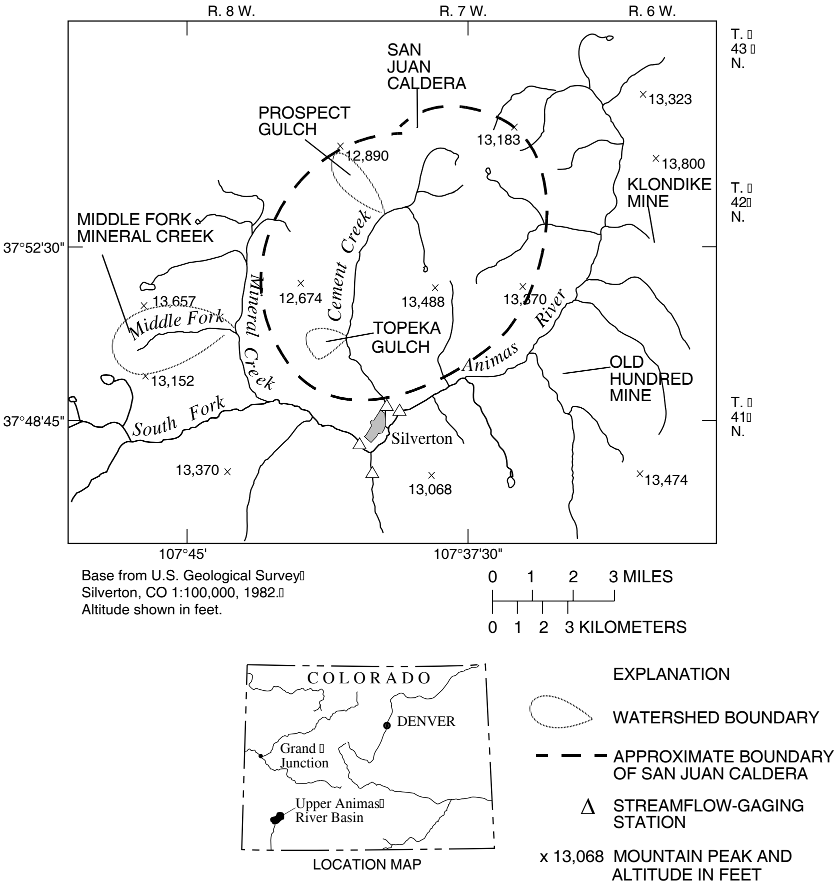
Natural and Mining-Related Sources of Dissolved Minerals During Low Flow in the Upper Animas River Basin, Southwestern Colorado

As part of the Clean Water Act of 1972 (Public Law 92–500), all States are required to establish water-quality standards for every river basin in the State. During 1994, the Colorado Department of Public Health and Environment (CDPHE) proposed to the Colorado Water Quality Control Commission (CWQCC) an aquatic-life standard of 225 µg/L (micrograms per liter) for the dissolved-zinc concentration in the Animas River downstream from Silverton (fig. 1). Dissolved-zinc concentrations in this section of the river vary from about 270 µg/L during high flow when rainfall and snowmelt runoff dilutes the dissolved minerals in the river (U.S. Geological Survey, 1996, p. 431), to 960 µg/L (Colorado Department of Public Health and Environment, written commun., 1996) during low flow (such as late summer and middle of winter when natural springs and drainage from mines are the main sources of water for the streams). It is difficult, however, to distinguish between naturally occurring and mining-related sources of dissolved minerals, including zinc, in the basin. In the context of this fact sheet, the term "natural sources of dissolved minerals" refers to springs and streams where no effects from mining are present. "Mining-related sources of dissolved minerals" refers to: (1) Water draining from mines, and (2) water seeping from mine-waste dump piles where the waste piles were saturated by water draining from mines. Although rainfall and snowmelt runoff from mine-waste piles might affect water quality in streams, work described in this fact sheet was done during low-flow conditions when springs and drainage from mines were the main sources of dissolved minerals affecting the streams. Data are being collected by the U.S. Geological Survey (USGS) to determine the magnitude and sources of dissolved minerals during rainfall- and snowmelt-runoff periods.



