

QUANTIFICATION OF METAL LOADING TO SILVER CREEK THROUGH THE SILVER MAPLE CLAIMS AREA, PARK CITY, UTAH, MAY 2002

By Briant A. Kimball, Kevin K. Johnson, Robert L. Runkel, and Judy I. Steiger

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CONVERSION FACTORS, DATUMS, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
kilogram per day (kg/day)	2.2	pound per day
milligram per second (mg/s)	.1901	pound per day
liter per second (L/s)	.0353	cubic foot per second (ft ³ /s)
meter (m)	3.281	foot (ft)
micrometer (μm)	3281000	foot (ft)
milliliter (mL)	.000264	gallon

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

$$^{\circ}\text{F} = 9/5(^{\circ}\text{C}) + 32.$$

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Chemical concentration and water temperature are reported only in metric units. Chemical concentration is reported in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the mass of solute per unit volume (liter) of water. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is reported in microsiemens per centimeter at 25 degrees Celsius (μS/cm).

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ABSTRACT

The Silver Maple Claims area along Silver Creek, near Park City, Utah, is administered by the Bureau of Land Management. To quantify possible sources of elevated zinc concentrations in Silver Creek that exceed water-quality standards, the U.S. Geological Survey conducted a mass-loading study in May 2002 along a 1,400-meter reach of Silver Creek that included the Silver Maple Claims area. Additional samples were collected upstream and downstream from the injection reach to investigate other possible sources of zinc and other metals to the stream. Many metals were investigated in the study, but zinc is of particular concern for water-quality standards. The total loading of zinc along the study reach from Park City to Wanship, Utah, was about 49 kilograms per day. The Silver Maple Claims area contributed about 38 percent of this load. The Silver Creek tailings discharge pipe, which empties just inside the Silver Maple Claims area, contributed more than half the load of the Silver Maple Claims area. Substantial zinc loads also were added to Silver Creek downstream from the Silver Maple Claims area. Ground-water discharge upstream from the waste-water treatment plant contributed 20 percent of the total zinc load, and another 17 percent was contributed near the waste-water treatment plant. By identifying the specific areas where zinc and other metal loads are contributed to Silver Creek, it is possible to assess the needs of a remediation plan. For example, removing the tailings from the Silver Maple Claims area could contribute to

lowering the zinc concentration in Silver Creek, but without also addressing the loading from the Silver Creek tailings discharge pipe and the ground-water discharge farther downstream, the zinc concentration could not be lowered enough to meet water-quality standards. Additional existing sources of zinc loading downstream from the Silver Maple Claims area could complicate the process of lowering zinc concentration to meet water-quality standards.

INTRODUCTION

Thousands of historical mining sites are located on Federally managed lands in the Western United States. Federal land management and regulatory agencies, often in cooperation with stakeholder groups, are faced with the challenge of choosing sites where they can implement remediation to lessen the effect of zinc and other toxic metals on streams in mountainous watersheds. Decisions about remediation of individual sites in a watershed require an understanding of the location and magnitude of metal loading.

Tracer-injection methods and synoptic sampling have been combined to quantify mass loading in many watersheds affected by abandoned and inactive mines and tailings. Mass-loading studies, together with geologic and biologic studies, can provide information that is needed to make science-based decisions for improvement of water quality in a watershed (Buxton and others, 1997). The Silver Maple Claims (CERCLIS # TUD980951396) area along Silver Creek, near Park City, Utah, is administered by the Bureau of Land Management (BLM). Mason (1989) investigated the hydrology of the Prospector Square area. Results of

that study indicate a substantial increase in zinc (Zn) load in the vicinity of the Silver Maple Claims area, and that is attributed to the high concentrations of Zn that were measured in discharge from the Silver Creek tailings discharge pipe (CERCLIS # UTD980951404). A consultant report describes the details of the discharge pipe (Dames and Moore, written commun., 1975). Giddings and others (2001) observed elevated metal concentrations in streambed sediments of Silver Creek. The geology of the area is described by Broomfield and Crittenden (1971).

The purposes of this report are to (1) determine the net metal loading to Silver Creek through the Silver Maple Claims area, (2) identify locations of metal loading through the study reach, and (3) calculate mass loading at additional sites outside the study reach. To meet these objectives, the U.S. Geological Survey (USGS) designed a mass-loading study along a 1,400-m study reach that included the Silver Maple Claims area (fig. 1). Seven additional samples were collected outside of this injection reach, one upstream from the injection reach in Park City, one from the Pace-Homer ditch near the injection reach, and five downstream from the injection reach, the farthest one being in Wanship. Thus, two scales were used for the mass-loading calculations: a detailed scale in the injection reach, and a larger scale over the length of the Silver Creek study reach from Park City to Wanship.

This work was funded by the Bureau of Land Management and the Utah Department of Environmental Quality through the cooperative program of the U.S. Geological Survey. Valuable field assistance was given by many individuals from the stakeholder group including: Heidi Hadley and Tim H. Ingwell of the Bureau of Land Management; John Whitehead, Alan V. Jones, and Ann Tilia of the Utah Department of Environmental Quality; Luke Chavez of the U.S. Environmental Protection Agency; Jay Cederberg and Steve Gerner of the U.S. Geological Survey; and Kerry Gee and Paul Lammers of United Park City Mines Company. James Mason, of the U.S. Geological Survey provided many useful suggestions on the hydrology of the area.

METHODS

The application of tracer-injection methods to mine drainage has been developed as part of the USGS Toxic Substances Hydrology Program (Bencala and McKnight, 1987; Kimball and others, 1994; Kimball and others, 2002). To evaluate the relative importance of multiple sources and the effects of instream processes, the stream and inflows must be considered in the hydrologic context of loads, not just in terms of concentrations. The load of a constituent is the product of its concentration and the discharge at the sampling site. One inflow could have a low metal concentration, and another could have a high concentration, but their discharges could differ enough so that their loads might be the same, in which case they would have the same effect on the downstream concentration.

Quantification of discharge in mountain streams presents unique challenges. In the Silver Maple Claims area, numerous beaver dams retard the flow of Silver Creek. The traditional area-velocity method of measuring discharge does not work in the sequence of ponds and braided channels. Thus, a measurement of discharge in the stream channel may miss a substantial percentage of the streamflow, resulting in an underestimate of metal loads.

A tracer-dilution approach is better suited for the problem of source determination in such a stream. In a complex stream like Silver Creek, the tracer must be injected for a sufficiently long time to come to a plateau, or steady-state condition, along the injection reach. Synoptic sampling of instream and inflow chemistry provides a spatially detailed "snapshot" of stream water quality. This sampling occurs during the tracer plateau. Typically one integrated sample is collected at a specified distance. In Silver Creek, this was possible at several locations at the beginning and end of the Silver Maple Claims area and a few other locations. Where the stream was spread out over a wide area because of beaver ponds, samples were collected near the left, center, and right of the stream area at the specified distances (table 1).

Sampling sites were selected during two reconnaissance visits to the study reach (table 1). Three samples were collected from inflows and 44 samples were collected from the stream. Eight quality-assurance samples were also collected to test replication, field equipment, and filtering equipment. Although it was possible to identify where most of the water was

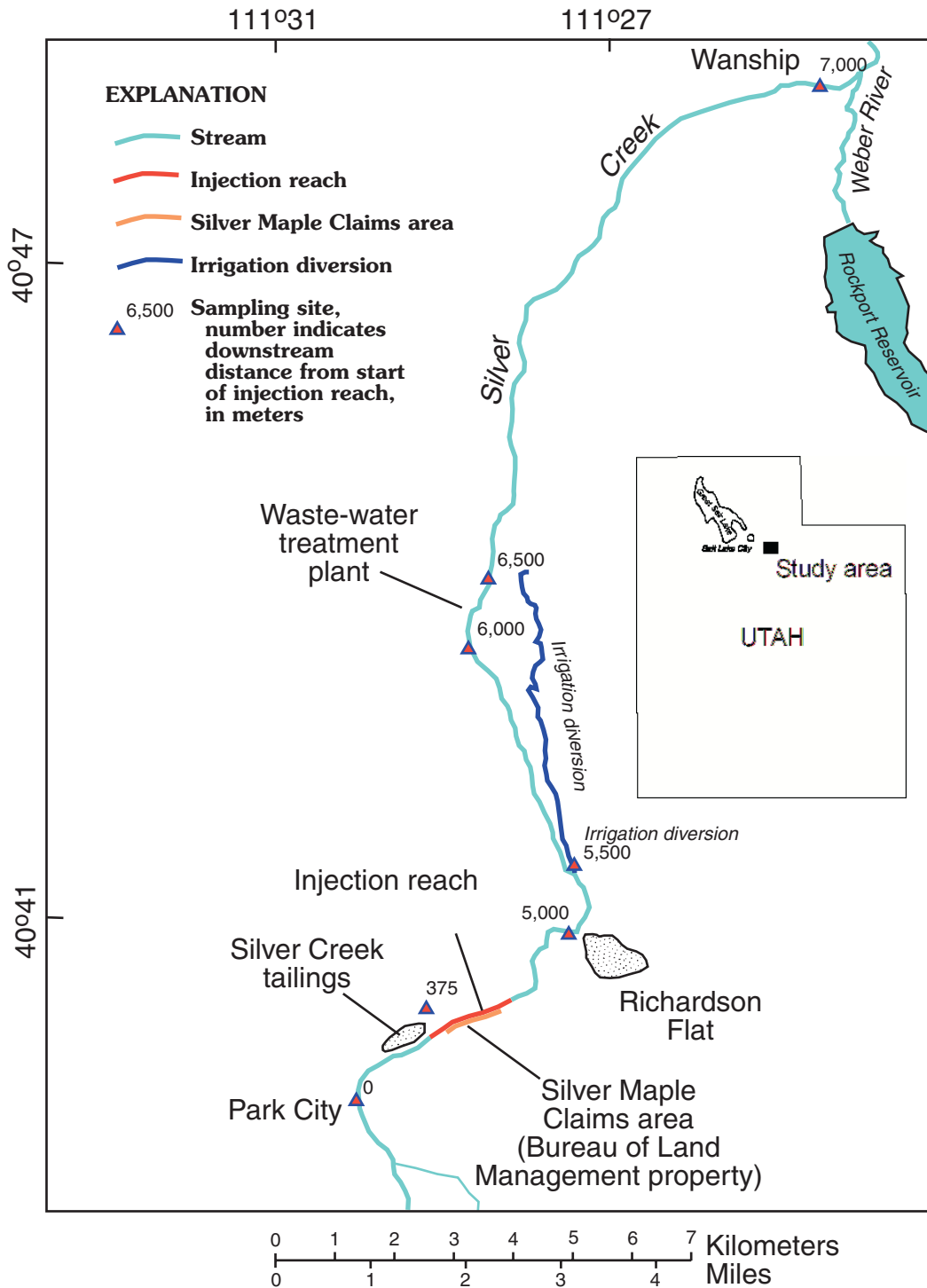


Figure 1. Location of study reach, injection reach, and sampling sites outside the study reach, Silver Creek, Utah.

Table 1. Sample identification, source, downstream distance, site description, location, discharge, and tracer concentration for synoptic sampling sites, Silver Creek, Utah

[Sample identification, unique sample identifier; Source: S, stream; LBI, left bank inflow; Distance along the study reach, in meters; BLM, Bureau of Land Management; Latitude and Longitude, in decimal degrees; L/s, liters per second; mg/L, milligrams per liter; NC, discharge not calculated, sample was not in the main channel; <, less than]

Sample identification	Source	Distance (meters)	Segment	Site description	Latitude	Longitude	Discharge (L/s)	Concentration of bromide (mg/L)
¹ SCS-0000	S	0	S1	Silver Creek below confluence of Ontario, Empire & Deer Valley	40.65003	111.50002	71.9	0.15
SCS-0072	S	72	S2	Stream up from road culvert, upstream from injection	40.66685	111.48520	42.5	.15
SCS-0225	S	225	S3	Upstream from footpath culvert	40.66667	111.48334	42.5	4.57
SCS-0265	S	265	S4	T1 site - Upstream end of Prospector park pond	40.66781	111.48340	42.5	4.53
SCS-0360	S	360	S5	T2 site - Weir at end of Prospector park pond - start of Silver Maple Claims area (BLM property)	40.66827	111.48228	42.5	4.21
SCI-0370	LBI	370	-	End of Silver Creek tailings ground-water pipe	40.66838	111.48231	² 12.7	.77
¹ SCI-0375	LBI	375	-	Pace Homer Ditch at U.S. Highway 248 (across road from park pond)	40.66668	111.48647	³ 95	<.05
SCI-0378	LBI	378	-	Standing water to right of tailings, upstream from BLM fence	40.66668	111.46676	NC	.44
SCS-0398A	S	398	S6	Outflow of pond with Prospector pipe discharge - replicate	40.66843	111.48209	84.9	2.88
SCS-0398B	S	398	S6	Outflow of pond with Prospector pipe discharge - replicate	40.66843	111.48209	84.9	2.98
SCS-0490R	S	498	-	Toward middle of marsh area	40.66668	111.46675	NC	2.90
SCS-0498C	S	498	S7	Channel outside fence along right bank	40.66668	111.47190	84.9	2.83
SCS-0498L	S	499	-	Sample toward left bank	40.66883	111.48130	NC	3.36
SCS-0543L	S	542	-	Left bank upstream from beaver pond	40.66761	111.47141	NC	2.76
SCS-0543C	S	543	S8	Center upstream from beaver pond	40.66668	111.46675	85.1	2.89
SCS-0543R	S	544	-	Right side at start of beaver pond	40.66805	111.46675	85.1	2.72
SCS-0576	S	576	S9	At breach made in mud beaver pond	40.66668	111.46675	85.1	2.92
SCS-0637L	S	637	S10	Overflow from small dam/pond	40.66758	111.47134	85.1	2.90
SCS-0637R	S	637	S10	Overflow from small dam/pond	40.66758	111.47134	85.1	2.98
SCS-0684	S	684	S11	Center at start of central pond	40.66941	111.47910	85.1	3.02
SCS-0711	S	710	S12	Left at return of right bank channel outside fence	40.66935	111.47878	85.1	2.96
SCS-0778A	S	778	S13	T3 site - Downstream end of small pond below large pond	40.66985	111.47832	NC	2.73
SCS-0778B	S	778	S13	T3 site - Downstream end of small pond below large pond	40.66985	111.47832	NC	2.63
SCS-0832L	S	831	-	Left side near fallen tree along left bank - most of flow on left	40.67002	111.47771	90.2	2.66
SCS-0832C	S	832	S14	Center near fallen tree along left bank	40.67002	111.47771	90.2	2.73
SCS-0832R	S	833	-	Right side near fallen tree along left bank	40.67002	111.47771	90.2	2.70
SCS-0877	S	877	S15	Upstream end of pond with large beaver lodge	40.66997	111.47725	90.2	2.75
SCS-0940	S	940	S16	Channel flow downstream from beaver pond at cut bank	40.66793	111.47022	90.2	2.75
SCS-0990L	S	989	-	Left side with spread out channel near post	40.66792	111.47052	NC	2.67
SCS-0990C	S	990	-	Center channel between two other samples	40.66787	111.47051	NC	2.68
SCI-0991	LBI	991	-	Left bank ditch as possible inflow water	40.66795	111.50123	NC	.46
SCS-0992	S	992	S17	Channel gathered - good for discharge measurement	40.67017	111.47632	90.2	2.83
SCS-1017	S	1,017	S18	Fence at downstream; end of Silver Maple Claims area (BLM property)	40.67030	111.47572	90.2	2.75
SCS-1079L	S	1,079	-	Left side at small dam down from Silver Maple	40.67052	111.47511	NC	2.70
SCS-1079C	S	1,080	-	Center at small dam down from Silver Maple	40.67052	111.47511	NC	2.81
SCS-1079R	S	1,081	S19	Right side at small dam down from Silver Maple	40.67052	111.47511	90.2	2.82
SCI-1140	LBI	1,140	-	Drainage from breach of Pace Homer Ditch	40.67093	111.47482	NC	.06
SCS-1162	S	1,162	-	At a dam up from bridge	40.67083	111.47419	NC	2.62
SCS-1165	S	1,165	-	Left bank sample in channel with irrigation inflow	40.67098	111.47419	NC	2.09
SCS-1212	S	1,212	S20	Upstream end of pond at final bridge	40.67101	111.47368	90.2	2.78
SCS-1344A	S	1,344	S21	T4 site - Down from pond at bridge - replicate	40.66818	111.46868	90.2	2.80
SCS-1344B	S	1,344	S21	T4 site - Down from pond at bridge - replicate	40.66818	111.46868	90.2	2.64
SCS-1380	S	1,380	S22	At small, old wood walking bridge	40.67095	111.47168	90.2	2.61
SCS-1420	S	1,420	S23	End of reach down from pipes across stream	40.67129	111.47154	90.2	2.61
¹ SCS-5000A	S	5,000	S24	Silver Creek 100 meters above Richardson Flat	40.68108	111.45805	165	<.05

Table 1. Sample identification, source, downstream distance, site description, location, discharge, and tracer concentration for synoptic sampling sites, Silver Creek, Utah—Continued

Sample identification	Source	Distance (meters)	Segment	Site description	Latitude	Longitude	Discharge (L/s)	Concentration of bromide (mg/L)
¹ SCS-5000B	S	5,500	S25	Silver Creek 50 meters below U.S. Highway 248 road crossing	40.68562	111.45286	235	<.05
¹ SCS-6000A	S	6,000	S26	Silver Creek above Silver Creek waste-water treatment plant	40.71946	111.47138	28.9	<.05
¹ SCS-6000B	S	6,500	S27	Silver Creek below Silver Creek waste-water treatment plant	40.73404	111.47636	117	<.05
¹ SCS-7000	S	7,000	S28	Silver Creek at town of Wanship	40.80351	111.40272	532	<.05

¹Sample collected on 5/1/2002, outside of mass-loading study reach.

²Measured by flow meter at the end of the pipe.

³Discharge of ditch does not contribute to the discharge of Silver Creek in the study reach.

moving along the study reach in those parts of Silver Creek affected by beaver dams, in some areas all the water entered large beaver ponds. Each stream sample that was considered in the main channel (table 1) defines the downstream end of a stream segment. Each stream segment was given a sequential number from upstream to downstream, and each represents the mass loading contributed by a given part of the watershed. The length of the segment is the difference between the upstream and downstream distances. A schematic view of the sampling sites for the injection reach is shown in figure 2.

To quantify the arrival, plateau, and departure of the tracer, continuous samples were collected at four sites along the study reach. During the 72 hours prior to the synoptic sampling, samples at these transport sites define the hydrologic properties of the stream. The arrival and departure of the tracer provide information about the residence time between sites, stream cross-sectional area, exchange rate of the stream with the hyporheic zone, and the stream discharge as the tracer reaches a plateau concentration. Transport samples were collected by individuals at the transport sites during the arrival and departure periods and by auto-sampler throughout the plateau of the injection period. Transport sites were located at the upstream end of the pond in Prospector Park (T1), at the weir at the downstream end of the pond in Prospector Park (T2), downstream from the largest beaver pond where there is a majority of flow for a short reach (T3), and at the end of the study reach (T4). Only one 125-mL bottle of filtered, untreated (FU) water is collected for the transport sampling.

Several publications provide details about tracer injections, including Bencala and others (1990), Broshars and others (1993), Kimball and others (1994, 1999, 2001, and 2002), and Zellweger and others (1988).

Tracer Injection

The tracer injection began with a careful evaluation of all visible inflows to the injection reach, which was accomplished by walking the entire reach from Prospector Park to the end near 1,421 m (fig. 2). Sampling sites within the injection reach are referenced in this report by the measured downstream distance along the injection reach. The distance from one stream site to the next site downstream represents a stream segment. The injection began at 10:55 hours on April 29, 2002, and continued until 16:55 hours on May 2, 2002. Sodium bromide was selected for the injection solution. Bromide (Br) was considered a good tracer because of the high pH of the stream and the lack of geologic sources of Br in the watershed. The injection solution had a Br concentration of 255,500 mg/L, and was injected at a rate of 0.00107 L/s.

Precision metering pumps were used to inject the tracer. A Campbell CR-10 data logger controlled the pumps by counting pump revolutions and adjusting the voltage to maintain a constant number of revolutions for each 2-minute period. This careful control assures that any observations of tracer concentration downstream result from hydrologic change and not from pump variation. In the analysis of this experiment, Br is assumed to be a conservative tracer. No adverse effects were observed from the injection of the tracer solution.

