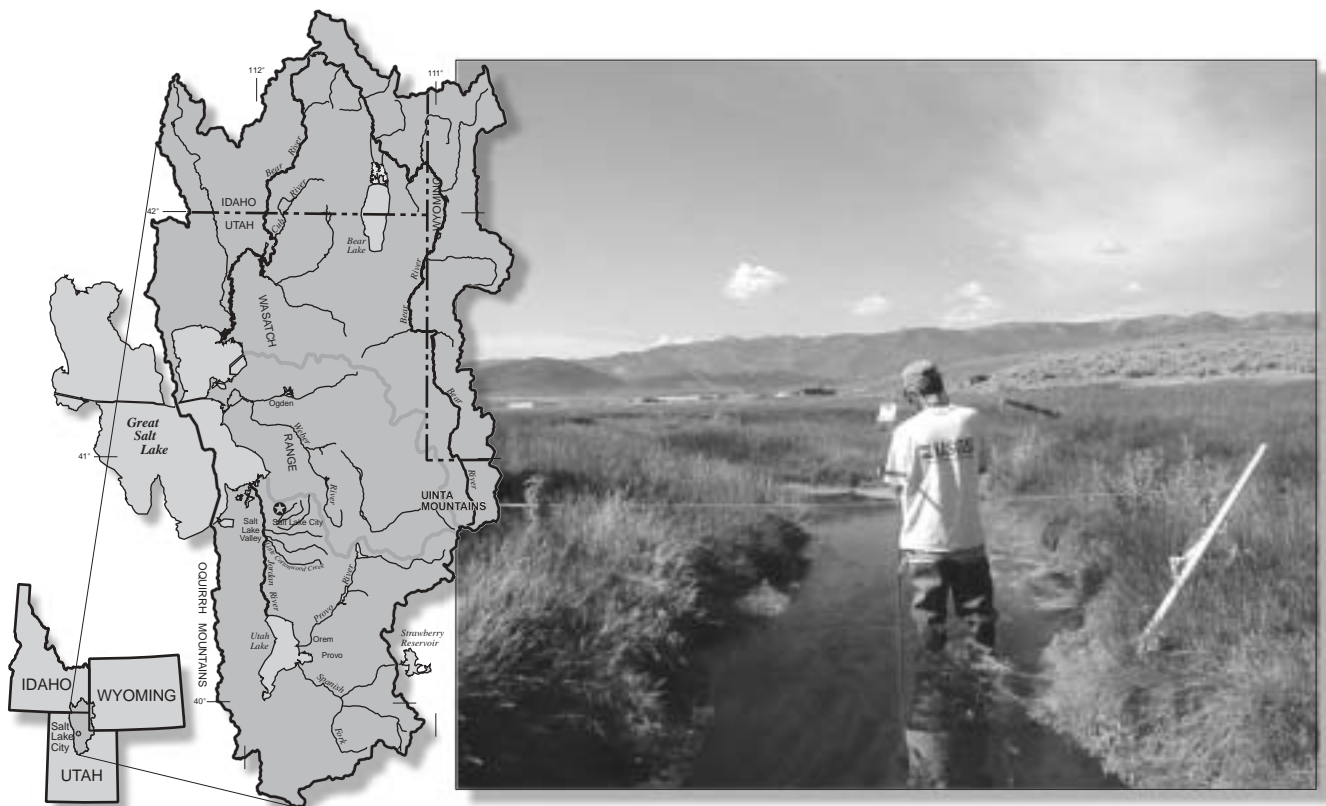


Trace-Metal Concentrations in Sediment and Water and Health of Aquatic Macroinvertebrate Communities of Streams near Park City, Summit County, Utah

Water-Resources Investigations Report 01-4213



**TRACE-METAL CONCENTRATIONS IN SEDIMENT
AND WATER AND HEALTH OF AQUATIC MACROINVERTEBRATE
COMMUNITIES OF STREAMS NEAR PARK CITY, SUMMIT COUNTY,
UTAH**

By Elise M. Giddings, Michelle I. Hornberger, and Heidi K. Hadley

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 01-4213

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM



**Salt Lake City, Utah
2001**

U.S. DEPARTMENT OF THE INTERIOR

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U.S. GEOLOGICAL SURVEY

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FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. (<http://www.usgs.gov/>). Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity *and* quality, even more critical to the long-term sustainability of our communities and ecosystems.

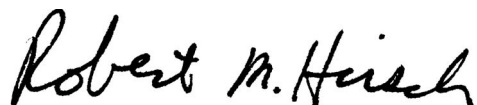
The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. (<http://water.usgs.gov/nawqa>). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. (<http://water.usgs.gov/nawqa/nawqamap.html>). Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings. (<http://water.usgs.gov/nawqa/natsyn.html>).

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.



Associate Director for Water

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
foot	0.3048	meter
ton	907.18	kilogram
cubic foot per second	0.02832	cubic meter per second
mile	1.609	kilometer
inch	2.54	centimeter

Water temperature is reported in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$^{\circ}\text{F} = 1.8(^{\circ}\text{C}) + 32.$$

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Chemical concentration is reported only in metric units. Chemical concentration in surface water is reported in milligrams per liter (mg/L), micrograms per liter (µg/L), or nanograms per liter (ng/L). Milligrams per liter is a unit expressing the solute per unit volume (liter) of water and is about the same as parts per million unless concentrations are greater than 7,000 milligrams per liter. One thousand micrograms per liter is equivalent to 1 milligram per liter. One million nanograms per liter is equivalent to 1 milligram per liter.

Chemical concentration in sediment is reported in micrograms per gram (µg/g), which is equal to parts per million (ppm), or micrograms per kilogram (µg/kg), which is equal to parts per billion (ppb). Specific conductance is reported in microsiemens per centimeter at 25 degrees Celsius (µS/cm).

TRACE-METAL CONCENTRATIONS IN SEDIMENT AND WATER AND HEALTH OF AQUATIC MACROINVERTEBRATE COMMUNITIES OF STREAMS NEAR PARK CITY, SUMMIT COUNTY, UTAH

By Elise M. Giddings, Michelle I. Hornberger, and Heidi K. Hadley

ABSTRACT

The spatial distribution of metals in streambed sediment and surface water of Silver Creek, McLeod Creek, Kimball Creek, Spring Creek, and part of the Weber River, near Park City, Utah, was examined. From the mid-1800s through the 1970s, this region was extensively mined for silver and lead ores. Although some remediation has occurred, residual deposits of tailing wastes remain in place along large sections of Silver Creek. These tailings are the most likely source of metals to this system. Bed sediment samples were collected in 1998, 1999, and 2000 and analyzed using two extraction techniques: a total extraction that completely dissolves all forms of metals in minerals and trace elements associated with the sediment; and a weak-acid extraction that extracts the metals and trace elements that are only weakly adsorbed onto the sediment surface. This latter method is used to determine the more biologically relevant fraction of metal complexed onto the sediment. Water samples were collected in March and August 2000 and were analyzed for total and dissolved trace metals.

Concentrations of silver, cadmium, copper, lead, mercury, and zinc in the streambed sediment of Silver Creek greatly exceeded background concentrations. These metals also exceeded established aquatic life criteria at most sites. In the Weber River, downstream of the confluence with Silver Creek, concentrations of cadmium, lead, zinc, and total mercury in streambed sediment also exceeded aquatic life guidelines, however, concentrations of metals in streambed sediment of McLeod and Kimball Creeks were lower than Silver Creek. Water-column concentrations of zinc, total mercury, and methylmercury in Silver Creek were high relative to unimpacted sites, and

exceeded water quality criteria for the protection of aquatic organisms. Qualitative measurements of the macroinvertebrate community in Silver Creek were compared to the spatial distribution of metals in streambed sediment. The data indicate that impairment related to metal concentration exists in Silver Creek.

INTRODUCTION

The National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) is designed to assess water-quality conditions, determine spatial and temporal trends, and identify the physical, chemical, and biological factors affecting surface and ground waters of the United States (Gilliom and others, 1995). The Great Salt Lake Basins study unit (fig. 1) is 1 of 51 study units that are included in this national program. Each study unit addresses questions that balance local, regional, and national interests, and uses consistent sampling protocols. The NAWQA Program is designed to be interdisciplinary in nature by combining chemical, physical, and biological data to reach specific goals. An important component to this approach is the spatial and temporal distribution of metals and organic contaminants in freshwater aquatic environments, including surface and ground water, streambed sediment, and resident biota. Coordinated sampling efforts, which include a combination of these disciplines, allow for a well-integrated assessment of water-quality conditions.

Mining activities since the mid-1800s have greatly accelerated metal cycling in aquatic systems. Although naturally enriched ore bodies can contribute relatively minor loadings to these systems, anthropogenic activities such as the extraction and processing of metals can introduce highly enriched material to surrounding water bodies (Moore and Luoma, 1990; Axtmann and Luoma, 1991). Although many metals are biologically essential in trace amounts (for example, chromium, copper, and zinc), excessive quantities can

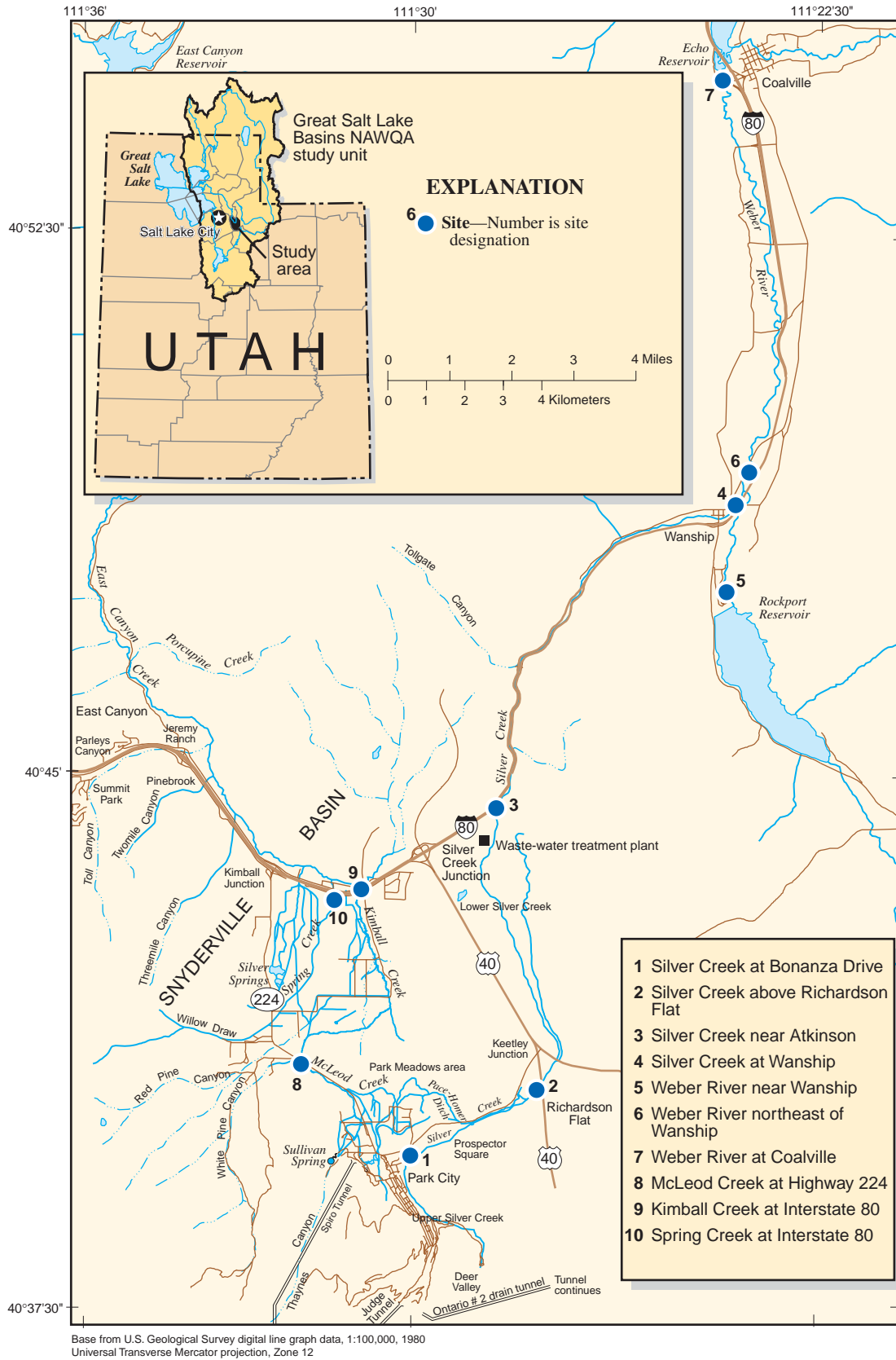


Figure 1. Location of study area and sampling sites in the upper Weber River drainage near Park City, Utah

interfere with physiological processes. Non-essential metals such as cadmium, lead, mercury, and silver also can accumulate in the tissues of aquatic organisms and cause adverse biological impacts in aquatic organisms (Lau and others, 1998).