Base from U.S. Geological Survey
Silverton, CO 1:100,000, 1982.
Altitude shown in feet.

Figure 1. Location of the Silverton Caldera and locations of study sites in the Upper Animas River Basin.

Cleanup of mining sites in the Upper Animas River Basin to meet the proposed zinc standard has far reaching implications for the region. Citizens, industry, local governments, and Federal land-management agencies could be affected. With regard to sites owned by citizens, many of the mining sites in the basin were developed between about 1872 and the 1940's, with only a few mines operated until the early 1990's. The ownership of the mines may have changed since the mines have been abandoned. For local governments, mining sites represent part of our nation's heritage, tourists are attracted to the historic mining sites, and governments are obligated to protect the historic mining sites according to the

National Historic Preservation Act (Public Law 89–665). Tax dollars might be spent if it is necessary to remediate sites owned by Federal land-management agencies (such as the Bureau of Land Management and the U.S. Forest Service). If natural sources of dissolved minerals in the basin are large, reduction of the present (1997) dissolved-mineral concentrations down to natural levels may be more technically defensible than trying to meet a proposed standard, which might not be achievable through remediation of mining-related activities.

This fact sheet, prepared by the USGS, in cooperation with the Southwestern Colorado Water Conservation District, presents results of studies at selected sites in the Upper Animas River Basin that determined natural and mining-related sources of dissolved minerals. Studies by the USGS addressing natural and mining-related sources of dissolved minerals are continuing in the basin with the Animas River Stakeholders Group and as part of the Department of the Interior Abandoned Mine Lands Initiative. The results of all these studies will provide useful information for determining appropriate water-quality standards in the basin.

Mineralized Volcanic Rocks Affect Water Quality in the Upper Animas River Basin

The rocks of the Upper Animas River Basin are mineralized as a result of the ancient Silverton Caldera (fig. 1), which was the second of two volcanoes that collapsed and formed cylindrical pits (or calderas) about 26 million years ago (Varnes, 1963; Luedke and Burbank, 1996). Lavas were deposited within and around the caldera, and volcanic ashes accumulated in thick deposits throughout the region. Doming and collapse of the Silverton Caldera were accompanied by the development of faults (fractures or fracture zones in the rocks). The faults acted as a plumbing system for later circulation of hot, acidic ground water that contained large amounts of dissolved copper, gold, lead, manganese, silica, sulfur, and zinc (Casadevall and Ohmoto, 1977). As these ore fluids cooled near the land surface, minerals were precipitated in the faults forming veins. These veins were the target for prospectors and miners. The ore fluids also altered and leached the surrounding host rocks. During the ice ages, glaciers then carved the volcanoes into steep mineralized mountains that to this day receive large quantities of snow during winter.

Within the caldera boundary (fig. 1), veins are present throughout the lavas, and pyrite (iron sulfide, or fools gold) is dispersed throughout the rocks. Water from natural springs and mines in these rocks can be acidic and can have high concentrations of dissolved minerals. Veins are less common outside the caldera, and the rocks frequently contain greater proportions of calcium carbonate, which tends to improve the water quality from natural springs and draining mines. Some of the rocks in the basin were highly altered and mineralized by a combination of intrusive magma bodies (molten rock that never breached the land surface) and the circulation of hot, mineral-rich fluids. Water from natural springs and draining mines in areas of altered rocks can have very poor quality (fig. 2). Where the rocks are not as altered, water from natural springs can have fair quality. Water that drains from mines developed in unaltered rocks usually is of better quality than the quality of water from mines in altered rocks.

