

# Determination of Instream Metal Loads Using Tracer-Injection and Synoptic- Sampling Techniques, Wightman Fork, Southwestern Colorado, July 1999

By Roderick F. Ortiz

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## CONVERSION FACTORS AND ACRONYMS

	Multiply	By	To obtain
	gram	0.03527	ounce
	kilogram	2.205	pound
	kilometer	0.6214	mile
	liter	0.2642	gallon
	liter per second	0.03531	cubic feet per second
	meter	3.281	feet
	micrometer	0.0000394	inch
	milliliter	0.0339	ounce

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

### Acronyms Used in This Report:

CDPHE	Colorado Department of Public Health and Environment
COC	Constituent of Concern
MRL	Method Reporting Limit
NWD	North Waste Dump
SDI	Summitville Dam Impoundment
SWTF	Summitville Water Treatment Facility
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

# Determination of Instream Metal Loads Using Tracer-Injection and Synoptic-Sampling Techniques, Wightman Fork, Southwestern Colorado, July 1999

By Roderick F. Ortiz

## Abstract

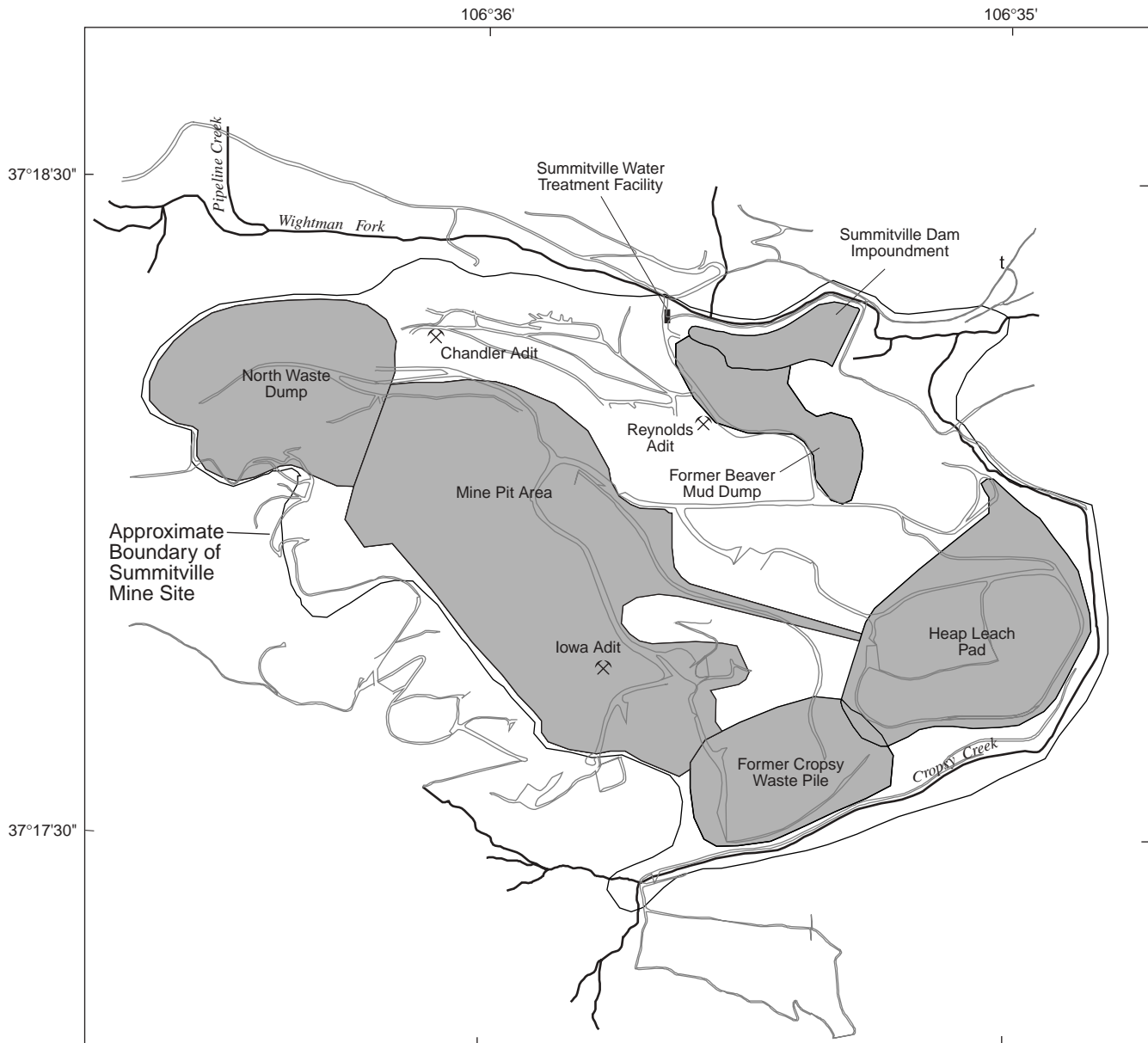
In July 1999, a tracer-injection study was conducted concurrently with synoptic sampling to generate mass-load profiles in Wightman Fork near the Summitville Mine site. The mine site is located in the San Juan Mountains of southwestern Colorado at an elevation of about 3,500 meters above sea level. Metal loads increased substantially along the 2,815-meter study reach along the boundary of the mine site. Spatial determinations of dissolved aluminum, copper, iron, manganese, and zinc loads were used to identify potential source areas to the stream. Overall, four source areas appeared to contribute most of the specific load at the end of the study reach. One source area was along a 60-meter reach downgradient from the toe of the North Waste Dump that generally corresponded to a region of radial faults. Another source area was a short reach that included inputs from the Summitville Water Treatment Facility and the Pump House Fault. In July 1999, seepage from the Summitville Dam Impoundment was a substantial contributor of metal load at the end of the study reach. Finally, the metal load contributed along a 60-meter reach that included Cropsy Creek is considered a substantial source of metal load to Wightman Fork.

## INTRODUCTION

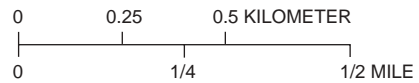
The Summitville Mine site is located at an elevation of about 3,500 meters above sea level in the San Juan Mountains of southwestern Colorado (fig. 1). Mine-drainage waters from the Summitville Mine are

among the most acidic and metal-rich waters in Colorado (Plumlee and others, 1995); high concentrations of aluminum, copper, iron, zinc, and several other metals are present in Wightman Fork. In 1992, the U.S. Environmental Protection Agency (USEPA) assumed responsibility for cleanup and remediation of the newly designated Superfund site. The contaminants of concern (COC) identified in the ecological risk assessment of the Superfund site were aluminum, cadmium, cyanide, copper, iron, lead, manganese, nickel, zinc, and pH (Morrison Knudsen Corporation, 1995). In 1998, the Colorado Department of Public Health and Environment (CDPHE) assumed shared management responsibilities for the Superfund site with the USEPA. Several interim remedial actions have been implemented to reduce the amount of acid mine drainage leaving the site. These actions include (1) the capture of acid mine drainage water in the Summitville Dam Impoundment (SDI) and treatment of the water in the Summitville Water Treatment Facility (SWTF), (2) detoxification of the heap leach pad, (3) capping and backfilling of the open mine pits and underground entrances, and (4) sitewide reclamation and revegetation. Water treatment at the SWTF is focused on decreasing the acidity and metal concentrations of the treated water.

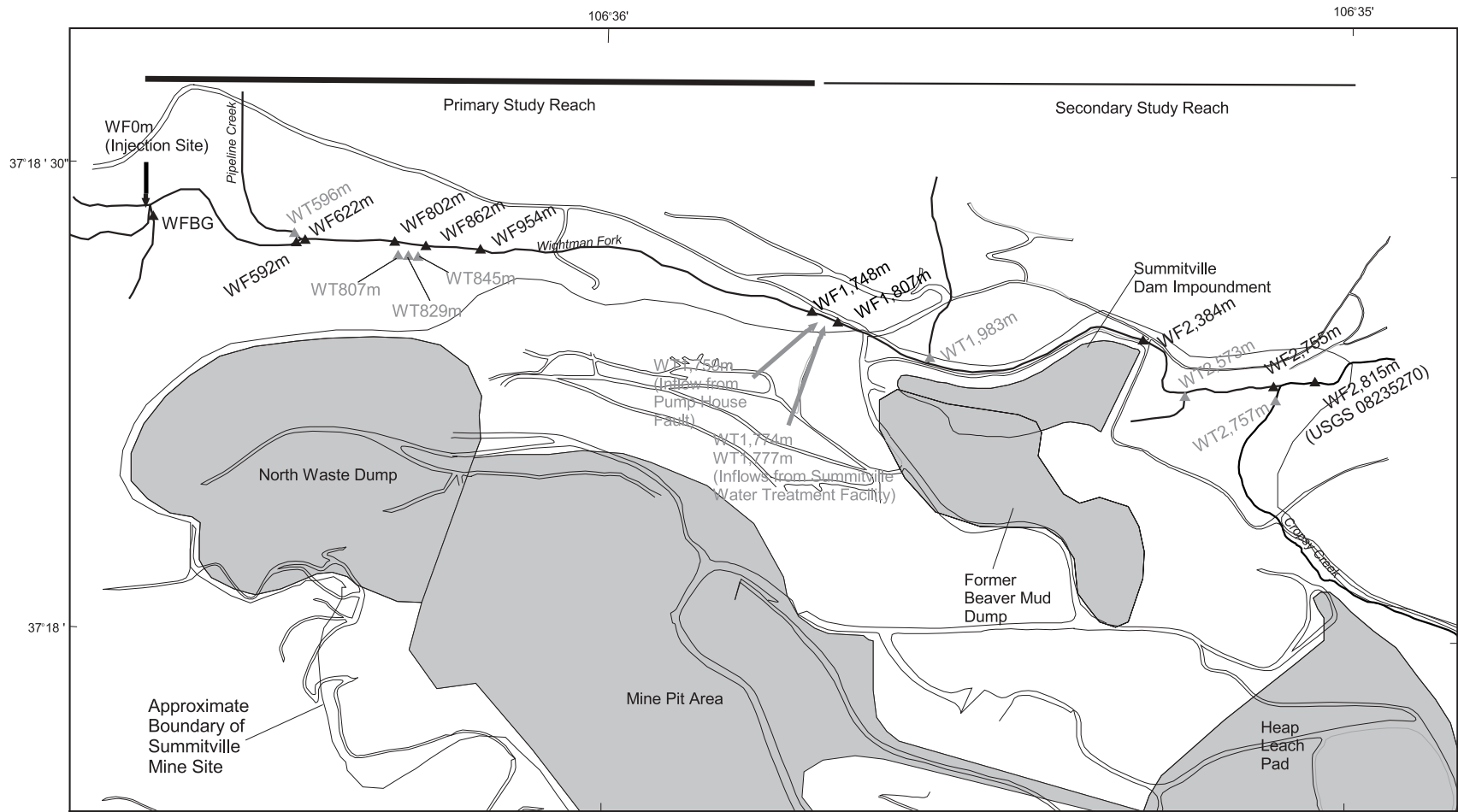
Metal loads from upper Wightman Fork are a substantial part of the total load leaving the mine site (Ortiz and Bencala, 2001). Historical ferricrete masses along the northern boundary of the mine site indicate the North Waste Dump (NWD) (fig. 2) represents a substantial source of acid drainage to Wightman Fork; large amounts of sulfidic waste rock are still present in the NWD. Along the toe of the NWD, springs related to a northwest/southeast-trending fault escarpment are apparent (Morrison Knudsen Corporation, 1997). Farther downstream, effluent from the SWTF and discharge from the Pump House Fault are point



Base modified from Morrison Knudsen Corporation, 1997  
 Albers Equal-Area Conic Projection  
 Standard Parallels 37°30' N and 40°30' N  
 Central Meridian 105°30' W



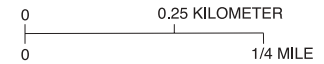
**Figure 1.** Location of Summitville Mine site.



Base modified from Morrison Knudsen Corp., 1997  
 Albers Equal-Area Conic Projection  
 Standard Parallels 37° 30' N and 40° 30' N  
 Central Meridian 105° 30' W

**EXPLANATION**

- ▲ WF1.592m WIGHTMAN FORK SAMPLING SITE AND IDENTIFICATION NUMBER
- ▲ WT2.757m INFLOW SAMPLING SITE AND IDENTIFICATION NUMBER



**Figure 2.** Locations of injection site, selected sites on Wightman Fork, and selected inflow sites to Wightman Fork.

sources of metal loading to Wightman Fork (Ortiz and Bencala, 2001). Cropsy Creek, which flows along the southern and eastern boundary of the mine site, is in close proximity to the Heap Leach Pad. Numerous acidic seeps have been identified downgradient from the Heap Leach Pad (Morrison Knudsen Corporation, 1997). In 1997, metal loads from Cropsy Creek accounted for a substantial part of the total load leaving the mine site (Ortiz and Bencala, 2001).

In September 1997, the U.S. Geological Survey (USGS), in cooperation with the USEPA and the CDPHE, investigated metal loading in Wightman Fork at the Summitville Mine site by using tracer-injection and synoptic-sampling techniques (Ortiz and Bencala, 2001). Determination of dissolved aluminum, copper, iron, manganese, and zinc loads at multiple sites on Wightman Fork provided a detailed understanding of source areas to upper Wightman Fork during base-flow conditions. In July 1999, a similar study was done in cooperation with the USEPA and the CDPHE to quantify loads to Wightman Fork during near-peak flow conditions. The resulting mass-load profiles for the same constituents allowed the USEPA and the CDPHE to identify and target source areas for future remediation efforts at the Summitville Mine site.

## Purpose and Scope

This report describes the results of a tracer-injection and synoptic-sampling study done in Wightman Fork at the Summitville Mine site on July 29 and 30, 1999. The report quantifies pH and selected metal loads at 23 sites on Wightman Fork from near the headwaters to the eastern boundary of the Superfund site. Discharge along the primary study reach was calculated using data derived from a continuous tracer injection. Discharge along the secondary study reach was determined using instantaneous discharge measurements. Synoptic sampling along the entire 2,815-meter study reach provided the concentration data needed to calculate the metal loads. Mass-load profiles were generated for dissolved aluminum, copper, iron, manganese, and zinc along the two study reaches. The profiles were used to identify and quantify potential source areas of metal loading to Wightman Fork during near-peak flow conditions. Additionally, the mass-load profiles were compared to similar profiles generated in 1997 during base-flow conditions.