Historic mining activities in the vicinity of Park City, Utah, have greatly impacted Silver Creek, a tributary to the Weber River in northern Utah. Park City was founded as a mining town in the mid-1800s, when large deposits of lead and silver were discovered in the nearby mountains. For the next 100 years, silver, lead, and other minor minerals were mined and processed in the Park City area. By the late 1970s, mining activities began to decrease as the ski industry surpassed mining in economic importance. Since then, Park City has grown into a recreationally based urban area.

Previous studies identify impacts to Silver Creek from historic mining activities (Mason, 1989), raw sewage discharge (Smith, 1959), and potential urban growth impacts (Brooks and others, 1998). The ground- and surface-water hydrology of the area are described by Holmes and others (1986), and Brooks and others (1998). Adjacent watersheds of McLeod Creek, Kimball Creek, and Spring Creek have also been affected by mining and urban activities, although the relative impacts are not well defined. These creeks are tributaries of the Weber River, an important river for recreation and water supply.

Purpose and Scope

The Weber River at Coalville was sampled in 1998 as part of a study-unit wide assessment of metals in bed sediment and tissue. Concentrations of some metals were higher in sediments from this site than other sites sampled in the study unit. The upstream drainage of Silver Creek was suspected as a source because of the known historic mining in the area. Further sediment sampling in 1999 on the Weber River and Silver Creek was conducted by using a multi-acid digestion that extracts all forms of metals in minerals and trace elements associated with the sediment. Results from that sampling indicated substantial streambed sediment contamination in Silver Creek, and a synoptic study was undertaken in 2000, which used a second method of analysis to further assess the degree of risk to biological organisms.

In 2000, a synoptic approach was employed to examine the occurrence and spatial distribution of metals in bed sediment and surface water of streams near the Park City area. Included were sites on Silver Creek,

McLeod Creek, Kimball Creek, and part of the Weber River. Streambed sediment samples were collected and this time analyzed by using a weak-acid digestion, which extracts the metals and trace elements that are more loosely bound to the sediment surface and thus have a higher potential to be bioavailable to aquatic organisms. Surface-water samples were collected during spring and summer low-flow periods to assess the distribution of metals during two seasons. Mercury, which appeared to be a metal of concern, was analyzed by using low-level detection limits at a subset of sites. Metal concentrations were evaluated by comparing with established toxicity guidelines for aquatic life. In addition, bioassessment samples of the aquatic macroinvertebrate community were collected to examine potential impairment.

Description of Study Area

Park City, Utah, is situated at an altitude of about 6,100 feet about 30 miles southeast of Salt Lake City, and the surrounding Wasatch Mountains rise to more than 10,000 feet (fig. 1). Average annual precipitation (1961-90) ranges from 19 to 44 inches, of which approximately 75 percent occurs as snow from October to April. Extending north from Park City through Snyderville Basin is a low topographic divide. Streams on the west side of the divide drain into East Canyon Creek and then to the lower Weber River, near Morgan, Utah. On the east side of the divide, Silver Creek drains into the upper Weber River near Wanship, Utah.

On the west side of the low divide, McLeod Creek originates at the mouth of Thaynes Canyon and collects water from Sullivan Spring, the Spiro Tunnel, and White Pine Canyon as it flows north to join Kimball Creek. Kimball and Spring Creeks arise from ground-water seeps and springs in the unconsolidated valley-fill deposits of Snyderville Basin and flow north toward East Canyon Creek.

Silver Creek, on the east side of the divide, originates as snowmelt runoff from mountains to the south of Park City; however, much of the runoff in the upper drainage seeps into the subsurface prior to reaching the stream channel (Brooks and others, 1998). Additional ground water is diverted into upper Silver Creek from the Judge mine-drain tunnel during part of the year, and flow increases downstream as a result of inputs from the Pace-Homer Ditch, a repository for ground-water discharge and surface runoff from surrounding land-use operations.

Land Use

Mining in the Park City district began in 1869 for lead, silver, and zinc ore and continued until 1978. Galena (lead sulfide) and sphalerite (zinc sulfide) are the principal ores of the Park City district. Both of these ores are found near igneous intrusions in the bedrock of the district. Silver is often found in association with pyrite and galena (Boutwell, 1912).

The Silver King mine, located near the headwaters of Silver Creek, was one of the largest and longest operating mines in the area (fig. 2). Throughout the mining era, ground-water flooding of the mines was a continuous problem, and it was not uncommon for ore veins to be abandoned because of flooding. To relieve some of the great underground flow, tunnels were specifically dug to dewater the Ontario, Silver King, and Daly-Judge mines, but costly pumping of ground water from the mine was still necessary (Thompson and Fraser, 1993).

Water from the mining tunnels has been reclaimed for other uses. Beginning in the late 19th century, water from the Ontario tunnel was collected and

used to generate electricity for Park City and the Ontario mill. Water from the Judge tunnel was used both for domestic supply and at the Silver King plant since 1904 (Boutwell, 1912). Currently, ground water from the Spiro and Judge tunnels is used as a public water supply for Park City (Jerry Gibbs, Park City Public Works, oral commun., 2001).

The hundred-plus years of mining have affected the water in the Park City area in many ways. Wood was the primary building and fuel source (Thompson and Fraser, 1993), and the resulting deforestation caused sediment to easily move into the streams. Raw sewage from the growing mining town of Park City was disposed of in Silver Creek until passage of the Clean Water Act in 1972 (Smith, 1959). Milling processes in the Park City area left waste-rock and tailings piles, which have eroded and leached metals into the streams. Mercury, which was used for a short time in processing the ore, has also contaminated land in the study area (Boutwell, 1912).

Tailings piles still exist in many areas of the Silver Creek drainage (fig. 3). A large pile adjacent to Sil-



Figure 2. Silver King mine and tailings piles near Park City, Utah.

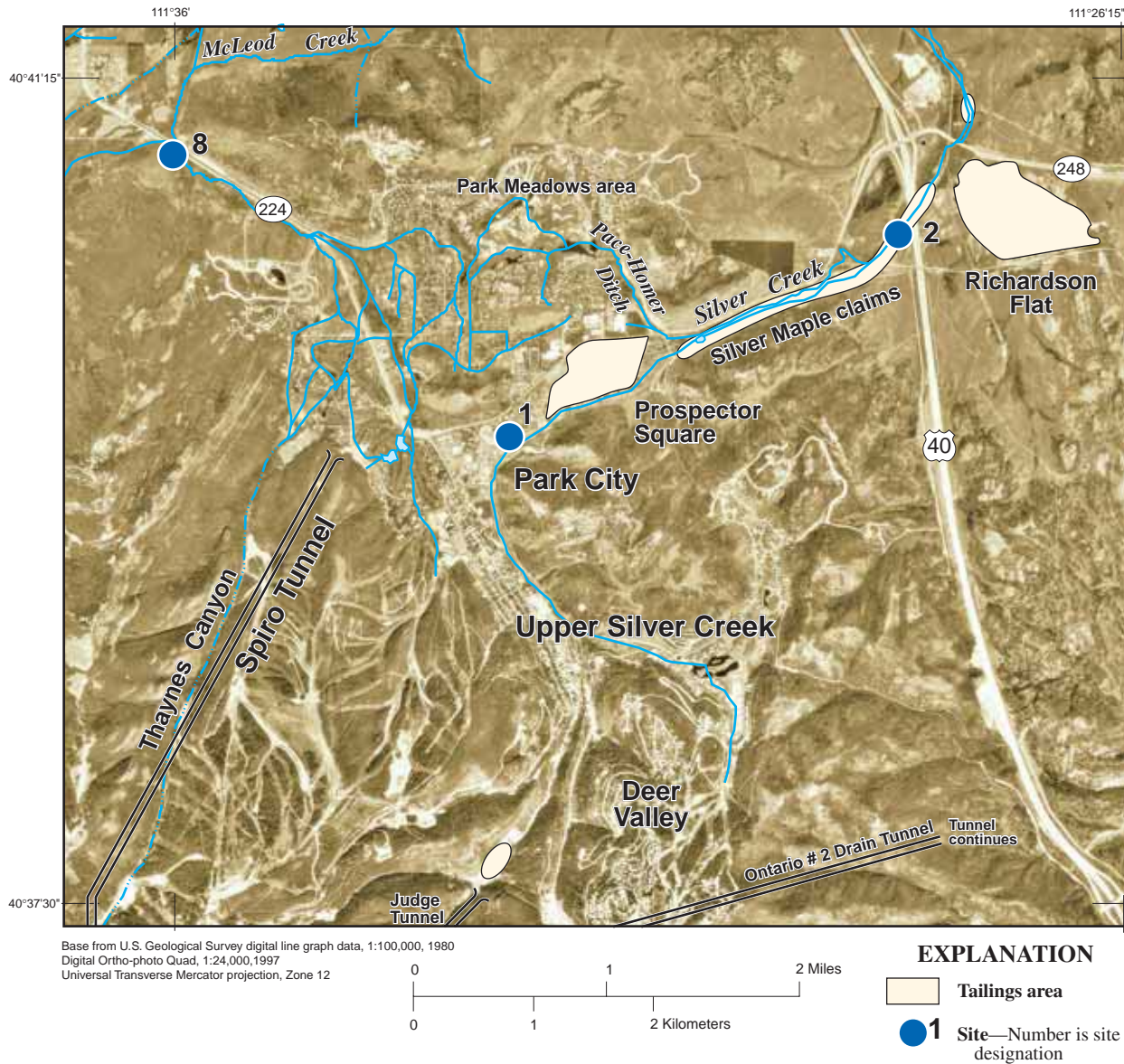


Figure 3. Location of tailings piles in the upper Silver Creek study area near Park City, Utah.

ver Creek (Prospector Square) was capped as a mitigation measure to cease or slow the leaching of metals into the creek and to allow real estate development. However, uncapped tailings still exist along the south side of Silver Creek (the Silver Maple claims) where it parallels U.S. Highway 248.

In the late 20th century, real estate development occurred on a large scale. Erosion of sediment associated with construction is one of the largest impacts from the rapid growth of the Park City area. Many of the res-

idential developments are on the sites of older tailings piles. As the Park City area continues to grow, water-quality impacts resulting from urban runoff and increased water withdrawals are likely to increase.

Selected Stream Sites

Ten sites in the Park City area were sampled for streambed sediment, surface water, and biota in 1998-2000 (table 1, fig. 1). Not all types of samples were collected at each site, but the largest data set exists for eight sites sampled in 2000 (table 2). Four of the sites

Table 1. Location and altitude of study sites near Park City, Utah

Site no.	Site name	Station number	Latitude	Longitude	Altitude (feet)
1	Silver Creek at Bonanza Drive	403938111300201	403938	1113002	6,815
2	Silver Creek above Richardson Flat	404026111273001	404026	1112730	6,632
3	Silver Creek near Atkinson	404431111282901	404431	1112829	6,441
4	Silver Creek at Wanship	404847111240501	404847	1112405	5,832
5	Weber River near Wanship	10129500	404734	1112415	5,890
6	Weber River northeast of Wanship	404925111234900	404925	1112349	5,800
7	Weber River at Coalville	10130500	405343	1112404	5,600
8	McLeod Creek at Hwy 224	404055111320301	404055	1113203	6,633
9	Kimball Creek at Interstate-80	404318111310401	404318	1113104	6,370
10	Spring Creek at Interstate-80	404318111313401	404318	1113134	6,375

sampled in 2000 are on Silver Creek, one site is on the Weber River, and three sites are on other drainages in the Park City area. Two additional sites were sampled on the Weber River in 1999. One site on the Weber River was sampled both in 1998 and 2000.

Silver Creek at Bonanza Drive (site 1) is the farthest upstream site sampled on Silver Creek (fig. 1, table 1). This site is located near the center of Park City in a commercial area, and the creek above this point receives storm-water runoff from the older urban area of Park City. Most of the historic mining activities took place upstream of this site, in the mountains surrounding Park City.