A continuously injected chemical tracer provides a way to measure discharge that includes the hyporheic flow of the stream because it follows the water as it moves in and out of the streambed. During base-flow conditions, tracer dilution allows the detection of increases in streamflow of only a few percent. Once the tracer reaches a steady concentration at each point along the stream, called the plateau condition,

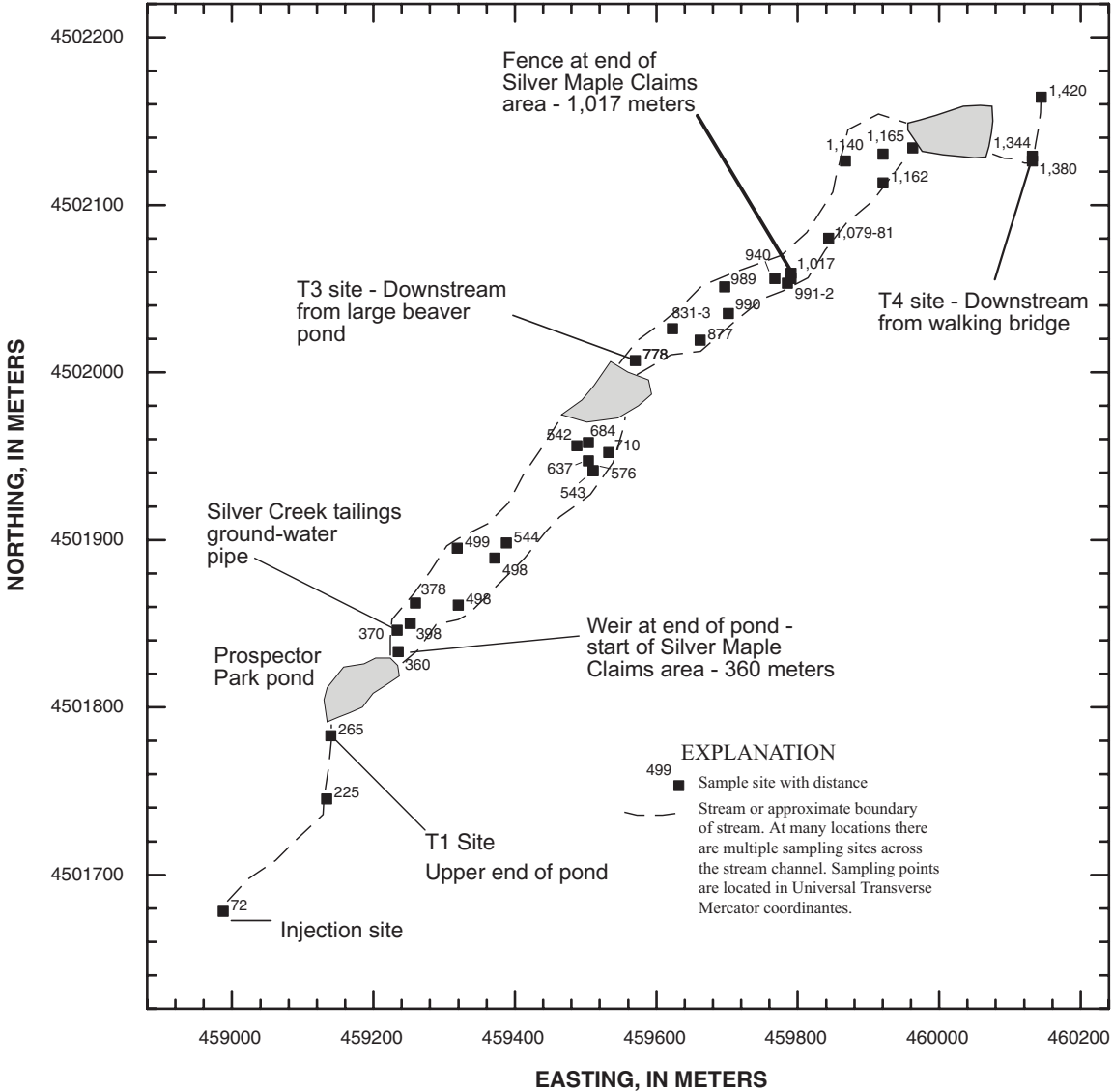


Figure 2. Schematic map of injection reach, Silver Creek, Utah.

discharge can be calculated at any point. During the tracer plateau, numerous samples along the stream provide a synoptic sampling. Each stream sample has a measured discharge because of the tracer concentration in the synoptic sample.

Concentrations of bromide in stream environments are typically low, with background concentrations at or near the lower detection limits. Spatial variability in background concentrations is low, such that background concentrations are nominally uniform. Assuming uniform background concentrations, stream discharge at any location downstream from the injection is given by:

$$Q_D = \frac{(Q_{INJ}C_{INJ})}{C_D - C_B} \quad (1)$$

where

Q_D is stream discharge, in L/s,

Q_{INJ} is the injection rate, in L/s,

C_{INJ} is the injectate concentration, in mg/L,

C_D is the tracer concentration at plateau, in mg/L, and

C_B is the naturally occurring background concentration, in mg/L.

The amount of tracer dilution between two consecutive stream sites indicates the total inflow from surface and ground water for that segment of the injection reach. Tracer dilution accounts for visible inflows,

such as tributaries and springs, as well as dispersed, subsurface inflow. To divide the total inflow within a stream segment into surface- and ground-water components would require a secondary discharge measurement of the inflow.

Sample Collection and Analysis

Synoptic sampling is used to quantify discharge and detailed longitudinal profiles of chemistry along a stream reach. For the injection reach, sampling proceeded from downstream (1,421 m) to upstream (72 m) to avoid disturbing the bed materials. Samples outside the injection reach were collected the day prior to the synoptic sampling. Because the flow was spread out over most of the bottom area of Silver Creek, many of the samples were grab samples across a transect of the area of flow. Where possible, samples were collected at well-defined stream cross sections by using integrating techniques (Ward and Harr, 1990). A hand-held, depth-integrating, Teflon sampler was used for both the single vertical grab samples and the width-integrated samples. Temperature was measured at the time of sample collection and recorded along with field notes about the sampling conditions, character of the streambed, and any important observations. Samples were transported to a centrally located field laboratory where filtration could occur with standardized procedures to control contamination. The processing included a (1) raw, untreated (RU) sample for pH and conductance; (2) a raw, acidified sample (RA) for total-recoverable metals; (3) a 0.45- μm filtered, acidified (FA) sample for filtered metal concentrations; and (4) a 0.45- μm filtered, untreated (FU) sample for tracer and other anions.

Colloidal metal concentrations are important for understanding the transport and transformation of metals (Kimball and others, 1995). The colloidal concentration was calculated as the difference between the total-recoverable and the filtered concentrations (Kimball and others, 1995). Metal concentrations were determined by inductively coupled argon plasma - mass spectrometry for calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), aluminum (Al), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), lithium (Li), manganese (Mn), molybdenum (Mo), nickel (Ni), strontium (Sr), silica (SiO_2), vanadium (V), and Zn. Anions were determined by ion chromatography and included sulfate (SO_4), chloride

(Cl), fluoride (F), the Br tracer, and nitrate (NO_3). Alkalinity, as calcium carbonate (CaCO_3), was determined by titration.

Mass-Loading Analysis

Because of the beaver dams throughout the injection reach, quantifying stream discharge was difficult. To quantify the change in load for the Silver Maple Claims area required accurate discharge and chemical measurements at the beginning (360 m) and end (1,017 m) of the area. Stream discharge measurements were possible because both locations had reasonably well channelized cross sections and were easily sampled. To quantify more detailed changes in load was not as straightforward. Obtaining changes in discharge from the tracer was possible only for those segments where there was a clear change in tracer concentration. There were many individual segments for which discharge was unchanged. To quantify loads for those sites outside the injection reach required accurate discharge measurements by flow meter. Flow-meter measurements do not include water transported in the hyporheic zone, which is quantified by a tracer-injection study (Kimball and others, 2002).

Profiles of mass load along the study reach use three different views of load. Sampled instream load at individual sampling sites is calculated as:

$$M_a = C_a Q_a (0.0864) \quad (2)$$

where

M_a is the constituent load at location a , in kg/day,

C_a is the concentration of the selected constituent at location a , in mg/L,

Q_a is the discharge at location a , in L/s, and

0.0864 is the conversion factor from mg/s to kg/day.

Sampled instream load is calculated from the total-recoverable concentration of the constituent, but this value for load can be divided between the dissolved and the colloidal load if both filtered and total-recoverable samples are collected. The longitudinal profile of sampled instream load is the basic data from the mass-loading study.

The change in load between a pair of stream sites, or for a stream segment, accounts for the gain or loss of constituent load for that segment. For the change in load for the segment starting at location a and ending at location b , we calculate:

$$\Delta M_s = (C_b Q_b - C_a Q_a)(0.0864) \quad (3)$$

where

ΔM_s is the change in sampled instream load from location a to b , in kg/day,

C_b is the concentration of the selected constituent at location b , in mg/L,

Q_b is the discharge at location b , in L/s,

C_a and Q_a are defined above, and

0.0864 is the conversion factor from mg/s to kg/day.

Gains in constituent load (ΔM_s is greater than zero) imply that there is a source that contributes to the stream between the two stream sites. Instream load also can decrease within a stream segment (ΔM_s is less than zero), meaning that there was a net loss of the constituent from physical, chemical, or biological processes. Summing all the increases in load between sampling sites along the study reach (positive values of ΔM_s) leads to the cumulative instream load. At the end of the study reach, the cumulative instream load is the best estimate of the total load added to the stream but is likely a minimum estimate because it only measures the net loading between sites and does not account for loss resulting from reaction.

For those segments that include a sampled inflow, it is possible to calculate a second value for load that is based upon the change in discharge between stream sites. This change, multiplied by constituent concentration in an inflow sample, produces an estimate of the inflow load for a stream segment. If stream sites a and b surround an inflow sample, location i :

$$\Delta M_i = C_i(Q_b - Q_a)(0.0864) \quad (4)$$

where

ΔM_i is the change in sampled inflow load from location a to b , in kg/day,

C_i is the concentration of the selected constituent at inflow location i , in mg/L,

Q_a and Q_b are defined above, and

0.0864 is the conversion factor from mg/s to kg/day.

Summing the inflow loads along the study reach produces a longitudinal profile of the cumulative inflow load. This sum can be compared to the cumulative instream load to indicate how well the sampled inflows account for the load measured in the stream. The cumulative instream and cumulative inflow pro-

files would be equal if the sampled inflows were representative of the constituent concentration for all the water entering the stream, but that is rarely the case. Ground-water inflow in streams affected by mine drainage commonly has higher concentrations of metals than the surface-water inflows in the same stream segment. This causes the profile of cumulative instream load to be greater than the profile of cumulative inflow load, and can indicate important areas of unsampled inflow, which is defined as:

$$\text{Unsampled inflow} = \Delta M_s - \Delta M_i \quad (5)$$

This can be calculated for individual stream segments if the segment included a sampled inflow, or for the entire injection reach. If the value is negative for the entire study reach, however, it can still be positive for some individual stream segments.

In considering estimates of stream discharge and metal concentration at each stream site, it is possible to predict an error for the change in load along a stream segment. The error is determined by the precision of both discharge and chemical measurements (Taylor, 1997), according to an equation from McKinnon (2002):

$$\text{Load Error} = (\sqrt{Q_a^2 \Delta C_a^2 + C_a^2 \Delta Q_a^2})(0.0864) \quad (6)$$

where

Q_a is the discharge at the upstream site, in L/s,

ΔC_a is the concentration error at the upstream site, in mg/L,

C_a is the concentration at the upstream site, in mg/L,

ΔQ_a is the discharge error at the upstream site, in mg/L, and

0.0864 is the conversion factor from mg/s to kg/day.

Load error can be calculated for each stream site and compared to the change in load from that site to the next site downstream, ΔM_s . If ΔM_s is greater than the calculated load error, then there has been a significant change in load. Only the changes of instream load that are greater than the load error are included in the longitudinal profiles of sampled instream load and the cumulative instream load.

QUANTIFICATION OF METAL LOADING

Descriptions of synoptic sampling sites, calculated discharge, and tracer concentrations are listed in table 1. Results of chemical analyses for the synoptic samples are presented in tables 2, 3, and 4. Although 41 stream sites were sampled, these sites define only 28 stream segments because some samples were multiple samples collected across the channel at the same distance and others were replicates collected at individual sites. Samples that are considered to be collected from the main channel of flow are indicated by segment numbers in the "Segment" column of table 1, and data from these samples are used to calculate loads for stream segments.

Six stream samples and one inflow sample were collected outside the injection reach; a footnote indicates these samples in table 1. The stream segments they represent are of a much different scale than that of the samples collected in the injection reach. Only one of these stream segments contained an inflow sample. Although there were inflows that could have been sampled in these segments, that was not an objective of this study. Changes in tracer concentration in these segments can still provide information about possible metal loading to the stream.

The precision and accuracy of metal and anion analyses were determined by running sets of certified standards and standard reference samples repeatedly. This allowed the calculation of single operator precision by the method suggested by Friedman and Erdmann (1982). Precision was determined as a function of concentration and was calculated for individual samples from a power equation in load calculations. The coefficient and exponent of the power equations for each element are listed in table 5, along with lower detection limits and the average accuracy of repeated analyses of certified standards.

Discharge

Breakthrough of the tracer was sampled at four sites along the study reach (transport sites are indicated as T1 through T4 in table 1). The difference in plateau concentration at these sites indicates the dilution from inflows to the stream between sites (fig. 3). Bromide concentration varied substantially during plateau periods for the transport sites. Samples were run several times to determine if this was an analytical problem,

but the results were similar each time. Because other tracer-injection studies have not shown this kind of variation in Br concentration, something peculiar about the water in this area of beaver ponds could have caused the variation. The variation did not adversely affect the determination of plateau concentrations, however. Arrival of the tracer at each transport site indicates the average residence time for constituents between sites.

Along the entire study reach from Park City to Wanship, discharge increased from 71.9 to 538 L/s, for a total increase of 466 L/s. Discharge at the site upstream from the waste-water treatment plant (6,000 m) was only 28.9 L/s, which was much less than the discharge of 235 L/s measured at 5,500 m. A reconnaissance of the section between the sites at 5,500 and 6,000 m in May 2003 revealed that these two discharges are not related. The discharge at 6,000 m represents dispersed discharge of ground water to the Silver Creek channel after the water at 5,500 m flows in an irrigation diversion (fig. 1). Thus, segment S25 represents the end of the load accounting that starts at segment S1, and segment 26 represents water draining the piles and flood-plain deposits of mine tailings between these two sites. The increase in discharge at 6,500 m represents the discharge of the waste-water treatment plant as well as a substantial ground-water inflow that could contribute to metal loading.

Discharge increased by 47.7 L/s through the Silver Maple Claims area (from 360 m to 1,017 m). Bromide concentrations (fig. 4) only indicated three increases in discharge within the Silver Maple Claims area. The first increase occurred between 360 m and 398 m where the pipe draining the Silver Creek tailings discharged to the stream. Tracer dilution accounted for an increase of 42.4 L/s in that stream segment, which was 89 percent of the increase through the Silver Maple Claims area. An individual measurement of discharge was made at the end of the pipe by using a flow meter and determining the cross-sectional area at the end of the pipe, indicating 12.7 L/s for the discharge of the pipe. This is slightly higher than 8.5 and 10.5 L/s, which were measured in 1987 before the end of the pipe was under water (Mason, 1989). Thus, 30 percent of the increase in flow that was measured by the tracer was from the pipe and 70 percent was from dispersed, subsurface inflow.

Table 2. Physical properties of synoptic and quality-assurance samples, Silver Creek, Utah

[Source: S, stream, LBI, left bank inflow]

Sample identification	Source	Distance (meters)	Date	Time	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	pH (standard units)	Temperature (degrees Celsius)
SCS-0000	S	0	05/01/02	11:25	1,668	8.40	9.0
SCS-0072	S	72	05/02/02	15:00	1,621	8.90	12.0
SCS-0225	S	225	05/02/02	14:54	1,561	8.88	12.0
SCS-0265	S	265	05/02/02	14:50	1,542	8.91	11.5
SCI-0300	LBI	300	05/02/02	14:47	1,894	9.58	21.0
SCS-0360	S	360	05/02/02	14:33	1,596	8.83	13.5
SCI-0370	LBI	370	05/02/02	14:18	2,130	6.32	9.5
SCI-0375	LBI	375	05/01/02	12:05	994	7.98	12.5
SCI-0378	LBI	378	05/02/02	14:41	3,710	6.72	11.5
SCS-0398A	S	398	05/02/02	14:02	1,693	7.65	13.0
SCS-0398B	S	398	05/02/02	14:09	1,681	7.67	12.5
SCS-0490R	S	497	05/02/02	13:56	1,788	7.69	14.0
SCS-0490R	S	497	05/02/02	13:56	1,788	7.69	14.0
SCS-0498C	S	498	05/02/02	13:51	1,785	7.85	14.0
SCS-0498L	S	499	05/02/02	13:42	1,906	7.83	12.0
SCS-0543L	S	542	05/02/02	13:33	1,861	7.96	12.5
SCS-0543C	S	543	05/02/02	13:28	1,782	8.22	13.0
SCS-0543R	S	544	05/02/02	13:21	1,852	7.92	12.0
SCS-0576	S	576	05/02/02	13:15	1,792	7.84	12.0
SCS-0637R	S	637	05/02/02	13:08	1,773	8.55	11.5
SCS-0637L	S	638	05/02/02	12:59	1,788	7.82	11.5
SCS-0684	S	684	05/02/02	12:45	1,778	7.77	11.5
SCS-0711	S	710	05/02/02	12:40	1,773	7.77	12.0
SCS-0778A	S	778	05/02/02	11:52	1,836	7.77	9.0
SCS-0778B	S	778	05/02/02	11:55	1,835	7.76	9.0
SCS-0832L	S	831	05/02/02	11:43	1,855	7.73	9.0
SCS-0832C	S	832	05/02/02	11:40	1,857	7.77	8.5
SCS-0832R	S	833	05/02/02	11:24	1,870	7.76	9.0
SCS-0877	S	877	05/02/02	11:19	1,884	7.78	8.5
SCS-0940L	S	940	05/02/02	10:57	1,904	7.72	
SCS-0990L	S	989	05/02/02	11:08	1,880	7.67	8.0
SCS-0990C	S	990	05/02/02	11:15	1,883	7.61	8.0
SCI-0991	LBI	991	05/02/02	10:52	2,480	7.36	7.5
SCS-0992	S	992	05/02/02	10:49	1,906	7.73	8.0
SCS-1017	S	1,017	05/02/02	10:38	1,913	7.77	7.5
SCS-1079L	S	1,079	05/02/02	10:30	1,957	7.76	8.0
SCS-1079C	S	1,080	05/02/02	10:26	1,936	7.74	7.0
SCS-1079R	S	1,081	05/02/02	10:23	1,931	7.74	7.0
SCI-1140	LBI	1,140	05/02/02	10:09	999	8.10	9.5
SCS-1162	S	1,162	05/02/02	10:13	1,934	7.72	6.5
SCS-1165	S	1,165	05/02/02	10:05	1,801	7.76	8.0
SCS-1212	S	1,212	05/02/02	9:55	1,920	7.68	6.0
SCS-1344A	S	1,344	05/02/02	9:38	1,942	7.65	6.0

Table 2. Physical properties of synoptic and quality-assurance samples, Silver Creek, Utah—Continued

Sample identification	Source	Distance (meters)	Date	Time	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	pH (standard units)	Temperature (degrees Celsius)
SCS-1344B	S	1,344	05/02/02	9:40	1,939	7.69	6.0
SCS-1380	S	1,380	05/02/02	9:30	1,801	7.75	6.0
SCS-1420	S	1,420	05/02/02	9:25	1,923	7.78	6.0
SCS-5000A	S	5,000	05/01/02	15:45	1,463	8.03	12.0
SCS-5000B	S	5,500	05/01/02	15:35	1,449	8.11	12.0
SCS-6000A	S	6,000	05/01/02	15:00	1,835	7.69	
SCS-6000B	S	6,500	05/01/02	14:10	1,790	7.86	11.0
SCS-7000	S	7,000	05/01/02	13:05	710	8.14	8.5
SCF1-BLNK	QA	8,888	05/02/02				
SCF2-BLNK	QA	8,888	05/02/02				
SCL-BLNK	QA	8,888	05/02/02				

The second increase of only 0.2 L/s occurred in segment S8 and probably was dispersed, subsurface inflow also. This was less than 1 percent of the increase. The final increase of 5.1 L/s occurred in segment S13 and accounted for 11 percent of the total. The largest beaver pond was present in this segment. No inflows were present, however, and the increase was likely from dispersed, subsurface inflow.

