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

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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 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). The CWQCC delayed implementation of this water-quality standard until further information was collected and a plan for the cleanup of abandoned mines was developed. Dissolved-zinc concentrations in this section of the river ranged from about 270 µg/L during high flow, when rainfall and snowmelt runoff dilute 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).

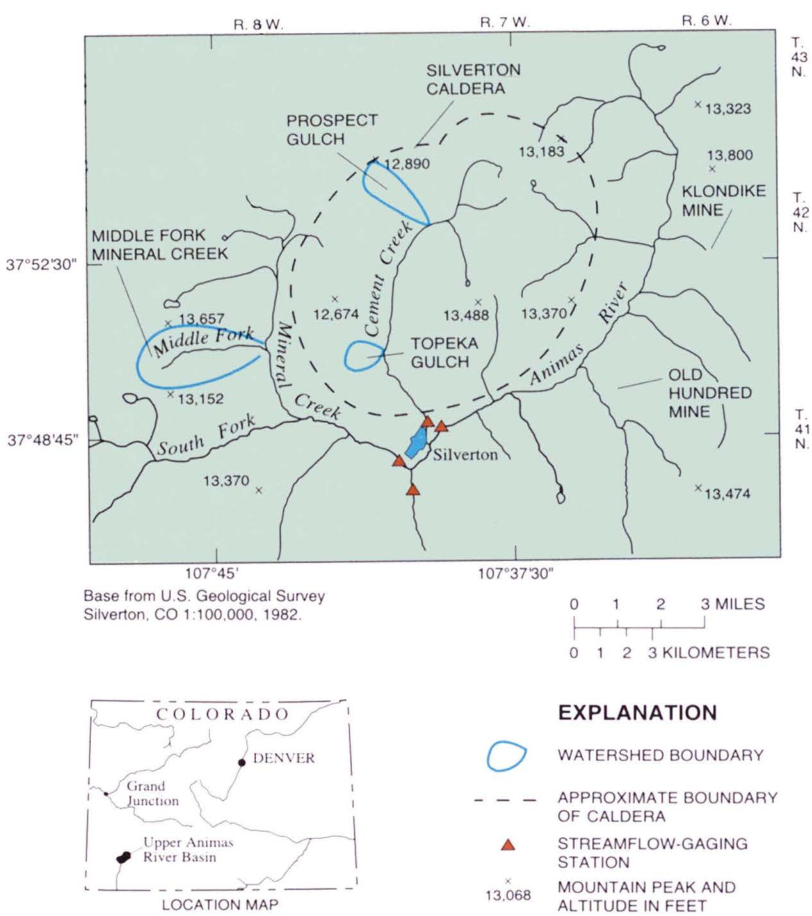

Figure 1. Location of the Silverton Caldera and locations of study sites in the Upper Animas River Basin.

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. For local governments, mining sites represent part of the 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).

In the context of this fact sheet, the term "natural sources of dissolved minerals" refers to springs and streams where no effects from mining were determined. "Mining-related sources of dissolved minerals" are assumed to be: (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.

This fact sheet presents results of studies done by the USGS in collaboration with the Animas River Stakeholders Group and was prepared in cooperation with the Southwestern Colorado Water Conservation District. The studies were done at selected sites in the Upper Animas River Basin to determine natural and mining-related sources of dissolved minerals and 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 these studies will provide useful information for determining 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 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 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 springs and draining mines in areas of highly altered rocks can have very poor quality (fig. 2). Where the rocks are less altered, water from springs can have fair quality. Water that drains from mines developed in less altered rocks usually is of better quality than the quality of water from mines in highly 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 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 focus the water 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).

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.

Figure 2. Area of highly 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.

Methods for Determining Sources of Dissolved Minerals During Low Flow

As with many mineralized areas, the presence of dissolved minerals in streams in the Upper Animas River Basin has a mining-related component and a natural component. Mineral-rich springs are present throughout the Upper Animas River Basin. Springs that have naturally high dissolved-mineral concentrations outnumber the abandoned mines in the study basins.

During reconnaissance of the Middle Fork Mineral Creek, 73 natural springs and 17 mines and prospect pits were identified. Seven of the mine sites were determined to be draining mines. An example of a natural mineral-rich spring, located in lower Prospect Gulch of the Cement Creek Basin (fig. 1), is shown in figure 4. Mineral deposits from the spring water appear similar to the mineral deposits from the mine drainage (fig. 3).

