 503 kg/day
Downstream from Mineral Creek
Calculated Sum
Dissolved 100 kg/day
Colloidal 744 kg/day
Observed
Dissolved 11 kg/day
Colloidal 488 kg/day
Dissolved loss 89 kg/day
Colloidal loss 256 kg/day
Settled Colloidal Aggregates


Upstream from Cement Creek
Dissolved < 0.1 kg/day
Colloidal 22.3 kg/day
Cement Creek
Dissolved 210 kg/day
Colloidal 114 kg/day
Dispersed Aggregated Colloids
Downstream from Cement Creek
Sum
Dissolved 210 kg/day
Colloidal 136 kg/day
Observed
Dissolved 135 kg/day
Colloidal 242 kg/day
Dissolved loss 75 kg/day
Colloidal gain 106 kg/day
Mineral Creek
Dissolved 310 kg/day
Colloidal 482 kg/day
Settled Colloidal Aggregates
Downstream from Mineral Creek
Sum
Dissolved 445 kg/day
Colloidal 724 kg/day
Observed
Dissolved 192 kg/day
Colloidal 490 kg/day
Dissolved loss 253 kg/day
Colloidal loss 234 kg/day

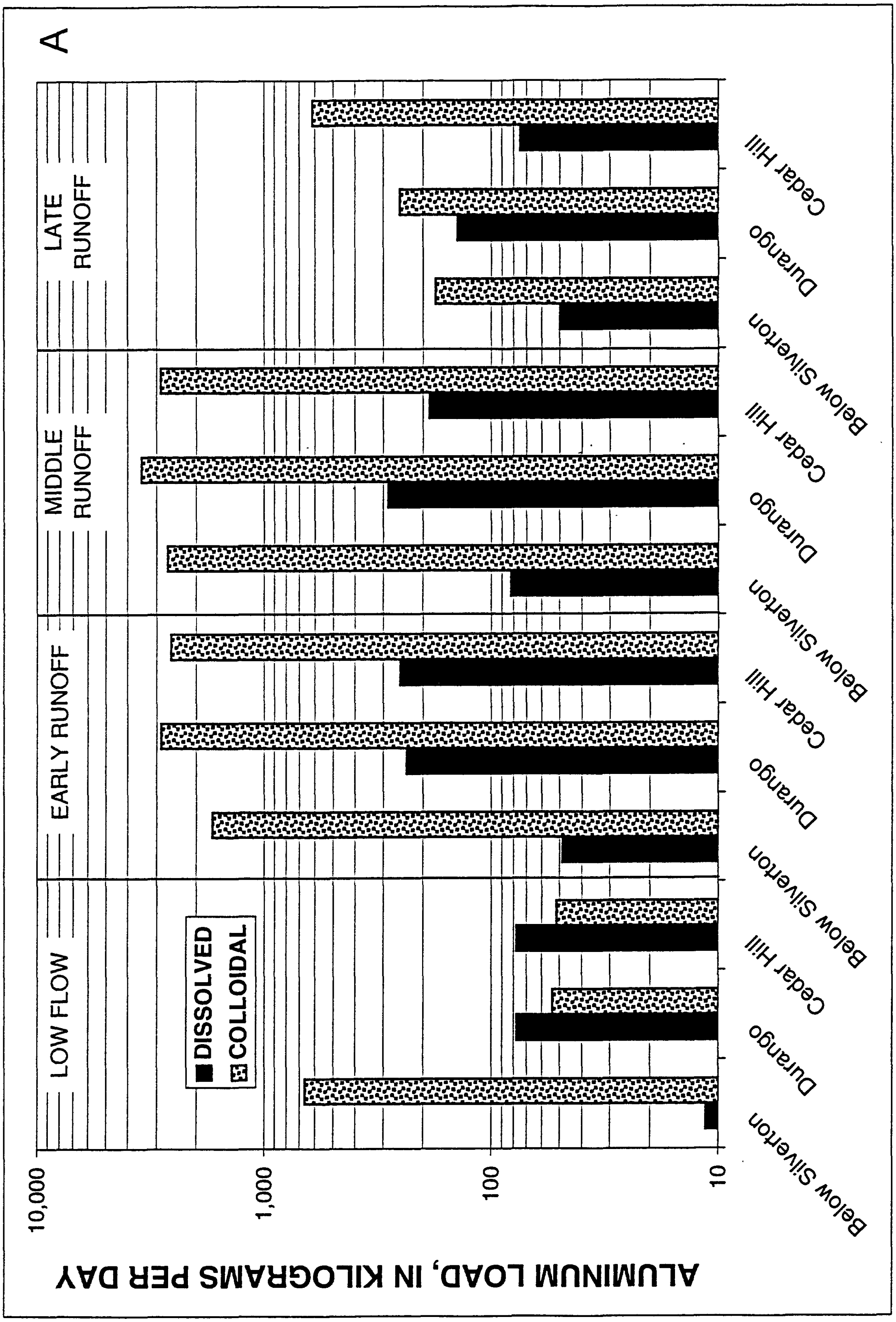
Not only was the colloidal load the dominant phase for these six metals, but the mass of colloidal load at high flow was much greater than at low flow. For example, at Durango, the colloidal zinc load was 15 kg/day during low flow, but 1,060, 1,450, and 114 kg/day were observed during the three high-flow sampling periods. High-flow trends of colloidal aluminum and zinc loads were comparable. Thus, during high flow from snowmelt runoff, the colloidal material that was deposited in the bed sediments during low flow was resuspended and flushed downstream. This annual event has important implications for water use downstream because water piped or stored from the Animas River during high flow will have a much greater colloidal load than at low flow. Without filtration and removal from the water, these colloids would be transported through any pumping system almost as if they were dissolved solutes.

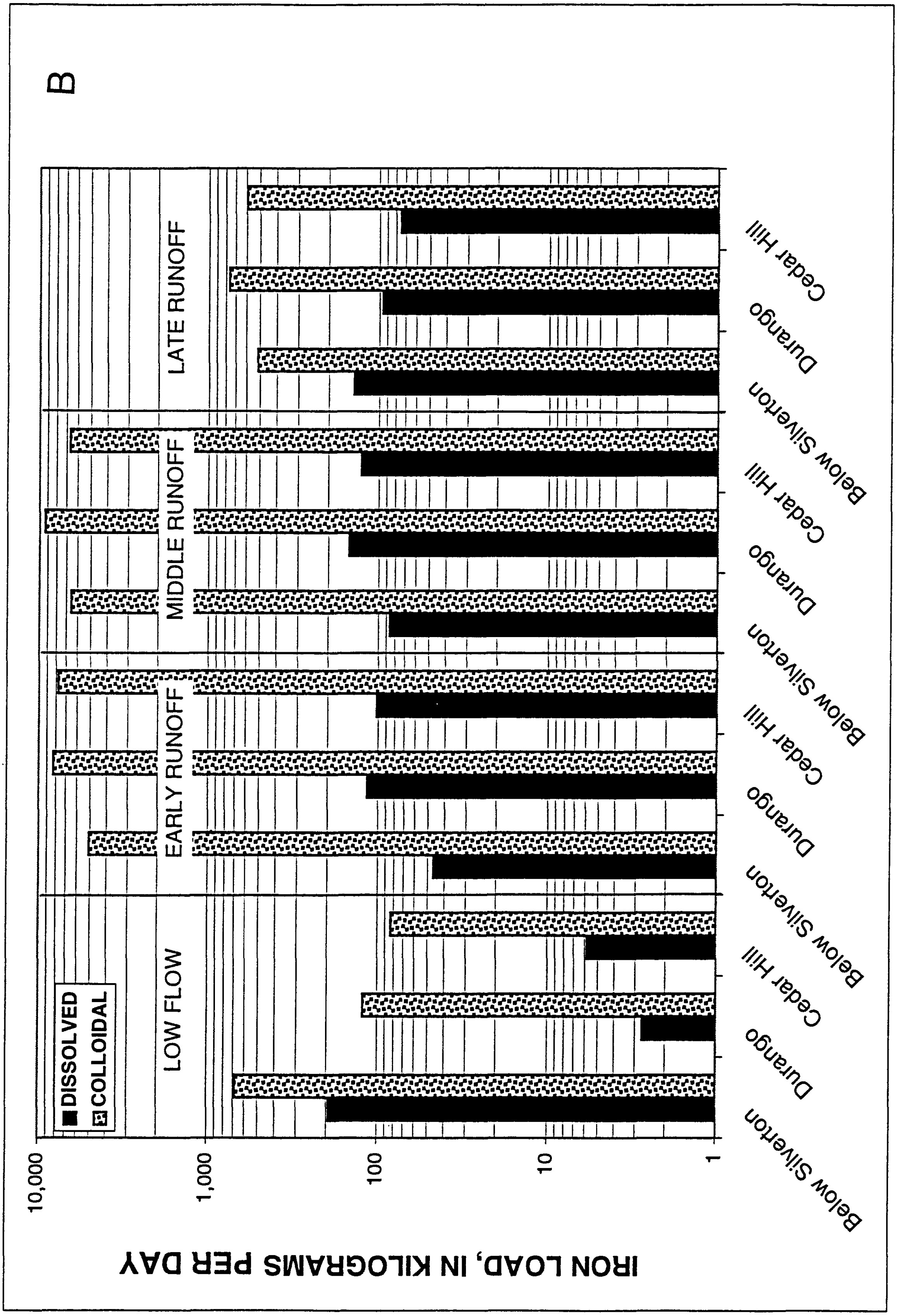
RESULTS FROM STREAM-SEDIMENT DATA

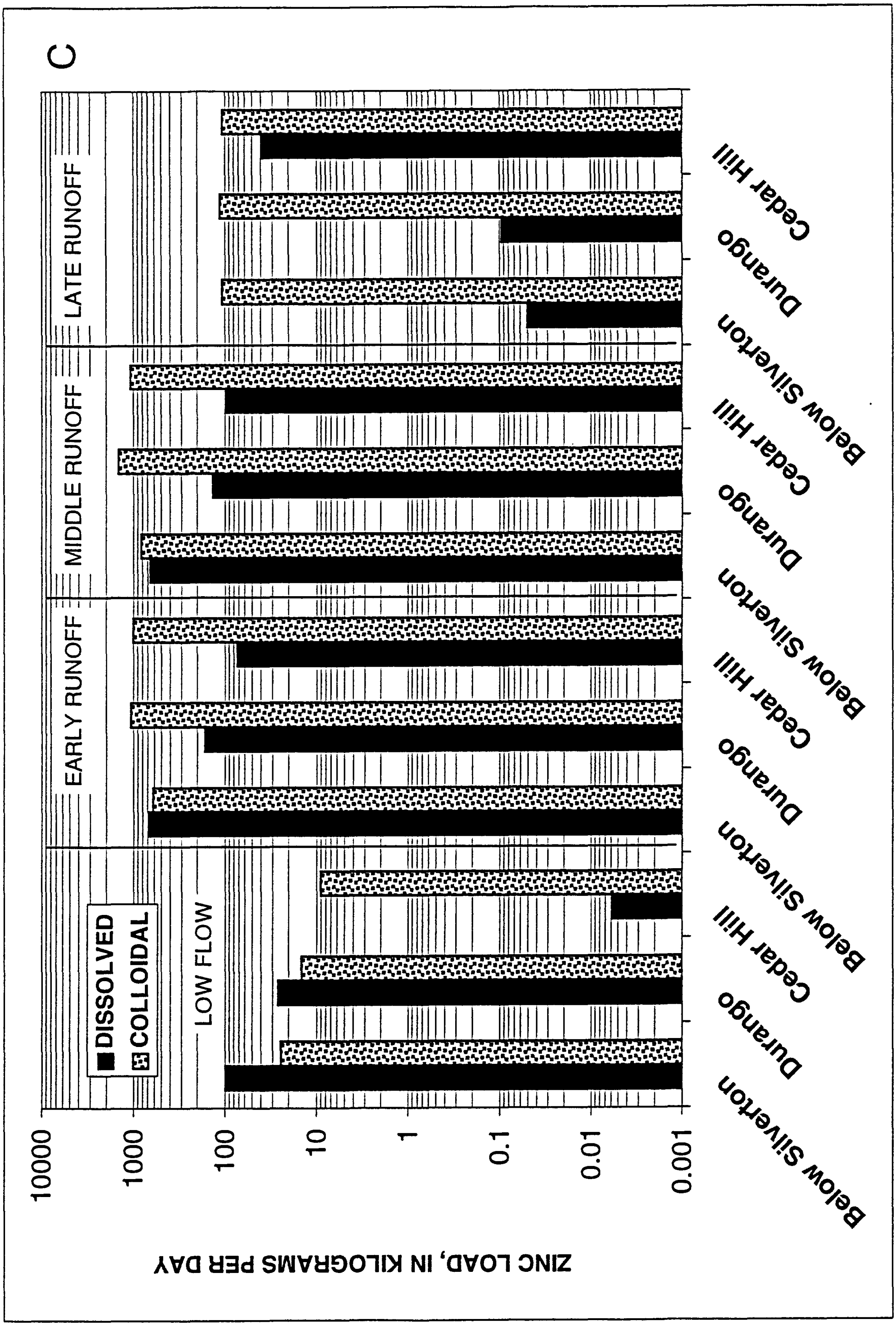
In the following discussion, we focus on the geochemical results from the main tributaries using data for seven elements: arsenic (As), cobalt (Co), copper (Cu), lead (Pb), strontium (Sr), vanadium (V), and zinc (Zn). The concentrations of cobalt, strontium, and vanadium do not vary significantly in the rocks underlying the Animas River watershed and reflect the rock geochemistry throughout the Animas River watershed, whereas the other four metals are largely derived from the various mineral deposits or alteration zones within the upper Animas River watershed upstream from Silverton. The enrichment of metals above crustal abundance values (CAV) is not only environmentally significant, but is used in assessing areas where mineral deposits might be present. In mineral exploration, areas characterized by metal concentrations three or more times above the CAV are routinely evaluated. For the seven elements discussed below, the CAV is: As, 1.8 ppm; Co, 29 ppm; Cu, 68 ppm; Pb, 13 ppm; Sr, 384 ppm; V, 136 ppm; and Zn, 76 ppm (Fortescue, 1992). Whereas we will use this enrichment concept in the discussion and evaluation of the metal distribution profiles, the CAV for an element in any given area should not be assumed to represent the background in that area. The geochemical background prior to mining must be determined by looking at premining sediments within the watershed.

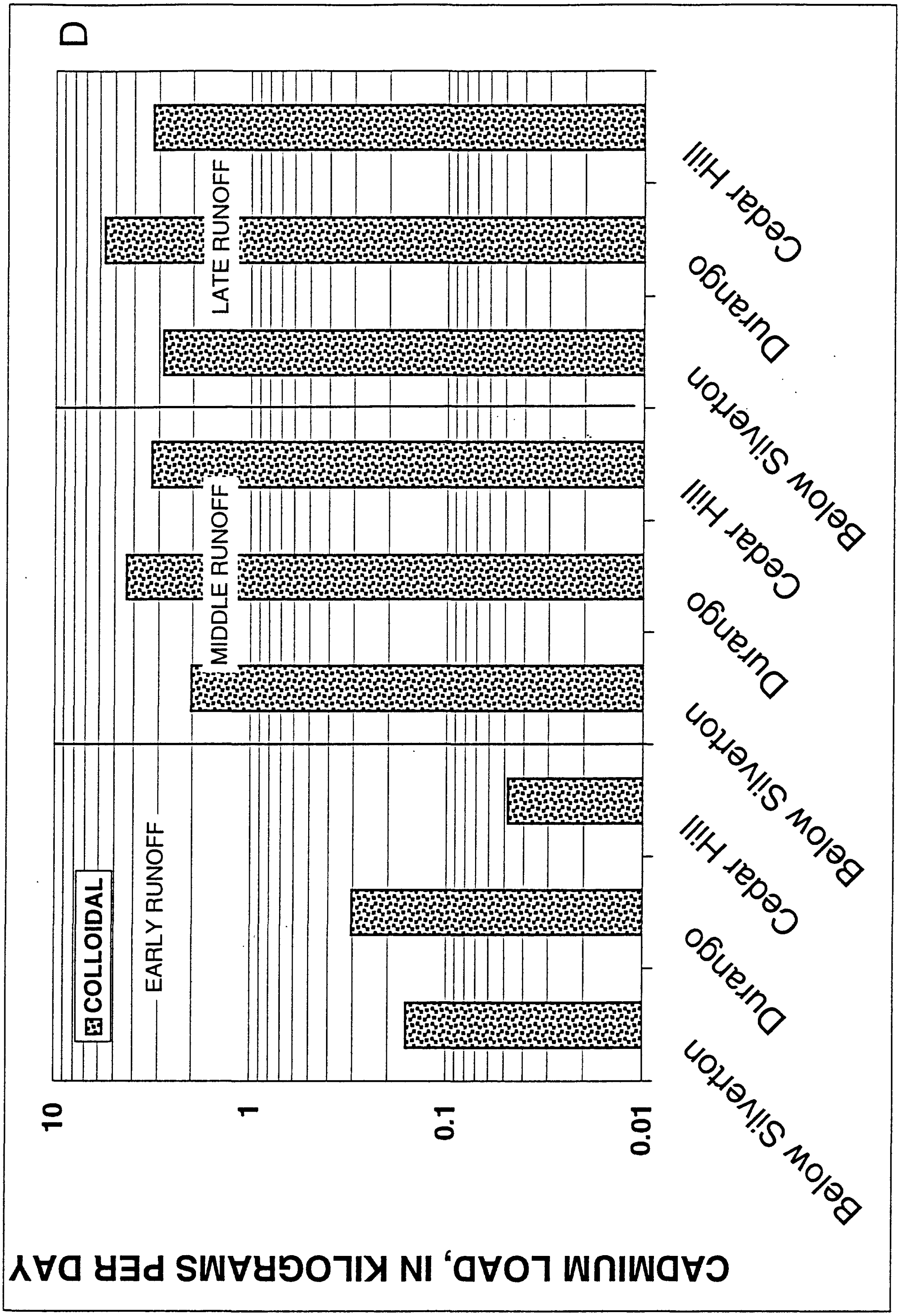
These seven metals are present in several different mineralogical sites in the rocks and mineralized zones in the watershed. Metals sorbed onto the iron-hydroxides are weakly bound and are totally released by the 2M HCl-1%H_2O_2 digestion. Metals in the oxide and sulfide phases will be partially to completely digested by the 2M HCl-1%H_2O_2 leach procedure whereas metals in the silicate phases will not be removed 2M HCl-1%H_2O_2 digestion (Church and others, 1987). Minor amounts of metals reside in carbonate phases. Strontium, for example resides almost entirely in the silicate phase. Vanadium resides in the iron oxides hematite and magnetite in volcanic and plutonic rocks. Cobalt resides in both silicate phases and in pyrite. Copper, lead, and zinc reside in silicate phases, but are greatly enriched in mineral deposits as are arsenic and antimony. We will focus our geochemical discussion primarily on the geochemical results from the 2M HCl-1%H_2O_2 digestion procedure because this digestion removes all of the metals present in iron-hydroxide phases, including the colloidal precipitates. We refer to the metals removed by this leach as the "labile" metal component. Comparisons of the yields from the 2M HCl-1%H_2O_2 digestion procedure relative to the data from the total digestion are very useful because significant portions of some metals in the stream sediments may be transported as detrital oxide and sulfide minerals. The primary sulfide minerals are: arsenopyrite (the primary source of arsenic), which is not digested by the 2M HCl-1%H_2O_2 leach procedure; pyrite (the primary source of cobalt), which is not digested by the 2M HCl-1%H_2O_2 leach procedure; chalcopyrite (the primary source of copper), which is not digested by the 2M HCl-1%H_2O_2 leach procedure; galena (one primary source of lead), which is readily digested by the 2M HCl-1%H_2O_2 leach procedure; sphalerite (the primary source of zinc), which is partially digested by the 2M HCl-1%H_2O_2 leach procedure; and tetrahedrite (a source of copper, lead, silver, arsenic, and antimony), which is not digested by the 2M HCl-1%H_2O_2 leach procedure (S.E. Church, unpubl. data). Thus, a comparison between the two data sets will provide some measure of the distribution of the metals present in the different mineralogical phases present in the bed sediments. In addition, vanadium in this environment is concentrated in magnetite and specular hematite, which are the "heavy" iron-oxide minerals. Some vanadium associated with the weathering of magnetite or hematite can be extracted by the 2M HCl-1%H_2O_2 digestion procedure, but vanadium data from the total digestion will be used as an indicator of placer accumulation of heavy minerals at the sites where bed-sediment samples were collected.

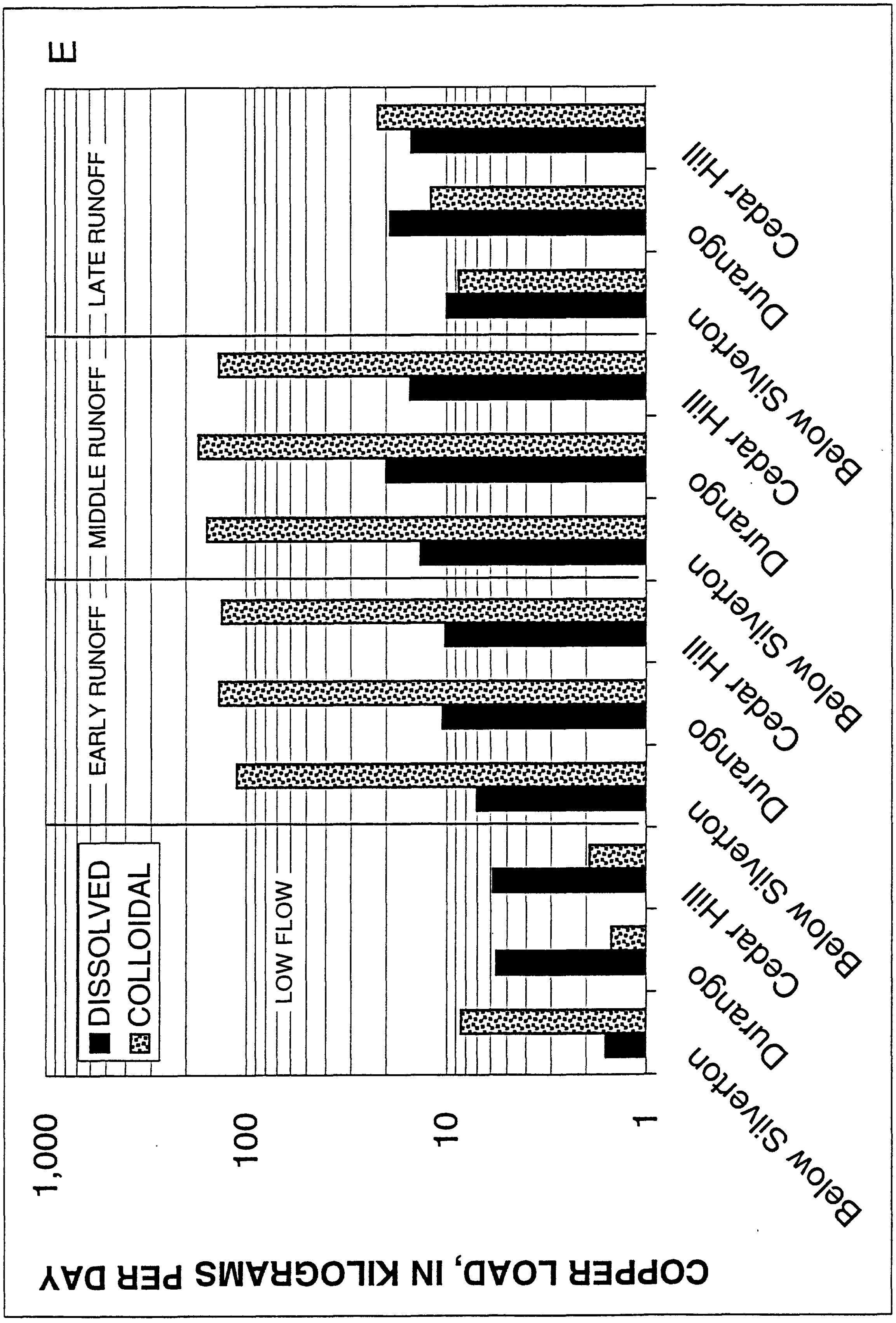
Figure 18. Metal loads of aluminum (A), iron (B), zinc (C), cadmium (D), copper (E), and lead (F) at high and low flow in the Animas River. Results are grouped by sampling trips; low-flow conditions, Oct. 1995, and high-flow conditions, May 9-10, May 21-22, and June 18-19. Steam flow discharge is on figure 9.

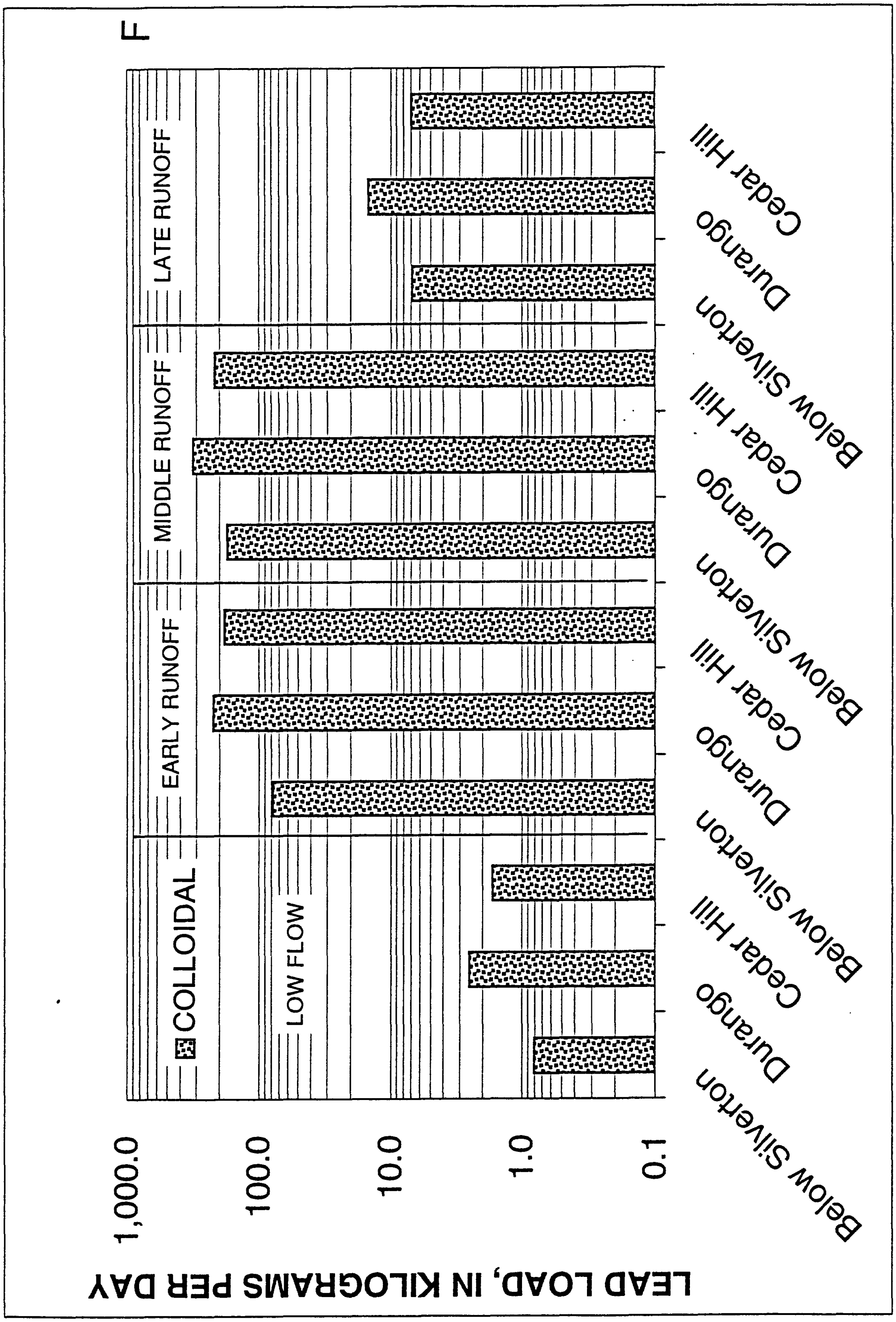

A
LOW FLOW
EARLY RUNOFF
MIDDLE RUNOFF
LATE RUNOFF
DISSOLVED
COLLOIDAL
10,000
1,000
100
10
ALUMINUM LOAD, IN KILOGRAMS PER DAY
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill


B
IRON LOAD, IN KILOGRAMS PER DAY
10,000
1,000
100
10
1
DISSOLVED
COLLOIDAL
LOW FLOW
EARLY RUNOFF
MIDDLE RUNOFF
LATE RUNOFF
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill


C
ZINC LOAD, IN KILOGRAMS PER DAY
10000
1000
100
10
1
0.1
0.01
0.001
DISSOLVED
COLLOIDAL
LOW FLOW
EARLY RUNOFF
MIDDLE RUNOFF
LATE RUNOFF
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill


D
CADMIUM LOAD, IN KILOGRAMS PER DAY
10
1
0.1
0.01
COLLOIDAL
EARLY RUNOFF
MIDDLE RUNOFF
LATE RUNOFF
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill


E
COPPER LOAD, IN KILOGRAMS PER DAY
1,000
100
10
1
DISSOLVED
COLLOIDAL
LOW FLOW
EARLY RUNOFF
MIDDLE RUNOFF
LATE RUNOFF
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill


F
COLLOIDAL
LOW FLOW
EARLY RUNOFF
MIDDLE RUNOFF
LATE RUNOFF
1,000.0
100.0
10.0
1.0
0.1
LEAD LOAD, IN KILOGRAMS PER DAY
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill
Below Silverton
Durango
Cedar Hill

Placer accumulation occurs when the carrying capacity of the stream is high and the silicate detrital rock fragments are carried away while leaving the heavy-mineral phases behind. Most of the heavy-mineral phases have a density (specific gravity, sp. gr.) between 4.3 and 5.3 with the exception of galena (sp. gr. of 7.6) and gold (sp. gr. between 15-19); magnetite has a sp. gr. of 5.2. Thus, the monitoring of magnetite distribution is an excellent measure of the placering process. Since we are interested in the supply of metals to the streams rather than concentration of metals at a specific site in a stream reach by hydraulic processes, the use of the vanadium concentration provides a measure of the distribution of magnetite and shows the influence of the placering effect on the geochemical data set.

Bed-sediment samples collected from stream reaches for this study were analyzed for both the labile and total metal content. The geochemical data are presented in two formats, a map format and a profile format plotted against river distance, to aid in the interpretation of the metal dispersion or dilution patterns downstream. Geochemical data showing the dispersion of copper, lead, and zinc from the main tributaries and the Animas River are in a map format on figures 19-21. The metal concentrations for the intervals are the same as those used in the regional geochemical maps (see figs. 6-8). A comparison of the reconnaissance geochemical map for copper (fig. 6) with the "ribbon" map showing the dispersion of copper (fig. 19) indicates that the concentration of copper in bed sediments exceeds 200 ppm for all of the Animas Canyon reach and for much of the lower Animas River south to Durango. In contrast, the copper concentration in stream sediments from tributaries throughout the watershed in areas underlain by either the Precambrian rocks that crop out in the Animas Canyon reach or the Paleozoic, Mesozoic, and Tertiary sedimentary rocks (fig. 3) that crop out in the lower Animas River generally have concentrations in the 40 ppm or less range (fig. 6). Clearly the source of copper in the bed sediments of the Animas River south of Silverton is from the Animas River watershed upstream from Silverton. The lead (fig. 7 and fig. 20) and the zinc "ribbon" maps (fig. 8 and fig. 21) show a pattern similar to that of copper, although the concentrations vary in magnitude.

For ease of presentation, the geochemical and lead-isotopic data in the profiles are plotted against downstream distances measured in kilometers (km) from the confluence of Mineral Creek with the Animas River below Silverton, which was arbitrarily assigned a value of 25 km. The reaches of the Animas River above and below Silverton are plotted separately. The sample site on the Animas River below the confluence (that is, site A-72 in the CDPHE data base at 26.25 km) is plotted as the most downstream point on all of the geochemical and lead-isotopic plots of data from the main tributaries (figs. 22-27) and the most upstream point on the plots of the data from the lower Animas River (figs. 28-29).

Sample types on these diagrams have been divided into five different categories: River (bed-sediment samples from the main tributaries or the Animas River), Tribs (bed-sediment samples from small tributary basins), Ovrbk seds (fine-grained sediment samples collected from bars or from the stream banks representing sediment transported during high water that has been subjected to wetting and drying and are a source of water-soluble salts), Other (largely samples of water-soluble efflorescent salts associated with the overbank sediments collected), and Mill tails (fine-grained deposits of mill tailings within the flood plain). Identification of specific sample types is in the data tables in the appendices and on individual figure captions.

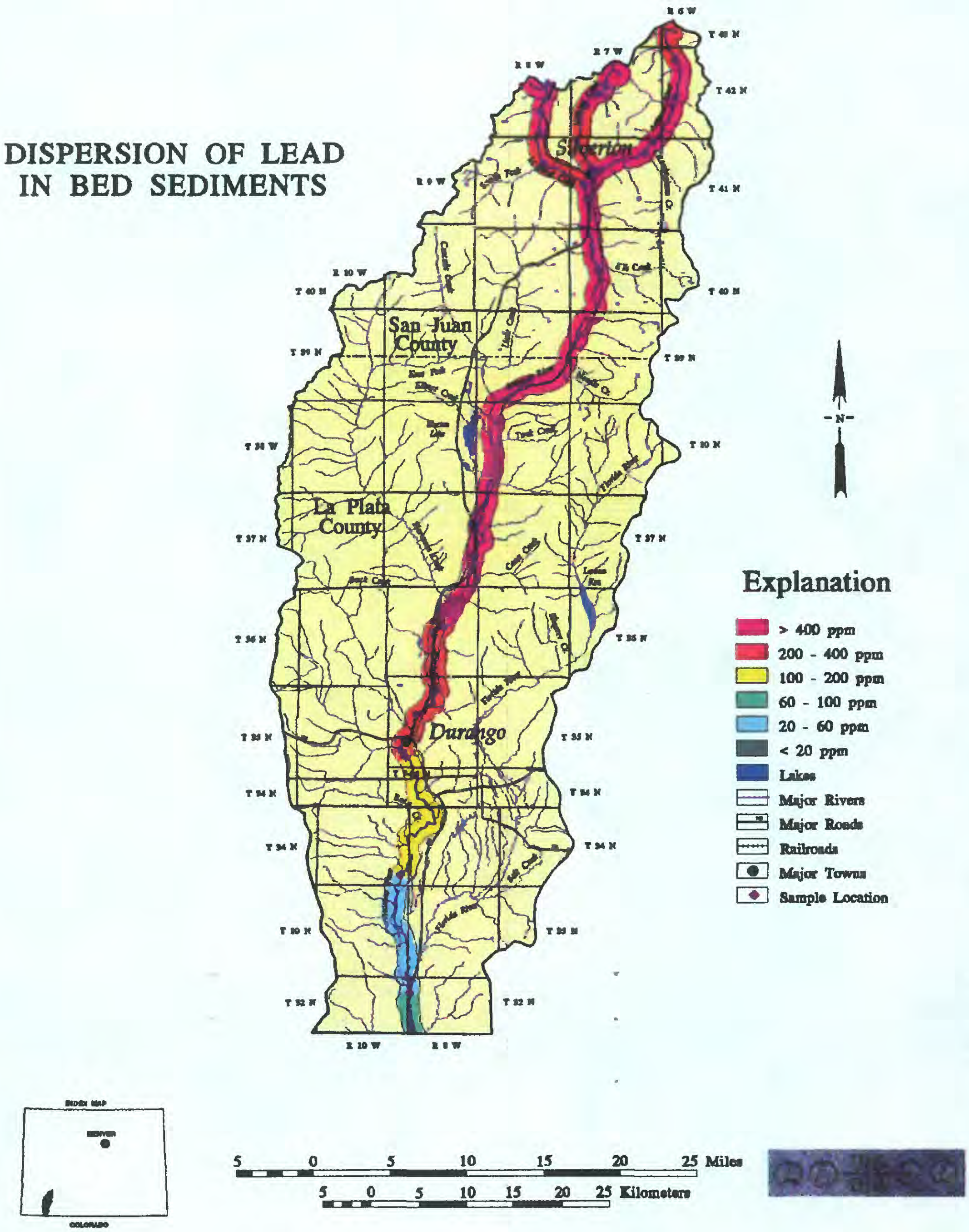
Figure 19. Ribbon map showing the dispersion of copper in bed sediments in Mineral and Cement Creeks and the Animas River. Data from the major tributary streams during the 1995 sampling to evaluate the contributions of metals from the major tributary drainages in the Animas River watershed. Important tributary streams are labeled for reference; hydrology data are from USGS (1989); and the towns, railroads, and roads are from ESRI (1992).

Figure 20. Ribbon map showing the dispersion of lead in bed sediments in Mineral and Cement Creeks and the Animas River. Data from the major tributary streams during the 1995 sampling to evaluate the contributions of metals from the major tributary drainages in the Animas River watershed. Important tributary streams are labeled for reference; hydrology data are from USGS (1989); and the towns, railroads, and roads are from ESRI (1992).

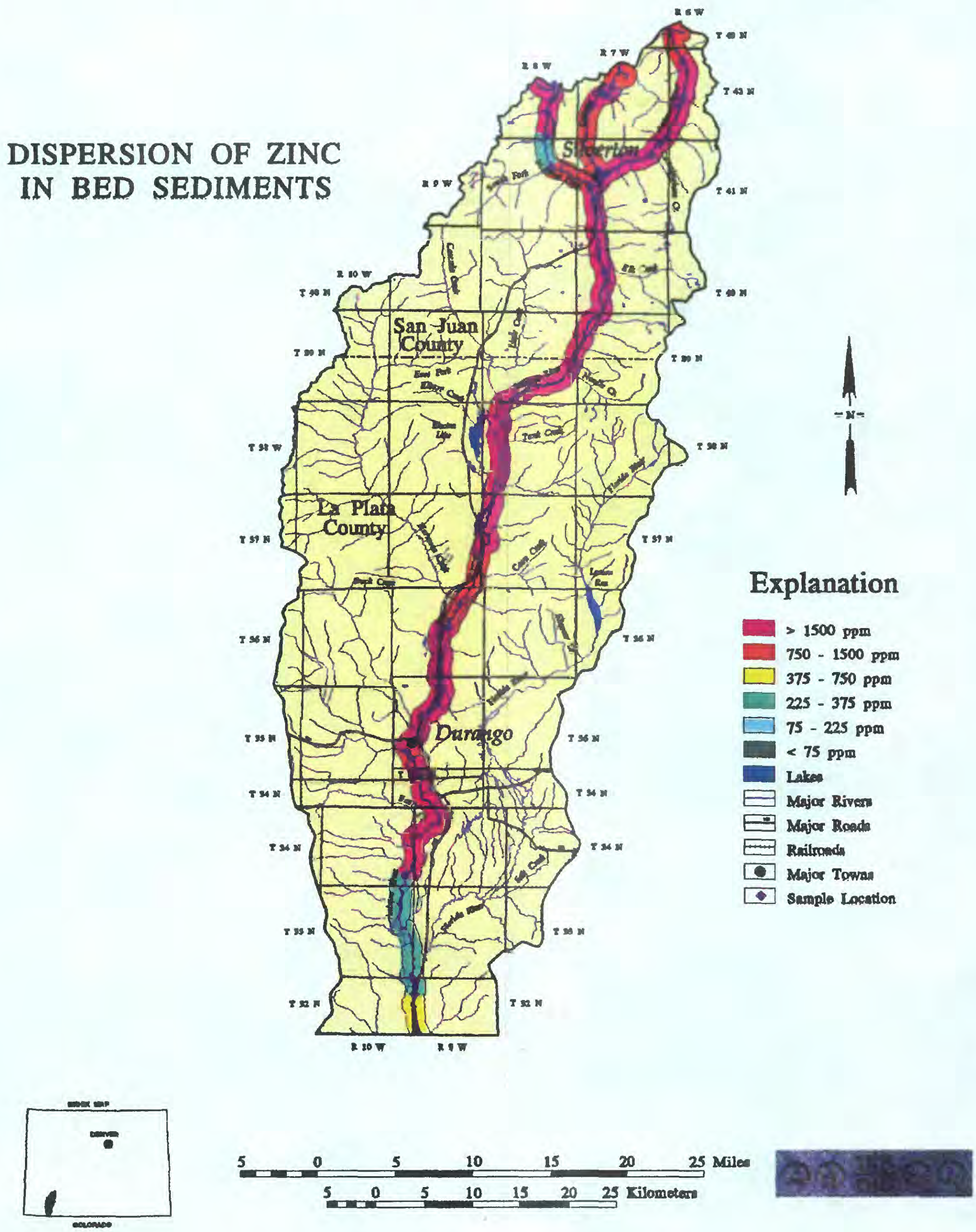
Figure 21. Ribbon map showing the dispersion of zinc in bed sediments in Mineral and Cement Creeks and the Animas River. Data from the major tributary streams during the 1995 sampling to evaluate the contributions of metals from the major tributary drainages in the Animas River watershed. Important tributary streams are labeled for reference; hydrology data are from USGS (1989); and the towns, railroads, and roads are from ESRI (1992).


ANIMAS RIVER WATERSHED STUDY
SOUTHWESTERN COLORADO
DISPERSION OF COPPER
IN BED SEDIMENTS
Silverton
San Juan County
La Plata County
Durango
Explanation
> 1300 ppm
650 - 1300 ppm
325 - 650 ppm
200 - 325 ppm
65 - 200 ppm
< 65 ppm
Lakes
Major Rivers
Major Roads
Railroads
Major Towns
Sample Location
N
5 0 5 10 15 20 25 Miles
5 0 5 10 15 20 25 Kilometers

ANIMAS RIVER WATERSHED STUDY
SOUTHWESTERN COLORADO



ANIMAS RIVER WATERSHED STUDY
SOUTHWESTERN COLORADO



sample types is in the data tables in the appendices and on individual figure captions. Data from both the total digestion data and the 2M HCl-1% H_2O_2 data are plotted; these data will be referred to as the total metal and the labile metal concentrations.

We also analyzed the labile component for the lead-isotopic composition of the samples to "fingerprint" different sources of lead within the basin and to quantify the relative contributions of metals from the different mining districts to the total mass of metal in the bed sediments. Lead-isotopes can be used as a tracer of the fluvial processes because the unmineralized rocks and mineral deposits have differing lead-isotopic signatures. Three of the four isotopes of lead increase with time because they are the daughter products of the radioactive decay of uranium and thorium. For example, the amount of ^{206}Pb has approximately doubled over the age of the earth. Relative to ^{204}Pb, which has no radioactive parent, the $^{206}Pb/^{204}Pb$ value has increased from about 9.35 at the time of the formation of our solar system to about 18.8 today. This change has resulted from the decay of ^{238}U. Similar changes have occurred for the growth in ^{207}Pb resulting from the decay of ^{235}U, and ^{208}Pb resulting from the decay of ^{232}Th, although the change in the $^{207}Pb/^{204}Pb$ is now insignificant for this particular application because of the short half-life of ^{235}U. The "fingerprinting" of the different mineral deposit districts is possible because, at the time of the formation of the deposits, the lead contained in the deposits was separated from the radioactive parents and the composition of the lead-isotopic ratios was "frozen" into the deposits. In contrast, lead in the rocks within the Animas River watershed continues to change with time in direct proportion to the ratio of the parent isotopes to ^{204}Pb. Lead is abundant in these mineral deposits. Lead from the deposits is readily removed by weathering and deposited in the bed sediments by sorbtion to or precipitation with the iron-hydroxide precipitates. This lead is readily removed by the 2M HCl-1%H_2O_2 leach procedure (100%). In contrast, only a small portion of the silicate-bound lead in unmineralized rock is released by weathering of the silicate minerals in the rocks that crop out in the basin. About 20-25 percent of the "silicate-bound rock lead" is extracted by the 2M HCl-1%H_2O_2 leach procedure. This "rock-lead" signature will be more radiogenic than the composition one would obtain from the total digestion as shown in earlier work (Gulson and others, 1992; Church and others, 1993). Therefore, the abundant lead from the mineral deposits, which is often present at hundreds to thousands of ppm, overwhelms the lead derived from weathering of silicate-bound lead from unmineralized rocks that crop out within the Animas River watershed and provides a sensitive tracer to measure the contribution of metals from mineralized areas within the basin.

Lead-isotopic data from galena in the deposits in the Silverton area are given in table 2. These limited data suggest that lead-isotopic composition of galena from the vein-type ore from the Eureka graben (fig. 4) varies over a small range (samples 1-3, table 2). The data from the two samples collected from the Eureka Mill and the Sunnyside Mill and from float in Cement Creek are of less value because we do not know which deposits they represent. The analysis from the Marcella Mine represents ore from a deposit associated with the Sultan Stock (fig. 4). The analysis of the lead from the white precipitate from the Paradise portal on the Gem claim on the Middle Fork of Mineral Creek indicates that this deposit differs from that of the vein-type ore lead from the Eureka graben. The composition of lead from the iron-hydroxide precipitate from the Koehler adit (appendix VII) also differs from the Eureka graben vein-type ore lead. The compositions of the galena samples are plotted on the lead-isotope diagrams when the mineralization type is present within the individual subbasin.

Mineral Creek Drainage Basin

Geochemical and lead-isotopic results from the bed sediments from Mineral Creek are summarized in figures 22-23. At the headwaters of Mineral Creek, an iron-hydroxide precipitate sample from the Koehler adit contains enriched concentrations of ore-related metals. This sample was totally digested by the 2M HCl-1%H_2O_2 leach demonstrating that metals deposited by precipitation from aqueous AMD solutions in the iron-hydroxides phases are completely extracted by this acid leach solution. The Koehler adit drains into a small collection basin from one of the chimney deposits (fig. 4), which are base-metal-rich breccia pipes associated with porphyry-type mineral deposits (Cox, 1986). Direct discharge of sediments into the headwaters of Mineral Creek from the collection basin below the Koehler adit is not certain. The data from the Koehler adit discharge is used in this report to indicate that the chimney deposits are a source, rather than the only source of these metals.

Arsenic

Arsenic concentration in the Koehler adit sample (4,400 ppm) is about 2,500 times CAV. The concentration of arsenic in bed sediments of Mineral Creek downstream from the Koehler adit show a continuous dilution of arsenic resulting from addition of sediments from the tributaries in the basin (fig. 22A).

Table 2. Lead-isotopic data from mineral deposits and mill sites in the Silverton study area

Locality	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Sunnyside Mine[1]			
DH-B1	18.285	15.556	37.919
74BRD-4	18.294	15.563	37.949
74BRD-3	18.367	15.562	37.959
Sunnyside Mill[1]			
66DV-1	18.549	15.603	38.242
Eureka Mill Site[2]			
95ABS105-GN	18.228	15.537	37.787
Kittimac Mill Site[2]			
95ABS106	18.787	15.635	38.278
Galena in float, Cement Creek[2]			
95ABS120-GN	18.367	15.551	37.944
Paradise portal, Gem claim[2]			
95ABSPD	18.781	15.581	38.142
Marcella Mine, Kendall Mountain[1]			
46DV39	18.498	15.595	38.056

[1] Data from Doe and others (1979).
[2] New data from this study.