Not all mines have water draining from them, but those mines that do have drainage can affect the water quality of streams because mines tend to speed up natural weathering processes. Minerals in the mines are exposed on freshly broken rock surfaces, and air moves through the mines. The exposure to air enhances

Figure 2. Area of altered rocks in the Upper Animas River Basin where poor water quality might be expected in water from natural and mining-related sources. Red iron minerals are present naturally in soils developed from these altered rocks.

the weathering of minerals and changes the chemical makeup of some of the minerals into forms that more readily dissolve in water; therefore, high concentrations of dissolved minerals might be present in water that drains from some mines. Mines also can divert ground water from its original flow paths, and the water can be collected into a single discharge at the mine entrance. Hence, the water flow and quality in the vicinity of a mine can be affected (fig. 3).

Figure 3. Historic, collapsed mine entrance, Upper Animas River Basin. Red iron minerals are present in this water from the effects of mining.

Mineral-rich springs are present throughout the Upper Animas River Basin. Springs that have naturally high dissolved-mineral concentrations far outnumber the abandoned mines in the Upper Animas River Basin. One such spring (fig. 4), located in lower Prospect Gulch of the Cement Creek Basin (fig. 1), is an example of a natural mineral-rich spring. Mineral deposits from the spring water (fig. 4) appear similar to the mineral deposits from the mine drainage (fig. 3).

Not all rocks and mountains are as mineralized as those in the Upper Animas River Basin. The rocks in this area are unique because of the extensive amount of mineralization related to the volcanic history. Water from springs in other mountainous areas of southwestern Colorado is not always affected by mineralized rocks.

Methods for Determining Sources of Dissolved Minerals During Low Flow

One method for distinguishing between natural and mining-related sources of dissolved minerals is a mass-balance approach in which all natural and mining-related sources are sampled, and measurements are made of the flow of water from springs, streams, and mines. The approach is best applied when there are no fluctuations in streamflow (such as during low-flow conditions). To determine the dissolved mineral load (or dissolved-mineral mass), concentrations of dissolved minerals are multiplied by the flow of water. The mass of minerals from natural sources and the mass of minerals from mining-related sources are computed. The percentage of dissolved minerals from natural and mining-related sources is then determined. Characterization was done through fracture mapping, examination of mine maps, and examination of water-chemistry data to determine whether springs were affected by mines.

Another method being used (work is currently in progress) to distinguish between natural and mining-related dissolved minerals is the use of the isotope fingerprint of dissolved sulfate. Dissolved sulfate is created from the weathering of copper, iron, zinc, and other minerals in the volcanic rocks. The sulfate has an isotope fingerprint (like the DNA fingerprint in humans) that is specific to the chemical reactions that resulted in the dissolved sulfate. The isotope fingerprint can be different depending on the source (natural or mining-related) of the chemical reaction. The laboratory measurement of the isotope fingerprint is very accurate compared with other measurements.

Sources of Dissolved Minerals in Study Sites of the Upper Animas River Basin

Study sites in the Upper Animas River Basin were Topeka Gulch and the Middle Fork Mineral Creek subbasins (fig. 1). Sources of dissolved minerals were determined for the study sites. Water sampling was performed during the dry, low-flow periods of late summer to avoid the diurnal fluctuations of streams caused by snowmelt. Sampling also was done in two mines—the Klondike Mine and the Old Hundred Mine (fig. 1)—where samples were collected of water entering the back of the mines and of water leaving the mine entrances. After characterization of fractures and examination of mine maps, it was determined that no other mines affect the water that was entering the back of the mines. Both mines are located outside of the caldera (fig. 1).

Results of water-quality data collected from the study sites indicate that high concentrations of dissolved minerals are present in water from natural and mining-related sources—especially in areas underlain by altered rocks (table 1). In table 1, footnoted sites were used in mass-balance calculations for the study subbasins. These sites usually were located at the outflow of drainages within the study subbasins. Water-quality data also are listed in table 1 for sites not used in the mass-balance calculations as examples of the concentrations of dissolved minerals that were reported in water from natural and mining-related sources.