Silver Creek above Richardson Flat (site 2) is about 2 miles downstream from site 1. In the reach between sites 1 and 2, Silver Creek flows past Prospector Square, a mine-tailings deposit. This deposit was reworked to extract additional silver in the 1940s, and most of the tailings were capped with 6 to 10 inches of soil, prior to being developed into a residential area (Mason, 1989). After flowing through Prospector Square, Silver Creek enters a short, narrow canyon. The south side of this canyon is lined with uncovered, fine-grained mill tailings (Silver Maple claims). Site 2 is located at the base of this canyon.

Silver Creek near Atkinson (site 3) is about 3.5 miles downstream from site 2. In the reach between sites 2 and 3, Silver Creek flows past another large tailings area (Richardson Flat) and enters an open, shallow-gradient meadow. About 0.5 mile upstream of site 3, water is discharged from a waste-water treatment plant.

Downstream from site 3, Silver Creek flows through a relatively high-gradient canyon for about 5 miles to the final site on Silver Creek, Silver Creek at

Wanship (site 4), before it discharges into the Weber River. Land use upstream from this site consists of grazing and irrigated hay-lands, with some residential development in the town of Wanship.

Silver Creek enters the Weber River about 2 miles downstream from Rockport Reservoir. Site 5 (Weber River near Wanship) is between Rockport Reservoir and the confluence of Silver Creek. Because most sediment that enters the Weber River upstream of the reservoir is trapped, site 5 serves as a reference site for evaluating the effects of Silver Creek on the downstream reach of the Weber River. Two downstream sites on the Weber River (sites 6 and 7) can be compared with site 5. Site 6 (Weber River northeast of Wanship) is about 0.5 mile downstream of the Silver Creek confluence and site 7 (Weber River at Coalville) is about 8 miles downstream. The flow of the Weber River is about two orders of magnitude greater than that of Silver Creek. At the time of sampling in August 2000, the discharge of the Weber River was 170 cubic feet per second, and that of Silver Creek was 2 cubic feet per second. So, inflows from Silver Creek are subjected to considerable dilution in the downstream reaches of the Weber River.

Historic mining activities took place in the upper drainage of East Canyon Creek, but large tailings deposits did not remain. A limited evaluation using selected tributaries was made at sites 8, 9, and 10 on McLeod, Kimball, and Spring Creeks, respectively.

Table 2. Types and dates of samples collected at selected sites near Park City, Utah

Site no.	Site name	Water				Sediment			Biota
		Trace metals, dissolved	Trace metals, whole water	Mercury	Stable isotopes	Trace metals, total	Trace metals, weak-acid	Mercury	Macro-invertebrates
1	Silver Creek at Bonanza Drive	03/10/00 08/16/00	08/16/00	07/13/00	08/15/00 08/16/00		07/13/00	07/13/00	
2	Silver Creek above Richardson Flat					07/22/99			
		03/14/00 04/24/00 05/16/00 06/12/00							
3	Silver Creek near Atkinson	08/16/00	08/16/00	07/13/00	08/16/00		07/13/00	07/13/00	08/16/00
		03/10/00 08/16/00			08/16/00		07/13/00	07/13/00	08/16/00
4	Silver Creek at Wanship					07/22/99			
		03/13/00 08/21/00					07/14/00		08/17/00
5	Weber River near Wanship					07/22/99			
		08/14/00			08/14/00				
6	Weber River northeast of Wanship					07/22/99			
7	Weber River at Coalville			10/30/98		09/08/98		10/30/98	
		03/21/00 08/23/00			08/23/00		07/14/00		
8	McLeod Creek at Hwy 224	03/10/00 08/21/00	08/23/00 08/21/00		08/21/00		07/13/00		08/22/00
9	Kimball Creek at Interstate-80						07/14/00		08/14/00
10	Spring Creek at Interstate-80	03/11/00 08/08/00			08/08/00				

METHODS OF SAMPLE COLLECTION AND ANALYSIS

Streambed Sediment

In the summer of 1999, two sites (sites 2 and 4) were sampled in Silver Creek, and two sites (sites 5 and 6) were sampled along the Weber River (table 2). These samples were analyzed for 42 total recoverable metals by using a multi-acid digestion (Briggs and Meier, 1999). This method provides a total extraction of metals, including silicate-bound metals, and is the method that was used at the Weber River at Coalville (site 7) in 1998. The top inch of sediments was composited from five depositional areas of the stream, according to the methods of Shelton and Capel (1994). Composite samples were wet-sieved with ambient stream water by using 63- μm nylon mesh sieves. Reported values represent the analysis of the fine-grained (<63 μm), composited material.

In July 2000, sediment samples were collected from four sites on Silver Creek, one site on the Weber River, and one site each on Kimball and McLeod Creeks (table 2). These samples were analyzed for partially extractable metals by using a 5-percent (0.6N) hydrochloric acid digestion (Hornberger and others, 1999). Metals analyzed with this procedure (weak-acid extraction) included silver, cadmium, chromium, copper, iron, manganese, nickel, lead, and zinc. This method extracts the most easily mobilized metal from the sediment surface, which has the potential for exposure to and uptake by resident biota. Metals extracted with this method have been shown to correspond to bioaccumulation in resident aquatic organisms (Luoma and others, 1995). At each site, three separate samples were collected from the surface of three depositional areas by using methods described in Dodge and others (2000). Samples were wet-sieved to 63 μm with ambient river water. The three samples were analyzed individually, and reported values represent the mean and standard deviation of the individual replicates.

Because trace elements are disproportionately associated with different particle sizes, the particle-size distribution of a bulk sample can greatly influence metal concentrations of that sample (Salomons and Forstner, 1984). Sieving bed-sediment samples to a common size class of particles allows comparisons of metal concentrations to be standardized among sites and reduces potential biases that could distort interpretations of the spatial distribution in metal concentration. The interpretation of sieved sediment is also more bio-

logically relevant because fine particles are often trapped within the matrix of periphyton and filamentous algae, part of the microhabitat of many insect species. Fine-grained sediment concentrations have correlated significantly to metal concentrations in benthic insects and are a useful indicator of the metal exposure to the biota (Cain and others, 1992).

In October 1998 or July 2000, sediments at sites 1, 2, and 3 on Silver Creek and site 7 on the Weber River were collected for mercury analysis (table 2). A composite sample of surficial sediments from three depositional areas of the stream was sieved to 63 μm and analyzed for total mercury and methylmercury. Laboratory methods for total mercury followed U.S. Environmental Protection Agency (EPA) method 1631: Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluorescence Spectrometry (CVAFS). Sediment samples were digested with nitric and sulfuric acid, and oxidized with bromium chloride, then analyzed according to method 1631. Laboratory methods for methylmercury followed EPA draft method 1630: Methyl Mercury in Water by Distillation, Aqueous Ethylation, Purge and Trap, and CVAFS, with minor modifications. Sediment samples for methylmercury were digested with a mixture of potassium chloride, sulfuric acid, and copper sulfate before being analyzed with method 1630. Field and laboratory methods are described in Olson and DeWild (1999).

To assess the biological relevance of the sediment data, the weak-acid extraction sediment concentrations were compared to sediment screening values used by the National Oceanic and Atmospheric Administration (NOAA), as reported in Buchman (1999). Although these screening values identify contaminants that pose a threat to aquatic organisms in a freshwater system, they do not represent official policy or clean-up levels. For sediments, multiple screening values are available, and each metal may not have the same type of screening value. In this report, the authors primarily use the Threshold Effects Levels (TEL) and Probable Effects Levels (PEL) when available. These criteria are based on field data that develop associations between chemical concentrations and biological effects, as well as laboratory toxicity test results (Smith and others, 1996). The TEL is a conservative screening value, below which concentrations of contaminants have not been shown to cause an effect on aquatic organisms. The PEL is a screening value above which toxic effects are likely to occur, and compounds that exceed it are more probably elevated to toxic levels.

In the case of silver, TEL and PEL values are not available. Instead, the authors use two screening values. The Effects Range-Median (ERM) is the median concentration of sediments reported to have toxic effects (Long and Morgan, 1991). Like the PEL, it is a screening value above which toxic effects are likely to occur. The Upper Effects Threshold (UET) is determined by relating chemical concentrations in sediments to biological impacts and represents a screening value above which adverse effects would always be expected by the biological indicator used in its development. These screening values provide tools to assess which metals exceed established aquatic life criteria at the sampled sites.

Surface Water

Water samples were collected in March and August 2000 from seven sites in the Park City area and analyzed for dissolved and total trace elements (table 2). During each of these periods, a synoptic approach to sampling was taken, in which the sites were sampled in a short period of time. By minimizing the period of time to sample the sites, an assessment can be made of the spatial distribution of metals and other water-quality parameters in the water column. The two periods selected represent the low flow condition before and after spring runoff.

Four of the sampled sites are located on Silver Creek (sites 1-4), one is located on the Weber River, downstream from the confluence of Silver Creek (site 7), and one site each is on McLeod Creek (site 8) and Spring Creek (site 10) (fig. 1). Methods of collection followed NAWQA Program guidelines for sampling water using parts per billion (ppb) detection limits (Shelton, 1994). Water samples were analyzed for 22 dissolved trace elements, 21 total trace elements, and isotopes of oxygen, deuterium, and sulfur at the USGS National Water Quality Laboratory, Denver, Colorado. Water from three sites was also analyzed for unfiltered (total) and methylmercury in August 2000, and one site was analyzed in October 1998. Mercury samples were analyzed by using EPA method 1631: Mercury in Water by Oxidation, Purge and Trap, and CVAFS, and EPA draft method 1630: Methyl Mercury in Water by Distillation, Aqueous Ethylation, Purge and Trap, and CVAFS, as detailed in Olson and DeWild (1999).

Metal concentrations in surface water were compared with EPA Ambient Water Quality Criteria (AWQC) for aquatic organisms. These criteria are rules developed to provide protection for aquatic organisms and are used by the States to develop water-quality stan-

dards (U.S. Environmental Protection Agency, 1999). Concentrations that exceed the AWQC could be in violation of State water-quality standards and pose a threat to the health of aquatic organisms.

Aquatic Macroinvertebrate Communities

Qualitative macroinvertebrate samples were collected from sites 2, 3, and 4 in Silver Creek and sites 8 and 9 on McLeod and Kimball Creeks (respectively) in August 2000 (table 2). Methods followed standard NAWQA protocols reported in Cuffney and others (1993). The objective of the sampling was to obtain as complete a list of invertebrate taxa in a sampling reach as possible by sampling multiple habitat types. A D-frame kick net with a 210- μ m mesh was used to collect the samples. Taxonomic identification was conducted by the USGS National Water Quality Laboratory Biological Unit. Taxa were identified to the lowest taxa group possible but were not enumerated.

Several invertebrate metrics were calculated to assess the relative health of the stream sites. Taxa richness, or the number of distinct taxa collected, is a common measure representing the diversity of a macroinvertebrate sample. Increasing diversity correlates with increasing health of the assemblage and indicates that niche space, habitat, and food source, as well as water quality, are adequate to support survival and propagation of many species (Barbour and others, 1999). A second common richness metric is the percentage of distinct taxa belonging to the orders of Ephemeroptera, Plecoptera, and Trichoptera (% EPT). These aquatic insect orders are sensitive to perturbation and generally decline in relative importance as health of the assemblage declines (Barbour and others, 1999). The third metric calculated was the percentage of intolerant taxa. Tolerance values are generally non-specific to the type of stressor but represent general sensitivity of an organism to perturbation. Each taxa is classified on a scale from 0 to 10, zero representing an extremely sensitive organism, and ten representing an organism tolerant to many types of perturbation. Tolerance values used here were developed in Idaho and are listed by Barbour and others (1999). Intolerant taxa for this report are considered to be those taxa with tolerance values of 3 or less.

To compare macroinvertebrate metrics to metals concentrations at the selected sites, a metals index was calculated. Concentrations (μ g/g) of weak-acid extracted silver, cadmium, copper, manganese, lead, and zinc in sediments were standardized for the selected sites on a scale from 0 to 10 as follows:

$$\text{index} = \sum_{i=1}^N (X_i/X_{i\max})^{10} \quad (1)$$

where:

- N = number of metals in the index,
 X_i = concentration of one of the N metals at a site,
 $X_{i\max}$ = maximum concentration of the metal observed at all sites.

Because the index number represents the relative concentration of these six metals at the five selected sites, the site with the highest concentrations of these metals has the highest index number.