Chemical Character of Synoptic Samples

Three distinct changes in the chemical character of stream water occurred along the study reach (table 6). Upstream from the Silver Maple Claims area (segments S1 through S5), the dominant ions were Na and Cl, and the median pH was 8.89 (table 6, group 1; fig. 5A). Downstream from the Silver Creek tailings discharge pipe (segment S6), Ca and SO₄ concentrations increased (fig. 5B) and pH decreased to a median of 7.82 (table 6; fig. 5A). Finally, at the downstream end of the largest beaver pond (segment S13), the concentration of most of the major ions increased slightly, but the increase was greatest for Na and Cl. At that same location, pH decreased to a median of 7.75 (table 6, group 3).

Instream metal concentrations ranged from less than 1 µg/L for several constituents to greater than 3,000 µg/L for Zn (fig. 6). Many samples had concentrations of Al, Fe, Mn, Sr, and Zn that exceeded 100 µg/L. Median concentrations of colloidal Al, Cu, Fe, and Pb were greater than the median dissolved concen-

trations, which is consistent with the high pH along the study reach and the normal geochemical behavior of these metals (Nordstrom and Alpers, 1999).

The spatial variation of metal concentrations was greater than the variation of the major ions. Three general patterns of variation occurred along the study reach. Upstream from the Silver Maple Claims area (segments S1 through S5), colloidal concentrations of Al, Cu, and Fe were relatively high, as illustrated by the variation of Al concentration (fig. 7). At the beginning of the Silver Maple Claims area, concentrations of these metals decreased, possibly as a result of flow through thick vegetation in the wetland. Colloidal concentrations of these metals, however, continued through the wetland at a lower level.

A second pattern of concentration was important for most metals and SO₄ (fig. 5B). The pattern was distinguished by an increase in concentration downstream from the Silver Creek tailings discharge pipe at segment S6; the concentration of Zn doubled along that segment (fig. 8). A second increase in Zn concentration occurred downstream from the largest beaver pond (segment S13). A similar increase occurred for arsenic (As), Fe, Pb, Mn, and Sr, but not for Cd or Cu (table 4). Total-recoverable Zn remained nearly constant along the remainder of the injection study reach, but a part of the Zn was transformed from the dissolved to the colloidal phase because of the high pH of the stream (fig. 8). Note that Zn concentrations exceeded aquatic-life standards along the entire study reach; the standards are indicated on figure 8.

Table 3. Results of chemical analyses of major constituents in synoptic and quality-assurance samples, Silver Creek, Utah

[Treatment: FA, 0.45-micrometer filtered, RA, total recoverable; mg/L, milligrams per liter]

Sample identification	Treatment	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Alkalinity as CaCO ₃ (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica, as Si (mg/L)
SCS-0000	FA	110	25.0	172	2.7	101	135	366	0.93	5.22
SCS-0000	RA	96.5	23.4	146	2.5	101	135	366	.93	5.16
SCS-0072	FA	105	24.3	167	2.8	77.4	117	377	1.28	5.56
SCS-0072	RA	106	25.3	164	2.7	77.4	117	377	1.28	6.61
SCS-0225	FA	106	24.2	153	2.6	99.4	145	319	.95	5.35
SCS-0225	RA	103	23.8	143	2.8	99.4	145	319	.95	6.23
SCS-0265	FA	94.0	22.0	131	2.5	84.4	127	280	.88	4.52
SCS-0265	RA	100	23.7	145	2.8	84.4	127	280	.88	6.13
SCI-0300	FA	92.7	23.9	217	3.4	40.8	152	430	1.24	1.45
SCI-0300	RA	89.5	24.1	203	3.3	40.8	152	430	1.24	1.26
SCS-0360	FA	109	24.3	160	2.9	96.4	149	333	.92	4.98
SCS-0360	RA	108	24.5	150	2.9	96.4	149	333	.92	5.64
SCI-0370	FA	288	40.1	118	5.7	66.9	638	305	1.99	12.0
SCI-0370	RA	292	41.7	116	6.0	66.9	638	305	1.99	16.1
SCI-0375	FA	104	35.4	28.9	1.5	136	214	80.8	.52	4.64
SCI-0375	RA	116	38.4	32.1	1.8	136	214	80.8	.52	7.13
SCI-0378	FA	319	59.1	399	7.6	112	785	728	3.32	10.7
SCI-0378	RA	334	60.5	415	7.1	112	785	728	3.32	11.1
SCS-0398A	FA	132	26.9	151	3.2	91.1	219	322	1.04	6.00
SCS-0398A	RA	128	26.5	142	3.3	91.1	219	322	1.04	6.45
SCS-0398B	FA	118	24.1	125	3.1	74.7	183	287	1.04	4.82
SCS-0398B	RA	122	24.6	129	2.8	74.7	183	287	1.04	5.68
SCS-0490R	FA	136	27.8	164	3.3	93.2	222	348	1.05	5.40
SCS-0490R	RA	133	27.2	153	3.2	93.2	222	348	1.05	5.75
SCS-0498C	FA	138	28.2	167	3.2	92.0	213	365	1.06	5.40
SCS-0498C	RA	130	27.4	158	3.2	92.0	213	365	1.06	5.44
SCS-0498L	FA	120	25.0	160	3.3	85.8	185	339	1.41	4.30
SCS-0498L	RA	125	25.6	168	3.3	85.8	185	339	1.41	5.02
SCS-0543L	FA	133	26.9	186	3.5	93.9	204	387	1.14	5.21
SCS-0543L	RA	125	26.3	171	3.3	93.9	204	387	1.14	5.26
SCS-0543C	FA	112	24.3	143	3.0	76.9	178	308	1.13	4.27
SCS-0543C	RA	114	25.1	145	3.1	76.9	178	308	1.13	4.40
SCS-0543R	FA	125	26.1	147	3.1	81.9	191	328	1.26	4.43
SCS-0543R	RA	125	26.8	151	3.1	81.9	191	328	1.26	5.26
SCS-0576	FA	140	28.6	173	3.5	98.1	220	370	1.17	5.47
SCS-0576	RA	123	26.6	146	3.0	98.1	220	370	1.17	4.83
SCS-0637R	FA	138	27.4	163	3.3	94.6	218	351	1.10	5.51
SCS-0637R	RA	127	26.9	153	3.3	94.6	218	351	1.10	5.47
SCS-0637L	FA	120	24.9	141	3.4	82.5	190	308	1.15	4.59
SCS-0637L	RA	127	27.6	158	3.2	82.5	190	308	1.15	5.28
SCS-0684	FA	122	25.0	142	2.9	86.7	190	311	1.10	4.36
SCS-0684	RA	120	24.9	137	2.9	86.7	190	311	1.10	4.58
SCS-0711	FA	121	25.3	139	3.0	80.9	190	308	1.10	4.25
SCS-0711	RA	122	25.2	144	3.0	80.9	190	308	1.10	4.74

Table 3. Results of chemical analyses of major constituents in synoptic and quality-assurance samples, Silver Creek, Utah—Continued

Sample identification	Treatment	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Alkalinity as CaCO ₃ (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica, as Si (mg/L)
SCS-0778A	FA	135	28.0	166	2.9	98.5	210	356	1.27	5.73
SCS-0778A	RA	132	28.1	163	3.1	98.5	210	356	1.27	5.19
SCS-0778B	FA	135	28.9	172	3.4	99.9	214	364	1.24	5.39
SCS-0778B	RA	131	28.3	160	2.8	99.9	214	364	1.24	5.21
SCS-0832L	FA	124	26.0	147	3.0	89.0	190	324	1.26	4.18
SCS-0832L	RA	126	27.9	163	3.0	89.0	190	324	1.26	4.96
SCS-0832C	FA	127	27.3	154	2.8	91.4	194	337	1.18	4.36
SCS-0832C	RA	127	28.5	165	3.2	91.4	194	337	1.18	5.06
SCS-0832R	FA	138	29.0	178	3.5	112	217	369	1.25	5.03
SCS-0832R	RA	124	27.7	158	3.0	112	217	369	1.25	4.86
SCS-0877	FA	144	29.6	187	3.4	105	227	393	1.32	5.16
SCS-0877	RA	124	28.6	166	3.2	105	227	393	1.32	4.96
SCS-0940L	FA	141	29.1	182	3.6	102	221	384	1.33	5.26
SCS-0940L	RA	132	29.0	169	3.2	102	221	384	1.33	5.16
SCS-0990L	FA	129	26.6	152	3.0	86.6	181	349	1.15	4.23
SCS-0990L	RA	130	28.6	170	3.1	86.6	181	349	1.15	5.03
SCS-0990C	FA	129	27.0	154	3.0	92.6	195	339	1.26	4.40
SCS-0990C	RA	127	28.5	167	3.2	92.6	195	339	1.26	5.16
SCI-0991	FA	175	36.7	292	4.6	138	291	569	2.81	6.68
SCI-0991	RA	172	35.2	268	4.4	138	291	569	2.81	7.03
SCS-0992	FA	145	30.1	181	3.3	106	224	388	1.37	5.87
SCS-0992	RA	136	29.4	177	3.2	106	224	388	1.37	5.28
SCS-1017	FA	131	27.9	159	3.1	94.9	199	348	1.42	4.28
SCS-1017	RA	142	29.9	175	3.4	94.9	199	348	1.42	5.56
SCS-1079L	FA	147	32.7	189	3.3	108	230	405	1.38	5.18
SCS-1079L	RA	135	29.9	166	3.2	108	230	405	1.38	4.53
SCS-1079C	FA	127	27.1	157	3.2	91.2	194	341	1.23	4.21
SCS-1079C	RA	125	27.0	158	3.1	91.2	194	341	1.23	4.69
SCS-1079R	FA	126	26.8	157	3.0	91.3	193	341	1.40	4.25
SCS-1079R	RA	137	29.5	178	3.2	91.3	193	341	1.40	5.18
SCI-1140	FA	105	33.2	30.6	1.5	129	192	99.0	.54	4.74
SCI-1140	RA	107	36.1	31.2	1.6	129	192	99.0	.54	5.16
SCS-1162	FA	125	27.6	157	3.0	94.2	195	337	1.31	4.34
SCS-1162	RA	140	29.0	171	3.3	94.2	195	337	1.31	4.95
SCS-1165	FA	123	29.5	130	2.7	103	195	291	1.07	3.88
SCS-1165	RA	141	34.1	149	3.3	103	195	291	1.07	5.19
SCS-1212	FA	128	27.8	160	2.9	94.6	198	345	1.38	4.29
SCS-1212	RA	143	30.1	178	3.3	94.6	198	345	1.38	5.25
SCS-1344A	FA	147	31.2	188	3.7	106	232	399	1.33	5.08
SCS-1344A	RA	142	29.6	172	3.3	106	232	399	1.33	4.94
SCS-1344B	FA	129	27.3	161	3.3	92.0	200	346	1.39	4.31
SCS-1344B	RA	136	30.1	177	3.1	92.0	200	346	1.39	5.02
SCS-1380	FA	128	26.8	158	2.7	91.0	199	341	1.38	4.44
SCS-1380	RA	140	29.2	169	3.3	91.0	199	341	1.38	4.86
SCS-1420	FA	143	30.9	189	3.5	90.6	196	432	1.42	5.42

Table 3. Results of chemical analyses of major constituents in synoptic and quality-assurance samples, Silver Creek, Utah—Continued

Sample identification	Treatment	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Alkalinity as CaCO ₃ (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica, as Si (mg/L)
SCS-1420	RA	145	31.2	186	3.2	90.6	196	432	1.42	5.92
SCS-5000A	FA	119	35.0	87.8	2.3	117	223	204	.94	3.37
SCS-5000A	RA	121	34.5	88.2	2.3	117	223	204	.94	3.62
SCS-5000B	FA	123	34.5	80.5	2.3	120	230	191	.94	3.87
SCS-5000B	RA	125	36.4	82.6	2.5	120	230	191	.94	4.37
SCS-6000A	FA	204	51.9	98.4	3.5	143	461	333	1.40	11.1
SCS-6000A	RA	202	52.3	100	3.7	143	461	333	1.40	11.5
SCS-6000B	FA	146	40.3	145	9.1	158	333	364	1.24	10.8
SCS-6000B	RA	151	38.7	139	8.3	158	333	364	1.24	11.9
SCS-7000	FA	60.0	12.8	40.5	3.1	113	76	184	.08	8.70
SCS-7000	RA	61.9	13.9	41.2	3.1	113	76	184	.08	10.3
SCF1-BLNK	FA	.088	.029	.067	.040					.05
SCF1-BLNK	RA	.088	.029	.067	.015					.05
SCF2-BLNK	FA	.088	.029	.067	.015					.05
SCF2-BLNK	RA	.088	.029	.067	.015					.05
SCL-BLNK							.03	.02	.01	
SCT-BLNK	RA	.088	.029	.067	.015					.05

The final pattern of concentration was unique to the variation of Na and Cl and consisted in a nearly constant concentration along the injection reach (fig. 9). The concentration of Na and Cl correlated with the high concentrations of salt on the highway next to the Silver Maple Claims area. The equivalents of Cl actually exceed the equivalents of Na in the stream. The excess Cl balances some of the Ca and Mg, indicating that these alkaline-earth chlorides may be used as road salt along with NaCl.

Only five inflow samples were collected along the study reach (table 1). This small number could be a result of the high flow that may have covered some inflows that would be visible at a lower stage of the stream. The Pace-Homer Ditch (375 m) was sampled across the highway from the injection study reach. The inflow sample at 1,140 m represented water flowing to the stream from a breach in the Pace-Homer Ditch, and this relatively small flow started mixing with the stream at about 1,165 m. Two inflow samples at 378 m and 991 m were collected from small ponds that had no visible connection to the flow in the stream. These may represent water that drains from tailings piles along the study reach. For purposes of quantifying loads, the most important inflow sample was the end of the ground-water drain pipe from the Silver Creek tailings (sample PS-DR-1 of Mason, 1989). Obtaining a sample

from the Prospector pipe was complicated because the discharge from the end of the pipe was below the surface of a pond at the upstream end of the BLM property (fig. 10).

The inflow sample from the Silver Creek tailings pipe had a Br concentration of 0.77 mg/L, indicating that the sample included some fraction of pond water. This could have happened as the vertical-integrating sampler was lowered from the surface to the end of the pipe. Assuming that the pipe sample should have had a Br concentration closer to a background concentration of 0.06 mg/L, and given the plateau concentration of Br at the upstream end of the pond of 4.21 mg/L, it is possible to determine the fraction of pond water in the sample:

$$\begin{aligned}
 (4.21)x + (0.06)y &= 0.77 \\
 x + y &= 1 \\
 x &= 0.17; y = 0.83
 \end{aligned}
 \tag{7}$$

where

x is the fraction of pond water, and
 y is the fraction of pipe discharge.

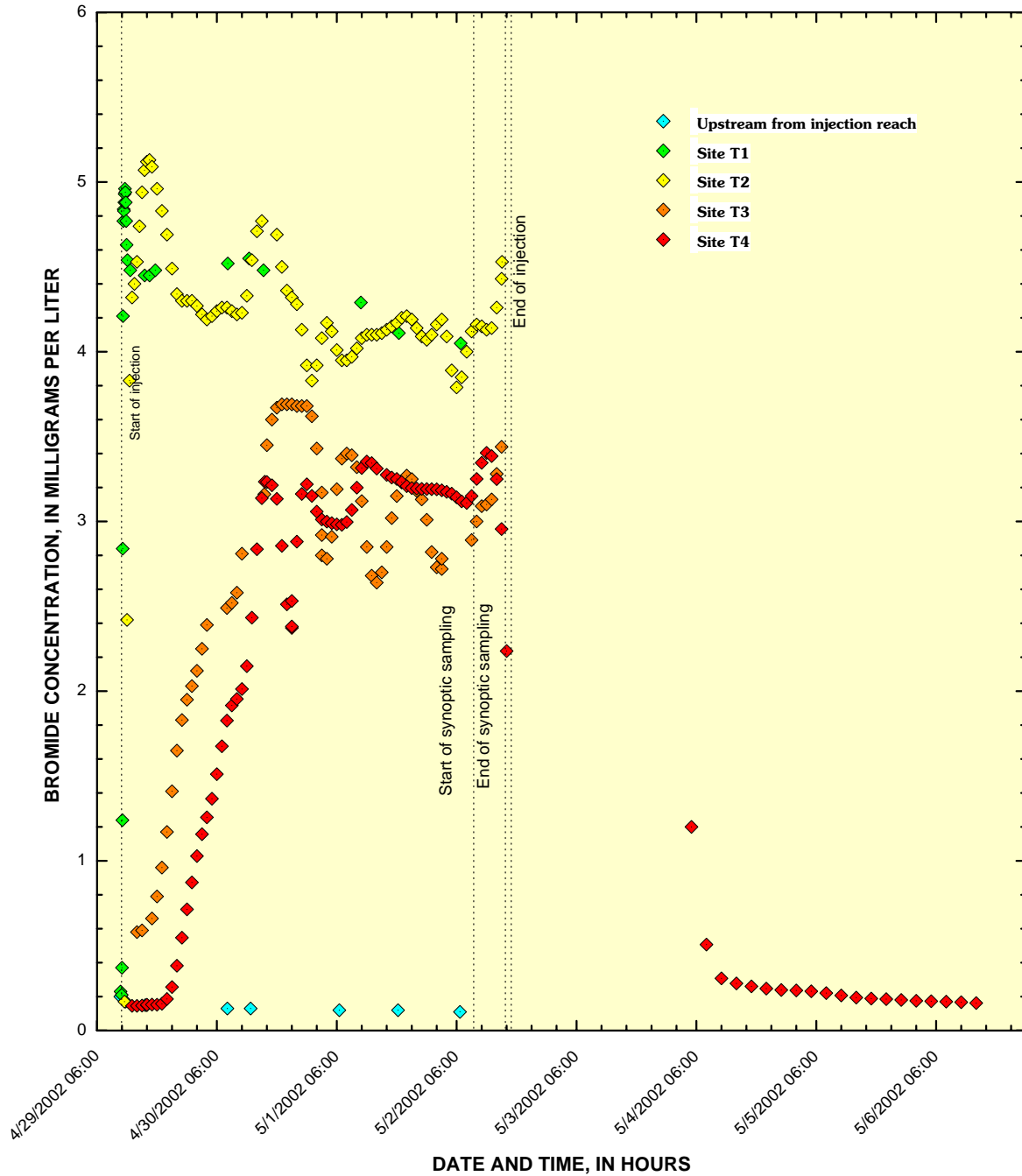


Figure 3. Variation of bromide concentration at transport sites with time, Silver Creek, Utah, April and May 2002.