## Description of Study Area

Wightman Fork flows east along the northern perimeter of the Summitville Mine site (fig. 2). The study reach was divided into two contiguous reaches. The primary study reach extended 1,748 meters from near the headwaters to just upstream from the SWTF outfall (fig. 2) and was consistent with the 1997 study. Quantification of metal loads upstream from the SWTF were of greatest interest to the cooperators because available data were limited and the metal-loading profile of Wightman Fork in this reach at high flow was largely unknown. Water quality in this reach is unaffected by discharge from the SWTF. Pipeline Creek is the largest tributary in the reach, although several small tributaries, springs, and seeps also are present. Ground-water inflow occurs in the reach as well (Ortiz and Bencala, 2001). The secondary study reach extended 1,067 meters from just upstream from the SWTF outfall to the USGS gaging station (site WF2,815m) at the eastern boundary of the mine site (fig. 2). Significant inflows along this reach include the SWTF outfall and Cropsy Creek. Treated water from the SWTF was highly buffered and averaged 64.3 liters per second during July 1999 (Camp Dresser McKee Federal Programs Corporation, 2000). Discharge at the USGS gaging station (08235270) can vary greatly during July and August. In 1996, the mean monthly discharge for the two months was 66 liters per second (Crowfoot and others, 1997). The mean monthly discharge during July and August 1997 (210 liters per second), 1998 (186 liters per second), and 1999 (310 liters per second) was substantially higher (Crowfoot and others, 1998, 1999, 2000).

Metal loads were determined at 23 main-stem sites on Wightman Fork, including a background site (WFBG) (table 1). Of these 23 sites, 18 were located in the primary study reach, 4 were located in the secondary study reach, and 1 (WF1,748m) was located in both reaches. Site WF1,748m was included in both reaches for comparison of loads between the two reaches. All sites were identified by the measured distance, in meters, downstream from the injection point. In addition to the sites located on Wightman Fork, numerous inflow sites were sampled as part of the study. The sites on Wightman Fork were designated by a WF prefix, and the inflow sites to Wightman Fork were designated by a WT prefix. Only those sites specifically identified in this report are shown in figure 2. Site locations and field properties



for the inflow sites are summarized in table 6 in the Appendix at the back of the report, and selected chemical data for synoptic samples collected from main-stem and inflow sites are summarized in tables 7 and 8 in the Appendix at the back of the report.

## STUDY APPROACH

The study design for this work was similar to that for the tracer-injection and synoptic-sampling study done at the Summitville Mine site in September 1997 (Ortiz and Bencala, 2001). Chloride was selected as the injection tracer for this study to be consistent with the 1997 study; background chloride samples were collected again. Fewer

Wightman Fork main-stem and inflow sites were sampled in 1999 than in 1997, but the key site locations were retained. Tracer-injection techniques and synoptic sampling were used to calculate dissolved metal loads along the primary reach on July 29, 1999 (Kimball, 1997). Instantaneous discharge measurements using standard measurement techniques (Rantz and others, 1982) and synoptic sampling (Horowitz and others, 1994) were used to calculate metal loads along the secondary reach on July 30, 1999; rain at the mine site negated the use of the tracer-injection data along the secondary reach on July 29, 1999. The primary difference between this study (1999) and the study done in 1997 was the higher discharge conditions in 1999. The goal of the 1999 study was to quantify the dissolved metal loads during high flow.

**Table 1.** Site locations for tracer-injection and synoptic-sampling study on Wightman Fork at the Summitville Mine site, July 29 and 30, 1999

[NA, not applicable; USEPA, U.S. Environmental Protection Agency; USGS, U.S. Geological Survey; shaded area denotes secondary study reach]

Site identification number (and transport site number)	Sampling date	Sample collection time	Distance from injection site (meters)	Stream reach	Description of site location or stream characteristics
WFBG	07-29-99	1035	-7	NA	Background site
WF13m (T1)	07-29-99	1039	13	Primary	
WF31m	07-29-99	1047	31	Primary	
WF325m	07-29-99	1118	325	Primary	
WF592m	07-29-99	1136	592	Primary	Upstream from Pipeline Creek
WF622m (T2)	07-29-99	1143	622	Primary	Downstream from Pipeline Creek
WF802m	07-29-99	1151	802	Primary	
WF817m	07-29-99	1201	817	Primary	White precipitate present
WF832m	07-29-99	1213	832	Primary	
WF862m (T3)	07-29-99	1226	862	Primary	
WF954m	07-29-99	1310	954	Primary	Previous site USEPA WF2
WF1,042m	07-29-99	1330	1,042	Primary	
WF1,102m (T4)	07-29-99	1344	1,102	Primary	
WF1,163m	07-29-99	1349	1,163	Primary	Downstream from old dam structure
WF1,259m	07-29-99	1404	1,259	Primary	Upstream from unnamed tributary
WF1,392m	07-29-99	1440	1,392	Primary	
WF1,485m	07-29-99	1506	1,485	Primary	
WF1,645m	07-29-99	1514	1,645	Primary	
WF1,748m (T5)	07-29-99	1519	1,748	Primary	Upstream from treatment facility outfall
WF1,748m (T5)	07-30-99	1010	1,748	Secondary	Upstream from treatment facility outfall
WF1,807m	07-30-99	1015	1,807	Secondary	Downstream from treatment facility outfall
WF2,384m	07-30-99	1045	2,384	Secondary	
WF2,755m	07-30-99	1105	2,755	Secondary	Upstream from Cropsy Creek
WF2,815m (T6)	07-30-99	1125	2,815	Secondary	At USGS streamflow-gaging station 08235270

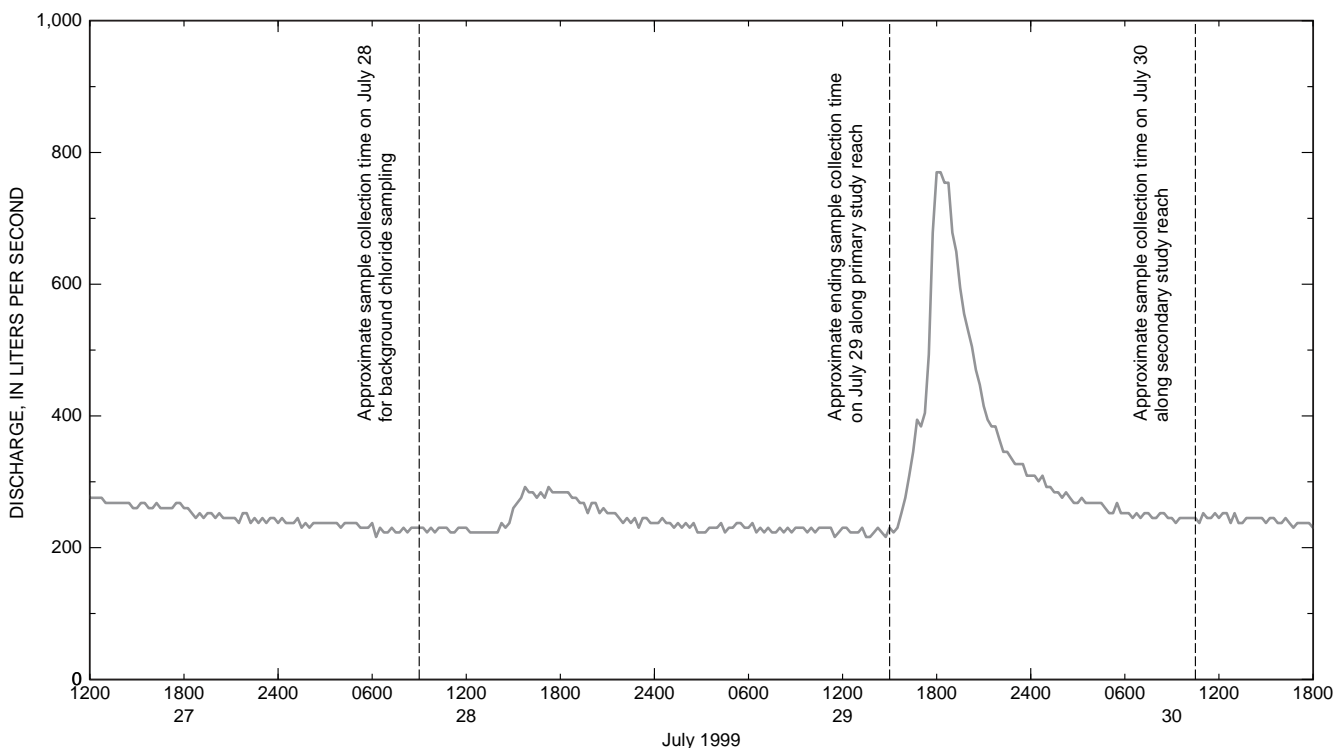
Tracer-injection and synoptic-sampling techniques are well suited for the determination of source loading in small mountain streams. To calculate discharge, a conservative salt tracer is added to a stream and the amount of dilution is measured as the tracer moves downstream (Bencala and others, 1990; Kimball, 1997; Ortiz and Bencala, 2001). The mass of salt added to the stream is known because the concentration of the injection tracer and the rate at which the salt is added to the stream are controlled (Zellweger and others, 1988). Conservation of mass then is used to calculate discharge by measuring the concentration of the tracer upstream and downstream from the injection point (Kimball and others, 1999a). Coupled with synoptic sampling, a detailed spatial determination of the metal loads in the stream can be generated, and potential source areas contributing the greatest loads can be identified for remedial action (Kimball, 1997; Kimball and others, 1999b). The tracer-injection and synoptic-sampling techniques used in this study are described in the following sections.

## Background Chloride Sampling

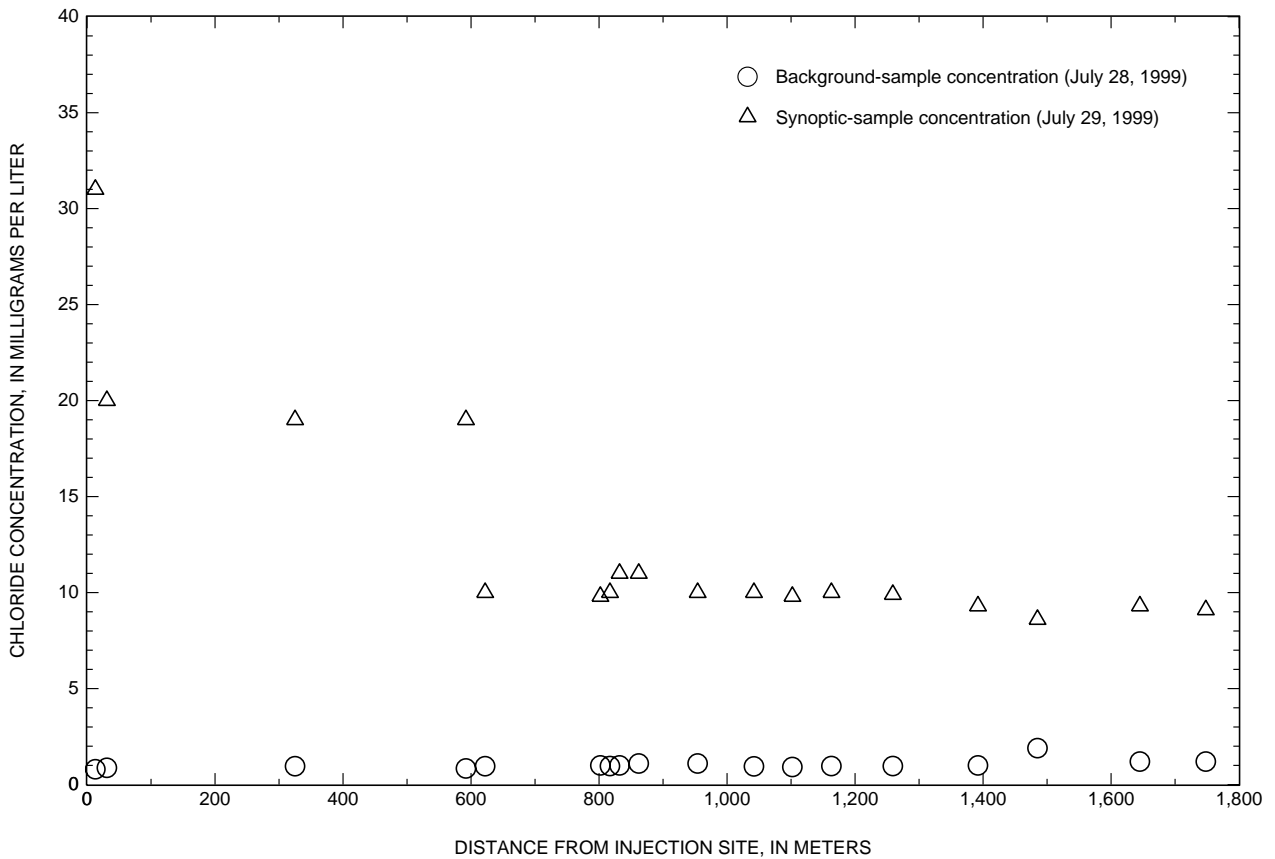
In order to quantify the background chloride concentrations in Wightman Fork, a pre-synoptic sampling for chloride was done just before the start of the chloride injection. Chloride data from 18 sites upstream from the SWTF outflow were used as part of this study; rain on July 29 negated the use of these data from sites downstream from the SWTF (fig. 2). Discharge conditions in Wightman Fork upstream from the SWTF outflow were similar during the background sampling on July 28 and synoptic samplings on July 29 (fig. 3). Background concentrations for the 18 sites upstream from the SWTF ranged from 0.80 to 1.9 milligrams per liter (fig. 4).