The procedure used to determine if a sampling site (spring or stream) was affected by mining was to do a reconnaissance of the subbasin and determine if there was a mine located in the same subbasin as the sampling site. A visual assessment of the mine dump pile would help determine the size and extent of the mine (a small mine dump pile usually indicates a mine of small extent; a large mine dump pile usually indicates a mine of large extent). If there was any doubt that a sampling site could be affected by a mine, fractures were mapped in the area to determine whether the fractures could be transporting mining-related water from the mine workings through the ground-water system to the sampling site. If these procedures could not differentiate whether a sampling site was natural or mining related, the sampling site was assumed to be affected by mining.

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

For stream reaches where the effects of mining were so great that differentiating natural from mining-related water was too difficult, the stream was sampled upstream and downstream from the mining-related area, and all dissolved-mineral loads through that reach were categorized as mining affected.

One method for determining sources of natural and of mining-related dissolved minerals is a mass-balance approach in which all 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). Flow was measured by using volumetric techniques or a pygmy meter (Rantz and others, 1982a, 1982b). 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 estimated.

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. Based on the examination of mine maps and a reconnaissance of the area, there is no evidence of mining above or upgradient from the Klondike Mine. Water entering the back of the Old Hundred

Mine is not suspected to be affected by mining, based on an evaluation of the extent of the workings of the Old Hundred Mine. 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 highly 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.

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 differences in pH and dissolved-mineral concentrations between water from highly altered rocks and water from less altered rocks are indicated by data listed in table 1. The pH values of water from natural and mining-related sources in highly 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 less altered rocks ranged from 3.95 to 7.58 (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).

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.

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 using the percentages from the mass-balance loading calculations (table 1). 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. For the Klondike and Old Hundred Mine, concentrations of dissolved zinc entering and leaving the mine study sites are listed in table 2.

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 sulfides 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 compared to natural sources (fig. 5). However, a greater percentage of aluminum, copper, iron, and sulfate in the streams came from natural sources compared to mining-related sources (fig. 5). 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 rainstorms 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.

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

[dd, degrees; mm, minutes; ss, seconds; ddd, degrees; ft^3/s, cubic feet per second; µg/L, micrograms per liter; mg/L, milligrams per liter; <, less than; --, no data]

Site description	Latitude Longitude dd mm ss ddd mm ss	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, highly altered rock	37 51 01 107 41 28	09–02–94	3.77	.03	22,000	7	45,000	480	196
Stream, highly altered rock[1]	37 51 01 107 41 28	09–02–94	3.56	.04	16,000	14	31,000	370	156
Spring, highly altered rock[1]	37 50 55 107 41 24	09–03–94	2.90	.01	16,000	48	13,000	400	995
Spring, iron deposit	37 51 06 107 41 45	09–04–94	4.32	.001	7,100	6	20,000	290	90
Stream, highly altered rock	37 51 06 107 41 45	09–04–94	3.49	.002	5,300	5	670	230	68
Stream, highly altered rock[1]	37 50 50 107 41 13	09–09–94	3.45	.03	6,600	37	3,600	190	379
Mining-related sources									
Mine drainage[1]	37 50 49 107 41 10	09–08–94	6.95	.009	16	5	3,800	770	6
Mine drainage[1]	37 50 50 107 41 13	09–09–94	6.85	.14	7	7	12,000	1,100	42
MIDDLE FORK MINERAL CREEK SUBBASIN									
Natural sources									
Stream, highly altered rock	37 50 24 107 44 56	09–19–95	3.12	.17	45,000	10	22,400	460	250
Stream, highly altered rock[1]	37 50 37 107 44 48	09–20–95	3.39	1.6	43,000	27	58,300	660	260
Spring, less altered rock	37 51 02 107 46 39	09–18–95	5.32	.02	390	<1	<1	61	32
Stream, less altered rock[1]	37 50 52 107 46 17	09–18–95	4.47	.5	590	<1	320	28	<1
Spring, glacial moraine	37 50 15 107 46 16	10–11–95	6.84	.34	20	2	<1	210	36
Spring, less altered rock	37 50 13 107 46 14	10–11–95	5.72	.07	1,700	11	8,960	1,200	120
Spring, less altered rock	37 50 14 107 46 14	10–11–95	5.43	.05	720	9	425	1,000	33
Stream, less altered rock[1]	37 50 28 107 45 58	09–21–95	5.79	2.4	140	4	19	240	68
Spring, less altered rock[1]	37 50 40 107 44 55	09–20–95	5.98	.03	20	2	<1	210	<1
Spring, less altered rock,	37 51 00 107 44 16	09–19–95	6.83	.02	10	1	<1	54	<1
Spring, less altered rock[1]	37 50 50 107 45 32	09–14–95	6.56	.02	10	<1	7	25	<1
Mining-related sources									
Mine drainage, less altered rock[1]	37 50 45 107 45 05	09–18–95	6.36	1.03	<1	3	470	200	39
Spring, less altered rock	37 50 45 107 46 15	09–13–95	3.95	.007	2,210	--	780	90	<1
Mine drainage, Paradise Portal[1]	37 50 33 107 45 50	09–28–95	5.70	.6	8,600	13	67,000	1,200	530
Mine drainage, less altered rock[1]	37 50 52 107 44 07	09–19–95	5.54	.03	160	2	9,350	83	260
Mine drainage, highly altered rock	37 50 40 107 44 22	09–26–95	3.19	.04	4,410	<1	12,600	--	243
Spring below mine, highly altered rock[1]	37 50 42 107 44 15	09–26–95	3.45	.02	7,600	43	2,370	260	380
Mine drainage, highly altered rock	37 50 40 107 44 12	09–26–95	3.14	.06	8,300	<1	10,500	--	4,090
Spring below mine, highly altered rock[1]	37 50 42 107 44 10	09–26–95	3.12	.15	11,000	165	4,660	440	5,178
MINE STUDY SITES									
Klondike Mine, less altered rock, ground water entering back of mine	37 53 46 107 32 28	08–25–95	7.58	.01	9	3	6	150	1,950
Klondike Mine, less altered rock, water leaving mine entrance	37 53 54 107 32 40	08–25–95	6.32	.02	14	6	5	40	2,710
Old Hundred Mine, less altered rock, ground water entering back of mine	37 49 5 107 34 23	08–24–95	6.82	1.05	3	4	5	200	1,180
Old Hundred Mine, less altered rock, water leaving mine entrance	37 49 28 107 35 07	08–24–95	7.35	2.52	8	6	5	210	321