Arsenic is diluted from about 130 times CAV on the upper part of Mineral Creek at Chattanooga to about 11 times CAV above the confluence with the Animas River below Silverton. A comparison of the yields for arsenic in the 2M HCl-1%H_2O_2 digestion versus the total digestion indicates that arsenic is consistently present in the bed sediments at a concentration of 20-30 ppm higher in the total digestion on a sample-to-sample basis (fig. 22B). This indicates that arsenic is present in both the iron-hydroxide phase as well as in a sulfide phase, probably arsenopyrite. At the Chattanooga site, as much as 85-90 percent of the arsenic may have come from the Koehler adit or from acid mine drainage directly from these chimney deposits. There is no direct measure of the arsenic component that may have been derived from the altered area surrounding the mineral deposits on Red Mountain.

Cobalt

Cobalt concentration is low in the sample from the Koehler adit, and the cobalt concentrations in the total digestions of the bed sediments of Mineral Creek are only slightly elevated above the concentrations in the tributaries (fig. 22C). The cobalt concentrations in the bed sediments of Mineral Creek are at or near CAV (29 ppm)and range between 10 and 30 ppm. Cobalt concentrations show no regular increase or decrease along the entire course of Mineral Creek. Comparison of the partial (labile) and total digestion data indicates that some portion of the cobalt is probably being transported in the bed sediments in pyrite.

Copper

Copper concentrations are about three times CAV (210 ppm) at the Koehler adit, are elevated to 5.6 times CAV at Chattanooga, and rise to about 13 times CAV at Burro Bridge above the confluence of the Middle Fork of Mineral Creek (fig. 22D). Below the Middle Fork of Mineral Creek to the confluence with the

Animas River, the concentration of copper drops to 100-110 ppm (about 1.5 times CAV) indicating that there are no substantive sources of copper to the bed sediments of Mineral Creek in these stream reaches. About 30-50 ppm of copper occurs in the sulfide phases, probably in chalcopyrite or a solid-solution component in pyrite. The increase in the copper concentration at Burro Bridge is entirely in the labile phase. Copper concentrations in bed sediments from the main tributaries to Mineral Creek are not supplying substantial amounts of copper to the bed sediments in these stream reaches. The source of the copper in the upper reaches of Mineral Creek has not been identified.

Lead

Lead concentrations at Koehler adit are 3,500 ppm (about 270 times CAV). Lead concentrations from bed sediments in the headwaters of Mineral Creek at Chattanooga (about 70 times CAV) and at Mill Creek (about 60 times CAV) indicate that the lead baseline is significantly elevated here (fig. 22E). Substantial mineral production and milling were done in the Red Mountain district near Chattanooga beginning in 1882 (Sloan and Skowronski, 1975). The chimney deposits at the headwaters of Mineral Creek are a major source of lead in the bed sediments of Mineral Creek. Lead concentrations from tributaries, including the Middle Fork of Mineral Creek, are in the range of 90-140 ppm. Lead concentrations drop to 200-240 ppm (15-18 times CAV) in bed sediments in the reach between the South Fork of Mineral Creek and the confluence with the Animas River below Silverton. Lead concentrations in the two digestions are essentially the same; small differences between the measured concentrations are presumed to be due to sample heterogeneity.

Strontium

Strontium concentration data from the total digestion of the bed sediments shows that there is relatively little strontium in the Koehler adit sample relative to that in the rocks being eroded within the basin. The strontium profile for Mineral Creek is relatively flat and the strontium concentrations in bed sediments from the tributaries brackets the concentration profile for bed sediments in Mineral Creek (fig. 22F). The average strontium concentration (223 ppm) is below the CAV (384 ppm).

Zinc

Labile zinc in the sample from Koehler adit is 200 ppm or about 2.6 times CAV. Zinc concentrations in the bed sediments differ substantially between the 2M HCl-1%H_2O_2 digestion (fig. 22G) and the total digestion (fig. 22H) suggesting that a substantial portion of the zinc in the bed sediments is transported in the sulfide mineral sphalerite. Sphalerite accounts for as much as 85 percent of the zinc in the bed sediments from the site at Chattanooga. Substantial sphalerite is also being added to this stream reach from Browns Gulch. The sphalerite component in the bed sediments of Mineral Creek drops to about 60 percent at Burro Bridge and the zinc concentration in the iron-hydroxide phase is also increased as did the concentration of labile copper at this site. Stream flow at the site above Burro Bridge was slow; the increase in metals associated with the colloidal phase in the bed sediments may be the result of accumulation of colloidal components at this site. Both sphalerite and labile zinc concentrations drop substantially between the Middle and South Forks of Mineral Creek. Downstream of the confluence of the South Fork, sphalerite and labile zinc concentrations again increase dramatically as Mineral Creek enters the mining area west of Silverton.

Vanadium

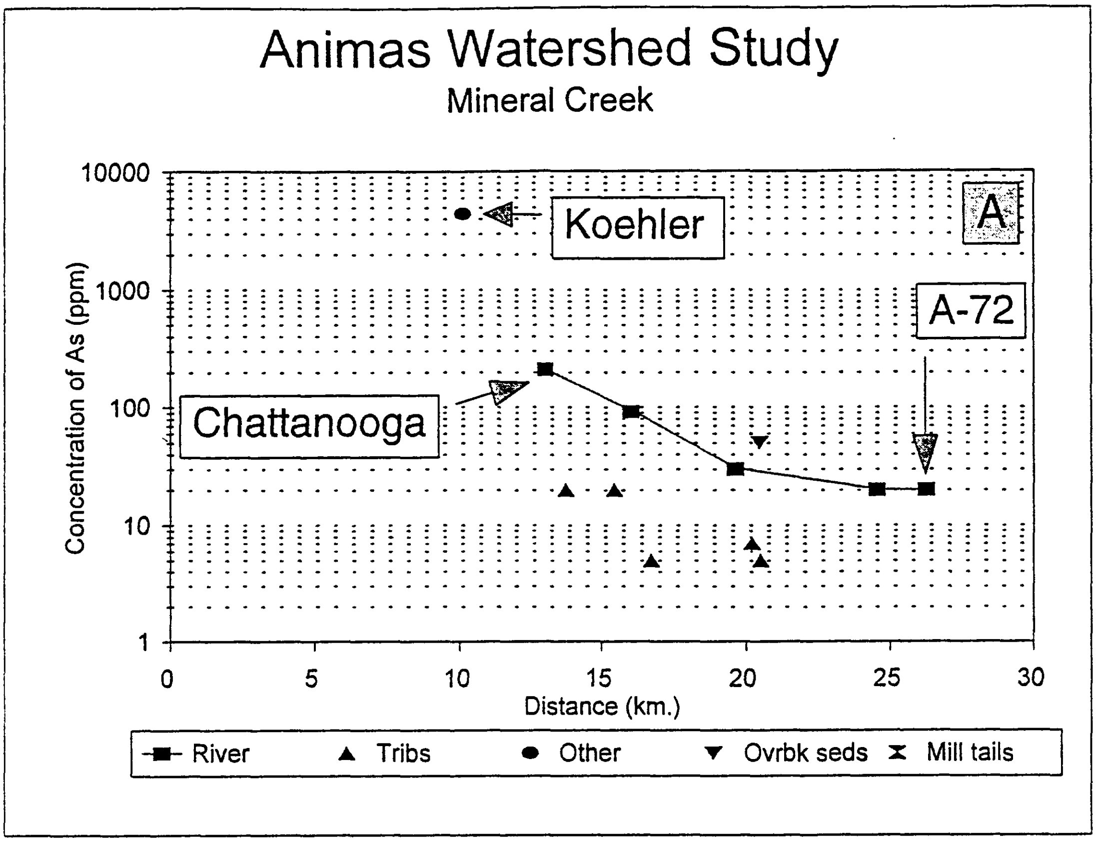
The profile of vanadium concentrations from the total digestion (fig. 22H) is relatively flat along the course of Mineral Creek averaging 110 ppm (CAV is 136 ppm), although the vanadium profile for Mineral Creek shows more variation than that for Cement Creek or the upper Animas River upstream from Silverton. Vanadium concentrations from tributaries are close to the values from the Mineral Creek samples and indicate that the samples from these localities are not significantly biased by hydrologic concentration of heavy minerals at any particular site. The site above the confluence of the South Fork of Mineral Creek does have low concentrations of vanadium suggesting that this sample may be somewhat biased toward the iron-hydroxide component rather than the heavy-mineral phases. We conclude that the elevated zinc concentrations are the result of addition of sphalerite to the stream reaches rather than concentration of heavy-mineral phases in a placer.

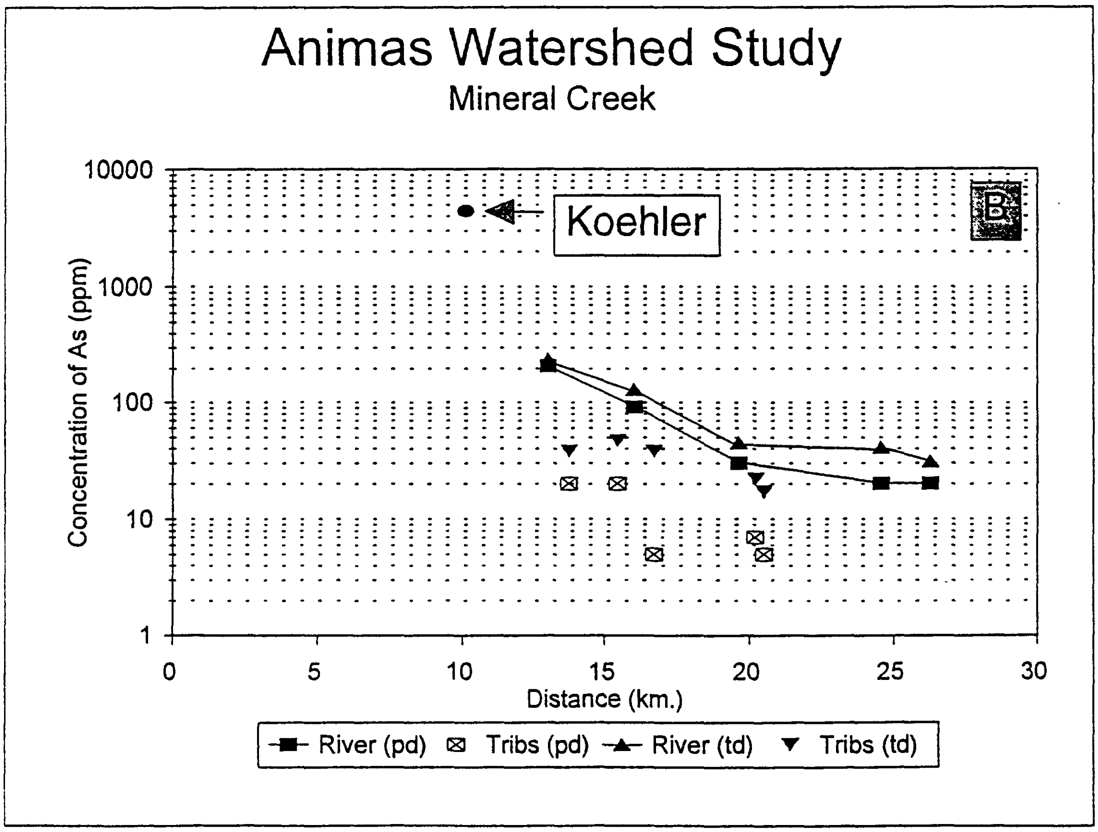
Lead-isotopic data

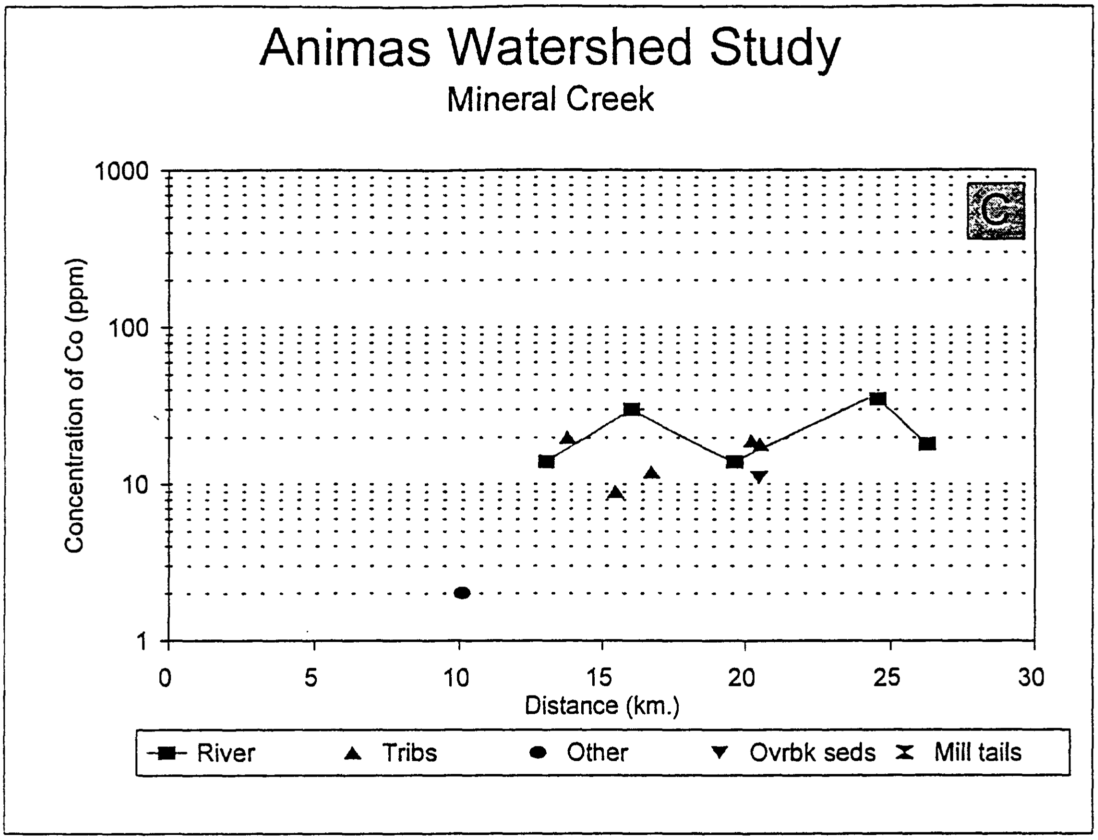
The lead-isotopic data (fig. 23A and B) from the Mineral Creek drainage indicate metals from several different deposit types are being added to bed sediments from the mineral deposits in the basin. Since there are no published lead-isotopic data from the chimney deposits, the results from the Koehler adit will be used as the signature of this deposit type. The lead-isotopic data available on galena from known mine sites or stream reaches is shown in these diagrams. Note that the composition of lead in the bed sediment from Chattanooga does not match well with the Koehler adit results for $^{208}Pb/^{204}Pb$, and that it is even more enriched in ^{208}Pb relative to the vein-type ore deposits than lead-isotopic data from the Koehler adit. The lead-isotopic data from Mill Creek and from the Middle and South Forks of Mineral Creek, all of which are on the west side of the Mineral Creek drainage, have lead-isotopic values that are more radiogenic than the vein-type ore signature whereas the bed-sediment sample from Browns Gulch matches the Eureka graben vein-type ore signature. The composition of lead in the sample from Burro Bridge on Mineral Creek above the confluence of the Middle Fork reflects the addition of vein-type ore lead from Browns Gulch. Between the confluence of Middle and South Forks of Mineral Creek, the lead-isotopic data indicate that the influence of the Eureka graben vein-type ore lead is being diluted by the addition of rock lead similar to that found in the tributaries on the west side of the Mineral Creek drainage. The overbank sediment sample from the confluence of the South Fork, however, matches the geochemical and lead-isotopic data from the upper reaches of Mineral Creek and represents a fluvial high-water deposit that contains a larger component of ore and ore-related metals from the upper part of the basin. The lead-isotopic composition in bed-sediments from Mineral Creek at low flow is higher than that of the Eureka graben vein-type ore lead signature, indicating that a different component of ore lead dominates the composition of lead in bed sediments from this drainage. This is not the case for bed sediments from Cement Creek or the upper Animas River above Silverton as will be shown below.

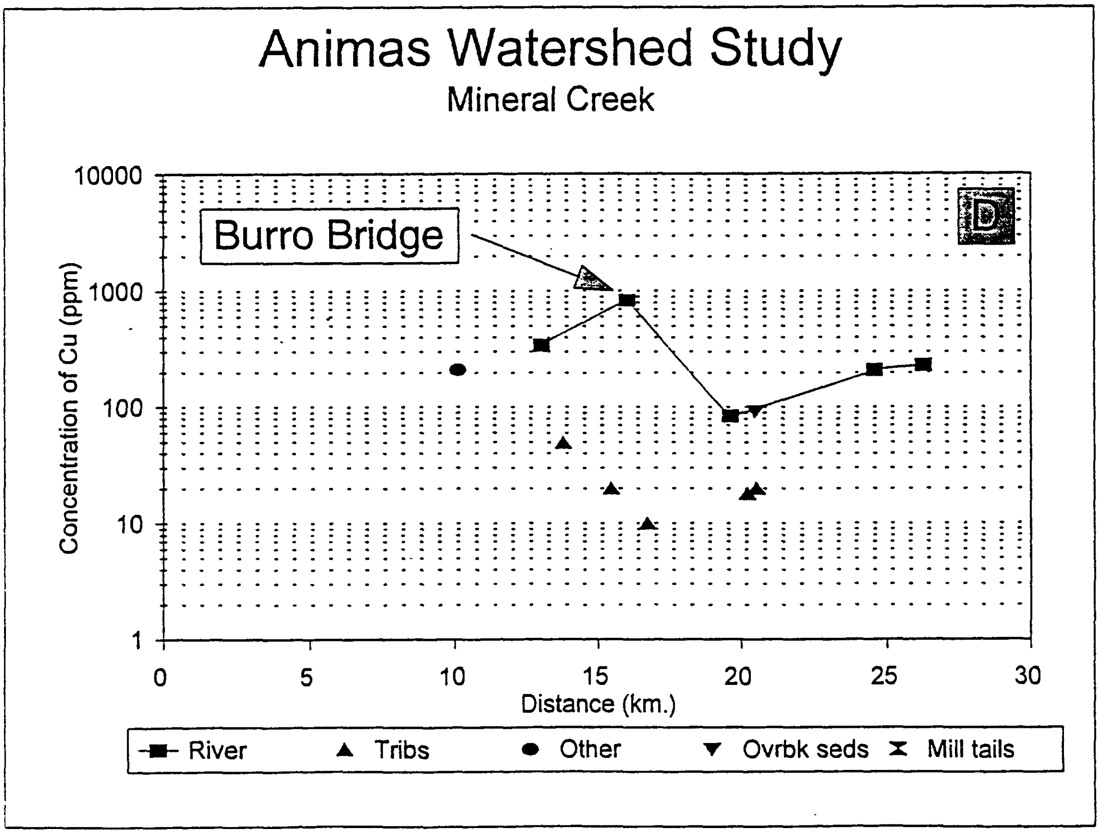
Figure 22. Metal distribution profiles (A-H) for Mineral Creek; metal concentrations for labile arsenic (As), total arsenic, total cobalt (Co), labile copper (Cu), labile lead (Pb), total strontium(Sr), labile and total zinc (Zn; pd--labile zinc from the partial digestion and td--total zinc) and total vanadium (V) are plotted against river distance measured upstream from the confluence of Mineral Creek (at 25 km) with the Animas River below Silverton, Colo. Data from four different sample types are plotted as indicated by the explanation on the diagrams; no mill tailings were sampled on Mineral Creek. Sample localities plotted are, beginning at the headwaters: Mineral Creek--Chattanooga (13 km), Burro Bridge (16 km), Mineral Creek above the confluence with the South Fork (19.6 km), Mineral Creek at the gaging station above the confluence with the Animas River (24.5 km), and the tie point at site A-72 on figure 28; the tributary samples--Mill Creek (13.75 km), Browns Gulch (15.45 km), Middle Fork Mineral Creek (16.7 km), South Fork Mineral Creek (2 samples, one in 1995, one in 1996; 20.45 km); and Other--the Koehler adit (10.1 km).

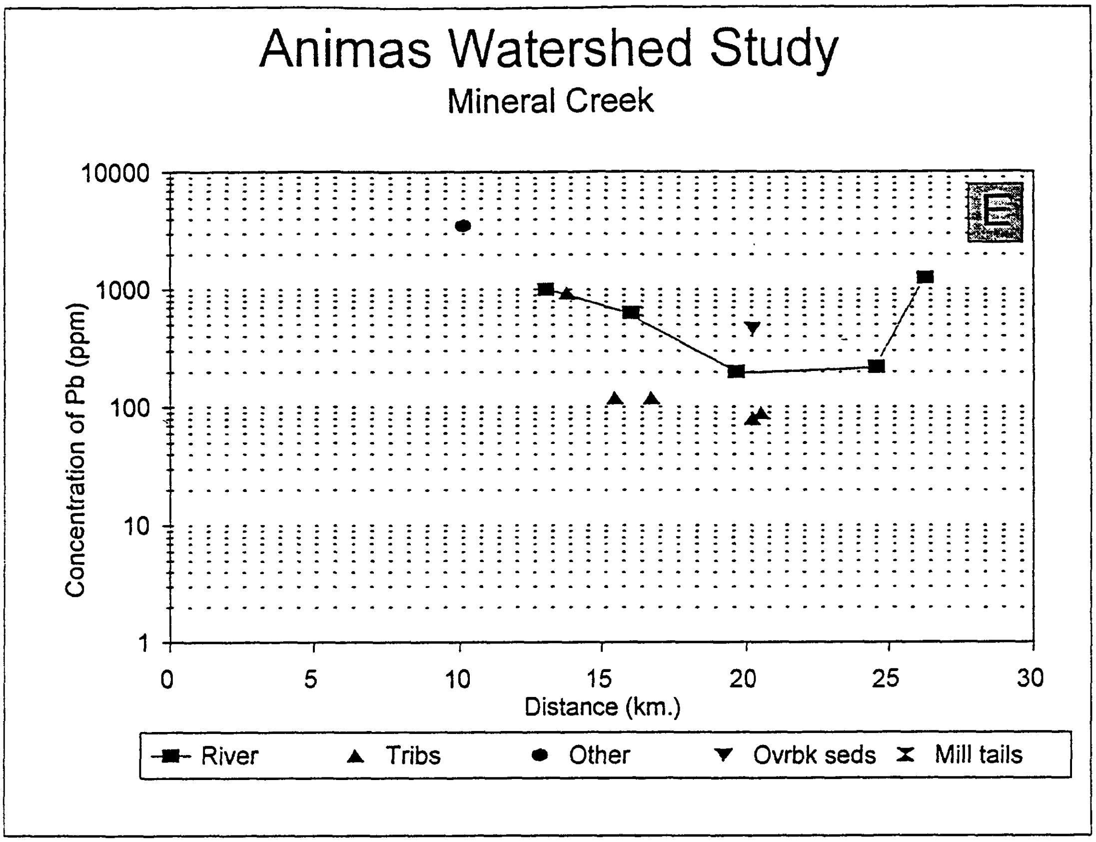
Figure 23. Lead-isotope distribution profiles for Mineral Creek plotted against river distance measured upstream from the confluence of Mineral Creek (at 25 km) with the Animas River below Silverton, Colo. Data from different sample types are plotted as indicated by the explanation on the diagrams; distances are as noted in the explanation for figure 22. Lead-isotopic data from the Paradise portal on the Gem claim on the Middle Fork of Mineral Creek and from the Eureka graben vein-type ore (table 2) are plotted for comparison. The data from site A-72, the first site on the Animas River below the confluence, are plotted on all the diagrams to provide a tie-point with the data on figure 29.

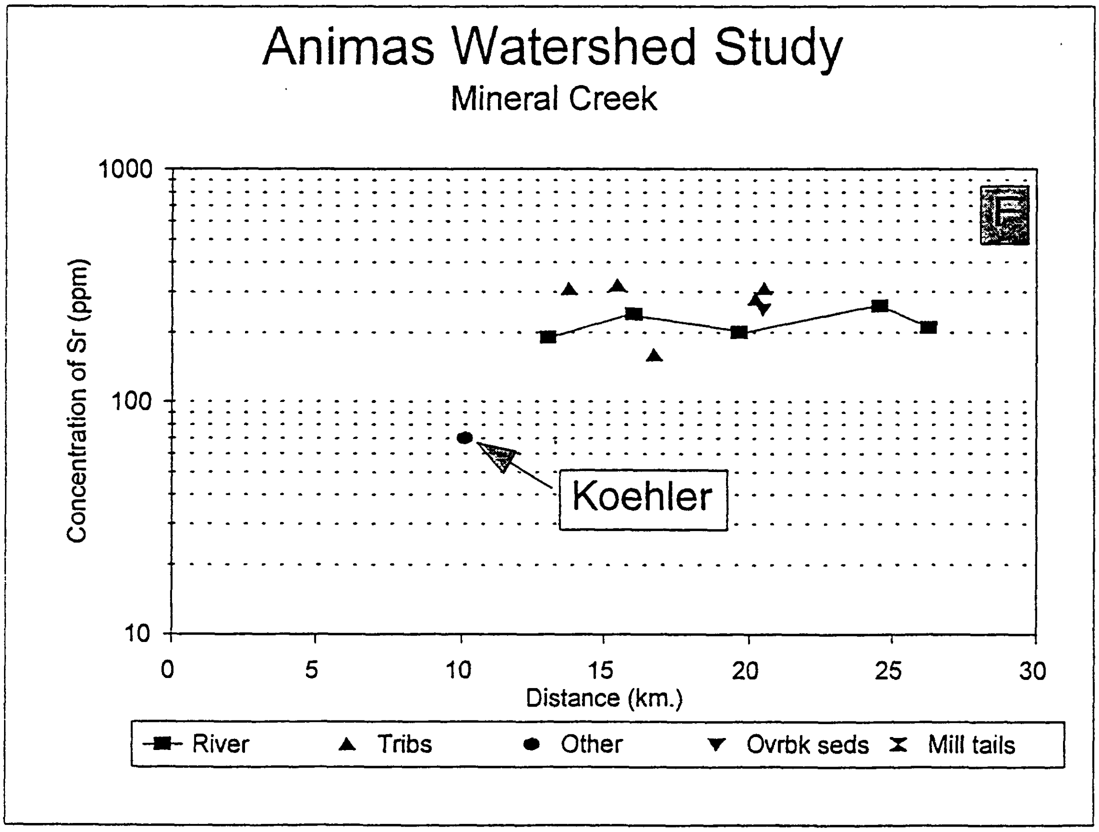

Animas Watershed Study
Mineral Creek
A
Koehler
A-72
Chattanooga
Concentration of As (ppm)
10000
1000
100
10
1
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails

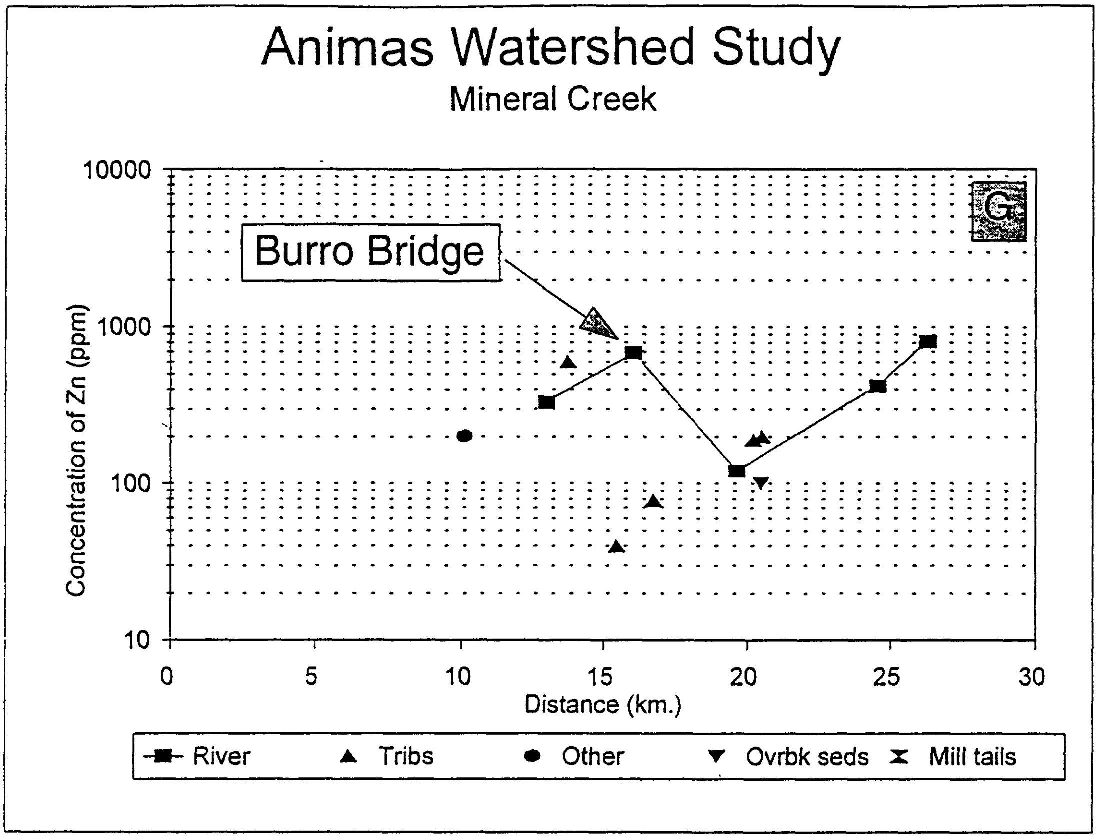

Animas Watershed Study
Mineral Creek
B
Koehler
Concentration of As (ppm)
10000
1000
100
10
1
0
5
10
15
20
25
30
Distance (km.)
River (pd)
Tribs (pd)
River (td)
Tribs (td)

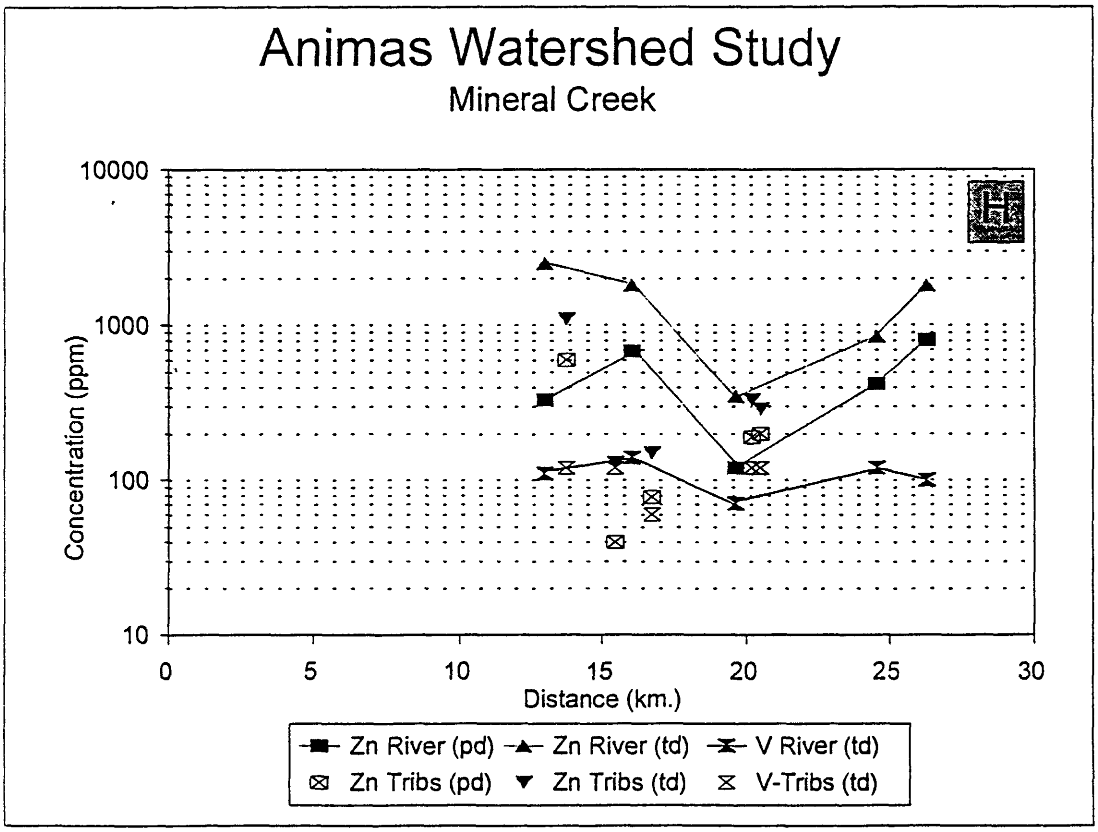

Animas Watershed Study
Mineral Creek
C
1000
100
10
1
Concentration of Co (ppm)
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails

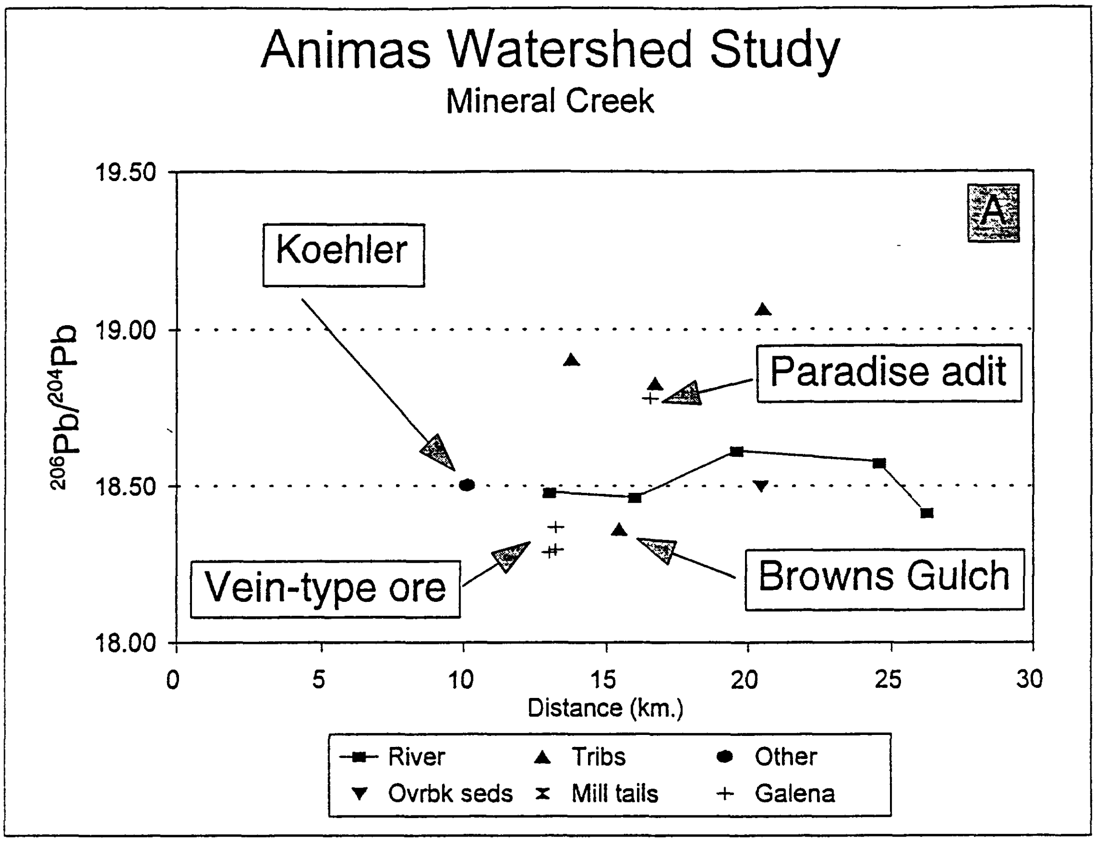

Animas Watershed Study
Mineral Creek
D
Burro Bridge
10000
1000
100
10
1
Concentration of Cu (ppm)
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails

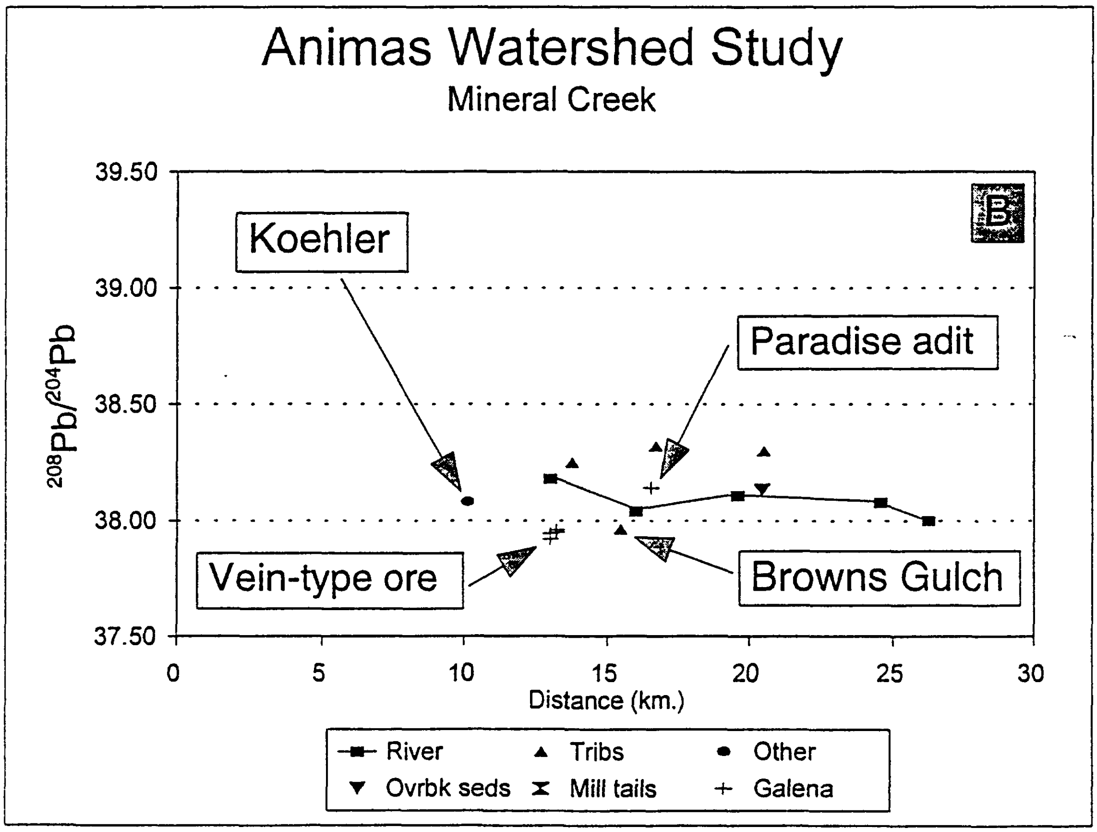

Animas Watershed Study
Mineral Creek
Concentration of Pb (ppm)
10000
1000
100
10
1
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails


Animas Watershed Study
Mineral Creek
Concentration of Sr (ppm)
1000
100
10
Koehler
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails


Animas Watershed Study
Mineral Creek
Burro Bridge
G
Concentration of Zn (ppm)
10000
1000
100
10
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails


Animas Watershed Study
Mineral Creek
H
Concentration (ppm)
10000
1000
100
10
0
5
10
15
20
25
30
Distance (km.)
Zn River (pd)
Zn River (td)
V River (td)
Zn Tribs (pd)
Zn Tribs (td)
V-Tribs (td)


Animas Watershed Study
Mineral Creek
A
Koehler
Paradise adit
Vein-type ore
Browns Gulch
$^{206}Pb/^{204}Pb$
19.50
19.00
18.50
18.00
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails
Galena


Animas Watershed Study
Mineral Creek
B
Koehler
Paradise adit
Vein-type ore
Browns Gulch
$^{208}Pb/^{204}Pb$
39.50
39.00
38.50
38.00
37.50
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails
Galena

Cement Creek Drainage Basin

The geochemical and lead-isotopic results from the bed-sediments from Cement Creek are summarized in figures 24-25. Geochemical profiles of Cement Creek differ substantially from those of Mineral Creek or the upper Animas River. Two samples labeled as "Other" are important in discerning the influence of natural weathering and spring seepage processes from mining activities on metal concentrations in the bed sediments. The sample upstream from the first bed-sediment sample of Cement Creek is from a ferricrete deposit on the west-facing slope of Cement Creek. A ferricrete is any rock cemented by iron oxides. Ferricretes may contain rounded or angular rock fragments cemented together by iron oxides that precipitate from natural weathering of mineral deposits. The second "Other" sample is from an iron bog forming below a spring on the west side of Cement Creek in the creek bed. Since this sample was collected from a small terrace just above Cement Creek at the low-flow stage, the chemistry of the sample will be affected by bed sediment material and water from Cement Creek entrapped during high-flow conditions. However, the very different geochemistry of the iron-hydroxide precipitates clearly shows that most of the metals in the iron bog are deposited from a different source.

Arsenic

Arsenic concentrations in bed sediments are elevated ranging from 23 to 43 times CAV (42-78 ppm) and the profile (fig. 24A and B) of both the partial and the total digestion data indicate that the arsenic concentration in the bed sediments increases significantly below the inflow at the Gladstone Mine and the confluence below Tiger Gulch. This increase is due to a higher arsenic in the iron-hydroxide phases and may represent accumulation of colloidal materials in the bed sediments. As we stated above, if the elevated arsenic concentrations reflect the addition of the chimney-type deposits, the increased arsenic levels could represent an unsampled source of metals coming from Prospect Gulch which drains the east side of Red Mountain. Copper, lead, and zinc do not show a significant change over this stream reach. The sample from Topeka Gulch, a small tributary drainage which has not been substantially affected by mining, contained similar concentrations (46 ppm) of arsenic to those found in the bed sediments of Cement Creek, but much less of it is in the labile phase (fig. 24B). In contrast, the arsenic concentration in the ferricrete sample was less than 10 ppm and in the iron bog sample was 6.7 ppm. The arsenic concentration in the bed sediments of Cement Creek at Memorial Park in Silverton is about twice that in either Mineral Creek or the upper Animas River at site A-72 in Silverton.

Cobalt

Cobalt concentrations in the bed sediments of Cement Creek are low and relatively constant at about 13 ppm (fig. 24C). The range is from about 10-30 ppm, near the CAV and showing a similar range to the other two major tributaries. Cobalt in the ferricrete sample is quite low, but in the iron bog sample is very similar to that in the bed sediments. Cobalt in the bed sediment from Topeka Gulch is higher than that in bed sediments in Cement Creek.

Copper

Copper concentrations (fig. 24D) in the headwaters of Cement Creek are elevated to about six times CAV (410 ppm). Copper concentrations in the ferricrete sample are also elevated (360 ppm) suggesting that some component of the elevated copper concentrations in the headwaters of Cement Creek may represent premining conditions. However, there are a few small mines in Ross Basin which were not sampled that may contribute copper and other ore-related metals to this upper reach of Cement Creek. Over most reaches of Cement Creek, the copper concentration is between 1-2 times CAV. The overbank sediment from just below the confluence of the South Fork of Cement Creek contains 290 ppm copper indicating that this sediment was transported from the uppermost reach of Cement Creek.

Lead

Lead concentrations (fig. 24E) range from 670 ppm (52 times CAV) at the headwaters to 320 ppm (25 times CAV) at Memorial Park in Silverton. Lead concentrations in both the ferricrete and the iron bog samples are much lower, in the 5 ppm range. The concentration of lead in the bed sediments from Topeka Gulch is about six times CAV, but substantially below that found in Cement Creek. Again, the lead concentration in the overbank sediment from below the confluence with the North and South Forks of Cement Creek is much higher than that in the sample from Cement Creek at this location.

Strontium

Strontium concentrations in all samples except those from the ferricrete and the iron bog are relatively constant, averaging 250 ppm and are lower than CAV (384 ppm). The profile is relatively flat (fig. 24F). Strontium in solution behaves conservatively and is not sorbed or retained by the iron-hydroxide minerals; thus, strontium concentrations in the ferricrete and spring seep samples (iron bogs) are very low.

Zinc

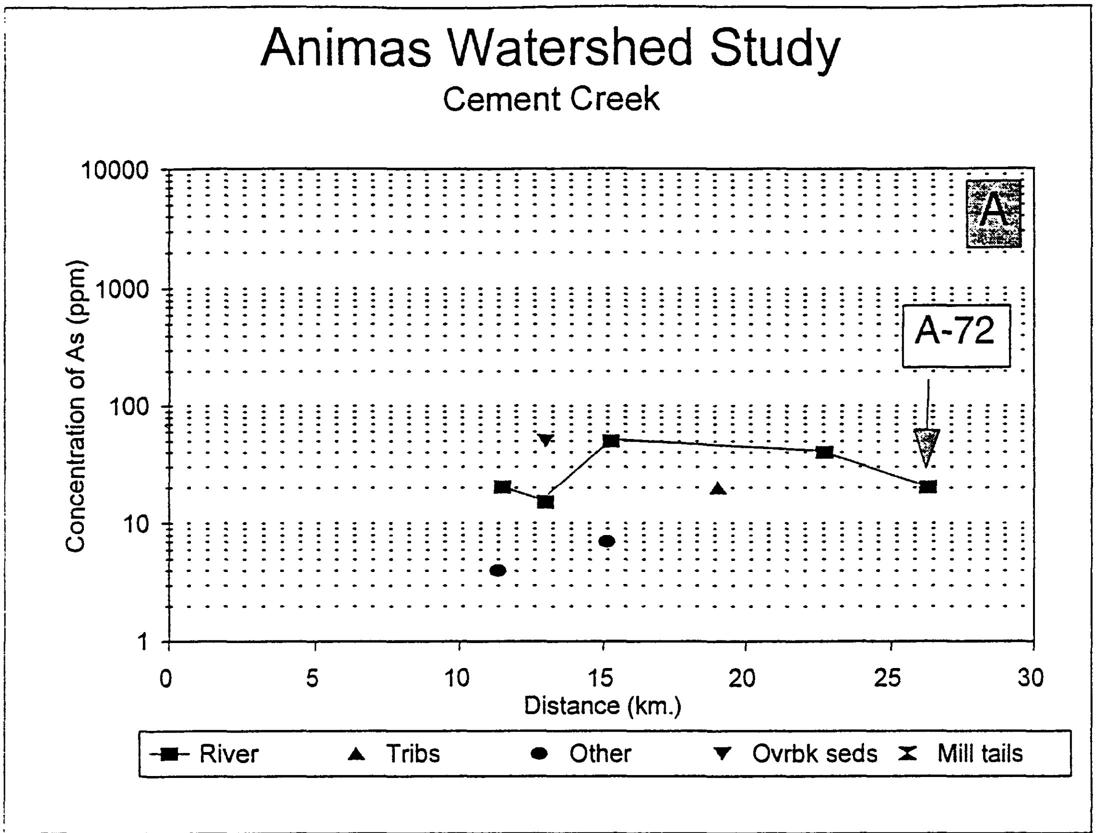
Labile zinc concentrations (fig. 24G) are relatively constant over the course of Cement Creek near 200 ppm (2.6 times CAV) except for the sample from the headwaters where the zinc concentrations are slightly elevated (280 ppm or 3.7 times CAV). Contrasting the leach results from the bed sediments with the total zinc concentration data (fig. 24H) shows that about 33 percent of the zinc in the bed-sediment sample from the headwaters is labile whereas 67 percent is bound in more resistant sulfide mineral phase sphalerite. Microscopic identification of mineral phases and emission-spectrographic analysis of the residue from the leachate confirms that sphalerite, rather than tetrahedrite is present in the residual phase. The concentration of sphalerite-bound zinc in bed sediments remains relatively constant downstream from the Gladstone Mine, where it is 1,200 ppm, to Memorial Park in Silverton, where it is 1,000 ppm. The total zinc concentration in bed sediments at the confluence of Cement Creek with the upper Animas River is about 1,200 ppm or about 16 times the CAV.