## Tracer Injection

A continuous injection of a concentrated sodium chloride solution began at 11:00 a.m. on July 28, 1999. A metered injection pump was programmed to deliver the solution at 335 milliliters per minute. A sample of the injection solution was collected from the pump at



**Figure 3.** Discharge at U.S. Geological Survey streamflow-gaging station 08235270, July 27–30, 1999.



**Figure 4.** Background- and synoptic-sample chloride concentrations in Wightman Fork, July 28 and 29, 1999.

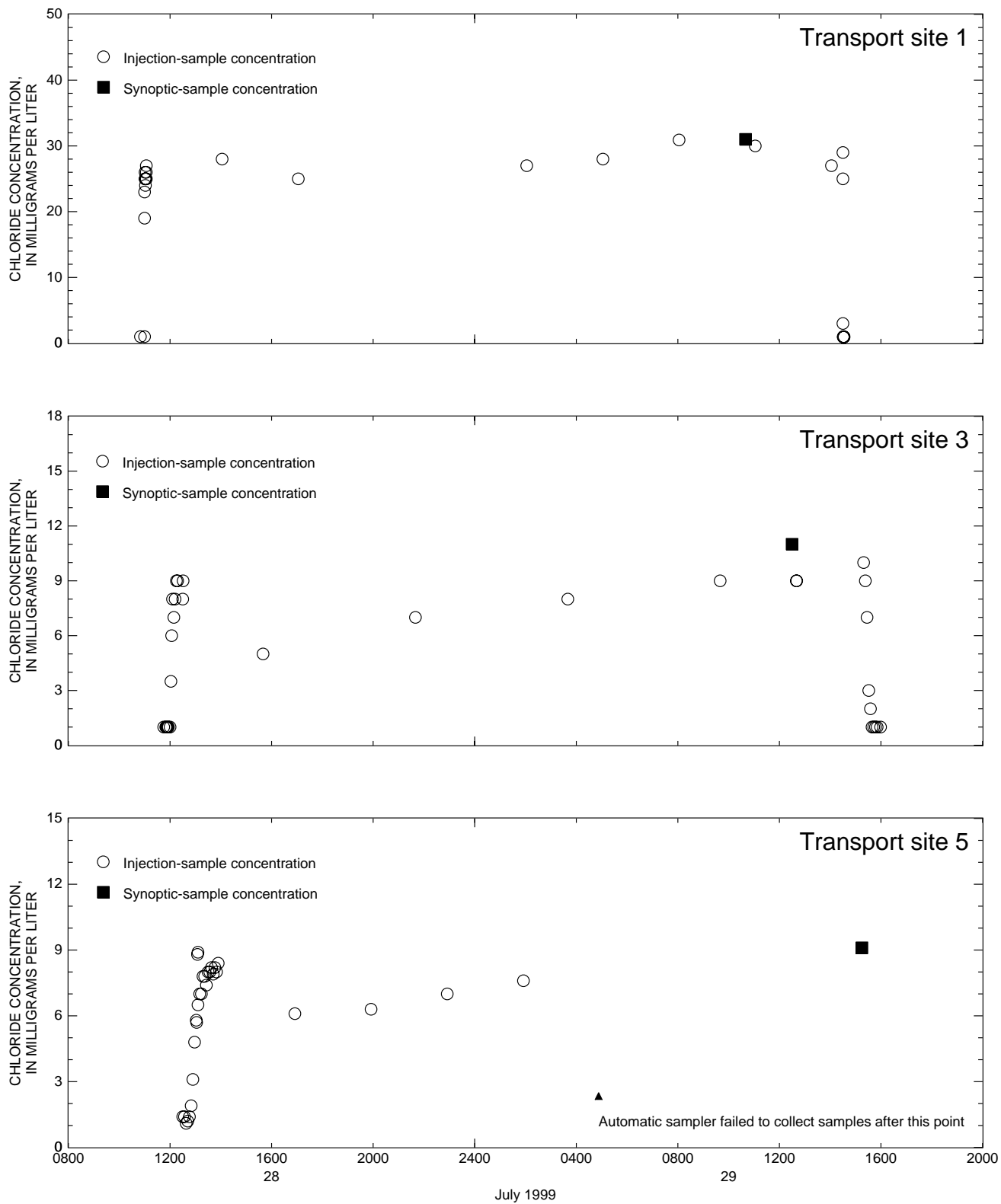
the start of the injection for the determination of chloride flux. Five additional samples were collected in the same manner during the continuous injection. Numerous chloride samples also were collected at six transport sites on Wightman Fork (table 1) to ascertain traveltime estimates and to confirm that chloride concentrations in the stream had reached an equilibrium before initiation of synoptic sampling (fig. 5). The continuous injection was terminated at 2:23 p.m. on July 29, 1999; the total injection time was about 27.5 hours.

### Synoptic Sampling

Synoptic sampling provides a spatially detailed description of stream-water quality and is accomplished by sampling numerous sites in a relatively short time. Analysis of the synoptic samples provides tracer-concentration data to calculate discharge and

specific constituent concentration data to calculate metal loads. The constituents discussed in this report are pH and dissolved aluminum, copper, iron, manganese, and zinc. The constituents are a subset of the COC's identified in the 1995 ecological risk assessment (Morrison Knudsen Corporation, 1995) and are associated with acid mine drainage at the Superfund site (Ecology and Environment, Inc., 1993). Additional selected chemical data, including total-recoverable data, for all synoptic samples collected during the study period are in tables 7 and 8 in the Appendix at the back of the report.

Synoptic sampling was done along the primary study reach on July 29, 1999. Samples were collected at 19 main-stem sites and 19 inflow sites. Sampling on that day was restricted to the primary study reach because rainfall at the mine site changed discharge conditions downstream along the secondary study reach (fig. 3); sample collection along the primary



**Figure 5.** Injection- and synoptic-sample chloride concentrations at selected transport sites (table 1) on Wightman Fork, July 28 and 29, 1999.

study reach occurred before rainfall runoff affected discharge. Synoptic sampling along the secondary study reach was done on July 30 after discharge in Wightman Fork had returned to a level comparable to the previous day; samples were collected at five main-stem sites and six inflow sites. The five main-stem sites included site WF1,748m, which was resampled to provide a comparison to data collected the previous day. All water-quality samples were analyzed for anions, including chloride, and selected dissolved metals. Field measurements of specific conductance and pH were made at all sites.

Synoptic samples were collected in a downstream order to follow a parcel of water as it moved downstream. Samples were collected in 3-liter plastic containers near the bank of the stream using grab-sample techniques. Particular care was taken to avoid disturbance of the stream bottom. Samples were transported to a nearby laboratory area for immediate processing. Samples collected for analysis of dissolved constituents were passed through 0.1-micrometer nitrocellulose plate filters. Samples collected for analysis of dissolved metals were preserved with nitric acid. All samples were packaged and transported to the USGS research laboratory in Boulder, Colo., for analysis. Standard quality-assurance procedures were followed; a 5-percent error in analytical precision was assumed for all metals data (J. Ball, U.S. Geological Survey, oral commun., 2000).

Field quality-assurance and quality-control samples were collected as part of the study. Duplicate samples were collected at sites WT807m and WF2,384m during routine synoptic sampling (table 9 in the Appendix at the back of the report). The relative percent difference was less than 10 percent in 87 percent of these duplicate data. A duplicate sample also was collected at WF2,815m during a rainstorm. Rapidly changing discharge conditions during sample collection probably accounted for the large relative percent difference for total-recoverable metals.

Three field blanks were collected during the study (table 10 in the Appendix at the back of the report). A field blank was a collection of final rinse water from decontaminated sampling and processing equipment. The blank sample also included water passed through clean sample tubing and filters. About 80 percent of the blank-sample data were reported below the method reporting limit (MRL). Only 5 percent of the blank-sample data were greater

than five times the MRL for the analyses. Total-recoverable iron concentrations were elevated in the blanks (greater than 20 times the MRL in 2 of 3 blank samples), but this was not considered a data quality problem because of the relatively high concentrations in the environmental samples.

## TRACER-INJECTION RESULTS

Analysis of the six mass-flux measurements (injection rate multiplied by the injection-sample concentration) indicated the chloride flux was relatively constant during the injection period (fig. 6). The relative percent difference between the maximum and minimum flux was about 1 percent. The median flux of 889 milligrams per second (standard deviation 3.66) was used to calculate the discharge along the primary study reach. Analytical error for the chloride analyses was estimated to be 3 percent (J. Ball, U.S. Geological Survey, oral commun., 2000).

Chloride concentrations in Wightman Fork attributable to the continuous tracer injection were determined by subtracting background-sample concentrations from synoptic-sample concentrations (fig. 4). The chloride differences (delta-chloride concentrations) were smoothed to produce a chloride profile that showed decreasing concentrations downstream (fig. 7); the underlying assumption was that discharge increased downstream. Smoothing was accomplished by identifying where substantial decreases in chloride concentration occurred along the stream and where identifiable tributary inputs (increased dilution) were observed. Chloride concentrations at selected sites were used as endpoints to delineate subreaches or transitions in chloride concentration from higher to lower concentration. A linear interpolation of the delta-chloride concentrations was done for intermediate sites along a subreach. The delta-chloride concentrations taken from the smoothed chloride profile were used to determine discharges (fig. 7).

Discharges at sites downstream from the injection site were calculated by considering the injection-solution flux (injection rate multiplied by the injection concentration) and the tracer concentrations in the stream. A discharge profile along the primary study reach (fig. 8 and table 2) was developed using the following equation from Broshears and others (1993):

$$Q = Q_{INJ}(C_{INJ}) / (C - C_p) \quad (1)$$

where

- $Q$  is the discharge, in liters per second;
- $Q_{INJ}$  is the rate of the tracer injection into the stream, in milligrams per second;
- $C_{INJ}$  is the tracer concentration in the injection solution, in milligrams per liter;
- $C$  is the tracer concentration in the synoptic sample, in milligrams per liter; and
- $C_p$  is the tracer concentration in the background sample, in milligrams per liter.

The denominator ( $C - C_p$ ) in equation 1 is the concentration derived from the smoothed delta-chloride concentrations just described. An error estimation of  $\pm 5$  percent was applied to estimates of discharge along the primary study reach. The error provides a conservative estimation of the variation due to analytical error in the chloride analysis (3 percent) and variation in the chloride flux (1 percent) during the injection period.

Instantaneous discharge measurements were made at several sites along the secondary study reach on July 30, 1999, because rainfall from the previous

day had negated the ability to estimate discharge using tracer-injection techniques. Measurements were made after discharge conditions in Wightman Fork had returned to pre-rainfall levels (fig. 3); the continuous injection was terminated by this time. The measurements made along the secondary study reach were rated as fair and, as such, an error estimation of  $\pm 8$  percent is shown in figure 8 for discharges along this reach. In Wightman Fork, four measurements were made downstream from the SWTF outfall, and one was made just upstream from the SWTF at site WF1,748m. The measurement at site WF1,748m provided a comparison for the estimates of discharge made the previous day using tracer-injection techniques. Three input sites also were measured using standard measurement techniques (Rantz and others, 1982).

Discharge in Wightman Fork increased nearly eightfold along the 2,815-meter study reach (fig. 8). The increase along the primary study reach consisted primarily of inflow from Pipeline Creek (site WT596m). The increase along the secondary study reach consisted primarily of inflow from the SWTF (sites WT1,774m and WT1,777m) and Cropsy Creek (site WT2,757m).