Table 4. Results of chemical analyses of trace constituents in synoptic and quality-assurance samples, Silver Creek, Utah

[Source: S, stream; LBI, left bank inflow; Treatment: FA, 0.45-micrometer filtered, RA, total recoverable; µg/L, micrograms per liter]

Sample identification	Treatment	Aluminum (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)
SCS-0000	FA	38.1	2.80	110	7.18	0.13	0.34	2.59	5.37	0.66
SCS-0000	RA	302.2	3.81	120	8.80	.45	.47	4.57	343	15.0
SCS-0072	FA	41.6	2.98	103	2.69	.13	.36	3.14	8.92	.68
SCS-0072	RA	423.9	4.86	110	6.65	.71	.53	6.83	477	14.3
SCS-0225	FA	33.4	3.59	103	3.68	.14	.29	3.13	5.56	.70
SCS-0225	RA	436.8	5.01	106	7.42	.70	.56	6.98	470	14.4
SCS-0265	FA	27.2	2.99	101	3.62	.13	.32	2.83	4.32	.63
SCS-0265	RA	452.1	5.10	120	7.67	.72	.53	6.92	480	15.6
SCI-0300	FA	37.0	7.54	109	.10	.15	.21	2.56	11.0	.88
SCI-0300	RA	217.3	8.08	112	2.10	.45	.28	3.78	321	19.7
SCS-0360	FA	33.5	2.95	96.2	3.46	.12	.31	2.83	3.90	1.24
SCS-0360	RA	321.6	4.60	104	6.67	.50	.47	5.21	330	14.0
SCI-0370	FA	36.0	1.08	23.8	34.3	.11	.88	1.35	54.0	.47
SCI-0370	RA	2,469.5	76.0	45.4	43.6	4.21	3.25	29.2	8,859	182
SCI-0375	FA	41.1	7.10	48.6	.22	.15	.38	.80	4.81	.60
SCI-0375	RA	451.0	8.47	49.2	.40	.61	.49	2.53	418	12.4
SCI-0378	FA	119.2	6.90	62.4	26.2	.14	12.7	13.3	2,600	4.03
SCI-0378	RA	113.0	11.5	55.9	26.9	.12	15.1	11.2	4,533	17.1
SCS-0398A	FA	33.6	2.54	80.3	8.08	.10	.35	2.07	4.40	1.03
SCS-0398A	RA	317.3	3.49	88.6	12.1	.51	.51	5.11	348	15.1
SCS-0398B	FA	23.2	2.42	90.5	9.47	.11	.46	2.18	3.78	.91
SCS-0398B	RA	263.5	3.86	89.1	11.9	.49	.45	5.17	314	15.6
SCS-0490R	FA	31.5	2.59	86.2	7.53	.09	.31	1.93	4.58	1.03
SCS-0490R	RA	170.2	2.42	104	11.4	.32	.41	3.95	196	9.28
SCS-0498C	FA	30.0	2.70	93.7	6.02	.09	.35	2.05	6.26	.86
SCS-0498C	RA	156.9	3.70	97.0	9.43	.30	.39	3.84	206	9.90
SCS-0498L	FA	26.9	9.67	92.9	5.77	.06	.85	2.17	19.5	.40
SCS-0498L	RA	109.1	5.70	84.9	7.97	.21	.82	4.00	434	9.27
SCS-0543L	FA	32.5	2.43	87.0	3.35	.05	.53	1.43	17.6	.39
SCS-0543L	RA	217.3	5.29	88.6	7.27	.40	.58	4.98	569	17.2
SCS-0543C	FA	79.1	2.38	84.6	3.77	.11	.31	1.83	9.35	.53
SCS-0543C	RA	70.5	3.88	90.5	5.72	.21	.30	2.94	195	7.00
SCS-0543R	FA	25.4	2.65	94.6	8.04	.09	.33	1.69	4.58	1.36
SCS-0543R	RA	189.5	3.00	95.3	10.6	.32	.37	3.68	222	13.5
SCS-0576	FA	37.5	2.14	77.5	5.45	.08	.30	1.73	7.22	.84
SCS-0576	RA	98.4	3.22	84.1	8.73	.24	.35	3.61	199	9.81
SCS-0637R	FA	29.0	2.09	85.6	5.55	.08	.31	1.45	6.90	.84
SCS-0637R	RA	137.9	3.43	90.3	8.90	.28	.41	3.52	230	10.2
SCS-0637L	FA	40.1	1.80	76.3	4.30	.07	.28	1.39	8.43	.60
SCS-0637L	RA	98.1	3.90	96.5	8.23	.23	.37	3.11	246	10.2
SCS-0684	FA	24.3	2.34	88.7	5.03	.07	.26	1.37	7.57	.62
SCS-0684	RA	85.9	3.46	92.6	7.36	.23	.36	3.15	209	9.41
SCS-0711	FA	24.1	1.72	89.6	4.59	.08	.20	1.52	5.44	.91
SCS-0711	RA	104.6	3.25	82.4	6.56	.24	.25	3.13	189	13.0
SCS-0778A	FA	29.0	2.58	82.5	3.56	.05	.36	1.22	11.0	.75
SCS-0778A	RA	115.5	4.39	96.3	7.67	.26	.42	3.99	265	17.3
SCS-0778B	FA	34.1	1.89	86.0	3.83	.05	.35	1.32	11.2	.74
SCS-0778B	RA	119.2	4.30	87.8	7.03	.21	.41	3.88	280	19.1

Table 4. Results of chemical analyses of trace constituents in synoptic and quality-assurance samples, Silver Creek, Utah—Continued

Sample identification	Treatment	Lithium (µg/L)	Manganese (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Silver (µg/L)	Strontium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
SCS-0000	FA	8.84	140	1.49	2.05	0.08	415	0.70	963
SCS-0000	RA	8.36	169	1.41	1.99	.47	388	1.12	1,038
SCS-0072	FA	8.93	121	1.75	1.30	.08	429	.94	259
SCS-0072	RA	9.21	171	1.75	1.77	.36	456	1.62	741
SCS-0225	FA	9.31	121	1.82	1.44	.08	420	.94	358
SCS-0225	RA	9.31	160	1.88	2.12	.33	461	1.64	876
SCS-0265	FA	8.07	108	1.82	1.21	.08	462	.83	327
SCS-0265	RA	9.64	167	1.96	2.17	.39	407	1.57	874
SCI-0300	FA	10.3	24.0	3.37	1.03	.08	466	2.41	17.0
SCI-0300	RA	12.1	66.8	3.32	1.59	.14	453	2.99	214
SCS-0360	FA	7.50	124	1.59	1.43	.08	465	.88	357
SCS-0360	RA	9.53	161	1.62	2.00	.37	407	1.35	830
SCI-0370	FA	17.7	615	.17	15.8	.08	602	.23	7,930
SCI-0370	RA	18.7	1,010	.53	19.4	7.21	556	9.69	8,557
SCI-0375	FA	8.84	23.4	2.20	1.08	.08	769	1.14	57.7
SCI-0375	RA	10.5	49.0	2.32	1.27	.10	727	1.91	72.0
SCI-0378	FA	32.1	3,220	1.14	18.5	.08	692	.02	17,068
SCI-0378	RA	37.3	3,244	1.34	21.5	.11	765	.09	17,419
SCS-0398A	FA	8.33	206	1.38	3.36	.08	472	.67	1,646
SCS-0398A	RA	10.3	226	1.41	3.95	.41	455	1.17	1,882
SCS-0398B	FA	9.48	182	1.56	4.25	.08	480	.77	1,560
SCS-0398B	RA	9.18	217	1.37	4.84	.36	426	1.18	1,720
SCS-0490R	FA	8.75	175	1.28	2.95	.08	476	.65	1,528
SCS-0490R	RA	9.55	187	1.45	4.12	.23	497	1.01	1,651
SCS-0498C	FA	10.5	167	1.36	3.19	.08	448	.72	1,240
SCS-0498C	RA	10.6	180	1.35	3.32	.21	456	1.01	1,361
SCS-0498L	FA	10.3	391	1.93	3.57	.08	493	.33	1,422
SCS-0498L	RA	11.9	402	1.74	3.14	.17	430	.65	1,631
SCS-0543L	FA	9.78	299	1.69	2.93	.08	490	.34	1,201
SCS-0543L	RA	12.4	290	1.63	4.25	.22	430	.97	1,366
SCS-0543C	FA	11.4	127	1.57	2.96	.08	461	.63	863
SCS-0543C	RA	10.4	135	1.50	2.51	.11	445	.78	990
SCS-0543R	FA	8.69	158	1.20	2.94	.08	473	.55	1,378
SCS-0543R	RA	8.85	181	1.19	3.21	.23	435	.86	1,601
SCS-0576	FA	8.66	196	1.30	2.89	.08	478	.48	1,484
SCS-0576	RA	9.11	189	1.35	3.73	.13	454	.74	1,445
SCS-0637R	FA	8.26	175	1.32	3.10	.08	438	.47	1,455
SCS-0637R	RA	12.7	184	1.46	4.72	.16	471	.87	1,608
SCS-0637L	FA	8.81	182	1.34	2.89	.08	485	.39	1,314
SCS-0637L	RA	10.7	208	1.49	3.90	.17	457	.68	1,580
SCS-0684	FA	9.30	148	1.38	3.05	.08	506	.41	1,333
SCS-0684	RA	11.5	163	1.53	4.42	.15	509	.75	1,402
SCS-0711	FA	9.74	104	1.51	3.28	.08	469	.50	1,152
SCS-0711	RA	9.75	127	1.46	4.85	.16	402	.73	1,248
SCS-0778A	FA	8.91	241	1.37	3.37	.08	503	.29	1,882
SCS-0778A	RA	11.1	250	1.54	4.76	.20	480	.62	1,938
SCS-0778B	FA	9.14	250	1.43	3.89	.08	504	.31	1,819
SCS-0778B	RA	9.93	247	1.45	4.27	.17	502	.59	1,955

Table 4. Results of chemical analyses of trace constituents in synoptic and quality-assurance samples, Silver Creek, Utah—Continued

Sample identification	Treatment	Aluminum (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)
SCS-0832L	FA	28.6	2.75	81.5	2.64	.04	.37	1.13	8.81	.86
SCS-0832L	RA	133.0	5.59	101	5.54	.25	.44	3.82	303	21.7
SCS-0832C	FA	35.1	2.95	93.6	2.43	.04	.39	.96	10.3	.72
SCS-0832C	RA	129.5	5.18	89.7	4.92	.21	.40	3.13	308	22.7
SCS-0832R	FA	42.3	2.90	75.5	1.81	.04	.35	1.04	10.6	.72
SCS-0832R	RA	103.7	5.11	89.1	4.33	.19	.38	2.78	258	18.0
SCS-0877	FA	43.1	3.19	80.3	2.32	.05	.29	1.28	71.0	3.53
SCS-0877	RA	81.0	4.08	87.4	3.54	.18	.33	2.24	219	11.8
SCS-0940L	FA	27.1	3.19	80.0	1.10	.03	.34	.92	13.5	.74
SCS-0940L	RA	185.9	5.67	93.0	4.01	.31	.45	4.39	382	29.1
SCS-0990L	FA	25.2	3.13	96.5	2.20	.04	.34	.97	9.20	.73
SCS-0990L	RA	117.0	5.44	87.5	4.82	.21	.40	3.08	281	20.2
SCS-0990C	FA	28.1	2.51	94.1	2.20	.03	.35	1.14	38.1	.63
SCS-0990C	RA	97.7	5.27	83.6	4.35	.22	.40	2.96	302	15.8
SCI-0991	FA	30.5	1.10	20.0	46.1	.01	.10	1.93	1.51	1.80
SCI-0991	RA	75.9	1.40	18.3	43.8	.12	.11	2.49	54.0	5.70
SCS-0992	FA	30.0	2.82	89.4	1.31	.03	.37	1.01	18.0	.64
SCS-0992	RA	126.7	4.73	97.1	3.81	.23	.38	3.24	339	22.5
SCS-1017	FA	24.8	2.33	84.4	1.29	.03	.41	1.04	15.7	.59
SCS-1017	RA	172.5	7.00	104	4.71	.34	.48	4.88	422	29.5
SCS-1079L	FA	33.8	2.88	79.4	1.82	.03	.17	1.34	6.71	.67
SCS-1079L	RA	52.4	3.62	77.9	3.14	.11	.19	1.87	145	7.66
SCS-1079C	FA	26.0	3.51	88.2	1.14	.03	.41	.74	12.1	.73
SCS-1079C	RA	155.3	6.84	97.1	4.69	.34	.50	5.12	427	32.0
SCS-1079R	FA	24.2	6.39	84.0	1.23	.02	.33	.92	17.0	.69
SCS-1079R	RA	110.8	4.94	87.4	3.43	.22	.37	3.09	288	17.5
SCI-1140	FA	40.4	5.43	43.8	.33	.19	.40	.86	3.67	.53
SCI-1140	RA	90.9	6.35	45.4	.38	.27	.38	1.47	110	5.01
SCS-1162	FA	26.4	3.18	91.9	1.43	.04	.36	1.16	11.0	.87
SCS-1162	RA	102.1	5.13	90.9	3.85	.19	.38	3.22	244	14.5
SCS-1165	FA	25.0	3.01	74.0	1.90	.05	.12	1.60	5.93	.92
SCS-1165	RA	165.6	5.06	76.2	3.52	.30	.22	3.57	271	24.8
SCS-1212	FA	29.1	2.77	93.5	1.44	.04	.35	1.22	18.6	.89
SCS-1212	RA	118.7	3.33	89.7	8.58	.27	.38	3.25	290	11.4
SCS-1344A	FA	35.3	3.01	73.5	1.80	.03	.32	1.56	9.27	1.66
SCS-1344A	RA	86.9	5.20	85.4	3.64	.16	.32	3.16	232	20.3
SCS-1344B	FA	26.4	3.54	87.3	1.91	.03	.33	1.33	7.08	1.49
SCS-1344B	RA	90.5	4.99	81.4	3.92	.17	.38	3.53	233	17.6
SCS-1380	FA	30.2	2.91	77.7	2.67	.02	.61	1.74	8.30	2.66
SCS-1380	RA	104.0	6.39	87.2	6.18	.27	.73	8.47	318	37.5
SCS-1420	FA	37.9	3.21	93.2	2.83	.02	.58	1.82	32.2	2.95
SCS-1420	RA	135.3	6.16	86.2	5.18	.26	.72	7.47	357	41.1
SCS-5000A	FA	31.5	2.54	59.8	3.18	.06	.41	2.60	16.4	1.85
SCS-5000A	RA	60.4	5.33	63.4	3.93	.10	.34	4.39	243	27.7
SCS-5000B	FA	32.6	2.97	59.7	2.14	.06	.25	2.81	10.9	4.11
SCS-5000B	RA	153.8	5.23	61.3	3.25	.21	.30	6.15	319	41.4
SCS-6000A	FA	40.0	8.87	57.9	12.6	.04	1.20	6.19	17.0	1.34
SCS-6000A	RA	32.0	13.7	55.0	13.8	.04	.99	7.05	219	10.4

Table 4. Results of chemical analyses of trace constituents in synoptic and quality-assurance samples, Silver Creek, Utah—Continued

Sample identification	Treatment	Lithium (µg/L)	Manganese (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Silver (µg/L)	Strontium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
SCS-0832L	FA	9.48	254	1.35	3.66	.08	536	.28	1,688
SCS-0832L	RA	10.7	279	1.54	4.93	.18	557	.63	1,969
SCS-0832C	FA	9.70	263	1.39	3.59	.08	492	.25	1,695
SCS-0832C	RA	9.82	284	1.33	3.49	.20	433	.48	1,948
SCS-0832R	FA	9.00	302	1.31	3.37	.08	516	.24	1,794
SCS-0832R	RA	9.53	284	1.44	3.71	.11	467	.48	1,846
SCS-0877	FA	8.85	258	1.31	3.54	.08	502	.28	1,741
SCS-0877	RA	11.0	246	1.38	4.56	.09	474	.43	1,824
SCS-0940L	FA	9.00	300	1.38	3.66	.08	528	.22	1,674
SCS-0940L	RA	10.9	299	1.42	4.03	.24	463	.58	1,869
SCS-0990L	FA	9.16	263	1.34	3.37	.08	472	.23	1,685
SCS-0990L	RA	9.61	296	1.41	4.17	.17	501	.49	2,008
SCS-0990C	FA	9.61	245	1.55	4.08	.08	521	.27	1,643
SCS-0990C	RA	10.1	264	1.45	4.08	.16	471	.48	1,889
SCI-0991	FA	14.6	78.3	.83	2.13	.08	601	.02	8,598
SCI-0991	RA	17.0	82.9	.85	3.06	.08	517	.07	8,421
SCS-0992	FA	9.53	297	1.47	3.75	.08	496	.22	1,741
SCS-0992	RA	10.7	308	1.47	3.83	.20	464	.48	1,899
SCS-1017	FA	10.1	293	1.51	4.02	.08	508	.22	1,570
SCS-1017	RA	11.3	337	1.60	4.83	.21	581	.65	1,957
SCS-1079L	FA	12.3	158	1.38	3.40	.08	551	.17	1,453
SCS-1079L	RA	11.4	157	1.31	3.00	.08	522	.27	1,465
SCS-1079C	FA	9.43	301	1.28	3.42	.08	481	.18	1,533
SCS-1079C	RA	11.1	318	1.52	4.87	.24	565	.66	1,752
SCS-1079R	FA	9.64	276	1.48	3.80	.08	522	.20	1,552
SCS-1079R	RA	10.7	289	1.45	4.47	.14	559	.42	1,817
SCI-1140	FA	11.2	26.1	2.05	1.22	.08	814	1.12	70.0
SCI-1140	RA	8.60	46.1	1.96	1.69	.08	719	1.14	82.1
SCS-1162	FA	10.8	249	1.67	4.27	.08	525	.25	1,485
SCS-1162	RA	11.2	282	1.63	4.09	.13	513	.48	1,711
SCS-1165	FA	9.67	81.7	1.40	2.46	.08	608	.31	1,159
SCS-1165	RA	9.85	146	1.53	3.25	.23	570	.71	1,426
SCS-1212	FA	9.91	246	1.62	3.92	.08	528	.23	1,490
SCS-1212	RA	10.3	281	1.44	3.51	.19	470	.79	1,859
SCS-1344A	FA	9.28	275	1.41	3.27	.08	532	.17	1,650
SCS-1344A	RA	10.2	263	1.41	3.19	.14	441	.32	1,697
SCS-1344B	FA	9.77	241	1.43	3.14	.08	502	.18	1,463
SCS-1344B	RA	11.0	271	1.46	4.38	.13	557	.42	1,751
SCS-1380	FA	9.24	259	1.44	3.56	.08	507	.19	1,629
SCS-1380	RA	10.9	279	1.67	4.01	.29	518	.49	1,881
SCS-1420	FA	9.47	287	1.44	3.39	.08	507	.18	1,875
SCS-1420	RA	11.0	305	1.55	4.44	.28	563	.47	1,950
SCS-5000A	FA	11.3	119	2.33	2.02	.08	776	.36	716
SCS-5000A	RA	11.2	146	2.21	2.01	.14	661	.51	819
SCS-5000B	FA	12.0	112	2.28	1.90	.08	844	.31	673
SCS-5000B	RA	12.4	139	2.08	1.86	.19	701	.57	789
SCS-6000A	FA	20.3	433	2.93	3.87	.08	1,182	.23	3,736
SCS-6000A	RA	20.7	448	2.60	3.72	.10	972	.24	3,880

Table 4. Results of chemical analyses of trace constituents in synoptic and quality-assurance samples, Silver Creek, Utah—Continued

Sample identification	Treatment	Aluminum (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)
SCS-6000B	FA	42.1	10.3	46.1	4.69	.20	.32	4.16	19.0	3.28
SCS-6000B	RA	44.0	12.9	49.9	5.28	.15	.32	7.18	104	26.8
SCS-7000	FA	104.4	6.40	72.8	.60	.14	.11	2.61	47.8	2.09
SCS-7000	RA	601.0	8.26	94.9	1.45	.58	.26	5.01	452	29.7
SCF1-BLNK	FA	34.4	.06	.10	.09	.01	.01	.25	1.19	.05
SCF1-BLNK	RA	28.9	.03	.10	.09	.06	.01	.25	11.5	.27
SCF2-BLNK	FA	24.3	.08	.13	.09	.01	.01	.25	1.60	.06
SCF2-BLNK	RA	24.6	.03	.10	.09	.04	.01	.25	38.4	.08
SCL-BLNK	FA									
SCT-BLNK	RA	4	.03	.10	.09	.01	.01	.25	1.00	.03

These fractions allow for a correction of the measured concentrations to make them representative of the undiluted pipe water. Corrected concentrations are listed in table 7. This is important for accurate calculation of load from the pipe.

Mass Loading

Mass-loading profiles were prepared according to the methods described by Kimball and others (2002), but several considerations were necessary for these data. First, load was calculated only for those sites that were judged to be in the main part of the flow (these sites are indicated by segment numbers in table 1). This was a subjective field observation when two or three samples were collected across the stream channel at essentially the same downstream distance along the study reach (fig. 2). Second, the calculated inflow load for the Silver Creek tailings discharge (370 m) was calculated from the measured discharge at the end of the pipe (table 1) and the adjusted concentrations of the constituents (table 5). This inflow load was comparable but somewhat greater than the instream load for most constituents in the segment from 360 m to 398 m that receives the Silver Creek tailings discharge. Third, loads calculated at 5,500 m and 6,000 m do not represent downstream change. The load at 5,500 m essentially is the end of accounting for the upstream load (segment S25). The load at 6,000 m represents the input from ground water downstream from the diversion (segment S26). The difference in constituent load between 6,000 m and 6,500 m, however, does represent a change that principally resulted from two inflows. One of the inflows was from the waste-water treatment

plant and the other was from ground-water drainage to the stream that had a high specific-conductance value, but neither inflow was sampled. Finally, the comparison of load calculated at 6,500 m and 7,000 m is not certain (segment S27). The stream between the two sites was not studied in detail, but the net change between 6,500 m and 7,000 m is reported to give an indication of changes downstream (segment S28).