The differences in pH and dissolved-mineral concentrations between water from altered rocks and water from unaltered rocks are indicated by data listed in table 1. The pH values of water from natural and mining-related sources in altered rocks ranged from 2.90 (which is considered to be very acidic water) to 3.77 (table 1). The pH values of water from natural and mining-related sources in unaltered rocks ranged from 3.95 to 7.58 (which is considered to be neutral water) (table 1). During low-flow periods, dissolved-zinc concentrations in water from natural and mining-related sources ranged from less than 1 to 5,178 µg/L (table 1).

A summary of the dissolved-zinc concentrations in water from the study sites during low flow is listed in table 2. The natural and mining-related dissolved-zinc concentrations for the Topeka Gulch subbasins and Middle Fork Mineral Creek were determined through mass-balance loading calculations. The dissolved-zinc concentrations leaving the outflow of the subbasins equals the sum of the natural and mining-related dissolved-zinc concentrations for that subbasin. In the Topeka Gulch subbasin during low flow of September 1994, natural sources contributed about 82 percent of the dissolved-zinc concentration, and mining-related sources contributed about 18 percent of the dissolved-zinc concentration (Wright and Janik, 1995). In the Middle Fork Mineral Creek subbasin during low flow of September–October 1995, natural sources contributed about 33 percent of the dissolved-zinc concentration, and mining-related sources contributed about 67 percent of the dissolved-zinc concentration. The actual concentrations of dissolved zinc entering and leaving the mine study sites are listed in table 2. Substantial amounts of natural dissolved zinc enter the back of these mines.

The percentage of natural and mining-related sources of dissolved minerals depends on which mineral is in question. In the Upper Animas River Basin, minerals such as zinc usually are located along veins, and the mines follow the veins. In the Middle Fork Mineral Creek subbasin, a greater percentage of the dissolved zinc in the streams came from mining-related sources when compared to natural sources (fig. 5). However, a greater percentage of the aluminum, copper, iron, and sulfate in the streams came from natural sources when compared to mining-related sources (fig. 5). Natural weathering processes contribute dissolved minerals to the streams because there is acidic weathering of naturally occurring minerals throughout the rocks.

The flow of water in the streams of the Upper Animas River Basin varies greatly throughout the year because of deep snowpack during winter, snowmelt runoff during spring, and mountain rain storms during summer. The results presented in this fact sheet represent conditions during low-flow periods. Work is in progress by the USGS to describe the natural and mining-related sources of dissolved minerals throughout the year.

Figure 4. Natural mineral-rich spring in lower Prospect Gulch, Upper Animas River Basin. Red iron minerals are present naturally in water from this spring.

Table 1. Water-quality data collected from the Topeka Gulch subbasin, Middle Fork Mineral Creek subbasin, and mine study sites

[ft^3/s, cubic feet per second; μg/L, micrograms per liter; mg/L, milligrams per liter; <, less than; --, no data; MFMC, Middle Fork Mineral Creek subbasin]

