Determination of Instream Metal Loads Using Tracer-Injection and Synoptic-Sampling Techniques in Wightman Fork, Southwestern Colorado, September 1997

By Roderick F. Ortiz and Kenneth E. Bencala

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CONVERSION FACTORS AND ACRONYMS

Multiply	By	To obtain
liter	0.2642	gallon
liters per second	0.0353	cubic feet per second
kilogram	2.205	pound
milliliter	0.0339	ounce
milligram	0.00003527	ounce
micrometer	0.0000394	inch

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:

USEPA	United States Environmental Protection Agency
CDPHE	Colorado Department of Public Health and Environment
SWTF	Summitville Water Treatment Facility
NWD	North Waste Dump
SDI	Summitville Dam Impoundment
USGS	United States Geological Survey

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Abstract

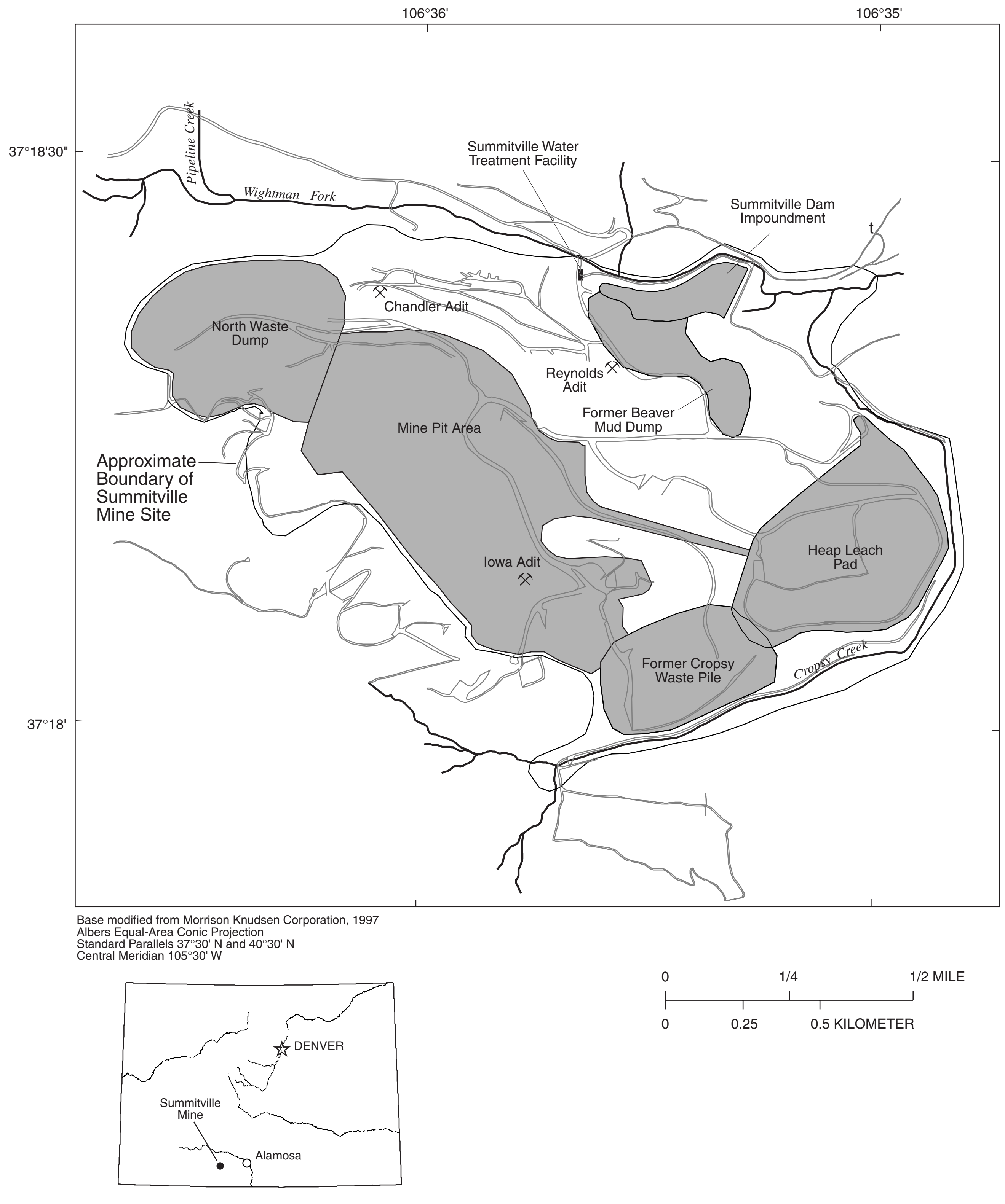
Spatial determinations of the metal loads in Wightman Fork can be used to identify potential source areas to the stream. In September 1997, a chloride tracer-injection study was done concurrently with synoptic water-quality sampling in Wightman Fork near the Summitville Mine site. Discharge was determined and metal concentrations at 38 sites were used to generate mass-load profiles for dissolved aluminum, copper, iron, manganese, and zinc. The U.S. Environmental Protection Agency had previously identified these metals as contaminants of concern.

Metal loads increased substantially in Wightman Fork near the Summitville Mine. A large increase occurred along a 60-meter reach that is north of the North Waste Dump and generally corresponds to a region of radial faults. Metal loading from this reach was equivalent to 50 percent or more of the dissolved aluminum, copper, iron, manganese, and zinc load upstream from the outfall of the Summitville Water Treatment Facility (SWTF). Overall, sources along the entire reach upstream from the SWTF were equivalent to 15 percent of the iron, 33 percent of the copper and manganese, 58 percent of the zinc, and 66 percent of the aluminum load leaving the mine site. The largest increases in metal loading to Wightman Fork occurred as a result of inflow from Cropsy Creek. Aluminum, iron, manganese, and zinc loads from Cropsy Creek were equivalent to about 40 percent of the specific metal load leaving the mine site. Copper, iron, and manganese loads from Cropsy Creek were nearly as large or larger than the load from sources upstream from the SWTF.

INTRODUCTION

The Summitville Mine site is located at an elevation of 11,500 feet above sea level in the San Juan Mountains of southwestern Colorado (fig. 1). Historically, the site was operated as an underground gold mine. Mine-drainage waters from the Summitville Mine are among the most acidic and metal rich 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 operating company abandoned the mine site, and the U.S. Environmental Protection Agency (USEPA) assumed responsibility for cleanup and remediation of the newly designated Superfund site. The Colorado Department of Public Health and Environment (CDPHE) assumed shared management responsibilities for the Summitville Mine site with the USEPA in 1998.

Remedial strategies at the mine site have focused on two main objectives: (1) reduction of acid-mine drainage by decreasing exposure of sulfide minerals to air and water; and (2) capture and treatment of the acid mine drainage before it reaches Wightman Fork. Major remediation efforts at the site have included plugging several mine adits, relocating waste material to the mine pits, capping the mine pits



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.

and the heap leach pad, increasing the storage capacity of impoundment structures, and increasing the capacity of the Summitville Water Treatment Facility (SWTF). Remediation efforts at the Summitville Mine have resulted in a large decrease in metal loads[1] discharging from the old mine workings (Morrison Knudsen Corporation, 1997). Although remediation efforts at the Summitville Mine site have been relatively successful, areas of concern still exist.

Metal loads from upper Wightman Fork could be a significant part of the total load leaving the mine site. Historical ferricrete masses (a hard conglomerate of sand and gravel cemented by iron oxide) along the northern boundary of the mine site indicate that the North Waste Dump (NWD) (fig. 1) represented 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). Seepage around the plugged Chandler Adit (fig. 1) and seeps adjacent to, and hydraulically downgradient from, the adit also could be a potential source of metals to upper Wightman Fork (Morrison Knudsen Corporation, 1997). Although a collection system along the northern perimeter of the mine site redirects surface water to the Summitville Dam Impoundment (SDI) (fig. 1), results of previous water-quality sampling have shown that high concentrations of metals are present in upper Wightman Fork (J. Fox, Environmental Chemical Corporation, written commun., 1998). Effluent from the SWTF represents a point source of metal load to Wightman Fork; however, metal concentrations generally were low in this water (Environmental Chemical Corporation, 1998). 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, 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. By determining discharge and tracer concentration at multiple sites, investigators provided a detailed understanding of source areas to upper Wightman Fork. The resulting mass-loading profiles would allow 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 conducted September 16–19, 1997, to identify and quantify sources of metal loading to Wightman Fork adjacent to the Summitville Mine site. Metal loads were calculated using (1) discharge data derived from a continuous chloride injection and (2) concentration data collected during synoptic water-quality sampling. The report quantifies metal loads and pH at 38 sites in Wightman Fork from near the headwaters to the eastern boundary of the mine site. The study reach is 2,815 meters long. Mass-loading profiles were generated for aluminum, copper, iron, manganese, and zinc along two study reaches.

Description of Study Area

Wightman Fork flows east along the northern perimeter of the Summitville Mine site (fig. 1). The study area consisted of two contiguous reaches on Wightman Fork. The primary study reach extended 1,748 meters from near the headwaters to just upstream from the SWTF outfall (fig. 2). Quantification of metal loads upstream from the SWTF were of greatest interest to the cooperators since available data were limited and the metal loading profile of Wightman Fork in this reach was largely unknown. Thirty-four main-stem sites, including a background site (WF_BG), were located in the primary reach (table 1). Sites were selected to provide good spatial resolution of the metal loading in Wightman Fork. Pipeline Creek is the largest tributary along the primary reach, although several small tributaries, springs, and seeps also exist. Ground-water inflow most likely occurs as well.