Load calculations for selected constituents are summarized in table 8. These values represent only the positive or negative changes of instream load for individual segments. Segments where the five greatest loads occur for each constituent are indicated by numbers in parentheses in table 8. If no value is listed for a segment in the table, the change in load for that segment was less than the load error calculated from equation 6. In table 8, and in the figures representing loads, the change of instream load that might be attributed to a particular inflow is accounted for by the change in load for the segment that contains the inflow. For example, the instream load from the Silver Creek tailings discharge pipe is accounted for by segment S6. That is why there are only stream sites listed in table 8.

The first of three patterns among the constituent load profiles along the study reach was typical of Cd and Zn and is illustrated by the mass-loading profile of Zn (fig. 11). Two ways to account for the loading of Zn are presented in figure 11. A spatially oriented view (fig. 11A), includes details of the dissolved, colloidal, and total sampled instream loads (eq. 2), the cumulative instream load (eq. 3), and the inflow load (eq. 4). A comparative view (fig. 11B) for each segment allows a visual indication of which segments contribute the most to the mass load of Zn as well as which segments indicate a net loss of load ($\Delta M_s < 0$). The loads are

Table 4. Results of chemical analyses for trace constituents in synoptic and quality-assurance samples, Silver Creek, Utah—Continue

Sample identification	Treatment	Lithium (µg/L)	Manganese (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Silver (µg/L)	Strontium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
SCS-6000B	FA	12.9	220	5.08	2.40	.08	798	.66	1,616
SCS-6000B	RA	14.4	217	4.98	2.40	.18	693	.72	1,784
SCS-7000	FA	6.72	61.9	1.18	.91	.08	302	1.70	243
SCS-7000	RA	8.94	74.3	1.21	1.37	.14	290	2.47	328
SCF1-BLNK	FA	.70	8.00	.02	.49	.08	.46	.02	2.00
SCF1-BLNK	RA	.70	8.00	.02	.49	.08	.46	.01	2.00
SCF2-BLNK	FA	.70	8.00	.02	.49	.08	.76	.01	2.00
SCF2-BLNK	RA	.70	8.00	.02	.49	.08	.60	.01	2.00
SCL-BLNK	FA								
SCT-BLNK	RA	.70	8.00	.02	.49	.08	.46	.01	2.00

divided between the sampled inflow load (ΔM_i , eq. 4) and the unsampled inflow (eq. 5). The load of Zn was dominated by the discharge from the Silver Creek tailings pipe (segment S6) and the ground-water inflows upstream and downstream from the wastewater treatment plant (segments S26 and S27). Other substantial loading included sources upstream from the study reach (accounted for by segment S1), loading near the largest beaver pond (segment S13), and loading downstream from the injection reach at Richardson Flat (segment S25). This pattern also was typical of Cd (tables 8 and 9).

The second pattern was typical of SO₄, Mn, Na, and Sr (table 8); the pattern is illustrated by the mass-loading profile of SO₄ (fig. 12). For these constituents, substantial loading occurred from upstream sources (segment S1) and the Silver Creek tailings discharge pipe (segment S6). This pattern differs because of the large contributions to load from sources upstream from Richardson Flat (segment S24) and from Richardson Flat (segment S25). The third pattern was typical of Al, Cl, Cu, Fe, and Pb (table 8). The mass-loading pattern for Fe illustrates the third pattern (fig. 13). The unique characteristic of this pattern is the large increase in load in the last stream segment, S27.

Principal Locations of Mass Loading

These three patterns of mass-loading indicate eight principal sources of constituent loading:

1. Upstream from Silver Maple Claims area—includes segments S1 through S5 (table 6): This was most important for Na and Cl, which is an indication of the salt used on the roads. All the other constituents had measurable loads from upstream sources.
2. Silver Creek tailings discharge pipe—includes segment S6 (table 6): Every constituent had a measurable loading from the pipe discharge, but this was the major source of mass loading for Cd and Zn. It also was important for Cl, Mn, Na, Ni, and SO₄.
3. Remainder of Silver Maple Claims area—includes segments S7 through S18 (table 6): Measurable mass loading occurred for Al, Fe, Pb, Mn, Na, Ni, Zn, SO₄, and Cl. The mass loading was relatively small compared to other locations, however, and most loading occurred in segment S13.
4. Downstream from Silver Maple Claims area and upstream from Richardson Flat—includes segments S19 through S24 (table 6): Mass loading of Cd, Cu, and Pb was important in the segments S20 and S22. The greatest mass loading of Sr and SO₄ occurred in segment S24, which is upstream from Richardson Flat (5,000 m). This is the location of the “flood-plains” tailings along the left bank of the stream.
5. Richardson Flat—includes segment S25 (table 6): There was substantial mass loading for many constituents in the segment that brackets Richardson Flat (table 6). It was the second greatest mass loading for Al, Cu, Fe, Pb, Sr, and SO₄, and the third greatest for Ni and Zn. All the constituents in table 6 had a measurable mass loading in this segment.

Table 5. Average accuracy, precision of chemical analyses, and detection limits for synoptic samples, Silver Creek, Utah

[Minimum, percent variation from standard closest to zero; Maximum, percent variation from standard farthest from zero; Median, constituent value of median percent variation; Coefficient and Exponent, terms for precision equation of an exponential equation to calculate precision in percent]

Constituent	Minimum percent	Maximum percent	Median percent	Coefficient	Exponent	Detection limit (micrograms per liter)
Calcium	-2.3	58.3	7.9			88
Magnesium	-.4	9.3	2.3			29
Sodium	4.6	-13.0	9.2	4.8248	.0067	67
Potassium	-1.9	11.0	5.3			15
Sulfate	-.77	-1.40	1.09	11.279	-.5244	.57
Chloride	.43	.46	.45	.9821	.1175	.15
Bromide ¹	5.2	5.4	5.3	.2985	4.3189	.15
Silica	.5	-50.6	5.6			48
Aluminum	-2.0	50.3	5.2	14.114	-.104	4
Arsenic	-2.3	-57.5	13.1			.03
Barium	2.5	15.6	6.2			.1
Cadmium	2.9	52.2	4.5	9.3566	-.1178	.02
Cadmium	.9	20.1	3.9			.02
Chromium	-3.0	25.5	4.5			.01
Cobalt	.0	17.1	4.5			.01
Copper	-.5	17.7	3.5	7.4538	-.0153	.25
Iron	-2.0	6.0	3.4	1.8432	.0664	1
Lead	-2.5	20.9	5.4	4.3394	.0481	.03
Lithium	.6	20.9	4.7			.7
Manganese	.0	7.5	3.2	4.7533	-.0312	8
Molybdenum	-.4	33.7	4.0			.02
Molybdenum	-1.3	14.6	4.0			.02
Nickel	2.0	-56.6	7.4	16.396	-.1946	.49
Silver	-.4	-473.7	32.4			.01
Strontium	.1	16.3	4.2	5.1452	.0216	.46
Vanadium	-2.5	-54.8	9.2			.01
Zinc	-.5	7.2	3.9	4.1745	-.0127	2

¹Bromide equation is linear with the slope and intercept given as coefficient and exponent.

6. Ground-water inflows upstream from waste-water treatment plant—includes segment S26 (table 6). The flow in the stream at this point is from discharge of ground water to the channel of Silver Creek, downstream from the diversion for irrigation (fig. 1). The load of Zn was almost as great here as it was from the Silver Creek tailings discharge pipe. The occurrence of substantial Mn loading indicates the influence of tailings, where Mn likely occurs in the residue gangue minerals.
7. Waste-water treatment plant / ground-water inflow—includes segment S27 (table 6). This segment had the greatest load for Na and SO₄, and second greatest load for Cl. Several metals had substantial loading, including Cu, Pb, Mn, Ni, and Zn. There were two substantial inflows in this stream segment, however, and neither was sampled so that it is not possible to say which one could be responsible for the large loadings that were measured. In figures 11 to 15, this load is evenly divided between surface-water and unsampled inflow.

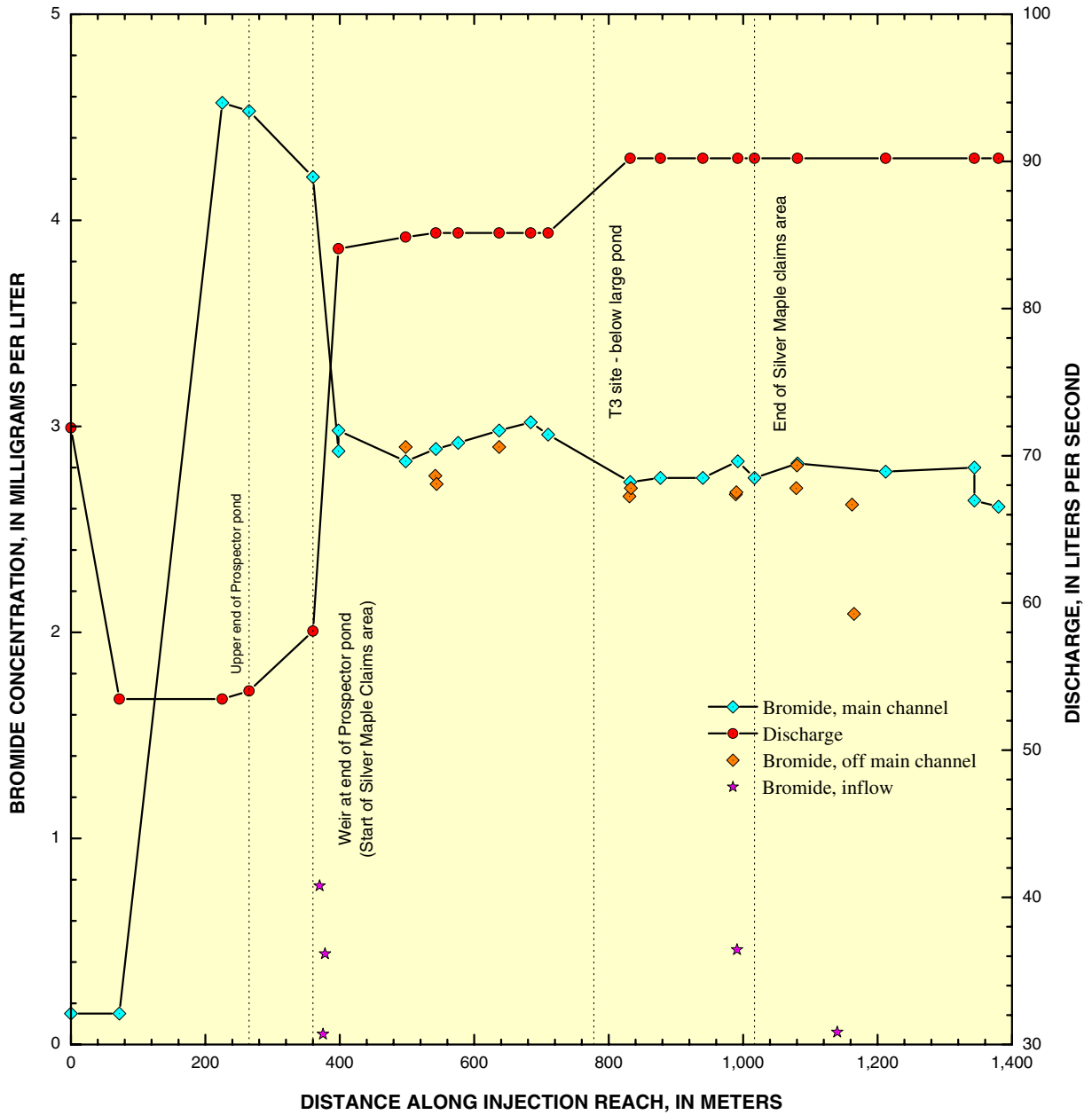


Figure 4. Variation of bromide concentration and calculated discharge with distance, Silver Creek, Utah.

Table 6. Median concentration of selected constituents, grouped by chemical similarity among synoptic samples, Silver Creek, Utah

[mg/L, milligrams per liter; µg/L, micrograms per liter]

Constituent	Unit	Phase	Group 1	Group 2	Group 3	Utah Department
			Upstream from	Downstream from	Downstream from	of Environmental
			Silver Maple Claims	Silver Creek tailings	Downstream from	Quality samples
			Number of samples			
			4	8	14	6
pH	Standard units	Dissolved	8.89	7.82	7.75	8.07
Calcium	mg/L	Dissolved	106	125	130	121
Magnesium	mg/L	Dissolved	24.2	26.1	27.9	34.7
Sodium	mg/L	Dissolved	157	143	160	93.1
Alkalinity, as CaCO ₃	mg/L	Dissolved	105	98.3	110	140
Sulfate	mg/L	Dissolved	157	228	234	267
Chloride	mg/L	Dissolved	349	374	411	264
Fluoride	mg/L	Dissolved	.94	1.10	1.33	.94
Aluminum	µg/L	Dissolved	33.5	29.0	29.5	39.1
	µg/L	Colloidal	393	127	86.2	75.1
Arsenic	µg/L	Dissolved	2.99	2.43	2.93	4.69
	µg/L	Colloidal	1.77	1.34	2.16	2.46
Cadmium	µg/L	Dissolved	3.54	5.03	2.03	3.94
	µg/L	Colloidal	3.85	3.27	2.51	.99
Copper	µg/L	Dissolved	2.98	1.60	1.15	2.71
	µg/L	Colloidal	3.77	1.97	2.14	2.19
Iron	µg/L	Dissolved	4.94	6.26	11.6	16.7
	µg/L	Colloidal	467	217	272	267
Lead	µg/L	Dissolved	.69	.86	.74	1.97
	µg/L	Colloidal	13.6	9.62	17.4	24.7
Manganese	µg/L	Dissolved	121	167	261	129
	µg/L	Colloidal	44.8	15.3	17.3	20.9
Nickel	µg/L	Dissolved	1.37	2.96	3.58	2.04
	µg/L	Colloidal	.63	1.01	.58	.49
Strontium	µg/L	Dissolved	446	476	507	787
	µg/L	Colloidal	13.5	.46	.46	.46
Zinc	µg/L	Dissolved	342	1,314	1,636	840
	µg/L	Colloidal	500	153	214	110

8. Downstream from waste-water treatment plant to Wanship—includes segment S28 (table 6). This long section of Silver Creek, which was accounted for at the town of Wanship, contributed the greatest mass load for many of the constituents (table 6, segment S28; recall that the values of distance for the last five sites in table 6 are arbitrary). Details of mass loading along segment S28 are not known because there was no detailed evaluation downstream from the site at 6,500 m. The large increases in loads for Al, Cu, Fe, and Pb mostly were increases in the colloidal phase. Note, however, that the greater loads do not necessarily mean greater concentrations; the concentration of

Zn, for example, is near the toxicity standards at 7,000 m (fig. 8).

A comparison of mass loading for Cd, Cu, Pb, and Zn is presented in figure 14. For Cd, the greatest mass loading was in the area of segments S19 through S24. This area also contributed the second greatest mass of SO₄ (table 6). Large deposits of tailings material occur along the stream in this area. The principal area of loading for Cu (fig. 14B) and Pb (fig. 14C) was the Wanship segment (S28). This pattern was the same for Al and Fe (table 6) and reflects a colloidal load in the sample from Wanship (sample at 7,000 m in fig. 7). Metal sources in this part of the study reach were not investigated. There also were several upstream sources, however, particularly Richardson Flat (segment S25).

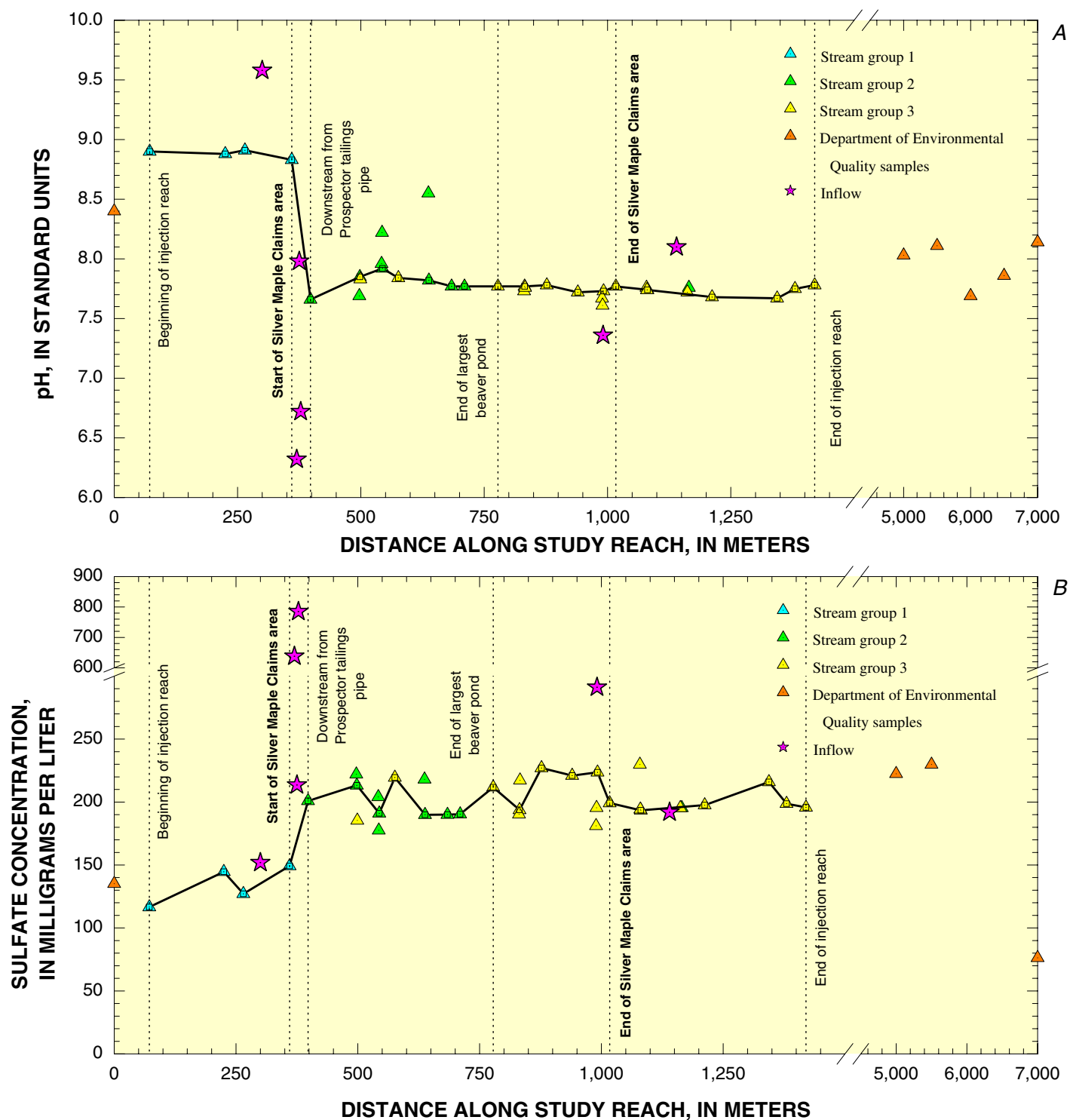


Figure 5. Variation of (A) pH and (B) sulfate concentration with distance, Silver Creek, Utah.