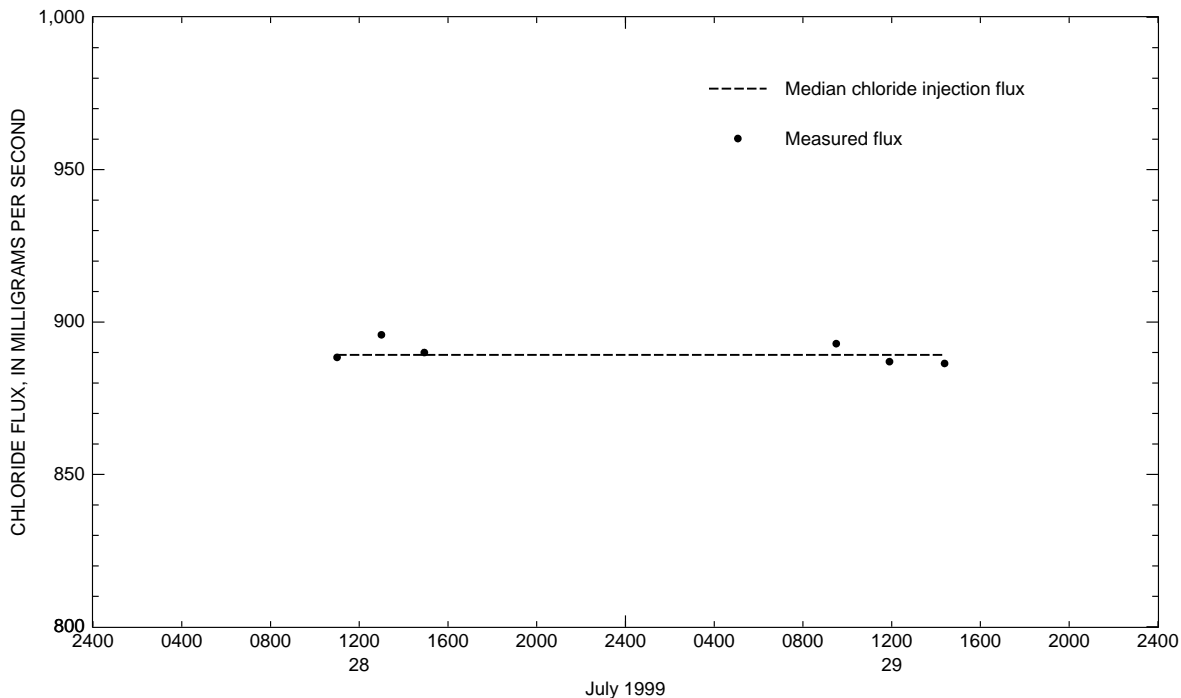
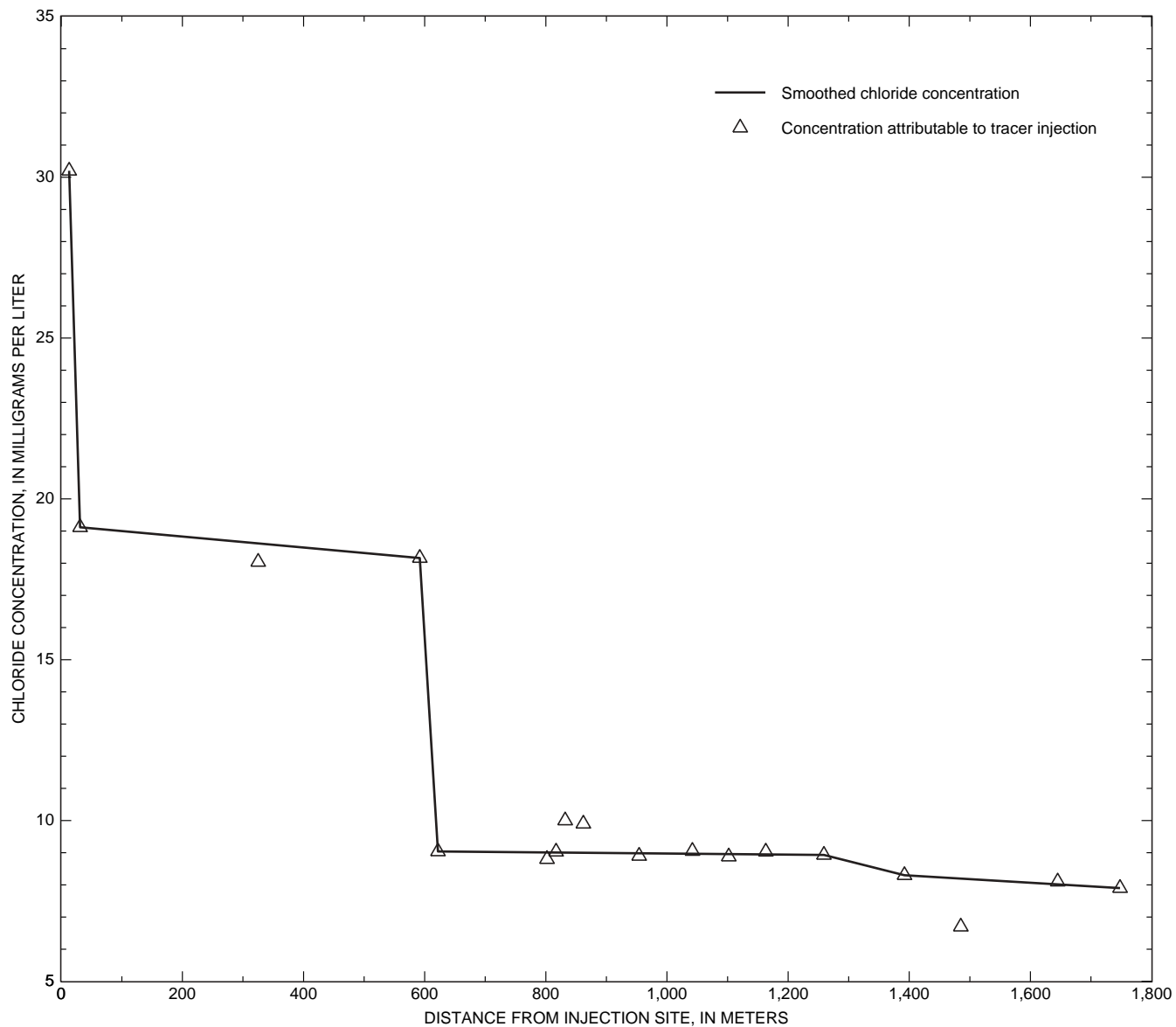


Figure 6. Mass flux of chloride into Wightman Fork during continuous tracer injection, July 28 and 29, 1999.

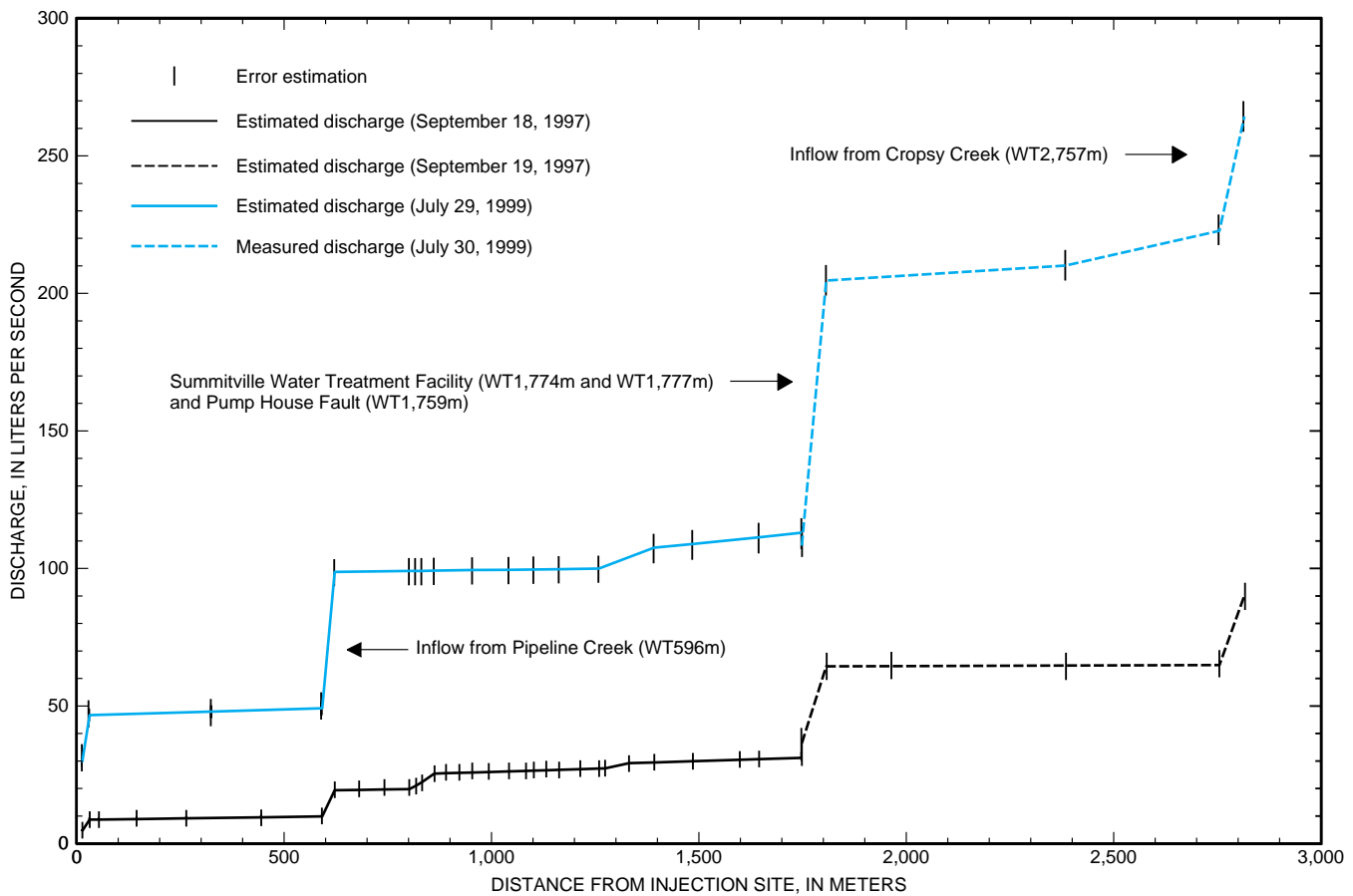


**Figure 7.** Chloride concentrations in Wightman Fork attributable to continuous tracer injection, July 29, 1999.

### SYNOPTIC-SAMPLING RESULTS

The pH of Wightman Fork along both study reaches ranged from 3.3 to 4.7 standard units (fig. 9 and table 2). The highest measured pH in Wightman Fork occurred downstream from Pipeline Creek (site WT596m) at site WF622m. Near-neutral water from Pipeline Creek (pH 6.6) raised the pH in this short reach from 4.2 to 4.7 standard units (table 2). About 200 meters downstream, however, the pH had reverted to 4.2 standard units as low-pH water

continued to enter Wightman Fork. The values of pH in Wightman Fork decreased slightly downstream to the SWTF outfall before increasing sharply to 4.6 standard units as inflow of alkaline water from the treatment facility entered the stream (fig. 9). The SWTF uses a treatment process that, in part, relies on raising the pH of the influent to promote precipitation of metals from the water. The effect of the treated water discharged to Wightman Fork was apparent along the entire secondary study reach.



**Figure 8.** Discharge profiles for Wightman Fork during synoptic sampling, September 18 and 19, 1997, and July 29 and 30, 1999.

Downstream-concentration profiles for dissolved aluminum, copper, iron, manganese, and zinc in Wightman Fork were relatively similar to those in September 1997 (Ortiz and Bencala, 2001). Metal concentrations upstream from Pipeline Creek (site WT596m) were elevated, but the concentrations decreased as water from Pipeline Creek entered the stream (table 2). Concentrations increased substantially along a 60-meter reach between sites WF802m and WF862m, but the percent increases were less than those observed in September 1997 (table 3). In 1999, dissolved metal concentrations at WF862m, with the exception of dissolved iron, were about one-third of those in September 1997. Concentrations remained about the same between site WF862m and the site upstream from the SWTF outfall (site WF1,748m). Dissolved aluminum and zinc concentrations decreased just downstream from the SWTF outfall as alkaline water was released to Wightman Fork

(table 2). Overall, metal concentrations increased slightly downstream from WF1,807m to the end of the study reach.

Dissolved metal concentrations composed a substantial proportion of the total-recoverable metal concentrations in Wightman Fork (table 8 in the Appendix at the back of report). The median percentages of dissolved aluminum, copper, iron, manganese, and zinc relative to the total-recoverable concentration were 92, 98, 66, 100, and 98 percent, respectively. The high percentage of dissolved to total-recoverable aluminum, copper, manganese, and zinc was expected because of the highly acidic nature of the stream. The percentage of dissolved aluminum did decrease to 63 to 68 percent where substantial amounts of near-neutral or alkaline water entered the stream. The decrease was observed immediately downstream from Pipeline Creek and downstream from the STWF along the secondary study reach to WF2,815m (fig. 2).



## METAL LOADS

Dissolved aluminum, copper, iron, manganese, and zinc loads in Wightman Fork are discussed in the following sections. Loads for other metals are not presented. Data collected from inflow sites were used to help identify source areas along the two study reaches (tables 6 and 7 in the Appendix at the back of report). In general, metal sources were not specifically identified but were generalized as source areas within a stream reach. Loads in the primary study reach were calculated using discharges derived from the chloride-tracer and synoptic-sample concentration data collected on July 29, 1999; loads in the secondary study reach were calculated using instantaneous discharge and synoptic-sample concentration data

collected on July 30, 1999. Estimations of error for the discharge calculations (5 percent) and estimated error associated with the metals analyses (5 percent) are shown with the mass-load profiles; an error of 8 percent was assumed for instantaneous discharge measurements in the secondary study reach. Tracer-derived discharges were unavailable for the secondary study reach on July 29, 1999. Metal loads at site WF1,748m were calculated for both days to provide a semiquantitative comparison between the two study reaches because the two load profiles were not continuous along the entire study reach. The two discharge estimates were within 5 percent of each other, and differences in load calculations at this site ranged from 4.4 percent for dissolved manganese to 12 percent for dissolved iron (table 2).

**Table 2.** Estimated discharge, pH, dissolved metal concentrations, and calculated dissolved metal loads in Wightman Fork at the Summitville Mine site, July 29 and 30, 1999

[Al, aluminum; Cu, copper; Fe, iron; Mn, manganese; Zn, zinc; shaded area denotes secondary study reach]

Site identification number	Estimated discharge (liters per second)	pH (standard units)	Dissolved metal concentration (micrograms per liter)					Calculated dissolved metal load (kilograms per day)				
			Al	Cu	Fe	Mn	Zn	Al	Cu	Fe	Mn	Zn
WF13m	29.6	3.3	8,100	120	3,200	1,700	950	20.69	0.31	8.17	4.34	2.43
WF31m	46.7	3.7	5,500	79	1,900	1,200	680	22.19	.32	7.66	4.84	2.74
WF325m	47.9	4.1	4,900	71	1,600	1,100	600	20.30	.29	6.63	4.56	2.49
WF592m	49.2	4.2	4,500	67	1,700	1,100	600	19.11	.28	7.22	4.67	2.55
WF622m	98.8	4.7	1,800	34	960	640	350	15.36	.29	8.19	5.46	2.99
WF802m	99.1	4.6	2,400	54	1,100	750	390	20.55	.46	9.42	6.42	3.34
WF817m	99.1	4.5	4,100	120	1,100	920	480	35.10	1.03	9.42	7.88	4.11
WF832m	99.1	4.2	10,000	350	1,300	1,600	820	85.61	3.00	11.13	13.70	7.02
WF862m	99.2	4.2	11,000	520	1,400	1,700	910	94.27	4.46	12.00	14.57	7.80
WF954m	99.4	4.2	12,000	580	1,400	1,700	970	103.1	4.98	12.02	14.60	8.33
WF1,042m	99.5	4.2	12,000	590	1,600	1,900	980	103.2	5.07	13.76	16.34	8.43
WF1,102m	99.6	4.2	13,000	640	1,600	1,900	1,000	111.9	5.51	13.77	16.36	8.61
WF1,163m	99.7	4.2	13,000	670	1,500	1,700	1,100	112.0	5.77	12.93	14.65	9.48
WF1,259m	100	4.2	14,000	740	1,700	2,200	1,100	120.9	6.39	14.68	19.00	9.50
WF1,392m	108	3.7	13,000	720	1,300	1,900	940	120.8	6.69	12.08	17.66	8.73
WF1,485m	109	3.9	11,000	710	1,300	1,800	970	103.5	6.68	12.23	16.93	9.12
WF1,645m	111	4.0	13,000	750	1,300	1,900	910	125.0	7.21	12.50	18.27	8.75
WF1,748m	113	3.9	10,000	580	1,200	1,500	780	97.63	5.66	11.72	14.64	7.62
WF1,748m	108	4.0	11,000	670	1,100	1,700	900	103.0	6.27	10.29	15.91	8.42
WF1,807m	205	4.6	6,500	770	1,600	1,900	650	114.9	13.62	28.29	33.60	11.49
WF2,384m	210	4.6	6,800	700	1,500	2,200	600	123.4	12.71	27.23	39.94	10.89
WF2,755m	223	4.5	7,600	1,100	2,100	3,000	810	146.3	21.17	40.41	57.73	15.59
WF2,815m	264	4.5	6,600	940	2,000	3,100	910	150.7	21.47	45.68	70.80	20.78