TRACE-METAL CONCENTRATION IN STREAMBED SEDIMENT

Spatial Distribution of Streambed Sediment Concentrations

Sediment samples collected in 1999 (total extraction) and 2000 (weak-acid extraction) from Silver Creek and the adjacent drainages were examined for trends in concentration from upstream to downstream sites (appendixes A and B). In general, metal concentrations from the weak-acid extraction at site 1 (Silver Creek at Bonanza Drive) were approximately half that of sites 2 and 3 (fig. 4). Concentrations of silver at this site were highly variable ($1.5 \mu\text{g/g} \pm 1.7$), but other metals, such as cadmium ($20.3 \mu\text{g/g} \pm 0.9$), copper ($112 \mu\text{g/g} \pm 21$), lead ($922 \mu\text{g/g} \pm 176$), and zinc ($2,893 \mu\text{g/g} \pm 121$), did not exhibit such high variability.

Sites 2 and 3 (Silver Creek above Richardson Flat and Silver Creek at Atkinson), in the middle reach of Silver Creek, had similar concentrations of cadmium (40 and $36 \mu\text{g/g}$, respectively), copper (447 and $509 \mu\text{g/g}$, respectively), lead (6,832 and $6,915 \mu\text{g/g}$, respectively), and zinc (6,198 and $6,714 \mu\text{g/g}$, respectively). Variability among replicate measures for these metals was less than 36 percent (fig. 4). However, there is a high degree of variability in replicate measures of silver concentrations at both site 2 ($6.8 \mu\text{g/g} \pm 6.6$) and site 3 ($16.7 \mu\text{g/g} \pm 10.9$). The spatial heterogeneity of silver within a site indicates that the sediment is strongly influenced by localized inputs from mine tailings.

Concentrations of metals at site 4 displayed one of two patterns: 1) a sharp decrease in concentration, relative to the upstream sites, as shown with silver and copper, or 2) very little change from concentrations measured in the upstream reach, as shown for cadmium, lead, and zinc (fig. 4). The disparity in these

trends indicates that the spatial pattern is metal specific, controlled by geochemical and/or physical processes.

Metal concentrations at the Weber River at Coalville (site 7) were typically lower than those at the Silver Creek sites, indicating that the sediments are diluted by cleaner sediments. Concentrations were: cadmium ($6.4 \mu\text{g/g} \pm 0.7$), lead ($739 \mu\text{g/g} \pm 70$), and zinc ($1,724 \mu\text{g/g} \pm 156$). Concentrations of cadmium, copper, lead, silver, and zinc were all lower at McLeod Creek (site 8) than at the Weber River at Coalville (site 7), and concentrations of cadmium, copper, lead, and zinc were lower at Kimball Creek (site 9) than McLeod Creek.

As expected, concentrations of metals from the total extraction were consistently higher than concentrations from the weak-acid extraction (appendixes A and B). As with the weak-acid extraction, sediment analyzed in 1999 with the total extraction had the highest concentrations at site 2, near the headwaters (Silver Creek above Richardson Flat), and lower concentrations at site 4 (Silver Creek at Wanship) (fig. 4). Concentrations (total extraction) of arsenic, cadmium, copper, lead, manganese, mercury, selenium, silver, and zinc at site 2 are substantially elevated relative to concentrations at site 5, the reference site. However, metal concentrations at site 4 (Silver Creek at Wanship) were typically 50 to 75 percent lower than values measured at site 2 (Silver Creek above Richardson Flat) (fig. 4).

Three sites in the Weber River were analyzed by using the total extraction (table 2, appendix B). The Weber River near Wanship (site 5) is about 1.5 miles upstream of the confluence of Silver Creek. This site is not impacted by historic mining activities and concentrations of silver, arsenic, cadmium, copper, mercury, lead, and zinc are close to background concentrations reported by Buchman (1999). These background concentrations are compiled from a variety of sources but primarily are from the International Joint Commission (1988). At the Weber River northeast of Wanship (site 6) and Weber River at Coalville (site 7), concentrations of most metals are substantially higher than those reported for the Weber River near Wanship.

Relation Between Enrichment and Source

For those elements that are enriched above background levels, the concentration generally increases from site 1 (Silver Creek at Bonanza Drive) to site 2 (Silver Creek above Richardson Flat) and remains similar downstream to site 3 (Silver Creek at Atkinson). Because of the close proximity between tailing sources and the flow path of Silver Creek, inputs from the tail-

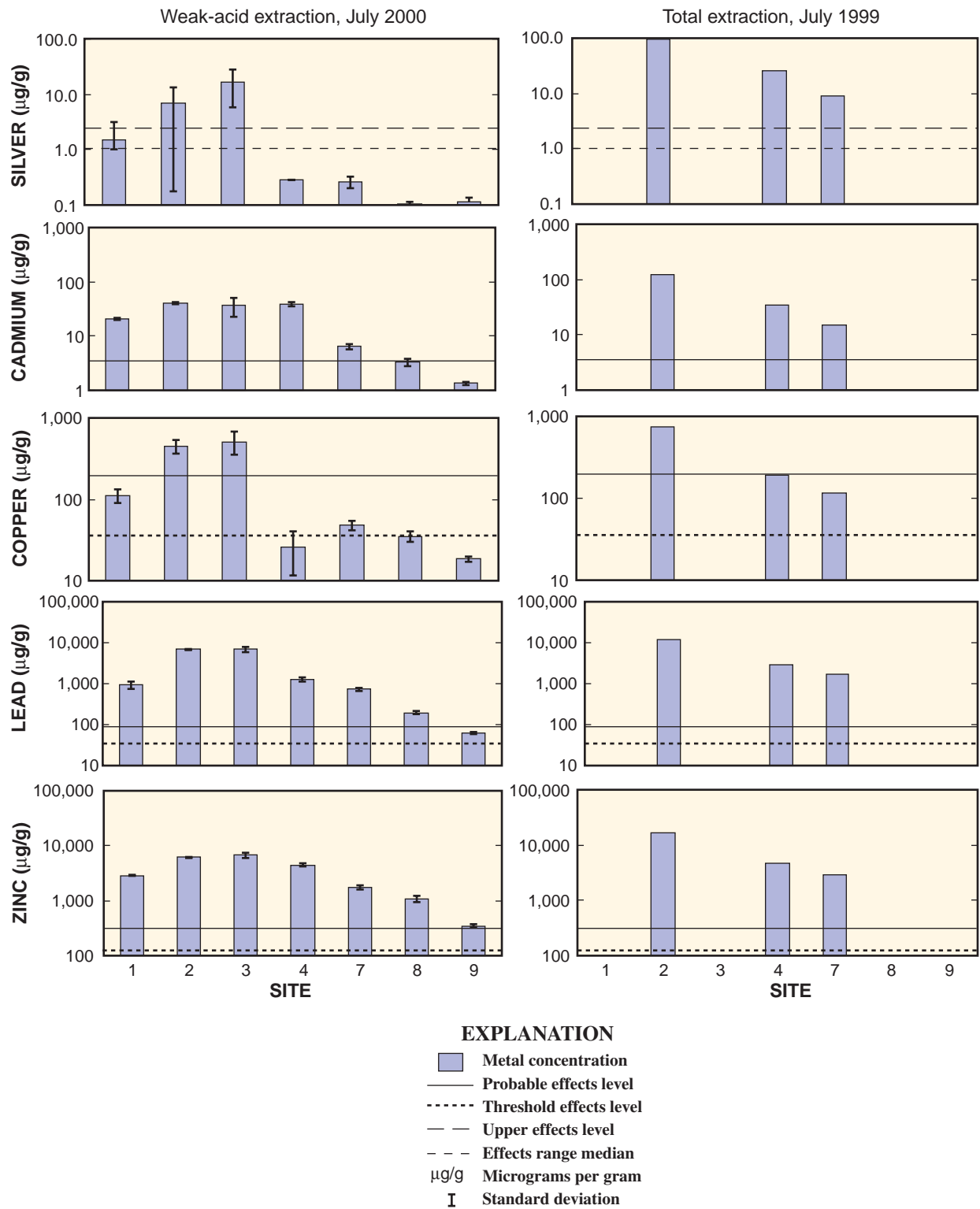


Figure 4. Concentration of selected metals in streambed sediments obtained by using two extraction methods for selected sites near Park City, Utah, 1999-2000.

ing deposits are the most likely source of metals to this reach. Although the Prospector Square tailings, between sites 1 and 2, have been treated and capped, some of the enriched riverbank deposits may have been mobilized by natural stream processes (such as slumping and scouring). Additionally, mill tailings at the Silver Maple claims have never been treated and remained fully exposed as late as 1990. This would provide a direct source from the contaminated floodplain and banks into the stream channel. Richardson Flat tailings deposits, between sites 2 and 3, were not treated but were capped in the late 1980s. With distance downstream from the sources, the concentration of metals in Silver Creek and the Weber River is diluted by uncontaminated sediments. However, the ratio of total metal concentrations for arsenic, cadmium, lead, and zinc is similar at the two sites on Silver Creek (sites 2 and 4) and the two sites on the Weber River below Silver Creek (sites 6 and 7), but differs for the site on the Weber River above Silver Creek (site 5) (fig. 5). This indicates a common source of metals to sites 2, 4, 6, and 7.

McLeod and Kimball Creeks drain out of the Park City area and also have many abandoned mine sites in their headwaters. However, unlike Silver Creek, they do not flow past large tailings deposits. Although somewhat elevated, weak-extractable metal concentrations in sediments at these sites were considerably lower than those at the sites in the Silver Creek Drainage (fig. 4).

Enrichment Relative to Aquatic Life Criteria

The metal concentrations obtained from the weak-acid extraction can be useful for comparison to aquatic threshold guidelines because they represent the concentration of metals potentially available for uptake by aquatic organisms. Weak-acid extraction metal concentrations in Silver Creek exceeded established threshold guidelines (Long and Morgan, 1991; Long and others, 1995; Buchman, 1999) for silver, cadmium, copper, manganese, lead, and zinc (fig. 4). The Weber River at Coalville, as well as McLeod and Kimball Creeks, showed exceedences for at least some of these

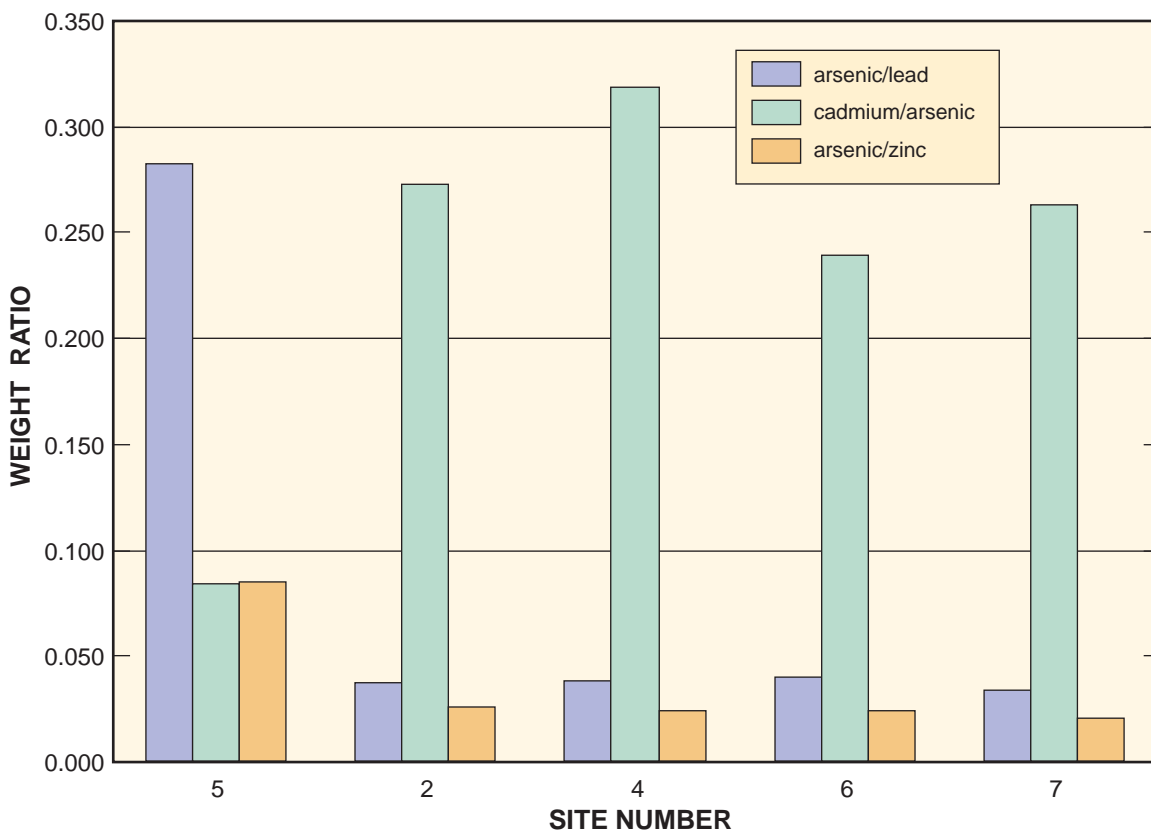


Figure 5. Weight ratios of arsenic/lead (As/Pb), cadmium/arsenic (Cd/As), and arsenic/zinc (As/Zn) in streambed sediments for selected sites near Park City, Utah, 1999. All data used were total extraction concentrations.

metals. All metal concentrations in Silver Creek show substantial enrichment relative to McLeod and Kimball Creeks (fig. 4).