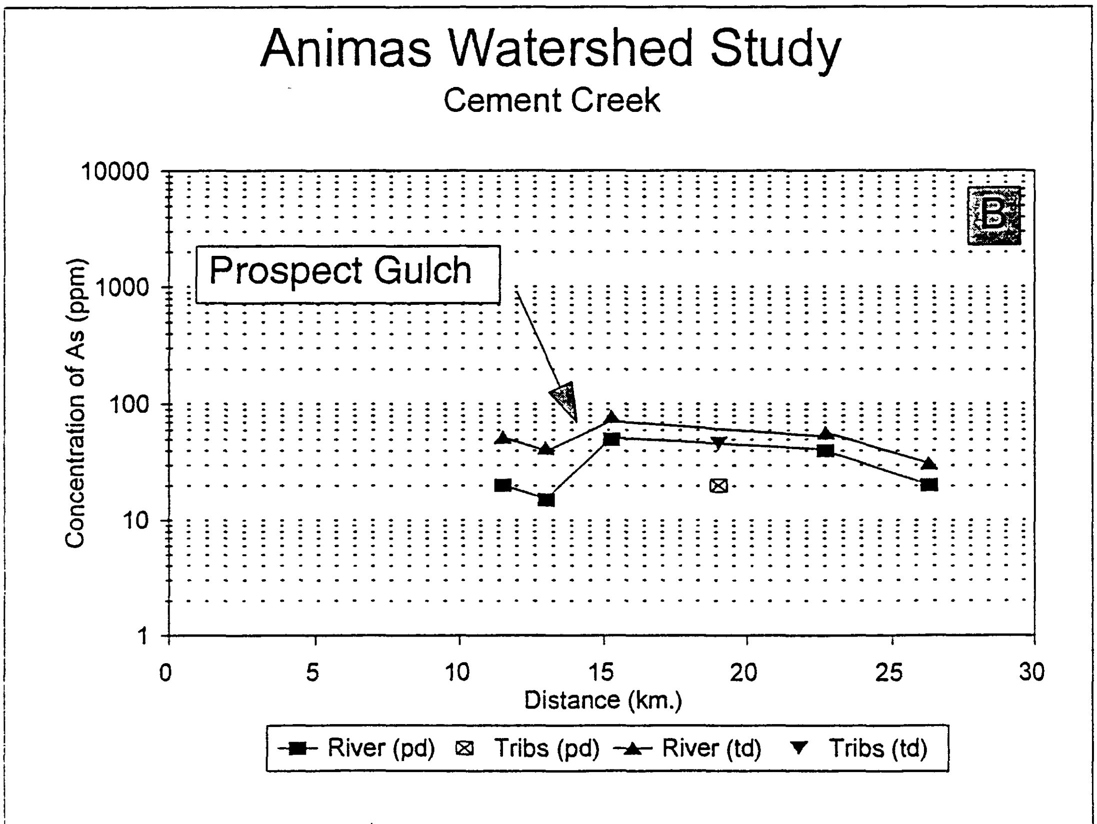
Vanadium

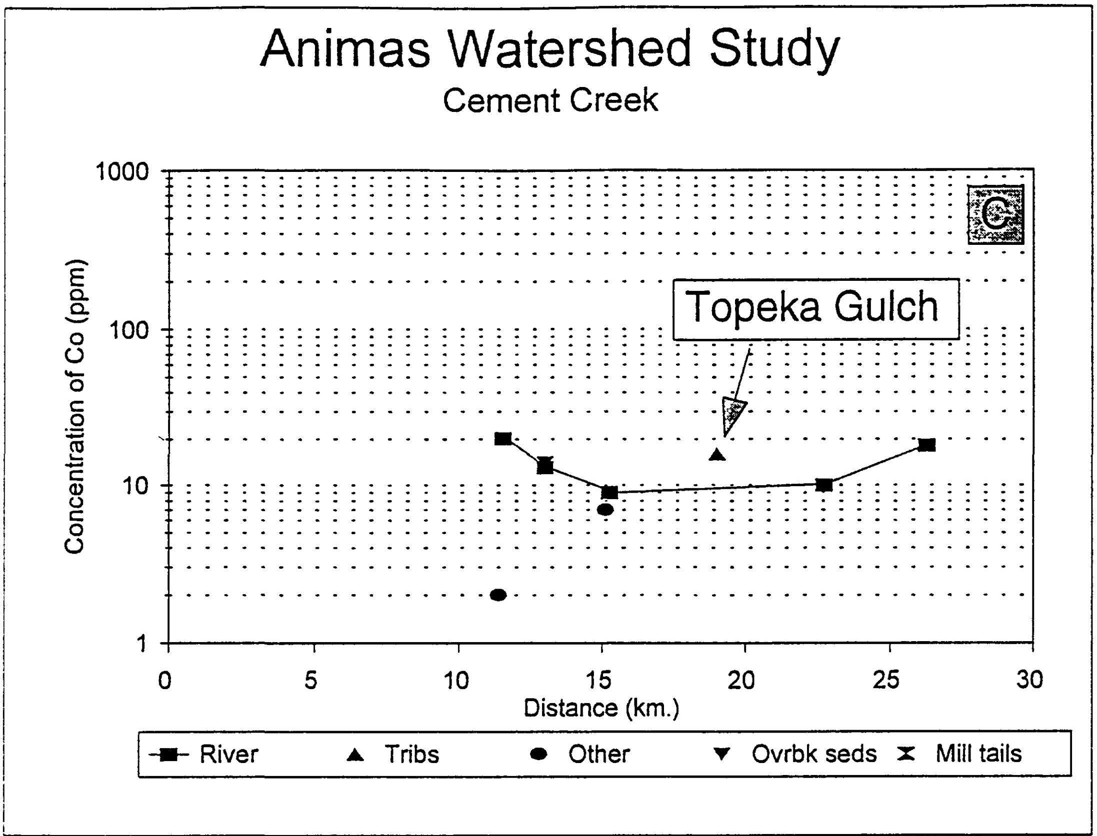
Vanadium concentrations remain constant (averaging 143 ppm) throughout the course of Cement Creek at concentrations near CAV (fig. 24H). The vanadium profile indicates that there are no samples from Cement Creek that are biased by hydrologic concentration of either iron-hydroxide minerals or placering of heavy minerals.

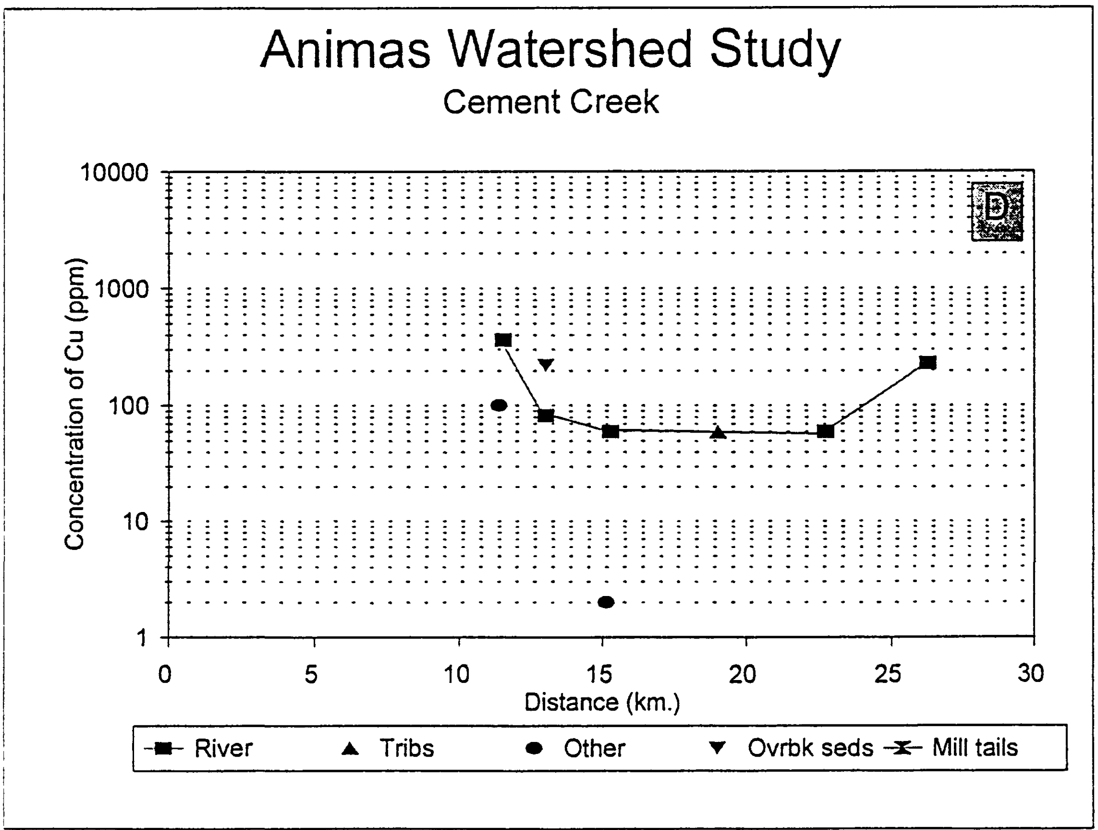
Figure 24. Metal distribution profiles (A-H) for Cement Creek; metal concentrations for labile arsenic (As), total arsenic, total cobalt (Co), labile copper (Cu), labile lead (Pb), total strontium(Sr), labile and total zinc (Zn; pd--labile zinc from partial digestion and td--total zinc) and total vanadium (V) are plotted against river distance measured upstream from the confluence of Cement Creek (at 24 km) with the Animas River below Silverton, Colo. Data from four different sample types are plotted as indicated by the explanation on the diagrams; no mill tailings were sampled on Cement Creek. Sample localities plotted are, beginning at the headwaters: Cement Creek--Cement Creek above the Gold King Mine (11.5 km), Cement Creek below the confluence of the North and South Fork confluence and below the inflow of the Gladstone Mine (13 km), Cement Creek below the confluence with Tiger Gulch (15.25 km), Memorial Park below gaging station (22.7 km), and the tie point at site A-72 on figure 28; the tributary sample--Topeka Gulch (19 km); and Other is one sample of ferricrete (11 km) and one sample from an iron bog fed by a spring (15.1 km).

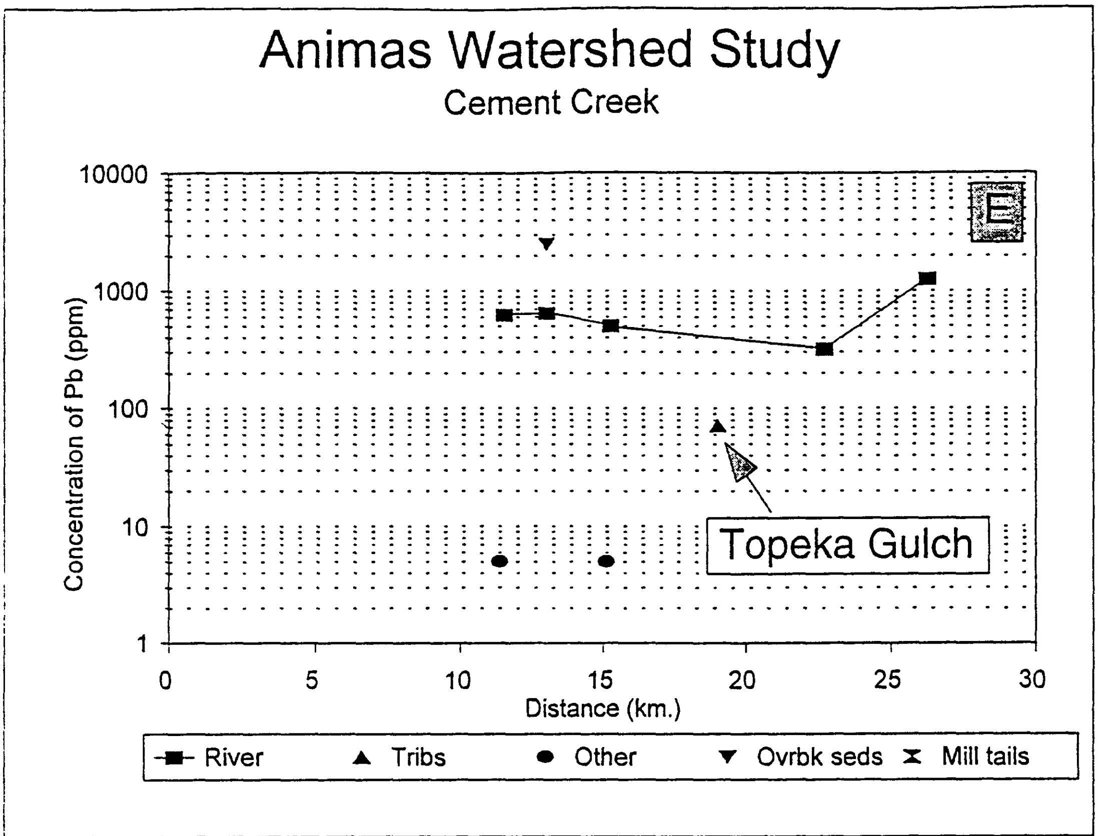
Figure 25. Lead-isotope distribution profiles for Cement Creek plotted against river distance measured upstream from the confluence of Cement Creek (at 24 km) with the Animas River below Silverton, Colo. Data from four different sample types are plotted as indicated by the explanation on the diagrams; no mill tailings were sampled on Cement Creek. Data from different sample types are plotted as indicated by the explanation on the diagrams; distances are as noted in the explanation for fig. 24. Lead-isotopic data from the vein-type ore from the Sunnyside Mine (table 2) are plotted for comparison. The data from site A-72, the first site on the Animas River below the confluence, are plotted on all the diagrams to provide a tie-point with the data on figure 29.


Animas Watershed Study
Cement Creek
A
A-72
Concentration of As (ppm)
10000
1000
100
10
1
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails

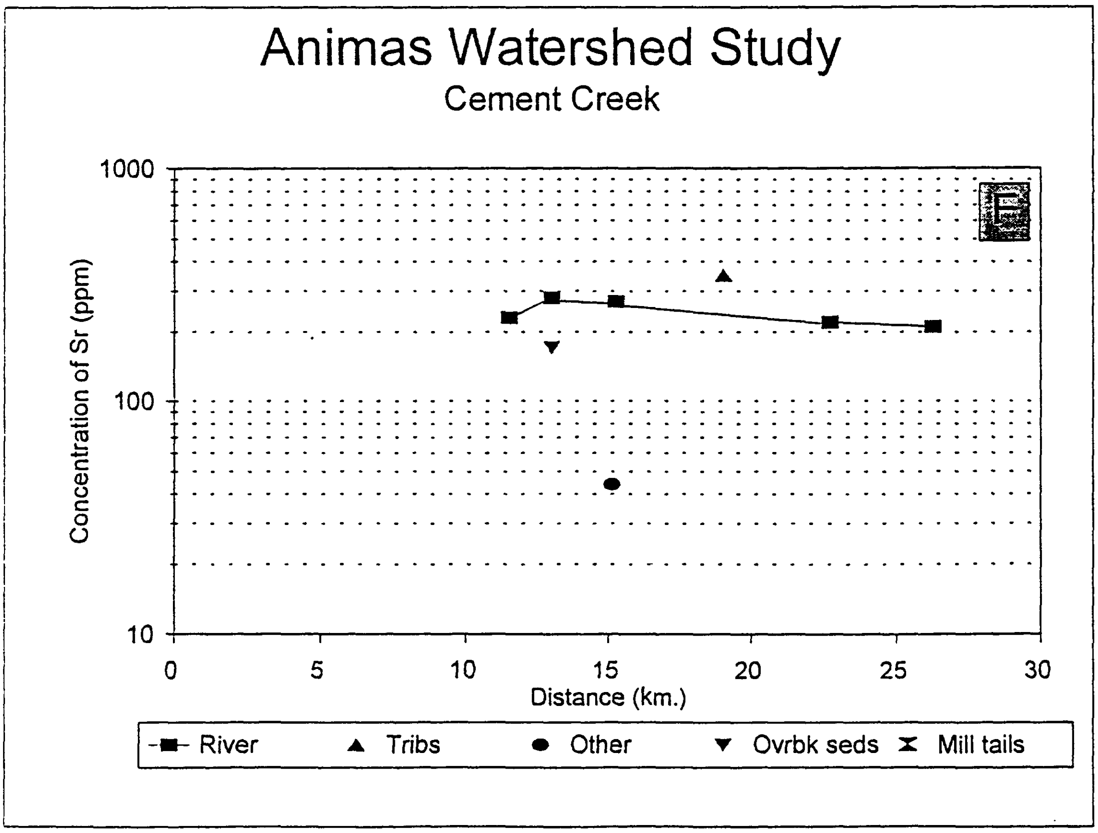

Animas Watershed Study
Cement Creek
B
Prospect Gulch
Concentration of As (ppm)
10000
1000
100
10
1
0
5
10
15
20
25
30
Distance (km.)
River (pd)
Tribs (pd)
River (td)
Tribs (td)


Animas Watershed Study
Cement Creek
C
Topeka Gulch
Concentration of Co (ppm)
1000
100
10
1
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails

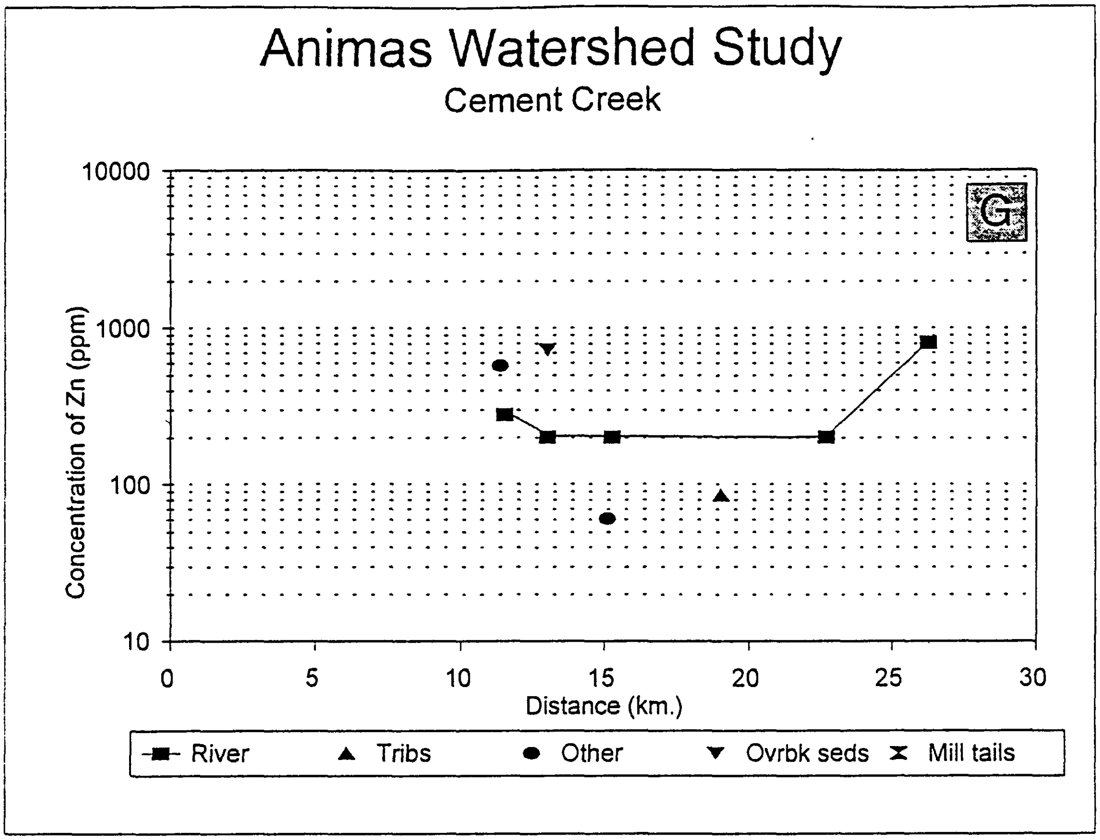

Animas Watershed Study
Cement Creek
D
Concentration of Cu (ppm)
10000
1000
100
10
1
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails

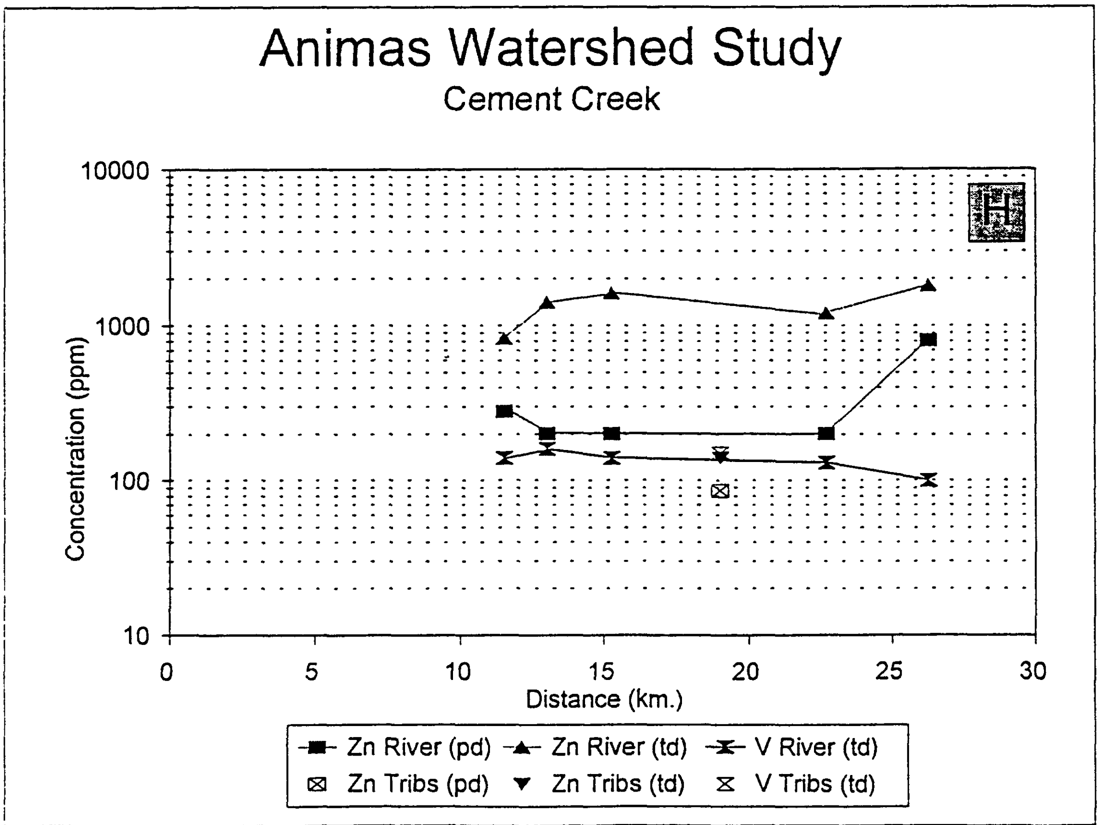


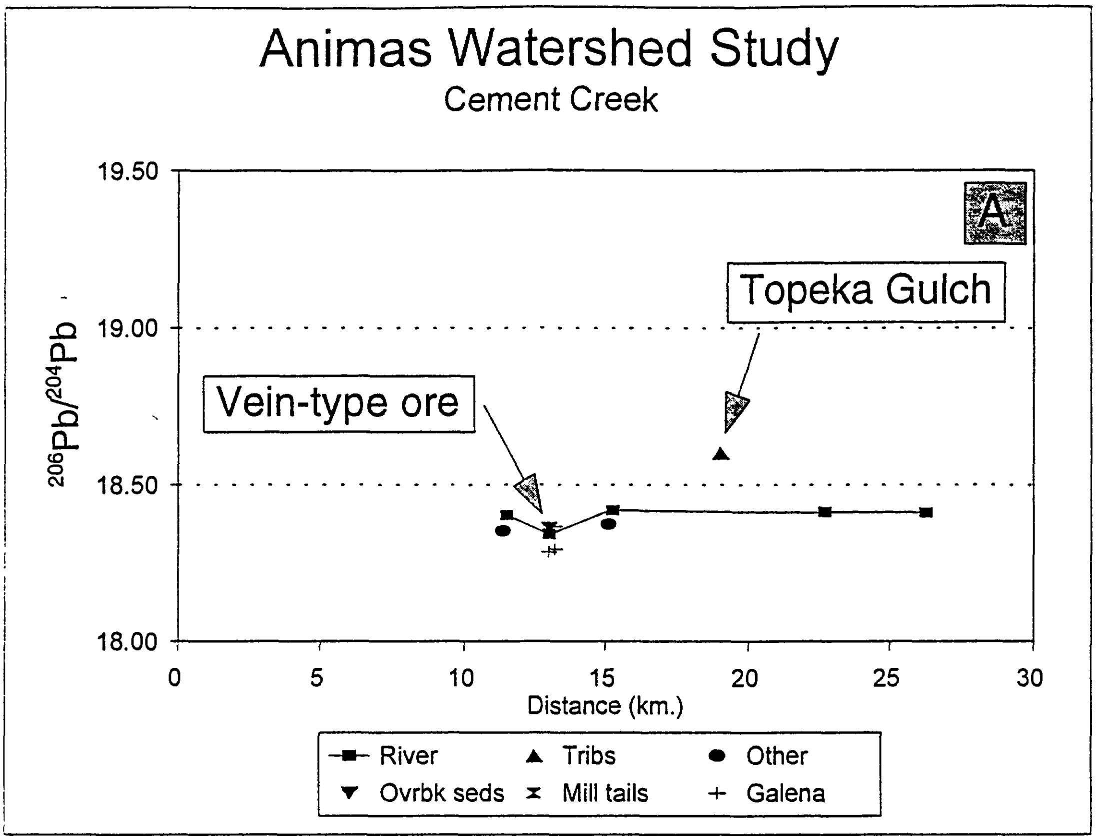
Animas Watershed Study
Cement Creek
Concentration of Pb (ppm)
10000
1000
100
10
1
0
5
10
15
20
25
30
Distance (km.)
Topeka Gulch
River
Tribs
Other
Ovrbk seds
Mill tails

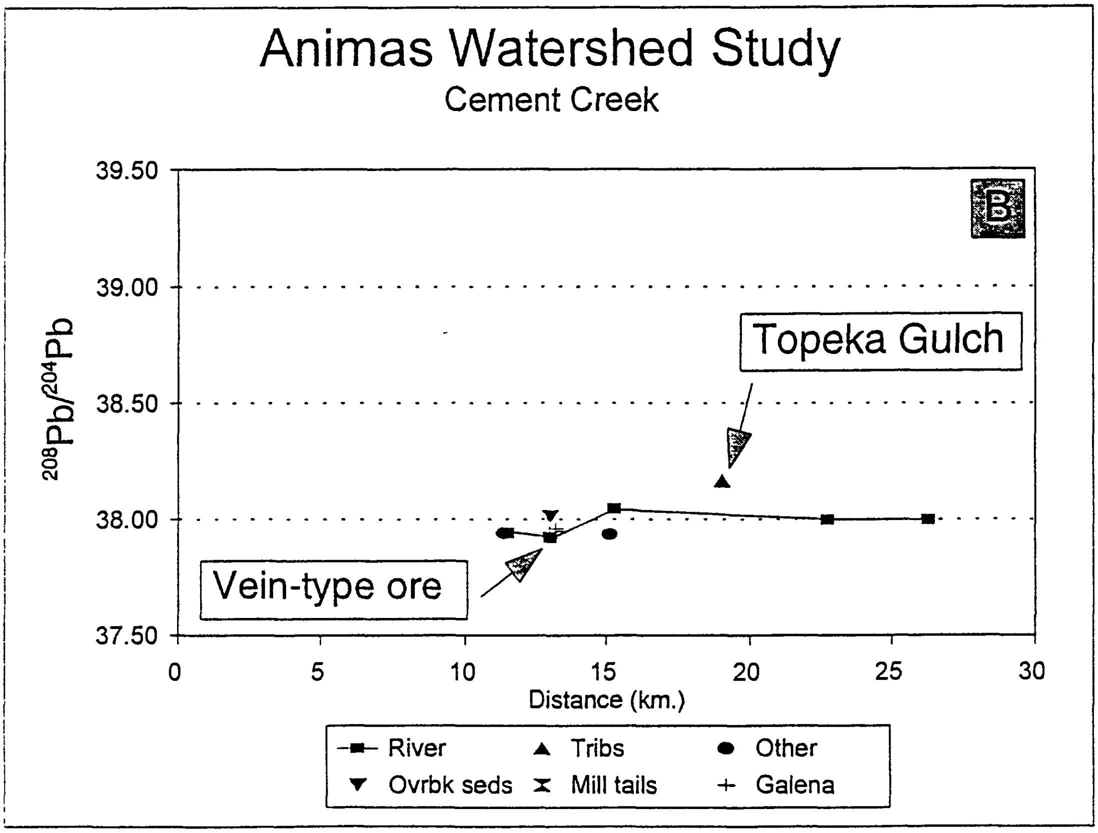


Animas Watershed Study
Cement Creek
Concentration of Sr (ppm)
1000
100
10
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails


Animas Watershed Study
Cement Creek
G
10000
1000
100
10
Concentration of Zn (ppm)
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails


Animas Watershed Study
Cement Creek
H
10000
1000
100
10
Concentration (ppm)
0
5
10
15
20
25
30
Distance (km.)
Zn River (pd)
Zn River (td)
V River (td)
Zn Tribs (pd)
Zn Tribs (td)
V Tribs (td)


Animas Watershed Study
Cement Creek
A
Topeka Gulch
Vein-type ore
$^{206}Pb/^{204}Pb$
19.50
19.00
18.50
18.00
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails
Galena


Animas Watershed Study
Cement Creek
B
Topeka Gulch
Vein-type ore
$^{208}Pb/^{204}Pb$
39.50
39.00
38.50
38.00
37.50
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails
Galena

Lead-isotopic data

Lead-isotopic data from the bed sediments, the overbank sediment, and the ferricrete and iron bog samples closely match the lead-isotopic signature of the Eureka graben vein-type mineralization (figs. 25A and B). The bed-sediment sample from Topeka Gulch, which is largely unimpacted by mining activity, has a composition that differs substantially from the rest of the samples from the Cement Creek drainage and may reflect the contribution of lead from altered, unmined country rock. However, mass balance calculations show that the total contribution of lead of this type to the bed sediment of Cement Creek is small and insignificant. The lead-isotopic data indicated that the majority of the lead in the bed-sediments from Cement Creek below the Gladstone mine matches that of the Eureka graben vein-type ore. Even though the lead-isotopic compositions of the ferricrete and iron-bog samples match the lead-isotopic composition of the vein-type ore, the lead concentrations in these samples are very low and thus, these sources add very little lead to the bed sediments in Cement Creek.

Animas River Drainage Basin Upstream from Silverton

Geochemical and lead-isotopic data from bed sediments from the upper Animas River, that is the segment of the Animas River above the confluence with Mineral Creek (25 km), are in figures 26 and 27. One mill site, the Kittimac Mill (13.8 km), was sampled specifically because the mill is immediately adjacent to the upper Animas River. This mill processed material from mines on the north side of Minnie Gulch (Sloan and Skowronski, 1975).

Arsenic

Arsenic concentrations from the 2M HCl-1%H_2O_2 digestion data indicate a uniform, albeit a gradually decreasing concentration profile throughout the course of the upper Animas River (figs. 26A and B). The total and the partial digestion data have very similar profiles. The maximum concentration of arsenic found was about 100 ppm (about 55 times CAV) in the upper reach of the Animas River just above the Eureka townsite (a 1996 sample collection site). The arsenic concentration drops steadily along the course of the upper Animas River to 35 ppm just above the confluence with Cement Creek. Arsenic concentrations in Cement Creek and the upper Animas River at their confluence are essentially the same. Arsenic concentrations in the bed sediments from Picayne Gulch near the headwaters are higher than those in the bed sediments at the confluence of Picayne Gulch with the upper Animas River which suggests that the source of elevated arsenic may be from this tributary. Elsewhere along the course of the upper Animas River, the concentration of total and labile arsenic in the stream sediments from the tributaries samples are less than that in the bed sediments of the upper Animas River. Arsenic concentrations in the overbank sediment collected near Eureka are also higher than in the bed sediments at that point indicating transport from upstream during high flow. The efflorescent salt samples collected from along the course of the upper Animas River, except for one sample collected near Eureka, do not concentrate arsenic. The arsenic concentration in the composite surface sample from the Kittimac Mill site is also low. We conclude that the Kittimac Mill site does not appear to be a significant source of arsenic to the bed sediments of the Animas River.

Cobalt

The concentration of cobalt in bed sediments from the upper Animas River (averaging 18 ppm) and its tributaries (averaging 20 ppm) show little variation about the CAV (fig. 26C). The profile is essentially flat and comparable to that from both Mineral and Cement Creeks. The concentration of cobalt is elevated (50-100 ppm) in three of the four water-soluble salt samples.

Copper

Copper concentrations in the bed sediments of the upper Animas River at Animas Forks are comparable to those in Cement Creek and much of Mineral Creek (fig. 26D). However, just above the confluence with Eureka Gulch and below the Eureka Mill site, labile copper concentrations exceed 4,000 ppm on the coatings of pebbles and reach almost 500 ppm (about seven times CAV) in bed sediments. The total copper concentration in this sample collected from below the confluence with Eureka Gulch is 550 ppm (eight times CAV) sample and more than 80 percent of the copper is labile. Copper concentrations are also elevated in the sample from the Kittimac Mill site as well as in the sample taken below the braided section of the upper

Animas River above Howardsville. Below Howardsville, the total copper concentration in bed sediments drops to 270 ppm below the confluence with Cunningham Creek. Copper concentrations in bed sediments are elevated in the section of the upper Animas River adjacent to the Mayflower Mill (between Boulder Gulch and Arrastra Creek). Copper concentrations in stream sediments from the tributaries are below CAV in the upper reaches of the upper Animas River, but are 2,200 ppm (32 times CAV) in Arrastra Creek, 50 percent of which is labile, and 420 ppm in bed sediments at the confluence of Boulder Gulch, 70 percent of which is labile. From the perspective of aquatic-life standards, it is important to note the high concentrations of copper are present in the white efflorescent precipitates that form by evaporation. Rain storms wash these water-soluble salts into the Animas River creating a spike of dissolved copper and other toxic metals that may exceed the acute toxicity standard for copper for aquatic life.

Lead

The concentration profile (fig. 26E) of lead in bed sediments from the upper Animas River is comparable to that of copper. High concentrations (1,600-2,000 ppm or more) characterize the braided stream reaches below Eureka and below the Mayflower mill. The lead-isotopic data discussed below clearly indicate that the source of the lead in this stretch of the upper Animas River is not from Arrastra Creek. With the exception of the sample from Arrastra Creek, lead in stream sediments from the tributaries is substantially lower in concentration than in the bed sediments of the Animas River ranging from about 160 ppm at Animas Forks (12 times CAV) to 700 ppm in Eureka Gulch (more than 50 times CAV). The concentration of lead in stream sediments in Arrastra Creek is 4,000 ppm (more than 300 times CAV). The lead concentration in the stream-sediment sample from lowermost Boulder Gulch is 1,200 ppm, far too high to be from an unmineralized area. We suspect that the bed-sediment sample from Boulder Gulch has been contaminated by material from the tailings ponds upstream from the sample site. Lead concentrations in the overbank sediment from Eureka and from all of the efflorescent salt samples are substantially elevated above that in the bed sediments of the upper Animas River samples. Again, a rain storm would send a spike of water-soluble lead into the river and perhaps could exceed the acute aquatic-life standard for lead. The highest concentration of lead (17,000 ppm) was found in the mill tailings at the Kittimac Mill site.

Strontium

Strontium concentrations (fig. 26F) are again relatively constant throughout the course of the upper Animas River averaging 190 ppm if the site just below Cunningham Creek is excluded. There is a major change in concentration of strontium in the bed sediments of the Animas River below the confluence with Cunningham Creek which is consistent with the elevated strontium concentrations in the stream-sediment samples from Cunningham Creek and Maggie Gulch. These elevated strontium concentrations reflect the presence of the Leadville and Dyer limestones outcrops in the headwaters of these basins that are too small to show at the scale of the regional geologic map (see fig. 3). Strontium concentrations are highly variable in the precipitates and vary directly with the calcium concentration. Strontium in the sample from the Kittimac Mill site is very low as is the measured calcium concentration. These measurements verify the low acid-buffering capacity of these mill tailings.

Zinc

The profile and the pattern of both labile and total zinc concentrations (figs. 26G-H) are comparable to those of copper and lead. Total zinc concentrations range between 3,500-4,400 ppm in the reaches of the upper Animas River adjacent to the Eureka and Mayflower mill sites. The overbank sediment and the bed sediments from Cunningham and Arrastra Creeks have zinc concentrations that are higher than those from adjacent segments of the upper Animas River whereas zinc concentrations from other tributaries are lower. The distribution profiles for labile and total zinc concentrations parallel one another. Fifty to 65 percent of the total zinc in bed sediments in the upper Animas River is labile; the remainder is present in the sulfide mineral sphalerite. In contrast, 75-80 percent of the zinc from Cunningham and Arrastra Creeks is labile and 85 percent of the zinc in the Boulder Gulch sample is labile indicating a high fraction of the zinc is carried in the iron-hydroxide phase. Zinc concentrations in three of the four precipitate samples range between 16,000 and 27,000 ppm (about 200-350 times CAV). The overbank sample contains a very high concentration of these water-soluble zinc salts as shown by the comparison between the data from the total and the 2M HCl-1%H_2O_2 digestion. Zinc in the sample from the Kittimac Mill site is low (310 ppm or four times CAV).

Mineral separates were made from the residue fraction of the leachate sample from sites (fig. 11) collected from the Animas River just above Howardsville (95ABS108) and from Cunningham Creek (95ABS109). The dominant sulfide mineral in the sample from Cunningham Creek was a ruby-red variety of sphalerite. In contrast, the dominant sulfide mineral present in the Howardsville sample was the blackjack variety of sphalerite; there were minor amounts of pyrite present. Magnetite and hematite were also present in about equal abundance in sample 95ABS108. The bulk composition of these heavy-mineral concentrates are given in table 3. An analysis of the magnetic fraction is also given. Note the increased concentration of zinc in the nonmagnetic fractions and the concentration of vanadium in the magnetic fraction. The magnetic fraction contains magnetite only whereas the nonmagnetic fraction from 95ABS108 contains some portion of hematite.

Vanadium

Vanadium concentrations in bed sediments from both the tributaries (average 122 ppm) and the upper Animas River (average 105 ppm) are essentially the same and form a flat profile indicating that the changes in ore and ore-related metal concentrations are not the result of hydrologic concentration of heavy minerals in placers (fig. 26H). The vanadium profile of all three main tributaries to the Animas River, that is Mineral Creek, Cement Creek, and the upper Animas River above Silverton, indicate that the streams have an essentially constant supply of vanadium from magnetite and hematite in the Tertiary volcanic rocks (fig. 3).

Table 3. Semi-quantitative emission spectrographic data from heavy-mineral separates[1], Cunningham Creek and Animas River upstream from Howardsville

Sample[2]	Fe wt. pct.	Ti wt. pct.	Ag ppm	As ppm	Ba ppm	Cd ppm	Co ppm	Cu ppm	Mn ppm	Mo ppm	Ni ppm	Pb ppm	Sb ppm	V ppm	Zn ppm
95ABS108-NM	3.0	0.7	1.5	<500	1500	50	20	200	1000	10	<10	50	<200	100	5000
95ABS109-Mag	20.0	0.5	<1	<500	<50	<50	50	10	500	<10	50	<20	<200	300	<500
95ABS109-NM	7.0	1.0	<1	<500	2000	<50	30	100	700	<10	10	30	<200	150	2000

[1] S.J. Sutley, analyst.
[2] NM, nonmagnetic heavy mineral separated from sample following 2M HCl-H_2O_2 digestion; Mag, magnetite separated from sample following 2M HCl-1%H_2O_2 digestion.

Lead-isotopic data

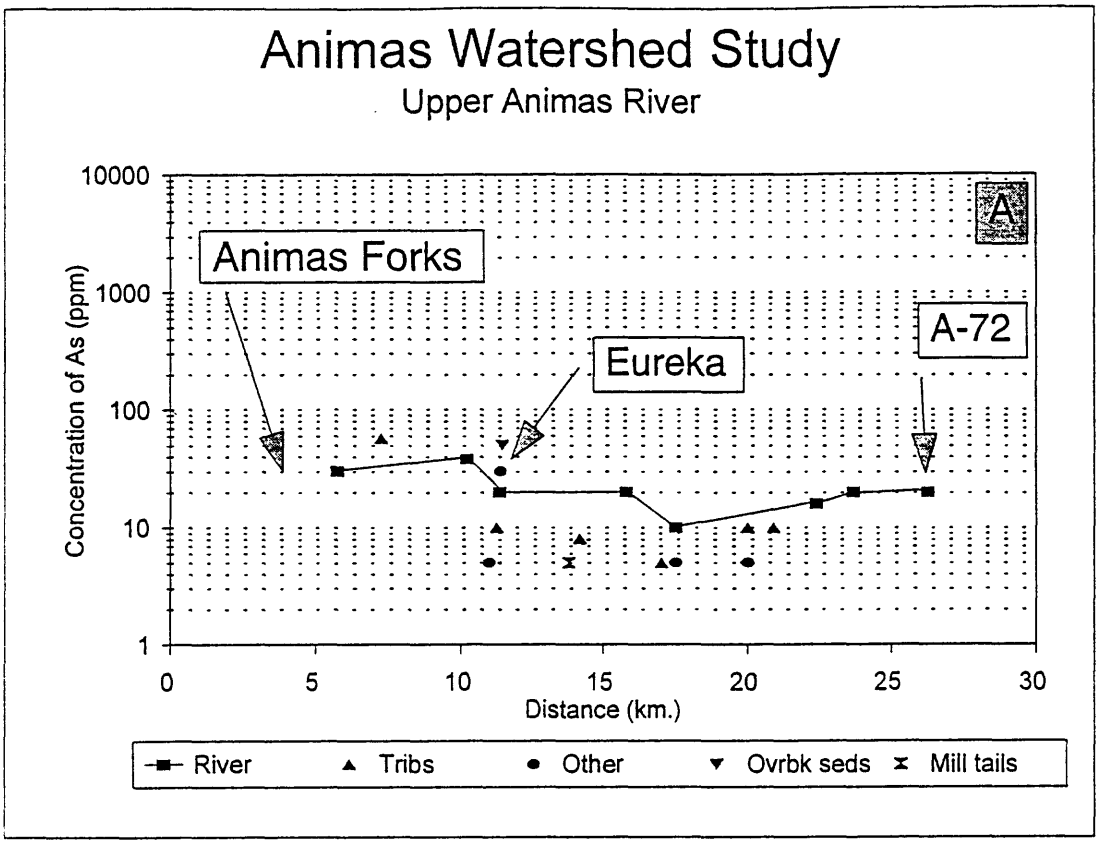
Lead-isotopic data (figs. 27A and B) show that the mineralization above Animas Forks differs from the Eureka graben vein-type ore. Likewise, lead-isotopic data from stream sediments from Picayne Gulch reflect a different lead-isotopic signature from that of the Eureka graben vein-type ore. Samples from Eureka Gulch and from the Animas River between Eureka and Howardsville reflect the Eureka graben vein-type ore lead signature. The lead-isotopic composition of mill tailings from the Kittimac Mill site is more radiogenic and reflects a third mineralization style in the upper Animas River subbasin. Since ore from the north side of Minnie Gulch was processed at this mill, it is important to note that the lead-isotopic composition of the stream sediments from Maggie Gulch also differs from that of the Eureka graben vein-type ore lead signature. The lead-isotopic signature from both Cunningham and Arrastra Creeks also differs from the previous three mineralization signatures. As the ore from the South Silverton district was more precious-metal rich, it is not surprising to see that the lead-isotopic signatures differ between the Eureka graben vein-type ore lead of which the Sunnyside mine is typical, and the ore from the South Silverton district. The lead-isotopic composition of the bed sediments in the upper Animas River below the confluence of Cunningham Creek changes slightly indicating the addition of this new lead component. The lead-isotopic composition of the sediments from Boulder Gulch indicates that they also contain some of this more radiogenic component of lead, the source of which cannot be determined at this time. Although there are several mineral districts in the upper Animas River subbasin, each of which seem to have differing lead-isotopic signatures, the isotopic composition of lead in the bed sediments of the upper Animas River is dominated by the Eureka graben vein-type ore lead signature as shown by the results in figure 27. Contributions of lead and their associated metals from the other centers of mineralization in the Animas River subbasin appear to be minor.