The secondary reach extended from just upstream of the SWTF outfall to the USGS gaging station (08235270; site WF_2,815m) at the eastern boundary of the mine site (fig. 2). Only six main-stem sites were located along this 1,067-meter reach

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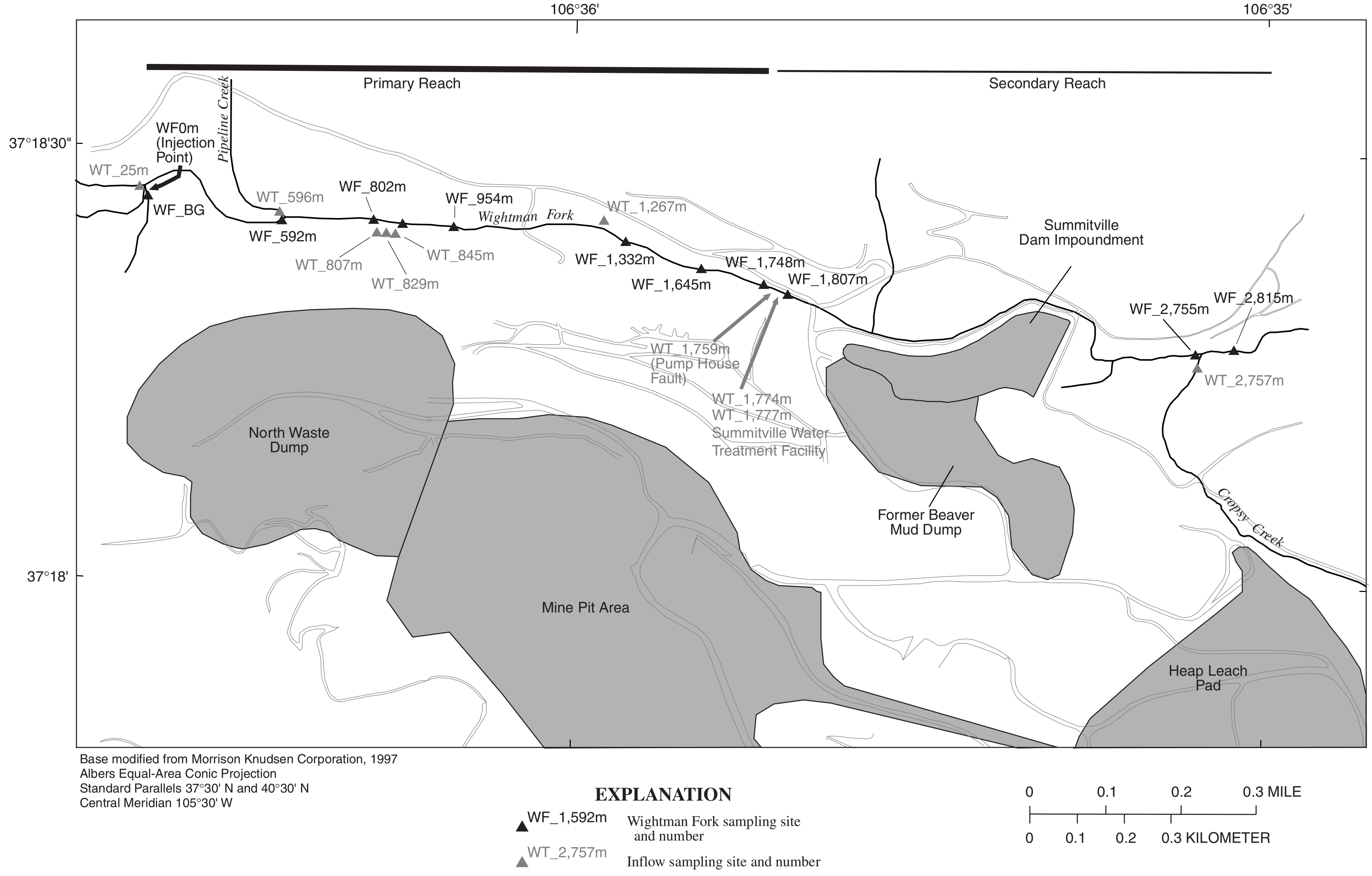
[1] Load is defined as the mass of a target analyte in the stream per unit time and is the product of analyte concentration and discharge.



Base modified from Morrison Knudsen Corporation, 1997
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Central Meridian 105°30' W

Figure 2. Location of injection site, selected sampling sites on Wightman Fork, and selected inflow sites to Wightman Fork.

Table 1. Site locations for tracer-injection and synoptic-sampling study in Wightman Fork at the Summitville Mine site, September 18 and 19, 1997

[NA, not applicable; USEPA, U.S. Environmental Protection Agency; SDI, Summitville Dam Impoundment; USGS, U.S. Geological Survey; shaded area denotes extent of secondary study reach]

Site identification and transport site number	Sampling date	Sampling time	Distance from injection site (meters)	Stream reach	Description of site location or stream characteristics
WF_BG	09–18–97	1520	–7	NA	Background site; unaffected by injection
WF_0m	NA	NA	0	NA	Injection point
WF_13m (T1)	09–18–97	1515	13	Primary	First transport site: upstream from tributary
WF_31m	09–18–97	1505	31	Primary	Downstream from tributary
WF_54m	09–18–97	1500	54	Primary	Grayish-white precipitate apparent
WF_145m	09–18–97	1445	145	Primary	Deeply cut channel in tundra
WF_265m	09–18–97	1435	265	Primary	Middle of grassy meanders
WF_445m	09–18–97	1425	445	Primary	
WF_592m	09–18–97	1355	592	Primary	Upstream from Pipeline Creek
WF_622m	09–18–97	1345	622	Primary	Downstream from Pipeline Creek
WF_682m (T2)	09–18–97	1340	682	Primary	Second transport site
WF_742m	09–18–97	1330	742	Primary	Less precipitates on stream bottom
WF_802m	09–18–97	1320	802	Primary	Aluminum precipitates very apparent
WF_817m	09–18–97	1310	817	Primary	White precipitate present; no orange floc
WF_832m	09–18–97	1305	832	Primary	Orange floc downstream from site
WF_862m (T3)	09–18–97	1250	862	Primary	Third transport site
WF_890m	09–18–97	1245	890	Primary	
WF_922m	09–18–97	1205	922	Primary	Algae apparent
WF_954m	09–18–97	1200	954	Primary	Abiotic floc: previous site USEPA WF2
WF_993m	09–18–97	1145	993	Primary	
WF_1,042m	09–18–97	1135	1,042	Primary	Algae and floc apparent
WF_1,083m	09–18–97	1130	1,083	Primary	Green algae
WF_1,102m (T4)	09–18–97	1100	1,102	Primary	Fourth transport site
WF_1,131m	09–18–97	1055	1,131	Primary	Upstream from old dam structure
WF_1,163m	09–18–97	1045	1,163	Primary	Downstream from old dam structure; less floc
WF_1,214m	09–18–97	1040	1,214	Primary	Less algae
WF_1,259m	09–18–97	1017	1,259	Primary	Upstream from unnamed tributary
WF_1,274m	09–18–97	1010	1,274	Primary	Downstream from unnamed tributary
WF_1,332m	09–18–97	1000	1,332	Primary	
WF_1,392m	09–18–97	0955	1,392	Primary	Sparse algae
WF_1,485m	09–18–97	0950	1,485	Primary	
WF_1,599m	09–18–97	0935	1,599	Primary	
WF_1,645m	09–18–97	0930	1,645	Primary	Bromide spot injection location
WF_1,748m (T5)	09–18–97	0920	1,748	Primary	Upstream from treatment facility outfall
WF_1,748m (T5)	09–19–97	1040	1,748	Secondary	Fifth transport site
WF_1,807m	09–19–97	1020	1,807	Secondary	Downstream from treatment facility outfall
WF_1,964m	09–19–97	1005	1,964	Secondary	Upstream from unnamed tributary
WF_2,384m	09–19–97	0950	2,384	Secondary	Before culvert at SDI dam
WF_2,755m	09–19–97	0930	2,755	Secondary	Upstream from Cropsy Creek
WF_2,815m (T6)	09–19–97	0920	2,815	Secondary	At USGS streamflow-gaging station 08235270

(table 1). Discharge from the SWTF and Cropsy Creek are the most significant inflows along the secondary reach. Discharge at the gaging station during September generally ranged from 85 to 170 liters per second (Crowfoot and others, 1997, 1998).

Site WF_1,748m was included in both study reaches; it represented the downstream end of the primary study reach and the upstream end of the secondary reach. The site was used for comparison of metal loads between the two reaches. Thirty-eight inflow sites also were sampled as part of the study plan (table 6 in the Appendix at the back of report). All sampling sites were identified by a two-letter prefix and the measured distance (in meters) downstream from the injection point (WF_0m). Main-stem sites are designated by the prefix WF and inflow sites are designated by the prefix WT. Only those sites that were specifically addressed in the report are shown in figure 2.

Acknowledgments

The authors thank Briant Kimball, Robert Runkel, Katherine Walton-Day, Robert Broshears, Jonathan B. Evans, Tracy B. Yager, and Fred Rossi of the USGS Toxic Substances Hydrology Program for their assistance in the collection of the data used in this report. Special thanks to Sheryl Ferguson and Robert Stogner of the USGS for effort and assistance during the study.

STUDY APPROACH

Tracer-injection and synoptic-sampling techniques are well suited for the determination of source loading in small mountain streams. Discharge can be measured with good precision by adding a conservative salt tracer to a stream and calculating discharge from the amount of dilution as the tracer moves downstream (Bencala and others, 1990; Kimball, 1997). By controlling the concentration of the salt tracer and the rate at which it is added to the stream, the mass of salt added to the stream is known (Zellweger and others, 1988). Discharges can then be calculated by measuring the concentration of the tracer upstream and downstream from the injection point and using conservation of mass to derive the discharge (Kimball and others, 1999a). Coupled with synoptic water-quality sampling, a detailed spatial determination of the loading in the stream can be generated and source areas contributing the greatest loads can be identified for remedial action (Kimball, 1997; Kimball and others, 1999b).