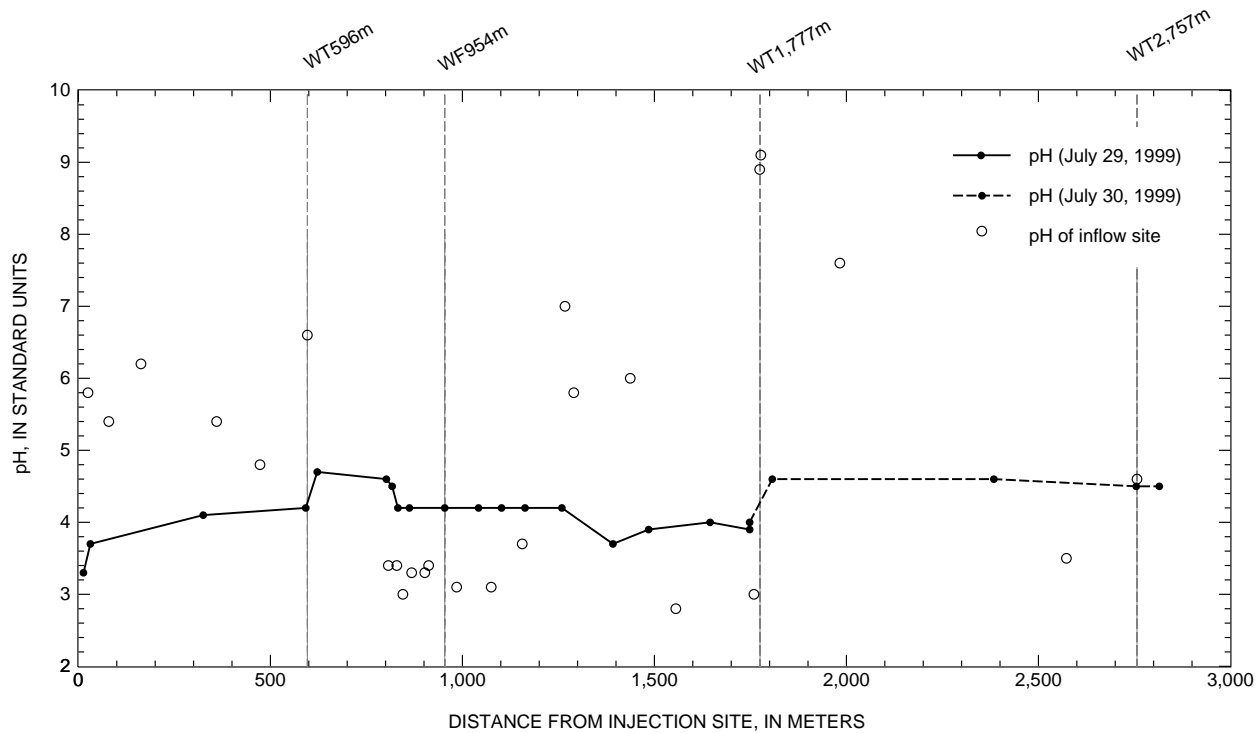


Figure 9. pH profiles for sites on Wightman Fork and inflow sites to Wightman Fork, July 29 and 30, 1999.

Table 3. Dissolved metal concentrations at two sites on Wightman Fork, September 1997 and July 1999

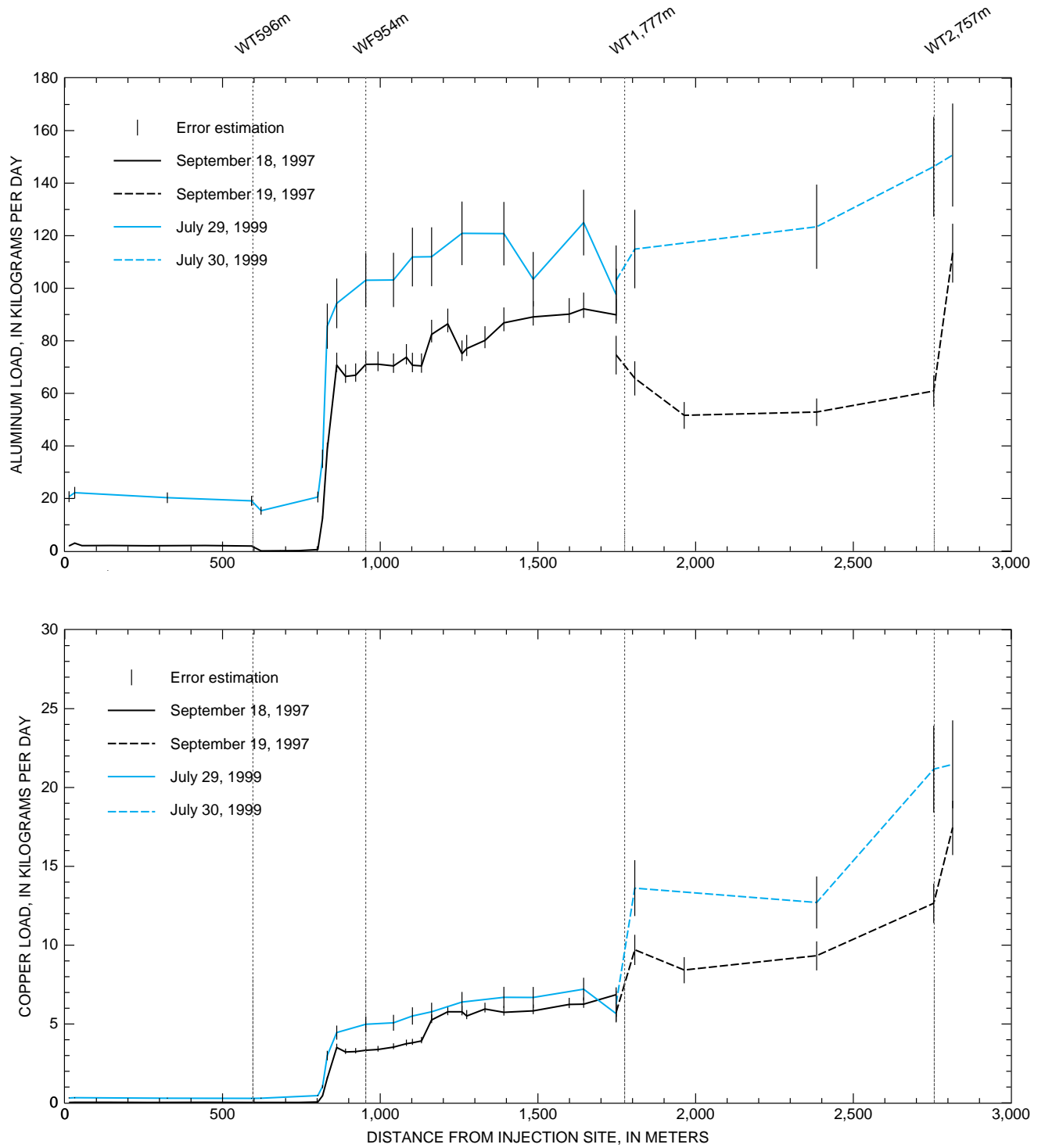
Metal of concern	Concentration in September 1997 <sup>a</sup> (micrograms per liter)		Concentration in July 1999 (micrograms per liter)		Percent increase in concentration between sites WF802m and WF862m	
	Site WF802m	Site WF862m	Site WF802m	Site WF862m	September 1997	July 1999
Aluminum	320	32,000	2,400	11,000	9,900	358
Copper	30	1,600	54	520	5,230	863
Iron	380	1,600	1,100	1,400	321	27
Manganese	700	4,600	750	1,700	557	127
Zinc	380	2,400	390	910	531	133

<sup>a</sup>Concentration data from Ortiz and Bencala (2001).

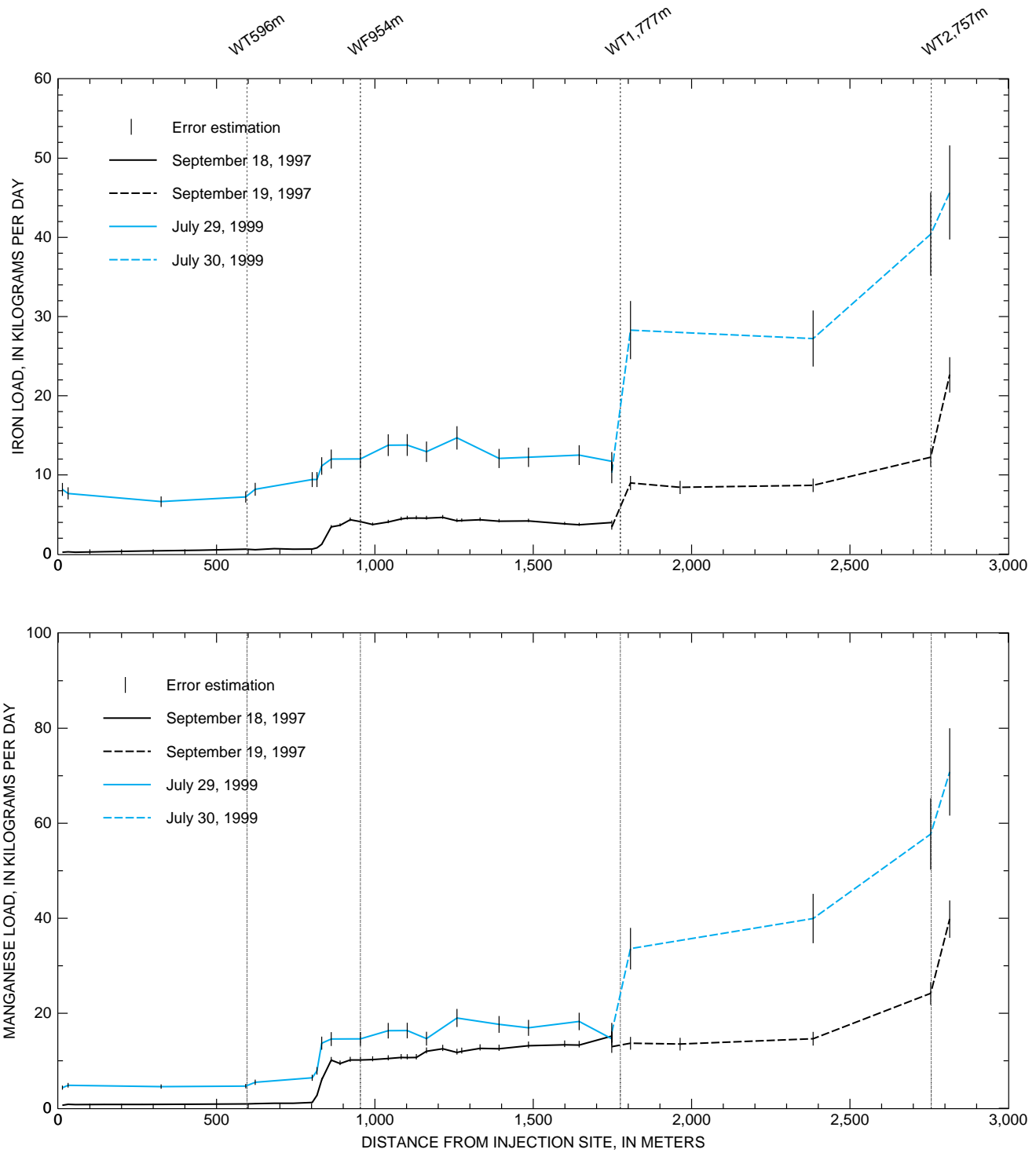
## Primary Study Reach

Downstream load profiles for dissolved aluminum, copper, iron, manganese, and zinc along the primary study reach in July 1999 were similar to profiles presented by Ortiz and Bencala (2001) for September 1997 (figs. 10–12). Although the metal concentrations were typically smaller in July 1999, the metal loads typically were much larger

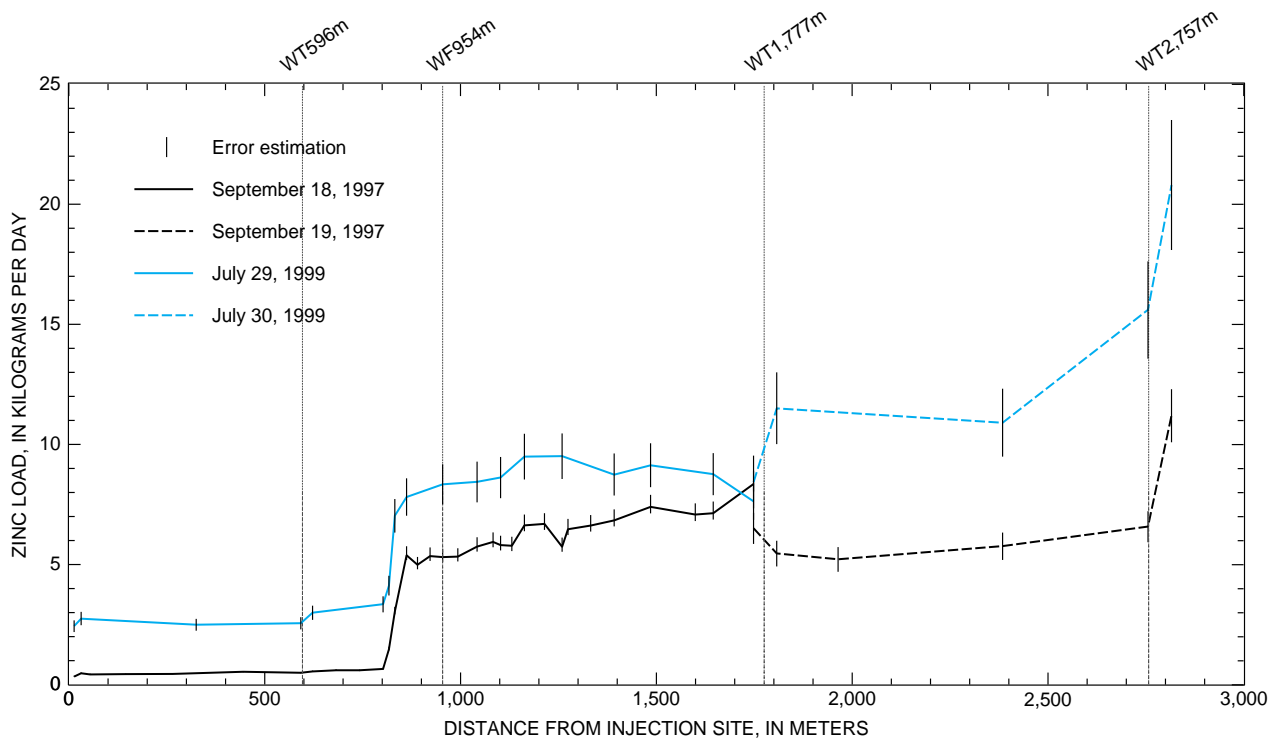
because of increased discharge in Wightman Fork. From the injection site to about 800 meters downstream, dissolved aluminum, copper, iron, manganese, and zinc loads were relatively small and generally remained stable. Aluminum loads did, however, decrease slightly just downstream from Pipeline Creek (site WT596m) as near-neutral pH water entered Wightman Fork. It is likely that precipitation



**Figure 10.** Mass-load profiles for dissolved aluminum and copper in Wightman Fork, September 18 and 19, 1997, and July 29 and 30, 1999.