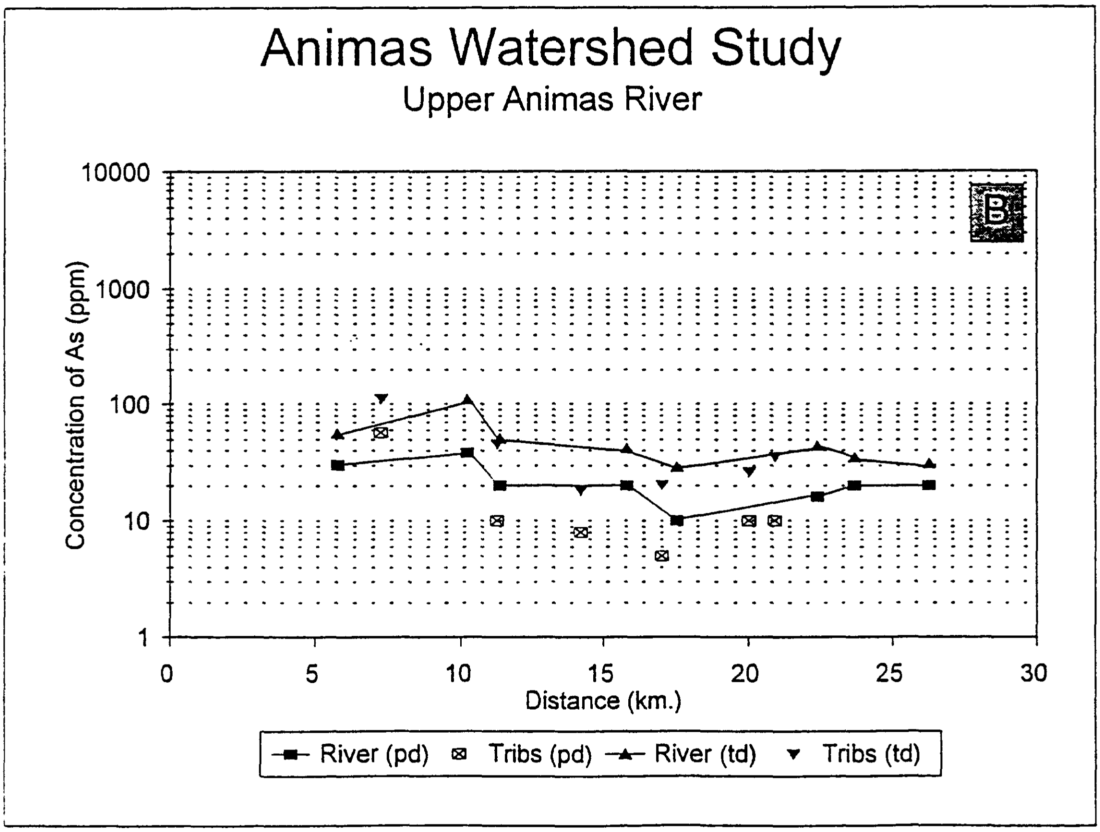
The isotopic composition of lead in the bed sediments of Cement Creek at the confluence with the Animas River (24 km) is identical to that measured in bed sediments from the Animas River above the confluence, so no calculation of the relative contributions to the total metal in the bed-sediments from Cement Creek can be made from the lead-isotopic data. There are significant changes in the metal concentrations in bed sediments of the upper Animas River between the site above the confluence of Cement Creek and site A-72 below the confluence with Mineral Creek. However, the sampling density does not allow a definitive calculation of the relative amounts of material added to the bed sediments of the upper Animas River by Cement and Mineral Creeks separately.

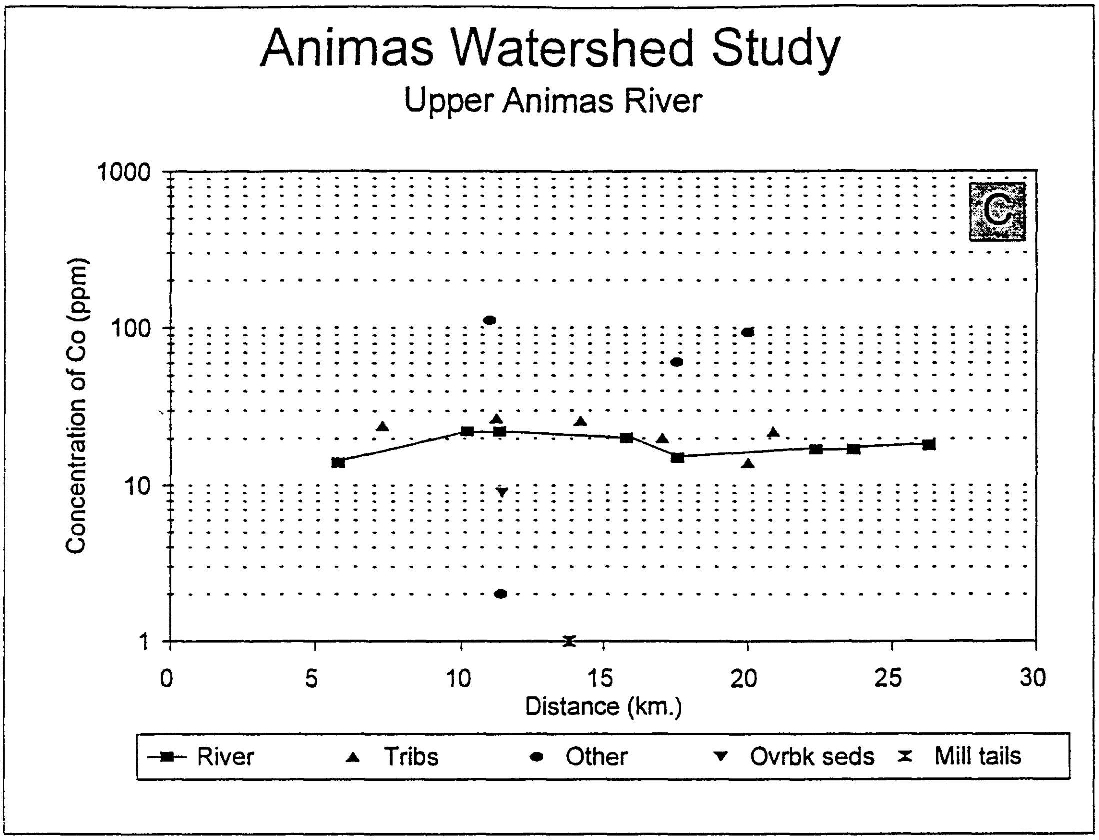
The isotopic composition of lead in the bed sediments of Mineral Creek is somewhat different from that of the upper Animas River above the confluence with Cement Creek. These data will be used below to calculate an upper limit for the percentage of material added to the bed sediments of the Animas River by Mineral Creek.

Figure 26. Metal distribution profiles (A-H) for the upper Animas River above Silverton; metal concentrations for labile arsenic (As), total arsenic, total cobalt (Co), labile copper (Cu), labile lead (Pb), total strontium(Sr), labile and total zinc (Zn; pd--labile zinc from the partial digestion and td--total zinc) and total vanadium (V) are plotted against river distance measured upstream from the confluence of Mineral Creek (at 25 km) with the Animas River below Silverton, Colo. Data from five different sample types are plotted as indicated by the explanation on the diagrams. Sample localities plotted are, beginning at the headwaters: upper Animas River (uAR) below Animas Forks (5.75 km), uAR above Eureka (a sample collected in 1996; 10.1 km), uAR below Eureka (a sample collected in 1995; 11.35 km), uAR above Howardsville (15.8 km), uAR below the confluence with Cunningham Creek (17.05 km), uAR above the trailer park (a sample collected in 1996; 22.5 km), uAR at bridge in Silverton (23.7 km), and the tie point at site A-72 with the data on figure 28. The tributary samples are from Picayne Gulch (7.25 km), Eureka Gulch (11.25 km), Maggie Gulch (14.2 km), Cunningham Creek (17.05 km), Arrastra Creek (20 km), and Boulder Gulch (20.9 km). Samples indicated as "Other" are water-soluble precipitates collected from the stream bed above low-flow water and are from the same sites as the overbank sediments. The mill tailings are from the Kittimac Mill site (13.8 km).

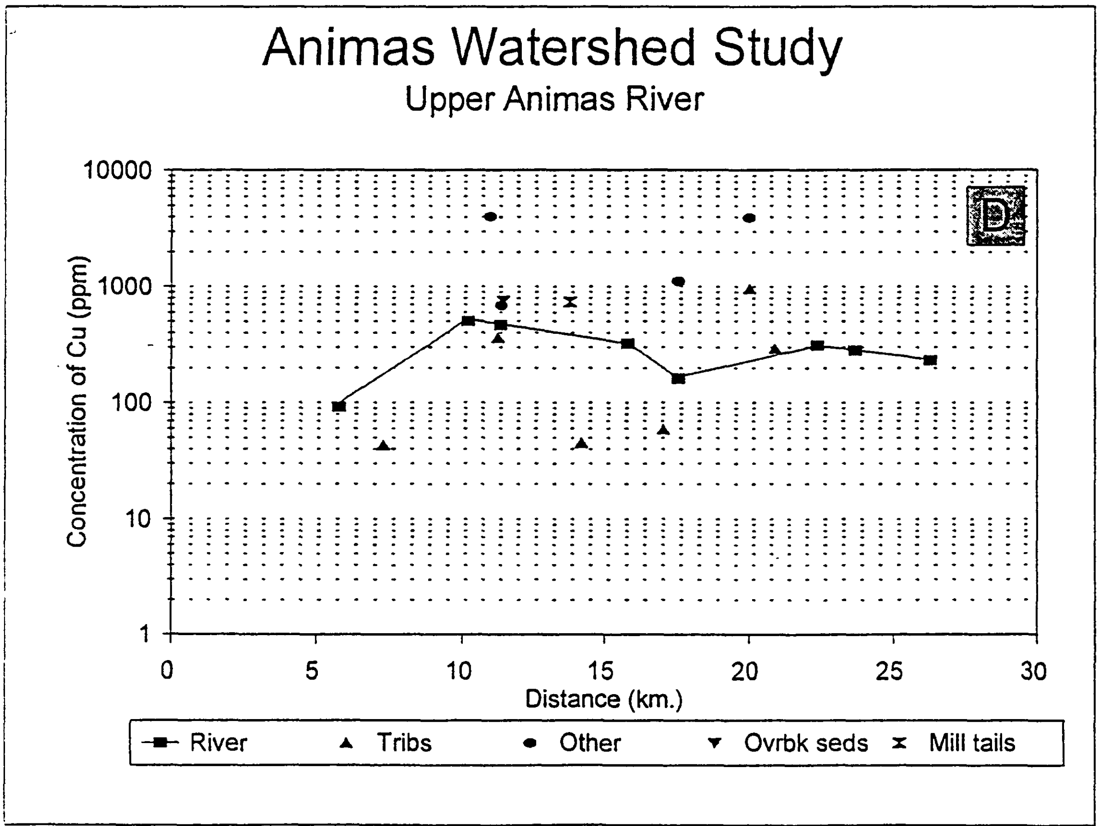
Figure 27. Lead-isotope distribution profiles for the upper Animas River plotted against river distance measured upstream from the confluence of Mineral Creek (at 25 km) with the Animas River below Silverton, Colo. Data from five different sample types are plotted as indicated by the explanation on the diagrams; distances are as noted in the explanation for figure 26. Samples indicated as "Other" are water-soluble precipitates collected from the stream bed above the low-flow water. The mill tailings are from the Kittimac Mill site. Lead-isotopic data from the vein-type ore are plotted for comparison (table 2). The data from site A-72, the first site on the Animas River below the confluence, are plotted on all the diagrams to provide a tie-point with the data on figure 29.


Animas Watershed Study
Upper Animas River
A
Animas Forks
Eureka
A-72
Concentration of As (ppm)
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails

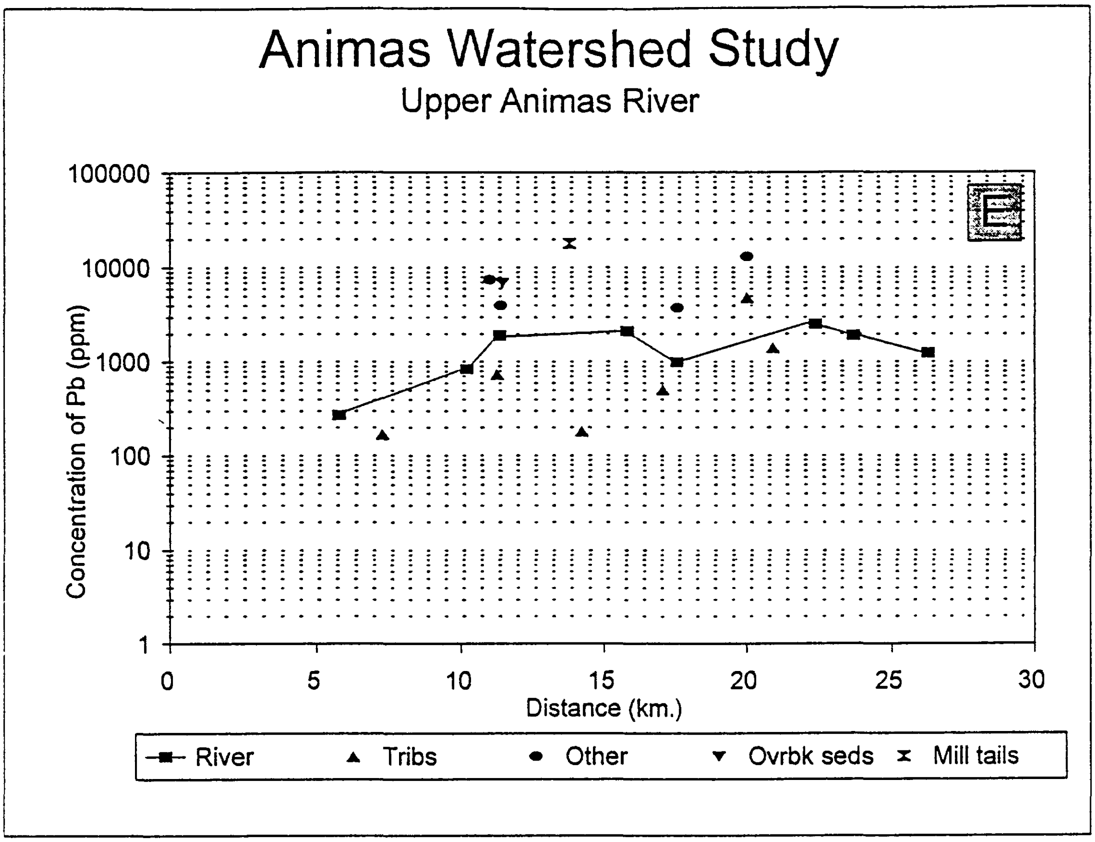

Animas Watershed Study
Upper Animas River
B
Concentration of As (ppm)
Distance (km.)
River (pd)
Tribs (pd)
River (td)
Tribs (td)



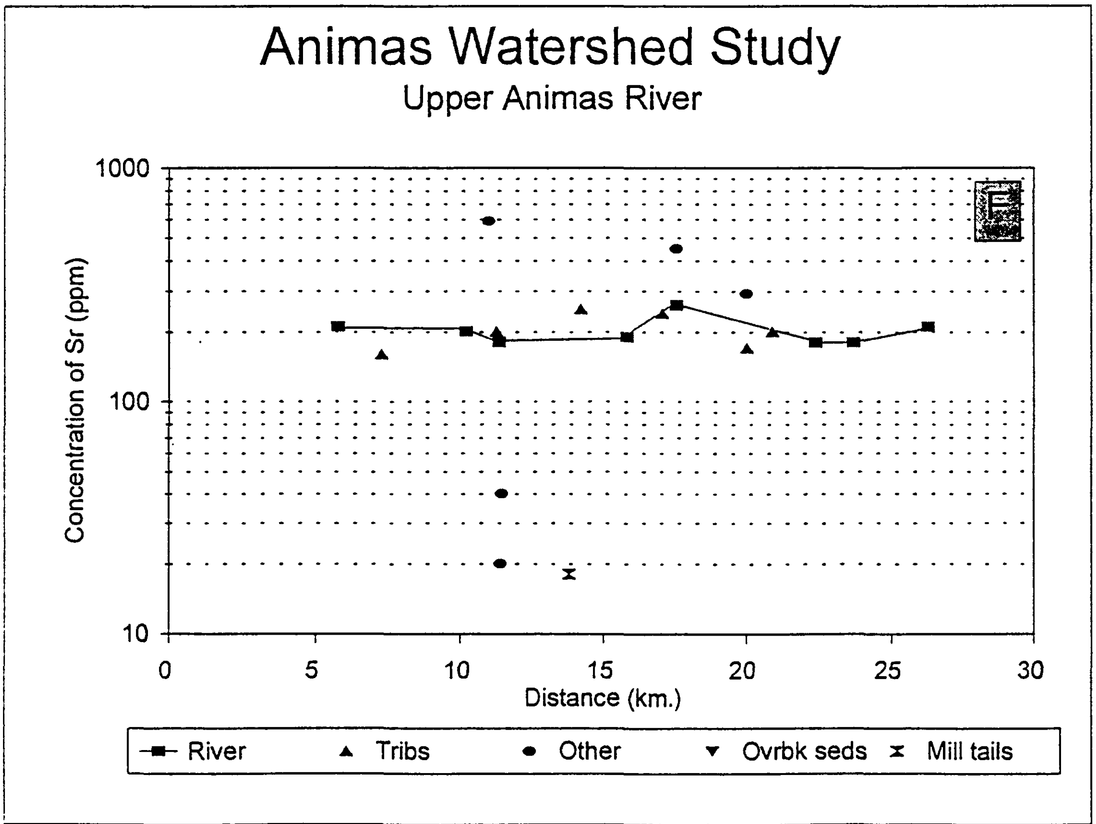
Animas Watershed Study
Upper Animas River
C
Concentration of Co (ppm)
1000
100
10
1
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails



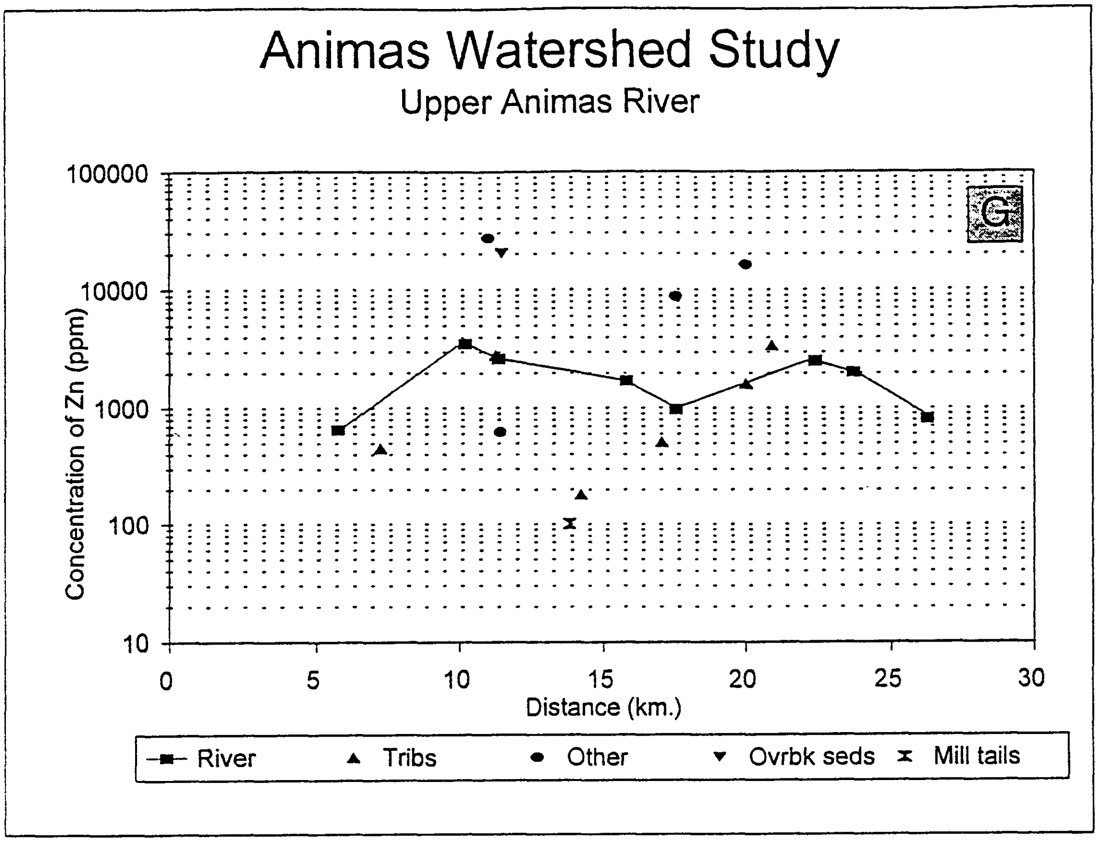
Animas Watershed Study
Upper Animas River
D
Concentration of Cu (ppm)
10000
1000
100
10
1
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails

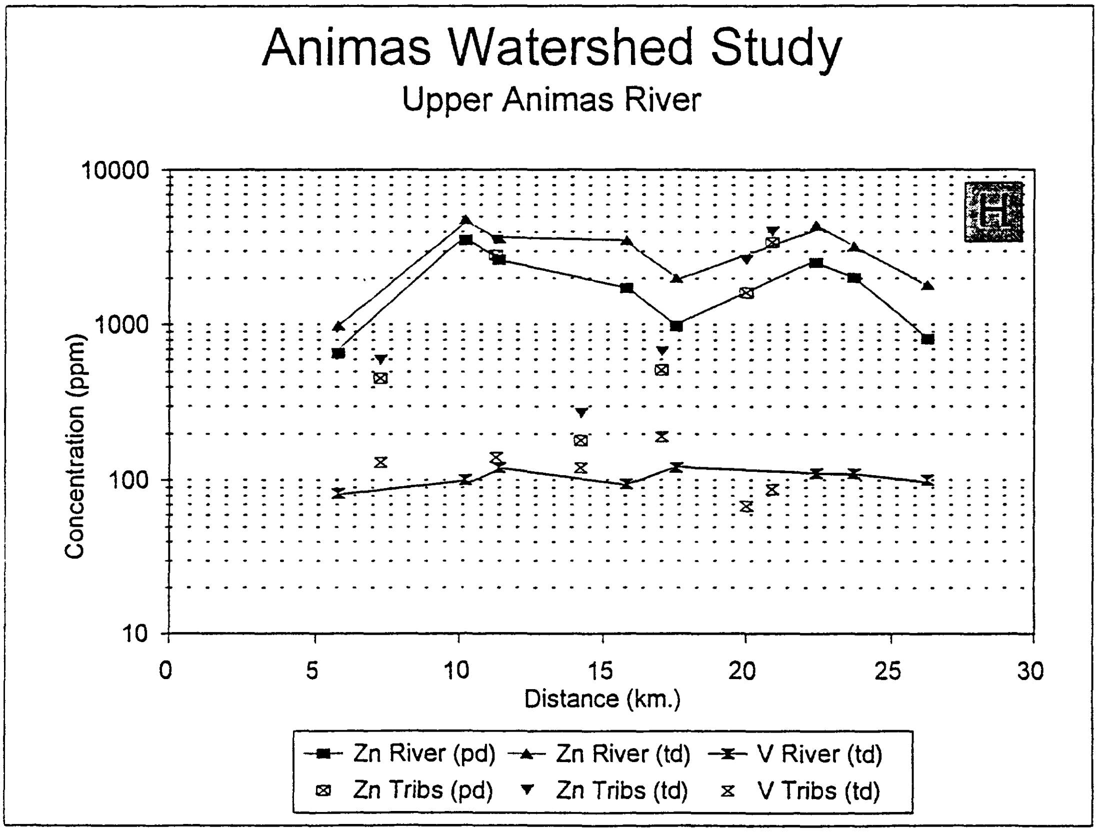


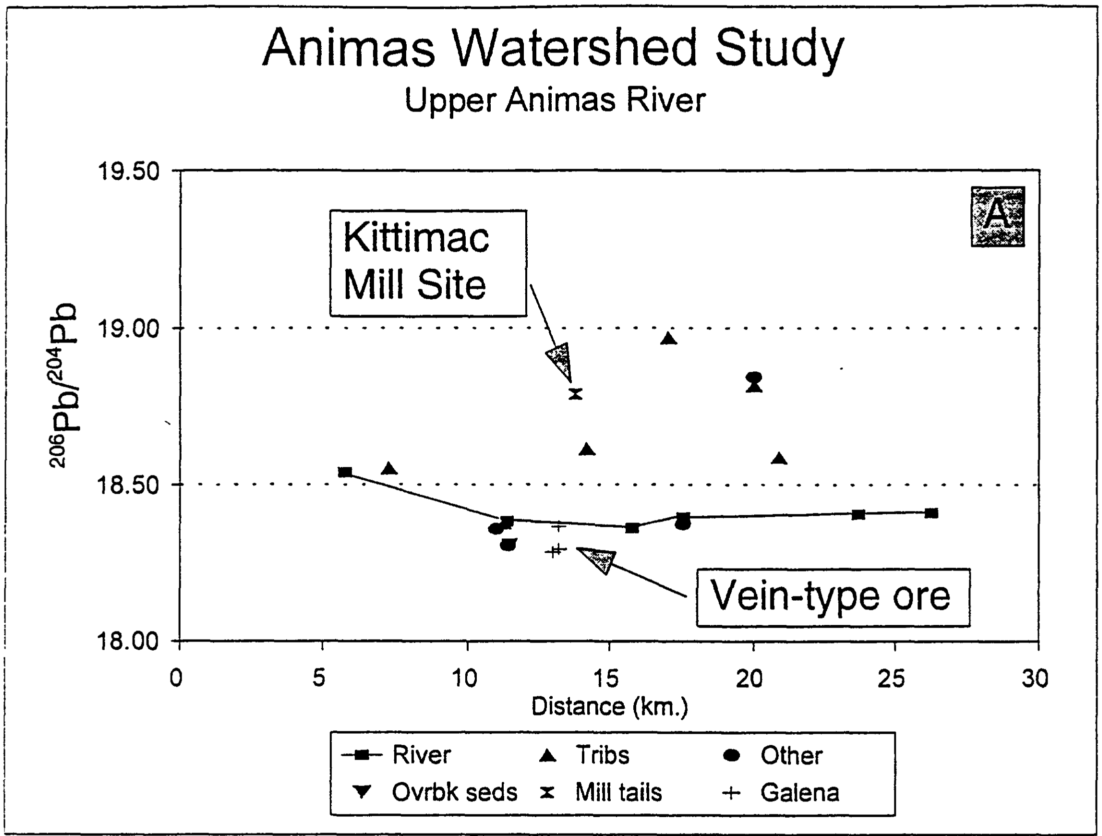
Animas Watershed Study
Upper Animas River
Concentration of Pb (ppm)
100000
10000
1000
100
10
1
0
5
10
15
20
25
30
Distance (km.)
E
River
Tribs
Other
Ovrbk seds
Mill tails



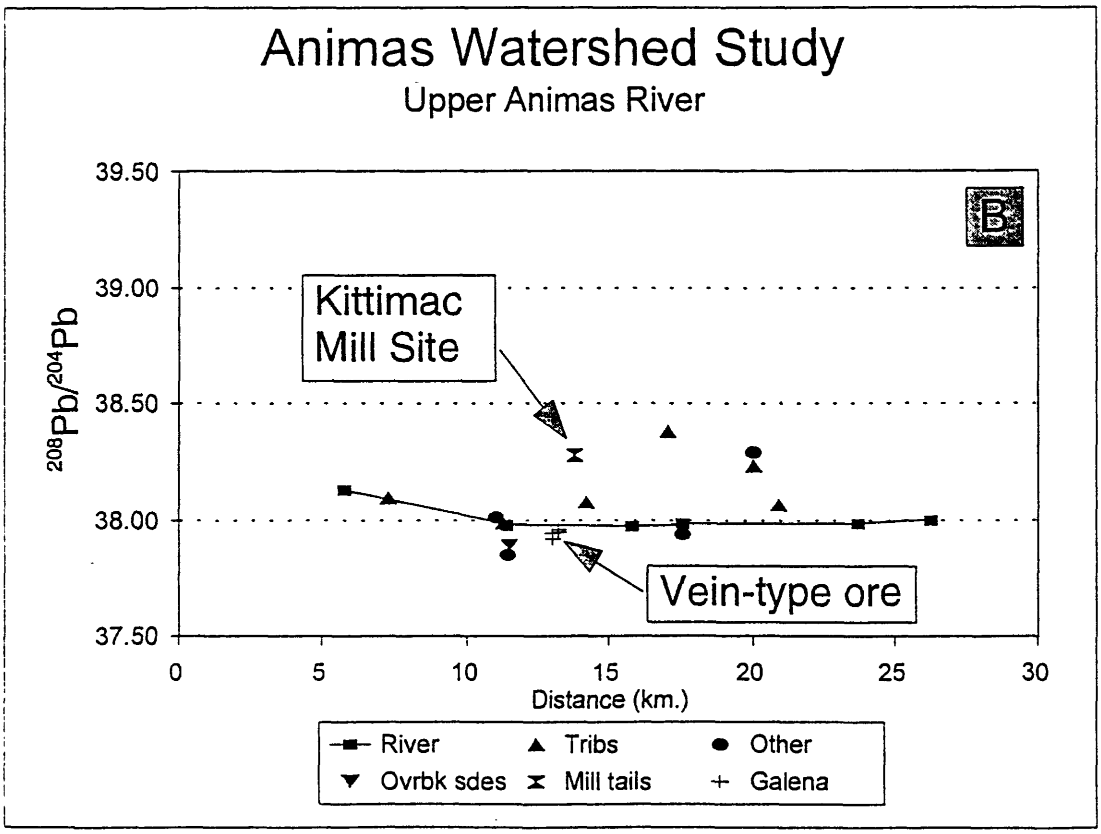
Animas Watershed Study
Upper Animas River
Concentration of Sr (ppm)
1000
100
10
0
5
10
15
20
25
30
Distance (km.)
F
River
Tribs
Other
Ovrbk seds
Mill tails


Animas Watershed Study
Upper Animas River
G
100000
10000
1000
100
10
Concentration of Zn (ppm)
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails


Animas Watershed Study
Upper Animas River
H
10000
1000
100
10
Concentration (ppm)
0
5
10
15
20
25
30
Distance (km.)
Zn River (pd)
Zn River (td)
V River (td)
Zn Tribs (pd)
Zn Tribs (td)
V Tribs (td)



Animas Watershed Study
Upper Animas River
A
Kittimac Mill Site
Vein-type ore
$^{206}Pb/^{204}Pb$
19.50
19.00
18.50
18.00
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails
Galena



Animas Watershed Study
Upper Animas River
B
Kittimac Mill Site
Vein-type ore
$^{208}Pb/^{204}Pb$
39.50
39.00
38.50
38.00
37.50
0
5
10
15
20
25
30
Distance (km.)
River
Tribs
Other
Ovrbk sdes
Mill tails
Galena

Animas River Drainage Basin: Silverton, Colorado to Aztec, New Mexico

The Animas Canyon reach, defined as that reach of the Animas River below Silverton to the KOA Campground sample site below Bakers Bridge (at 72.5 km), and the lower Animas River have very different geologic and resulting physiographic character. In the Canyon reach, the bedrock is Precambrian in age (fig. 3), very resistant to weathering, and supplies a small amount of sediment to the Animas River. The Animas River is highly incised and flows rapidly through the Animas Canyon reach transporting the metals and sediments with little addition to the bed sediments from the tributaries. In contrast, in the lower reaches, the Animas River has formed a wide flood plain on glacial terraces, and it flows in wide, meandering courses containing numerous oxbow lakes. In the lower Animas River reach, the bedrock consists of Paleozoic, Mesozoic, and Tertiary sedimentary rocks that are much more readily weathered. The amount of sediment added by individual tributaries varies greatly. In addition, the Animas River passes through the city of Durango and picks up metal loads of possible anthropogenic origin. This contrast in the basic physiographic and morphological features contribute differentially to the total mass of metals in the bed sediments of the Animas River.

Two overbank samples, one from Elk Park (34 km) and one from the KOA Campground below Bakers Bridge (72.5 km), and a stream-sediment sample from Hermosa Creek (80 km) warrant special mention. The two overbank samples, unlike those from the stream reaches above Silverton, do not have metal concentrations elevated above those found in the Animas River at the point where they were collected. Thus, these data, with the exception of zinc, plot on the metal profile curve for the bed sediments from the Animas River and will not be discussed further in this section. The stream-sediment sample from Hermosa Creek (95ABS135, "Other") was collected from a 0.4 km section of Hermosa Creek that is used by an irrigation company to transfer Animas River water from one irrigation canal to another. This sample, shown as the "Other" sample in figure 28, matches the bed sediment profile of the Animas River quite well. A second sample was collected later from Hermosa Creek at the gaging station (96ABS111) to provide geochemical data for Hermosa Creek. Data from this stream prompted us to look more closely at the samples collected in the earlier reconnaissance geochemical studies and to eliminate sediment samples that were affected by metals present in the water from the irrigation canal as noted above. These sites do not represent the geochemistry of the surrounding area and therefore were eliminated from the geochemical data base used to develop the regional geochemical maps. However, they clearly represent a stream-sediment sample whose geochemistry was greatly influenced by the precipitation of metals from the transported Animas River water.

Arsenic

Arsenic concentrations in bed sediments of the Animas River below Silverton drop from 20 ppm in the leach (about 10 times CAV) to near the limit of detection at 4 ppm near Durango (fig. 28A). Comparison of the leach data with the total digestion data (fig. 28B) indicates that the bed-sediment samples from the Animas River contain 5-15 ppm arsenic in either sulfide or silicate phases. Total arsenic concentrations increase immediately downstream in the Animas Canyon at Elk Park (34 km) and may reflect the addition of material from Deadwood Gulch (26.5 km) and Deer Park Creek (28 km) which drain mineralized areas on Sultan Mountain south of Silverton. Sediments from tributaries draining into the Animas Canyon reach contain 5-10 ppm arsenic whereas the samples from the tributaries south of Durango contain 3-5 ppm. Total arsenic concentrations increase from 5 to 7 ppm (three to four times CAV) below Durango (105 km) and may indicate the addition of arsenic from sediments derived from the Mesozoic and Tertiary rocks being eroded in this reach or from the abandoned copper smelter south of Durango.

Cobalt

Cobalt concentrations in the bed sediments of the Animas River below Silverton are nearly constant at about 18 ppm (fig. 28C) except for one site at Weaselskin Bridge (at 122 km). Cobalt concentrations in stream sediments from the tributaries range between 10-15 ppm and are generally somewhat less than that of the bed sediments from the Animas River for most of its distance. Above the confluence of the Florida River (136 km), the concentration of cobalt in the bed sediments of the Animas River and the stream sediments from the tributaries drops to about 12 ppm.

Copper

Copper concentrations in the leach digestion decrease uniformly through the Animas Canyon reach from 250 ppm (3.7 times CAV) at Silverton to 58 ppm at Weaselskin Bridge (122 km; fig. 28D). Total copper concentrations over this reach drop steadily from 330 ppm at Silverton to 200 ppm at the KOA Campground site (72.5 km), to 120 ppm at Weaselskin Bridge (122 km). Below the confluence with the Florida River (136 km), this component virtually drops abruptly from about 70 ppm to about 20 ppm. This pattern is noted to a lesser degree in the cobalt profile, but is also very pronounced in the zinc and vanadium profiles. From above the confluence of the Florida River southward (136 km), it would appear that all of the metals transported in the heavy-mineral fraction have been effectively buried in the bed sediments and are removed from active communication with the river water except during high-flow stages.

Lead

Lead concentrations in the bed sediments of the Animas River below Silverton drop from 1,200 ppm (about 90 times CAV) to about 300 ppm in Durango (100 km; about 20-25 times CAV) and to 140 ppm (122 km; 10 times CAV) at Weaselskin Bridge (fig. 28E). Below the confluence of the Florida River (136 km), the lead concentration drops to about 30 ppm. However, at Aztec (172 km), the lead concentration rises to 64 ppm. Labile lead concentrations in stream sediments from the tributary samples are uniformly low, generally less than 10 ppm, whereas the total lead concentration in stream sediments from the tributaries is closer to 20 ppm, suggesting that about 50 percent of the lead in the stream sediments from the tributaries is in the silicate phases. However, the lead concentration in the bed sediments over much of the course of the Animas River from Silverton to the confluence of the Florida River (136 km) is totally dominated by leachable lead sorbed onto the iron-hydroxide phase. The rise in the lead concentration in the bed sediment sample from Aztec is interpreted to be the result of accumulation of the iron-hydroxide phase in the sediments because the total digestion data contain only 9 ppm of silicate-bound lead, but 64 ppm of labile lead.

Strontium

The profile of strontium reflects the geochemistry of bedrock geology of the drainage basin. Through the Animas Canyon reach, there is no change in the strontium concentration in the bed sediments (fig. 28F). Strontium concentrations in the tributaries draining Precambrian rocks (fig. 3) are lower than that in the bed sediments of the Animas River and have only a minor dilution effect on strontium concentrations in the bed sediments. Below the KOA Campground (72.5 km), strontium concentrations drop in response to sediment being added by tributaries draining basins underlain by Paleozoic rocks. Between Durango and the confluence of the Florida River (100-136 km), there is a dramatic increase in strontium in the bed sediments reflecting sediments derived from the Upper Cretaceous Picture Cliffs, Kirtland, and Fruitland Formations, and the lower Tertiary Animas Formation (fig. 3). The sample from Basin Creek (118 km) has a strontium concentration of 420 ppm. South of the confluence with the Florida River, the strontium concentration in the bed sediments of the Animas River again drops to 200 ppm at Aztec. The strontium data and the heavy-mineral data from the copper, vanadium and zinc profiles all indicate that there is a substantial volume of sediment added to the Animas River between Durango and the Colorado-New Mexico state line (140 km).

Zinc

Zinc concentrations in the 2M HCl-1%H_2O_2 digestion are about 800 ppm at Silverton and increase to 1,200 ppm in the bed sediment from the Animas River collected from the KOA Campground site (72.5 km) at the base of the Animas Canyon reach (fig. 28G) indicating a substantial gain in labile zinc in the iron-hydroxide phase in the Animas Canyon reach. This corresponds to a loss of dissolved zinc mass from the water in this stream reach. Labile zinc in stream sediments from the tributaries, except for those from Deadwood Gulch and Deer Park Creek (26.5-28 km), have zinc concentrations of less than 100 ppm. Labile zinc concentrations in the two overbank sediments are lower than in the bed sediments from the Animas River. This is the reverse of what was seen in overbank sediments from reaches above Silverton where the zinc concentration in overbank sediments was always elevated above the concentration in the bed sediment collected at that site. Labile zinc concentrations drop substantially between the KOA Campground site (72.5 km) and the Trimble Bridge site (82 km), and then gradually increase to the Weaselskin Bridge site (122 km).

Below the confluence of the Florida River (136 km), labile zinc concentrations drop from 1,100 ppm to 240 ppm but rise again to 290 ppm at Aztec (172 km).

Total zinc concentrations behave quite differently (fig. 28H). At the Animas River site below Silverton (A-72) only 44 percent of the zinc is in the iron-hydroxide phase. Most of the zinc in the bed sediments is in sphalerite. At Elk Park (34 km), the labile zinc concentration decreased to only 30 percent of the total zinc present. At the KOA Campground site (72.5 km), labile zinc constitutes 75 percent of the total zinc in the bed sediments. This pattern is relatively constant through the stretch between the KOA Campground and Weaselskin Bridge (72.5-122 km). Below Weaselskin Bridge, the amount of sediment being added by the tributaries increases dramatically and sphalerite virtually disappears as a heavy-mineral phase in the active bed sediments of the Animas River. The difference between the total and the labile zinc concentrations is reduced to about 50-100 ppm. This difference is comparable to that which we see between the labile and the total zinc concentrations in stream sediments from the tributaries where 50-100 ppm of zinc is silicate-bound. Since the zinc concentration in the sediment from Basin Creek (118 km) is very low (38 ppm), the fact that the labile zinc concentration increases from 230 to 290 ppm between the confluence of the Florida River (136 km) and Aztec (172 km) indicates that the zinc in the iron-hydroxide phase is settling out of the water column and into the bed sediments over this reach of the Animas River.

Vanadium

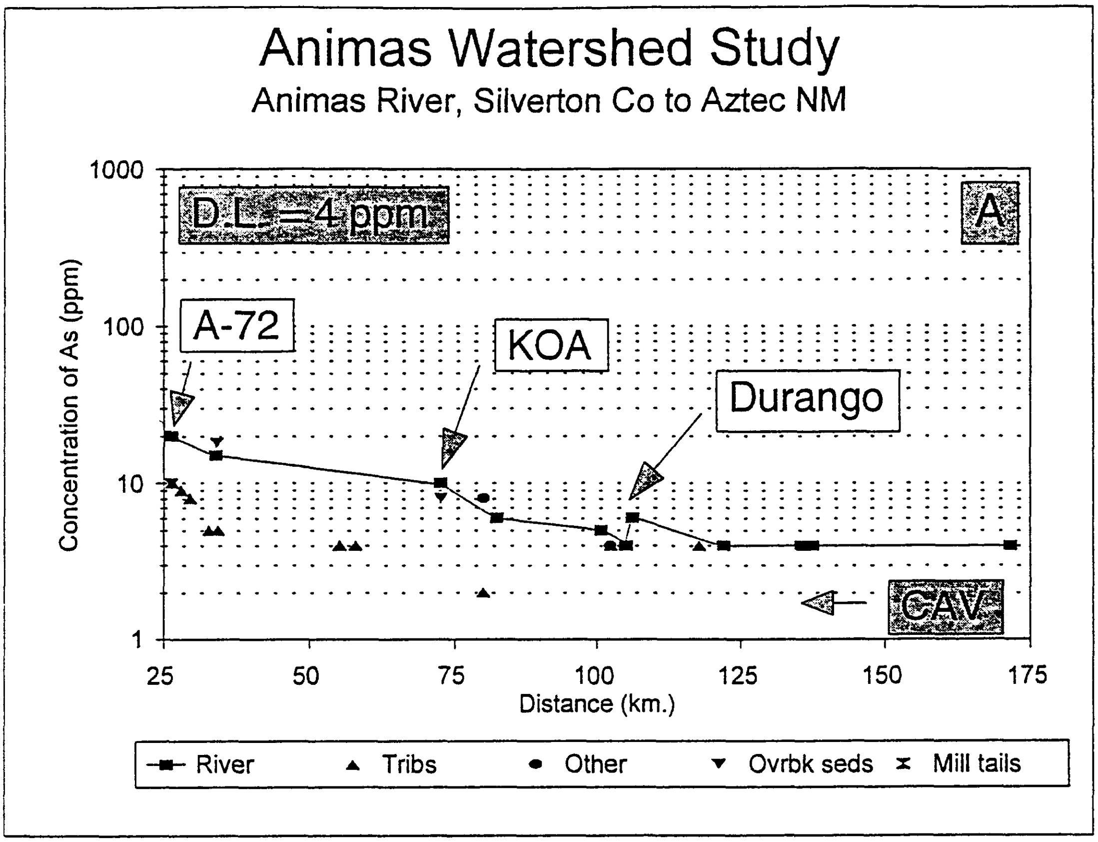
Vanadium concentrations in the bed sediments of the Animas River Canyon reach (26.5-72.5 km; fig. 28H) have a relatively flat profile and reflect the concentrations in Mineral and Cement Creeks and the upper Animas River above Silverton. Between the KOA Campground site below Bakers Bridge and Weaselskin Bridge (72.5 - 122 km), there is a gradual increase in vanadium from about 150 to 180 ppm. This increase cannot be attributed to the addition of vanadium in stream sediments being added by the tributaries. To the contrary, the addition of sediments from the tributaries should lower the vanadium concentration in the bed sediments of the Animas River (fig. 28H). We attribute the increase of vanadium and of total zinc concentrations to the accumulation of the heavy minerals magnetite and sphalerite in the near-surface bed sediments of the Animas River below the Animas Canyon reach. Between Weaselskin Bridge (122 km) and the confluence of the Florida River (136 km), the vanadium concentration drops to about 100 ppm matching that of the sediment from the Basin Creek tributary. Since the source of the sediments in Basin Creek is sedimentary rocks, we assume that the vanadium is largely in the silicate minerals.

Lead-isotopic data

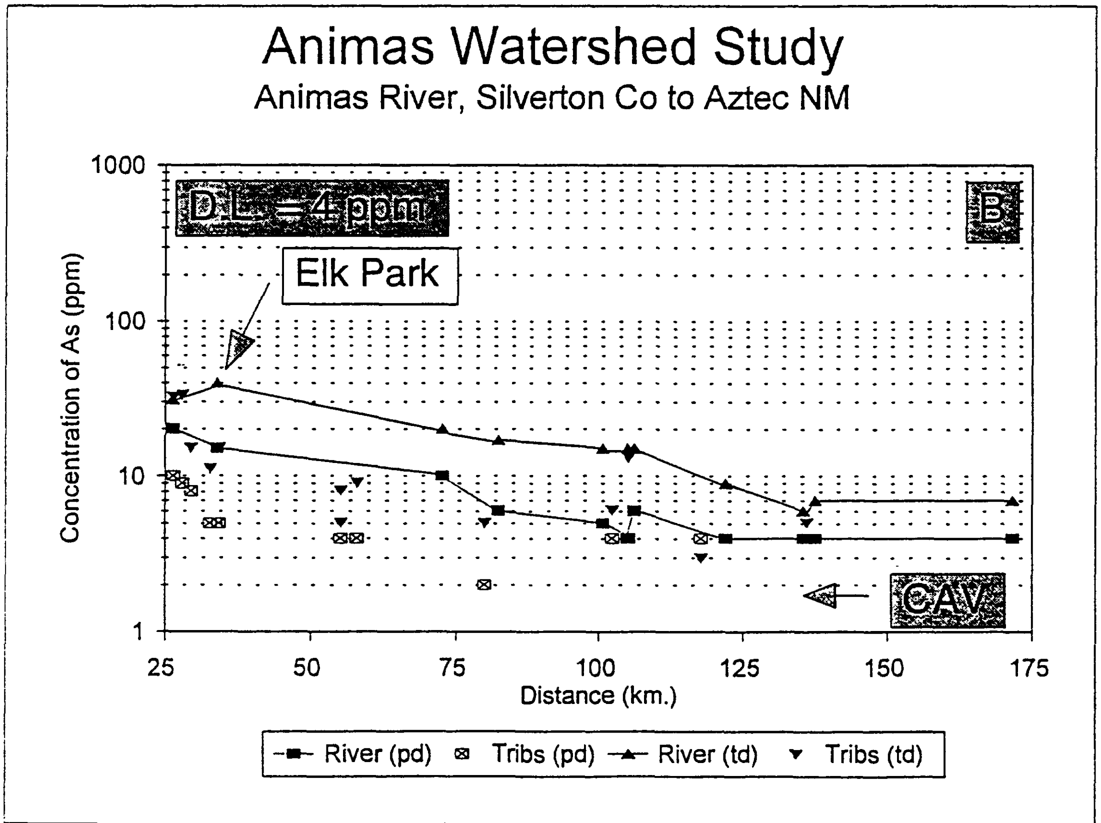
Lead-isotopic data from the Marcella Mine on Kendall Mountain closely matches that from the bed sediments of Deadwood Gulch and Deer Park Creek (26.5 and 28 km respectively) and is slightly elevated above that of the bed sediments of the Animas River below Silverton (figs. 29A and B). Throughout the rest of the Precambrian section exposed in the Animas Canyon reach, lead from the stream sediments sampled from tributaries draining the Precambrian rocks differs substantially from that in the bed sediments of the Animas River in the Canyon reach. The gradual increase in lead-isotopic ratios indicates a small addition of sediment derived from Precambrian rock to the bed sediment of the Animas River. Likewise, sediments derived from erosion of Paleozoic and Mesozoic sedimentary rocks cropping out between the KOA Campground site (72.5 km) and Durango (100 km) add sediment, which results in a gradual change in the lead-isotopic ratios along the course of the Animas River. It is clear from these data, however, that the lead concentration in the bed sediments of the Animas River is dominated by lead from above Silverton that is sorbed to the precipitated colloidal component in the bed sediments.