Background Chloride and Streamflow Conditions

A tracer is usually chosen because the addition of a reasonable amount of the tracer into the stream dominates the relatively low background concentration of the tracer already present in the water. Chloride was selected as the injection tracer even though the spatial variability of chloride in the study reach was mostly unknown. However, previous data had shown chloride concentrations at site WF_2,815m to be about 4 to 6 milligrams per liter (S.A. Ferguson, U.S. Geological Survey, oral commun., 1998). In order to quantify the background chloride concentrations in Wightman Fork, a presynoptic sampling for chloride was conducted the day before the start of the chloride tracer injection. Background chloride samples were collected at 29 main-stem synoptic sampling sites (fig. 3). Chloride concentrations were estimated for nine additional sites where no samples were collected or analytical values were suspect. Background concentrations along the primary study reach ranged from 0.24 to 2.69 milligrams per liter. An increase in chloride concentration occurred at the SWTF and persisted throughout the secondary reach; background chloride concentrations ranged from 2.69 to 4.84 milligrams per liter. Nevertheless, background chloride concentrations in Wightman Fork were substantially lower than synoptic chloride concentrations.

An assumption was made that discharge in Wightman Fork upstream from the SWTF was similar during the presynoptic (September 16) and synoptic (September 18) sampling periods. The assumption was based on the lack of appreciable rainfall at the mine site during this period (B.T. Marshall, Rocky Mountain Consultants Inc., written commun., 2000) and the base discharge conditions at the site. A change in discharge, however, did occur along the secondary study reach due to discontinuous operations at the SWTF (fig. 4). Synoptic samples along this reach were not collected until the discharge had returned to levels similar to those observed during the presynoptic (background) sampling. As such, synoptic sampling along the secondary reach did not occur until September 19, 1997.

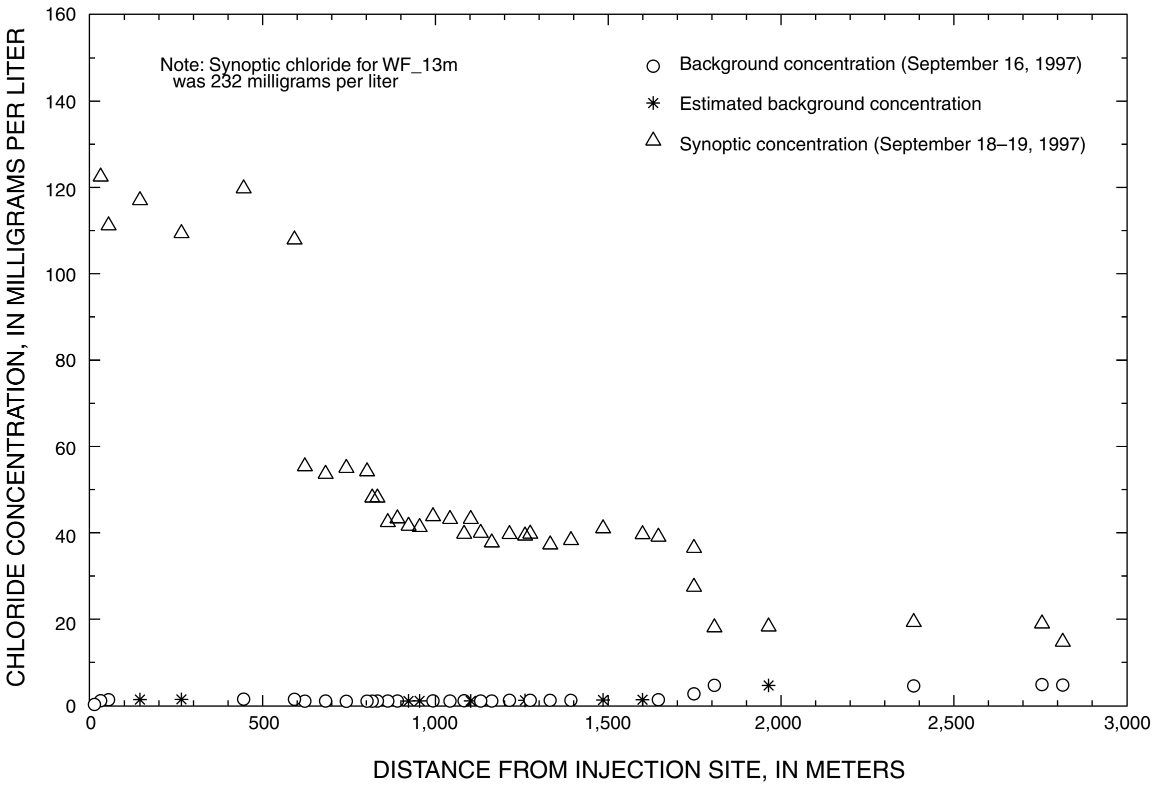

Figure 3. Background and synoptic chloride concentrations in Wightman Fork, September 16–19, 1997.

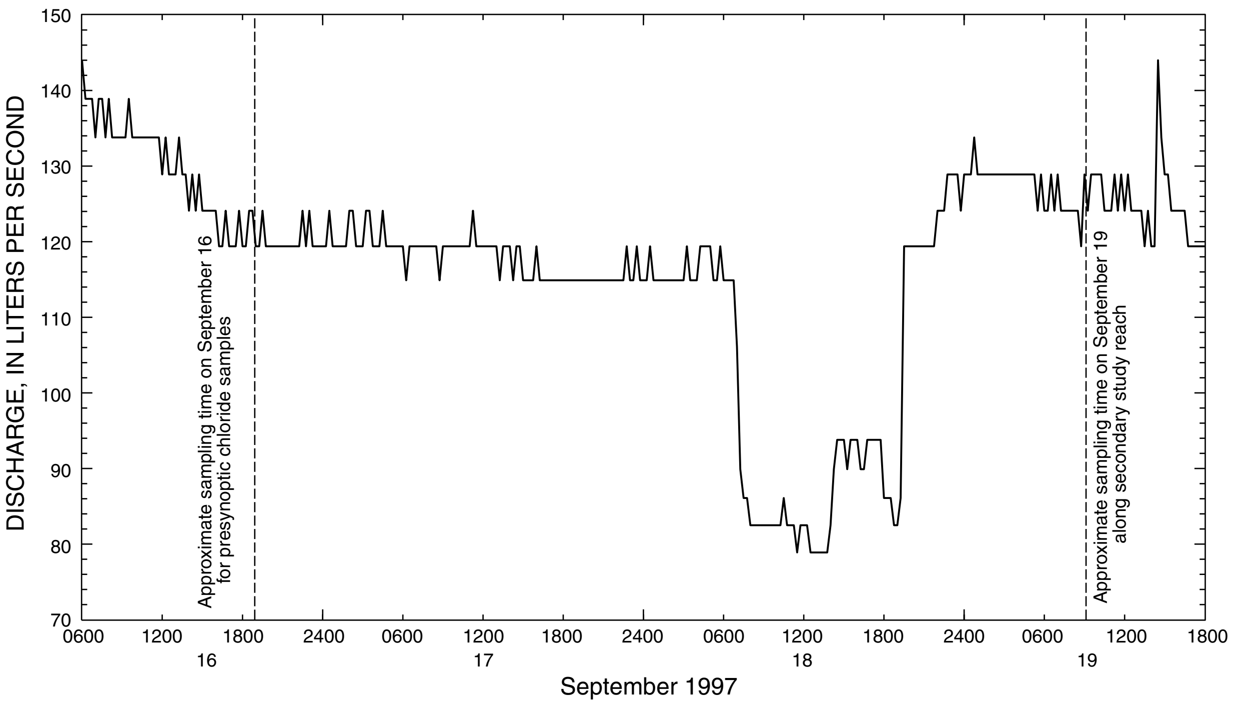

Figure 4. Discharge at U.S. Geological Survey streamflow-gaging station 08235270, September 16–19, 1997.

Tracer Injection

A simultaneous injection of sodium chloride (NaCl) and lithium chloride (LiCl) solutions began at 11:00 a.m. on September 17, 1997. The two salts were selected as injectates for various reasons, but for the purpose of this report, only chloride is discussed. Metered injection pumps were operated in parallel to deliver the two salt solutions at specified rates. Initial injection rates were 512 milliliters per minute of NaCl and 105 milliliters per minute of LiCl. Samples of the two injectates were collected from the pumps at the start of the injection to quantify the initial chloride flux[2] to the stream. The chloride flux is additive because chloride is present in both salts. Eight sets of injectate samples were collected during the course of the continuous injection to quantify the chloride flux.

Multiple chloride samples were collected at six transport sites (T1–T6) on Wightman Fork (table 1). The samples were used to quantify traveltimes in Wightman Fork and to confirm that tracer chloride concentrations had reached a plateau in the stream prior to and during synoptic sampling. Figure 5 illustrates the typical pattern observed at the transport sites. The continuous injection was terminated, after 46 hours, at 9:00 a.m. on September 19, 1997.

A spot injection of sodium bromide was done upstream from the SWTF (site WF_1,645m) on September 19, 1997 (fig. 2). The spot injection was intended as an independent check of the discharge estimate at this site provided by the chloride tracer.

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[2] Flux is defined as the mass of chloride (in milligrams) delivered per unit time (in seconds).