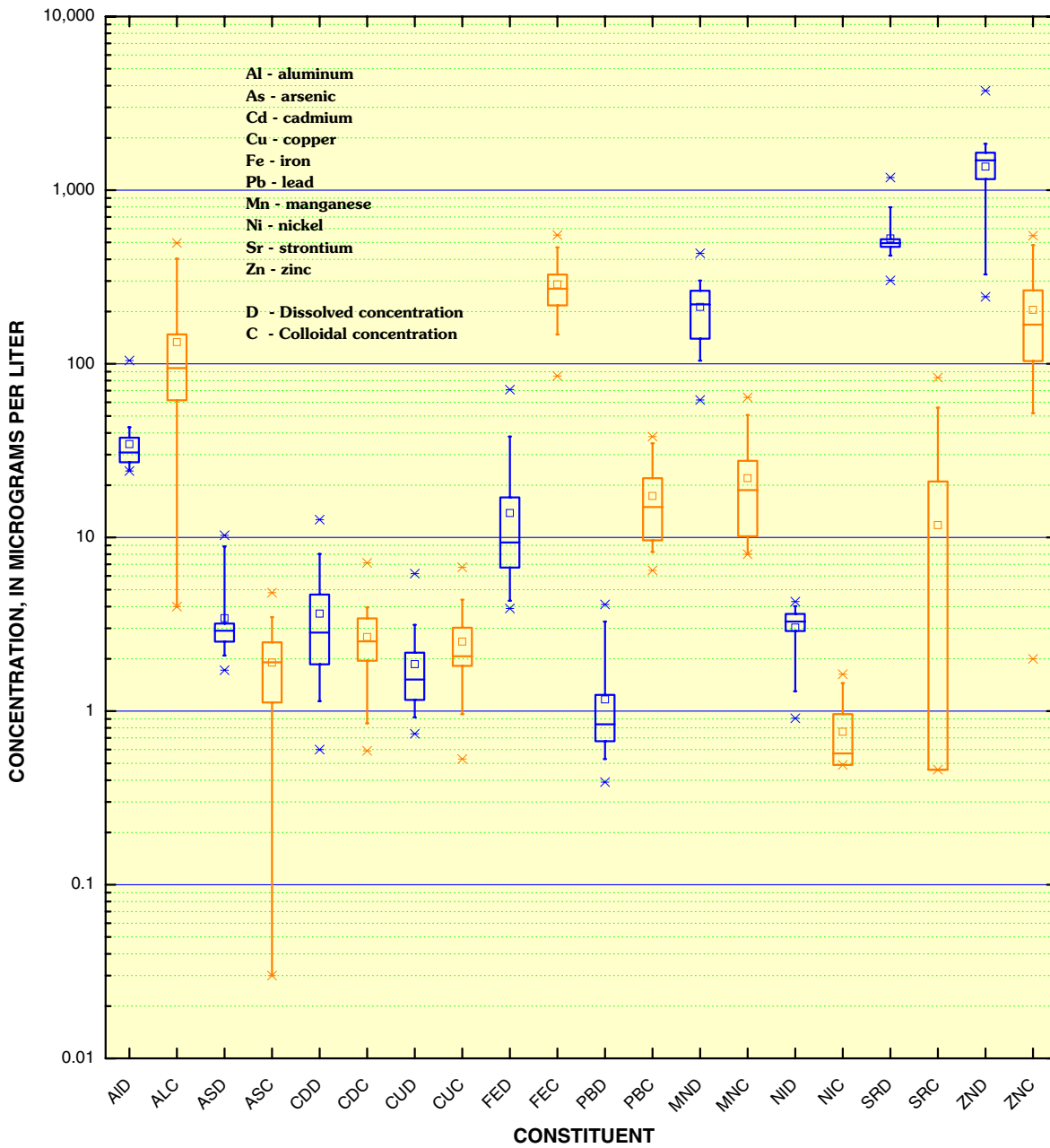


Figure 6. Distribution of dissolved and colloidal concentration of metals in synoptic stream samples, Silver Creek, Utah.

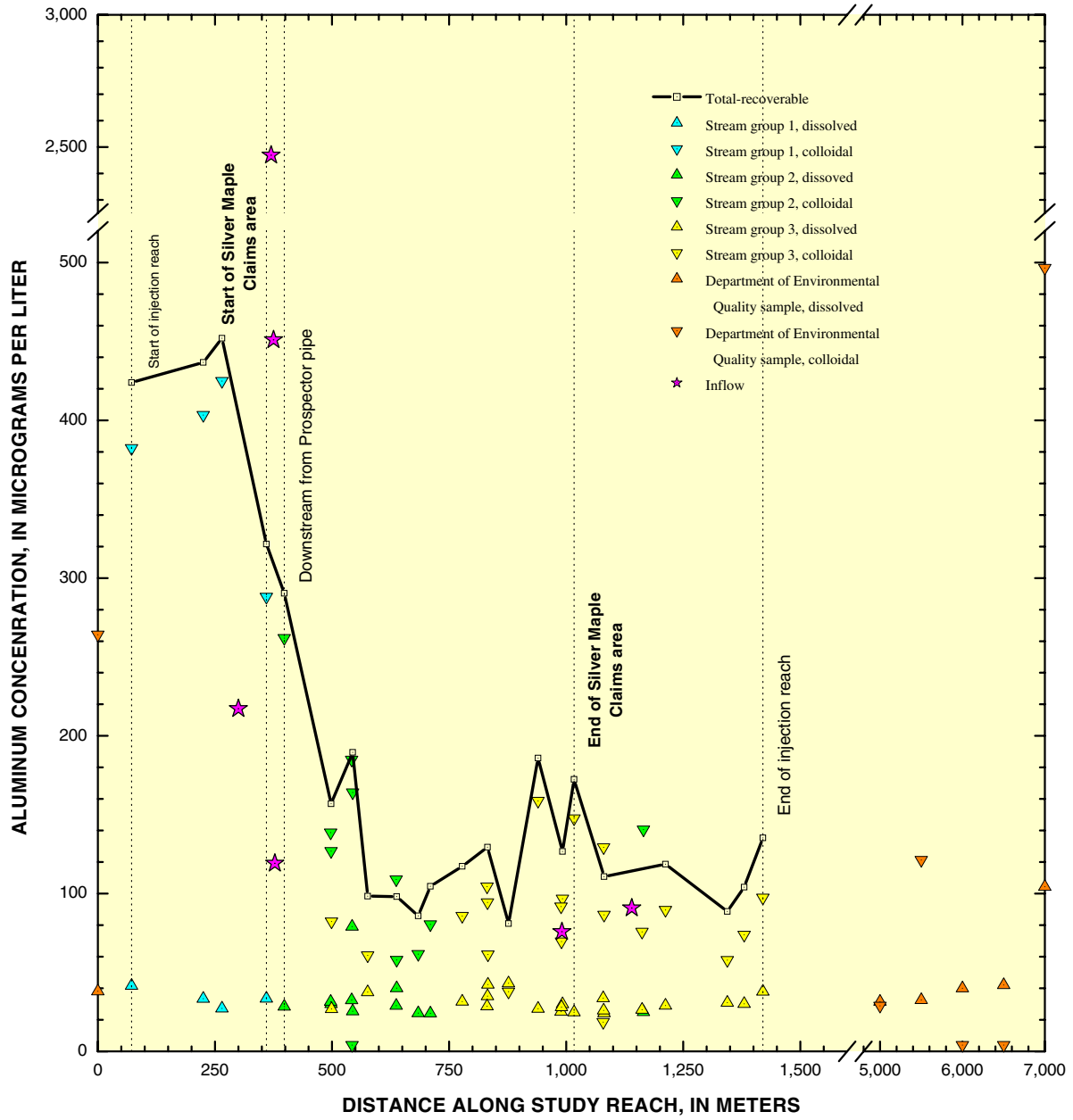


Figure 7. Variation of dissolved and colloidal aluminum concentration with distance for Silver Creek, Utah.

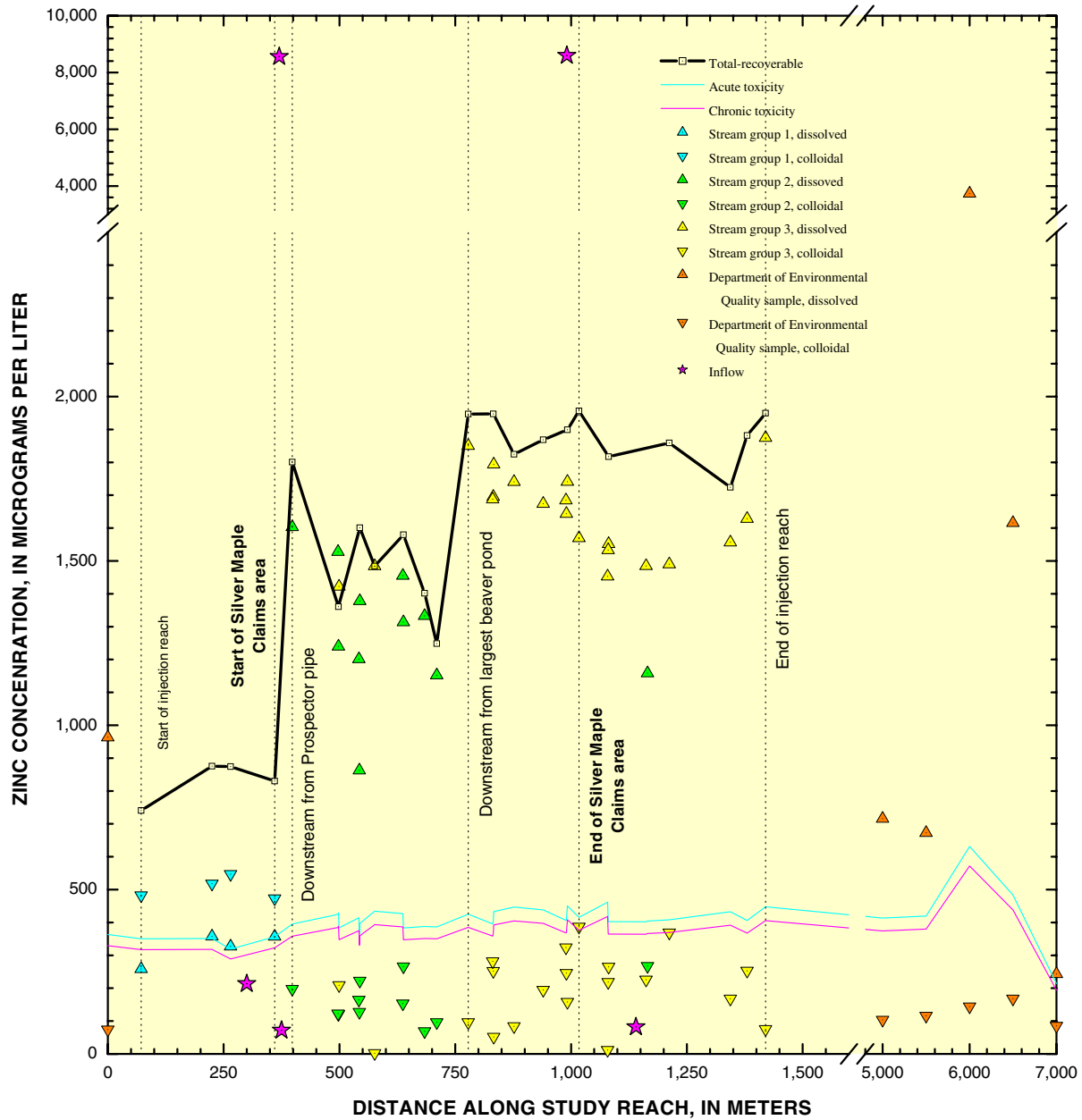


Figure 8. Variation of dissolved and colloidal zinc concentration with distance for Silver Creek, Utah.

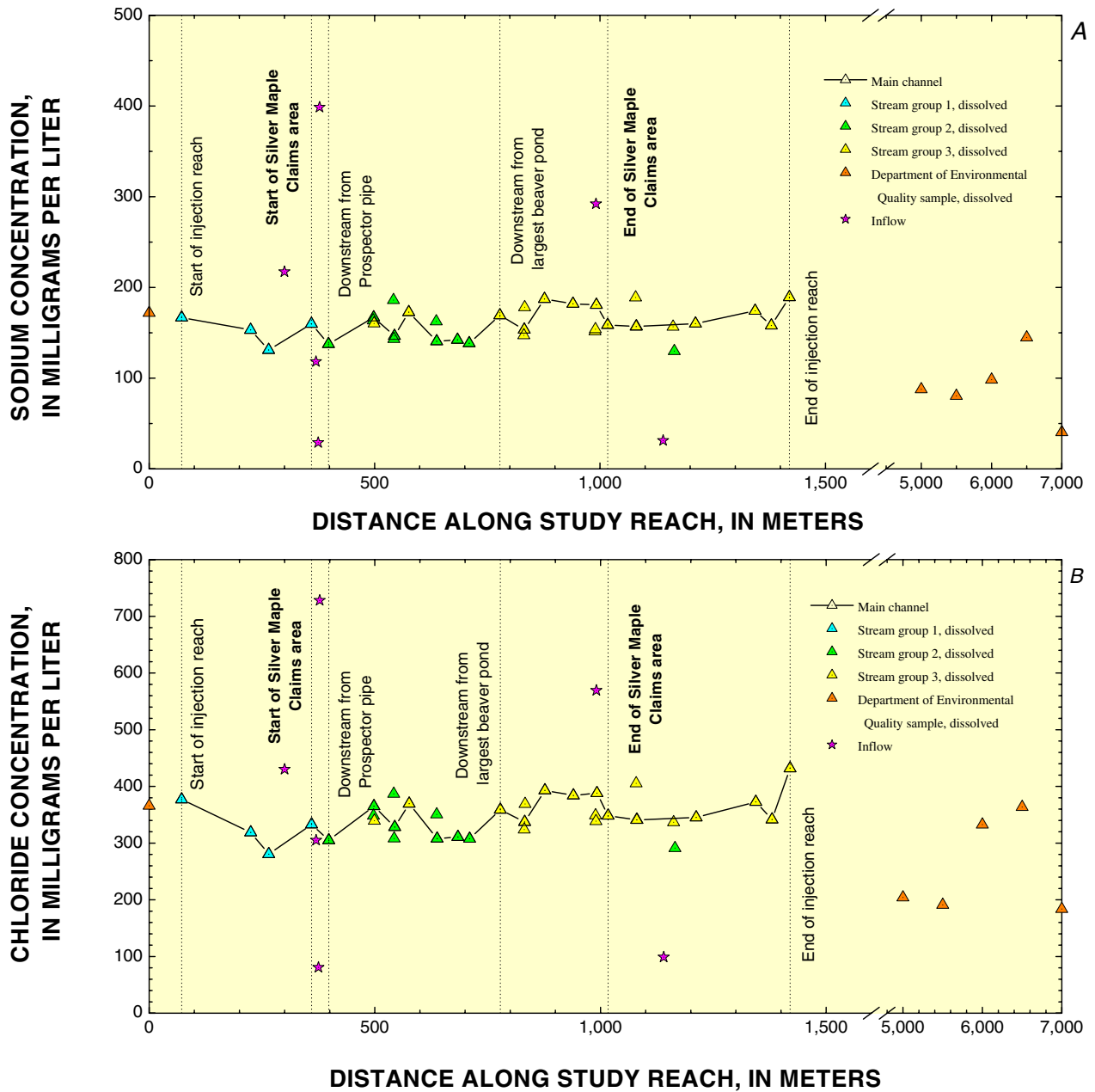


Figure 9. Variation of dissolved (A) sodium and (B) chloride concentration with distance for Silver Creek, Utah.

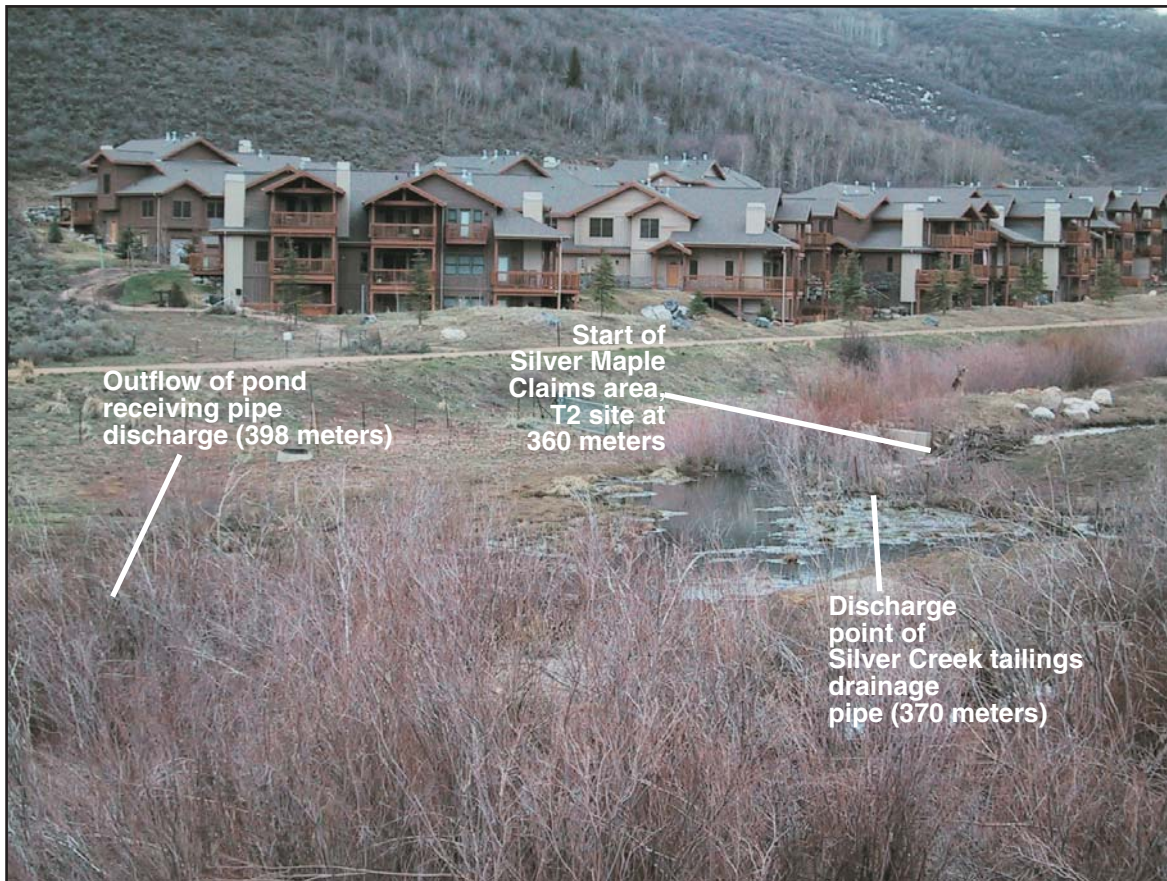


Figure 10. Pond receiving discharge from the Silver Creek tailings discharge pipe, near Park City, Utah.

The greatest loading for Zn (fig. 14D) was from the Silver Creek tailings discharge pipe (segment S6). The load from the remainder of the Silver Maple Claims area (segments S7 through S18), however, was nearly as great, comparing the instream loads. The Zn load contributed by ground-water inflows upstream from the waste-water treatment plant (segment S26) was almost as large as the load from segment S6. Because the loads from these locations are comparable, it is possible that remediation efforts focused only on one location might not decrease Zn concentrations in Silver Creek to levels below the aquatic toxicity standards.

For each of these elements, the inflow load measured for the Silver Creek tailings discharge pile (segment S6) was greater than that for the instream load.

The difference was relatively small, only 4 percent, for Cd (fig. 14A) and 20 percent for Zn (fig. 14D). The difference was 70 percent for Cu (fig. 14B) and 83 percent for Pb (fig. 14C). The mass load that is implied by these percentages is consistent with a greater affinity of Cu and Pb to associate with the solid phase and be removed from solution. There likely was substantial Fe colloidal material because almost all of the inflow load of Fe was removed (fig. 13A).

Unsampled Inflow

Unsampled inflow was greater than 50 percent for all the constituents except Zn (summary calculations in table 9). Much of this unsampled inflow occurred in the Silver Maple Claims area, downstream from the Silver Creek tailings discharge pipe, and

Table 7. Calculated concentration of selected constituents in water from Silver Creek tailings discharge pipe, Silver Creek, Utah

Constituent	Measured value	Adjusted value
Dissolved (milligrams per liter)		
Calcium	288	440
Magnesium	40.1	59.5
Sodium	118	156
Sulfate	652	1,020
Chloride	312	433
Total recoverable (micrograms per liter)		
Aluminum	2,470	2,910
Arsenic	76	90.6
Cadmium	43.6	51.2
Copper	29.2	34.1
Iron	8,860	10,600
Lead	182	216
Manganese	1,010	1,180
Nickel	19.4	22.9
Strontium	556	630
Zinc	8,560	10,100

between the Silver Maple Claims area and Richardson Flat (table 6), as indicated in the mass-loading profiles for Zn (fig. 11B), SO₄ (fig. 12B), and Fe (fig. 13B). Tailings that are visible between 398 m and 1,420 m are a plausible source for these loads, but the unsampled inflow likely indicates ground-water discharge in this location where the alluvium is somewhat constricted by bedrock.