Figure 28. Metal distribution profiles (A-H) for the Animas River below Silverton to Aztec, New Mexico; metal concentrations for labile arsenic (As), total arsenic, total cobalt (Co), labile copper (Cu), labile lead (Pb), total strontium(Sr), labile and total zinc (Zn; pd–labile zinc from the partial digestion and td–total zinc) and total vanadium (V) plotted against river distance measured downstream from the confluence of Mineral Creek (25 km) with the Animas River below Silverton, Colo. Data from four different sample types are plotted as indicated by the explanation on the diagrams; no mill tailings were sampled. Note that metal concentrations in stream sediments from tributary streams below the confluence, but within the Sultan Stock where mines are still present (fig. 4) still have elevated metal concentrations. Metal concentrations in tributary streams below 30 km that drain primarily the area underlain by sedimentary rocks in the Animas watershed have metal concentrations at or below that of crustal abundance values (CAV). Sample localities on the Animas River are indicated, plotted as a function of distance: site A-72 below the confluence with Mineral Creek (26.25 km), Elk Park (34 km), the KOA Campground site below Bakers Bridge (72.5 km), below the Trimble Bridge below the quarry (82.35 km), above the 32nd Street Bridge in Durango (100.75 km), at the Red Lion Inn above the confluence with Lightner Creek (105 km), at the park above Colo. highway 550 (106.2 km), south of Weaselskin Bridge (122 km), above the Bondad Bridge (135.5 km), at the Cedar Hill gaging station (137.5 km), and above the bridge in Aztec, New Mexico (171.5 km). Sample localities of the tributaries to the Animas River are indicated, plotted as a function of distance from north to south: Deadwood Gulch (26.5 km), Deer Park Creek (28 km), Sultan Creek below the Molas Mine (29.5 km), Molas Creek above the confluence with the Animas River (32.75 km), Elk Creek (34.35 km), Lime Creek upstream from U.S. 550 (55 km), Cascade Creek upstream from U.S. 550 (55.05 km), Cascade Creek above the confluence with the Animas River (55.1 km), Grasshopper Creek (57.8 km), Hermosa Creek at the gaging station (80 km), Junction Creek 1.7 km west of town (102.4 km), Lightner Creek (105.1 km), Basin Creek (117.75 km), and the Florida River (136 km). The "Other" samples are from the contaminated segment of Hermosa Creek (80 km) and from Junction Creek (102.35 km) in the city limits of Durango.

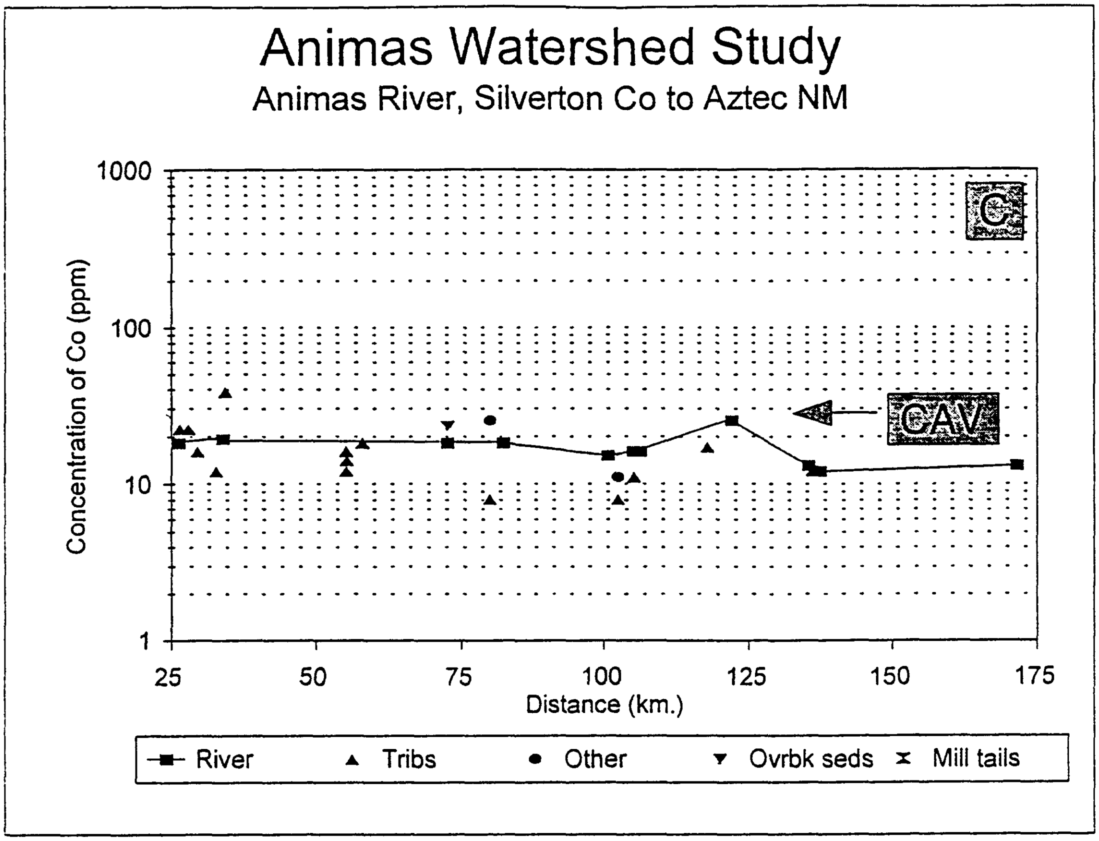
Figure 29. Profile plots of the lead-isotopic signatures of acid-soluble metals from sediments from the tributaries draining into the Animas River below the confluence with Mineral Creek (25 km) with the upper Animas River at Silverton Colo. and from sediments from the main course of the Animas River. Data from four different sample types are plotted as indicated by the explanation on the diagrams; distances are as noted in the explanation for figure 28. No mill tailings were sampled. Lead-isotopic data from Deadwood gulch and Dear Park Creek match closely the lead-isotopic signature from the Marcella Mine in the Sultan Stock. Note that the lead-isotopic compositions from tributaries draining the Precambrian rocks have a highly radiogenic $^{206}Pb/^{204}Pb$ value relative to that from tributaries draining Paleozoic and Mesozoic sedimentary rocks. The two "Other" samples are from the contaminated segment of Hermosa Creek (80 km) and from Junction Creek in the city limits of Durango. Note that the lead-isotopic signature from this Hermosa Creek sample matches that of the area above Silverton. The lead-isotopic data indicate that most of the lead in the bed sediments of the Animas River was derived from the area above Silverton, Colo.

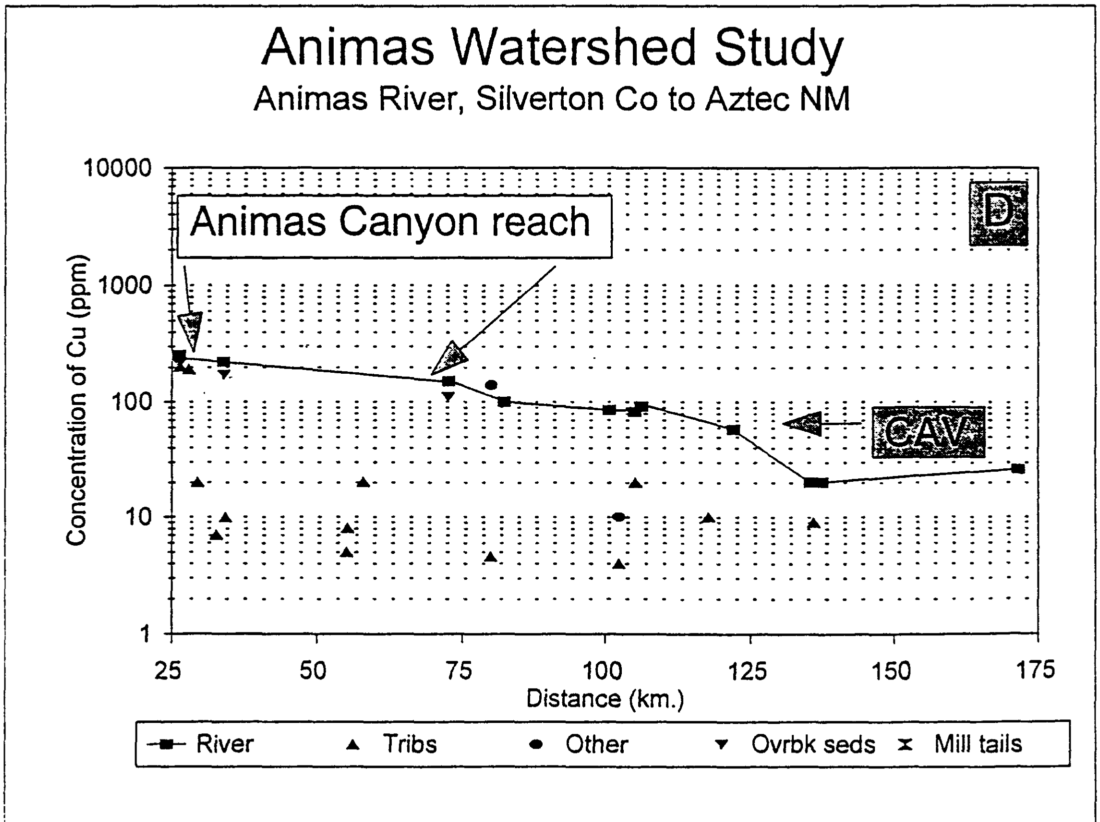


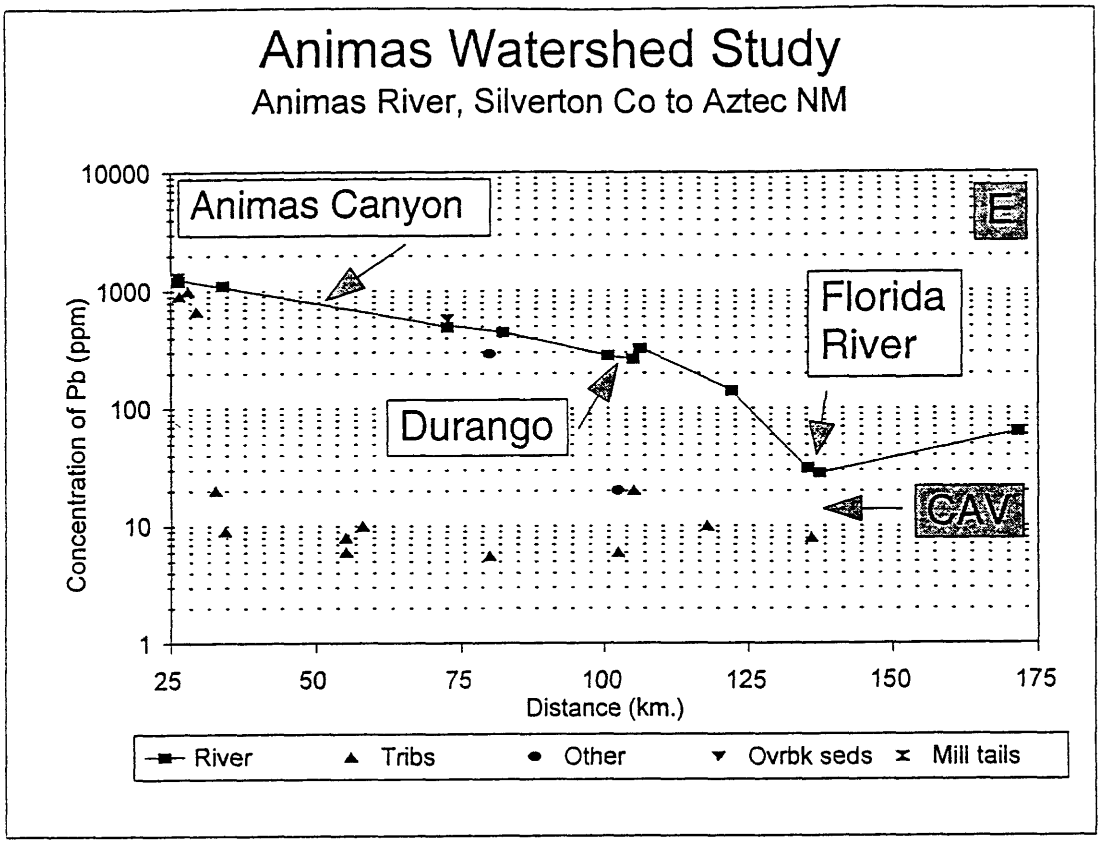
Animas Watershed Study
Animas River, Silverton Co to Aztec NM
D.L. = 4 ppm
A
A-72
KOA
Durango
CAV
Concentration of As (ppm)
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails

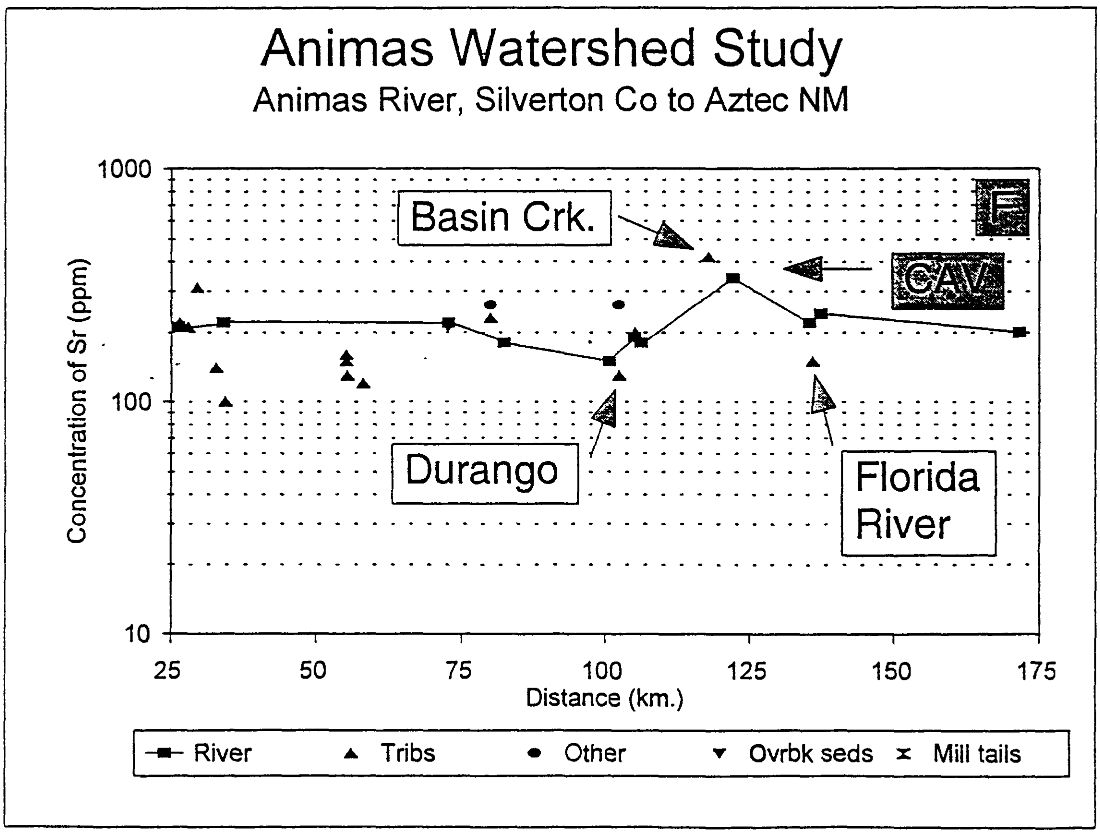


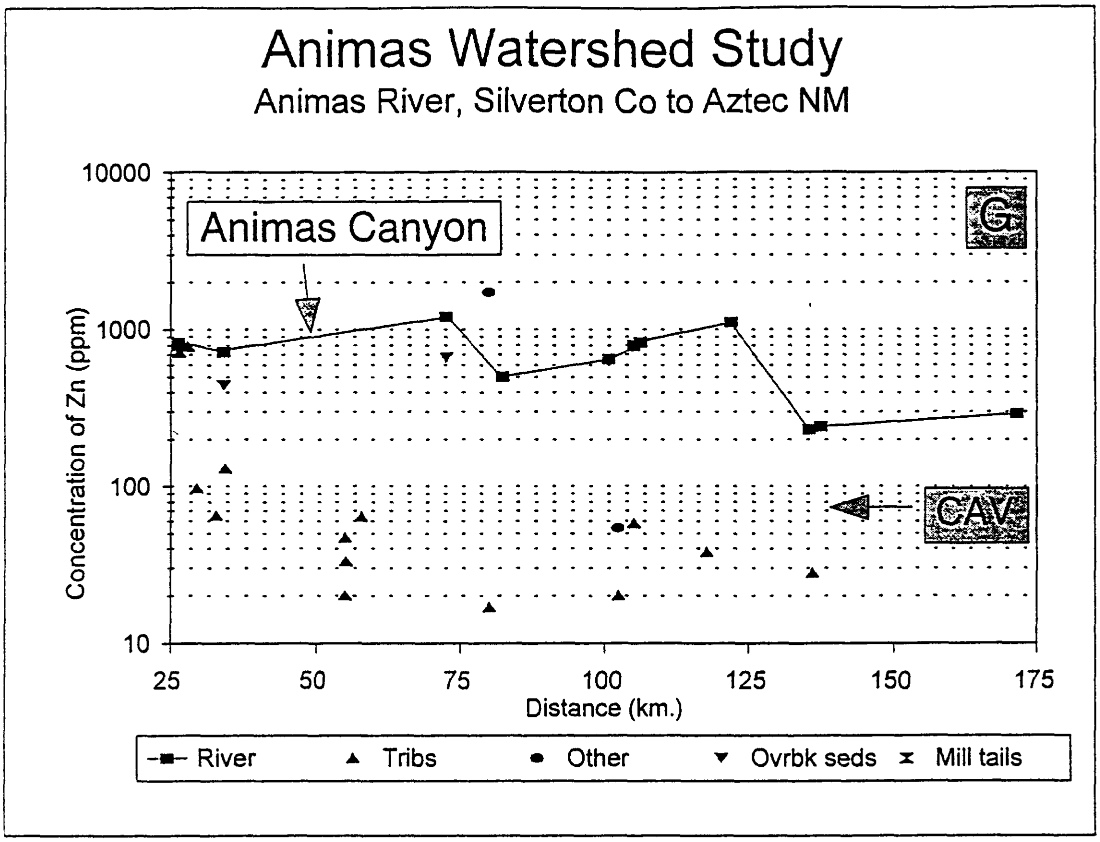
Animas Watershed Study
Animas River, Silverton Co to Aztec NM
D.L. = 4 ppm
B
Elk Park
CAV
Concentration of As (ppm)
Distance (km.)
River (pd)
Tribs (pd)
River (td)
Tribs (td)


Animas Watershed Study
Animas River, Silverton Co to Aztec NM
C
CAV
Concentration of Co (ppm)
1000
100
10
1
25
50
75
100
125
150
175
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails

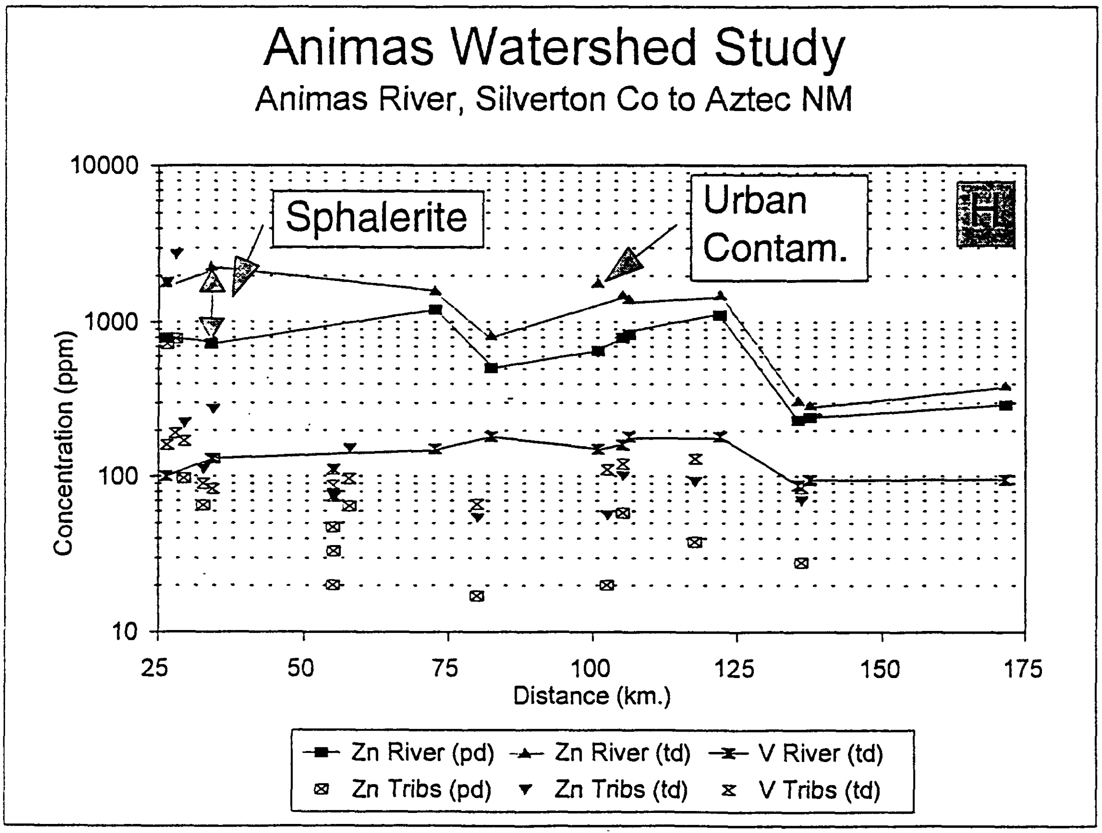

Animas Watershed Study
Animas River, Silverton Co to Aztec NM
Animas Canyon reach
D
CAV
Concentration of Cu (ppm)
10000
1000
100
10
1
25
50
75
100
125
150
175
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails


Animas Watershed Study
Animas River, Silverton Co to Aztec NM
Animas Canyon
E
Florida River
Durango
CAV
Concentration of Pb (ppm)
10000
1000
100
10
1
25
50
75
100
125
150
175
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails

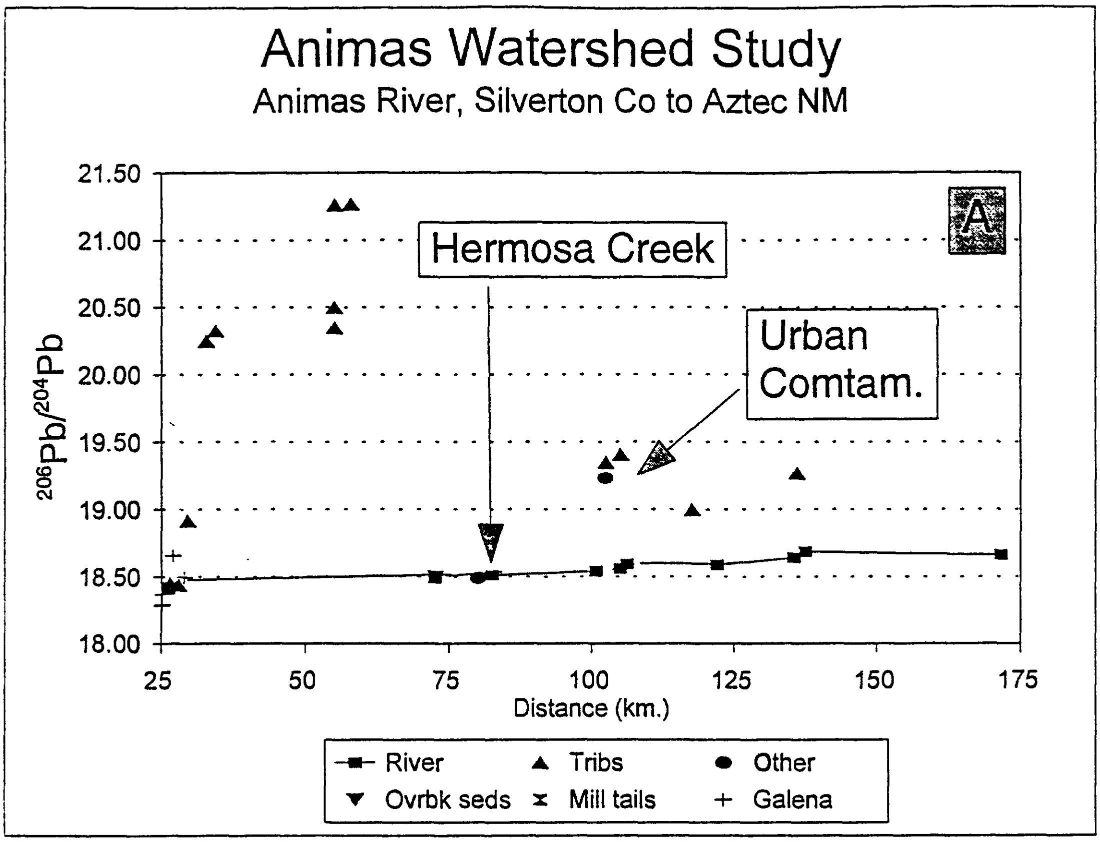

Animas Watershed Study
Animas River, Silverton Co to Aztec NM
Basin Crk.
F
CAV
Durango
Florida River
Concentration of Sr (ppm)
1000
100
10
25
50
75
100
125
150
175
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails

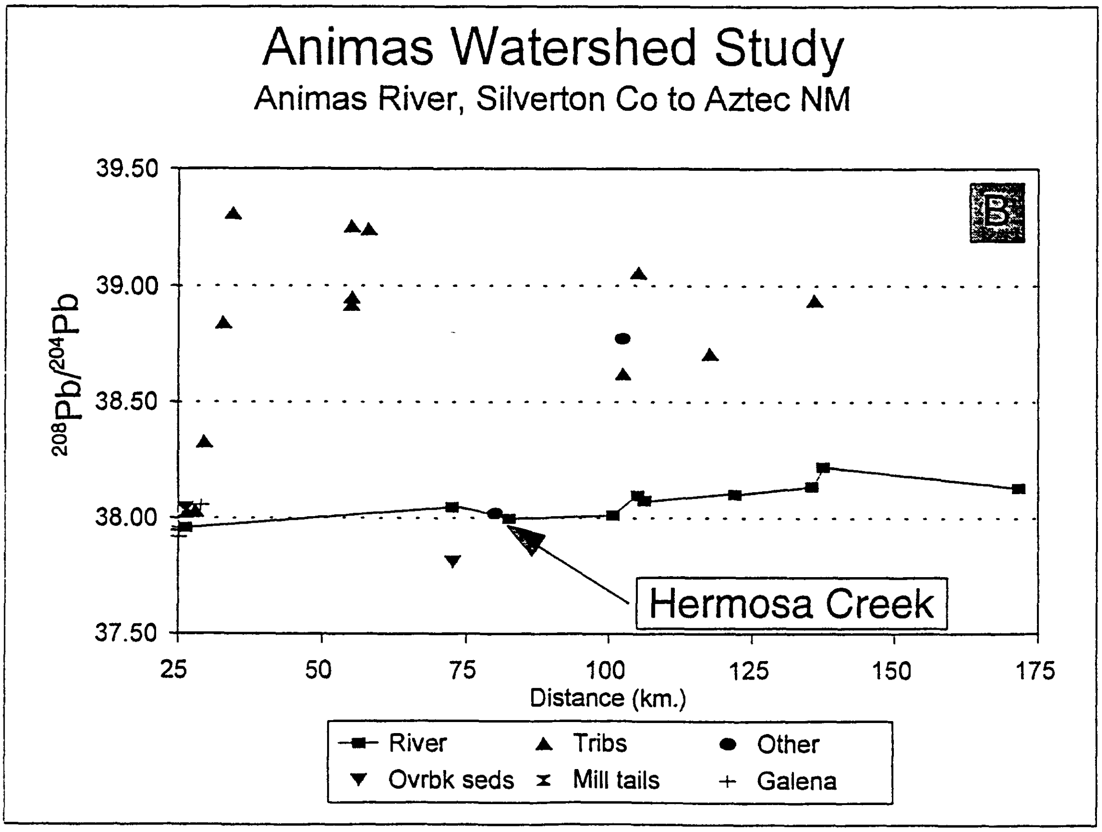


Animas Watershed Study
Animas River, Silverton Co to Aztec NM
Animas Canyon
G
CAV
Concentration of Zn (ppm)
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails



Animas Watershed Study
Animas River, Silverton Co to Aztec NM
Sphalerite
Urban Contam.
H
Concentration (ppm)
Distance (km.)
Zn River (pd)
Zn River (td)
V River (td)
Zn Tribs (pd)
Zn Tribs (td)
V Tribs (td)


Animas Watershed Study
Animas River, Silverton Co to Aztec NM
A
Hermosa Creek
Urban Comtam.
206Pb/204Pb
21.50
21.00
20.50
20.00
19.50
19.00
18.50
18.00
25
50
75
100
125
150
175
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails
Galena


Animas Watershed Study
Animas River, Silverton Co to Aztec NM
B
Hermosa Creek
208Pb/204Pb
39.50
39.00
38.50
38.00
37.50
25
50
75
100
125
150
175
Distance (km.)
River
Tribs
Other
Ovrbk seds
Mill tails
Galena

Metal Transport from the La Plata Mining District

Eckel and others (1949) describe the geology, mines, and production from the La Plata mining district near the headwaters of Junction Creek and the La Plata River. The La Plata deposit is a porphyry copper deposit associated with the intrusion of a syenite porphyry. Eckel and others (1949) report production of 2,336 tons of copper ore yielding about 224,000 pounds of copper and about 4,500 ounces of silver from a small open-pit from the Copper Hill Mine in the La Plata River watershed. Minor amounts of gold were produced with byproduct copper and silver from the Bay City Mine. Small amounts of both gold and silver were produced from precious-metal veins primarily from the Cumberland Mine, the Doyle Group, the Durango Girl Mine, the Eagle Pass Mine, the Gold King Mine, the Incas Mine, the Jumbo-Morovoratz Mine, the Lucky Discovery Mine, the Mason Mine and the Neglected Mine. The May Day and the Idaho Mines produced the bulk of the precious metals from the district, reporting total production of about 123,000 ounces of gold and 1,140 ounces of silver between 1903 and 1943. These two mines also reported minor byproduct lead and copper. Both cinnabar and native mercury are reported from the precious-metal veins. Of the mines listed above having recorded production, only the Durango Girl Mine and the Neglected Mine are in the headwaters of Junction Creek.

In the National Geochemical data base (Hoffman and Buttleman, 1994), six stream-sediment samples were collected from along Junction Creek downstream from the La Plata mining district and two new stream-sediment samples were collected in this study near Durango. None of the stream-sediment samples contained elevated concentrations of copper, lead, or zinc (figs. 6-8) except for sample 95ABD138 which was collected in Durango, inside the city limits. We see no evidence of the transport of metals to the Animas River from the La Plata mining district via Junction Creek.

Metals from the Smelter Sites South of Durango

The U.S. EPA conducted a preliminary site assessment of the copper smelter site located on the west bank of the Animas River about 1 km south of the confluence with Lightner Creek. Slag from the copper smelter is exposed on the west bank of the Animas River (U.S. EPA, 1996a). Analyses of the slag shows high concentrations of copper, lead, zinc, arsenic, manganese and iron were present. Analyses of bed sediments from the Animas River did not indicate that the slag pile was a source of metals to the Animas River (U.S. EPA, 1996b). No remedial action was recommended by the U.S. EPA (1996a). However, this site cannot be ruled out as the source for the small increase in arsenic concentrations found in the bed sediment data (fig. 28A and B) south of Durango. This small change may not be significant given the larger upstream sources of metals.

The EPA conducted a preliminary site assessment of buried slag from a lead smelter located on the west bank of the Animas River about 0.2 km south of the confluence with Lightner Creek. Slag from the lead smelter is exposed in the west cut bank of the Animas River (U.S. EPA, 1996c). Analyses of bed-sediment samples from the Animas River show that there are elevated zinc (28,500 ppm) and cadmium (498 ppm) concentrations at the cut bank site that reflect erosion of slag material from the cut bank, but both upstream and downstream, the metal concentrations were not elevated (U.S. EPA, 1996d). No remedial action was recommended by the U.S. EPA (1996c).

Urban Metal Signatures

Two samples, one from Junction Creek collected in Durango, and one from the Animas River at the park above the 32nd Street Bridge, show some urban metal contamination signatures. These urban metal sources contribute small amounts of metal contamination relative to the metal in the bed-sediments from the area above Silverton.

In the river-sediment sample from the park above 32nd Street Bridge (95ABS137), there are elevated concentrations of zinc and copper (fig. 28H). Elevated dissolved copper concentrations were also noted at this site. The absence of tin in the bed sediments would suggest that this is not likely from particulate brass contamination. The source of this urban metal signature is unknown.

The increased metal signature in Junction Creek is evident when comparing the data from sample 95ABS138 (collected one block west of U.S. 550 in Durango) with the data from sample 95ABS139 (collected from Junction Creek where it crosses a farm 1.7 km upstream and outside the city limits of Durango; sample collected with permission of the property owner). The sample from Junction Creek collected in the city limits of Durango (95ABS138) contains elevated concentrations of arsenic, chromium, copper, mercury, nickel, lead, vanadium, and zinc, all metals used in our industrial society. Furthermore, the lead-isotopic compositions in the two samples from Junction Creek differ, probably reflecting lead added to the environment by the combustion of gasoline. These urban metal sources contribute only small amounts of metals to the Animas River.

Selenium and Mercury in Bed Sediments of the Animas River

Selenium concentrations in bed sediments from Mineral and Cement Creeks, the Animas River, and their respective tributaries are presented in figure 30A. Although the diagram contains many data points, the most important feature of the plot is the small variation in the data set as a whole. Selenium is isochemical with sulfur and substitutes for sulfur in the sulfide minerals. It is not surprising that the sediments derived from the area above Silverton contain 1-2 ppm selenium and that the bed sediments of the Animas Canyon reach contain about 1 ppm selenium. The crustal abundance value for selenium is 0.5 ppm (Fortescue, 1992). With the influx of sediment from tributaries draining the Paleozoic and Mesozoic rocks below the KOA Campground site (72.5 km), selenium concentrations in the bed sediments drop to CAV. In Durango, selenium concentrations in bed sediments again rise to about 1 ppm in response to sediments derived locally from the Mancos Shale which crops out just above Lightner Creek (105 km). Sediments from Lightner Creek are characterized by a large component of Mancos Shale and contain 2.7 ppm selenium. Below the confluence with the Florida River (136 km), the selenium concentration drops again to 0.4 ppm reflecting the large component of sediments supplied by tributaries draining areas underlain by Tertiary rocks (fig. 3).

Mercury concentrations at several sites above Silverton (fig. 30B) are significantly elevated above the crustal abundance value (0.09 ppm; Fortescue, 1992). Five of the sites above Silverton contain elevated mercury concentrations, above 0.3 ppm (about three times CAV). All of these sites, except the Kittimac Mill site, are from the headwaters of the respective drainages where early mining activities took place. We cannot distinguish from these data and published geochemical data on the mineral deposits whether these elevated mercury concentrations are related genetically to the epithermal vein mineralization or to early gold recovery practices by individual miners. However, below Silverton, the only sample that contained elevated concentrations of mercury is the sample from Junction Creek in the city of Durango (102 km) which we interpret as urban contamination. Mercury concentrations in bed sediments of the Animas River below Silverton are generally at or below CAV.

Undiscovered Mineral Resources in the Silverton Area

The lead-isotopic and chemical data from stream sediments from Mineral and Cement Creeks and their tributaries suggest that the mineralized structures in the Eureka Graben (fig. 4) may extend west of the Gladstone Mine near the confluence of North and South Forks of Cement Creek into the headwaters of Burro Gulch in the Mineral Creek drainage. The lead-isotopic signature of the vein-type ore found in the Sunnyside Mine is present in the sediments of Browns Gulch (fig. 23). The surface expressions of these veins in Prospect Gulch may have been overprinted by the later intrusion and alteration associated with the chimney deposits of the Red Mountain district. Exploration for concealed extensions of the vein-type ore may be warranted in the western portion of upper Cement Creek between Prospect Gulch and Minnesota Gulch west to the headwaters of Browns Gulch where mineralization having the Eureka graben vein-type ore lead-isotopic signature is exposed.

Geochemical Signature of Colloid Component in Waters and Bed Sediments

The colloidal component dominates the leachable chemistry component of the bed sediments. Aggregated colloidal material is deposited during the low-flow cycle like a blanket on the stream bed and adds a substantial amount of metal to the bed sediments (fig. 18). The mass transfer of metals, as shown by the loss of dissolved and colloidal loads, is an indication that the bed sediments are gaining metals. The constant concentration ratios of iron to zinc in the colloids and in the 2M HCl-H_2O_2 digestions of the bed sediments are

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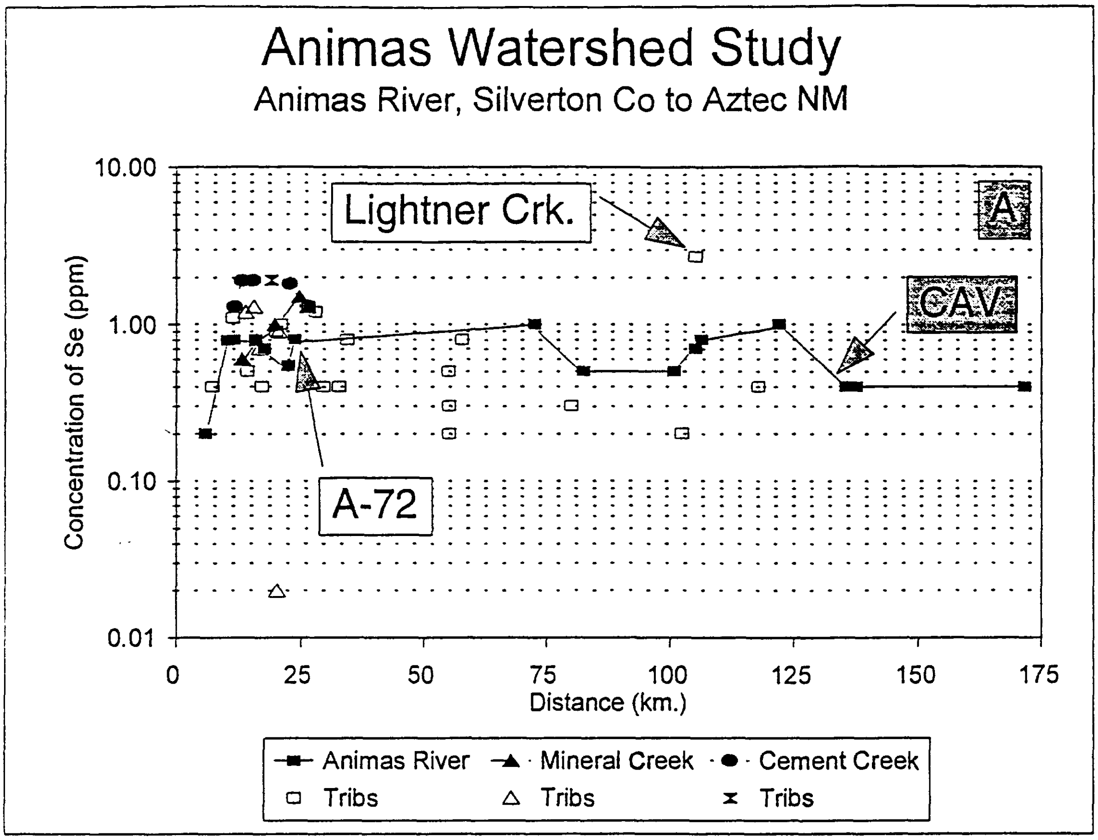
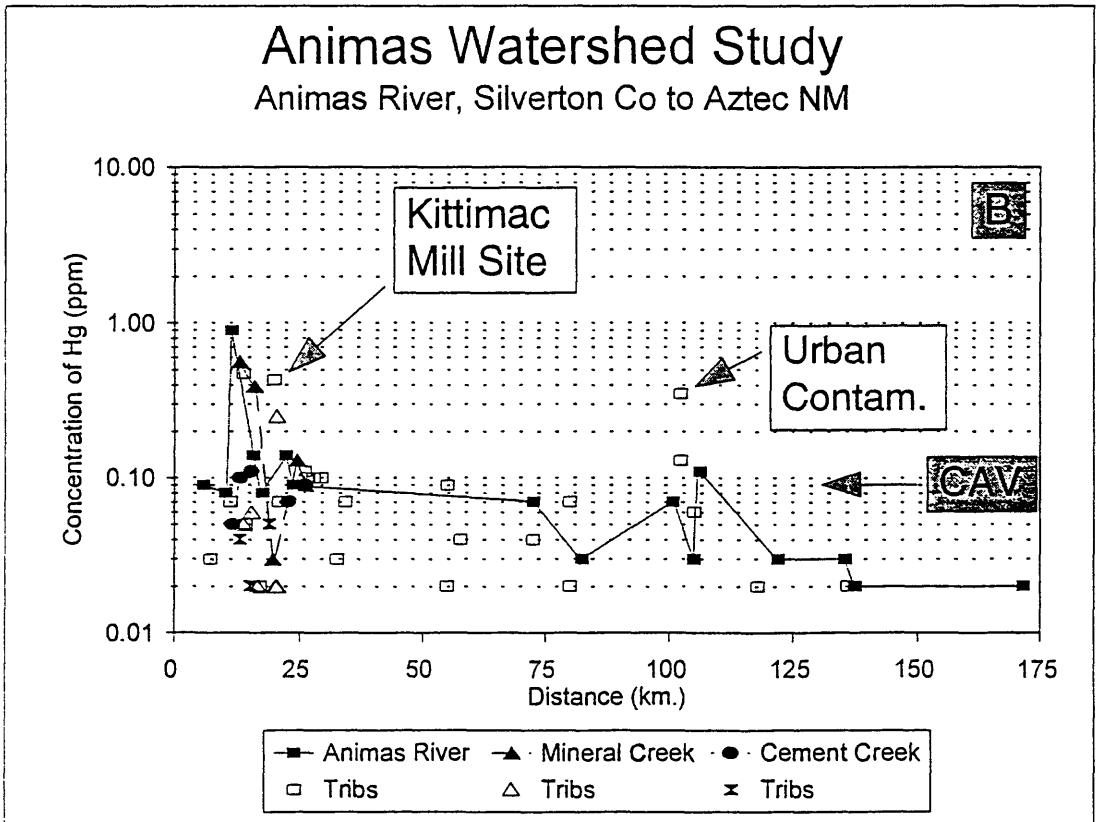
Figure 30. Metal distribution profiles for selenium (Se) and mercury (Hg) for the Animas River below Silverton to Aztec, New Mexico plotted against river distance measured downstream from the confluence of Mineral Creek (25 km) with the upper Animas River below Silverton, Colo. The limit of detection for selenium was 0.02 ppm and for mercury was 0.02 ppm.


Animas Watershed Study
Animas River, Silverton Co to Aztec NM
Lightner Crk.
A
CAV
A-72
Concentration of Se (ppm)
10.00
1.00
0.10
0.01
0
25
50
75
100
125
150
175
Distance (km.)
Animas River
Mineral Creek
Cement Creek
Tribs
Tribs
Tribs


Animas Watershed Study
Animas River, Silverton Co to Aztec NM
Kittimac
Mill Site
B
Urban
Contam.
CAV
Concentration of Hg (ppm)
10.00
1.00
0.10
0.01
0
25
50
75
100
125
150
175
Distance (km.)
Animas River
Mineral Creek
Cement Creek
Tribs
Tribs
Tribs

a measure of the intimate mixing between colloids and bed sediments downstream from Silverton. Upstream from Silverton and downstream from Cement Creek, the ratios did not agree. Downstream from Mineral Creek, however, after colloids had settled from the Animas River and zinc had sorbed to them, the ratios agreed very well. In fact, the iron to zinc ratios were comparable for a 100-km reach of the Animas River (fig. 31A). The close agreement in the iron to zinc ratio indicates that the iron hydroxide component digested from the bed sediments was essentially the same as the colloidal material. Some part of the colloidal material that settled to the stream bed had become part of the bed sediment coatings.

A similar correspondence of concentration ratios between colloids and bed sediments occurred for the ratios of aluminum (fig. 31B) and copper (fig. 31C) with respect to zinc, although the agreement is not as striking. The amount of aluminum deposition from water to bed sediments downstream from the confluence of Mineral Creek was about 260 kg/day. This amount of deposition had a substantial influence on the chemistry of the iron hydroxide fraction of the bed sediments, and thus the metal ratios in the colloids and the bed sediments varied together.

Comparison of the 1995 and the 1996 Bed-Sediment Data

Comparisons of the yields from samples collected at the same sites in both 1995 and 1996 indicates that the metals associated with the iron-hydroxide phases, that is copper, lead, and zinc in particular, are enriched in the 1996 data set from 10-50 percent over what these same sites were in 1995. This indicates that the hydrograph affects the amount of colloidal component that accumulates at any given site during the year. The snowpack in 1996 was low and the resulting low-volume spring runoff may not have completely flushed the streams of cumulated colloidal components (fig. 9). Whereas the general form of the metal profiles from year-to-year are the same, it would be difficult to use the sediment samples as a monitoring tool to evaluate the effects of remediation because of the variability caused by this flushing process (see appendix VII). Water chemistry probably provides a better monitoring tool because it provides an instanteous measure of metals in the stream whereas the sediment sample provides a variable, annual integrated measure of the metals in the streams.

Calculation of the Contribution to the Total Amount of Metal in Bed Sediments from Various Sources

The partitioning of copper, lead, and zinc between the water, colloidal and bed sediments as a function of pH is very evident from the combined water, colloid, and bed-sediment data in this report. In Cement Creek at Memorial Park, where the pH at low flow was 3.89, copper concentrations were high in the dissolved phase and labile copper in the bed sediments upstream from Memorial Park was in the range of 50-80 ppm (fig. 24D). In the upper Animas River above Silverton, where the pH at low flow was 6.82, copper concentration in the water were low whereas labile copper concentrations in the bed sediments were in the range of 300-500 ppm (fig. 26D). Smith and others (1992) demonstrated that the partitioning of metals in acidic, iron-rich waters followed a predictable path that could be modeled using sorbtion partitioning data and the iron hydroxide content of these waters (fig. 32A and B). As the colloidal content of the water decreases, the pH at which metals are sorbed by the colloids increases. We interpret the data from our study to indicate that copper is partitioned to the bed sediments through the sorption of copper to the colloids as a function of increasing pH. The aggregation and settling of the colloidal phase to the bed sediments results in a partitioning of the metal load from the dissolved and suspended colloids to storage in a static blanket of colloidal material in the bed sediments.