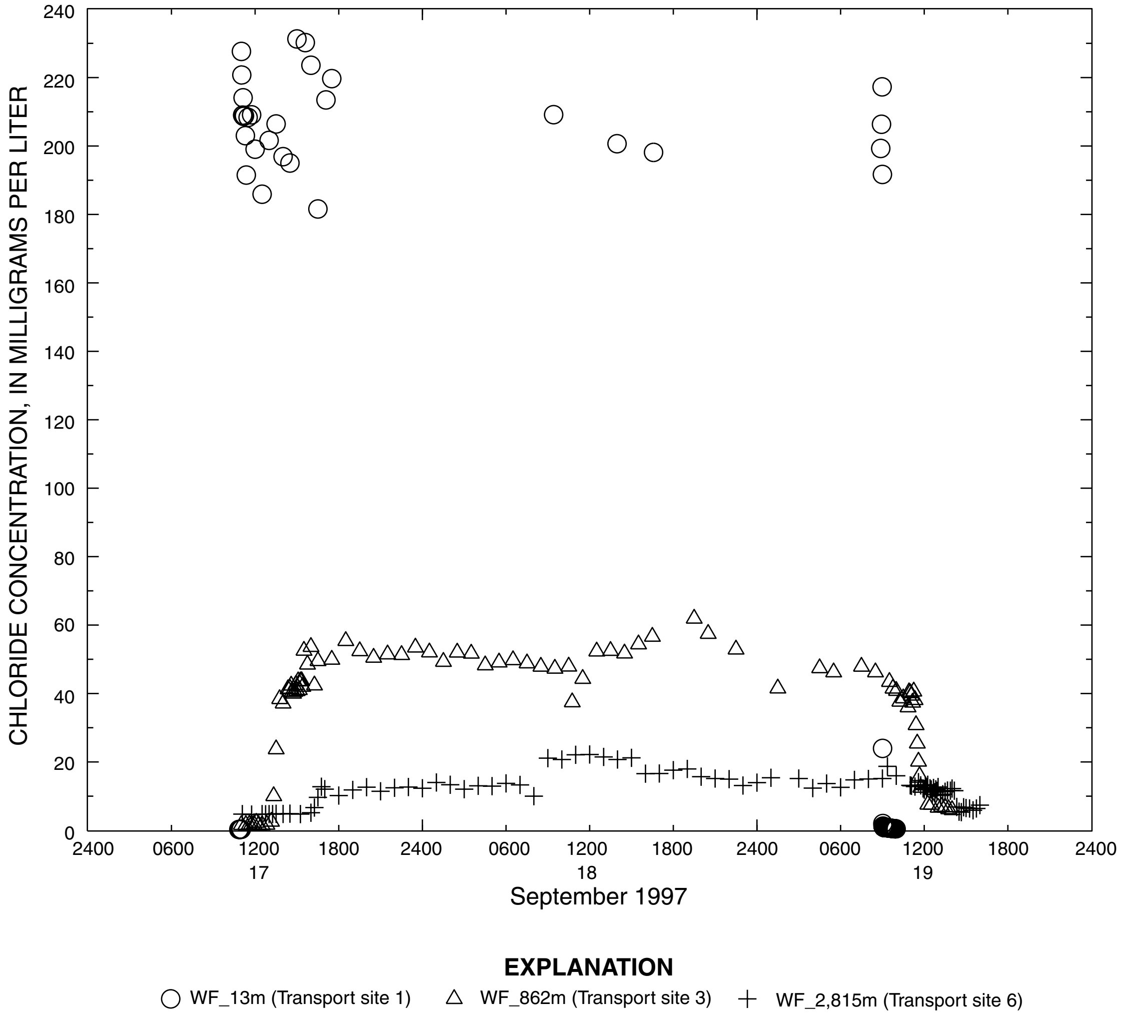

Figure 5. Chloride concentrations at selected transport sites in Wightman Fork during tracer-injection and synoptic-sampling study, September 16–19, 1997.

Synoptic Sampling

Synoptic sampling provides a spatially detailed description of the water quality in a stream and is accomplished by sampling numerous sites in a relatively short time. Analysis of the synoptic samples provides both tracer-concentration data needed for estimation of discharge and concentration data for specific constituents needed for load calculations. Constituents of concern in Wightman Fork were pH, dissolved aluminum, copper, iron, manganese, and zinc. The following discussion focuses on these six parameters. Analytical data for other constituents are in table 8 in the Appendix at the back of the report.

Two synoptic-sampling efforts were conducted during the continuous tracer injection. Including the background site, 33 sites were sampled on September 18, 1997, along the primary reach in Wightman Fork (table 1). In addition, 30 inflow sites along this reach were sampled (table 6 and table 7 in the Appendix at the back of report). Samples were analyzed for anions, including chloride, and selected dissolved metals. In addition, specific conductance and pH were measured. Synoptic sampling was not done along the secondary study reach on September 18 because discharge from the SWTF was discontinuous at the time (fig. 4).

Synoptic sampling along the secondary study reach took place on September 19 after operations at the SWTF had reestablished routine discharge to Wightman Fork (fig. 4). Six sites were sampled in Wightman Fork; site WF_1,748m was resampled to provide a comparison of data collected on the previous day (table 1). Eight inflow sites were sampled (table 6 and table 7 in the Appendix at the back of report). Samples were analyzed for anions, including chloride, and selected dissolved metals. In addition, specific conductance and pH were measured.

Synoptic samples were collected in an upstream order to avoid potential contamination of sampling sites. Samples were collected in 3-liter plastic containers near the centroid of the stream by using grab-sample techniques. Samples were transported to a nearby laboratory area for immediate processing. Sample water for analysis of dissolved constituents was passed through 0.1-micrometer plate filters and preserved with nitric acid. All samples were packaged and transported to the USGS Utah District laboratory for analysis.

Data-collection and analytical procedures used in this study incorporated practices designed to control, verify, and assess the quality of sample data. Methods and associated quality control for collection and processing of water samples are described by Horowitz and others (1994). In general, quality-assurance methods were comparable to those described in Kimball and others (1999a) and Cleasby and others (2000). A 5-percent error in analytical precision was assumed for all metals data (Briant Kimball, U.S. Geological Survey, oral commun.,1999).

TRACER-INJECTION AND SYNOPTIC-SAMPLING RESULTS

Metal loads are the product of stream discharge and concentration. Synoptic sampling provides the required concentration data. Estimation of discharge using tracer-injection techniques, however, requires additional data analysis. First, the chloride flux to the stream during the synoptic sampling must be determined. Second, downstream chloride concentrations attributable to the tracer needs to be established. Lastly, an appropriate equation is applied to calculate the discharge. The following sections will describe the methodology used to calculate metal loads in Wightman Fork on September 18 and 19, 1997.

Chloride Flux

Analysis of the mass flux data (injection rate times injectate concentration) indicated that the chloride flux was not constant during the 46-hour injection period (fig. 6). However, chloride flux was less variable on September 18 than any other period during the injection. As such, the flux measurements on September 18 were most representative of the chloride flux during synoptic sampling on that day since traveltime was less than 6 hours to the downstream end of the primary reach. An average flux of 1,053 milligrams per second was used to calculate discharge on September 18 along the primary study reach. One chloride flux measurement was made at 9:00 a.m. on September 19, 1997. Available pump data indicated that the pumping parameters at that time were similar to those observed 6 to 7 hours earlier. Given that traveltimes

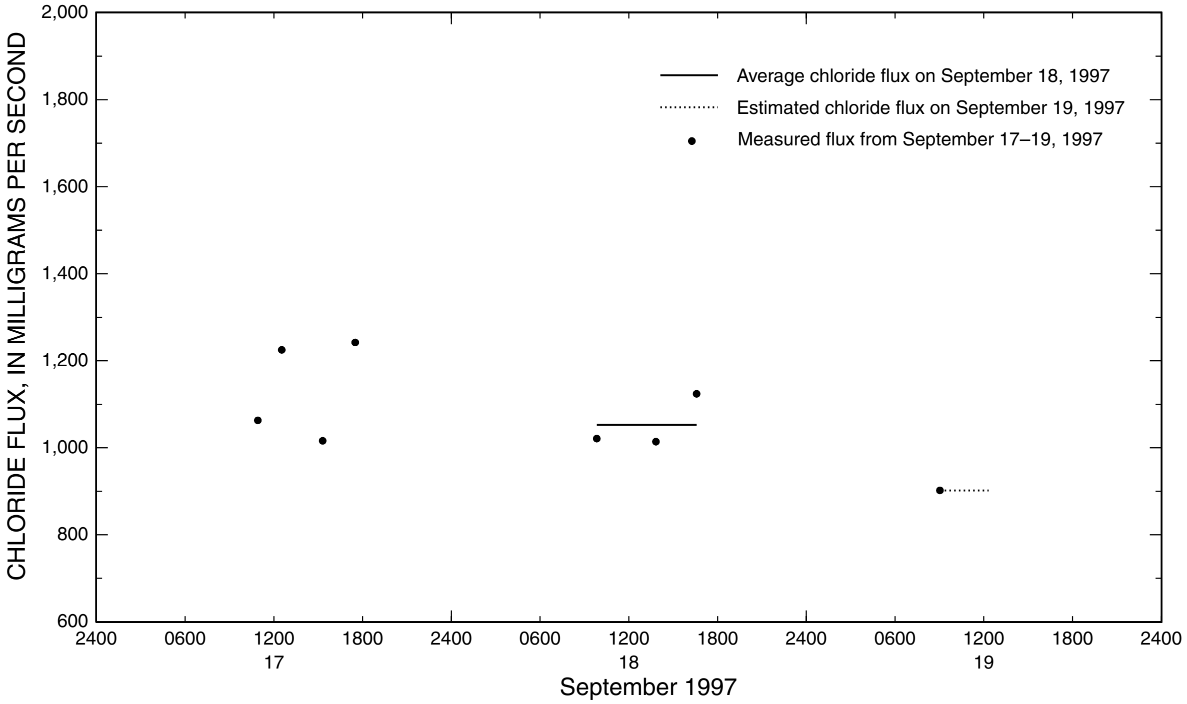

Figure 6. Mass flux of chloride into Wightman Fork during continuous injection, September 17–19, 1997.

along the secondary study reach were greater than 6 hours, this single flux measurement of 902 milligrams per second generally was representative of the chloride flux during the synoptic sampling on September 19, 1997.