Silver concentrations in bed sediment exceed either the Upper Effects Threshold (UET) of 4.5 $\mu\text{g/g}$ (Buchman, 1999) or the Effects Range Median (ERM) of 1.0 $\mu\text{g/g}$ (Long and others, 1995) at three sites in Silver Creek. Silver concentrations at site 1 (Silver Creek at Bonanza Drive) exceed the ERM, with a value of 1.5 $\mu\text{g/g}$, but fall below the UET. Concentrations at sites 2 and 3 (6.8 $\mu\text{g/g}$ and 16.7 $\mu\text{g/g}$ respectively) exceed both the ERM, by a factor of 6 to 16 fold, and the UET, by a factor of 1.5 to 4 fold (fig. 4 and appendix A). All other sites sampled do not exceed the sediment quality guidelines and range from 0.1 to 0.3 $\mu\text{g/g}$.

Concentrations of cadmium, lead, and zinc in Silver Creek were all highly enriched relative to the aquatic life guidelines (fig. 4). Cadmium concentrations in Silver Creek were as much as ten fold higher than the Probable Effects Level (PEL) value of 3.5 $\mu\text{g/g}$. Concentrations of cadmium in the Weber River (site 7) bed sediment were two fold higher than the PEL guideline, and concentrations at McLeod and Kimball Creeks (sites 8 and 9) fell below the PEL. Concentrations of lead in Silver Creek ranged from 922 to 6,915 $\mu\text{g/g}$, 10 to 75 fold higher than the PEL of 91 $\mu\text{g/g}$ (fig. 4, appendix A). Both the Weber River at Coalville (site 7) and McLeod Creek (site 8) also showed evidence of elevated lead concentrations (739 $\mu\text{g/g}$ and 197 $\mu\text{g/g}$, respectively). Kimball Creek (site 9) had the lowest lead values, with a mean of 63 $\mu\text{g/g}$. All samples collected exceeded the Threshold Effects Level (TEL) for both cadmium (0.6 $\mu\text{g/g}$) and lead (35 $\mu\text{g/g}$).

Zinc concentrations in Silver Creek were enriched 9 to 20 fold when compared to the PEL of 315 $\mu\text{g/g}$. Concentrations ranged from 1,000 to 6,000 $\mu\text{g/g}$ at the Silver Creek sites, the Weber River and McLeod Creek. Kimball Creek (site 9) had a lower concentration but still exceeded the PEL (347 $\mu\text{g/g}$) (fig. 4). Copper concentrations were elevated above the PEL (197 $\mu\text{g/g}$) at only sites 2 and 3 in Silver Creek (450 to 510 $\mu\text{g/g}$). However, concentrations exceeded the TEL (35.7 $\mu\text{g/g}$) at all sites in Silver Creek and at the Weber River at Coalville.

TRACE-METAL CONCENTRATION IN SURFACE WATER

Dissolved and Total Metal Concentrations

Total and dissolved metals concentrations are reported in appendix C. Sixty-five to 90 percent of total zinc concentrations are comprised of dissolved zinc, and 75-95 percent of total arsenic concentrations are dissolved except for Silver Creek above Richardson Flat. At this site, total arsenic concentration is almost twice that of the dissolved concentration. At neutral pH, as in Silver Creek, most of the zinc and arsenic is expected to be in the dissolved phase. Total lead concentrations are much higher than dissolved concentrations (4 to 34 percent dissolved). The highest concentration of total lead is at Silver Creek above Richardson Flat, and only 4.3 percent of the total concentration is dissolved. This large difference is most likely because of the chemical nature of lead, which can readily adsorb to iron solids in the water at neutral pH. It is common to find lead mostly present in the solid phase instead of the dissolved phase, except at a very low pH (Smith, 1999).

Loads of Metals

Water column samples were collected during March 10-14, 2000, and August 16-21, 2000. Flow conditions were steady low flow during both of these periods, although rain was noted immediately preceding the August sampling period. Computations of selected metal loads indicate a possible increase in downstream loading of arsenic and lead in both March and August (table 3). The March sampling was conducted over several days, so results are not conclusive. However, in August, sites 1 to 3 were all sampled on the same day, so loads are most likely attributed to sources along the stream, rather than temporal variation. At these three sites, discharge increases along with the concentration of arsenic, copper, and lead. Concentration and load of zinc is highest at site 2, which could indicate a different source for these metals in the water column along the stream. These data indicate that there are multiple sources of metals to the water column along Silver Creek. A more detailed synoptic sampling could fully identify and quantify the location of sources of metals to the water column.

Table 3. Instantaneous load of arsenic, copper, lead, and zinc in surface water from selected sites near Park City, Utah, March and August 2000

[Reported in tons per day x 10⁻⁵; e, estimated; —, no data]

Site no.	Site	Arsenic		Copper		Lead		Zinc	
		March 2000	August 2000	March 2000	August 2000	March 2000	August 2000	March 2000	August 2000
1	Silver Creek at Bonanza Drive	0.445	0.261	6.38	0.127	0.120e	0.064	60.7	3.99
2	Silver Creek above Richardson Flat	21.8	1.19	4.53	.906	1.31 e	.440	2,550	280
3	Silver Creek near Atkinson	34.5	15.0	6.44	7.08	6.21	3.22	2,240	75.5
4	Silver Creek at Wanship	71.9	5.27	19.7	1.77	24.2	1.36	1,640	84.0
5	Weber River near Wanship	—	73.4	—	—	—	22.9 e	—	1,550
7	Weber River at Coalville	77.6 e	117	24.7 e	—	36.1 e	27.6 e	1,020 e	263
8	McLeod Creek at Hwy 224	70.9	8.01	26.3	1.49	1.43 e	.454e	115	18.6
10	Spring Creek at I-80	—	.028	—	.033 e	—	.013e	—	.097

Relation of Water Quality to Toxicity Limits

Comparisons with water-quality criteria can be useful in evaluating measured values in a field setting (fig. 6). A commonly used guideline for the protection of freshwater aquatic ecosystems is the EPA Ambient Water Quality Criteria (AWQC) for the protection of aquatic organisms (U.S. Environmental Protection Agency, 1999). The criteria for chronic exposure (Criteria Continuous Concentration) for arsenic is 150 µg/L. Lead, zinc, chromium, and copper criteria vary on the basis of the total hardness of the water. At hardness values measured in Silver Creek (about 400 mg/L CaCO₃, dissolved), the criteria are: lead 18.6 µg/L, zinc 388 µg/L, cadmium currently 7.3 µg/L, but a new proposal would reduce it to 0.71 µg/L (U.S. Environmental Protection Agency, 2001), and copper 30.5 µg/L. The zinc criteria is exceeded in all samples collected at site 2 (Silver Creek above Richardson Flat), and in samples collected during March at sites 3 and 4 (Silver Creek at Atkinson and Silver Creek at Wanship) (fig. 6).

Arsenic, copper, and lead criteria are not exceeded in any samples collected, although the March sample at site 1 approaches the copper standard. Cadmium concentrations do not exceed the current AWQC criteria, but March samples at all Silver Creek sites (sites 1 to 4) and April, June, and August samples at site 2 exceed the proposed criteria of 0.71 µg/L (fig. 6). Other samples are listed as < 1 µg/L, so may or may not exceed the standard. Although the samples are few in number, the values indicate possible harm to aquatic life from several metals in Silver Creek.

Samples collected in McLeod and Spring Creeks and the Weber River generally had concentrations of metals lower than those collected in Silver Creek and did not exceed AWQC criteria.

Isotopic Analysis

Oxygen and hydrogen isotope data were collected in this study to assist in determination of sources of water to Silver Creek. Isotopes of oxygen and hydrogen differ from other elements in the number of neutrons and protons in their molecular structure. Certain isotopes are stable and readily found in nature and are expressed as a ratio of the isotope to the element. The most common isotope ratios studied in natural environments are oxygen-18/oxygen-16 and hydrogen-2 (deuterium)/hydrogen-1 (Mazor, 1991). Precipitation and the amount of subsequent evaporation creates different ratios of oxygen and hydrogen isotopes in the originally precipitated water and the remaining evaporated water (Mazor, 1991).

Isotopic values are expressed in the del (δ) notation as permil differences between the sample and a standard. With oxygen, for example, δ¹⁸O is defined by:

$$\delta^{18}\text{O} = \frac{(^{18}\text{O}/^{16}\text{O})_{\text{sample}} - (^{18}\text{O}/^{16}\text{O})_{\text{standard}}}{(^{18}\text{O}/^{16}\text{O})_{\text{standard}}} \times 1000 \quad (2)$$

where:

(¹⁸O/¹⁶O)_{sample} is the isotope ratio of the sample,

and

(¹⁸O/¹⁶O)_{standard} is the isotope ratio of sea water.