**Figure 11.** Mass-load profiles for dissolved iron and manganese in Wightman Fork, September 18 and 19, 1997, and July 29 and 30, 1999.



**Figure 12.** Mass-load profile for dissolved zinc in Wightman Fork, September 18 and 19, 1997, and July 29 and 30, 1999.

of amorphous or poorly crystalline aluminum minerals occurred as the two water types mixed. Evidence of a white precipitation on the stream bottom immediately downstream from Pipeline Creek supports this conclusion.

Metal loads increased substantially along the 60-meter reach between sites WF802m and WF862m. Samples collected along the reach included sites WT807m, WT829m, and WT845m. All three samples were highly acidic (pH 3.0 to 3.4) and contained high concentrations of dissolved metals (tables 6 and 7 in the Appendix at the back of report). The reach is north of the NWD and is downgradient from spring and seep inflows from the northern toe of the NWD (fig. 2). The area generally corresponds to a region of radial faults as described in Morrison Knudsen Corporation (1997). Elevated copper, iron, and zinc concentrations in several springs in the area were similar to ground-water chemistry from the underground workings of the Summitville mine (Plumlee and others, 1996). Along this short

reach, aluminum loads increased by 359 percent and copper loads increased by 870 percent. Loads increased by 27 (iron), 127 (manganese), and 134 percent (zinc) (figs. 10–12 and table 2). Metal loads contributed by the 60-meter reach represented a substantial percentage of the dissolved aluminum (76 percent), copper (71 percent), iron (22 percent), manganese (56 percent), and zinc (59 percent) loads at the end of the primary study reach (table 4). The percent contributions of dissolved aluminum, manganese, and zinc loading from the 60-meter reach, relative to the metal loading at the end of the primary reach (WF1,748m), were generally similar in 1999 and 1997.

Generally, metal loads continued to increase downstream from site WF862m to site WF,1748m but at a much smaller rate. Diffuse subsurface inputs and small tributary inflows along the right bank (mine side) were the predominant sources of metals along this reach. Most of the inflow sites were characterized by low pH and high metals concentrations (tables 6

and 7 in the Appendix at the back of report). Possible sources might include natural seepage, springs and seeps at the toe of the NWD, seepage from the mine pit area, and leakage from the Chandler adit (fig. 1).

## Secondary Study Reach

Metal loads at site WF1,748m represented the dissolved metal loads contributed from the primary study reach. On July 30, 1999, the percent contribution from the primary study reach, as represented by site WF1,748m, to site WF2,815m ranged from about 22 percent for iron and manganese to 68 percent for aluminum (table 5). The percent contributions for copper and zinc were 29 percent and 41 percent, respectively. The percent contribution from the primary study reach in July 1999 was generally similar to those during low-flow conditions in September 1997 (table 5).

Metal loads in Wightman Fork continued to increase downstream along the secondary study reach. Dissolved metal loads increased 12 percent for aluminum, 117 percent for copper, 175 percent for iron, 111 percent for manganese, and 36 percent for zinc along the 59-meter reach between sites WF1,748m and WF1,807m (table 2 and figs. 10–12). Effluent from the SWTF (sites WT1,774m and WT1,777m) and discharge from the Pump House Fault (site WT1,759m) were the primary sources of metal loading along the 59-meter reach (B. Marshall, Rocky Mountain Consultants, written commun., 2000). The SWTF contributed a substantial amount of the aluminum

and manganese loads to the stream, whereas the Pump House Fault contributed a substantial amount of the copper, iron, and zinc loads.<sup>1</sup> The increases in load along the 59-meter reach were equivalent to between 8 percent (aluminum) and 39 percent (iron) of the load at the end of the study reach (table 5). For this reach, the percentages were about 10 to 25 percent higher than in September 1997 (table 5). Two factors may account for the apparent increase in contribution. First, the overall input of metal loads along this reach was much higher during the high-flow period. Second, the contribution of Cropsy Creek to the overall load leaving the site in July 1999 was substantially less than in September 1997.

In September 1997, dissolved aluminum and zinc loads decreased between sites WF1,748m and WF1,807m (table 5) because metals precipitated from the water column as alkaline water from the SWTF entered the stream (Ortiz and Bencala, 2001). In July 1999, losses were not observed along this short reach. Metal precipitation may have occurred but the overall result was a net gain. An estimation of the dissolved aluminum load contributed by the SWTF and Pump House Fault indicated that the increase in load between sites WF1,748m and WF1,807m, assuming conservation of mass, should have been more than two times what was observed.

<sup>1</sup> Loads were estimated using daily mean discharge data for the Summitville Water Treatment Facility outfall (July 30, 1999) and discharge at the Pump House Fault estimated from two instantaneous measurements (July 19 and August 2) along with chemical data collected by the USGS during synoptic sampling on July 29, 1999.

**Table 4.** Contribution of metal loads to Wightman Fork from a selected stream reach and percentage of load at end of primary study reach attributable to selected stream reach, September 18, 1997, and July 29, 1999

Dissolved metal	Metal load contributed from reach between sites WF802m and WF862m on July 29, 1999 (kilograms per day)	Metal load at site WF1,748m on July 29, 1999 (kilograms per day)	Percentage of load at site WF1,748m contributed from reach between sites WF802m and WF862m	
			September 18, 1997 <sup>a</sup>	July 29, 1999
Aluminum	73.72	97.63	78	76
Copper	4.00	5.66	50	71
Iron	2.58	11.72	70	22
Manganese	8.15	14.64	58	56
Zinc	4.46	7.62	57	59

<sup>a</sup>Mass-load data from Ortiz and Bencala (2001).

**Table 5.** Contribution of metal loads to Wightman Fork from selected stream reaches and percentage of load at end of secondary study reach attributable to selected stream reaches, September 19, 1997, and July 30, 1999

Dissolved metal	Metal load contributed from selected Wightman Fork reaches on July 30, 1999 (kilograms per day)			Metal load at site WF2,815m on July 30, 1999 (kilograms per day)	Percentage of load at site WF2,815m contributed from selected Wightman Fork reaches					
	Upstream from site WF1,748m	Site WF1,748m to site WF1,807m	Site WF2,755m to site WF2,815m		Upstream from site WF1,748m		Site WF1,748m to site WF1,807m		Site WF2,755m to site WF2,815m	
					September 1997 <sup>a</sup>	July 1999	September 1997 <sup>a</sup>	July 1999	September 1997 <sup>a</sup>	July 1999
	Aluminum	103.0	11.9		4.4	150.7	66	68	losses	8
Copper	6.27	7.35	.30	21.47	33	29	23	34	27	1
Iron	10.29	18.00	5.27	45.68	15	23	25	39	46	12
Manganese	15.91	17.69	13.07	70.80	33	22	2	25	39	18
Zinc	8.42	3.07	5.19	20.78	58	41	losses	15	41	25

<sup>a</sup>Mass-load data from Ortiz and Bencala (2001).

In July 1999, dissolved metal loads in Wightman Fork increased 19 percent for aluminum, 67 percent for copper, 48 percent for iron, 45 percent for manganese, and 43 percent for zinc as a result of inflow between sites WF2,384m and WF2,755m (table 2). Inflow in this reach was a mixture of seepage from the SDI, surface-water drainage from the heap leach pad, and ground-water seepage from areas southeast of the SDI (fig. 2). The majority of the metal loads in this reach could be attributed to seepage from the SDI (B. Marshall, Rocky Mountain Consultants, written commun., 2000), even though less than 10 percent of the discharge was attributable to seepage from the SDI. Overall, the increases in metal load along the 371-meter reach between sites WF2,384m and WF2,755m were equivalent to between 15 (aluminum) and 39 percent (copper) of the load at the end of the study reach.

In July 1999, the percent contribution of loads from a reach between WF2,755m and WF2,815m that includes tributary inflow from Cropsy Creek (site WF2,757m) was substantially less than was observed in September 1997; whereas dissolved metal loads contributed by Cropsy Creek in 1997 ranged from 27 (copper) to 46 percent (aluminum and iron) (Ortiz and Bencala, 2001), the contribution in 1999 was no more than 25 percent for any of the five dissolved metals of concern (table 5). The remediation work done in the Cropsy Creek valley in 1998 likely contributed to the decrease in loading emanating from Cropsy Creek (B. Marshall, Rocky Mountain Consultants, written commun., 2000).

Overall, in 1999, four source areas along the entire study reach appear to contribute most of the dissolved aluminum, copper, iron, manganese, and zinc load at the most downstream site in Wightman Fork. The source areas were (1) a reach between sites WF802m and WF862m downgradient from the toe of the NWD, (2) a reach between sites WF1,748m and WF1,807m that includes effluent from the SWTF and discharge from the Pump House Fault, (3) a reach between sites WF2,384m and WF2,755m that includes discharge and seepage from the SDI, and (4) a reach between sites WF2,755m and WF2,815m that includes tributary inflow from Cropsy Creek.

## SUMMARY

The Summitville Mine Superfund site is located in the San Juan Mountains of southwestern Colorado at an elevation of about 3,500 meters above sea level. Metal loads from upper Wightman Fork are a substantial part of the total load leaving the Summitville Mine site. In September 1997, a tracer-injection and synoptic-sampling study was done during base-flow conditions to identify stream reaches where metal loading occurred. A similar study was done in July 1999 to quantify loads during near-peak flow conditions. The metals of concern for the study were dissolved aluminum, copper, iron, manganese, and zinc.

Discharges were calculated for 18 sites on Wightman Fork by using data derived from a continuous tracer injection and at 4 sites using instantaneous discharge measurements. Synoptic samples were collected at all 22 sites: 18 in the primary study reach (0 to 1,748 meters downstream from the injection site) on July 29, 1999, and 4 in the secondary study reach (1,748 to 2,815 meters downstream) on July 30, 1999. Site WF1,748m, which represented the boundary between the two study reaches, was sampled both days to provide a comparison of loads on the two sampling days. Metal loads at all sites were calculated and mass-load profiles for each metal of concern were generated.

Metal loads increased substantially along the primary study reach, which was upstream from the outflow point of the Summitville Water Treatment Facility. Metal loads for all five metals of concern increased between 27 (iron) and 870 (copper) percent along a 60-meter reach between sites WF802m and WF862m. The reach is north of the North Waste Dump and is downgradient from spring and seep inflow from the northern toe of the dump. The area generally corresponds to a region of radial faults, and metal concentrations in several springs in the area compared well with ground-water chemistry from the underground workings of the mine. Dissolved aluminum, copper, manganese, and zinc loads contributed by this 60-meter reach were equivalent to about one-half to three-fourths of the load at the end of the primary study reach. Metal loads from the primary study reach as a whole (as represented by site WF1,748m on July 30, 1999) were equivalent to about 22 percent of the iron and manganese, 29 percent of the copper, 41 percent of the zinc, and 68 percent of the aluminum load at the most downstream site in the study area (site WF2,815m). The percent contributions in July 1999 were generally similar to those in September 1997.

Metal loads continued to increase along the secondary study reach between sites WF1,748m and WF2,815m. Effluent from the Summitville Water Treatment Facility and discharge from the Pump House Fault were the primary sources of metal loading between sites WF1,748m and WF1,807m. The increases were equivalent to between 8 (aluminum) and 39 percent (iron) of the load at the end of the study reach. The loads contributed from the reach were about 10 to 25 percent larger than the loads at low flow in 1997. Metal loads increased substantially between sites WF2,384m and WF2,755m. Dissolved metal loads along this 371-meter reach increased 19 percent

for aluminum, 67 percent for copper, 48 percent for iron, 45 percent for manganese, and 43 percent for zinc. Nearly all the increase in load was attributable to seepage from the Summitville Dam Impoundment. The increases in load were equivalent to between 15 (aluminum) and 39 percent (copper) of the load at the end of the study reach.

The percent contribution of metal load was no more than 25 percent for any of the five dissolved metals of concern along the reach between WF2,755m and WF2,815m that includes tributary inflow from Cropsy Creek. This was substantially less than was observed in September 1997 when the percent contribution ranged from 27 (copper) to 46 percent (aluminum and iron). The remediation work done in the Cropsy Creek valley in 1998 likely contributed to the decrease in loading emanating from Cropsy Creek.

Overall, four source areas along the entire study reach appear to contribute most of the dissolved aluminum, copper, iron, manganese, and zinc load at the most downstream site in Wightman Fork. The source areas were (1) a reach between sites WF802m and WF862m downgradient from the toe of the North Waste Dump, (2) a reach between sites WF1,748m and WF1,807m that includes effluent from the Summitville Water Treatment Facility and discharge from the Pump House Fault, (3) a reach between sites WF2,384m and WF2,755m that includes discharge and seepage from the Summitville Dam Impoundment, and (4) a reach between sites WF2,755m and WF2,815m that includes tributary inflow from Cropsy Creek.