Chloride Profiles

Chloride concentrations in Wightman Fork attributable to the tracer were determined by subtracting background concentrations from concentrations measured in the synoptic samples. The chloride differences (delta-chloride data) were smoothed to produce a chloride profile that showed decreasing concentration, or increasing discharge, in the downstream direction (fig. 7). Smoothing was accomplished by identifying sites in the stream where substantial decreases in chloride concentration occurred and identifiable tributary inflow (increased dilution) was observed. The concentrations at these Wightman Fork sites were used to delineate several subreaches or levels of chloride from highest to lowest 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 calculate stream discharges (fig. 7).

Discharge Profiles

Stream discharge at sampling points downstream from the injection is calculated by considering the injectate flux and the observed tracer concentrations (Broshears and others, 1993):

$$Q = Q_{INJ}(C_{INJ})/(C - C_P) \qquad (1)$$

where

Q is the stream discharge,

C_{INJ} is the tracer concentration in the injection solution,

Q_{INJ} is the rate of the tracer injection into the stream,

C is the tracer concentration measured in the synoptic sample, and

C_P is the tracer concentration measured in the presynoptic sample.

The denominator ($C - C_p$) in equation 1 is the delta-chloride concentration described in the previous section. A discharge profile along the two study reaches was developed using equation 1 (fig. 8). The discharge at the first site downstream from the injection, Q, is used to calculate the discharge at the next site. The calculated discharge is then used as the upstream discharge in order to calculate the next downstream discharge, and so on.

Estimations of error were assigned for discharges on September 18 using the range in flux measured on that day. September 19 discharges were assigned an error of plus or minus 15 percent, which represents a worst case scenario given the variability in injection parameters on September 19, 1997. In addition, three instantaneous discharge measurements were done on September 19 along the secondary study reach (fig. 8). Only the measurement at site WF_2,815m was done during synoptic sampling. The discharge estimate using the bromide spot injection represents conditions on September 19, whereas discharges in the primary study reach were calculated for conditions on September 18.

Discharge in Wightman Fork increased downstream nearly twentyfold along the 2,815-meter study reach. The major tributary inflows to the stream along the primary study area were Pipeline Creek (site WT_596m) and unnamed tributaries at sites WT_25m and WT_845m (fig. 8). In the secondary reach, inputs from the Summitville Water Treatment Facility (sites WT_1,774m and WT_1,777m) and Cropsy Creek (site WT_2,757m) composed nearly all the increase in discharge.

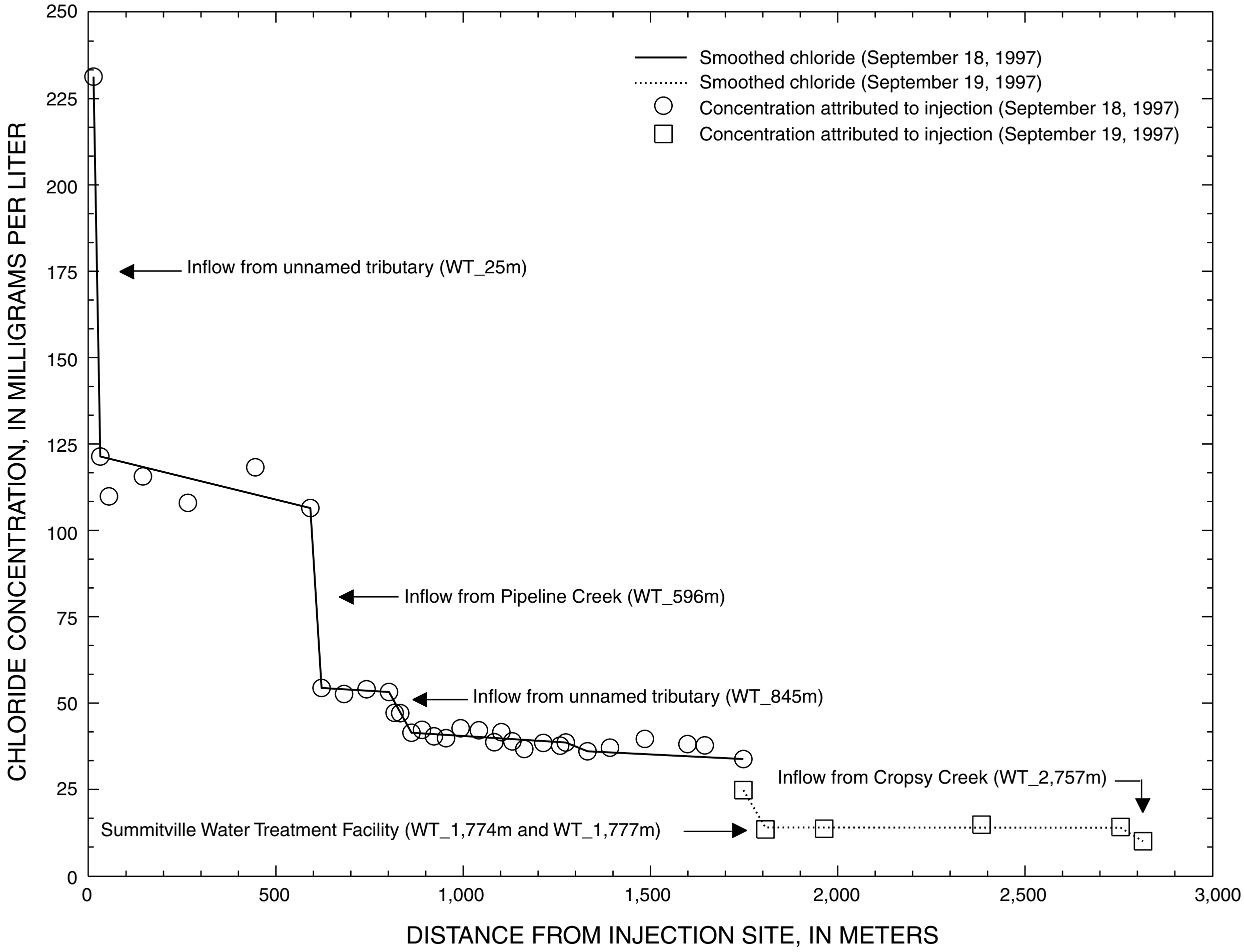

Figure 7. Chloride concentrations in Wightman Fork attributable to tracer injection, September 18 and 19, 1997.

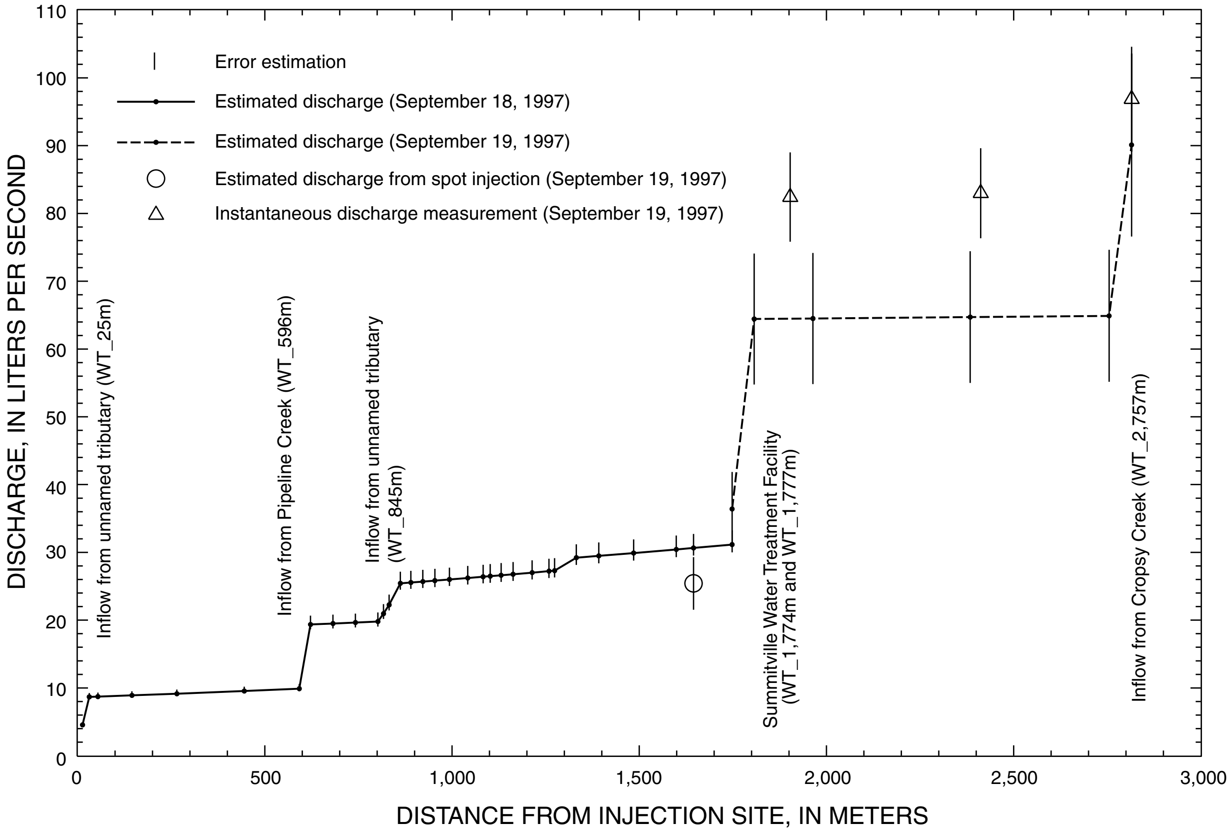

Figure 8. Discharge profiles in Wightman Fork during synoptic sampling, September 18 and 19, 1997.