Dissolved and colloidal lead concentrations in the waters of Mineral and Cement Creeks and the upper Animas River are all less than the limit of detection indicating that lead is partitioned into the colloidal phase at low pH and precipitated to the bed sediments as soon as it reaches the streams. The dramatic differences in the lead concentrations in the bed sediments between Cement Creek (a gradual decrease from

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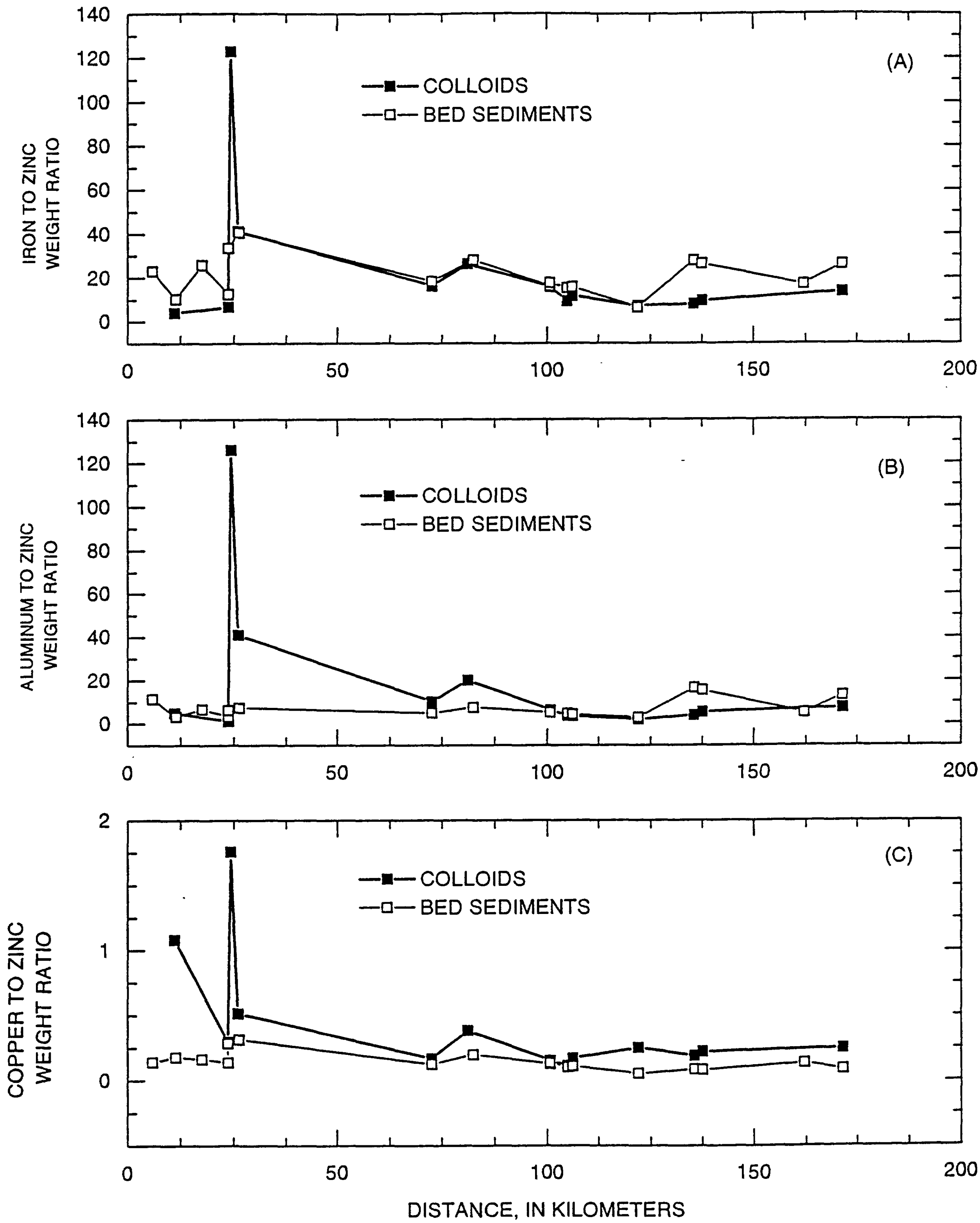
Figure 31. Downstream variation of the iron to zinc weight ratio (A) in colloids and bed sediments of the Animas River and tributaries (low flow, Oct. 1995), (B) downstream variation of the aluminum to zinc weight ratio in colloids and bed sediments of the Animas River and tributaries (low flow, Oct. 1995), and (C) downstream variation of the copper to zinc weight ratio in colloids and bed sediments of the Animas River and tributaries (low flow, Oct. 1995).


(A)
COLLOIDS
BED SEDIMENTS
IRON TO ZINC WEIGHT RATIO
0
20
40
60
80
100
120
140
0
50
100
150
200
(B)
COLLOIDS
BED SEDIMENTS
ALUMINUM TO ZINC WEIGHT RATIO
(C)
COLLOIDS
BED SEDIMENTS
COPPER TO ZINC WEIGHT RATIO
0
1
2
DISTANCE, IN KILOMETERS

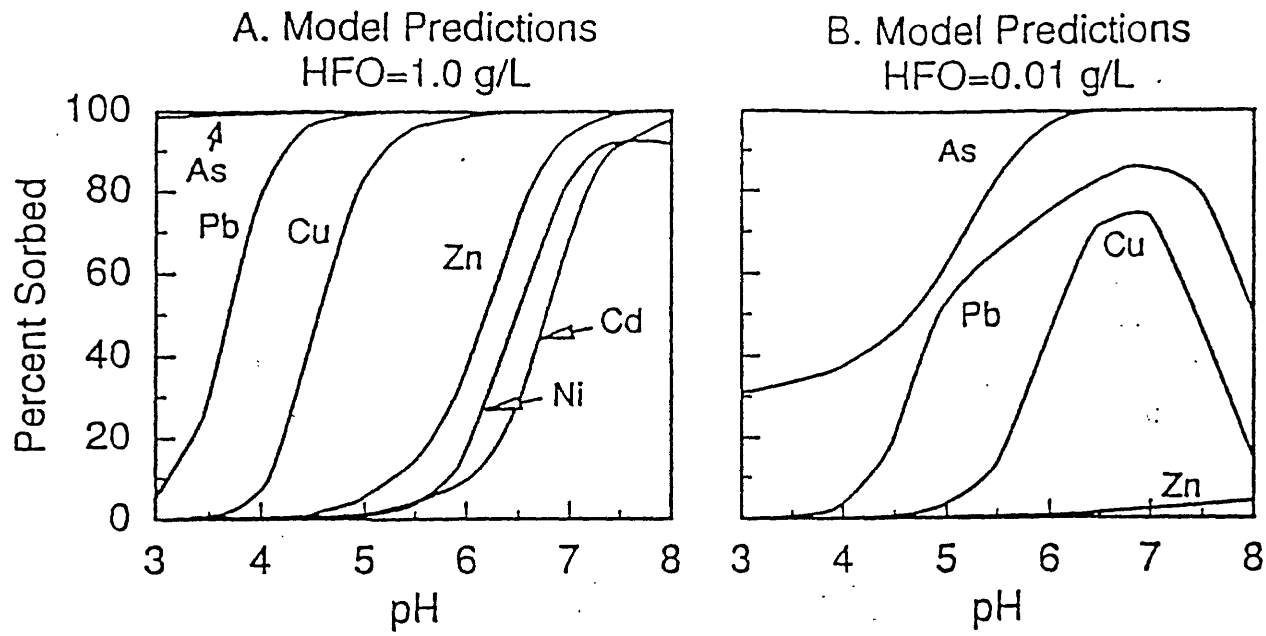


Figure 32. Plots of the predicted sorbtion of metals on suspended iron hydroxides as a function of pH for two different concentrations of iron colloids (HFO); A, model predictions at 1g/L and B, model predictions at 0.01 g/L (from Smith and others, 1992).

600 to 300 ppm; fig. 24E), the upper Animas River (generally greater than 1,000 ppm; fig. 26E), and Mineral Creek (1,000 ppm at the headwaters decreasing to about 200 ppm at the confluence, fig. 22E) demonstrates how lead in bed sediments responds over a short distance to the changes in the sources of lead as was shown previously in the study of acidic streams at Mount Emmons near Crested Butte, Colo. (Gulson and others, 1992). This concept is particularly dramatic in the changes in the lead-isotopic compositions seen in bed sediments from the profile of Mineral Creek (fig. 23A and B).

Zinc concentrations in Cement Creek, where pH at low flow was 3.89, were 1,338 ppb, and zinc in the bed sediments is about 200 ppm above Memorial Park (fig. 24G). In the upper Animas River above Silverton, where the pH at low flow was 6.62, the dissolved zinc concentration was 319 ppb and zinc in the bed sediments was in the range of 3,500-1,000 ppm (fig. 26G) indicating that much of the dissolved zinc has been partitioned to the colloidal phase in the bed sediments as described above. This process also continues through the Animas Canyon reach (fig. 13A). An understanding of this dynamic process of partitioning metals between the dissolved, colloidal, and bed sediment compartments is necessary to evaluate the process of metal transport over the hydrograph in the Animas River watershed (fig. 9) and their impact on water quality.

The geochemical profiles showing the dispersion and dilution of metals in the bed sediments of the Animas River below Silverton are convincing evidence that the source of these ore metals in the Animas River watershed is above Silverton. A very important question that should be addressed is:

> Can we isolate the contributions of the three major tributaries, Mineral and Cement Creeks and the upper Animas River, to determine which tributary provides what portion of the metals in the bed sediments?

There are two basic approaches to this fundamental question: mass balance calculations like those outlined in equation 1 and lead-isotope calculations as outlined in equation 2. We will use a combination of these two approaches to arrive at an estimate of the sediment added by Mineral and Cement Creeks to the total mass of the bed sediment in the Animas River below Silverton.

The mass balance or mixing calculations are straight forward. The total concentration of any given metal in the bed sediments is defined by:

$$T(Me)_{AB} = X(Me)_{MC} + Y(Me)_{CC} + Z(Me)_{UAR} \quad (1)$$

where: $T(Me)_{AB}$ is the total concentration (ppm) of the metal **Me** in the bed sediments of the Animas River below Silverton (site A-72),

X is the fraction of the total metal concentration contributed by bed sediments from Mineral Creek,

$(Me)_{MC}$ is the concentration of the metal **Me** in the bed sediments from Mineral Creek above the confluence,

Y is the fraction of the total metal concentration contributed by bed sediments from Cement Creek,

$(Me)_{CC}$ is the concentration of the metal **Me** in the bed sediments from Cement Creek above the confluence,

Z is the fraction of the total metal concentration contributed by bed sediments from the upper Animas River above the confluence with Cement Creek, and

$(Me)_{UAR}$ is the concentration of the metal **Me** in the bed sediments from the upper Animas River above the confluence.

The solution to this equation requires either an independent determination of one of the variables **X, Y,** or **Z,** or a series of equations which can be solved simultaneously. The critical question in this approach to ask is:

> What metal concentrations have sufficient variation and provide mathematical leverage in this calculation?

Since there is no significant variation in the geology of the subbasins, there is no significant variation in any of the lithophile element concentrations that can be used to derive percentages of materials added to the Animas River by either Mineral or Cement Creeks. Labile copper and zinc are actively precipitated from solution immediately below the confluence of Mineral and Cement Creeks, so the concentrations of these metals in the bed sediments are highly variable and cannot be used in the calculations. Labile lead concentrations, however, are stable as lead is present in both the colloidal phase and bed sediments in all three drainages.

Lead-isotopic data provide a powerful tool in evaluating the relative contributions of various sources to the bed-sediment concentrations of various metals. As the primary focus of this study was to evaluate the transport and partitioning of metals between the water column and the bed sediments from the Silverton area downstream, it is essential that we have a measure of the amount of metal added to the bed sediments by tributaries along the course of the Animas River. The measurement of the mass of sediment added by individual tributaries is possible using the lead-isotope ratios. The lead-isotope ratios are a function of mass rather than a function of concentration, allowing us to calculate the relative mass of lead added by individual tributaries that causes changes in the lead-isotopic ratios. These percentages are calculated using the following equation:

$$PC = \{[R_B - R_T]/[R_B - R_C]\} \times 100 \qquad (2)$$

where: **PC** is the percent of the metal derived from the contaminant source,

R_B is the $^{206}Pb/^{204}Pb$ value determined in stream sediments in tributaries draining a specific geologic terrain,

R_T is the $^{206}Pb/^{204}Pb$ value determined in the contaminated bed sediment of the Animas River today at a distance downstream from the source of the contaminant, and

R_C is the $^{206}Pb/^{204}Pb$ value determined at the source of the contaminant.

Similar calculations can be made using the $^{208}Pb/^{204}Pb$. Generally, there is not sufficient analytical resolution to make accurate calculations using the $^{207}Pb/^{204}Pb$ value unless the source rocks are more than two billion years old because of the short half-life of the parent isotope for ^{207}Pb, ^{235}U.

The amount of sediment added to the Animas River by Cement Creek cannot be determined using the lead-isotopic data because there is no lead-isotopic difference between the lead-isotopic composition in the labile phase of the bed sediments of Cement Creek and that in the Animas River. There is, however, a difference between the lead in the labile phase of the bed sediments of Mineral Creek and the Animas River. Since there is virtually no change in the isotopic composition of labile lead of the Animas River between site 95ABS113 above the confluence of Cement Creek and site A-72 below the confluence of Mineral Creek, it follows that the amount of labile lead added by Mineral Creek is small. We used equation 2 to determine the value of **X** in equation 1. The lead-isotope calculation indicates that about 3 percent of the total mass of the labile lead in the bed sediments at site A-72 was derived from Mineral Creek. This number is subject to significant measurement error due to the very small difference in the lead-isotopic values measured in the sediments of the Animas River. Given these analytical limits, we can use the lead-isotopic data to assign an upper limit on the contribution of metals from the bed sediments of Mineral Creek of less than 10 percent of the total labile lead in the Animas River at site A-72. In reality, the number may be closer to 5 percent.

The chemical data can then be used to estimate the contribution of Cement Creek to the Animas River from equation 1. As was shown earlier, both zinc and copper are being actively precipitated from the water below both the confluence of Cement and Mineral Creeks with the Animas River. Thus, the kinetics of the settling process and the variability that this introduces into the sampling precludes the use of either the copper or zinc data from the 2M HCl-1%H_2O_2 digestion in such a calculation. Only the zinc in the sphalerite component of the sediments is a stable chemical variable in this mixing zone. Unfortunately, there is little variance in the zinc data. The zinc in sphalerite from the Animas River is 1,200 ppm, from Cement Creek is 1,000 ppm, and in the Animas River below Silverton at site A-72 is also 1,000 ppm. There is, however, significant leverage in the lead concentration data which, when combined with the determination of the limits of the sediment contribution from Mineral Creek using the lead-isotopic data, can be used to make a mass balance calculation. The lead concentrations are as follows: $(Pb)_{UAR}$ = 1,900 ppm, $(Pb)_{CC}$ = 370 ppm, $(Pb)_{MC}$ = 270, and $(Pb)_{AB}$ = 1,200. Solving equation 1 and using 5 and 10 percent for the contribution of metals from the bed sediments from Mineral Creek based on the lead data from equation 2, we estimate that Cement Creek contributes about 35 to 40 percent of the total metals in the bed sediments of the Animas River below Silverton at site A-72. The copper data in the insoluble phase give a similar value although the copper data are subject to a much larger fundamental sampling error because the insoluble copper is contained largely in a heavy-mineral phase. If the chemical data had been based on a 50-g sample, the copper data would be more robust.

The lead-isotopic data can also be used to calculate the contributions of metals to the labile phase of the bed sediments for the Animas River below Silverton. We will use the lead-isotopic data from site A-72 below Silverton as the composition of the contaminant, R_C. Below Silverton, the composition of the lead supplied by the tributaries is different for the areas underlain by Precambrian, Paleozoic and Mesozoic, and Tertiary rocks. The areas are shown by the model for this calculation in figure 33A; values used for R_B and R_T are given in table 4. The results expressed in percent of the mass of the contaminant present **PC** at the point along the river course at R_T, are presented in figure 33B and in table 4. Through the Animas Canyon reach, there is little dilution due to the highly resistant nature of the Precambrian rocks to erosion. Major changes in the total mass of metal in the bed sediments of the Animas River take place downstream as stream sediments derived from the areas underlain by Paleozoic, Mesozoic, and Tertiary rocks are added by tributaries draining different sized basins and carrying differing bed sediment materials. Hermosa Creek and the Florida River are major sediment contributors to the bed sediments of the Animas River as indicated by the steep changes in the data in figure 33B. Furthermore, the gradient changes (fig. 33C) which reduces the carrying capacity of the Animas River causing sediment to be deposited in the stream bed.

Table 4. Lead-isotope parameters for calculation of dilution of the metals in the Animas River from Silverton[1]

Locality	Distance (km)	R_B	R_T	PC
Silverton (A-72)	26.26			100
KOA Campground	72.55	20.35	18.487	96
Trimble Bridge	82.35	19.25	18.510	88
Durango, 32nd Street Bridge	100.8	19.25	18.540	84
Durango, Red Lion Inn	105.0	19.25	18.559	82
Above Lightner Creek	106.2	19.20	18.592	78
Weaselskin Bridge	122	19.20	18.586	77
Above Bondad	135.5	19.20	18.637	71
Cedar Hill	139.5	19.20	18.684	65
Aztec, NM	171.5	19.00	18.661	57

[1]R_C is the value at A-72 below Silverton (18.407); the columns give the values used for R_B and R_T in the model (fig. 33). **PC** is the percent of the contaminant at each site calculated from equation 2.

Differential Sorbtion of Copper and Zinc by Colloids

Evidence of the sorbtion of copper and zinc to the colloids and the impact of this process on metal transport can be seen by normalizing the labile concentrations of copper, lead, and zinc in the bed sediments of the Animas River to those values measured for these metals at site A-72 below Silverton. The normalization procedure eliminates to problem of estimating dilution and transport losses of colloidal material as it moves downstream. Because lead is least likely to be affected by any process other than dilution (see fig. 32) and because we can measure the dilution effect as shown above using the lead-isotopic data (fig. 33 and table 4), gains in the total mass of copper and zinc by the colloids as a function of downstream distance can be demonstrated using these normalized data (fig. 34). The normalized lead data show the dilution curve of the colloidal component in the Animas River bed sediments caused by addition of materials by the tributaries draining the Animas River watershed downstream from Silverton. The copper curve plots slightly above the lead curve (fig. 34). Since there are no significant sources for copper other than the dissolved and suspended colloidal copper load described earlier, these gains in copper can be attributed to the aggregation and settling of the suspended colloidal material in the Animas Canyon reach. A much more dramatic change can be seen in the normalized zinc concentration data (fig. 34). Normalized zinc concentrations increase 50 percent below the Animas Canyon reach following an abrupt change in stream gradient (fig. 33C). When the dilution of the colloidal component is considered by examining the normalized lead data, the copper gain is about 30 percent and the zinc gain is almost 300 percent! Similar changes in the normalized zinc concentrations also were seen below Dumago where the stream gradient is low. We interpret these data to show the aggregation and settling of the colloidal component and its associated zinc loads to the bed sediments where they are stored until high-flow runoff.

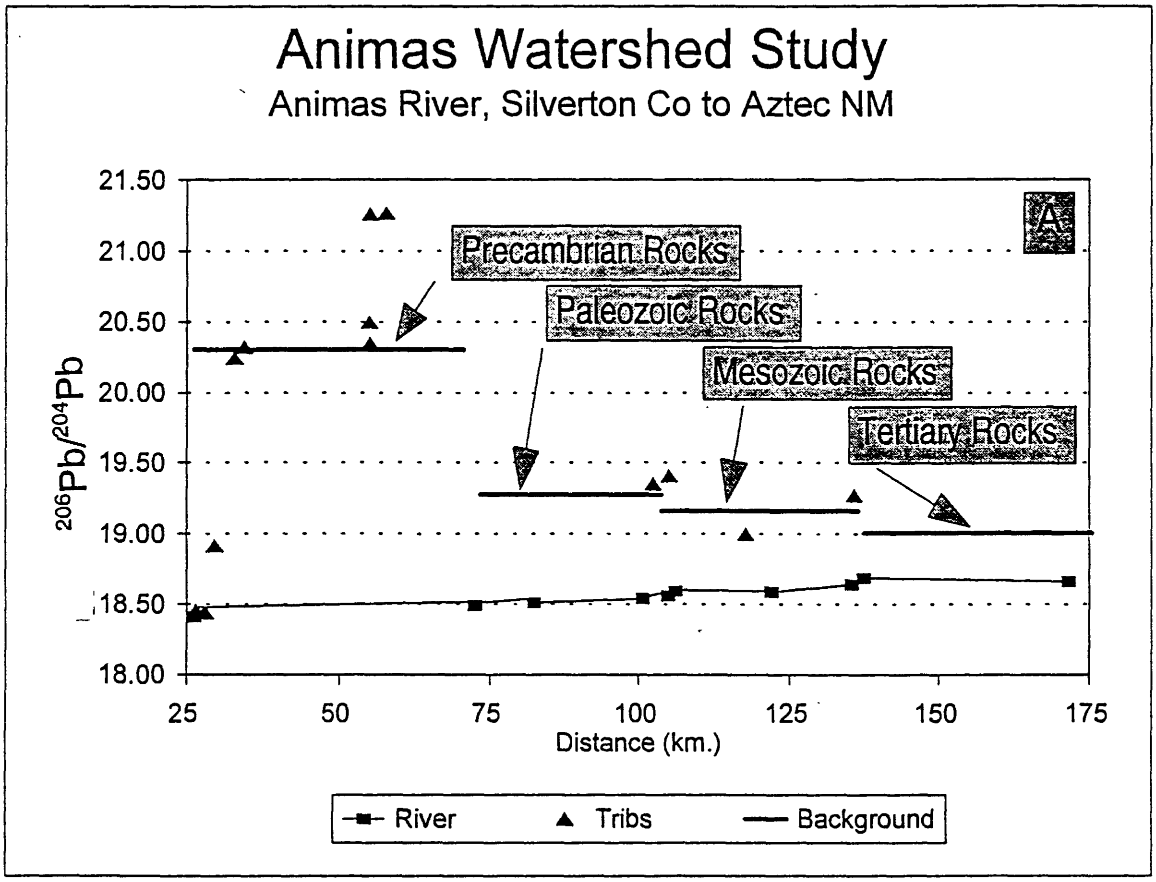
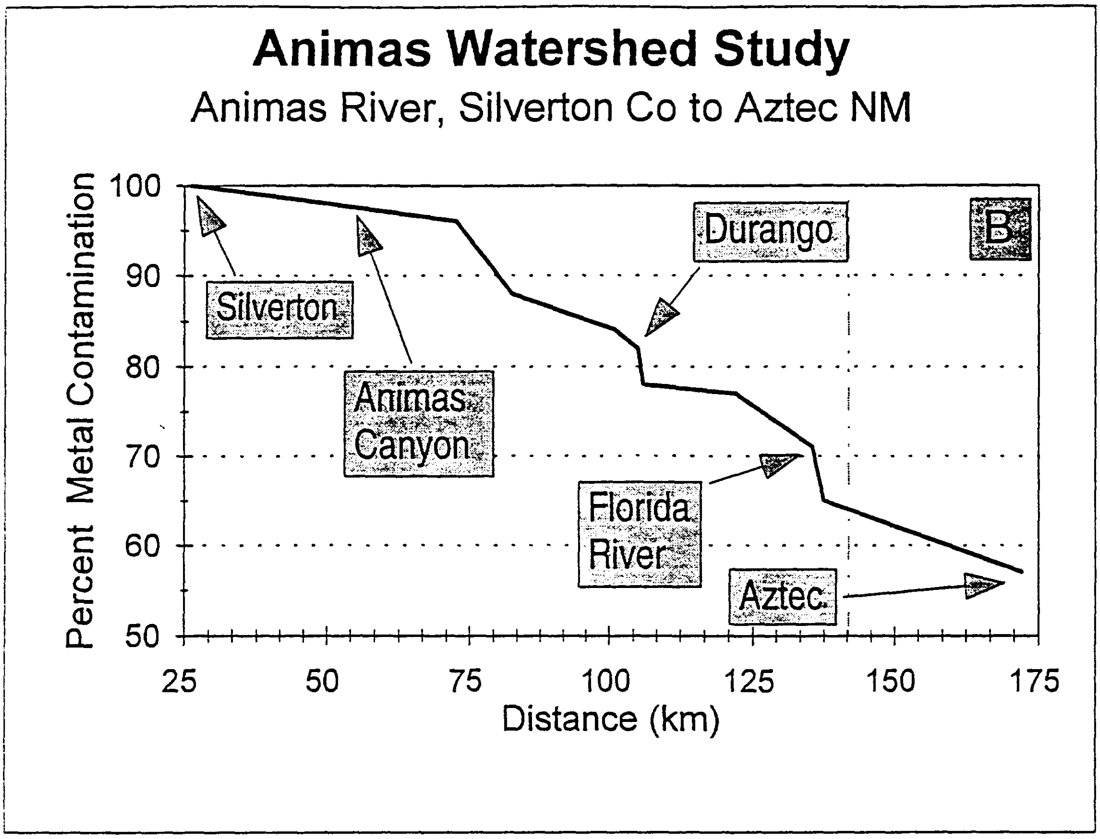
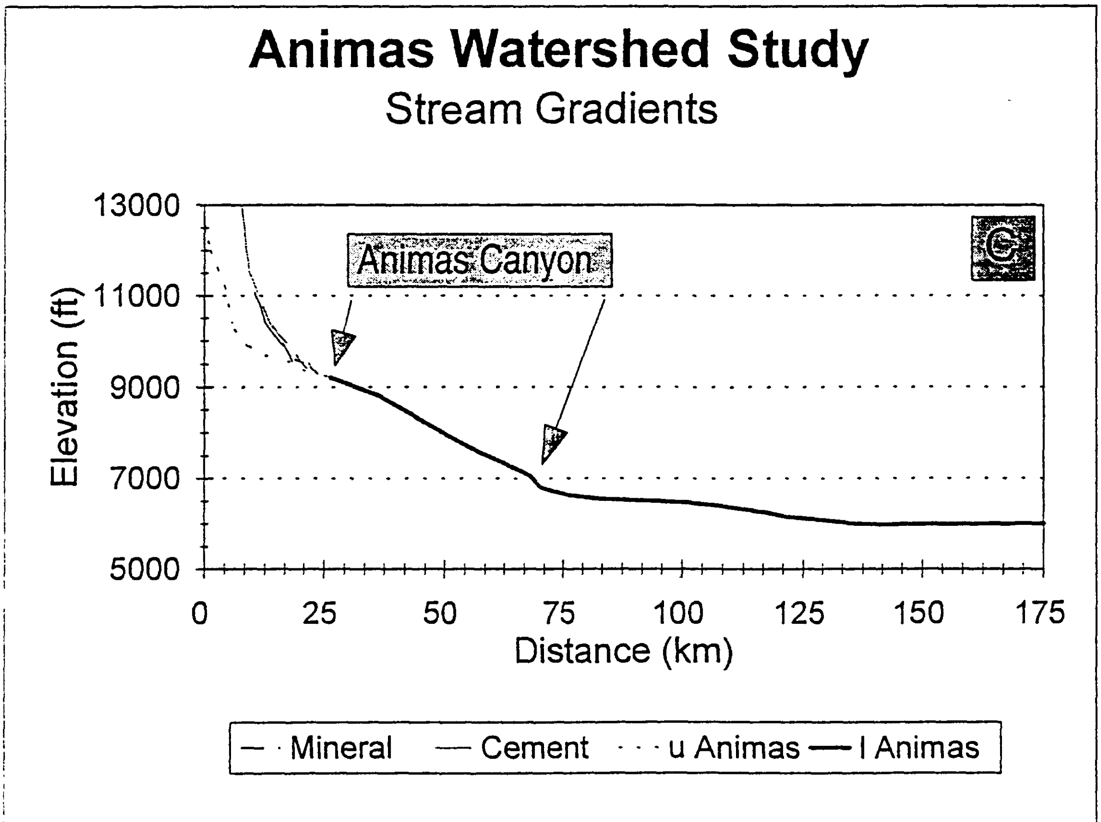


Figure 33. Lead-isotopic model for the Animas River from below Silverton (site A-72) to Aztec, New Mexico. The horizontal gray lines (A) indicate the lead-isotopic compositions used to model the contribution of sediments from the area underlain by Precambrian, Paleozoic and Mesozoic, and Tertiary rocks to the bed sediments of the Animas River. Solid squares indicate the measured lead-isotopic composition of bed sediments in the Animas River whereas the solid triangles indicate the lead-isotopic composition of stream sediments in the tributaries. The mathematical details of the model calculated from equation (1) are given in table 4. Figure B is a depiction of the percentage of the labile lead in each sample that can be attributed to lead from the Animas River using the data from site A-72 as the composition of the metal contaminant. About 80 percent of the lead in the bed sediments of the Animas River at Durango can be attributed to the area of the Animas River watershed above Silverton. Compare the dilution of the lead-isotopic signature to the change in river gradient plotted in figure C.


Animas Watershed Study
Animas River, Silverton Co to Aztec NM
Percent Metal Contamination
100
90
80
70
60
50
25
50
75
100
125
150
175
Distance (km)
Silverton
Animas Canyon
Durango
Florida River
Aztec
B


Animas Watershed Study
Stream Gradients
Elevation (ft)
13000
11000
9000
7000
5000
0
25
50
75
100
125
150
175
Distance (km)
Animas Canyon
C
Mineral
Cement
u Animas
l Animas

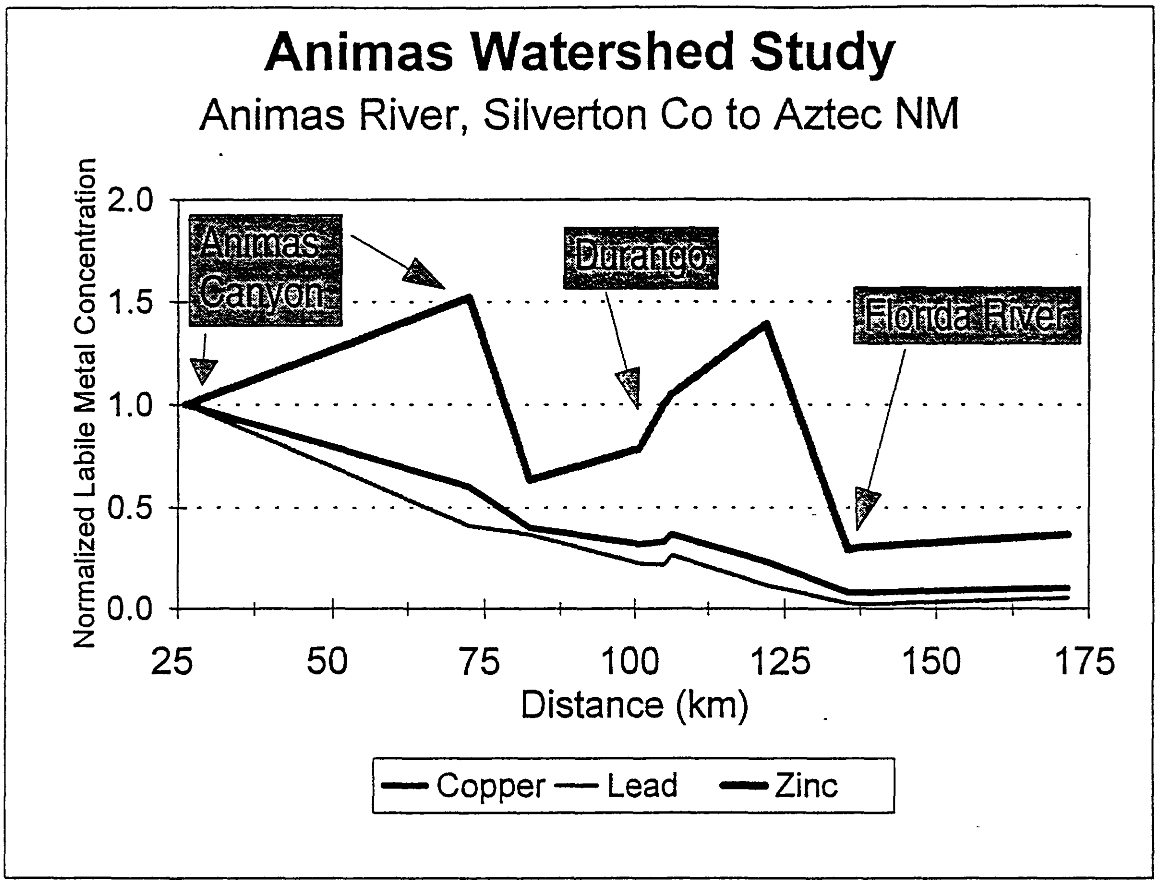


Figure 34. Plot of normalized labile concentrations of copper, lead, and zinc in bed sediments from the Animas River.

SUMMARY AND CONCLUSIONS

The water, colloid, and bed sediment data presented in this report demonstrate that the source of iron, aluminum, copper, lead, zinc, arsenic, and cadmium in the Animas River watershed is from the drainage basin upstream from site A-72 at Silverton. Partitioning of the metals between the dissolved, suspended colloidal, and bed sediment phases is dependent upon the source of the metals, the pH of the water, and the flow rate of the streams. Cement Creek has the lowest pH at low flow and carries most of its metal load in the dissolved phase. Mineral Creek carries most of its metal load in the colloidal phase whereas most of the metals in the upper Animas River (above the confluence with Cement Creek) resides in the colloidal component of the bed sediments. Downstream from the confluence of Cement Creek in the mixing zone, most of the metals transported in the dissolved metal load of Cement Creek are partitioned to the colloidal phase. Along the stream courses of upper Mineral Creek and the Animas River upstream from the confluence of Cement Creek, colloids aggregate, settle, and become an integral component of the bed sediments where they are stored until high-flow (snowmelt) runoff.

At low flow, dissolved zinc and aluminum concentrations exceed the acute aquatic-life standard at site A-72 whereas the concentrations of the other metals do not exceed the chronic aquatic-life standard. Dissolved manganese concentrations are just below the chronic aquatic-life standard. However, colloidal concentrations of copper, iron, zinc, and aluminum, if bioavailable as suggested by recent research, could exceed one or both of these aquatic-life standards at site A-72. There is a substantial loss of iron and aluminum colloids and their sorbed metal loads to the bed sediments in the Animas Canyon reach between Silverton and Bakers Bridge. More than 50 percent of the zinc in the bed sediments from Mineral Creek, more than 75 percent of the zinc in the bed sediments from Cement Creek, and more than 50 percent of the zinc in the bed sediments of the Animas River above the confluence with Cement Creek is in the form of sphalerite. Zinc concentrations in sphalerite from the bed sediments of the Animas River above the confluence with Cement Creek are about 1,000 ppm, from Cement Creek are about 800 ppm, and from Mineral Creek are about 400 ppm.

Three water and colloid samples collected at high flow during snowmelt runoff indicate that dissolved zinc concentrations far exceed the acute aquatic-life standard at site A-72 and are still twice that level as far downstream as Bondad. Metals stored in the colloidal phase or component of the bed load are flushed downstream in the water column during high flow as is indicated by the high colloidal iron, aluminum, and sorbed copper, lead, and zinc concentrations. Any remedial action that removes acidic metal-bearing discharges into Mineral and Cement Creeks and the upper Animas River or its tributaries should lessen the cumulative effect of potential metal toxicity on aquatic life.

At low flow, the lead-isotopic data indicate that Mineral Creek contributes 5 to 10 percent of the total mass of metals in the bed sediments at site A-72. Using mass balance calculations, the metals contributed from Cement Creek make up less than 40 percent of the metals in the bed sediments at site A-72. Fifty to 60 percent of the metals at site A-72 are derived from the Animas River upstream from the confluence with Cement Creek. Below site A-72, the lead-isotopic data are used to document the dilution of the metals derived from the Animas River Basin above Silverton by metal contributions from the tributaries. At Durango 75 km downstream, about 80 percent of the metals in the colloidal component of the bed sediments were derived from the Animas River watershed above Silverton whereas at Aztec, 57 percent of the metals were derived from this upstream source. No measurable contamination was found from the La Plata mining district at the headwaters of Junction Creek.

Sediment transport, as suggested by the lead-isotopic data and the normalized copper, lead, and zinc data from bed sediments from the Animas River indicate some differential transport of the colloidal phase of the bed sediments. The chemical data from the waters and colloids indicate sorption of dissolved metals as a function of pH which changes with downstream distance. This colloidal component of the bed sediments dominates the bed sediment chemistry. Loss of the colloidal component to the bed sediments reduces pore space between detrital grains in the bed, introduces toxic levels of metals into the food chain habitat for aquatic invertebrates, and, if bioavailable as suggested by recent research, may cause chronic toxicity to fish.

From the lead-isotopic data, we have identified five or more discrete mineralization events in the Silverton caldera. However, the dominant lead-isotopic signature in the bed sediments of both Cement Creek and the upper Animas River is from the vein-type ore mineralization in the Eureka district. Lead-isotopic data from stream sediments from Browns Gulch on the west side of the Mineral Creek drainage indicates that vein-type ore in the Eureka district extends to the west of Cement Creek. Exploration for concealed, undiscovered vein-type ore between Prospect and Minnesota Gulches could lead to the discovery of new ore reserves. The surface expression of this structure may be obscured by the hydrothermal alteration associated with Red Mountain No. 3.

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APPENDIX I--METHODS USED TO PREPARE REGIONAL SEDIMENT GEOCHEMICAL MAPS

Data were retrieved from the National Uranium Resource Evaluation (NURE) data base (Hoffman and Buttleman, 1994) covering a rectangular area of southwestern Colorado between 37° 00' and 38° 30' north latitude and 107° 00' and 109° 00' west longitude. The evaluation boundary extended outside of the watershed area to eliminate "edge effects" in the grid and contour generation. The total number of sample sites in the bounding area is 4,057, 444 of which are in the Animas River watershed. The NURE samples generally were collected along tributary drainage systems (Shannon, 1980; Warren and others, 1981).

The ASCII data files for copper, lead, zinc, and calcium concentrations were evaluated and formatted for grid and contour generation in EarthVision, a software package developed by Dynamic Graphics, Inc (ERDAS). Each chemical constituent was processed separately to evaluate the relative quality of the data and to compare with individual point coverages subsequently generated in ARC/INFO. The intervals generated for the contoured grid surface reflect multiples of the CAV (Fortescue, 1992). The multiples chosen for analysis and display are 1, 3, 5, 10, and 20 times crustal abundance values (CAV; figs. 5-8). The procedure in EarthVision involved a few basic steps:

1) defining raster input headers;
2) registering and transforming geographic coordinates;
3) creating a 2-D minimum-tension grid with 1,000 meter grid spacing;
4) visualizing and generating contour intervals based on crustal abundance values (CAV);
5) processing grid files in ERDAS including: flipping, resampling (100m), and converting the data into a vector format;
6) exporting grid files to ARC/INFO for vector processing.

The contoured surfaces were transferred to the vector-base ARC/INFO software package to allow overlay and integration with other spatial themes in the Animas River watershed. ARC/INFO processing steps included:

1) generating NURE point locations and linking attribute information;
2) clipping point and contour coverages with the Animas River watershed boundary;
3) conversion and smoothing of contours vectorized in ERDAS;
4) editing coverages and creating a relational data base
5) overlay analysis and map generation.

In addition to the tributary NURE information, sediment samples from major river drainages were collected by USGS personnel in the 1995-96 field season. These samples supplement the regional geochemical analysis of the NURE samples and provide current site-specific information along the Animas River. These data were processed in ARC/INFO using the procedures described above. The Animas River and its major tributaries were extracted from a hydrology layer and buffered (1000 meters) to create a polygon for shading based upon copper, lead, and zinc concentrations. This polygon or "ribbon" was segmented based on the concentration multiples (1,3,5,10, and 20) of CAV. The "ribbons" of concentration are shown in figures 19-21.

APPENDIX II--ANALYTICAL METHODS

Stream Sediments

The fine grained (minus-100 mesh, or minus-150-micron) fraction of the stream sediments was analyzed by inductively coupled plasma atomic emission spectroscopy (ICP-AES) utilizing both a total digestion procedure and a partial-digestion leach procedure (2M HCl-1%H_2O_2) on separate splits of each sample. The total decomposition procedure utilizes a combination of hydrochloric, nitric, perchloric and hydrofluoric acids, and is effective in dissolving most minerals, including silicates, oxides, and sulfides. Some resistant or refractory minerals such as zircon, chromite and selected tin oxide minerals are only partially attacked with this procedure (Crock and others, 1983; Briggs, 1996). Previous investigations using a variety of materials support the completeness of this digestion (Church, 1981; Church and others, 1987; Wilson and others, 1994). The partial-digestion leach procedure used involves an extraction performed on the samples using a solution of warm 2M HCl-1%H_2O_2 (appendix III of Church and others, 1993). This leaching solution dissolves hydrous amorphous iron- and manganese-oxide minerals, as well as some crystalline iron- and manganese-oxides. The procedure we used differed slightly from that described. We used a 2-g sample in 15 mL of reagent. The samples were placed in 90 mL Teflon FEP jars, sealed, and placed in the waterbath at 50° C for three hours to ensure complete removal of the iron- and manganese-oxide coatings from the sediment grains.

Selenium was determined using hydride generation-atomic absorbtion spectrophotometry (Hg-AAS), as was arsenic for those samples whose ICP-AES values were less than 20 ppm. Samples were digested using a combination of nitric, hydrochloric, perchloric, sulfuric and hydrofluoric acids in open teflon vessels (Hageman and Welsch 1996), resulting in total dissolution. The arsenic and selenium in the solutions were reduced to the +3 and +4 states respectively, using a potassium iodide-ascorbic acid solution, after which the respective hydrides were generated by the addition of and mixing with sodium borohydride. The gaseous hydrides were introduced into a heated quartz tube in the optical path of an atomic absorbtion spectrophotometer and analyzed.

Mercury was determined using a cold vapor-atomic absorbtion spectrophotometric method (CV-AAS). Samples were digested using concentrated nitric acid, with the addition of sodium dichromate (O'Leary and others, 1996). The solutions were then introduced into a continuous flow manifold and mixed with air and a sodium chloride-hydroxylamine hydrochloride-sulfuric acid solution. The mercury +2 was then reduced to elemental mercury using stannous chloride, and the vapor introduced into the optical path of an atomic absorbtion spectrophotometer and analyzed.

Samples were randomized and submitted to the laboratory as blind samples. Analytical precision and accuracy of the methods (quality control) were assessed by analyzing blind standard reference materials (SRMs) and a replicate sample (a split of a sample, submitted as two separate samples) with each analytical set. These data are given in table A-II for the SRM samples in the data tables in appendices V and VI for replicate analyses of blind duplicate samples. The SRMs were NIST-2704, NIST-2709, NIST-2710, and NIST-2711, available from the National Institute of Standards and Technology (NIST, 1993a, 1993b, 1993c and 1993d). The results for the total-digestion ICP-AES, and for arsenic, selenium and mercury compare favorably with previous work (Church and others, 1993, 1994, and 1995), and with the published NIST values.

The lead-isotopic data on the sediment samples were measured using the 2M HCl-1%H_2O_2 digestion solution following the procedure described in appendix IV of Church and others (1993). The lead was separated from solution in the HBr medium and the lead-isotopic ratios determined on a 68° sector, 12-inch radius, solid-source, thermal ionization NBS mass spectrometer. Analytical precision, based upon replicate analyses of NIST SRM materials is better than 0.1% per mass unit for the reported lead-isotopic ratios. The analytical results are reported in appendix V.

Water and Colloids

Legally and in many standard methods, a dissolved-metal concentration is defined as the concentration that passes through a 0.45-micrometers (µm) filter (Horowitz and others, 1996a). Hydrous iron oxides can be on the order of 0.001 µm when they initially form in stream water. However, such small particles rapidly aggregate, forming a continuous size range from 0.001 µm to greater than 1 µm (Stumm and Morgan, 1996). Thus, for iron-rich streams affected by mine drainage, 0.45 µm is neither an effective nor a natural break for the distinction of dissolved and particulate concentrations. These artifacts confound the sampling procedure and skew the data introducing sampling errors that make it difficult to make a meaningful geochemical interpretation (Shiller and Taylor, 1996; Horowitz and others, 1996b). Many standard methods of water sampling protocol rely on filtration to obtain "dissolved" concentrations. The accepted standard protocol for many regulatory statutes relies on filtration of water samples at an arbitrary breaking point of 0.45 µm. Horowitz and others (1996a) described numerous problems that result from filtration with standard 0.45-µm filters. A recent study in the upper Arkansas River basin demonstrated that iron colloids can be separated from river water and analyzed for their metal content using ultrafiltration (Kimball and others, 1995). The methods developed in that study have been followed here with only a slight change in the approach to separate and analyze the colloidal metal concentrations. In this study tangential-flow ultrafiltration through a membrane with an effective pore size less than 0.001 µm was used to differentiate between dissolved and particulate metal fractions (Hernandez and Stallard, 1988; Moran and Moore, 1989; Kimball and others, 1995).

The procedure to distinguish concentrations of metals in water from concentrations in colloidal particles is summarized in figure A-II. The integrated sample was screened to remove sand, gravel, and debris. However, there was very little material greater than 62 µm. Almost the entire load of the Animas River was dissolved and colloidal. A split of the screened sample allowed the determination of a "total recoverable metal concentration." The rest of the sample was used for ultrafiltration to determine two metal concentrations, the "dissolved" concentration in the filtrate less than 0.001 µm, and the "colloidal" concentration from the concentrated colloids in water. Tangential-flow filtration keeps solid material in suspension rather than forcing it against a filter membrane. This allows water to be removed by osmotic pressure across a filter membrane without "packing" the suspended solids onto a filter membrane, which would change the membrane pore size.

Indirect measurement of metal concentrations in colloids was made by calculating the difference between the metal concentrations in an unfiltered, acidified sample (a total recoverable concentration) and the ultrafiltrate sample. The indirect measurement was reliable for iron, manganese, and zinc at each of the sites, but the direct measurement was necessary for cadmium, copper, and lead because of their lower concentrations.

Dissolved and total recoverable metal concentrations were determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES; Briggs, 1996). Anions were analyzed in the 0.45-µm filtered, unacidified samples by ion chromatography. Alkalinity was measured by Gran titration of an unfiltered 0.45-µm filtered sample.

The low levels encountered for cadmium, copper, nickel, and lead indicate that either graphite furnace atomic adsorption or ICP Mass Spectrometry should be used for better quantification. The ICP-AES did not allow detection of lead at low levels because the lead concentrations were below the limit of detection.