[1]Data from this site were 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 average concentration of dissolved zinc (µg/L)	Mining-related average concentration of dissolved zinc (µg/L)
Topeka Gulch subbasin[1]	September 1994	121	26
Middle Fork Mineral Creek subbasin[1]	September–October 1995	97	196
Old Hundred Mine	August 1995	[2]1,180	[3]321
Klondike Mine	August 1995	[2]1,950	[3]2,710

[1]Load-weighted concentrations for the Topeka Gulch and Middle Fork Mineral Creek subbasins were calculated by dividing the sum of zinc load by the sum of discharge for all footnoted sources identified for each subbasin listed in table 1 and then by multiplying the average subbasin concentration by the percent contributed by natural and mining-related sources.

[2]Actual concentrations in ground water entering the back of the mines.

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

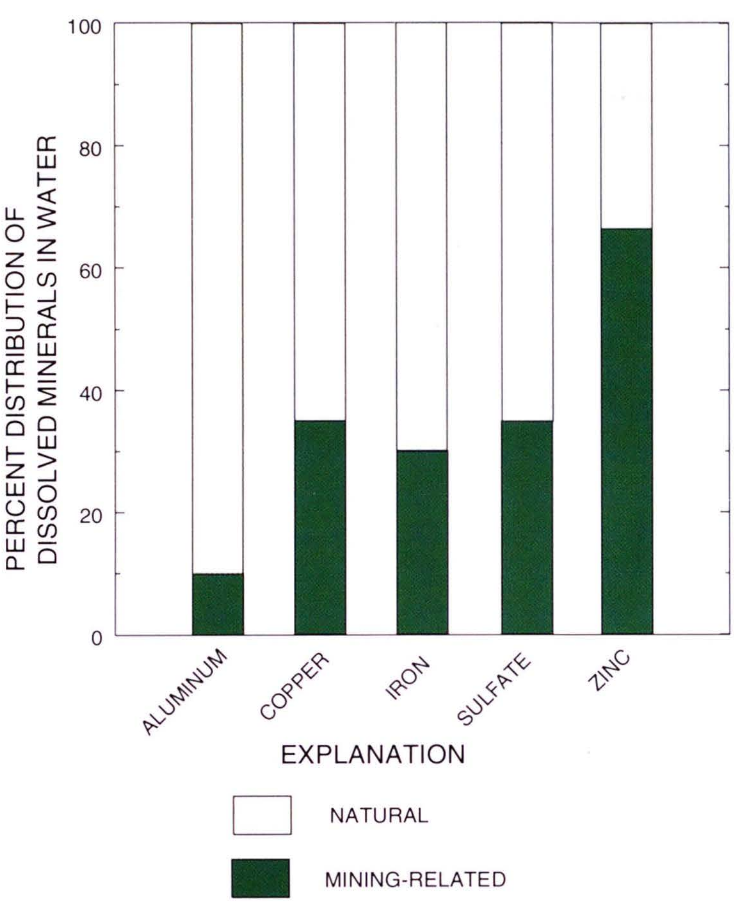

Figure 5. Percent distribution of selected dissolved minerals in the Middle Fork Mineral Creek subbasin during the low-flow period of September–October 1995.

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