Synoptic-Sampling Results

Dissolved aluminum, copper, iron, manganese, and zinc concentrations in Wightman Fork exhibited similar downstream profiles (table 2). Metal concentrations upstream from Pipeline Creek were slightly elevated but decreased as relatively clean water from Pipeline Creek entered the stream. Between sites WF_802m and WF_862m, concentrations of the five metals increased by fourfold to as much as a hundredfold. Concentrations continued to increase, by varying degrees, between site WF_862m and site WF_1,214m before decreasing slightly downstream to site WF_1,332m. A relatively clean tributary (WT_1,267m) enters Wightman Fork in this reach. A small increase in concentration occurred downstream to site WF_1,748m. Aluminum, copper, manganese, and zinc concentrations decreased just downstream from the SWTF as treated water was released to Wightman Fork (table 7 in the Appendix at the back of report). Near the end of the study area, concentrations increased primarily due to inflow from Cropsy Creek.

The pH of Wightman Fork was acidic along the entire study reach (fig. 9 and table 2). The highest pH values in the stream (pH 6.1) occurred just downstream from Pipeline Creek (WT_596m), although the effect of water contributed by Pipeline Creek (pH 7.5) was negated less than 200 meters downstream. The pH of Wightman Fork decreased to 4.5 by WF_817m and remained suppressed to the outfall from the SWTF (between WF_1,748m and WF_1,807m). Inflow pH values from tributaries and subsurface sampling pits along this reach were generally less than 4 standard units (table 6 in the Appendix at the back of report). Inputs of alkaline water from the treatment facility (pH 9.2) initially increased the pH in the stream slightly, but the pH remained near 4.6 along the entire secondary study reach (fig. 9).

Table 2. Estimated discharge, pH, dissolved metal concentrations, and calculated dissolved metal loads in Wightman Fork at the Summitville Mine site, September 18 and 19, 1997

[Al, aluminum; Cu, copper; Fe, iron; Mn, manganese; Zn, zinc; ND, not detected; shaded area denotes secondary study reach]

Site identification	Estimated discharge (liters per second)	pH (standard units)	Dissolved metal[1] concentration (milligrams per liter)					Calculated dissolved metal load (kilograms per day)				
			Al	Cu	Fe	Mn	Zn	Al	Cu	Fe	Mn	Zn
WF_13m	4.55	4.2	4.93	0.06	0.60	1.64	0.85	1.94	0.02	0.24	0.64	0.33
WF_31m	8.68	4.9	4.01	.04	.38	1.09	.63	3.01	.03	.28	.82	.47
WF_54m	8.72	4.9	2.74	.03	.31	1.03	.56	2.07	.03	.24	.78	.42
WF_ 145m	8.90	4.9	2.75	.04	.39	1.03	.55	2.12	.03	.30	.79	.43
WF_ 265m	9.14	4.9	2.52	.03	.50	1.03	.56	1.99	.02	.39	.81	.44
WF_ 445m	9.54	4.8	2.53	.03	.58	1.05	.64	2.09	.03	.48	.86	.53
WF_ 592m	9.89	4.8	2.26	.03	.72	1.06	.57	1.93	.02	.62	.90	.49
WF_ 622m	19.4	6.1	.04	.01	.34	.58	.32	.06	.02	.56	.97	.54
WF_ 682m	19.5	6.1	.05	ND	.41	.62	.35	.09	.02	.69	1.05	.59
WF_ 742m	19.6	5.9	.09	ND	.37	.61	.34	.16	.02	.62	1.04	.59
WF_ 802m	19.8	5.4	.32	.03	.38	.70	.38	.55	.05	.64	1.21	.65
WF_ 817m	21.0	4.5	6.91	.25	.44	1.50	.81	12.5	.45	.79	2.72	1.47
WF_ 832m	22.3	4.4	20.10	.81	.64	3.11	1.57	38.7	1.56	1.23	5.99	3.03
WF_ 862m	25.4	4.4	32.19	1.60	1.56	4.61	2.45	70.8	3.51	3.44	10.1	5.38
WF_ 890m	25.5	4.3	30.11	1.46	1.65	4.27	2.25	66.5	3.22	3.64	9.42	4.98
WF_ 922m	25.7	4.2	30.15	1.47	1.95	4.58	2.41	66.9	3.25	4.33	10.2	5.34
WF_ 954m	25.8	4.2	31.84	1.49	1.84	4.55	2.37	71.1	3.33	4.11	10.2	5.30
WF_ 993m	26.0	4.3	31.65	1.50	1.66	4.56	2.37	71.1	3.38	3.74	10.2	5.32
WF_ 1,042m	26.2	4.3	31.10	1.56	1.79	4.62	2.53	70.4	3.53	4.06	10.5	5.74
WF_ 1,083m	26.4	4.2	32.34	1.65	1.94	4.69	2.60	73.8	3.75	4.43	10.7	5.93
WF_ 1,102m	26.5	4.2	30.89	1.66	1.98	4.66	2.53	70.7	3.81	4.54	10.7	5.80
WF_ 1,131m	26.6	4.2	30.64	1.70	1.98	4.64	2.51	70.5	3.92	4.55	10.7	5.77
WF_ 1,163m	26.8	4.2	35.65	2.27	1.96	5.18	2.86	82.5	5.26	4.53	12.0	6.62
WF_ 1,214m	27.1	4.2	37.04	2.47	1.98	5.36	2.86	86.4	5.77	4.63	12.5	6.68
WF_ 1,259m	27.2	4.1	31.92	2.45	1.79	4.99	2.43	75.1	5.77	4.20	11.7	5.73
WF_ 1,274m	27.3	4.2	32.67	2.34	1.79	5.07	2.74	77.1	5.51	4.23	12.0	6.46
WF_ 1,332m	29.2	4.2	31.76	2.36	1.72	5.00	2.62	80.2	5.95	4.33	12.6	6.61
WF_ 1,392m	29.5	4.2	34.10	2.25	1.63	4.92	2.68	86.9	5.74	4.16	12.5	6.83
WF_ 1,485m	29.9	4.2	34.49	2.26	1.62	5.09	2.86	89.1	5.83	4.19	13.2	7.39
WF_ 1,599m	30.4	4.1	34.30	2.37	1.45	5.09	2.69	90.2	6.24	3.82	13.4	7.07
WF_ 1,645m	30.6	4.1	34.80	2.36	1.40	5.02	2.69	92.2	6.26	3.71	13.3	7.13
WF_ 1,748m	31.2	4.2	33.40	2.55	1.48	5.65	3.10	89.9	6.86	3.99	15.2	8.34
WF_ 1,748m	36.4	4.3	23.74	1.82	1.09	4.12	2.07	74.7	5.73	3.42	13.0	6.50
WF_ 1,807m	64.4	4.6	11.82	1.74	1.62	2.46	0.98	65.8	9.71	8.99	13.7	5.45
WF_ 1,964m	64.5	4.7	9.27	1.51	1.51	2.42	0.93	51.7	8.42	8.43	13.5	5.21
WF_ 2,384m	64.7	4.6	9.46	1.67	1.55	2.62	1.03	52.9	9.33	8.69	14.6	5.76
WF_ 2,755m	64.9	4.6	10.87	2.26	2.18	4.31	1.17	60.9	12.7	12.2	24.2	6.57
WF_ 2,815m	90.1	4.6	14.58	2.24	2.91	5.12	1.44	113	17.5	22.7	39.9	11.2

[1] Sample water filtered through 0.1-micrometer plate filter.

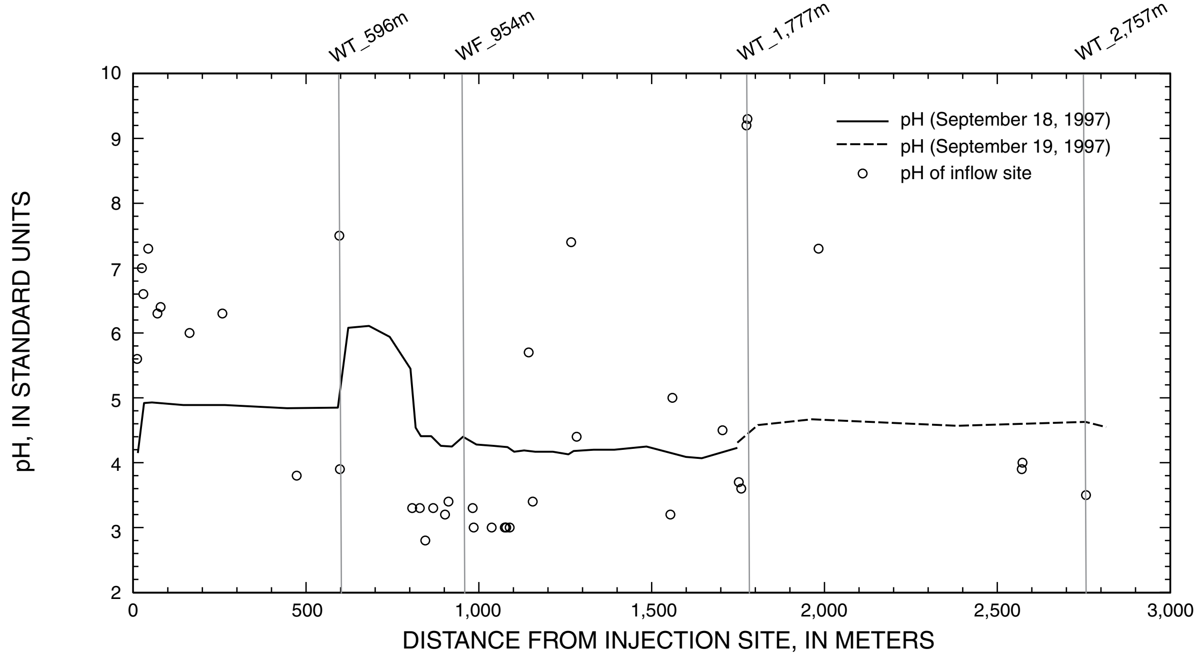

Figure 9. pH profiles in Wightman Fork and inflow sites, September 18 and 19, 1997.