Unsampled inflow for Na and Cl occurred in segment S6, which included the Silver Creek tailings discharge pipe (fig. 15). This likely indicates inflow of water that has been affected by road salt, because the pipe discharge accounted for all the load of tailings-related constituents, but not all the Cl load (fig. 15B). Loads of Ca, Mg, and Sr also occurred partly as unsampled inflow for segment S6, which is consistent with the likely composition of the other 70 percent of the discharge in this stream segment. These same constituents are important in the unsampled inflow for segment S13. That segment also had unsampled inflow of Zn and other metals, so it was likely affected by interaction with tailings in the Silver Maple Claims area.

The two main locations of unsampled inflow were downstream from the injection study reach at Richardson Flat and upstream from the town of Wanship (segment S25, fig. 13B and segment S38, fig.

15B). Loads in these segments were called unsampled inflow only because there were no inflow samples collected. Further work may indicate what the sources are for this mass loading.

Attenuation

Attenuation for many constituents occurred in three principal locations.

1. Between Park City and the injection study reach (segment S2)—All constituents, except Cu, lost mass in this segment. The cause of the mass loss is not known; the stream between 0 m and the injection reach at 72 m was not investigated as part of this study. Because most every constituent lost mass, the loss could result from a diversion of water, and thus mass. This is consistent with the decrease in discharge from 72 to 42 L/s (table 1).
2. Downstream from the Silver Creek tailings discharge pipe (segment S7)—Measurable attenuation occurred for all the constituents except SO₄ in this segment (table 8). It is very likely, however, that attenuation of all the constituents that were added from the Silver Creek tailings discharge pipe, accounted for in segment S6, was substantial in the pond area. Evidence for this attenuation is in the difference between large inflow loads and the smaller instream loads (see fig. 14). Because the increased flow in segment S6, calculated from the Br tracer, was comparable to a flow-meter measurement, and the sampled Zn concentration in the discharge pipe was high, there is no reason to think there is an error in this inflow load calculation. The same difference was indicated for SO₄ (fig. 12) and Fe (fig. 13).
3. Downstream from Silver Maple Claims area (segments S18 through S21)—Loads of As, Cd, Cu, Fe, Pb, and Mn all were attenuated substantially in these stream segments. A cause for the attenuation is not known because this location, downstream from the Silver Maple Claims study reach, was not studied in detail.

Table 8. Change in load for individual stream segments, Silver Creek, Utah

[Segment, stream segment; Distance, distance at the end of the segment; Na, sodium; SO₄, sulfate; Cl, chloride; Al, aluminum; Cd, cadmium; Cu, copper; Fe, iron; Pb, lead; Mn, manganese; Ni, nickel; Sr, strontium; Zn, zinc; all values reported in kilograms per day, except percents; blank cells indicate change in load is less than the calculated error; Italicized bold numbers in parentheses indicate rank for the five greatest loads]

Segment	Distance, in meters	Na	SO ₄	Cl	Al	Cd	Cu	Fe	Pb	Mn	Ni	Sr	Zn
S1	0	(2)1,070	840	(3)2,270	(3)1.88	(2)0.055	(5)0.028	(3)2.13	0.093	(4)1.05	(4)0.013	2.58	(4)6.45
S2	72	-456	-412	-890	-.322	-.030	-.003	-.379	-.041	-.423	-.006	-.908	-3.73
S3	225	-49.8	103	-213		.003				-.042	.001		.495
S4	265	-80.9	-64.3	-141					.005				
S5	360	106	81.3	192	-.478	-.004	-.006	-.548	-.006				
S6	398	(3)422	(5)926	(4)1,020	(4).949	(1).064	.019	(5)1.22	.061	(5)1.03	(2).025	1.78	(1)10.2
S7	498	215	90.5	442	-.978	-.019	-.010	-.916	-.040	-.308	-.008		-3.23
S8	544	-146	-158	-263	.243	.009	-.001	.121	.027	.017	-.001	.133	1.80
S9	576	192	209	304	-.670	-.014		-.167	-.027	.105	.004		-.856
S10	637	-236	-218	-454			-.004	.348					.700
S11	684				-.089	-.006		-.274	-.006	-.329			-1.31
S12	710				.137	-.006		-.143	.027	-.268		-.291	-1.13
S13	778	300	250	534	.145	.009	.008	.728	.046	1.02		.471	(5)5.99
S14	832	-122	-140		.095	-.019	-.006	.281	.034	.264	-.007		
S15	877	263	259	435	-.378	-.011	-.007	-.699	-.084	-.205	.008		-.959
S16	940				(5).818	.004	.017	(4)1.27	(5).135	.327			
S17	992				-.461		-.009	-.339	-.052				
S18	1,017	-172	-190	-311	.356	.007	.013	.653	.055	.224	.008	.663	
S19	1,081				-.481	-.010	-.014	-1.05	-.093	-.372			-1.09
S20	1,212					(3).040			-.048				
S21	1,344	109	143	214	-.234	-.037		-.449	.059				-1.05
S22	1,380	-127	-134	-242	.120	.019	(4).040	.670	(4).145				1.23
S23	1,420	244		704	.244	-.008	-.008	.304	.028	.201		.351	
S24	5,000	-224	(2)1,650	-455	-.194	.016		.675	.075	-.297	-.006	(1)6.67	-3.52
S25	5,500	(5)384	(3)1,490	(5)967	(2)2.26	.010	(2).062	(2)3.03	(2).445	.734	(5).010	(2)6.08	4.33
S26	6,000	246	(4)1,150	830	.100	(4).035	.018	.547	.026	(2)1.12	.010	(5)2.95	(2)9.69
S27	6,500	(1)1,220	(1)2,220	(2)2,840	.345	(5).019	(3).055	.504	(3).245	(3)1.11	(3).015	(4)5.11	(3)8.35
S28	7,000	(4)397		(1)4,770	(1)27.2	.013	(1).158	(1)19.7	(1)1.09	(1)1.19	(1).039	(3)5.83	-2.94

Table 9. Summary of load calculations for selected constituents, Silver Creek, Utah

[Na, sodium; SO₄, sulfate; Cl, chloride; Al, aluminum; Cd, cadmium; Cu, copper; Fe, iron; Pb, lead; Mn, manganese; Ni, nickel; Sr, strontium; Zn, zinc; all values reported in kilograms per day, except percents]

	Na	SO ₄	Cl	Al	Cd	Cu	Fe	Pb	Mn	Ni	Sr	Zn
Cumulative instream load	5,160	9,410	15,500	34.9	0.301	0.417	32.2	2.20	8.06	0.131	32.6	49.2
Cumulative inflow load	2,460	4,170	5,590	5.4	.130	.121	14.3	.576	3.46	.052	8.39	25.9
Percent inflow load	47.6	44	36.0	15.5	43.1	29.0	44	26.2	42.9	40.1	25.7	53
Unsampled inflow	2,710	5,240	9,930	29.5	.171	.3	17.9	1.6	4.60	.078	24.2	23.27
Percent unsampled	52.4	56	64.0	84.5	56.9	71.0	55.7	73.8	57.1	59.9	74.3	47.3
Attenuation	1,610	1,180	2,970	4.29	.164	.1	5.0	.0	1.92	.028	1.20	19.8
Percent attenuation	31.2	13	19.1	12.3	54.5	16.3	15.4	.0	23.8	21.3	3.7	40.3

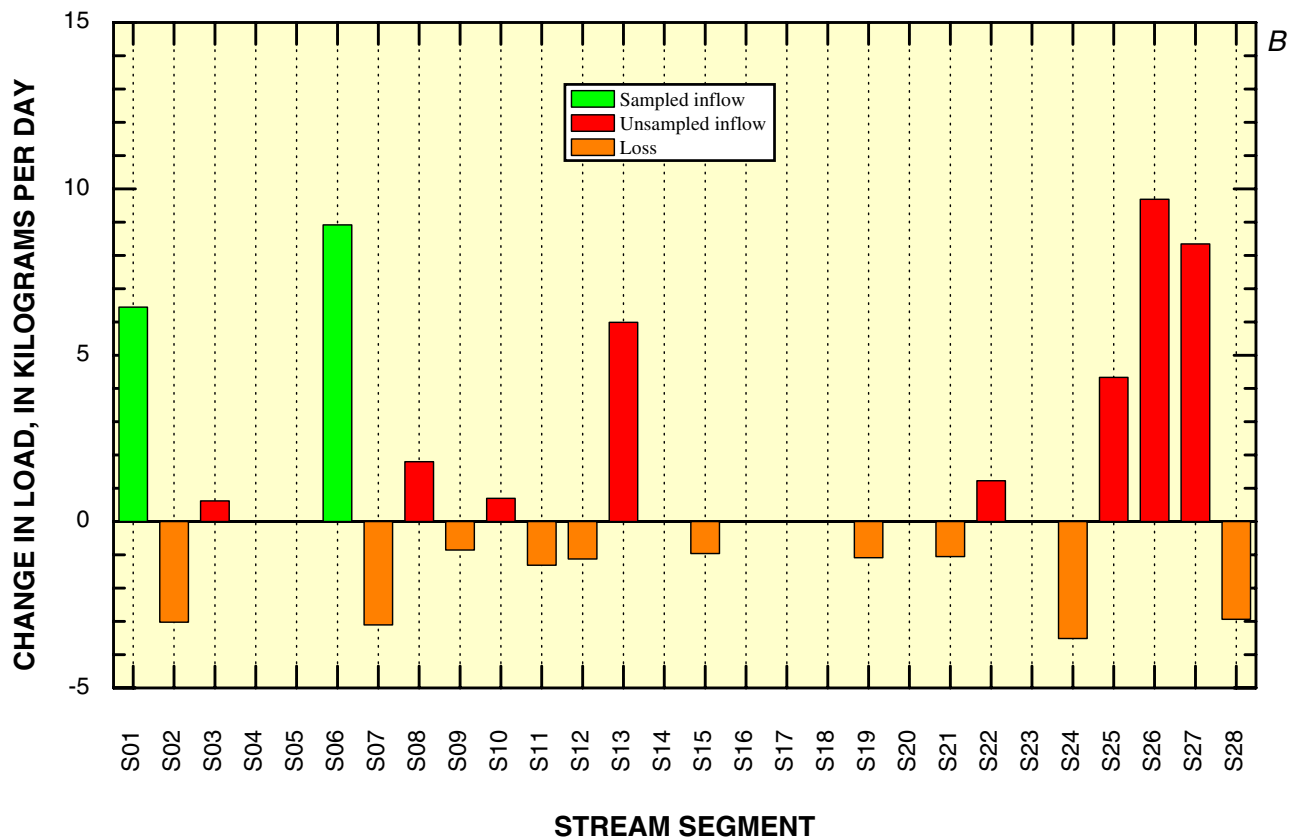
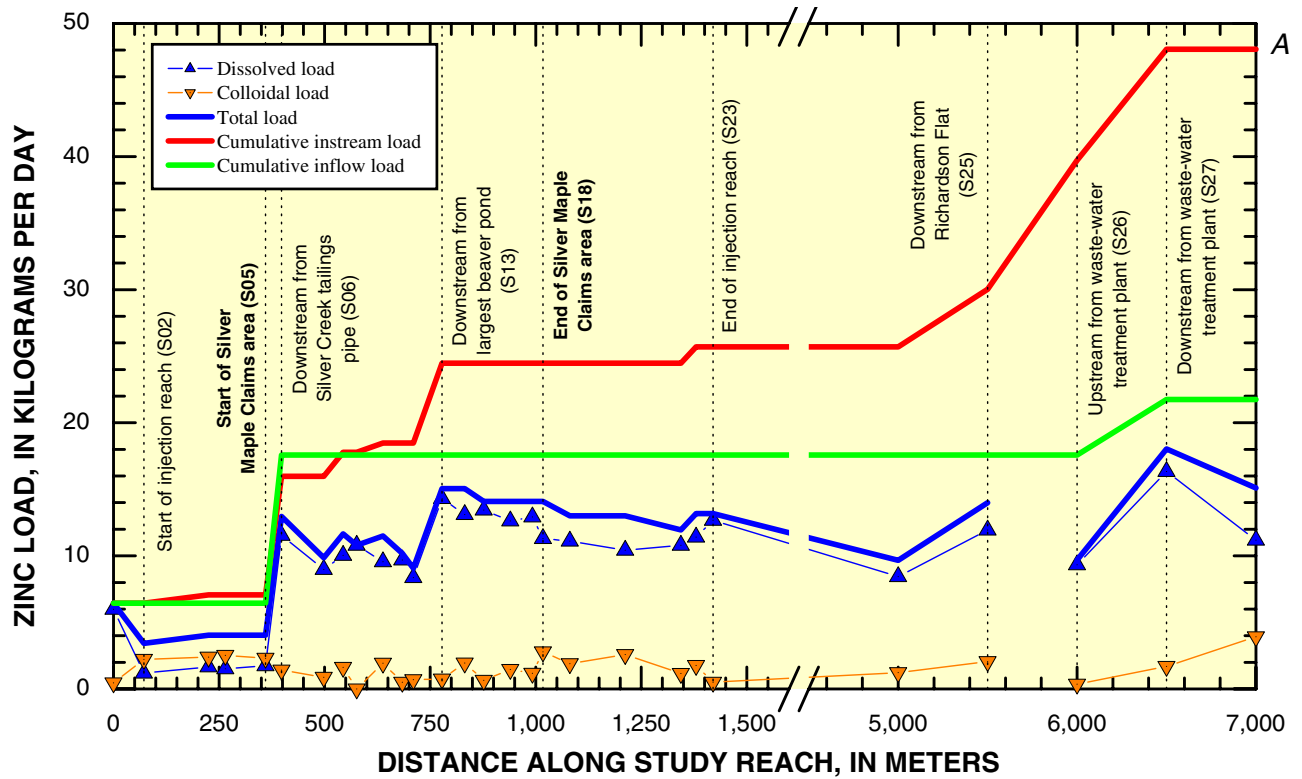


Figure 11. Variation of (A) zinc load with distance and (B) change in load for individual stream segments, Silver Creek, Utah.

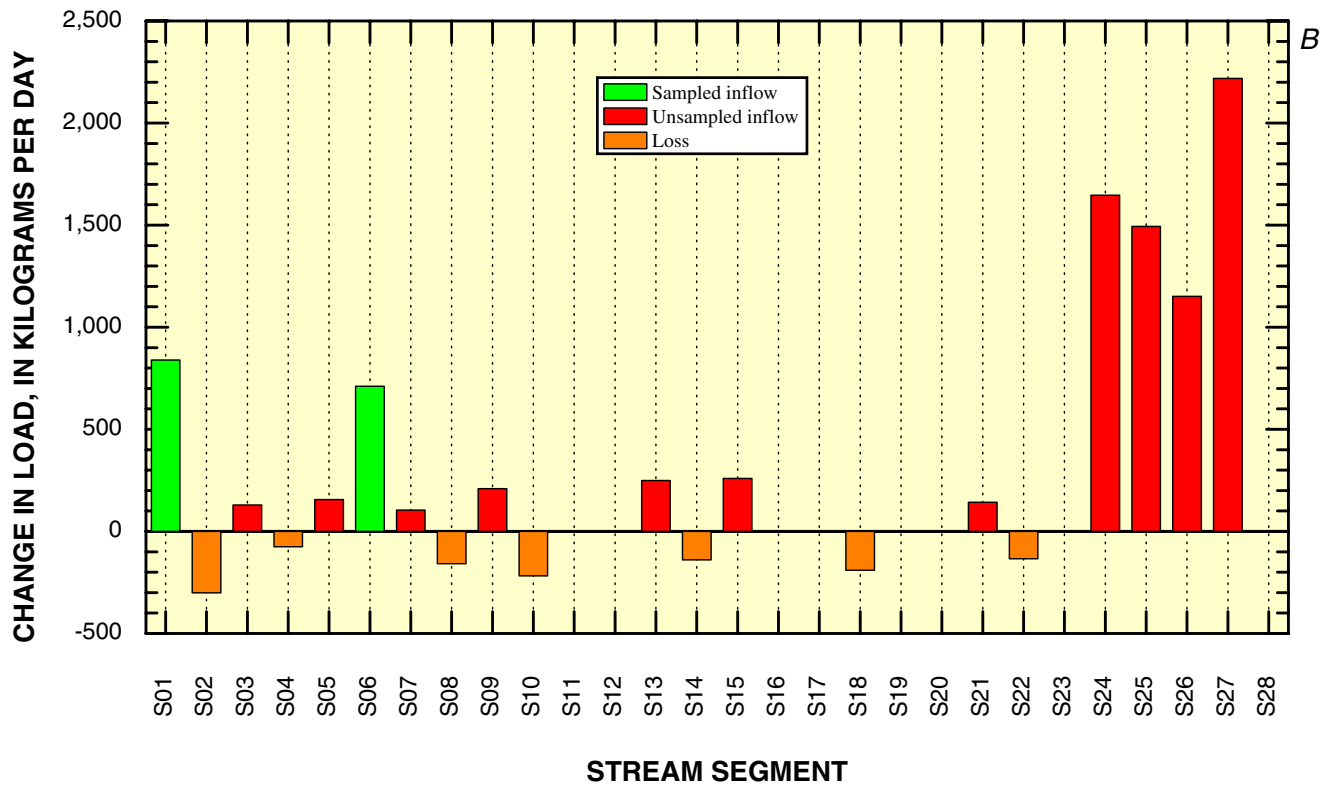
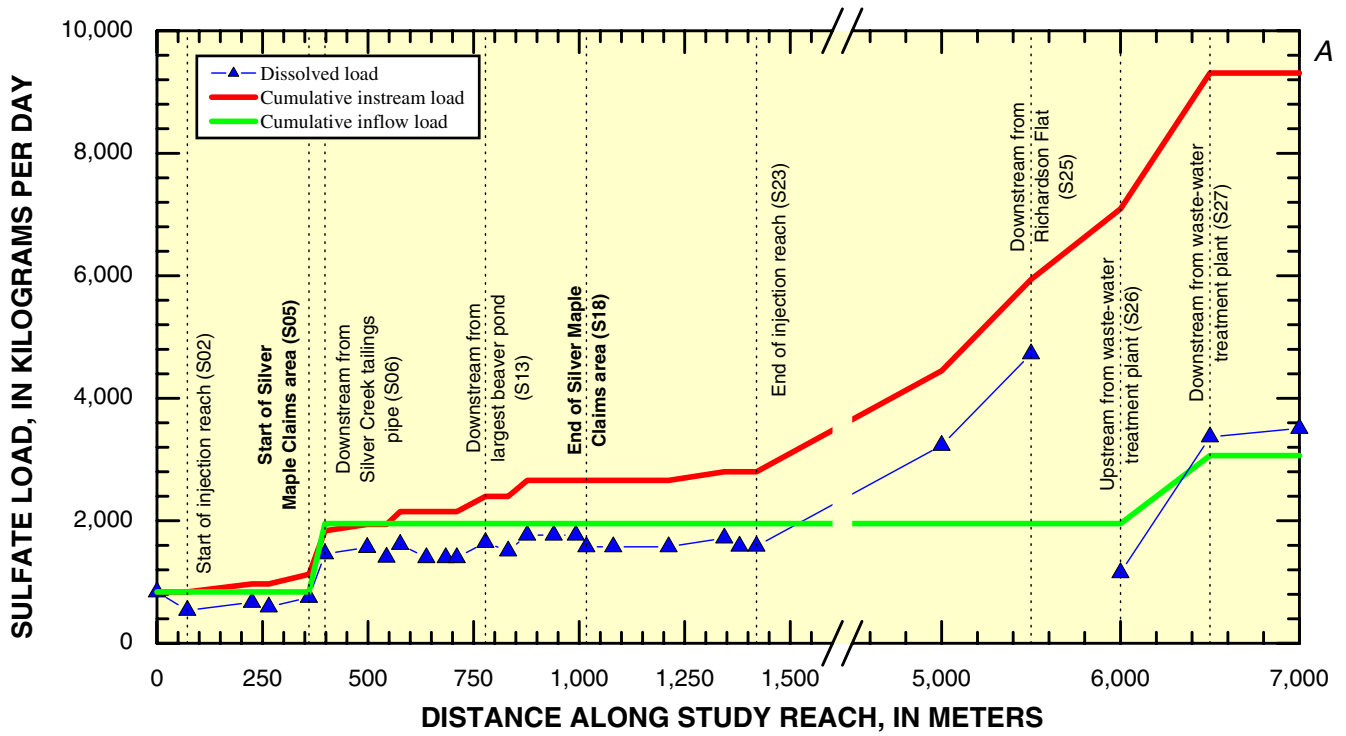


Figure 12. Variation of (A) sulfate load with distance and (B) change in load for individual stream segments, Silver Creek, Utah.