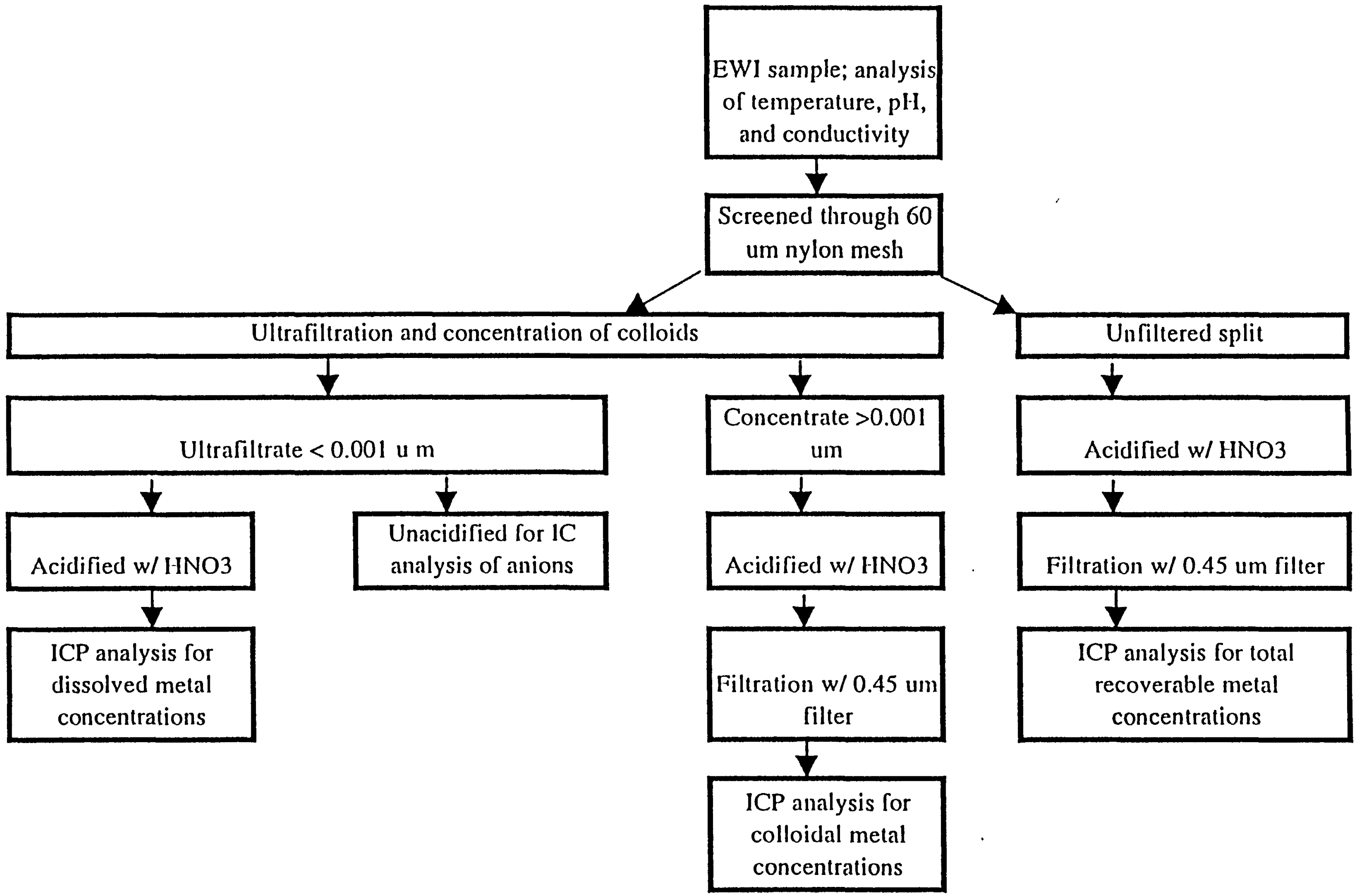

Figure A-II. Diagram showing processing procedures for water and colloid samples.

Table A-II. Total digestion and reference data from Standard Reference Materials

NIST No.	Al %	Ca %	Fe %	K %	Mg %	Na %	P %	Ti %	Ag ppm	As ppm	Ba ppm
96-RF-2704	5.8	2.70	4.1	1.9	1.20	0.59	0.10	0.26	< 2	23	390
96-RF-2704	6.2	2.70	4.2	2.0	1.20	0.64	0.11	0.33	< 2	22	430
96-RF-2704	6.0	2.70	4.1	1.9	1.20	0.58	0.10	0.30	< 2	18	400
SRM-2704[1]	6.11	2.60	4.11	2.00	1.20	0.55	0.10	0.46	--	23	414
96-RF-2709	7.2	1.90	3.5	1.9	1.40	1.10	0.07	0.32	< 2	23	880
96-RF-2709	7.3	2.00	3.5	1.9	1.50	1.20	0.07	0.31	< 2	21	910
96-RF-2709	7.2	2.00	3.5	1.8	1.50	1.20	0.07	0.32	< 2	22	870
SRM-2709[2]	7.50	1.90	3.50	2.03	1.51	1.16	0.06	0.34	0.4	17.7	968
96-RF-2710	6.40	1.30	3.60	2.00	0.88	1.10	0.11	0.26	33	680	680
SRM-2710[3]	6.44	1.25	3.38	2.11	0.85	1.14	0.11	0.28	35	626	707
96-RF-2711	6.40	3.10	3.00	2.30	1.00	1.20	0.08	0.24	4	94	670
96-RF-2711	6.10	2.90	2.80	2.20	1.00	1.10	0.09	0.26	3	100	650
96-RF-2711	6.20	2.90	2.80	2.30	1.00	1.10	0.09	0.25	3	110	670
96-RF-2711	6.60	3.00	2.90	2.50	1.10	1.30	0.09	0.26	4	97	730
SRM-2711[4]	6.53	2.88	2.89	2.45	1.05	1.14	0.09	0.31	4.6	105	726

[1] NIST (1993a); noncertified values in paranthes.
[2] NIST (1993b); noncertified values in paranthes.
[3] NIST (1993c); noncertified values in paranthes.
[4] NIST (1993d); noncertified values in paranthes.

Table A-II. Total digestion and reference data from Standard Reference Materials (cont.)

NIST No.	Be ppm	Bi ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	La ppm	Li ppm	Mn ppm	Mo ppm
96-RF-2704	2	< 10	3	55	16	140	87	14	28	43	560	< 2
96-RF-2704	2	< 10	3	72	16	150	99	15	36	49	580	< 2
96-RF-2704	2	< 10	3	59	16	150	88	17	31	47	580	< 2
SRM-2704	--	--	3.5	(72)	14	135	99	(15)	(29)	(50)	555	--
96-RF-2709	4	< 10	< 2	42	15	120	30	15	24	51	530	< 2
96-RF-2709	3	< 10	< 2	42	16	130	32	16	23	54	540	< 2
96-RF-2709	4	< 10	< 2	43	16	140	29	15	24	53	550	< 2
SRM-2709	--	--	0.4	(42)	13.4	130	34.6	(14)	(23)	--	538	--
96-RF-2710	2	21	20	55	11	36	2600	48	31	38	10000	15
SRM-2710	--	--	21.8	(57)	(10)	(39)	2950	(34)	(34)	--	10100	(19)
96-RF-2711	2	< 10	38	62	12	48	100	15	35	25	670	< 2
96-RF-2711	2	< 10	37	67	12	48	97	14	38	26	620	< 2
96-RF-2711	2	< 10	37	67	12	58	98	15	40	25	620	< 2
96-RF-2711	2	< 10	38	72	12	48	110	17	38	28	660	< 2
SRM-2711	--	--	41.7	(69)	(10)	(47)	114	(15)	(40)	--	638	(1.6)

Table A-II. Total digestion and reference data from Standard Reference Materials (cont.)

NIST No.	Nb ppm	Nd ppm	Ni ppm	Pb ppm	Sc ppm	Sr ppm	Th ppm	V ppm	Y ppm	Yb ppm	Zn ppm
96-RF-2704	14	25	43	140	11	130	7	85	23	2	430
96-RF-2704	14	32	42	150	12	140	12	91	25	2	440
96-RF-2704	14	32	42	140	12	130	11	90	23	2	420
SRM-2704	--	--	44	161	(12)	(130)	(9)	95	--	(2.8)	438
96-RF-2709	16	17	85	14	11	220	10	110	18	2	100
96-RF-2709	13	17	83	14	12	230	10	110	20	1	100
96-RF-2709	11	18	85	16	12	220	10	110	18	2	99
SRM-2709	--	--	88	18.9	(12)	231	10.8	112	18	(1.6)	106
96-RF-2710	13	27	14	4900	9	330	12	72	22	2	7000
SRM-2710	--	--	14.3	5532	(8.7)	--	13.5	76.6	(23)	(1.3)	6952
96-RF-2711	13	27	20	1000	9	240	13	79	26	3	380
96-RF-2711	19	29	20	990	9	230	13	76	25	2	330
96-RF-2711	20	30	20	930	9	240	13	76	26	2	340
96-RF-2711	15	28	19	1200	10	250	14	79	29	2	350
SRM-2711	--	--	20.6	1162	(9)	245	13.6	81.6	(25)	(2.7)	350

Appendix III--Site identifications, field data, and major ion chemistry for Animas River and major tributaries, 1995-96.
[DIST, downstream distance, in kilometers; Disch, discharge, in cubic feet per second; Cond, Conductivity, in microSiemens per centimeter at 25 degrees Celcius; Temp, temperature, in degrees Celcius; all concentrations are in milligrams per liter.]

1 Low Flow

Animas

DIST	SITE DESCRIPTION	DATE	Disch	Cond	pH	Temp	Calcium	Magnesium	Sodium	Chloride	Sulfate	Silica
11	ANIMAS RIVER AT EUREKA	951016	7	186	7.06	0.0	29.2	2.1	1.0	0.3	53	4.5
24	ANIMAS RIVER AT SILVERTON	951015	65	453	6.62	7.5	53.0	2.7	2.3	0.5	95	7.4
24	ANIMAS RIVER BLW CEMENT CREEK	951016	86	494	7.12	5.0	93.4	2.9	3.0	0.5	225	13.6
26	ANIMAS RIVER BLW SILVERTON	951016	116	453	6.62	7.5	68.7	3.6	2.6	0.6	201	11.0
50	ANIMAS RIVER AB CASCADE CREEK	951020	150	356	6.99	3.0	56.2	3.9	2.4	0.5	148	9.4
52	ANIMAS RIVER BLW CASCADE CREEK	951020	161	344	7.48	5.0	56.3	4.1	2.4	0.4	133	9.2
73	ANIMAS RIVER AT KOA CAMP	951017	232	302	7.87	7.0	46.6	4.1	2.1	0.5	99	7.5
81	ANIMAS RIVER AT DALTON	951017	237	453	7.34	13.0	70.2	8.1	15.0	15.1	106	8.8
101	ANIMAS RIVER AT 32nd ST BRIDGE	951017	283	556	7.53	12.5	79.0	10.3	20.7	20.1	122	9.5
105	ANIMAS RIVER AT DURANGO	951019	327	552	8.14	12.0	83.0	0.2	19.6	19.6	123	9.5
106	ANIMAS RIVER BLW DURANGO	951018	340	552	8.14	12.0	74.9	0.2	19.6	19.3	123	9.3
122	ANIMAS RIVER AT WEASELSKIN BRIDG	951019	341	553	8.27	7.5	79.5	12.3	21.8	19.3	126	7.1
136	ANIMAS RIVER NR BONDAD HILL	951019	341	555	8.58	12.5	81.5	0.1	21.9	19.0	120	6.3
138	ANIMAS RIVER NR CEDAR HILL	951018	341	513	8.59	13.0	74.2	0.0	22.1	16.6	99	6.2
172	ANIMAS RIVER AT AZTEC	951018	341	538	8.36	11.0	69.3	11.9	25.1	16.8	110	5.0

Tributaries

DIST	SITE DESCRIPTION	DATE	Disch	Cond	pH	Temp	Calcium	Magnesium	Sodium	Chloride	Sulfate	Silica
24	CEMENT CREEK NR MOUTH	951015	19	1,050	3.89	4.0	173.0	6.5	4.0	0.9	572	24.6
25	MINERAL CREEK NR MOUTH	951015	57	395	6.35	7.5	72.7	5.2	3.1	0.6	188	14.2
51	CASCADE CREEK NR MOUTH	951020	11	221	8.11	4.0	33.2	7.2	2.7	0.9	12	4.0
80	HERMOSA CREEK NR HWY 550	951017	36	400	7.07	6.5	59.6	6.7	3.1	1.2	122	7.5
102	JUNCTION CREEK AT PARK	951018	2	334	8.13	5.0	57.4	0.0	4.0	0.6	15	6.9
105	LIGHTNER CREEK NR MOUTH	951018	4	682	8.30	5.5	88.7	33.9	23.5	3.3	150	7.4

Appendix III--Site identifications, field data, and major ion chemistry for Animas River and major tributaries, 1995-96.

[DIST, downstream distance, in kilometers; Disch, discharge, in cubic feet per second; Cond, Conductivity, in microSiemens per centimeter at 25 degrees Celcius; Temp, temperature, in degrees Celcius; all concentrations are in milligrams per liter.]

1 Low Flow

Tributaries

DIST	SITE DESCRIPTION	DATE	Disch	Cond	pH	Temp	Calcium	Magnesium	Sodium	Chloride	Sulfate	Silica
118	BASIN CREEK NR MOUTH	951019	0	1,600	8.33	8.5	114.1	81.2	149.8	13.0	695	5.2
136	FLORIDA RIVER NR MOUTH	951019	7	367	8.43	8.0	52.1	8.7	27.2	5.8	17	5.5

2 Early Runoff

Animas

DIST	SITE DESCRIPTION	DATE	Disch	Cond	pH	Temp	Calcium	Magnesium	Sodium	Chloride	Sulfate	Silica
26	ANIMAS RIVER BLW SILVERTON	960509	901	174	7.08	3.7	20.0	1.5	0.9	0.4	61	2.6
105	ANIMAS RIVER AT DURANGO	960510	2,250	179	7.80	7.5	23.0	3.0	2.4	2.8	38	2.0
138	ANIMAS RIVER NR CEDAR HILL	960510	1,980	206	7.84	11.3	25.0	3.4	3.3			2.1

3 Middle Runoff

Animas

DIST	SITE DESCRIPTION	DATE	Disch	Cond	pH	Temp	Calcium	Magnesium	Sodium	Chloride	Sulfate	Silica
26	ANIMAS RIVER BLW SILVERTON	960521	1,670	115	7.46	6.5	16.0	1.2	0.9	0.3	40	2.2
105	ANIMAS RIVER AT DURANGO	960522	2,920	147	7.72	8.5	23.0	2.9	3.0			2.1
138	ANIMAS RIVER NR CEDAR HILL	960522	2,470	165	7.93	13.0	18.0	2.2	2.1			1.7

4 Late Runoff

Animas

DIST	SITE DESCRIPTION	DATE	Disch	Cond	pH	Temp	Calcium	Magnesium	Sodium	Chloride	Sulfate	Silica
26	ANIMAS RIVER BLW SILVERTON	960619	584		7.42		36.0	4.7	8.1	6.6	54	3.2
105	ANIMAS RIVER AT DURANGO	960618	1,110	277	7.80	14.0	40.0	5.7	11.0	6.6	54	2.8
138	ANIMAS RIVER NR CEDAR HILL	960618	870	320	7.99	15.0	23.0	1.5	1.2	0.6	50	2.7

Appendix IV--Metals in water and colloids in the Animas River and tributaries, 1995-96.

[ALD, dissolved alumunim; ALC, colloidal aluminum; CDD, dissolved cadmium; CDC, colloidal cadmium; CU, copper (with dissolved and colloidal); FE, iron; MN, manganese; PB, lead; SR, strontium; ZN, zinc; A blank or no value indicates the sample was below limit of detection; all concentrations in micrograms per liter.]

1 Low Flow

Animas

DIST	ALD	ALC	CDD	CDC	CUD	CUC	FED	FEC	MND	MNC	PBD	PBC	SRD	SRC	ZND	ZNC
11	0.039	0.059	0.001	0.000	0.006	0.013	0.001	0.05	0.216	0.002			0.872	0.002	0.461	0.012
24	0.066	0.023		0.000	0.006	0.006		0.14	0.000	0.042			0.817	0.002	0.319	0.021
24	0.417	1.176	0.000			0.016	0.641	1.15	0.717				0.878	0.003	0.871	0.009
26	0.040	1.720	0.003		0.006	0.022	0.677	1.73	0.347	0.016			0.913	0.002	0.347	0.042
73	0.100	0.354	0.000		0.003	0.006	0.012	0.56	0.127	0.023	0.023		0.868	0.004	0.154	0.035
81	0.088	0.118			0.002	0.002		0.16	0.068		0.025		0.877	0.020	0.092	0.006
101	0.080	0.067	0.001		0.008	0.002	0.003	0.17	0.070	0.010			0.817	0.006	0.063	0.011
105	0.097	0.060	0.001			0.002	0.004	0.15	0.117	0.008		0.001	0.626		0.032	0.016
106	0.085	0.039	0.002			0.002		0.13	0.102	0.008	0.003		0.405	0.010	0.029	0.011
122	0.079	0.029			0.002	0.004		0.10	0.055	0.006	0.010	0.000	0.688	0.011	0.029	0.015
136	0.097	0.050	0.005	0.000		0.002		0.10	0.026	0.008			1.030	0.000	0.017	0.013
138	0.093	0.057	0.002			0.002		0.10	0.022	0.009		0.001	0.494	0.004	0.006	0.010
172	0.082	0.047	0.002		0.002	0.002		0.09	0.026	0.009			0.178	0.001		0.006

Tributaries

DIST	ALD	ALC	CDD	CDC	CUD	CUC	FED	FEC	MND	MNC	PBD	PBC	SRD	SRC	ZND	ZNC
24	6.019	0.098		0.000	0.063	0.002	4.467	2.42	1.265			0.001	0.520	0.001	1.338	
25	0.086	3.584	0.001		0.003	0.055	2.211	3.43	0.205	0.021			2.060	0.001	0.324	0.025
80	0.096	0.184		0.000	0.000	0.005	0.002	0.27	0.132			0.001	0.708	0.001	0.119	0.021
102	0.063	0.021	0.000			0.002		0.03	0.002	0.001	0.053		0.578	0.001	0.011	0.000

Appendix IV--Metals in water and colloids in the Animas River and tributaries, 1995-96.

[ALD, dissolved alumunim; ALC, colloidal aluminum; CDD, dissolved cadmium; CDC, colloidal cadmium; CU, copper (with dissolved and colloidal); FE, iron; MN, manganese; PB, lead; SR, strontium; ZN, zinc; A blank or no value indicates the sample was below limit of detection; all concentrations in micrograms per liter.]

1 Low Flow

Tributaries

DIST	ALD	ALC	CDD	CDC	CUD	CUC	FED	FEC	MND	MNC	PBD	PBC	SRD	SRC	ZND	ZNC
105	0.162	0.044			0.003	0.002	0.012	0.09	0.011	0.002	0.051		0.948			0.000
118	0.314	0.014			0.002	0.001	0.003	0.01	0.010	0.001		0.001	0.661		0.014	
136	0.085	0.199				0.004		0.22	0.009	0.020	0.009		2.585	0.014		0.006

2 Early Runoff

Animas

DIST	ALD	ALC	CDD	CDC	CUD	CUC	FED	FEC	MND	MNC	PBD	PBC	SRD	SRC	ZND	ZNC
26	0.022	0.767		0.001	0.003	0.051		2.30	0.340	0.199		0.035	0.180	0.037	0.310	0.276
105	0.020	0.653		0.001	0.002	0.025		1.50	0.025	0.269		0.040	0.180	0.042	0.030	0.192
138	0.035	0.123		0.001	0.002	0.028		1.60	0.007	0.292		0.038	0.200	0.041	0.015	0.206

3 Middle Runoff

Animas

DIST	ALD	ALC	CDD	CDC	CUD	CUC	FED	FEC	MND	MNC	PBD	PBC	SRD	SRC	ZND	ZNC
26	0.043	0.519		0.001	0.003	0.039		1.60	0.230	0.187		0.043	0.140	0.019	0.160	0.200
105	0.040	0.487		0.001	0.003	0.024		1.30	0.005	0.305		0.045	0.190	0.045	0.019	0.203
138	0.052	0.093		0.001	0.003	0.023		1.10	0.018	0.228		0.036	0.140	0.034	0.016	0.176

4 Late Runoff

Animas

DIST	ALD	ALC	CDD	CDC	CUD	CUC	FED	FEC	MND	MNC	PBD	PBC	SRD	SRC	ZND	ZNC
26	0.052	0.533			0.007	0.006	0.099	0.75	0.095	0.035			0.390	0.053		0.075
105	0.031	0.474			0.007	0.004		0.36	0.042	0.069		0.008	0.450	0.075		0.042
138	0.035	0.289			0.007	0.010		0.28	0.310	0.039			0.230	0.026	0.018	0.050

Appendix V.1. Table of partial digestion (2M HCl-1% H_2O_2) data from sites sampled from the Animas River watershed, Oct. 1995
[Concentrations given in parts per million, ppm (µg/g)]

Sample No.	Sample Locality	Sample Type	Latitude Deg	Latitude Min	Latitude Sec	Longitude Deg	Longitude Min	Longitude Sec	Distance km.	Al ppm	Ca ppm	Fe ppm	K ppm
Animas River upstream from Silverton, Colo.													
95ABS101	upper Animas River below Cinnamon Gulch	fine sand & silt	37	55	25	107	33	47	5.75	7400	3800	15000	200
95ABS102	Picayne Gulch	fine sand & silt	37	54	42	107	33	18	7.25	7000	5600	26000	300
95ABS103	Eureka Creek	fine sand & silt	37	52	47	107	33	54	11.25	7500	3600	34000	300
95ABS104A	upper Animas River	fine sand & silt	37	52	39	107	33	44	11.35	8300	3900	27000	300
95ABS104C	upper Animas River	jarosite	37	52	39	107	33	44		870	19000	19000	200
95ABS104D	upper Animas River	white precipitate	37	52	39	107	33	44		1100	14000	37000	300
95ABS105	upper Animas River	colloids	37	52	48	107	33	45	11.00	100000	120000	190000	5600
95ABS106	Kittimac Mill site	tailings	37	51	30	107	34	21	13.80	200	300	19000	400
95ABS107	Maggie Gulch	fine sand & silt	37	51	15	107	34	11	14.20	4600	5600	19000	200
95ABS108	upper Animas River above Howardsville mill site	fine sand & silt	37	50	43	107	35	14	15.80	7200	5200	29000	400
95ABS109	Cunningham Creek	fine sand & silt	37	50	0	107	35	37	17.05	5900	6200	16000	300
95ABS110A	upper Animas River at	fine sand & silt	37	49	58	107	35	58	17.55	6500	4300	25000	300
95ABS110B	gaging station	coated pebbles	37	49	58	107	35	58		78000	43000	270000	4000
95ABS111A	Arrastra Creek	fine sand & silt	37	49	28	107	37	20	20.00	4000	3100	21000	200
95ABS111B	Arrastra Creek	coated pebbles	37	49	28	107	37	20		84000	32000	310000	5400
95ABS112	Boulder Creek	fine sand & silt	37	49	31	107	38	0	20.90	7200	5000	26000	200
95ABS113	Animas River at WRD gaging station	fine sand & silt	37	48	42	107	39	29	23.70	6500	5000	25000	200
Cement Creek													
95ABS114	Cement Creek, Memorial Park, Silverton, Colo.	fine sand & silt	37	49	2	107	39	40	22.70	5000	1000	150000	400
95ABSDP1 (95ABS114)	Cement Creek, Memorial Park, Silverton, Colo.	fine sand & silt	37	49	2	107	39	40	22.70	5100	2000	150000	400
Mean										5050	1500	150000	400
95ABS115	Topeka Gulch	fine sand & silt	37	50	41	107	40	45	19.00	12000	4400	76000	600
95ABS116	Cement Creek below iron bog	fine sand & silt	37	52	35	107	40	15	15.25	3800	1000	65000	500

Appendix V.1. Table of partial digestion (2M HCl-1% H_2O_2) data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	Sample Locality	Sample Type	Latitude Deg Min Sec	Longitude Deg Min Sec	Distance km.	Al ppm	Ca ppm	Fe ppm	K ppm
95ABS117	Iron bog, Cement Creek	fine sand & silt	37 52 35	107 40 15	15.10	3600	500	460000	300
95ABS118	Cement Creek above Gold King inflow	fine sand & silt	37 53 54	107 38 42	11.50	8800	1400	42000	420
95ABS120A	Below confluence of N and S Forks of Cement Creek	fine sand & silt	37 53 22	107 39 18	13.00	5100	1400	54000	500
95ABS120B	Below confluence of N and S Forks of Cement Creek	overbank sed	37 53 22	107 39 18	10.10	7000	1700	46000	700
Mineral Creek									
95ABS121	Koehler adit drainage	colloids	37 53 43	107 42 42	10.10	2700	1000	130000	2300
95ABS122	Mill Creek	fine sand & silt	37 52 21	107 44 16	13.75	4800	5000	22000	300
95ABS123	Mineral Creek	fine sand & silt	37 52 34	107 43 25	13.00	4800	2000	51000	400
95ABS124	Browns Gulch	fine sand & silt	37 51 25	107 43 24	15.45	3400	820	37000	400
95ABS125	Mineral Creek above Burro Bridge	fine sand & silt	37 51 5	107 43 31	16.00	7700	3100	38000	300
95ABS126	Middle Fork Mineral Crk above Bonner Mine	fine sand & silt	37 50 43	107 44 27	16.70	3500	1600	40000	300
95ABS-WD	Paradise portal, Gem claim, Middle Fork Mineral Creek	polybasite	37 50 33	107 45 50	16.55	220000	800	30000	< 200
95ABS127	Mineral Creek above S Fork	fine sand & silt	37 49 19	107 43 10	19.60	4900	1500	37000	400
95ABS128	South Fork Mineral Crk below iron bog	fine sand & silt	37 49 6	107 43 2	20.50	5600	4000	16000	300
95ABS129	South Fork Mineral Crk	overbank sed	37 49 10	107 43 7	20.45	5100	1200	44000	400
95ABS130	Mineral Creek gaging station in Silverton	fine sand & silt	37 48 12	107 40 22	24.55	6700	2500	34000	200

Appendix V.1. Table of partial digestion (2M HCl-1% H_2O_2) data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	Sample Locality	Sample Type	Latitude Deg	Latitude Min	Latitude Sec	Longitude Deg	Longitude Min	Longitude Sec	Distance km.	Al ppm	Ca ppm	Fe ppm	K ppm
Animas River below Silverton, Colo.													
95ABS131A (A-72)	Animas River at railroad bridge below Silverton	fine sand & silt	37	47	23	107	40	0	26.25	5800	2900	32000	240
95ABS131B	Animas River at railroad bridge below Silverton	overbank sed	37	47	23	107	40	0		4400	3200	22000	200
95ABSSB1	Deadwood Gulch	sand	37	47	3	107	40	12	26.50	4200	2700	26000	210
95ABSSB2	Deer Park Creek	sand	37	46	31	107	39	46	28.00	3800	2700	21000	200
95ABS132	Sultan Creek below Molas Mine	fine sand & silt	37	45	49	107	40	33	29.50	3800	12000	6700	280
95ABS-MC	Molas Creek above confl with Animas River	sand	37	44	7	107	39	40	32.75	3000	13000	9200	360
95ABS-EC	Elk Creek above confl with Animas River	sand	37	43	19	107	39	3	34.35	7400	2300	8700	620
95ABS133	Lime Creek abv US 550	fine sand & silt	37	43	57	107	45	2	55.00	3100	6100	4400	300
95ABS134	Cascade Crk above 550	fine sand & silt	37	39	35	107	48	43	55.05	2000	14000	5100	300
95ABS-CC	Cascade Creek above confl with Animas River	sand	37	35	57	107	46	32	55.10	2800	9700	7300	360
95ABS-GC	Grasshopper Creek above confl with Animas River	sand	37	34	42	107	46	28	57.80	9100	6700	23000	1200
95ABS135	Hermosa Creek above US 550	fine sand & silt	37	24	52	107	50	9	80.00	6300	37000	17000	410
95ABS136	Animas River above Trimble Bridge and below quarry	fine sand & silt	37	23	8	107	50	9	82.35	3800	3900	14000	340
95ABS137	Animas River above 32nd Street Bridge, Durango	fine sand & silt	37	18	1	107	52	3	100.75	3300	4800	10000	290
95ABSDP2 (95ABS137)	Animas River above 32nd Street Bridge, Durango	fine sand & silt	37	18	1	107	52	3	100.75	3600	5200	12000	310
Mean										3450	5000	11000	300
95ABS138	Junction Creek at park	fine sand & silt	37	17	18	107	52	33	102.35	2300	59000	9200	420

Appendix V.1. Table of partial digestion (2M HCl-1% H_2O_2) data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	Sample Locality	Sample Type	Latitude Deg	Latitude Min	Latitude Sec	Longitude Deg	Longitude Min	Longitude Sec	Distance km.	Al ppm	Ca ppm	Fe ppm	K ppm
95ABS139	Junction Creek west of Durango	fine sand & silt	37	18	4	107	52	52	102.40	1000	12000	3100	220
95ABS140	Lightner Creek above confluence with Animas River	fine sand & silt	37	16	6	107	53	14	105.10	2300	63000	16000	390
95ABS141	Animas River, Red Lion	fine sand & silt	37	16	9	107	53	8	105.00	3800	17000	12000	340
95ABS142	Basin Creek, west of US 550	fine sand & silt	37	11	11	107	52	48	117.75	9300	40000	16000	620
95ABS143	Animas River south of Weaselskin Bridge	fine sand & silt	37	9	5	107	53	6	122.00	3100	75000	7300	290
95ABS144	Florida River north of Co. Rd. 318 bridge	fine sand & silt	37	3	26	107	52	4	136.00	4100	12000	6700	420
95ABS145	Animas River above Bondad Bridge	fine sand & silt	37	3	5	107	52	31	135.50	3800	16000	6400	340
95ABS146	Animas River at Cedar Hill gaging station, Colo.	fine sand & silt	37	2	11	107	52	28	137.50	3700	24000	6300	310
95ABS147	Animas River above Bridge, Aztec New Mexico	fine sand & silt	36	49	41	107	59	59	171.50	3800	12000	7500	410
95ABS148	Animas River at BoR Pump station site above US 550, Durango, Colo.	fine sand & silt	37	15	48	107	52	53	106.20	3600	16000	13000	350
95ABS149A	Animas River at KOA Campground below Bakers Bridge	fine sand & silt	37	27	18	107	48	3	72.50	6000	4800	22000	400
95ABS149B	Animas River at KOA Campground below Bakers Bridge	overbank sed.	37	27	18	107	48	3	72.50	3700	4000	17000	300
Blanks													
95ABS100	Field blank	qtz sand								< 20	20	20	< 20
95ABS100	Field blank	qtz sand								< 7	< 7	< 7	< 7

Appendix V.1. Table of partial digestion (2M HCl-1% H_2O_2) data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	Mg ppm	Na ppm	P ppm	Ti ppm	Ag ppm	As ppm	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm
Animas River upstream from Silverton, Colo.														
95ABS101	3400	< 40	1500	< 40	< 2	30	41	3	< 8	< 2	53	9	4	92
95ABS102	3200	40	1400	< 40	2	57	160	1	< 7	< 2	42	10	6	43
95ABS103	3400	< 40	1500	50	4	10	110	2	10	10	45	20	4	360
95ABS104A	4100	40	1300	< 40	7	20	110	3	< 8	10	47	20	5	460
95ABS104C	600	< 80	600	< 80	30	30	140	< 2	< 20	< 3	7	< 3	< 3	680
95ABS104D	2300	100	300	< 70	40	50	9	< 2	< 20	74	< 6	9	< 3	750
95ABS105	50000	600	18000	400	30	< 20	190	50	30	70	1500	110	40	4000
95ABS106	< 200	< 200	600	< 200	60	< 30	40	< 3	80	< 6	< 10	< 6	< 6	730
95ABS107	2300	50	1800	< 40	< 2	8	150	1	< 8	< 2	58	20	< 2	45
95ABS108	3600	60	1500	70	20	20	120	2	8	6	44	20	3	320
95ABS109	3100	50	1700	< 40	< 2	< 8	140	< 0.8	< 8	< 2	43	10	3	59
95ABS110A	3900	60	1500	100	6	10	100	1	< 8	2	30	10	4	160
95ABS110B	47000	1200	12000	300	< 3	< 20	110	20	< 20	5	460	60	20	1100
95ABS111A	1900	40	1000	< 40	20	10	100	< 0.7	10	8	40	10	3	950
95ABS111B	53000	700	14000	300	10	< 20	300	8	20	40	440	93	40	3900
95ABS112	3800	< 40	1300	< 40	8	10	180	1	20	20	40	20	3	290
95ABS113	3700	40	1400	< 40	10	20	120	2	8	7	40	10	3	280
Cement Creek														
95ABS114	2300	< 200	2000	< 200	< 6	40	70	< 3	< 30	< 6	10	7	< 6	60
95ABSDP1	2300	< 200	2000	< 200	< 6	40	80	< 3	< 30	< 6	10	9	< 6	60
Mean	2300	< 200	2000	< 200	< 6	40	75	< 3	< 30	< 6	10	8	< 6	60
95ABS115	1300	100	1700	< 70	< 3	20	130	< 2	< 20	< 3	40	20	4	60
95ABS116	2000	< 200	2000	< 200	< 6	50	100	< 3	< 30	< 6	20	7	< 6	60
95ABS117	900	< 200	200	< 200	< 6	< 30	10	< 3	< 30	< 6	< 10	6	< 6	< 6
95ABS118	2500	< 40	1500	90	3	20	77	1	10	< 2	40	20	7	360
95ABS120A	2500	90	1600	200	< 3	< 20	70	< 2	< 20	< 3	20	8	5	82
95ABS120B	2700	< 80	1900	< 80	5	50	110	< 2	< 20	< 3	50	8	4	220

Appendix V.1. Table of partial digestion (2M HCl-1% H_2O_2) data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	Mg ppm	Na ppm	P ppm	Ti ppm	Ag ppm	As ppm	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm
Mineral Creek														
95ABS121	1000	< 200	15000	< 200	9	4400	220	< 3	< 30	< 6	20	< 6	10	210
95ABS122	1900	90	1800	< 40	< 2	20	110	1	< 7	3	40	10	2	50
95ABS123	1000	< 200	2000	< 200	< 6	210	200	< 3	< 30	< 6	20	8	< 6	340
95ABS124	810	100	1500	80	< 3	20	150	< 2	< 20	< 3	20	6	< 3	20
95ABS125	1400	90	1700	< 70	< 3	92	150	< 2	< 20	< 3	40	20	3	830
95ABS126	1200	< 70	1100	< 70	< 3	< 20	60	< 2	< 20	< 3	20	9	< 3	10
95ABS-WD	< 200	< 200	1000	< 200	< 6	< 30	< 3	20	< 30	< 6	20	< 6	< 6	< 6
95ABS127	1400	< 80	1200	< 80	< 3	30	88	< 2	< 20	< 3	20	10	< 3	84
95ABS128	2000	60	1300	100	< 2	< 8	80	< 0.8	< 8	< 2	30	10	3	20
95ABS129	1600	100	1400	80	< 3	50	160	< 2	< 20	< 3	20	9	< 3	91
95ABS130	830	30	1100	50	< 0.9	20	70	0.9	< 4	< 0.9	33	29	4	210
Animas River below Silverton, Colo.														
95ABS131A	1800	30	1300	50	5	20	85	1	< 4	2	31	20	2	250
95ABS131B	2000	20	1200	30	6	10	100	0.8	6	4	26	10	1	210
95ABSSB1	1200	20	1100	40	2	10	110	0.9	< 4	2	24	20	2	200
95ABSSB2	1400	30	1100	40	3	9	110	0.8	< 4	3	24	10	1	190
95ABS132	5100	50	1200	200	2	8	140	0.4	< 4	< 0.9	21	4	3	20
95ABS-MC	6500	60	740	90	< 0.9	5	120	0.5	< 4	< 0.9	20	6	5	7
95ABS-EC	1700	20	770	100	< 0.9	5	100	1	< 4	< 0.9	21	31	10	10
95ABS133	1300	20	1100	100	< 0.9	< 4	170	0.4	< 4	< 0.9	21	4	3	5
95ABS134	3000	30	1100	90	< 0.9	< 4	120	0.5	< 4	< 0.9	27	8	3	5
95ABS-CC	3300	30	960	100	< 0.9	< 4	100	< 0.4	< 4	< 0.9	20	7	5	8
95ABS-GC	4200	< 40	1200	620	< 2	< 9	170	< 0.9	< 9	< 2	57	10	9	20
95ABS135	2900	40	790	50	1	8	130	1	< 4	4	28	21	3	140
95ABS136	2200	30	1100	90	2	6	92	0.5	< 4	< 0.9	33	8	4	100
95ABS137	2200	40	850	60	3	4	83	0.4	< 4	2	21	7	3	80
95ABSDP2	2400	30	960	80	3	5	88	0.4	< 4	2	24	7	4	91
Mean	2300	35	905	70	3	5	86	0.4	< 4	2	23	7	4	86
95ABS138	6400	100	800	30	< 0.9	< 4	130	0.4	< 4	< 0.9	20	6	5	10
95ABS139	1600	30	780	30	< 0.9	< 4	190	< 0.4	< 4	< 0.9	10	3	2	4

Appendix V.1. Table of partial digestion (2M HCl-1% H_2O_2) data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	Mg ppm	Na ppm	P ppm	Ti ppm	Ag ppm	As ppm	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm
95ABS140	14000	100	850	< 20	< 0.9	< 4	130	0.4	< 4	< 0.9	20	8	6	20
95ABS141	2800	60	1100	70	2	4	110	0.5	< 4	2	26	8	5	83
95ABS142	5400	760	370	< 20	< 0.9	< 4	200	0.9	< 4	< 0.9	10	10	3	10
95ABS143	3000	100	730	< 20	< 0.9	< 4	210	0.4	< 4	5	20	10	1	58
95ABS144	1500	90	560	< 20	< 0.9	< 4	290	0.6	< 4	< 0.9	20	6	2	9
95ABS145	1500	80	500	< 20	< 0.9	< 4	190	0.6	< 4	< 0.9	10	7	1	20
95ABS146	1400	80	540	< 20	< 0.9	< 4	210	0.6	< 4	< 0.9	10	7	1	20
95ABS147	1700	100	590	< 20	< 0.9	< 4	180	0.6	< 4	< 0.9	22	7	2	26
95ABS148	3400	60	1200	70	2	6	130	0.5	< 4	2	27	8	4	92
95ABS149A	2700	30	1200	100	2	10	120	0.8	< 4	3	35	20	5	150
95ABS149B	2200	20	1300	70	2	8	110	0.5	< 4	2	33	9	3	110
Blanks														
95ABS100	< 20	< 20	< 20	< 20	< 0.9	< 4	< 0.4	< 0.4	< 4	< 0.9	< 2	< 0.9	< 0.9	< 0.9
95ABS100	< 7	< 7	< 7	< 7	< 0.3	< 2	< 0.2	< 0.2	< 2	< 0.3	< 0.6	< 0.3	< 0.3	< 0.3

Appendix V.1. Table of partial digestion (2M HCl-1% H_2O_2) data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	La ppm	Li ppm	Mn ppm	Mo ppm	Ni ppm	Pb ppm	Sb ppm	Sr ppm	Th ppm	V ppm	Y ppm	Zn ppm
Animas River upstream from Silverton, Colo.												
95ABS101	40	10	3300	< 2	4	270	< 4	10	< 3	20	20	650
95ABS102	20	9	4200	2	8	170	< 4	59	< 3	20	10	450
95ABS103	30	10	12000	4	9	730	< 4	51	< 3	10	10	2800
95ABS104A	30	20	12000	7	10	1900	< 4	40	< 3	20	10	2600
95ABS104C	< 6	< 6	41000	20	< 3	4000	20	20	< 6	< 3	4	620
95ABS104D	< 6	< 6	> 70000	20	< 3	6800	30	40	< 6	< 3	3	20000
95ABS105	590	170	49000	110	60	7400	10	590	96	140	240	27000
95ABS106	< 10	< 10	30	230	< 6	18000	< 20	10	< 10	< 6	< 6	100
95ABS107	30	9	1400	2	5	180	< 4	48	< 3	10	20	180
95ABS108	20	10	9800	9	6	2100	< 4	42	< 3	10	10	1700
95ABS109	20	10	1200	2	4	500	< 4	46	< 3	10	10	510
95ABS110A	20	10	4600	5	4	1000	< 4	30	< 3	20	10	970
95ABS110B	320	200	12000	8	40	3800	< 8	450	70	110	110	8700
95ABS111A	20	10	5700	43	3	4800	< 4	40	< 3	10	10	1600
95ABS111B	290	220	18000	40	30	13000	< 8	290	110	230	120	16000
95ABS112	20	20	19000	30	9	1400	< 4	54	< 3	10	10	3400
95ABS113	20	10	9600	10	6	1900	< 4	40	< 3	10	10	2000
Cement Creek												
95ABS114	< 10	< 10	520	< 6	< 6	320	< 20	40	< 10	30	< 6	200
95ABSDP1	< 10	< 10	540	< 6	< 6	310	< 20	40	< 10	30	< 6	200
Mean	< 10	< 10	530	< 6	< 6	315	< 20	40	< 10	30	< 6	200
95ABS115	20	< 6	870	< 3	< 3	72	< 7	120	< 6	20	10	86
95ABS116	< 10	< 10	520	< 6	< 6	500	< 20	50	< 10	20	< 6	200
95ABS117	< 10	< 10	< 10	< 6	< 6	< 10	< 20	10	< 10	20	< 6	60
95ABS118	20	7	2400	2	4	620	< 4	30	< 3	20	10	280
95ABS120A	10	8	660	< 3	< 3	640	< 7	50	< 6	20	4	200
95ABS120B	30	7	1100	< 3	4	2500	< 8	60	< 6	20	10	720

Appendix V.1. Table of partial digestion (2M HCl-1% H_2O_2) data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	La ppm	Li ppm	Mn ppm	Mo ppm	Ni ppm	Pb ppm	Sb ppm	Sr ppm	Th ppm	V ppm	Y ppm	Zn ppm
Mineral Creek												
95ABS121	10	< 10	200	< 6	< 6	3500	< 20	70	< 10	30	< 6	200
95ABS122	20	8	1600	7	2	930	< 4	77	< 3	7	10	600
95ABS123	10	< 10	670	< 6	< 6	1000	< 20	30	< 10	10	6	330
95ABS124	9	< 6	380	< 3	< 3	120	< 7	40	< 6	10	5	40
95ABS125	20	< 6	2200	< 3	4	630	< 7	50	< 6	10	20	680
95ABS126	9	< 6	830	< 3	< 3	120	< 7	20	< 6	8	6	78
95ABS-WD	< 10	< 10	< 10	< 6	< 6	30	< 20	7	< 10	80	20	< 6
95ABS127	10	< 6	1100	< 3	< 3	200	< 8	20	< 6	10	9	120
95ABS128	20	6	560	< 2	7	90	< 4	30	< 3	10	10	200
95ABS129	10	< 6	530	< 3	< 3	460	< 8	30	< 6	10	8	100
95ABS130	20	3	1400	< 0.9	5	220	< 2	27	< 2	10	20	420
Animas River below Silverton, Colo.												
95ABS131A	20	7	5200	4	4	1200	< 2	31	< 2	10	10	790
95ABS131B	10	8	6200	4	3	1300	< 2	26	< 2	10	8	820
95ABSSB1	10	5	4600	4	3	910	4	26	< 2	9	10	720
95ABSSB2	10	6	5200	3	3	1000	< 2	27	< 2	9	8	780
95ABS132	10	5	580	1	4	670	< 2	29	< 2	7	8	97
95ABS-MC	8	4	770	< 0.9	7	20	< 2	20	< 2	9	7	65
95ABS-EC	10	10	780	< 0.9	38	9	< 2	10	< 2	7	8	130
95ABS133	10	4	530	< 0.9	3	8	< 2	39	< 2	8	10	20
95ABS134	20	3	460	< 0.9	8	6	< 2	27	< 2	8	10	47
95ABS-CC	10	4	500	< 0.9	7	6	< 2	20	< 2	9	9	33
95ABS-GC	40	20	640	< 2	6	10	< 4	10	< 4	20	30	64
95ABS135	20	7	3200	< 0.9	9	290	< 2	160	< 2	10	20	1700
95ABS136	20	8	2300	3	4	440	< 2	33	4	10	10	500
95ABS137	10	8	2700	2	4	270	< 2	25	< 2	8	8	620
95ABSDP2	10	9	3000	2	5	290	3	27	4	9	9	680
Mean	10	9	2850	2	5	280	3	26	< 2	9	9	650
95ABS138	8	4	180	< 0.9	10	20	< 2	190	< 2	10	10	54
95ABS139	7	< 2	240	< 0.9	2	6	< 2	41	< 2	4	6	20

Appendix V.1. Table of partial digestion (2M HCl-1% H_2O_2) data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	La ppm	Li ppm	Mn ppm	Mo ppm	Ni ppm	Pb ppm	Sb ppm	Sr ppm	Th ppm	V ppm	Y ppm	Zn ppm
95ABS140	7	5	180	2	20	20	< 2	140	5	10	10	58
95ABS141	20	9	3300	1	7	260	< 2	73	< 2	10	10	790
95ABS142	5	4	610	< 0.9	4	10	< 2	300	< 2	20	9	38
95ABS143	8	4	4400	1	8	140	< 2	230	< 2	8	8	1100
95ABS144	9	3	540	< 0.9	4	8	< 2	72	< 2	6	8	28
95ABS145	6	3	1100	< 0.9	4	31	< 2	91	< 2	5	7	230
95ABS146	6	3	1100	< 0.9	4	28	< 2	110	< 2	5	7	240
95ABS147	10	4	1100	< 0.9	4	64	< 2	74	< 2	7	8	290
95ABS148	20	9	3200	2	7	320	< 2	66	2	20	10	830
95ABS149A	20	8	3400	3	9	490	< 2	36	< 2	10	10	1200
95ABS149B	20	7	2900	2	4	570	< 2	25	3	10	9	660
Blanks												
95ABS100	< 2	< 2	< 2	< 0.9	< 0.9	< 2	< 2	< 0.9	< 2	< 0.9	< 0.9	< 0.9
95ABS100	< 0.6	< 0.6	< 0.6	< 0.3	0.4	< 0.6	< 0.7	< 0.3	0.6	< 0.3	< 0.3	< 0.3

Appendix V.2. Table of partial digestion (2M HCl-1% H_2O_2) data from sites sampled from the Animas River watershed, Aug. and Oct. 1996
[Concentrations given in parts per million, ppm (µg/g)]

Field No.	Al ppm	Ca ppm	Fe ppm	K ppm	Mg ppm	Na ppm	P ppm	Ti ppm	Ag ppm	As ppm
Animas River upstream from Silverton, Colo.										
96-ABS-106	9700	3700	19000	290	3000	30	1100	< 30	8.1	38
96-ABS-105	6200	5900	23000	270	3400	30	1200	30	16	18
95-ABS-110A	6200	3900	22000	350	3600	41	1200	120	7.8	10
96-ABS-107	6400	5600	23000	270	3500	41	1200	30	15	17
Cement Creek										
96-ABS-104	4400	1700	56300	390	2100	57	1300	94	1.9	9.5
96-ABS-108	4100	1400	56100	350	2100	37	1200	58	2.0	18
96-ABS-108d	4200	1400	57700	360	2100	41	1200	57	2.7	20
Mineral Creek										
96-ABS-101	4600	1700	40500	260	1400	35	1000	< 30	6.2	180
96-ABS-102	5100	1500	41800	290	1100	48	1100	< 30	< 1	31
96-ABS-103	6300	3200	24000	240	1600	42	1100	69	< 1	6.9
96-ABS-109	12000	2500	40600	270	1200	57	1100	44	< 1	23
Animas River below Silverton, Colo.										
96-ABS-110A	7600	2900	39500	260	2100	36	1200	39	11	19
96-ABS-110B	6000	2000	29000	200	1500	31	820	35	8.5	15
95-ABS-131A	6000	2500	30000	370	2200	39	1000	35	7.1	16
96-ABS-125A	5400	3000	28000	270	2300	38	1200	39	8.2	16
96-ABS-125B	4400	2300	30900	300	2200	39	1200	40	9.6	20
96-ABS-112	10000	4800	28000	420	2500	51	1000	93	3.4	13
96-ABS-111	2000	49500	3800	420	3300	39	540	62	< 1	< 6
96-ABS-113	4200	7100	13000	450	2900	70	980	74	2.6	< 6
95-ABS-137	4100	5000	13000	470	2700	72	820	75	3.4	< 6

Sample localities given in appendix VI.2

Appendix V.2. Table of partial digestion (2M HCl-1% H_2O_2) data from sites sampled from the Animas River watershed, Aug. and Oct. 1996 (cont.)