METAL LOADS

Mass loading in Wightman Fork for dissolved aluminum, copper, iron, manganese, and zinc is discussed in the following sections and is graphically depicted in figures 10, 11, and 12. The load profiles incorporate estimations of error, as described previously, that include variation in chloride flux and analytical error. Loads in the primary reach were calculated using data collected on September 18, 1997; no metals data were collected along the secondary reach on that day. Loads in the secondary reach were calculated using data collected on September 19, 1997. As such, the two load profiles were not continuous along the entire study reach; however, metal loads at site WF_1,748m were calculated on both days and provide a semiquantitative comparison between the two reaches.

Data collected from inflow sites were used to help identify source areas along the two study reaches (table 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.

Primary Study Reach

Dissolved aluminum, copper, iron, manganese, and zinc loads were relatively low and generally remained stable from the injection point to site WF_802m (figs. 10–12 and table 2). Aluminum loads, however, decreased downstream from site WF_592m as near-neutral water (pH 7.5) from Pipeline Creek (WT_596m) entered Wightman Fork. Downstream from Pipeline Creek, the pH of the stream increased from 4.8 to 6.1 standard units (table 2), and aluminum precipitates were observed on the streambed.

Metal loads increased substantially between sites WF_802m and WF_862m. This 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). Three inflow sites were sampled along this 60-meter reach in an attempt to identify potential sources. The inflows consisted of seepage from a small ponded area situated above the stream (WT_807m), flow from an arroyo below the NWD (WT_829m), and flow from bogs at the edge of the NWD (WT_845m). The three samples generally were similar in chemistry and exhibited high metal concentrations (table 7 in the Appendix at the back of report). Plumlee and others (1996) reported elevated concentrations of copper, iron, and zinc in several springs in this area that compared well with ground water chemistry from the underground workings area. Along this short stream reach, aluminum load increased nearly 130-fold and copper load increased seventyfold. Iron, manganese, and zinc loads each increased between 5 and 10 times. Metal loads from these inflows represented a substantial percentage of the dissolved aluminum (78 percent), copper (50 percent), iron

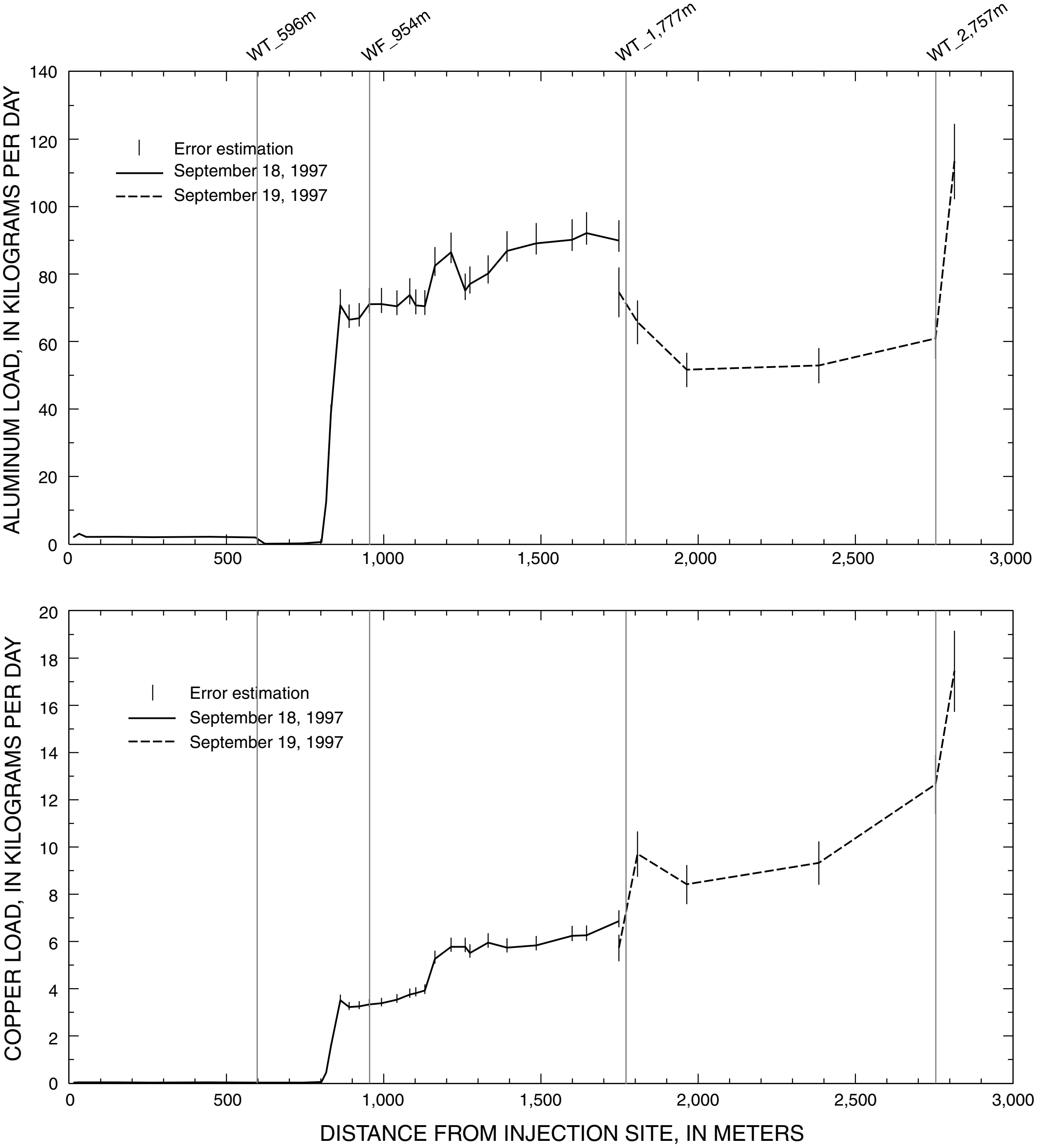

Figure 10. Mass-load profiles for dissolved aluminum and copper in Wightman Fork, September 18 and 19, 1997.

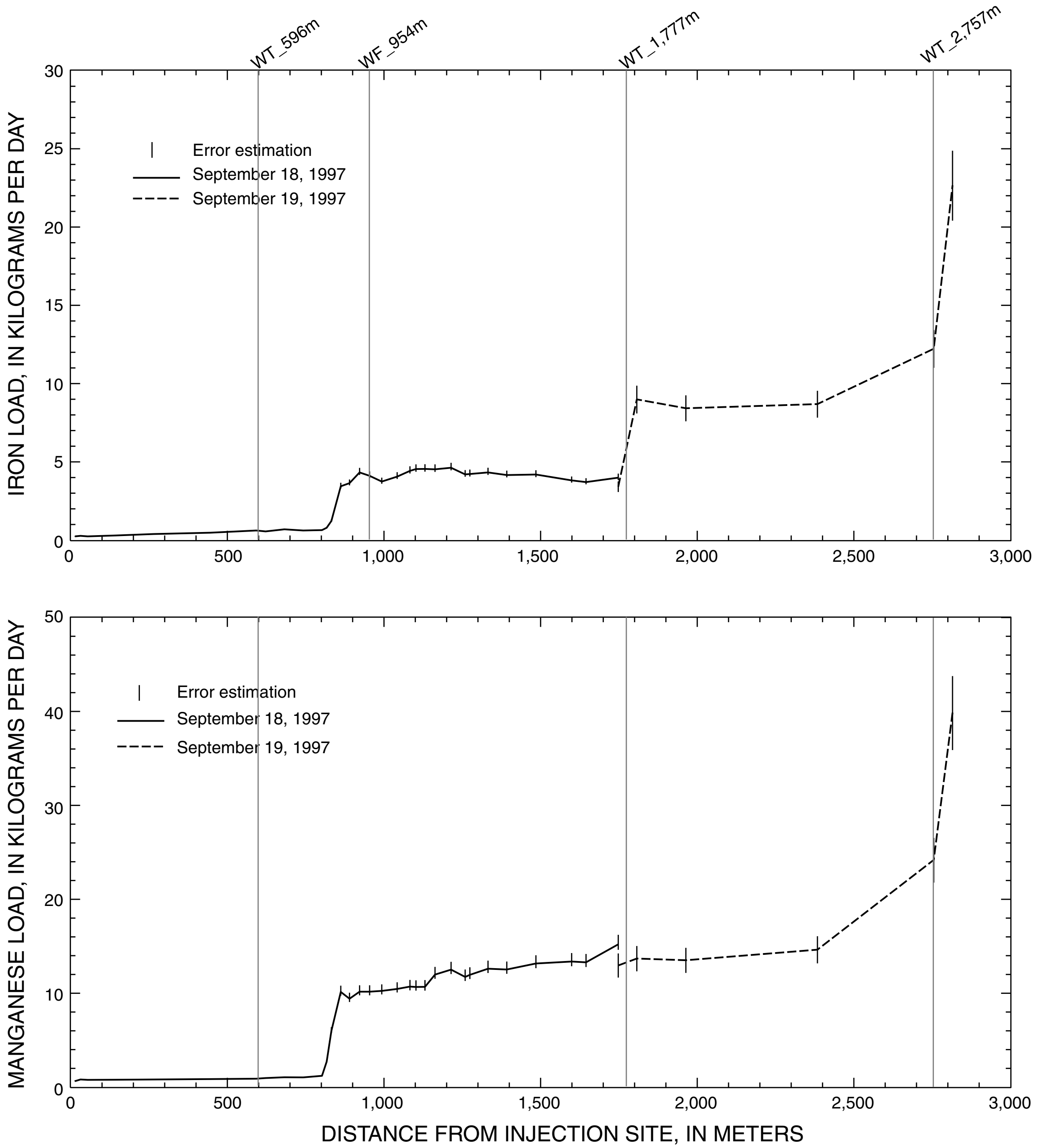

Figure 11. Mass-load profiles for dissolved iron and manganese in Wightman Fork, September 18 and 19, 1997.