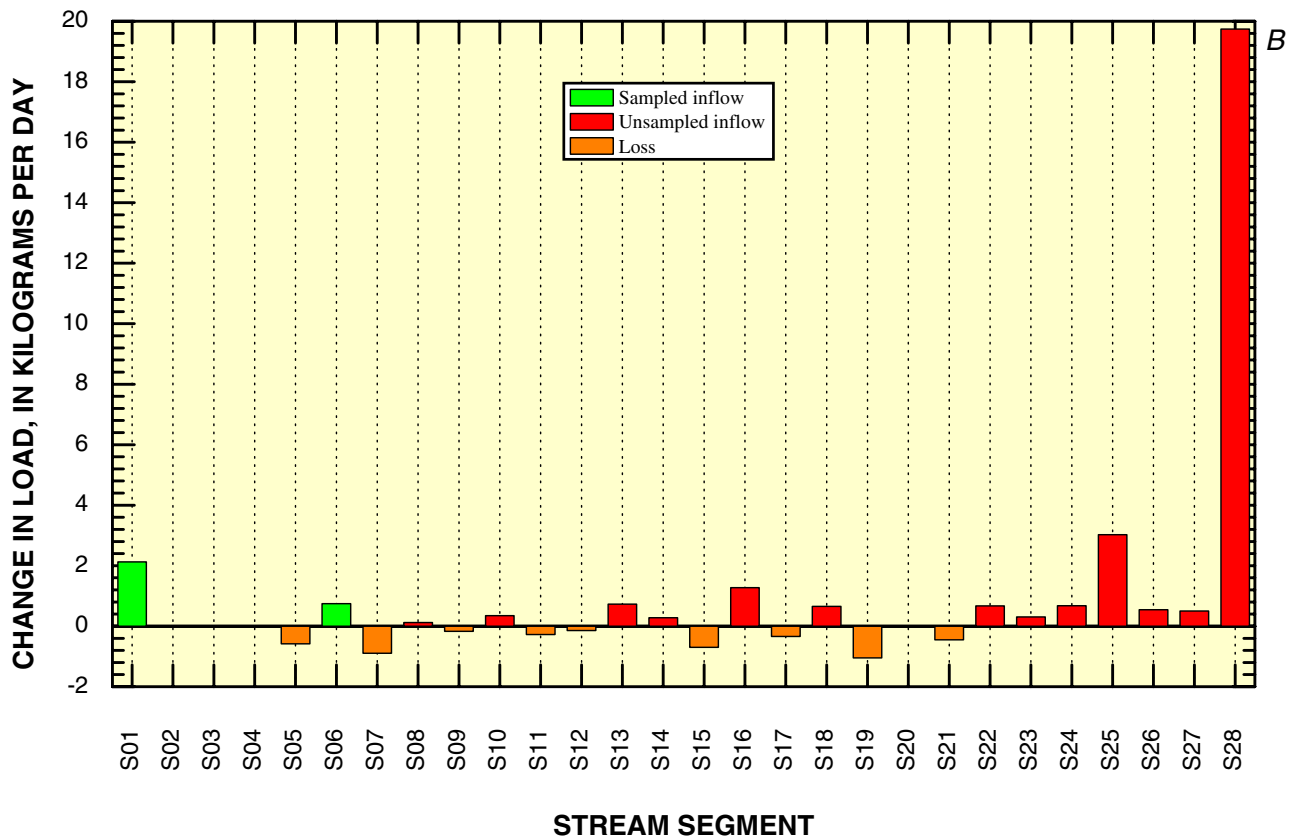
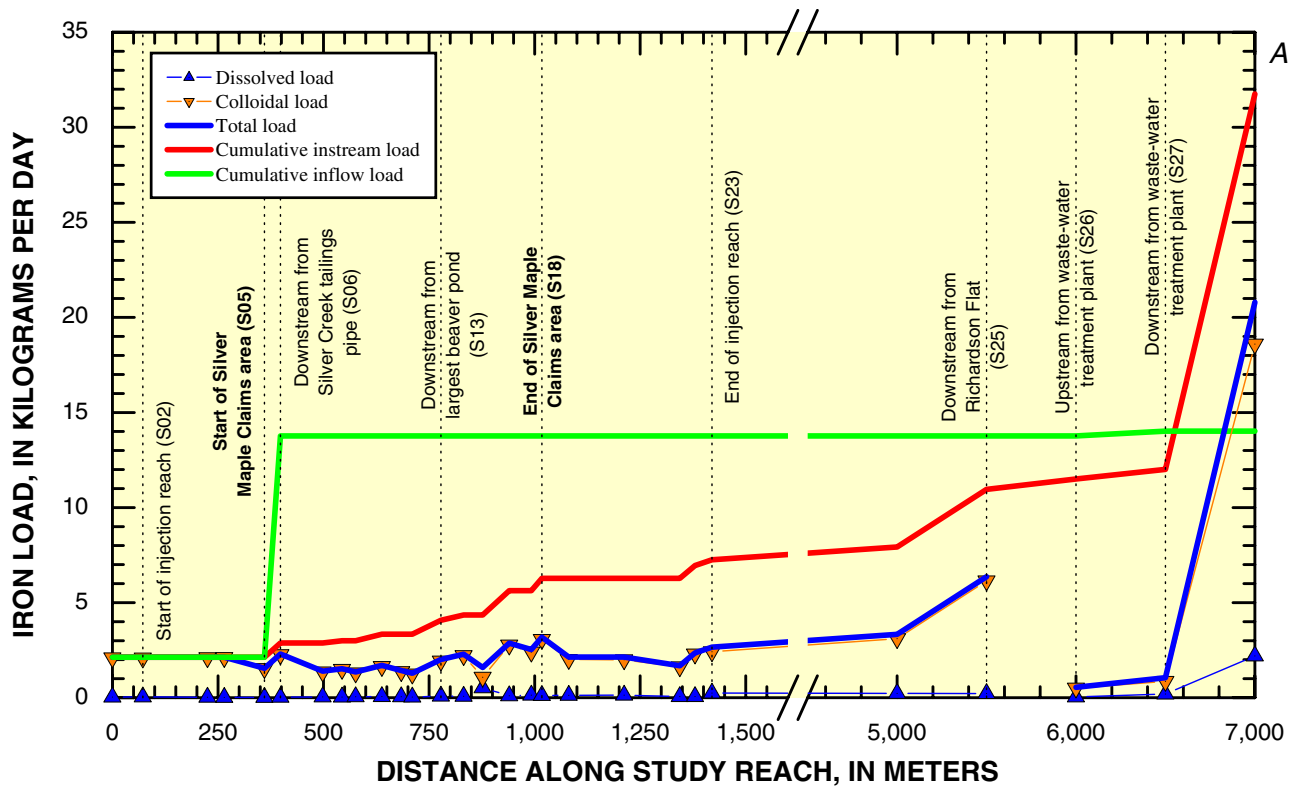


Figure 13. Variation of (A) iron load with distance and (B) change in load for individual stream segments, Silver Creek, Utah.

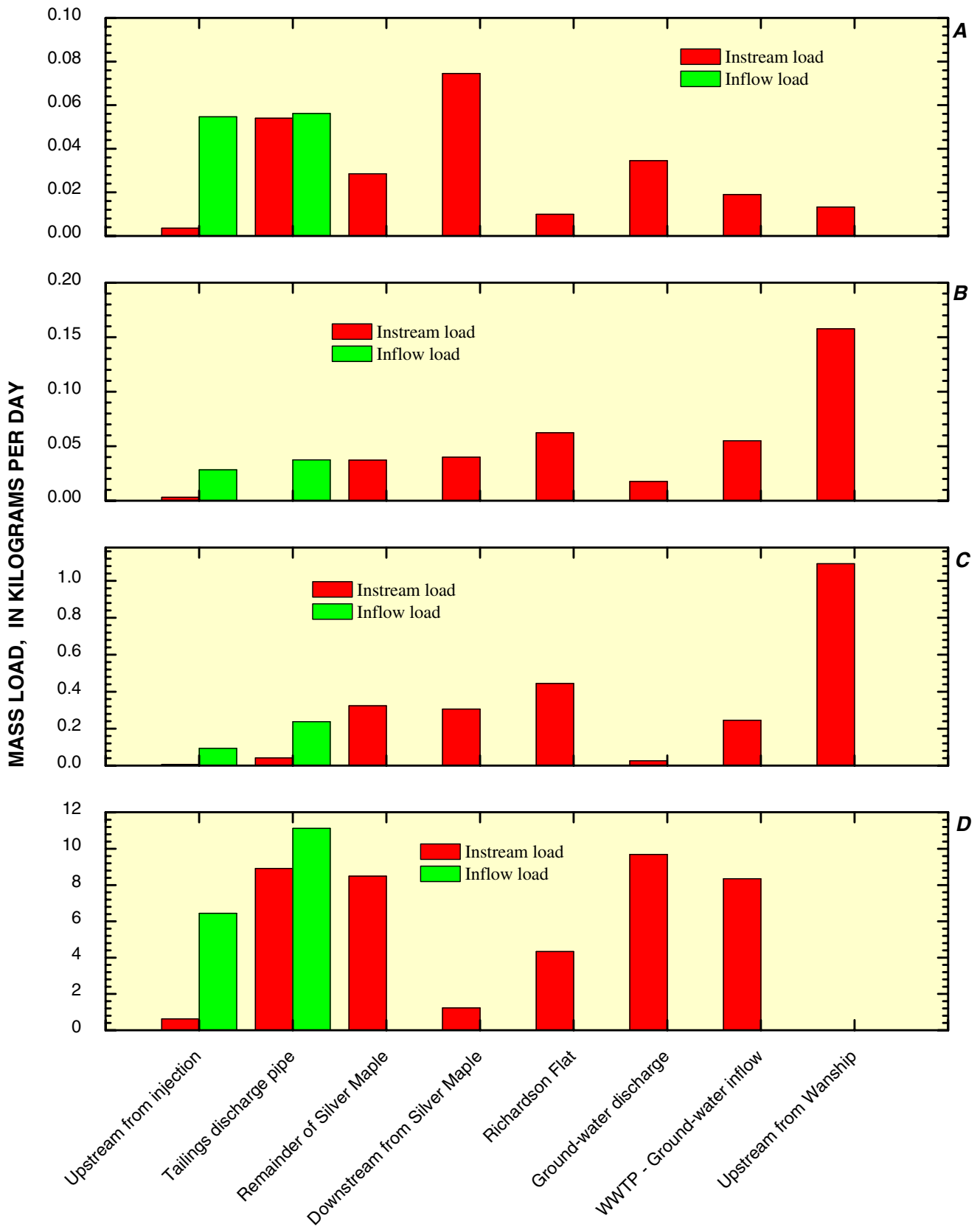


Figure 14. Load for (A) cadmium, (B) copper, (C) lead, and (D) zinc for principal locations, Silver Creek, Utah.

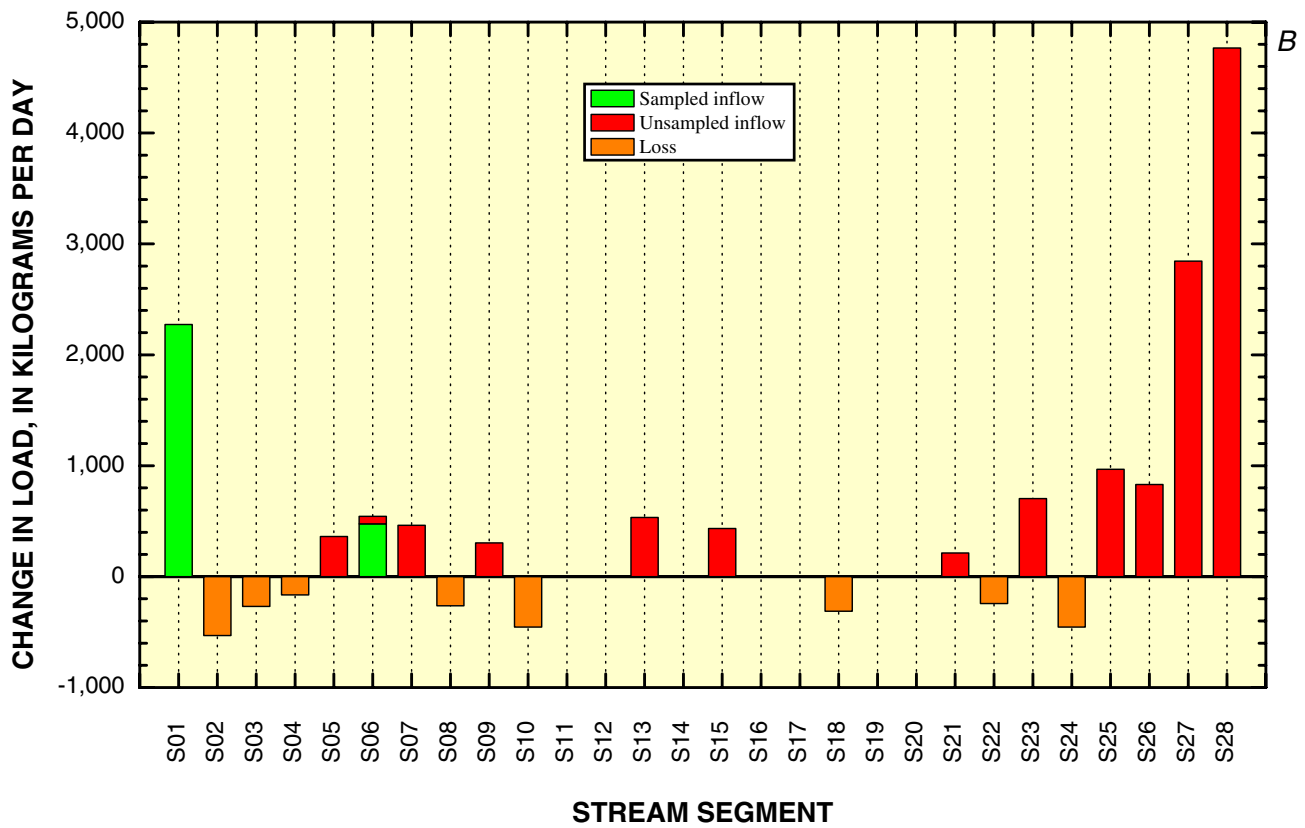
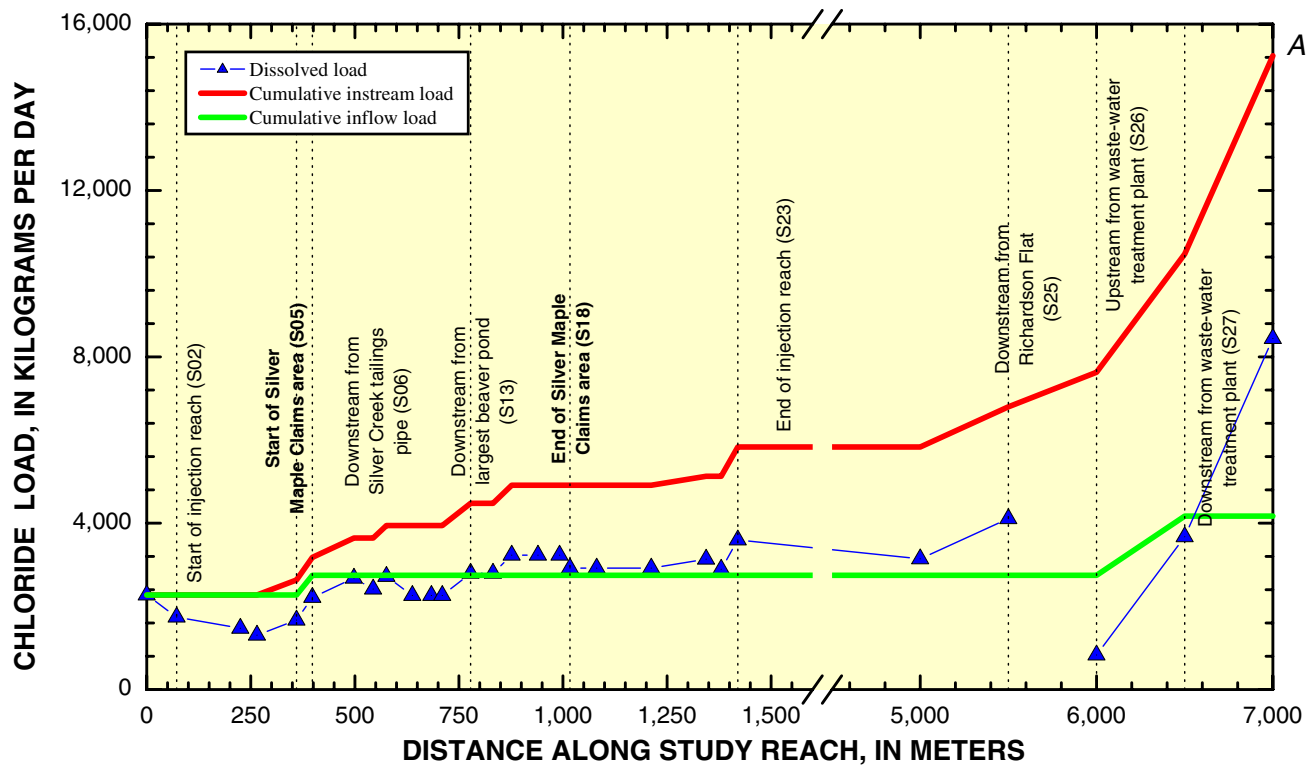


Figure 15. Variation of (A) chloride load with distance and (B) change in load for individual stream segments, Silver Creek, Utah..

SUMMARY

Sampling by the U.S. Geological Survey and other agencies, both upstream and downstream from the Silver Maple Claims area indicated that there was a substantial increase in metal loads in Silver Creek. Not enough data were collected, however, for the Bureau of Land Management, which administers the Silver Maple Claims area, to make science-based decisions about possible remediation in the area. In May 2002, the U.S. Geological Survey conducted a mass-loading study to provide the needed detail. The study included a tracer injection to provide values of discharge for chemical synoptic sampling along a 1,420-m reach of Silver Creek in Utah. Loads along a much longer study reach were calculated by area-velocity discharge measurements and by analyses of water samples collected at seven sites selected by the Utah Department of Environmental Quality.

Loads of constituents varied from a few kg/day for most metals to several thousand kg/day for major ions. For example, the cumulative instream load for Zn was 49.2 kg/day, and that for SO₄ was 9,410 kg/day. The study was able to divide the total loading of selected constituents into eight areas so that the relative importance of different sources is illustrated.

For example, a substantial load of Zn came from sources upstream from the Park City sample (segment S1). The greatest mass loading of Zn, however, occurred at the Silver Creek tailings discharge pipe, which drains into the Silver Maple Claims area. There was a substantial mass loading of Zn through the Silver Maple Claims area; most of this occurred where there was an increase in discharge about halfway through the area. For comparison, the instream load of Zn in the stream segment including the Silver Creek tailings discharge pipe was 10.2 kg/day and the cumulative instream load for the rest of the Silver Maple Claims area was 8.5 kg/day. Increases in Zn load and other metal loads in the vicinity of Richardson Flat also were substantial. Only a small increase in Zn load occurred downstream from the waste-water treatment plant and the town of Wanship, but for most constituents the greatest increases in load occurred in that area.

Distinction of the load contribution of the Silver Creek tailings discharge pipe from that of the rest of the Silver Maple Claims area helps to compare their relative influence on Silver Creek. Each metal load increased downstream from the Silver Creek tailings

discharge pipe. These increases were greater than the increases of mass load through the rest of the Silver Maple Claims area, except for Cu load. The Cu load from the pipe was 0.019 kg/day and from the rest of the Silver Maple Claims area was 0.038 kg/day. Understanding these relative contributions of load in the Silver Maple Claims area and along the larger study reach will help water and land managers make science-based decisions about remediation efforts.

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