Site description	Sampling date	pH (standard units)	Discharge (ft^3/s)	Aluminum (μg/L)	Copper (μg/L)	Iron (μg/L)	Sulfate (mg/L)	Zinc (μg/L)
TOPEKA GULCH SUBBASIN								
Natural sources								
Spring, altered rock, unaffected by mining	09–02–94	3.77	.03	22,000	7	45,000	480	196
Stream, altered rock, unaffected by mining[1]	09–02–94	3.56	.04	16,000	14	31,000	370	156
Spring, altered rock, unaffected by mining[1]	09–03–94	2.90	.01	16,000	48	13,000	400	995
Spring, iron deposit, unaffected by mining	09–04–94	4.32	.001	7,100	6	20,000	290	90
Stream, altered rock, unaffected by mining	09–04–94	3.49	.002	5,300	5	670	230	68
Stream, altered rock, unaffected by mining[1]	09–09–94	3.45	.03	6,600	37	3,600	190	379
Mining-related sources								
Mine drainage[1]	09–08–94	6.95	.009	16	5	3,800	770	6
Mine drainage[1]	09–09–94	6.85	.14	7	7	12,000	1,100	42
MIDDLE FORK MINERAL CREEK SUBBASIN								
Natural sources								
Stream, altered rock, red tributary south side of MFMC	09–19–95	3.12	.17	45,000	10	22,400	460	250
Stream, altered rock, red tributary south side of MFMC[1]	09–20–95	3.39	1.6	43,000	27	58,300	660	260
Spring, Crystal Lake basin, unaffected by mining	09–18–95	5.32	.02	390	<1	<1	61	32
Stream, Crystal Lake stream, unaffected by mining[1]	09–18–95	4.47	.5	590	<1	320	28	<1
Spring in glacial moraine, Paradise Basin, unaffected by mining	10–11–95	6.84	.34	20	2	<1	210	36
Spring issuing from bog, Paradise Basin, unaffected by mining	10–11–95	5.72	.07	1,700	11	8,960	1,200	120
Spring, unaltered rock, Paradise Basin, unaffected by mining	10–11–95	5.43	.05	720	9	425	1,000	33
Stream, Paradise Basin, unaffected by mining[1]	09–21–95	5.79	2.4	140	4	19	240	68
Spring, unaltered rock in forest, unaffected by mining[1]	09–20–95	5.98	.03	20	2	<1	210	<1
Spring, unaltered rock, north side MFMC, unaffected by mining	09–19–95	6.83	.02	10	1	<1	54	<1
Spring, unaltered rock, north side MFMC, unaffected by mining[1]	09–14–95	6.56	.02	10	<1	7	25	<1
Mining-related sources								
Mine drainage, unaltered rock, Ruby Trust Mine, north side MFMC[1]	09–18–95	6.36	1.03	<1	3	470	200	39
Spring, unaltered rock, affected by mining	09–13–95	3.95	.007	2,210	--	780	90	<1
Mine drainage, Governor Mine or Paradise Portal[1]	09–28–95	5.70	.6	8,600	13	67,000	1,200	530
Mine drainage, unaltered rock, north side MFMC[1]	09–19–95	5.54	.03	160	2	9,350	83	260
Mine drainage, altered rock, Independence Mine	09–26–95	3.19	.04	4,410	<1	12,600	--	243
Spring below Independence Mine, altered rock, affected by mining[1]	09–26–95	3.45	.02	7,600	43	2,370	260	380
Mine drainage, altered rock, Bonner Mine	09–26–95	3.14	.06	8,300	<1	10,500	--	4,090
Spring below Bonner Mine, altered rock, affected by mining[1]	09–26–95	3.12	.15	11,000	165	4,660	440	5,178
MINE STUDY SITES								
Klondike Mine, unaltered rock, water entering back of mine	08–25–95	7.58	.01	9	3	6	150	1,950
Klondike Mine, unaltered rock, water leaving mine entrance	08–25–95	6.32	.02	14	6	5	40	2,710
Old Hundred Mine, unaltered rock, water entering back of mine	08–24–95	6.82	1.05	3	4	5	200	1,180
Old Hundred Mine, unaltered rock, water leaving mine entrance	08–24–95	7.35	2.52	8	6	5	210	321

[1] Data from this site was used in mass-balance calculations for results listed in table 2. Sites used to calculate mass balance are at the outflow of subbasins. Sites not used in the mass-balance calculations are tributaries within these subbasins and are listed as examples of dissolved-mineral concentrations present in water from sites in the Upper Animas River Basin.

Table 2. Summary of natural and mining-related concentrations of dissolved zinc in water from study sites in the Upper Animas River Basin, southwestern Colorado

[μg/L, micrograms per liter or parts per billion]

Study site (fig. 1)	Date	Natural concentration of dissolved zinc (μg/L)	Mining-related concentration of dissolved zinc (μg/L)
Topeka Gulch subbasin[1]	September 1994	66	8
Middle Fork Mineral Creek subbasin[1]	September–October 1995	85	134
Old Hundred Mine	August 1995	[2]1,180	[3]321
Klondike Mine	August 1995	[2]1,950	[3]2,710

[1] Determined through mass-balance calculations from data listed in table 1. Dissolved-zinc concentrations leaving the outflow of the subbasins equal to the sum of the natural and mining-related concentrations.