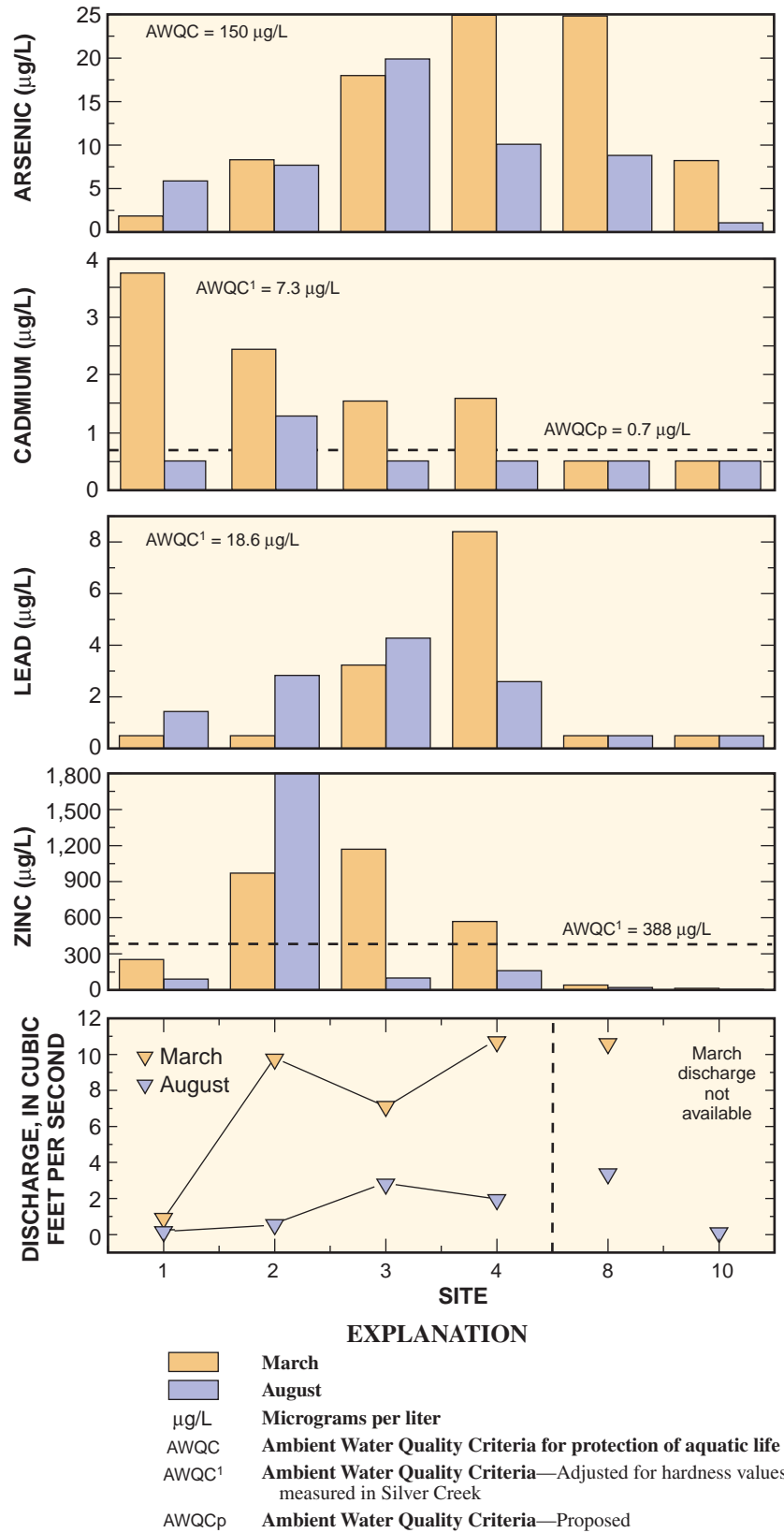


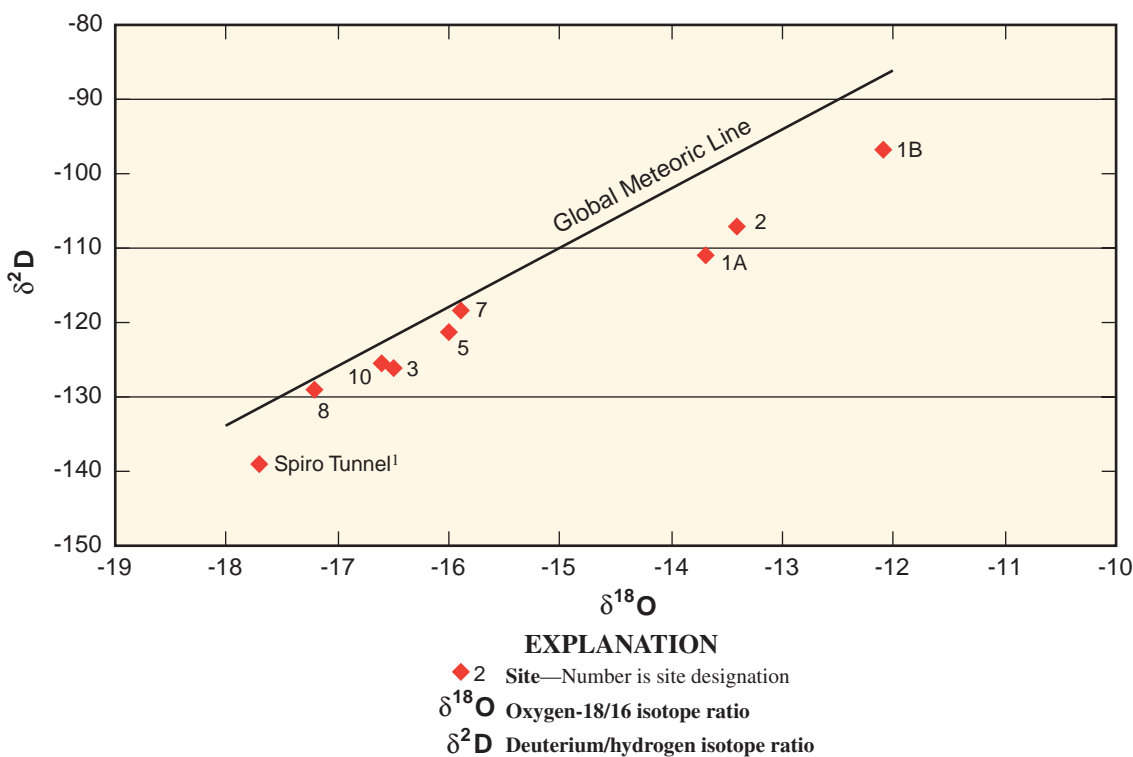
Figure 6. Concentration of dissolved arsenic, cadmium, lead, and zinc for selected study sites near Park City, Utah, March and August 2000.

Likewise, $\delta^2\text{D}$ is the same calculation using the isotope ratio of $^2\text{D}/^1\text{H}$ (deuterium/hydrogen). The comparative standard for oxygen and hydrogen isotopes is standard mean ocean water.

Most of the values for $\delta^2\text{D}$ and $\delta^{18}\text{O}$ at surface-water sites in the study area plot close to the global meteoric (average precipitation) water line, indicating that no significant evaporative or geochemical processes have changed the $\delta^2\text{D}$ and $\delta^{18}\text{O}$ values (fig. 7). Values from Silver Creek at Bonanza Drive (site 1) and above Richardson Flat (site 2) appear to deviate slightly from the global meteoric water line. Values of $\delta^2\text{D}$ and $\delta^{18}\text{O}$ for McLeod Creek (site 8) are the lightest (least enriched) of the samples collected, similar to the value reported by Mayo and others (1992) for the Spiro Tunnel. This could indicate that the water in McLeod Creek is similar to the water from the Spiro Tunnel. However, considering the limited amount of data available, it is not possible to identify the sources of water to the reaches of the stream (table 4).

MERCURY CONCENTRATION IN STREAMBED SEDIMENT AND SURFACE WATER

Mercury was used from the 1880s to early 1900s to process lead and silver ores in the Park City district (Boutwell, 1912). Elemental mercury is the primary form associated with natural ore deposits and mining sources and is not readily bioavailable. However, sulfate-reducing bacteria can transform inorganic mercury to methylmercury, a form readily available for biological uptake. Mercury concentration has been shown to increase in organisms at higher trophic levels and thus is considered to biomagnify in the food chain (Eisler, 1987). Because of this biomagnification, even small amounts of methylmercury in the environment can be harmful to aquatic biota, fish-eating wildlife, and humans. Environmental factors such as the extent of wetlands, concentration and form of sulfate, dissolved organic carbon, and pH of the water are important factors that control the amount of methylation of mercury in the environment (Krabbenhoft and others, 1999). Silver Creek flows through a large wetland area downstream of Richardson Flat, and oxidation of sulfide ores



¹ Value from Mayo and others (1992)

Figure 7. Oxygen/deuterium isotope ratio for selected sites near Park City, Utah, August 2000.

Table 4. Oxygen, deuterium, and sulfur isotopes in surface water from selected sites near Park City, Utah, August 2000[$\delta^{18}\text{O}$, del oxygen 18 ($^{18}\text{O}/^{16}\text{O}$); $\delta^2\text{D}$, del deuterium ($^2\text{D}/^1\text{H}$); $\delta^{34}\text{S}$, del sulfur 34 ($^{34}\text{S}/^{32}\text{S}$); —, no data]

Site no.	Site name	Date	$\delta^{18}\text{O}$	$\delta^2\text{D}$	$\delta^{34}\text{S}$
1	Silver Creek at Bonanza Drive	08/15/2000	-13.74	-110.9	9
1	Silver Creek at Bonanza Drive	08/16/2000	-12.07	-96.8	10.5
2	Silver Creek above Richardson Flat	08/16/2000	-13.44	-107.2	6.2
3	Silver Creek near Atkinson	08/16/2000	-16.54	-126	9.7
5	Weber River near Wanship	08/14/2000	-16.01	-121.3	10.8
7	Weber River at Coalville	08/23/2000	-15.95	-118.5	11.1
8	McLeod Creek at Hwy 224	08/21/2000	-17.24	-129.1	11.5
10	Spring Creek at I-80	08/08/2000	-16.63	-125.6	—
—	Spiro tunnel ¹	—	-17.7	-139.0	—

¹Spiro tunnel value from Mayo and others (1992).

from tailings piles provide adequate sulfate. These conditions make it likely that mercury methylation is occurring.

Total mercury concentration in unfiltered surface water at the three sampled Silver Creek sites (sites 1-3) ranged from 31 to 160 ng/L during July 2000. At the Weber River at Coalville (site 7), the concentration was 22 ng/L in October 1998 (table 5). Total mercury concentration in sieved sediments (< 63 μm) in Silver Creek ranged from 6,500 to 27,750 $\mu\text{g}/\text{kg}$ (dry weight), and in the Weber River at Coalville was 1,041 $\mu\text{g}/\text{kg}$. These values exceed established aquatic life standards. The EPA freshwater chronic criterion for total mercury is 12 ng/L, and the PEL for total mercury in sediment is 486 $\mu\text{g}/\text{kg}$ (National Irrigation Water Quality Program, 1998).

Methylmercury values in Silver Creek and the Weber River are less than 0.6 percent of the total mercury values. While the amount of total mercury available determines the amount of potential methylmercury production, as total mercury concentration increases, the amount of methylation stabilizes (Krabbenhoft and others, 1999). Methylmercury values in Silver Creek (sites 1-3) during July 2000 ranged from 0.06 to 0.39 ng/L in water and 6.4 to 25.8 $\mu\text{g}/\text{kg}$ in sieved sediments (table 5). At the Weber River at Coalville (site 7) during October 1998, methylmercury concentration in water was 0.10 ng/L and in sediments was 4.0 $\mu\text{g}/\text{kg}$. EPA has established criteria for the protection of fish-eating wildlife at 0.05 ng/L methylmercury in water (National Irrigation Water Quality Program, 1998). Samples collected at sites 2 (Silver Creek above Richardson Flat), 3 (Silver Creek at Atkinson), and 7 (Weber River at Coalville) exceeded this guideline. The sample from

Silver Creek at Bonanza had concentrations near the threshold value. No protection criteria have been established for methylmercury in sediments. Although these samples are few in number, they indicate that there is a potential risk for mercury exposure to terrestrial and aquatic organisms at these sites.

Total Mercury and Methylmercury

Because many factors are involved in the methylation of mercury, it is difficult to predict the amount of methylmercury (MHg) from the total mercury (THg) concentration, especially at very high total mercury values, as measured in Silver Creek. In streambed sediments of Silver Creek, total mercury increases from sites 1 to 3 but decreases substantially in the Weber River at Coalville (site 7) (fig. 8a). All four sites exceeded the PEL guideline of 486 $\mu\text{g}/\text{kg}$ total mercury in sediments. However methylmercury values do not follow a similar longitudinal trend. Methylmercury concentration drops from site 1 to site 2, increases again at site 3, and drops again at site 7 (fig. 8a). The concentration of methylmercury in sediments at sites 1 and 3 is very similar (25.8 $\mu\text{g}/\text{kg}$, 24.1 $\mu\text{g}/\text{kg}$) even though the concentration of total mercury in sediments at these sites is very different (6,498 $\mu\text{g}/\text{kg}$, 27,750 $\mu\text{g}/\text{kg}$). Despite a four-fold increase in total mercury concentration between sites 1 and 3, methylmercury concentration at these sites is relatively consistent. There is no established guideline for methylmercury concentration in sediments for protection of aquatic life.

Table 5. Concentration of total mercury and methylmercury in streambed sediment and surface water from selected sites near Park City, Utah, October 1998 and July 2000

[$\mu\text{g}/\text{kg}$, micrograms per kilogram; ng/L , nanograms per liter; THg, total mercury; MHg, methylmercury]

Site no.	Site name	Date	Sediment ($\mu\text{g}/\text{kg}$)		Water (ng/L)	
			THg	MHg	THg	MHg
1	Silver Creek at Bonanza Drive	July 13, 2000	6,498	25.8	31.0	0.06
2	Silver Creek above Richardson Flat	July 13, 2000	11,460	6.47	160	.39
3	Silver Creek near Atkinson	July 13, 2000	27,750	24.1	31.6	.18
7	Weber River at Coalville	Oct 30, 1998	1,041	4.02	21.8	.10
Criteria ¹			486	—	12.0	.05

¹Total mercury in sediment – Probable Effects Level; Total mercury in water – U.S. Environmental Protection Agency freshwater chronic criteria; Methylmercury in water – U.S. Environmental Protection Agency criteria for protection of fish-eating wildlife.

In water samples that were collected, total mercury and methylmercury concentrations show a similar spatial pattern of concentration. Total mercury concentration in water increases from site 1 to site 2, then decreases at site 3 and 7 (fig. 8b). Sites 1, 2, and 3 all exceeded the total mercury chronic life standard of 12 ng/L THg. Likewise, for methylmercury in water, concentrations increase from site 1 to site 2, then decrease at sites 3 and 7. All four sites exceeded the fish-eating wildlife standard for methylmercury of 0.05 ng/L MHg. However, as with sediments, the concentration of methylmercury in water cannot be predicted from the concentration of total mercury in water. The concentration of total mercury in water at sites 1 and 3 is very similar (31.0 ng/L , 31.6 ng/L , respectively), although the concentration of methylmercury in water at the same sites is very different (0.06 ng/L , 0.18 ng/L , respectively) (fig. 8b).