Field No.	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	La ppm	Li ppm
Animas River upstream from Silverton, Colo.										
96-ABS-106	91	5.8	6.0	14	57	10	5.7	540	41	12
96-ABS-105	130	1.3	7.8	8.3	32	8.5	4.3	340	18	11
95-ABS-110A	120	1.1	< 6	3.4	28	8.8	3.8	170	15	12
96-ABS-107	140	1.4	10	9.8	33	9.9	5.5	340	18	12
Cement Creek										
96-ABS-104	49	< 0.6	< 6	< 1	18	6.3	4.0	83	8.3	5.8
96-ABS-108	53	< 0.6	7.8	< 1	11	3.7	3.2	46	5.8	5.3
96-ABS-108d	54	< 0.6	6.3	< 1	13	3.8	3.6	46	6.2	5.4
Mineral Creek										
96-ABS-101	57	< 0.6	< 6	< 1	21	6.2	5.8	230	8.4	3.9
96-ABS-102	54	< 0.6	< 6	< 1	18	6.8	1.4	96	7.2	3.2
96-ABS-103	62	< 0.6	< 6	< 1	30	7.5	2.7	18	15	4.6
96-ABS-109	64	0.87	< 6	1.1	33	19	1.9	230	16	3.7
Animas River below Silverton, Colo.										
96-ABS-110A	91	1.1	10	6.0	34	15	4.1	380	17	7.2
96-ABS-110B	79	0.86	6.2	5.9	26	12	2.4	310	12	5.5
95-ABS-131A	92	0.83	< 6	3.3	28	10	2.8	250	14	7.5
96-ABS-125A	100	0.74	8.1	3.5	27	9.8	3.2	230	14	7.4
96-ABS-125B	120	< 0.6	7.7	2.3	25	9.2	3.2	180	11	6.4
96-ABS-112	120	1.3	< 6	7.0	39	19	4.8	230	20	9.0
96-ABS-111	100	< 0.6	< 6	< 1	13	2.4	3.2	5.3	6.7	2.8
96-ABS-113	150	< 0.6	< 6	3.0	24	6.4	4.7	89	12	9.1
95-ABS-137	150	< 0.6	< 6	3.2	26	5.6	4.6	97	13	8.3

Appendix V.2. Table of partial digestion (2M HCl-1% H_2O_2) data from sites sampled from the Animas River watershed, Aug. and Oct. 1996 (cont.)

Field No.	Mn ppm	Mo ppm	Ni ppm	Pb ppm	Sb ppm	Sr ppm	Th ppm	V ppm	Y ppm	Zn ppm
Animas River upstream from Silverton, Colo.										
96-ABS-106	9900	6.9	8.8	940	< 3	22	< 2	13	23	3600
96-ABS-105	10000	8.0	3.9	2600	3.3	32	< 2	12	9.9	1800
95-ABS-110A	4000	4.4	3.9	1000	< 3	28	< 2	14	8.6	960
96-ABS-107	10000	9.0	5.7	2400	< 3	34	< 2	12	11	2500
Cement Creek										
96-ABS-104	820	< 1	2.0	540	< 3	44	2.0	17	4.4	200
96-ABS-108	420	< 1	1.4	320	< 3	34	< 2	19	3.0	110
96-ABS-108d	440	< 1	1.8	340	< 3	35	2.7	20	3.2	120
Mineral Creek										
96-ABS-101	730	< 1	3.3	930	< 3	19	< 2	9.0	6.2	290
96-ABS-102	640	1.6	1.0	260	< 3	19	< 2	9.4	6.8	120
96-ABS-103	440	< 1	6.2	91	< 3	23	< 2	9.0	12	210
96-ABS-109	1200	1.7	3.6	240	< 3	25	< 2	10	20	460
Animas River below Silverton, Colo.										
96-ABS-110A	7400	8.0	4.6	1700	< 3	32	< 2	12	16	1100
96-ABS-110B	6700	6.6	3.5	1300	< 3	23	< 2	9.1	12	900
95-ABS-131A	4500	4.5	3.4	1200	< 3	29	< 2	12	11	840
96-ABS-125A	4700	4.9	3.8	1300	< 3	31	< 2	12	10	850
96-ABS-125B	3800	6.2	2.7	1200	< 3	26	2.1	12	7.3	530
96-ABS-112	4500	2.9	12	540	< 3	40	< 2	13	21	2400
96-ABS-111	310	< 1	3.3	5.6	< 3	150	< 2	7.9	7.4	18
96-ABS-113	2800	1.8	5.2	300	< 3	35	2.7	11	9.8	780
95-ABS-137	2700	1.8	4.4	310	< 3	28	2.3	11	8.2	800

Appendix VI.1 Table of total digestion data from sites sampled from the Animas River watershed, Oct. 1995
[Concentrations given in weight percent (wt. pct.) or parts per million, ppm (µg/g)]

Sample No.	Sample Locality	Sample Type	Latitude Deg	Latitude Min	Latitude Sec	Longitude Deg	Longitude Min	Longitude Sec	Distance km	Al wt. pct.	Ca wt. pct.	Fe wt. pct.	K wt. pct.
Animas River upstream from Silverton, Colo.													
95ABS101	upper Animas River below Cinnamon Gulch	fine sand & silt	37	55	25	107	33	47	5.75	6.8	0.56	3.5	3.6
95ABS102	Picayne Gulch	fine sand & silt	37	54	42	107	33	18	7.25	6.4	0.61	5.9	2.6
95ABS103	Eureka Creek	fine sand & silt	37	52	47	107	33	54	11.25	7.4	0.72	6.4	2.6
95ABS104A	upper Animas River	fine sand & silt	37	52	39	107	33	44	11.35	6.9	0.67	5.1	2.9
95ABS106	Kittimac Mill site	tailings	37	51	30	107	34	21	13.80	3.6	0.04	1.9	1.7
95ABS107	Maggie Gulch	fine sand & silt	37	51	15	107	34	11	14.20	6.9	0.75	5.5	2.5
95ABS108	upper Animas River above the Howardsville mill site	fine sand & silt	37	50	43	107	35	14	15.80	5.6	0.81	5.1	2.3
95ABS109	Cunningham Creek	fine sand & silt	37	50	0	107	35	37	17.05	7.3	0.76	7.8	2.2
95ABS110A	upper Animas River at gaging station	fine sand & silt	37	49	58	107	35	58	17.55	6.1	1.1	5.3	2.4
95ABS111A	Arrastra Creek	fine sand & silt	37	49	28	107	37	20	20.00	5.2	0.61	3.9	2.2
95ABS112	Boulder Creek	fine sand & silt	37	49	31	107	38	0	20.90	5.2	0.81	5.0	2.2
95ABS113	Animas River at WRD gaging station	fine sand & silt	37	48	42	107	39	29	23.70	5.7	0.75	5.2	2.2
Cement Creek													
95ABS114	Cement Creek at Memorial Park in Silverton, Colo.	fine sand & silt	37	49	2	107	39	40	22.70	5.5	0.43	14	1.9
95ABSDP1 (95ABS114)	Cement Creek at Memorial Park in Silverton, Colo.	fine sand & silt	37	49	2	107	39	40	22.70	5.6	0.42	14	1.9
Mean (95ABS114)										5.6	0.42	14	1.9
95ABS115	Topeka Gulch	fine sand & silt	37	50	41	107	40	45	19.00	8.6	0.45	8.5	2.6
95ABS116	Cement Creek below iron bog	fine sand & silt	37	52	35	107	40	15	15.25	6.4	0.42	8.2	2.2
95ABS117	Iron bog, Cement Creek	fine sand & silt	37	52	35	107	40	15	15.10	1.3	0.11	37	0.39
95ABS118	Cement Creek above Gold King inflow	fine sand & silt	37	53	54	107	38	42	11.50	7.5	0.58	6.8	2.5

Appendix VI. Table of total digestion data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	Sample Locality	Sample Type	Latitude Deg	Min	Sec	Longitude Deg	Min	Sec	Distance km	Al wt. pct.	Ca wt. pct.	Fe wt. pct.	K wt. pct.
95ABS120A	Below confluence of N and S Forks of Cement Creek	fine sand & silt	37	53	22	107	39	18	13.00	6.8	0.62	8.1	2.4
95ABS120B	Below confluence of N and S Forks of Cement Creek	overbank sed.	37	53	22	107	39	18	10.10	6.8	0.34	6.5	2.9
Mineral Creek													
95ABS122	Mill Creek	fine sand & silt	37	52	21	107	44	16	13.75	7.8	0.81	6.5	2.7
95ABS123	Mineral Creek	fine sand & silt	37	52	34	107	43	25	13.00	6.9	0.37	7.4	2.3
95ABS124	Browns Gulch	fine sand & silt	37	51	25	107	43	24	15.45	7.2	0.29	5.9	2.1
95ABS125	Mineral Creek above Burro Bridge	fine sand & silt	37	51	5	107	43	31	16.00	7.3	0.46	7.6	2.2
95ABS126	Middle Fork Mineral Creek above Bonner mine	fine sand & silt	37	50	43	107	44	27	16.70	6.4	0.33	5.3	2.2
95ABS127	Mineral Creek above South Fork	fine sand & silt	37	49	19	107	43	10	19.60	6.8	0.36	5.2	2.3
95ABS128	South Fork Mineral Creek below iron bog	fine sand & silt	37	49	6	107	43	2	20.50	6.6	1.2	5.2	2.0
95ABS129	South Fork Mineral Creek	overbank sed.	37	49	10	107	43	7	20.45	7.1	0.36	6.4	2.2
95ABS130	Mineral Creek gaging station in Silverton	fine sand & silt	37	48	12	107	40	22	24.55	6.8	0.76	7.1	2.0
Animas River below Silverton, Colo.													
95ABS131A	Animas River at railroad bridge below Silverton	fine sand & silt	37	47	23	107	40	0	26.25	6.2	0.59	5.3	2.0
95ABS131B	Animas River at railroad bridge below Silverton	overbank sed.	37	47	23	107	40	0		5.8	0.72	6.0	2.0
95ABSSB1	Deadwood Gulch	sand	37	47	3	107	40	12	26.50	5.9	0.76	7.7	1.9
95ABSSB2	Deer Park Creek	sand	37	46	31	107	39	46	28.00	5.6	0.70	8.5	2.0
95ABS132	Sultan Creek below Molas Mine	fine sand & silt	37	45	49	107	40	33	29.50	6.6	1.7	7.0	1.7
95ABS-MC	Molas Creek above conf. with Animas River	sand	37	44	7	107	39	40	32.75	5.4	1.5	4.1	1.6

Appendix VI.1 Table of total digestion data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	Sample Locality	Sample Type	Latitude Deg	Latitude Min	Latitude Sec	Longitude Deg	Longitude Min	Longitude Sec	Distance km	Al wt. pct.	Ca wt. pct.	Fe wt. pct.	K wt. pct.
95ABS-EC	Elk Creek above conf. with Animas River	sand	37	43	19	107	39	3	34.35	5.4	0.37	4.4	1.4
95ABS133	Lime Creek above US 550	fine sand & silt	37	43	57	107	45	2	55.00	6.1	0.82	4.0	1.9
95ABS134	Cascade Crk above US 550	fine sand & silt	37	39	35	107	48	43	55.05	5.2	1.8	5.0	1.8
95ABS-CC	Cascade Creek above conf. with Animas River	sand	37	35	57	107	46	32	55.10	5.7	1.4	3.5	1.7
95ABS-GC	Grasshopper Creek above conf. with Animas River	sand	37	34	42	107	46	28	57.80	6.4	2.0	6.4	1.9
95ABS135	Hermosa Crk abv US 550	fine sand & silt	37	24	52	107	50	9	80.00	5.8	3.8	3.8	1.8
95ABS136	Animas River, Trimble Bridge and below quarry	fine sand & silt	37	23	8	107	50	9	82.35	5.3	1.2	8.2	1.6
95ABS137	Animas River above 32nd Street Bridge, Durango	fine sand & silt	37	18	1	107	52	3	100.75	4.9	1.1	7.1	1.7
95ABSDP2 (95ABS137)	Animas River above 32nd Street Bridge, Durango	fine sand & silt	37	18	1	107	52	3	100.75	4.8	1.1	7.0	1.6
Mean (95ABS137)										4.9	1.1	7.0	1.7
95ABS138	Junction Creek at park	fine sand & silt	37	17	18	107	52	33	102.35	5.5	6.0	3.5	1.5
95ABS139	Junction Creek 1.7 km west of Durango	fine sand & silt	37	18	4	107	52	52	102.40	4.0	1.3	4.8	1.4
95ABS140	Lightner Creek above conf. with Animas River	fine sand & silt	37	16	6	107	53	14	105.10	5.7	5.8	2.8	1.3
95ABS141	Animas River, Red Lion Inn	fine sand & silt	37	16	9	107	53	8	105.00	4.9	2.1	6.6	1.6
95ABS142	Basin Creek, west of road	fine sand & silt	37	11	11	107	52	48	117.75	9.3	4.3	4.5	1.4
95ABS143	Animas River south of Weaselskin Bridge	fine sand & silt	37	9	5	107	53	6	122.00	4.8	8.2	5.9	1.3
95ABS144	Florida River north of Co. Rd. 318 bridge	fine sand & silt	37	3	26	107	52	4	136.00	5.7	1.2	3.4	1.4
95ABS145	Animas River above Bondad Bridge	fine sand & silt	37	3	5	107	52	31	135.50	6.2	1.6	3.3	1.7
95ABS146	Animas River at Cedar Hill gaging station, Colo.	fine sand & silt	37	2	11	107	52	28	137.50	6.0	2.2	3.5	1.5

Appendix VI.1 Table of total digestion data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	Sample Locality	Sample Type	Latitude Deg	Latitude Min	Latitude Sec	Longitude Deg	Longitude Min	Longitude Sec	Distance km	Al wt. pct.	Ca wt. pct.	Fe wt. pct.	K wt. pct.
95ABS147	Animas River above bridge, Aztec, New Mexico	fine sand & silt	36	49	41	107	59	59	171.50	5.5	1.3	3.8	1.6
95ABS148	Animas River at BoR pump station site above US 550, Durango, Colo.	fine sand & silt	37	15	48	107	52	53	106.20	4.8	2.0	7.0	1.6
95ABS149A	Animas River, KOA Campground below Bakers Bridge	fine sand & silt	37	27	18	107	48	3	72.50	6.0	1.3	6.9	1.8
95ABS149B	Animas River, KOA Campground below Bakers Bridge	overbank sed.	37	27	18	107	48	3		5.7	1.3	5.7	1.7
Blanks													
95ABS100	Field blank	qtz sand								0.03	0.006	0.02	< 0.01
95ABS100	Field blank	qtz sand								0.04	0.006	0.03	< 0.01

Appendix VI.1 Table of total digestion data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	Mg wt. pct.	Na wt. pct.	P wt. pct.	Ti wt. pct.	Ag ppm	As ppm	As ppm Hydride	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm
Animas River upstream from Silverton, Colo.																
95ABS101	0.90	1.1	0.15	0.25	< 2	56	--	970	3	< 10	< 2	84	14	17	120	14
95ABS102	0.94	0.48	0.14	0.38	2	110	--	740	2	< 10	< 2	82	24	24	70	17
95ABS103	1.0	0.47	0.16	0.37	3	45	--	740	2	< 10	10	85	27	23	430	24
95ABS104A	0.97	0.60	0.13	0.28	5	51	--	730	3	< 10	11	83	22	21	550	26
95ABS106	0.24	0.03	0.06	0.10	55	26	--	220	1	57	< 2	18	1	2	670	8
95ABS107	0.76	1.1	0.18	0.48	< 2	21	16	850	2	< 10	< 2	100	26	19	68	16
95ABS108	0.65	0.71	0.14	0.29	12	42	--	710	3	< 10	10	76	20	14	500	25
95ABS109	0.98	1.2	0.16	0.68	< 2	23	16	770	1	< 10	< 2	92	20	26	110	18
95ABS110A	0.71	0.94	0.14	0.41	6	29	--	800	2	< 10	3	76	15	17	270	23
95ABS111A	0.58	0.74	0.11	0.17	35	26	--	910	1	< 10	10	58	14	13	2200	16
95ABS112	0.73	0.49	0.11	0.23	10	35	--	980	2	14	14	69	22	14	420	20
95ABS113	0.73	0.74	0.13	0.34	12	35	--	750	2	< 10	8	72	17	16	470	26
Cement Creek																
95ABS114	0.61	0.48	0.15	0.38	< 2	57	--	550	1	< 10	< 2	61	10	19	110	11
95ABSDP1	0.62	0.51	0.15	0.35	< 2	58	--	570	1	< 10	< 2	61	10	18	140	10
Mean (95ABS114)	0.62	0.5	0.15	0.37	< 2	58	--	560	1	< 10	< 2	61	10	19	125	11
95ABS115	0.54	0.50	0.20	0.46	< 2	46	--	970	2	< 10	< 2	90	16	24	80	17
95ABS116	0.60	0.42	0.17	0.40	3	78	--	580	1	< 10	< 2	68	9	23	170	16
95ABS117	0.17	0.14	0.02	0.04	< 2	< 10	6.7	100	< 1	< 10	< 2	7	7	< 1	6	8
95ABS118	1.0	0.57	0.17	0.37	2	52	--	900	2	< 10	< 2	87	20	27	410	18
95ABS120A	0.77	0.64	0.18	0.51	2	42	--	650	1	< 10	< 2	85	13	25	170	17
95ABS120B	1.2	0.51	0.20	0.36	5	76	--	750	2	< 10	< 2	100	14	28	290	19
Mineral Creek																
95ABS122	0.83	1.4	0.18	0.36	< 2	38	--	760	2	< 10	< 2	93	20	15	81	19
95ABS123	0.66	0.84	0.15	0.40	3	240	--	830	1	< 10	< 2	75	14	23	380	23
95ABS124	0.48	0.82	0.18	0.46	< 2	47	--	870	1	< 10	< 2	82	9	17	50	16
95ABS125	0.67	0.89	0.17	0.49	3	130	--	990	2	< 10	< 2	93	30	20	880	22

Appendix VI.1 Table of total digestion data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	Mg wt. pct.	Na wt. pct.	P wt. pct.	Ti wt. pct.	Ag ppm	As ppm	As ppm Hydride	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm
95ABS126	0.52	0.98	0.10	0.22	< 2	38	--	630	1	< 10	< 2	67	12	7	17	11
95ABS127	0.58	1.0	0.12	0.23	< 2	45	--	700	1	< 10	< 2	66	14	8	100	14
95ABS128	0.90	1.3	0.13	0.40	< 2	20	15	670	2	< 10	< 2	81	18	31	29	15
95ABS129	0.65	0.86	0.15	0.37	< 2	80	--	880	1	< 10	< 2	83	11	17	110	20
95ABS130	0.70	1.0	0.14	0.36	< 2	41	--	750	2	< 10	< 2	84	35	25	240	18
Animas River below Silverton, Colo.																
95ABS131A	0.71	0.81	0.13	0.31	4	31	--	700	2	< 10	3	74	18	14	330	22
95ABS131B	0.72	0.74	0.13	0.41	7	29	--	740	2	< 10	6	77	18	17	380	21
95ABSSB1	0.72	0.67	0.13	0.44	2	32	--	950	2	< 10	< 2	79	22	22	340	21
95ABSSB2	0.70	0.67	0.13	0.56	5	33	--	860	2	< 10	4	79	22	28	390	22
95ABS132	1.1	1.7	0.11	0.57	< 2	15	--	840	2	< 10	< 2	89	16	40	36	16
95ABS-MC	0.90	1.1	0.08	0.28	< 2	< 10	11	460	2	< 10	< 2	69	12	49	11	11
95ABS-EC	0.62	0.58	0.09	0.27	< 2	14	17	410	2	< 10	< 2	67	38	62	34	12
95ABS133	0.80	1.4	0.10	0.34	< 2	< 10	7.5	600	2	< 10	< 2	90	12	50	17	15
95ABS134	0.81	1.4	0.12	0.43	< 2	< 10	5.1	790	2	< 10	< 2	100	16	70	14	15
95ABS-CC	0.88	1.6	0.09	0.28	< 2	< 10	5.1	550	2	< 10	< 2	82	14	51	17	14
95ABS-GC	1.2	1.3	0.14	0.62	< 2	< 10	8.7	720	2	< 10	< 2	120	18	50	20	19
95ABS135	0.91	0.98	0.10	0.23	< 2	18	--	560	2	< 10	3	76	25	34	160	16
95ABS136	0.75	1.2	0.11	0.52	< 2	15	19	680	2	< 10	< 2	110	18	56	190	19
95ABS137	0.69	1.1	0.09	0.39	< 2	14	15	690	2	< 10	< 2	120	16	62	340	19
95ABSDP2	0.69	1.1	0.09	0.39	< 2	12	16	660	2	< 10	< 2	99	15	58	330	17
Mean (95ABS137)	0.69	1.1	0.09	0.39	< 2	13	16	675	2	< 10	< 2	110	16	60	335	18
95ABS138	1.1	0.60	0.09	0.27	< 2	< 10	9.9	500	2	< 10	< 2	63	11	63	22	14
95ABS139	0.50	0.84	0.07	0.25	< 2	< 10	5.9	790	1	< 10	< 2	66	8	43	8	10
95ABS140	1.6	0.64	0.09	0.22	< 2	< 10	13	420	2	< 10	< 2	55	11	62	25	12
95ABS141	0.73	1.1	0.11	0.42	< 2	12	15	630	2	< 10	< 2	97	16	54	220	19
95ABS142	1.0	0.63	0.06	0.48	< 2	< 10	3	620	2	< 10	< 2	90	17	24	22	22
95ABS143	0.71	0.76	0.08	0.55	< 2	< 10	9.2	810	2	< 10	2	100	25	34	120	19
95ABS144	0.44	0.92	0.06	0.41	< 2	< 10	4.7	1100	2	< 10	< 2	120	12	27	23	15
95ABS145	0.43	0.81	0.06	0.39	< 2	< 10	5.9	1200	2	< 10	< 2	86	13	22	49	15

Appendix VI.1 Table of total digestion data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	Mg wt. pct.	Na wt. pct.	P wt. pct.	Ti wt. pct.	Ag ppm	As ppm	As ppm Hydride	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm
95ABS146	0.42	0.85	0.06	0.43	< 2	< 10	6.6	1300	2	< 10	< 2	88	12	22	49	14
95ABS147	0.49	0.91	0.07	0.41	< 2	< 10	7.2	1900	2	< 10	< 2	150	13	28	45	15
95ABS148	0.75	1.0	0.11	0.41	< 2	12	17	680	2	< 10	< 2	120	16	60	210	19
95ABS149A	0.88	1.1	0.12	0.44	2	20	--	790	2	< 10	< 2	100	23	42	200	18
95ABS149B	0.85	1.0	0.12	0.45	< 2	22	--	720	2	< 10	< 2	98	18	27	230	20
Blanks																
95ABS100	< 0.005	< 0.005	< 0.005	< 0.005	< 2	< 10	0.6	16	< 1	< 10	< 2	< 4	< 1	< 1	2	< 4
95ABS100	< 0.005	< 0.005	< 0.005	< 0.005	< 2	< 10	< 0.5	18	< 1	< 10	< 2	< 4	< 1	< 1	< 1	< 4

Appendix VI.1 Table of total digestion data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	Hg ppm	La ppm	Li ppm	Mn ppm	Mo ppm	Nb ppm	Nd ppm	Ni ppm	Pb ppm	Sc ppm	Se ppm Hydride	Sr ppm	Th ppm	V ppm	Y ppm	Yb ppm	Zn ppm
Animas River upstream from Silverton, Colo.																	
95ABS101	0.09	52	40	3200	3	22	37	7	300	9	0.2	210	13	82	24	2	980
95ABS102	0.03	41	29	3800	< 2	23	34	15	190	12	0.4	160	14	130	20	2	590
95ABS103	0.07	45	37	11000	8	25	34	14	820	14	1.1	200	11	140	20	2	3500
95ABS104A	0.89	45	37	13000	11	22	36	14	1900	12	0.8	180	12	120	21	2	3600
95ABS106	0.47	9	46	360	200	10	6	< 2	17000	4	2.5	18	5	38	6	< 1	310
95ABS107	0.05	48	35	1600	4	29	37	10	210	11	0.5	250	13	120	21	2	270
95ABS108	0.14	40	33	24000	12	18	30	7	2100	9	0.8	190	10	94	17	1	3500
95ABS109	0.02	39	44	1300	3	30	32	9	520	14	0.4	240	9	190	20	2	670
95ABS110A	0.08	39	36	12000	8	24	31	6	1000	11	0.7	260	10	120	18	2	2000
95ABS111A	0.43	31	56	5200	62	15	24	6	4700	7	0.9	170	9	68	15	2	2600
95ABS112	0.07	37	55	17000	50	17	25	11	1400	9	1.0	200	8	87	16	1	4000
95ABS113	0.09	38	38	20000	16	21	28	8	1900	10	0.8	180	9	110	16	2	3200
Cement Creek																	
95ABS114	0.07	28	18	840	4	20	25	4	370	12	1.8	220	12	130	11	1	1200
95ABSDP1	0.22	28	19	850	4	21	22	4	360	12	1.9	220	10	130	10	1	1300
Mean	0.15	28	19	845	4	21	24	4	365	12	1.9	220	11	130	11	1	1250
95ABS115	0.05	38	16	820	< 2	28	37	5	96	17	1.9	350	14	150	18	2	140
95ABS116	0.11	31	16	930	5	24	27	5	610	13	1.9	270	11	140	11	1	1600
95ABS117	<0.02	5	6	54	< 2	6	7	< 2	6	3	0.2	44	8	26	< 2	< 1	91
95ABS118	0.05	42	28	2800	5	23	37	10	790	15	1.3	230	13	140	18	2	830
95ABS120A	0.10	40	23	1100	3	26	30	7	680	15	1.9	280	13	160	13	1	1400
95ABS120B	0.04	56	33	1600	2	26	41	10	2700	16	0.9	170	14	150	20	2	2200
Mineral Creek																	
95ABS122	0.05	49	32	1800	8	29	41	6	940	11	1.2	310	11	120	18	2	1100
95ABS123	0.56	35	24	870	< 2	25	29	7	1100	12	0.6	190	15	110	15	1	2500
95ABS124	0.06	38	24	610	< 2	28	33	5	170	12	1.3	320	12	120	14	2	130
95ABS125	0.39	43	29	2300	< 2	28	38	10	660	12	0.8	240	14	140	23	2	1800
95ABS126	< 0.02	36	26	860	3	20	27	3	150	8	0.7	160	10	60	12	2	150

Appendix VI.1 Table of total digestion data from sites sampled from the Animas River watershed, Oct. 1995 (cont.)

Sample No.	Hg ppm	La ppm	Li ppm	Mn ppm	Mo ppm	Nb ppm	Nd ppm	Ni ppm	Pb ppm	Sc ppm	Se ppm Hydride	Sr ppm	Th ppm	V ppm	Y ppm	Yb ppm	Zn ppm
95ABS146	0.02	43	14	1300	< 2	23	35	9	39	7	0.4	240	10	94	18	2	290
95ABS147	0.02	78	17	1700	< 2	23	64	10	83	7	0.4	200	28	95	22	2	390
95ABS148	0.11	60	28	5900	4	26	52	15	340	10	0.8	180	23	180	24	2	1400
95ABS149A	0.07	52	28	5700	3	26	46	16	500	13	1.0	220	13	150	24	2	1600
95ABS149B	0.04	47	27	8800	4	25	39	11	620	13	1.2	210	16	130	18	2	1600
Blanks																	
95ABS100	<0.02	< 2	< 2	< 4	< 2	< 4	< 4	< 2	< 4	< 2	< 0.1	2	< 4	< 2	< 2	< 1	< 2
95ABS100	<0.02	< 2	2	6	< 2	< 4	< 4	< 2	< 4	< 2	< 0.1	< 2	< 4	< 2	< 2	< 1	4

Appendix VI.2. Table of total digestion data from sites sampled from the Animas River Watershed, Aug. and Oct. 1996
[Concentrations given in weight percent (wt. pct.) or parts per million, ppm (µg/g)]

Field No.	Sample Locality	Sample Type	Latitude Deg Min Sec	Longitude Deg Min Sec	Al wt. pct.	Ca wt. pct.	Fe wt. pct.	K wt. pct.
Animas River upstream from Silverton, Colo.								
96-ABS-106	Animas River 0.7 km upstream from Eureka (above site 95ABS105)	1	37 53 12	107 33 41	6.9	0.70	5.2	3.2
96-ABS-114	Cunningham Creek (same site as 95ABS109)	3	37 49 53	107 35 34	7.0	0.79	7.7	2.1
96-ABS-115	Cunningham Creek in beaver pond	3	37 49 53	107 35 34	7.1	0.72	4.5	2.2
96-ABS-116	Cunningham Creek below beaver pond	3	37 49 53	107 35 34	7.3	0.77	4.8	2.4
96-ABS-116d	outflow	d	37 49 53	107 35 34	7.4	0.77	4.8	2.4
96-ABS-105	Animas River at gaging station (same site as 95ABS110)	3	37 49 57	107 35 59	5.2	0.92	6.0	2.0
96-ABS-107	Animas River upstream from bridge at RV camp north of town (1.2 km above site 95ABS113)	1	37 49 1	107 38 53	5.5	0.87	5.4	2.2
Cement Creek								
96-ABS-104	Cement Creek below confluence of N and S Forks (same site as 95ABS120)	3	37 53 22	107 39 18	6.5	0.67	9.6	2.3
96-ABS-108	Cement Creek at Memorial Park	3	37 49 13	107 39 47	6.6	0.55	8.7	2.3
96-ABS-108d	(same site as 95ABS114)	d	37 49 13	107 39 47	6.6	0.53	8.7	2.3
Mineral Creek								
96-ABS-101	Mineral Creek at Chatnooga (same site as 95ABS123)	3	37 52 34	107 43 25	7.0	0.29	7.0	2.4
96-ABS-102	Mineral Creek above confluence with South Fork Mineral Creek (same site as 95ABS127)	3	37 49 21	107 43 16	6.7	0.40	7.1	2.2
96-ABS-103	South Fork Mineral Creek (0.3 km upstream from site 95ABS128)	1	37 49 7	107 43 11	6.6	1.20	6.5	2.0
96-ABS-109	Mineral Creek at gaging station (same site as 95ABS130)	3	37 48 12	107 40 22	7.0	0.75	8.4	1.9

Appendix VI.2. Table of total digestion data from sites sampled from the Animas River Watershed, Aug. and Oct. 1996 (cont.)

Field No.	Sample Locality	Sample Type	Latitude Deg Min Sec	Longitude Deg Min Sec	Al wt. pct.	Ca wt. pct.	Fe wt. pct.	K wt. pct.
Animas River below Silverton, Colo.								
96-ABS-110A	Animas River below confluence of Mineral Creek (A-72; same site as 95ABS131)	3	37 47 23	107 40 0	6.1	0.64	7.2	2.1
96-ABS-110B	Animas River below confluence of Mineral Creek (A-72; sampled 2 weeks later)	3	37 47 23	107 40 0	5.9	0.63	6.8	2.0
96-ABS-125A	Animas River at Elk Park (0.3 km above the confluence with Elk Creek)	1	37 43 26	107 39 15	5.9	0.80	6.8	2.1
96-ABS-125B	Animas River at Elk Park (0.3 km above the confluence with Elk Creek)	2	37 43 26	107 39 15	5.8	0.73	7.8	2.1
96-ABS-112	Animas River at KOA Campground (same site as 95ABS149)	3	37 27 18	107 48 3	6.2	1.20	6.8	1.9
96-ABS-111	Hermosa Creek at gaging station upstream from irregation ditch inflow	1	37 25 18	107 50 40	4.5	5.20	3.0	1.9
96-ABS-113	Animas River above 32nd Street Bridge, Durango, Colo. (same site as 95ABS137)	3	37 18 1	107 52 2	5.0	1.30	7.2	1.8

1=stream sediment sample from new site
2=overbank sediment sample
3=stream-sediment sample from site sampled in Oct. 1995.
d=duplicate analytical sample

Appendix VI.2. Table of total digestion data from sites sampled from the Animas River Watershed, Aug. and Oct. 1996 (cont.)

Field No.	Mg wt. pct.	Na wt. pct.	P wt. pct.	Ti wt. pct.	Ag ppm	As ppm	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Hg ppm
Animas River upstream from Silverton, Colo.																
96-ABS-106	0.87	0.81	0.13	0.26	6	110	620	7	< 10	19	92	22	23	580	29	0.08
96-ABS-114	0.94	1.20	0.17	0.66	< 2	13	610	1	< 10	< 2	68	20	26	86	13	--
96-ABS-115	0.94	1.10	0.16	0.38	4	19	580	1	< 10	3	67	16	20	160	15	--
96-ABS-116	0.97	1.10	0.16	0.40	2	16	590	1	< 10	3	70	17	19	140	16	--
96-ABS-116d	0.99	1.10	0.16	0.42	6	14	610	2	< 10	3	70	16	19	140	16	--
96-ABS-105	0.67	0.63	0.14	0.36	19	50	550	3	< 10	16	64	17	24	550	44	0.14
96-ABS-107	0.70	0.67	0.14	0.32	17	44	600	3	< 10	16	64	17	22	510	41	0.14
Cement Creek																
96-ABS-104	0.69	0.57	0.18	0.52	3	46	500	1	< 10	5	75	15	26	180	15	0.05
96-ABS-108	0.73	0.56	0.17	0.44	< 2	52	560	1	< 10	4	69	10	24	120	15	0.07
96-ABS-108d	0.73	0.56	0.16	0.39	< 2	60	570	1	11	4	64	10	23	120	14	0.07
Mineral Creek																
96-ABS-101	0.61	0.72	0.14	0.41	10	290	620	1	< 10	12	77	15	23	270	31	1.30
96-ABS-102	0.59	0.92	0.14	0.34	< 2	67	580	1	< 10	< 2	68	14	14	110	14	0.10
96-ABS-103	0.88	1.20	0.13	0.38	< 2	22	650	2	< 10	< 2	72	19	34	26	14	0.02
96-ABS-109	0.65	0.90	0.14	0.38	< 2	54	710	2	< 10	< 2	76	33	23	250	16	0.09
Animas River below Silverton, Colo.																
96-ABS-110A	0.70	0.68	0.14	0.33	11	56	620	2	< 10	11	69	25	21	520	32	0.12
96-ABS-110B	0.67	0.64	0.13	0.32	10	50	600	2	< 10	13	68	26	19	560	33	0.14
96-ABS-125A	0.70	0.77	0.15	0.41	8	40	590	2	< 10	8	59	19	23	370	28	--
96-ABS-125B	0.71	0.71	0.16	0.52	10	55	560	2	< 10	9	59	19	26	290	26	--
96-ABS-112	0.84	0.91	0.12	0.40	9	33	690	2	< 10	7	96	30	41	280	23	0.07
96-ABS-111	0.84	1.00	0.07	0.20	< 2	< 10	530	1	< 10	< 2	75	8	42	14	10	<0.02
96-ABS-113	0.74	1.10	0.10	0.42	< 2	21	580	2	< 10	5	100	17	67	180	21	0.04

Appendix VI.2. Table of total digestion data from sites sampled from the Animas River Watershed, Aug. and Oct. 1996 (cont.)

Field No.	La ppm	Li ppm	Mn ppm	Mo ppm	Nb ppm	Nd ppm	Ni ppm	Pb ppm	Sc ppm	Se ppm	Sr ppm	Th ppm	V ppm	Y ppm	Yb ppm	Zn ppm
Animas River upstream from Silverton, Colo.																
96-ABS-106	68	34	10000	10	15	45	16	900	10	0.54	200	13	100	34	2	4800
96-ABS-114	38	41	1200	< 2	21	28	9	400	13	--	220	8	180	24	1	620
96-ABS-115	37	41	570	2	19	30	8	950	12	--	210	7	110	21	1	720
96-ABS-116	38	42	760	< 2	18	31	9	740	12	--	220	9	120	22	1	730
96-ABS-116d	39	44	780	< 2	18	34	8	710	13	--	220	8	120	22	1	720
96-ABS-105	38	34	27000	9	13	29	8	2300	9	0.79	160	8	120	20	1	3900
96-ABS-107	37	34	24000	10	12	29	9	2200	9	0.85	180	8	110	21	2	4400
Cement Creek																
96-ABS-104	41	22	1400	2	19	34	6	560	15	2.00	290	14	160	20	2	1700
96-ABS-108	37	21	970	< 2	18	30	6	390	14	1.80	270	14	150	18	1	1300
96-ABS-108d	36	21	970	< 2	18	27	5	410	14	1.20	250	12	150	17	1	1400
Mineral Creek																
96-ABS-101	40	24	920	< 2	21	32	8	870	12	0.88	160	18	110	22	2	4200
96-ABS-102	37	23	860	3	18	31	5	260	10	1.10	220	14	94	20	2	450
96-ABS-103	41	25	850	< 2	19	35	18	92	11	0.92	280	9	120	25	2	330
96-ABS-109	43	22	1600	3	20	40	10	240	11	1.10	240	12	130	33	2	870
Animas River below Silverton Colo.																
96-ABS-110A	39	30	15000	9	13	33	9	1400	10	1.10	200	9	120	26	2	2700
96-ABS-110B	37	30	19000	12	16	32	9	1700	10	1.20	190	8	100	28	2	2900
96-ABS-125A	33	29	14000	6	18	27	8	1200	10	--	220	6	130	19	1	2300
96-ABS-125B	34	29	11000	12	20	26	8	1100	11	--	220	7	150	20	1	2800
96-ABS-112	54	30	7100	5	20	46	22	510	12	0.86	210	16	130	39	3	2800
96-ABS-111	42	25	460	< 2	11	34	14	12	6	0.27	230	13	66	17	1	54
96-ABS-113	52	29	5600	< 2	20	44	15	300	10	0.35	160	17	160	27	2	1400

Appendix VII. Lead-isotopic data from bed-sediment and other samples from the Animas River Watershed
[Concentration data given in parts per million, ppm (μg/g)]

Sample No.	Description of Location	Sample Type	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	Pb ppm (leach)
Above Silverton, Colo.						
95ABS101	upper Animas River below Cinnamon Gulch	fine sand & silt	18.538	15.586	38.129	270
95ABS102	Picayne Gulch	fine sand & silt	18.552	15.565	38.096	170
95ABS105	upper Animas River	coated pebbles	18.358	15.565	38.010	7400
95ABS103	Eureka Creek	fine sand & silt	18.377	15.567	37.988	730
95ABS104A	upper Animas River	fine sand & silt	18.383	15.564	37.976	1900
95ABS104C	upper Animas River	jarosite-Feox	18.305	15.535	37.849	4000
95ABS104D	upper Animas River	white precipitate	18.306	15.543	37.889	6800
95ABS107	Maggie Gulch	fine sand & silt	18.613	15.569	38.078	180
95ABS108	upper Animas River	fine sand & silt	18.377	15.585	38.034	2100
95ABS108D	above Howardsville		18.347	15.553	37.909	
95ABS108 aver	mill site		18.362	15.569	37.972	2100
95ABS109	Cunningham Creek	fine sand & silt	18.968	15.629	38.382	500
95ABS110A	upper Animas River at	fine sand & silt	18.396	15.557	37.985	1000
95ABS110B	gaging station	coated pebbles	18.375	15.559	37.939	3800
95ABS111A	Arrastra Creek	fine sand & silt	18.815	15.596	38.234	4800
95ABS111B	Arrastra Creek	coated pebbles	18.854	15.628	38.313	13000
95ABS112	Boulder Creek	fine sand & silt	18.589	15.568	38.068	1400
95ABS113	Animas River at WRD gaging station	fine sand & silt	18.406	15.565	37.984	1900
Cement Creek						
95ABS119A	Samples from natural ferricrete on hillside	goethite	18.351	15.557	37.939	5
95ABS118	Cement Creek above Gold King inflow	fine sand & silt	18.403	15.545	37.941	620
95ABS120A	Below confluence of N and S Forks of Cement Creek	fine sand & silt	18.342	15.552	37.919	640

Appendix VII. Lead-isotopic data from bed-sediment and other samples from the Animas River Watershed (cont.)

Sample No.	Description of Location	Sample Type	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	Pb ppm (leach)
95ABS120B	Below confluence of N and S Forks of Cement Creek	overbank sediment	18.360	15.584	38.010	2500
95ABS117	Iron bog, Cement Creek	fine sand & silt	18.374	15.556	37.935	5
95ABS116	Cement Creek below iron bog	fine sand & silt	18.419	15.580	38.046	500
95ABS115	Topeka Gulch	fine sand & silt	18.601	15.577	38.164	72
95ABS114	Cement Creek at Memorial	fine sand & silt	18.400	15.552	37.959	320
95ABS114D	Park in Silverton, Colo.		18.425	15.576	38.037	
Mineral Creek						
95ABS121	Koehler adit drainage	colloids	18.502	15.564	38.081	3500
95ABS123	Mineral Creek	fine sand & silt	18.477	15.610	38.180	1000
95ABS122	Mill Creek	fine sand & silt	18.905	15.596	38.252	930
95ABS124	Browns Gulch	fine sand & silt	18.361	15.564	37.961	120
95ABS125	Mineral Creek above Burro Bridge	fine sand & silt	18.461	15.564	38.038	630
95ABS126	Middle Fork Mineral Creek above Bonner mine	fine sand & silt	18.828	15.613	38.322	120
95ABS127	Mineral Creek above South Fork	fine sand & silt	18.611	15.573	38.108	200
95ABS129	South Fork of Mineral Creek	overbank sediment	18.497	15.590	38.133	460
95ABS128	South Fork of Mineral Creek below iron bog	fine sand & silt	19.064	15.635	38.303	90
95ABS130	Mineral Creek at gaging station in Silverton	fine sand & silt	18.571	15.568	38.078	220
Animas River below Silverton, Colo.						
95ABS131A	Animas River at railroad bridge below Silverton	fine sand & silt	18.407	15.557	37.958	1200
95ABS131B	Animas River at railroad bridge below Silverton	overbank sediment	18.414	15.588	38.040	1300

Appendix VII. Lead-isotopic data from bed-sediment and other samples from the Animas River Watershed (cont.)

Sample No.	Description of Location	Sample Type	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	Pb ppm (leach)
95ABSSB1	Deadwood Gulch	sand	18.452	15.571	38.024	910
95ABSSB-1D1			18.461	15.573	38.013	
95ABSSB-1D2			18.440	15.550	37.956	
95ABSSB2	Deer Park Creek	sand	18.437	15.567	38.030	1000
95ABS132	Sultan Creek below Molas mine	fine sand & silt	18.916	15.635	38.329	670
95ABS-MC	Molas Creek at Animas confl.	sand	20.248	15.734	38.842	20
95ABS-EC	Elk Creek at Animas confl.	sand	20.324	15.773	39.309	9
95ABS133	Lime Creek above US 550	fine sand & silt	20.500	15.759	38.920	8
95ABS134	Cascade Creek above US 550	fine sand & silt	20.347	15.802	38.950	6
95ABS-CC	Cascade Creek at confl.	sand	21.263	15.851	39.255	6
95ABS-GC	Grasshopper Creek at confl.	sand	21.269	15.839	39.242	10
95ABS149A	Animas River at KOA Campground above Bakers bridge	fine sand & silt	18.487	15.577	38.046	490
95ABS149B	Animas River at KOA Campground above Bakers bridge	overbank sediment	18.496	15.479	37.811	570
95ABS135	Hermosa Creek above US 550	fine sand & silt	18.474	15.550	37.976	290
95ABS135D			18.479	15.560	38.001	
95ABS136	Animas River above Trimble bridge and below quarry	fine sand & silt	18.510	15.558	37.995	440
95ABS137	Animas River above 32nd Street Bridge, Durango, Colo.	fine sand & silt	18.540	15.558	38.010	290
95ABS138	Junction Creek at park	fine sand & silt	19.233	15.660	38.772	20
95ABS139	Junction Creek 1.7 km west of Durango, Colo.	fine sand & silt	19.353	15.662	38.623	6
95ABS141	Animas River, Red Lion Inn	fine sand & silt	18.559	15.585	38.095	260
95ABS140	Lightner Creek above confluence with Animas River	fine sand & silt	19.407	15.687	39.056	20
95ABS148	Animas River at BoR pump station site above US 550, Durango	fine sand & silt	18.592	15.575	38.073	320

Appendix VII. Lead-isotopic data from bed-sediment and other samples from the Animas River Watershed (cont.)

Sample No.	Description of Location	Sample Type	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	Pb ppm (leach)
95ABS142	Basin Creek, west of road	fine sand & silt	18.997	15.629	38.709	10
95ABS143	Animas River south of Weaselskin Bridge	fine sand & silt	18.586	15.580	38.100	140
95ABS145	Animas River above Bondad Bridge	fine sand & silt	18.637	15.569	38.135	31
95ABS144	Florida River north of Co. Rd. 318 bridge	fine sand & silt	19.271	15.667	38.938	8
95ABS146	Animas River at Cedar Hill gaging station, Colo.	fine sand & silt	18.684	15.587	38.219	28
95ABS147	Animas River above bridge, Aztec, New Mexico	fine sand & silt	18.661	15.578	38.129	64
Standards						
SRM-2709	NIST Reference Soil		19.065	15.646	38.864	7
SRM-2710	NIST Reference Soil		17.819	15.537	38.141	5100
SRM-2711	NIST Reference Soil		17.086	15.419	36.888	1100
SRM-2711	NIST Reference Soil		17.097	15.430	36.936	1100
Blank						<0.01