[2] Actual concentrations entering the back of the mines.

[3] Actual concentrations leaving the mine entrances; combination of natural and mining-related sources.

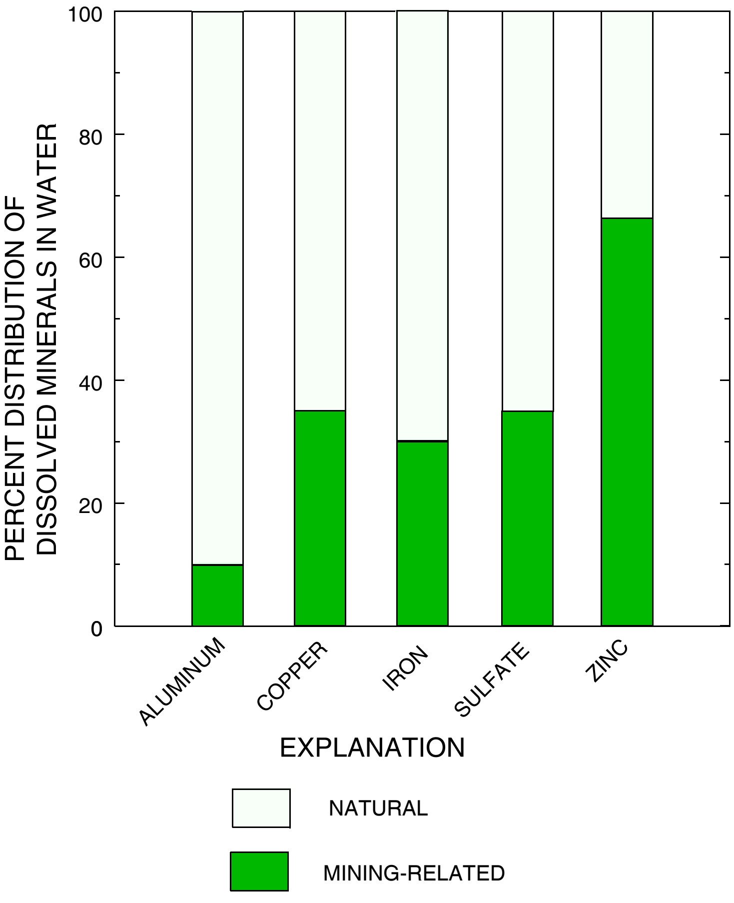


Figure 5. Percent distribution of selected dissolved minerals in the Middle Fork Mineral Creek subbasin during the low-flow period of September–October 1995.

References Cited

Casadevall, T., and Ohmoto, H., 1977, Sunnyside Mine, Eureka Mining District, San Juan County, Colorado—Geochemistry of gold and base metal ore deposition in a volcanic environment: Economic Geology, v. 72, p. 1285–1320.

Luedke, R.G., and Burbank, W.S., 1996, Preliminary geologic map of the Silverton 7.5-minute quadrangle, San Juan County, Colorado: U.S. Geological Survey Open-File Report 96–275, 15 p., 1 pl.

U.S. Geological Survey, 1996, Water resources data for Colorado, Water Year 1996, Volume 2—Colorado River Basin: U.S. Geological Survey Water-Data Report CO–96–2, 551 p.

Varnes, D.J., 1963, Geology and ore deposits of the south Silverton mining area, San Juan County, Colorado: U.S. Geological Survey Professional Paper 378–A, 53 p., 7 pl.

Wright, W.G., and Janik, C.J., 1995, Naturally occurring and mining-affected dissolved metals in two subbasins of the Upper Animas River Basin, southwestern Colorado: U.S. Geological Survey Fact Sheet FS–243–95, 4 p.

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