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# APPENDIX

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**Table 6.** Site locations, specific conductance, and pH for inflow sites to Wightman Fork, July 29 and 30, 1999

[m, meters;  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter at 25 degrees Celsius; USEPA, U.S. Environmental Protection Agency; rb, right bank; lb, left bank; shaded area denotes secondary study reach]

Site identification number	Sampling date and time	Field value		Inflow type	Feature or description of inflow
		Specific conductance ( $\mu\text{S}/\text{cm}$ )	pH (standard units)		
WT25m	07-29-99 1042	39	5.8	Tributary	Previously sampled as site USEPA WF1
WT79m	07-29-99 1058	140	5.4	Pit	Subsurface sampling pit near rb
WT163m	07-29-99 1106	36	6.2	Tributary	Small unnamed tributary along lb
WT360m	07-29-99 1123	29.7	5.4	Tributary	Small unnamed tributary along rb
WT473m	07-29-99 1131	772	4.8	Diffuse	Bog area along rb
WT596m	07-29-99 1138	28	6.6	Tributary	Tributary flow from Pipeline Creek along lb
WT807m	07-29-99 1158	2,550	3.4	Pit	Subsurface sampling pit adjacent to ponded area along rb
WT829m	07-29-99 1206	2,020	3.4	Diffuse	Seepage from arroyo cut along rb downstream from bogs
WT845m	07-29-99 1224	2,390	3.0	Tributary	Tributary flow along rb downstream from bog area
WT868m	07-29-99 1236	981	3.3	Pit	Subsurface sampling pit near rb
WT902m	07-29-99 1255	1,530	3.3	Pit	Subsurface sampling pit near rb
WT912m	07-29-99 1243	1,370	3.4	Pit	Subsurface sampling pit near rb
WT985m	07-29-99 1323	1,600	3.1	Pit	Subsurface sampling pit near rb
WT1,075m	07-29-99 1341	1,340	3.1	Tributary	Small unnamed tributary along rb
WT1,156m	07-29-99 1358	1,700	3.7	Tributary	Small unnamed tributary along rb downstream from dam
WT1,267m	07-29-99 1412	73	7.0	Tributary	Unnamed tributary along lb near historic building
WT1,290m	07-29-99 1738	377	5.8	Pit	Subsurface sampling pit near rb
WT1,437m	07-29-99 1446	109	6.0	Tributary	Small unnamed tributary along lb
WT1,556m	07-29-99 1501	1,80	2.8	Pit	Subsurface sampling pit near rb
WT1,759m	07-29-99 1527	2,050	3.0	Pipe	Discharge from Pump House Fault pipe
WT1,774m	07-29-99 1530	2,720	8.9	Pipe	Discharge from treatment-plant pipe
WT1,777m	07-29-99 1538	2,330	9.1	Pipe	Discharge from treatment-plant pipe
WT1,983m	07-30-99 1035	47	7.6	Tributary	Small unnamed tributary along lb
WT2,573m	07-30-99 1055	2,420	3.5	Seepage	Seepage below Summitville Dam Impoundment structure
WT2,757m	07-30-99 1115	493	4.6	Tributary	Inflow from Cropsy Creek along rb

**Table 7.** Selected chemical data for synoptic samples collected from inflow sites to Wightman Fork, July 29 and 30, 1999

[mg/L, milligrams per liter; µg/L, micrograms per liter; Total Rec, total recoverable; &lt;, less than; shaded area denotes secondary study reach]

Site identification number	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Bromide, dissolved (mg/L)	Silica, dissolved (mg/L)
WT25m	5.0	1.5	1.1	0.28	3.3	0.81	<0.15	<0.1	11
WT79m	6.6	1.6	1.3	.70	5.3	.22	<.15	<.1	8.3
WT163m	4.9	1.4	.83	.10	4.2	.21	<.15	<.1	8.1
WT360m	3.4	.76	.50	.06	7.4	<.20	<.15	<.1	5.7
WT473m	82	24	3.7	1.7	350	1.4	<.15	<.1	19
WT596m	3.3	.79	1.1	1.3	1.5	.21	<.15	<.1	25
WT807m	160	54	2.4	3.0	2,330	.50	.36	2.2	51
WT829m	110	39	3.4	2.9	1,880	4.4	<.15	<.1	55
WT845m	88	35	4.0	1.8	1,930	<.2	.22	2.3	76
WT868m	34	10	3.8	1.9	590	.98	.37	<.1	50
WT902m	62	24	2.6	1.0	980	2.1	.34	<.1	46
WT912m	56	22	2.7	1.9	940	2.0	<.15	<.1	49
WT985m	44	13	5.0	3.7	1,010	2.2	.38	<.1	69
WT1,075m	41	12	8.0	5.0	900	2.5	.31	<.1	67
WT1,156m	120	32	7.0	3.6	1,350	3.3	.42	<.1	60
WT1,267m	9.3	2.8	1.7	.82	7.6	.35	<.15	<.1	16
WT1,290m	66	15	6.4	2.1	190	.21	.33	<.1	24
WT1,437m	12	3.5	2.5	1.5	14	4.7	<.15	<.1	15
WT1,556m	180	20	16	1.2	650	56.0	<.15	<.1	20
WT1,759m	180	39	6.2	2.9	1,440	4.7	.56	<.1	35
WT1,774m	710	23	16	2.5	1,730	2.5	<.15	<.1	.25
WT1,777m	690	18	13	2.9	2,400	4.8	<.15	<.1	.21
WT1,983m	6.7	1.6	1.1	.38	2.3	.31	.13	<.1	13
WT2,573m	300	64	22	3.4	1,720	11.0	<.15	<.1	55
WT2,757m	60	7.9	4.5	1.6	220	1.4	<.15	<.1	15

**Table 7.** Selected chemical data for synoptic samples collected from inflow sites to Wightman Fork, July 29 and 30, 1999  
—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; Total Rec, total recoverable; <, less than; shaded area denotes secondary study reach]

Site identification number	Aluminum (µg/L)		Arsenic (µg/L)		Barium (µg/L)		Beryllium (µg/L)		Boron (µg/L)		Cadmium (µg/L)	
	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec
WT25m	90	130	<20	<20	34	36	<0.1	<0.1	12	9	<1	<1
WT79m	230	1,000	<20	<20	71	110	<.1	<.1	<3	<3	<1	<1
WT163m	170	850	<20	<20	37	52	<.1	<.1	12	13	<1	<1
WT360m	84	250	<20	<20	57	65	<.1	<.1	12	12	<1	<1
WT473m	220	310	<20	<20	73	76	<.1	<.1	4	6	<1	<1
WT596m	36	160	<20	<20	12	14	<.1	.2	12	20	<1	<1
WT807m	300,000	310,000	59	70	15	15	16	16	24	19	110	120
WT829m	240,000	250,000	66	72	18	18	15	15	15	11	100	100
WT845m	250,000	260,000	<20	31	9	8	17	17	5	6	120	120
WT868m	80,000	78,000	<20	<20	20	20	7	7	20	17	17	17
WT902m	120,000	140,000	58	50	20	20	11	11	25	14	45	46
WT912m	120,000	150,000	46	46	22	24	12	12	12	14	58	59
WT985m	130,000	130,000	31	39	24	24	13	13	16	13	17	16
WT1,075m	120,000	130,000	29	33	16	17	9	9	10	9	31	31
WT1,156m	160,000	160,000	56	66	18	36	20	21	8	11	67	70
WT1,267m	<30	220	<20	<20	24	27	<.1	<.1	11	13	<1	<1
WT1,290m	37	110	<20	<20	58	59	<.1	<.1	14	11	<1	<1
WT1,437m	<30	190	28	45	91	88	<.1	<.1	19	14	<1	<1
WT1,556m	5,100	6,700	<20	<20	20	24	2	3	8	20	3	3
WT1,759m	72,000	73,000	65	69	12	13	.1	4	21	18	51	52
WT1,774m	5,300	5,400	24	<20	11	11	.3	.3	15	11	<1	<1
WT1,777m	4,900	5,100	24	21	11	10	.2	.2	15	13	<1	<1
WT1,983m	41	98	<20	<20	25	30	.1	<.1	7	11	<1	<1
WT2,573m	99,000	90,000	<20	<20	12	13	12	12	7	6	65	64
WT2,757m	2,700	4,000	<20	<20	37	41	1	2	13	12	6	6

**Table 7.** Selected chemical data for synoptic samples collected from inflow sites to Wightman Fork, July 29 and 30, 1999  
—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; Total Rec, total recoverable; <, less than; shaded area denotes secondary study reach]

Site identification number	Chromium (µg/L)		Cobalt (µg/L)		Copper (µg/L)		Iron (µg/L)		Lead (µg/L)		Lithium (µg/L)	
	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec
WT25m	<1	<1	2	1	<1	<1	380	750	<6	<6	0.6	1
WT79m	<1	<1	6	7	<1	11	8,600	25,000	<6	14	<.5	.5
WT163m	<1	<1	<1	1	6	6	170	1,600	<6	<6	<.5	.6
WT360m	<1	<1	1	1	2	3	670	2,100	<6	<6	.7	.7
WT473m	<1	<1	<1	<1	<1	15	17,000	18,000	<6	<6	1	3
WT596m	<1	<1	<1	<1	4	2	190	500	<6	<6	<.5	<.5
WT807m	<1	<1	740	760	12,000	12,000	2,800	2,800	84	78	39	40
WT829m	<1	<1	640	630	11,000	11,000	4,600	5,400	71	76	31	32
WT845m	<1	<1	640	650	20,000	20,000	25,000	25,000	70	64	32	32
WT868m	<1	<1	180	170	1,500	1,500	2,100	2,200	23	24	11	11
WT902m	<1	<1	480	510	5,800	6,100	5,300	5,100	40	39	19	20
WT912m	<1	<1	520	510	11,000	12,000	1,900	2,100	35	36	19	20
WT985m	<1	<1	180	180	1,900	1,800	30,000	33,000	39	41	11	12
WT1,075m	<1	<1	210	210	7,600	7,700	17,000	17,000	40	40	<.5	<.5
WT1,156m	<1	<1	440	440	33,000	34,000	450	1,600	55	60	7	6
WT1,267m	<1	<1	<1	<1	3	3	220	840	<6	<6	<.5	<.5
WT1,290m	<1	<1	<1	<1	<1	5	2,100	2,300	<6	<6	<.5	<.5
WT1,437m	<1	<1	2	<1	6	35	750	2,100	<6	<6	<.5	<.5
WT1,556m	<1	<1	43	55	290	470	81,000	71,000	9	10	<.5	<.5
WT1,759m	<1	<1	340	350	68,000	65,000	180,000	180,000	160	160	<.5	<.5
WT1,774m	<1	<1	2	2	3	16	150	68	<6	<6	<.5	18
WT1,777m	<1	3	<1	<1	<1	16	2	71	<6	<6	16	14
WT1,983m	<1	<1	<1	1	2	<1	110	460	<6	<6	2	1
WT2,573m	<1	<1	580	590	22,000	20,000	35,000	35,000	49	52	32	30
WT2,757m	<1	<1	43	43	400	420	1,700	2,800	<6	6	5	4

**Table 7.** Selected chemical data for synoptic samples collected from inflow sites to Wightman Fork, July 29 and 30, 1999  
—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; Total Rec, total recoverable; <, less than; shaded area denotes secondary study reach]

Site identification number	Manganese (µg/L)		Nickel (µg/L)		Selenium (µg/L)		Strontium (µg/L)		Vanadium (µg/L)		Zinc (µg/L)	
	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec
WT25m	29	32	2	<1	<20	<20	63	64	<10	<10	21	21
WT79m	1,700	2,000	2	3	<20	<20	74	89	<10	<10	110	130
WT163m	9	58	5	6	<20	<20	47	51	<10	<10	39	56
WT360m	92	95	1	2	<20	<20	35	37	<10	11	23	27
WT473m	1,300	1,400	<1	<1	<20	<20	870	940	<10	<10	84	87
WT596m	16	22	<1	1	<20	<20	40	41	10	<10	<1	2
WT807m	31,000	32,000	890	910	<20	33	560	560	<10	<10	17,000	17,000
WT829m	27,000	27,000	760	740	34	<20	400	400	<10	<10	15,000	15,000
WT845m	29,000	29,000	860	860	<20	<20	290	290	<10	<10	18,000	15,000
WT868m	11,000	11,000	260	260	<20	<20	170	170	<10	<10	3,900	4,200
WT902m	23,000	24,000	490	510	29	36	260	260	<10	<10	11,000	11,000
WT912m	21,000	23,000	520	510	24	29	220	270	<10	<10	9,300	10,000
WT985m	10,000	10,000	240	250	<20	<20	210	210	<10	<10	5,900	5,600
WT1,075m	8,200	8,300	300	300	21	<20	210	210	<10	<10	9,000	9,200
WT1,156m	25,000	26,000	600	620	23	25	590	580	<10	<10	11,000	12,000
WT1,267m	42	48	<1	<1	<20	<20	110	110	<10	<10	2	4
WT1,290m	880	860	2	2	<20	<20	570	580	<10	<10	<1	20
WT1,437m	210	180	2	1	<20	<20	160	170	<10	<10	9	15
WT1,556m	5,400	4,800	62	72	<20	<20	700	530	<10	<10	850	1,400
WT1,759m	14,000	14,000	530	550	<20	<20	2,300	2,300	<10	<10	10,000	10,000
WT1,774m	2,000	2,100	<1	<1	<20	<20	790	820	<10	<10	4	9
WT1,777m	2,100	2,100	<1	2	<20	<20	780	750	<10	<10	2	9
WT1,983m	13	23	<1	<1	<20	<20	75	74	<10	<10	<1	6
WT2,573m	55,000	50,000	580	600	<20	<20	1,400	1,400	<10	<10	11,000	10,000
WT2,757m	5,300	5,100	46	47	<20	<20	400	410	<10	<10	800	950

**Table 8.** Selected chemical data for synoptic samples collected from sites on Wightman Fork, July 29 and 30, 1999

[mg/L, milligrams per liter; µg/L, micrograms per liter; Total Rec, total recoverable; &lt;, less than; nd, no data; shaded area denotes secondary study reach]