HEALTH OF AQUATIC MACROINVERTEBRATE COMMUNITIES

Aquatic invertebrate metrics are commonly calculated to compare communities at several sites (Barbour and others, 1999). Metrics are a way of summarizing complex macroinvertebrate data into easy to understand measures of the community. Several calculated metrics indicate low community quality in Silver Creek (table 6). The first metric, taxa richness, is a measure of species diversity. Taxa richness was lowest at sites 2 and 3 in Silver Creek, intermediate at site 4, and highest at McLeod Creek (site 8) and Kimball Creek (site 9). A decrease in diversity generally correlates with a decrease in the health of the macroinvertebrate assemblage (Barbour and others, 1999). The second metric, percent EPT, is the percentage belonging to the orders Ephemeroptera (E = mayflies),

Table 6. Aquatic macroinvertebrate richness; percentage of taxa belonging to Ephemeroptera, Plecoptera, and Trichoptera (EPT); percentage of intolerant taxa; and metals index for selected sites near Park City, Utah, August 2000

[Richness, taxa richness; %, percent; EPT, Ephemeroptera, Plecoptera, Trichoptera; #E, number of Ephemeroptera taxa; Intol, intolerant taxa]

Site no.	Site name	Date	Metals Index	Richness	% EPT	#E	% Intol
2	Silver Creek above Richardson Flat	8/16/2000	49.8	38	7.9	1	9.1
3	Silver Creek near Atkinson	8/16/2000	59.0	37	8.1	1	9.1
4	Silver Creek at Wanship	8/17/2000	25.1	42	21.4	1	20.0
8	McLeod Creek at Hwy 224	8/22/2000	7.2	50	28.0	3	35.6
9	Kimball Creek at I-80	8/14/2000	5.8	49	24.5	5	18.2

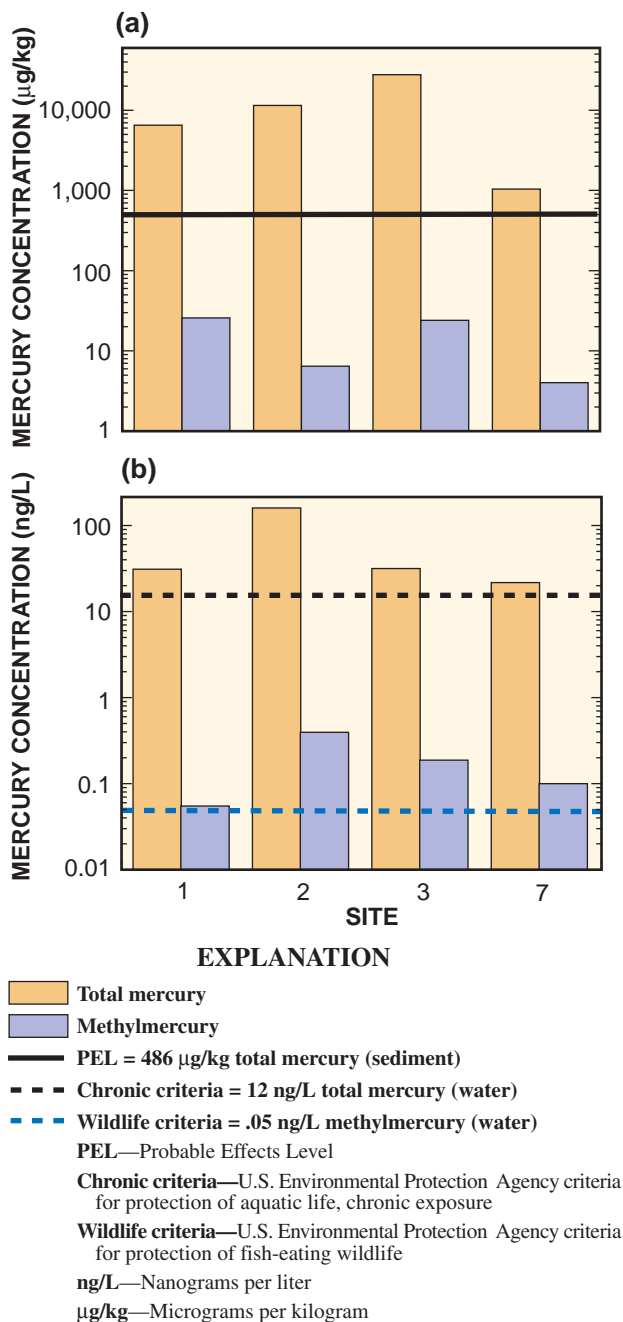


Figure 8. Total mercury and methylmercury in (a) streambed sediment and (b) surface water for selected sites near Park City, Utah, October 1998 and July 2000.

Plecoptera (P = stoneflies), and Trichoptera (T = caddisflies) (EPT). These aquatic insect orders are sensitive to perturbation and generally decline in relative importance as health of the assemblage declines (Barbour and others, 1999). In addition, Clements and others (1992) found a reduction in abundance and diversity of mayflies (Ephemeroptera) at sites contaminated by heavy metals. The percent EPT was lower at site 2 (Silver Creek above Richardson Flat) and 3 (Silver Creek at Atkinson) than at sites 4, 8, and 9, and the number of mayfly species increased from one at sites 2, 3, and 4, to 3 species at site 8, and 5 species at site 9. Both of these metrics indicate an impairment of the macroinvertebrate community in Silver Creek.

Taxa-tolerance values indicate the sensitivity of each taxa to perturbation of the stream environment (Barbour and others, 1999). The percentage of intolerant taxa (the third metric) at sites 2 and 3 was lower than at the other three sites (sites 4, 8, and 9). Tolerance values are not specific to the type of perturbation, so a decline in intolerant (sensitive) organisms implies a degradation of the stream environment, not a specific cause of the degradation. The difference in percentage intolerant taxa between sites 8 and 9, which have similar metal concentrations, indicates that there are additional factors at work at these sites, such as differences in habitat, which were not investigated here.

Although metrics alone do not identify the cause of impairment, they consistently indicate that Silver Creek at sites 2 and 3 has a less healthy macroinvertebrate community than that of Silver Creek at site 4, McLeod Creek (site 8), and Kimball Creek (site 9). To examine the relation between these metrics and the metals concentrations at the sites, the metals index was used. The index compares the relative weak-extract concentrations of silver, cadmium, copper, manganese, lead, and zinc (the six metals that exceeded aquatic-life guidelines) in sediments at the five sites where macroinvertebrate samples were collected. The metals index was negatively correlated to both taxa richness and percent EPT ($R^2 = 0.96$, $R^2 = 0.95$, respectively) (fig. 9), indicating that taxa and EPT richness declined as metals concentration increased. The percent of intolerant taxa also was related to the metals index, although not linearly (fig. 10). But the two sites higher on the metals index (sites 2 and 3) appear to have substantially lower percentages of intolerant taxa than the three sites with lower concentrations.

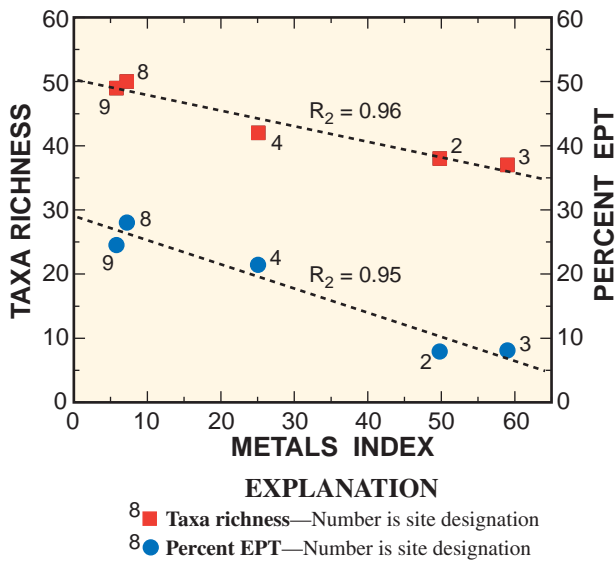


Figure 9. Macroinvertebrate taxa richness and percentage of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa by metals index for selected sites near Park City, Utah, August 2000.

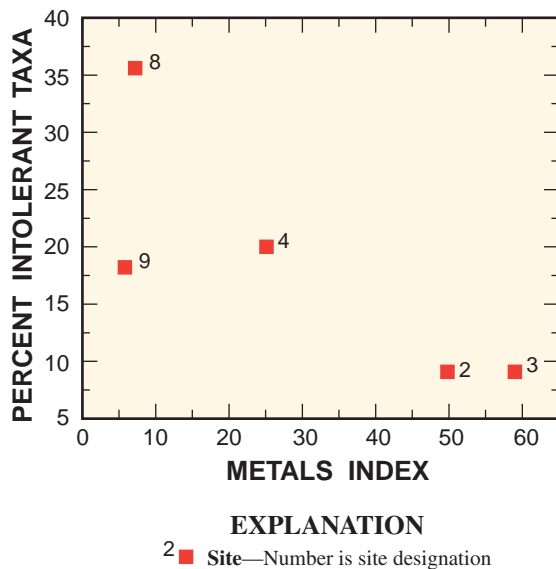


Figure 10. Percentage of intolerant macroinvertebrate taxa by metals index at selected sites near Park City, Utah, August 2000.

SUMMARY

The Great Salt Lake Basins study unit of the National Water-Quality Assessment Program is 1 of 51 study units designed to assess water-quality conditions and trends affecting surface and ground waters of the

United States. An important component to this approach is the occurrence and distribution of metals in freshwater aquatic environments. Historic mining activities in the vicinity of Park City, Utah, have greatly impacted Silver Creek, a tributary to the Weber River in Northern Utah, and the objective of this study was to examine the occurrence and spatial distribution of metals in bed sediment and surface water of streams near the Park City area.

Silver Creek is clearly affected by historic mining practices in the Park City, Utah, area. Concentrations of silver, cadmium, copper, mercury, lead, and zinc in streambed sediments for both the total and weak-acid extraction techniques are significantly elevated relative to background concentrations. Metal-enriched sediment is one probable route of exposure to aquatic organisms because they can either preferentially or incidentally ingest this material while they feed. Metal concentrations from the weak-acid extraction, a method that mobilizes the loosely associated, and thus more biologically relevant, fraction of metal in the streambed sediment, greatly exceed established aquatic life criteria guidelines. The total extraction does not differentiate between the proportion of metal associated with the mineralogical form and the proportion of metal contributed from anthropogenic activities. Therefore, the concentrations extracted using the weak-acid extraction are a more conservative estimate of metals concentrations to compare with aquatic criteria values.

Total mercury and methylmercury values in sediments and water and dissolved zinc also exceed aquatic life protection guidelines. The aquatic macroinvertebrate communities in upper Silver Creek are impaired compared to other sites in the area, with low richness and a higher percentage of tolerant taxa. These multiple lines of evidence further support the notion that the study sites in Silver Creek are severely impaired for aquatic life.

Silver Creek discharges into the Weber River, and although its flow is low relative to that of the Weber River, Silver Creek appears to have influenced the downstream reach, as evidenced by data collected at the Weber River at Coalville (site 7). Although concentrations of metals in the water column are below levels of concern at this site, concentrations of cadmium, lead, zinc, and mercury in streambed sediment remain elevated.

Eroded tailings deposited along Silver Creek and in the watershed are the most probable source of metals contamination to the stream. Several untreated and exposed tailings piles exist in the reaches between sites

1 and 3. Mitigation measures have been taken for most of the tailings piles, but it is likely that the creek sediments still reflect historical erosion.

McLeod, Kimball, and Spring Creeks, on the western side of Snyderville basin, are relatively unimpacted compared to Silver Creek, but lead and zinc concentrations in sediments may still pose a risk to aquatic life in McLeod Creek.