Site identification number	Sampling date and time	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Bromide, dissolved (mg/L)	Silica, dissolved (mg/L)
WFBG	07-29-99 1035	15	4.5	1.1	120	0.26	<0.1	15
WF13m	07-29-99 1039	16	5.1	1.0	130	.28	<.1	16
WF31m	07-29-99 1047	12	4.0	.8	95	.24	<.1	15
WF325m	07-29-99 1118	12	3.9	.8	78	.24	<.1	15
WF592m	07-29-99 1136	13	4.0	.8	79	.24	<.1	15
WF622m	07-29-99 1143	9	2.7	1.0	44	.16	<.1	19
WF802m	07-29-99 1151	10	3.1	1.0	50	.17	<.1	19
WF817m	07-29-99 1201	11	3.3	1.0	65	.17	<.1	19
WF832m	07-29-99 1213	13	4.3	1.1	110	.20	<.1	20
WF862m	07-29-99 1226	13	4.2	1.1	120	.19	<.1	20
WF954m	07-29-99 1310	14	4.3	1.1	130	.19	<.1	21
WF1,042m	07-29-99 1330	14	4.4	1.1	130	.20	<.1	21
WF1,102m	07-29-99 1344	14	4.4	1.1	140	.19	<.1	21
WF1,163m	07-29-99 1349	14	4.5	1.2	140	.19	<.1	21
WF1,259m	07-29-99 1404	15	4.7	1.2	140	.19	<.1	22
WF1,392m	07-29-99 1440	14	4.2	1.2	130	.20	<.1	19
WF1,485m	07-29-99 1506	14	4.2	1.2	120	.19	<.1	20
WF1,645m	07-29-99 1514	14	4.1	1.2	130	.20	<.1	18
WF1,748m	07-29-99 1519	15	3.5	1.2	130	.20	<.1	16
WF1,748m	07-30-99 1010	15	4.5	1.0	120	.19	<.1	19
WF1,807m	07-30-99 1015	240	11	1.5	650	.22	<.1	13
WF2,384m	07-30-99 1045	230	11	1.4	630	.26	<.1	13
WF2,755m	07-30-99 1105	230	12	1.5	660	.22	<.1	14
WF2,815m	07-30-99 1125	200	12	1.5	590	.26	<.1	14



**Table 8.** Selected chemical data for synoptic samples collected from sites on Wightman Fork, July 29 and 30, 1999  
—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; Total Rec, total recoverable; <, less than; nd, no data; shaded area denotes secondary study reach]

Site identification number	Aluminum (µg/L)		Arsenic (µg/L)		Barium (µg/L)		Beryllium (µg/L)		Boron (µg/L)		Cadmium (µg/L)	
	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec
WFBG	8,000	8,200	<20	<20	54	56	2	2	15	13	7	7
WF13m	8,100	7,700	<20	<20	50	51	1	1	9	9	6	5
WF31m	5,500	5,500	<20	<20	45	46	<.1	<.1	9	<3	3	3
WF325m	4,900	4,800	<20	<20	49	49	<.1	<.1	7	7	3	2
WF592m	4,500	4,800	<20	<20	51	53	<.1	<.1	5	8	3	3
WF622m	1,800	2,700	<20	<20	34	36	<.1	<.1	7	7	1	1
WF802m	2,400	3,300	<20	<20	39	39	1	1	22	12	3	3
WF817m	4,100	5,000	<20	<20	38	39	1	1	16	11	3	3
WF832m	10,000	11,000	20	20	38	39	1	1	8	15	6	6
WF862m	11,000	12,000	<20	<20	37	37	2	2	27	12	7	6
WF954m	12,000	13,000	<20	<20	36	35	2	2	16	13	7	7
WF1,042m	12,000	13,000	<20	<20	38	40	1	1	17	10	7	6
WF1,102m	13,000	14,000	<20	<20	38	38	2	2	11	13	7	7
WF1,163m	13,000	14,000	<20	<20	39	45	2	1	15	13	7	7
WF1,259m	14,000	14,000	23	<20	43	43	2	2	18	nd	7	8
WF1,392m	13,000	13,000	<20	<20	40	40	.3	.3	9	8	6	7
WF1,485m	11,000	13,000	<20	<20	37	41	.3	.3	8	10	6	6
WF1,645m	13,000	13,000	<20	<20	41	42	2	2	27	13	7	7
WF1,748m	10,000	13,000	<20	<20	41	44	2	2	11	12	7	6
WF1,748m	11,000	12,000	<20	<20	34	37	1	1	11	11	6	6
WF1,807m	6,500	9,500	<20	<20	28	30	1	1	18	13	4	4
WF2,384m	6,800	8,500	<20	<20	29	30	1	1	12	14	4	4
WF2,755m	7,600	12,000	<20	<20	27	29	1	1	14	12	5	5
WF2,815m	6,600	9,500	<20	<20	28	30	1	1	9	14	5	6

**Table 8.** Selected chemical data for synoptic samples collected from sites on Wightman Fork, July 29 and 30, 1999  
—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; Total Rec, total recoverable; <, less than; nd, no data; shaded area denotes secondary study reach]

Site identification number	Chromium (µg/L)		Cobalt (µg/L)		Copper (µg/L)		Iron (µg/L)		Lead (µg/L)		Lithium (µg/L)	
	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec
WFBG	<1	<1	20	23	130	130	2,800	3,900	<6	<6	2	3
WF13m	<1	<1	18	17	120	120	3,200	3,700	<6	<6	4	5
WF31m	<1	<1	11	11	79	80	1,900	2,700	<6	<6	3	2
WF325m	<1	<1	9	9	71	71	1,600	2,900	<6	<6	2	2
WF592m	<1	<1	9	9	67	70	1,700	2,700	<6	<6	2	2
WF622m	<1	<1	3	4	34	39	960	1,900	<6	<6	.8	1
WF802m	<1	<1	10	10	54	59	1,100	1,800	<6	<6	.7	3
WF817m	<1	<1	15	15	120	130	1,100	1,800	<6	<6	1	1
WF832m	<1	<1	30	31	390	400	1,300	1,900	<6	6	1	2
WF862m	<1	<1	34	33	520	520	1,400	2,200	6	<6	1	2
WF954m	<1	<1	32	35	580	570	1,400	2,100	<6	<6	2	2
WF1,042m	<1	<1	38	38	590	610	1,600	2,200	<6	<6	2	2
WF1,102m	<1	<1	36	35	640	650	1,600	2,300	<6	<6	2	2
WF1,163m	<1	<1	36	39	670	690	1,500	1,900	<6	<6	1	2
WF1,259m	<1	<1	40	39	740	750	1,700	2,400	<6	<6	1	2
WF1,392m	<1	<1	33	33	720	720	1,300	2,000	<6	<6	1	2
WF1,485m	<1	<1	32	33	710	710	1,300	2,000	<6	<6	4	3
WF1,645m	<1	<1	36	36	750	730	1,300	2,000	<6	<6	3	3
WF1,748m	<1	<1	37	37	580	730	1,200	2,200	<6	<6	3	3
WF1,748m	<1	<1	33	32	670	660	1,100	1,900	<6	<6	2	2
WF1,807m	<1	<1	24	24	770	820	1,600	2,100	8	8	6	6
WF2,384m	<1	<1	22	23	700	730	1,500	3,700	<6	<6	6	6
WF2,755m	<1	<1	36	34	1,100	1,200	2,100	2,700	<6	7	6	7
WF2,815m	<1	<1	36	37	940	980	2,000	2,600	<6	<6	6	6

**Table 8.** Selected chemical data for synoptic samples collected from sites on Wightman Fork, July 29 and 30, 1999  
—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; Total Rec, total recoverable; <, less than; nd, no data; shaded area denotes secondary study reach]

Site identification number	Manganese (µg/L)		Nickel (µg/L)		Selenium (µg/L)		Strontium (µg/L)		Vanadium (µg/L)		Zinc (µg/L)	
	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec	Dis- solved	Total Rec
WFBG	1,500	1,800	33	34	<20	<20	98	97	<10	<10	890	980
WF13m	1,700	1,700	31	33	<20	<20	92	94	<10	<10	950	950
WF31m	1,200	1,200	23	22	<20	<20	84	83	<10	<10	680	670
WF325m	1,100	1,100	20	20	<20	<20	88	87	<10	<10	600	620
WF592m	1,100	1,100	20	22	<20	<20	93	94	<10	<10	600	600
WF622m	640	650	11	13	<20	<20	72	73	<10	<10	350	350
WF802m	750	750	15	15	<20	<20	80	79	<10	<10	390	390
WF817m	920	920	19	19	<20	<20	82	83	<10	<10	480	490
WF832m	1,600	1,600	37	39	<20	<20	92	91	<10	<10	820	830
WF862m	1,700	1,700	44	42	<20	<20	88	88	<10	<10	910	920
WF954m	1,700	1,700	45	45	<20	<20	88	90	<10	<10	970	980
WF1,042m	1,900	1,900	46	46	<20	<20	89	90	<10	<10	980	980
WF1,102m	1,900	1,900	50	50	<20	<20	91	91	<10	<10	1,000	1,000
WF1,163m	1,700	1,700	52	52	<20	<20	97	96	<10	<10	1,100	1,100
WF1,259m	2,200	2,100	53	53	<20	<20	100	100	<10	<10	1,100	1,100
WF1,392m	1,900	1,900	46	46	<20	<20	100	100	<10	<10	940	990
WF1,485m	1,800	1,800	45	47	<20	<20	100	100	<10	<10	970	990
WF1,645m	1,900	1,900	51	48	<20	<20	110	100	<10	<10	910	1,000
WF1,748m	1,500	1,900	47	47	<20	<20	85	110	<10	<10	780	970
WF1,748m	1,700	1,700	43	42	<20	<20	110	100	<10	<10	900	880
WF1,807m	1,900	2,000	29	32	<20	<20	34	35	<10	<10	650	670
WF2,384m	2,200	1,700	27	28	<20	<20	33	33	<10	<10	600	610
WF2,755m	3,000	3,000	42	41	<20	<20	35	36	<10	<10	810	820
WF2,815m	3,100	3,100	41	41	<20	<20	36	37	<10	<10	910	920

**Table 9.** Selected chemical data for duplicate samples collected from sites on Wightman Fork and inflow sites to Wightman Fork, July 29 and 30, 1999

[mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; total rec, total recoverable]

Constituent	Duplicate analyses					
	WT807m		WF2,815m <sup>a</sup>		WF2,384m	
	07-29-99 at 1150	07-29-99 at 1151	07-29-99 at 1635	07-29-99 at 1636	07-30-99 at 1045	07-30-99 at 1046
Calcium, dissolved (mg/L)	160	160	210	210	230	230
Magnesium, dissolved (mg/L)	54	54	17	17	11	11
Potassium, dissolved (mg/L)	3.0	2.7	3.0	3.9	1.4	1.4
Sulfate, dissolved (mg/L)	2,330	2,320	600	600	630	640
Fluoride, dissolved (mg/L)	0.36	<0.15	0.30	0.30	0.26	0.27
Bromide, dissolved (mg/L)	2.2	2.4	<0.1	<0.1	<0.1	<0.1
Silica, dissolved (mg/L)	51	51	19	14	13	12
Aluminum, dissolved (µg/L)	300,000	300,000	4,400	3,700	6,800	5,300
Aluminum, total rec (µg/L)	310,000	310,000	56,000	85,000	8,500	8,600
Cadmium, dissolved (µg/L)	110	100	7	7	4	4
Cadmium, total rec (µg/L)	120	110	7	15	4	4
Copper, dissolved (µg/L)	12,000	12,000	670	640	700	680
Copper, total rec (µg/L)	12,000	12,000	1,500	2,600	730	730
Iron, dissolved (µg/L)	2,800	2,900	2,600	1,900	1,500	1,500
Iron, total rec (µg/L)	2,800	2,900	94,000	180,000	3,700	1,900
Manganese, dissolved (µg/L)	31,000	31,000	5,800	5,600	2,200	1,700
Manganese, total rec (µg/L)	32,000	31,000	7,100	8,800	1,700	1,700
Zinc, dissolved (µg/L)	17,000	18,000	1,000	1,100	600	580
Zinc, total rec (µg/L)	17,000	18,000	1,500	1,900	610	590

<sup>a</sup>Samples were collected during rapidly changing conditions due to rainfall at mine site.

**Table 10.** Selected chemical data for blank samples collected July 29 and 30, 1999

[FB, field blank; mg/L, milligrams per liter; µg/L, micrograms per liter; &lt;, less than; total rec, total recoverable]

Constituent	Method reporting limit	FB1	FB2	FB3
		07-29-99 at 1225	07-29-99 at 1406	07-29-99 at 1720
Calcium, dissolved (mg/L)	<0.05	<0.05	<0.05	<0.05
Magnesium, dissolved (mg/L)	<0.008	<0.008	<0.008	<0.008
Potassium, dissolved (mg/L)	<0.001	<0.001	<0.001	<0.001
Sulfate, dissolved (mg/L)	<0.4	<0.4	<0.4	<0.4
Fluoride, dissolved (mg/L)	<0.15	<0.15	<0.15	<0.15
Bromide, dissolved (mg/L)	<0.1	<0.1	<0.1	<0.1
Silica, dissolved (mg/L)	<0.04	<0.04	<0.04	<0.04
Aluminum, dissolved (µg/L)	<30	<30	<30	<30
Aluminum, total rec (µg/L)	<30	<30	<30	<30
Cadmium, dissolved (µg/L)	<1	<1	<1	<1
Cadmium, total rec (µg/L)	<1	<1	<1	<1
Copper, dissolved (µg/L)	<1	3	2	<1
Copper, total rec (µg/L)	<1	4	2	<1
Iron, dissolved (µg/L)	<1	2	4	3
Iron, total rec (µg/L)	<1	<1	21	23
Manganese, dissolved (µg/L)	<0.1	0.5	<0.1	<0.1
Manganese, total rec (µg/L)	<0.1	0.2	<0.1	<0.1
Zinc, dissolved (µg/L)	<1	<1	2	<1
Zinc, total rec (µg/L)	<1	<1	<1	<1