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APPENDIX A

Table A-1. Concentration of metals in streambed sediments, extracted by using a weak-acid (hydrochloric) technique for selected sites near Park City, Utah, July 2000

[$\mu\text{g/g}$, micrograms per gram; Mn, Mean; Std, Standard deviation; \pm , plus or minus; PEL, Probable Effects Level (Buchman, 1999); bold values exceed the PEL; TEL, Threshold Effects Level (Buchman, 1999); —, no data]

Site no.	Site		Aluminum ($\mu\text{g/g}$)	Cadmium ($\mu\text{g/g}$)	Chromium ($\mu\text{g/g}$)	Copper ($\mu\text{g/g}$)	Iron ($\mu\text{g/g}$)	Lead ($\mu\text{g/g}$)	Manganese ($\mu\text{g/g}$)	Nickel ($\mu\text{g/g}$)	Silver ($\mu\text{g/g}$)	Vanadium ($\mu\text{g/g}$)	Zinc ($\mu\text{g/g}$)
1	Silver Creek at Bonanza Drive	Mn	2,422	20.3	7.2	112	4,072	922	807	4.8	1.5	10.9	2,893
		Std	± 148	± 9	± 9	± 21	± 165	± 176	± 286	± 2	± 1.7	± 1	± 121
2	Silver Creek above Richardson Flat	Mn	1,564	40.5	4.1	447	11,737	6,832	1,267	4.9	6.8	11.9	6,198
		Std	± 106	± 1.7	± 5	± 85	$\pm 3,362$	± 171	± 294	± 1	± 6.6	± 7	± 94
3	Silver Creek near Atkinson	Mn	952	36.4	4.7	509	12,806	6,915	1,609	2.0	16.7	11.3	6,714
		Std	± 197	± 13.2	± 1.2	± 161	$\pm 4,630$	$\pm 1,176$	± 214	± 5	± 10.9	± 8.5	± 709
4	Silver Creek at Wanship	Mn	1,382	38.1	1.7	26	3,008	1,256	1,049	2.8	.3	6.4	4,478
		Std	± 60	± 3.5	± 2	± 15	± 106	± 149	± 580	± 3	—	± 4	± 335
7	Weber River at Coalville	Mn	952	6.4	1.5	48	2,789	739	1,101	1.6	.3	5.3	1,724
		Std	± 36	± 7	± 1	± 6	± 675	± 70	± 198	± 1	± 1	± 3	± 156
8	McLeod Creek at Highway 224	Mn	1,541	3.3	2.9	35	4,270	197	603	7.3	.1	5.7	1,087
		Std	± 214	± 6	± 1	± 5	± 712	± 20	± 221	± 1.1	± 0	± 1.1	± 161
9	Kimball Creek at Interstate-80	Mn	1694	1.4	2.0	18	4,524	63	710	3.3	.1	5.6	349
		Std	± 89	± 1	± 2	± 1.4	$\pm 1,221$	± 3.1	± 173	± 3	± 0.2	± 6	± 23
Guideline (PEL)			—	3.5	90	197	—	91	¹ 1,100	35.9	² 1.0	—	315
Guideline (TEL)			—	.60	37.3	35.7	—	35	—	18	¹ 4.5	—	123

¹Upper Effects Threshold, above which toxicity is expected.

²Effects Range Median, somewhat equivalent to PEL.

APPENDIX B

Table B-1. Total concentration of metals in streambed sediments, extracted by using a multi-acid, total extraction technique for selected sites near Park City, Utah, July 1999

[$\mu\text{g/g}$, micrograms per gram]

Constituent	Silver Creek		Weber River		
	Richardson (site 2)	Wanship (site 4)	Wanship (site 5)	Northeast Wanship (site 6)	Coalville (site 7)
Aluminum (percent)	3.9	5.0	4.7	4.2	4.3
Antimony ($\mu\text{g/g}$)	330	110	.42	65	65
Arsenic ($\mu\text{g/g}$)	440	110	4.8	67	58
Barium ($\mu\text{g/g}$)	680	730	430	530	480
Beryllium ($\mu\text{g/g}$)	1.5	1.4	1.2	1.4	1.6
Cadmium ($\mu\text{g/g}$)	120	35	.4	16	15
Chromium ($\mu\text{g/g}$)	72	59	52	47	50
Cobalt ($\mu\text{g/g}$)	28	9.1	6.5	7.7	7.3
Copper ($\mu\text{g/g}$)	750	190	17	130	120
Iron (percent)	7.6	2.9	2.0	2.5	2.4
Lead ($\mu\text{g/g}$)	12,000	2,900	17	1,700	1,700
Manganese ($\mu\text{g/g}$)	5,800	900	440	860	1,200
Mercury ($\mu\text{g/g}$)	19	6.8	.03	2.3	2.8
Molybdenum ($\mu\text{g/g}$)	5.6	1.2	<.5	.67	.64
Nickel ($\mu\text{g/g}$)	28	17	16	13	17
Selenium ($\mu\text{g/g}$)	20	2.0	.45	2	1.2
Silver ($\mu\text{g/g}$)	96	26	.28	11	9.0
Strontium ($\mu\text{g/g}$)	170	250	130	200	150
Thallium ($\mu\text{g/g}$)	6.3	2.2	<1	1.5	1.0
Uranium ($\mu\text{g/g}$)	4.4	2.9	2.7	2.9	2.6
Vanadium ($\mu\text{g/g}$)	66	64	53	57	48
Zinc ($\mu\text{g/g}$)	17,000	4,700	57	2,800	2,900

APPENDIX C

Table C-1. Physical properties and concentration of dissolved and total metals in water for selected sites near Park City, Utah, March

[cfs, cubic feet per second; °C, degrees Celsius; μS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; μg/L, micrograms per liter;

Site no.	Date sampled	Discharge (cfs)	Water Temperature (°C)	Specific conductance (μS/cm)	pH	Dissolved oxygen (mg/L)	Oxygen saturation (percent)	Arsenic (μg/L)	Barium (μg/L)	Beryllium (μg/L)	Boron (μg/L)	Cadmium (μg/L)	Chromium (μg/L)	Cobalt (μg/L)	Copper (μg/L)	Iron (μg/L)
Dissolved																
1	03/10/2000	0.89	0	7,430	8.0	11.9	99	1.85	128	<1	45.4	3.74	13.1	2.13	25.8	
1	08/16/2000	.16	16.1	1,490	7.3	6.6	86	5.88	124	<1	69.5	<1	<.8	<1	2.98	19.0
2	03/14/2000	9.7	1.1	1,260	7.8	11.0	99	8.31	55.1	<1	27.8	2.42	<1	1.19	1.73	27.4
2	04/24/2000		10.5	2,240	7.6	9.0	103	1.80	73.7	<1	46.8	2.94	<.8	1.50	3.41	5.87 e
2	05/16/2000	3 e		593	8.9			5.30	43.9	<1	32.5	<1	<.8	<1	2.25	
2	06/12/2000	.5		1,000	7.9			5.27	46.2	<1	37.5	1.54	.43 e	<1	2.18	
2	08/16/2000	.58	19.3	1,580	7.5	6.8	95	7.67	55.9	<1	67.8	1.26	<.8	1.17	5.56	33.2
3	03/10/2000	7.1	7.2	1,360	7.8	10.4	102	18.0	56.9	<1	71.8	1.52	<1	<1	3.32	
3	08/16/2000	2.8	22.8	1,630	7.6	8.5	126	19.9	35.0	<1	205	<1	<.8	<1	9.22	
4	03/13/2000	10.7	8.6	1,080	8.7	10.6	112	24.9	198	<1	101	1.58	<1	<1	6.76	
4	08/21/2000	1.9		1,210				10.1	155	<1	86.0	<1	<.8	<1	3.46	
5	03/14/2000	66.5	4.1	360	8.4	12.2	116									<10
5	08/14/2000	170	16.3	358	7.8	4.5	58	1.60	81.0	<1	19.3	<1	<.8	<1	<1	
7	3/21/2000	85. e	5.2	464	8.4	12.3	118	3.39	94.9	<1	23.3	<1	<1	<1	1.06	10.1
7	8/23/2000	205	18.0	394	8.2	10.3	133	2.12	88.4	<1	25.0	<1	<.8	<1	<1	11.2
8	03/10/2000	10.6	6.8	2,910	8.2	11.7	114	24.8	48.2	<1	18.8	<1	2.09	<1	9.05	
8	08/21/2000	3.4	11.3		8.2			8.82	38.9	<1	23.3	<1	<.8	<1	1.61	
10	03/11/2000		6.1	1,260	8.4	12.2	124	8.20	124	<1	17.5	<1	<1	<1	2.07	
10	08/08/2000	.1	12.5	630	8.2	10.2	120	1.05	139	<1	15.3	<1	<.8	<1	1.19	
Total																
1	08/16/2000							7.49	120	<5		1.59	<1	<1.8	<20	193
2	08/16/2000							14.2	56.2	<5		4.30	.572 e	<1.8	<20	671
3	08/16/2000							23.0	34.2	<5		.395	.648 e	<1.8	<20	43.8
4	08/21/2000							11.6	145	<5		2.04	1.09	<1.8	<20	152
7	8/23/2000							2.50 e	89.5	<5		.135	.582 e	<1.8	<20	168
8	08/21/2000							9.42	36.0	<5		<.11	.673	<1.8	<20	80.4
	Criteria ¹							150				7.3			30.5	
	Criteria ²							150				4.2			16.9	

¹Ambient Water Quality Criteria for protection of aquatic life (U.S. Environmental Protection Agency, 1999) chronic exposure criteria, calculated for hardness of 400 mg/L CaCO₃, typical values for sites 1-4.

²Ambient Water Quality Criteria, chronic exposure, calculated for hardness of 200 mg/L CaCO₃, typical values for sites 5-7.

to August 2000

e, estimated]

Site no.	Date sampled	Lead (µg/L)	Manganese (µg/L)	Thallium (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Silver (µg/L)	Strontium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)	Antimony (µg/L)	Aluminum (µg/L)	Lithium (µg/L)	Selenium (µg/L)	Uranium (µg/L)	Mercury (µg/L)
Dissolved																
1	3/10/2000	<1	1,460	<.9	1.92	2.07	<1	1,580	<1	252	7.68	29.9	19.7	0.954		
1	8/16/2000	1.43	52.0	<.9	3.97	<1	<1	478	1.20	89.6	4.78	4.276	10.6	.488 e		
2	3/14/2000	<1	405	<.9	2.08	1.51	<1	803	<1	970	2.79	1.09	10.7	1.29		
2	4/24/2000	2.18	437	<.9	1.19	5.46	<1	687	<1	1650	7.39	16.2	9.56	1.09		
2	5/16/2000	2.06	138	<.9	1.78	3.89	<1	658	<1	552	4.93	10.8	8.80	1.46		
2	6/12/2000	2.20	474	<.9	1.66	3.78	<1	752	<1	758	4.48	1.16	9.97	.815		
2	8/16/2000	2.83	713	<.9	2.90	2.05	<1	942	<1	1,800	9.06	<1	14.2	.831		
3	3/10/2000	3.24	410	<.9	6.66	<1	<1	678	<1	1170	11.2	1.86	12.9	.538 e		
3	8/16/2000	4.27	13.3	<.9	16.4	<1	<1	544	1.09	100	10.8	2.82	11.8	.832		
4	3/13/2000	8.40	347	<.9	3.92	<1	<1	1,020	2.09	569	16.9	2.42	22.9	.921		
4	8/21/2000	2.59	26.2	<.9	4.20	<1	<1	515	4.53	161	11.3	<1	12.8	.426 e		
5	03/14/00		20.5													
5	8/14/2000	<1	64.0	<.9	<1	<1	<1	164	1.04	33.9	<1	<1	4.80	<.7		
7	3/21/2000	1.58	37.0	<.9	<1	2.23	<1	227	<1	44.6	1.00	1.67	5.99	<.7		
7	8/23/2000	<1	22.8	<.9	<1	<1	<1	188	1.74	4.76	<1	<1	5.77	<.7		
8	3/10/2000	<1	101	2.22	4.11	1.17	<1	2,020	<1	40.4	10.5	6.90	8.85	1.84		
8	8/21/2000	<1	36.6	.491 e	2.43	<1	<1	779	1.28	20.4	2.78	<1	6.28	1.71		
10	3/11/2000	<1	46.4	<.9	1.85	<1	<1	582	<1	13.6	1.67	1.18	7.95	.937		
10	8/8/2000	<1	3.90	<.9	<1	<1	<1	476	1.14	3.6	<1	2.53	4.59	.442 e		
Total																
1	8/16/2000	12.8	63.4		2.65	1.68 e	<1	479		133	4.3	53.9	10.3	<2.6	2.36	<.3
2	8/16/2000	65.8	831		2.57	5.5	<1	958		2,060	9	47.2	13.1	<2.6	2.21	<.3
3	8/16/2000	15.7	17.8		12.7	1.85	<1	539		119	10.5	<28	10.9	<2.6		<.3
4	8/21/2000	24.1	55.7		2.97	1.70 e	<1	490		246	12.1	145	11.0	<2.6	1.78	<.3
7	8/23/2000	12.3	99.1		<1	<1.8	<1	174		23.7 e	1.1	104	5.87 e	<2.6	<1	
8	8/21/2000	1.45	41.4		2.52	<1.8	<1	748		<31	2.4	41.2	6.59 e	1.59 e	2.14	<.3
	Criteria ¹	18.6				168				388						
	Criteria ²	7.7				93.8				215						