(70 percent), manganese (58 percent), and zinc (57 percent) load measured at the end of the primary reach (table 3). Overall, metal loading from just 60 meters of the 1,748-meter reach was equivalent to 50 percent or more of the dissolved aluminum, copper, iron, manganese, and zinc load at the downstream end of the primary study reach.

Metal loads, although somewhat variable, continued to increase downstream from site WF_862m to the end of the primary study reach but at a much lower rate; the increase in load was less than twofold for all the metals of concern. Diffuse subsurface inputs were the predominant source of metals to Wightman Fork downstream from site WF_862m.

Secondary Study Reach

Metal loads at site WF_1,748m represented the dissolved metal load in Wightman Fork upstream from the SWTF (the primary study reach). On September 19, 1997, the dissolved metal load at site WF_1,748m was equivalent to 66 percent of the aluminum load, 33 percent of the copper load, 15 percent of the iron load, 33 percent of the manganese load, and 58 percent of the zinc load leaving the study area (table 4). It could be inferred from table 3 then that the metal loads from the reach between WF_802m to WF_862 were equivalent to about 51 percent of the aluminum load, 16 percent of the copper load, 10 percent of the iron load, 19 percent of the manganese load, and 33 percent of the zinc load leaving the secondary study area.

Metal loads in Wightman Fork showed some variability but generally continued to increase downstream along the secondary study reach (figs. 10–12 and table 2). Aluminum and zinc loads initially decreased between site WF_1,748m and site WF_1,807m. Effluent from the SWTF (WF_1,774m and WF_1,777m) and discharge from the Pump House Fault (WT_1,759m) were the primary sources of metal loading along this short reach (Environmental Chemical Corporation, 1998). The SWTF was a substantial source of aluminum load, whereas the Pump House Fault was a substantial source for copper and iron load.[3] Increased aluminum and zinc load was not observed farther downstream because alkaline water from the SWTF (pH 9.2) caused precipitation of the metals from the water column. Similar geochemical processes could have occurred for copper and iron but were likely masked by the loading from Pump House Fault. Manganese load along this short reach remained relatively stable. Overall, aluminum load decreased by 12 percent and zinc load decreased by 16 percent along this 59-meter reach. Copper load, however, increased 69 percent and iron load increased 163 percent. These increases accounted for about 25 percent of the copper and iron load at the end of the study reach (table 4).

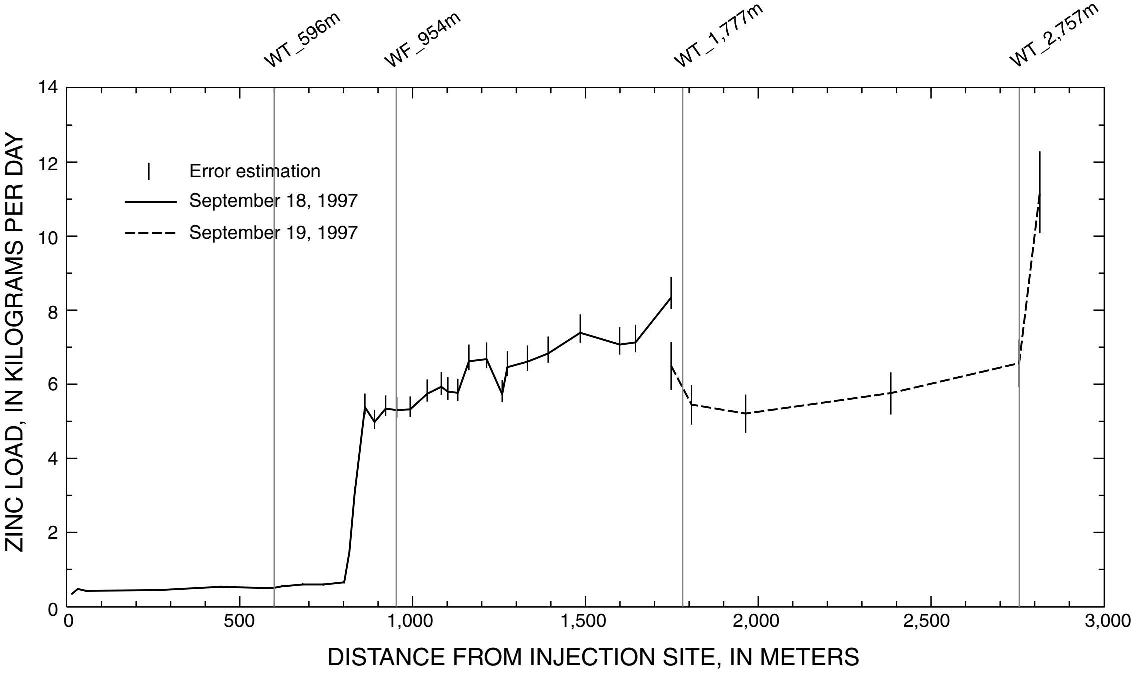

Figure 12. Mass-load profile for dissolved zinc in Wightman Fork, September 18 and 19, 1997.

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[3] Loads were estimated using daily mean discharge data for the treatment facility outfall (September 19) and an instantaneous discharge measurement of Pump House Fault (September 16) with USGS chemical data collected during the synoptic sampling on September 19, 1997.

Table 3. Increase in metal loads along a selected stream reach of Wightman Fork, and percentage of load from selected stream reach when compared to loads at the end of the primary study reach, September 18, 1997

Metal of concern	Increase in metal load between site WF_802m and site WF_862m (kilograms per day)	Metal load at site WF_1,748m (kilograms per day)	Percentage of load at site WF_1,748m attributable to stream reach between site WF_802m and site WF_862m
Aluminum	70.2	89.9	78
Copper	3.46	6.86	50
Iron	2.80	3.99	70
Manganese	8.89	15.2	58
Zinc	4.73	8.34	57

Table 4. Change in metal loads along selected stream reaches of Wightman Fork, and percentage of load from selected stream reaches when compared to loads at the end of the secondary study reach, September 19, 1997

Metal of concern	Change in metal load between selected Wightman Fork reach (kilograms per day)			Metal load at site WF_2,815m (kilograms per day)	Percentage of load at site WF_2,815m from selected stream reach		
	WF_13m to WF_1,748m	WF_1,748m to WF_1,807m	WF_2,755m to WF_2,815m		WF_13m to WF_1,748m	WF_1,748m to WF_1,807m	WF_2,755m to WF_2,815m
Aluminum	74.7	–8.90	52	113	66	losses occur	46
Copper	5.73	3.98	4.8	17.5	33	23	27
Iron	3.42	5.57	10.5	22.7	15	25	46
Manganese	13.0	.7	15.7	39.9	33	2	39
Zinc	6.50	–1.05	4.6	11.2	58	losses occur	41

In the secondary study reach, the largest increase in metal loading was as a result of inflow from Cropsy Creek (WT_2,757m) (figs. 10–12). Cropsy Creek delineates the southern and eastern boundary of the Summitville Mine and is in close proximity to the former Cropsy waste pile and the heap leach pad (fig. 2). Numerous acidic seeps (pH 2.2 to 3.2) were identified in areas downgradient from the heap leach pad (Morrison Knudsen Corporation, 1997); the pH of Cropsy Creek was 3.5 standard units. Just downstream from Cropsy Creek, aluminum and iron loads in Wightman Fork increased by about 85 percent while manganese and zinc loads increased by more than 65 percent. Copper loads increased the least (38 percent). Aluminum, iron, manganese, and zinc loads from Cropsy Creek were equivalent to about 40 percent of the specific metal load at the end of the study reach (site WF_2,815m); copper load was equivalent to 27 percent of the load at site WF_2,815m (table 4). Copper, iron, and manganese loads from Cropsy Creek were nearly as large or larger than the load from the primary study reach; aluminum and zinc loads were about 20 percent smaller.

SUMMARY

In September 1997, a tracer-injection and synoptic water-quality sampling study was done to identify stream reaches where metal loading occurred. The two techniques provide a description of streamflow and metal concentrations in the stream. From that information, mass loading in the stream can be determined and source areas contributing the greatest loads can be identified.

A continuous injection of chloride near the headwaters of Wightman Fork was done and mass loading of chloride to the stream was determined for two study reaches. Discharges at numerous sites in Wightman Fork were calculated and profiles were generated. During this study, 33 synoptic sites were sampled in the primary reach (0 to 1,748 meters) and 6 synoptic sites were sampled in the secondary reach (1,748 to 2,815 meters). Synoptic sampling occurred along the primary study reach on September 18, 1997, and along the secondary study on September 19, 1997. Samples

were analyzed for dissolved aluminum, copper, iron, manganese, and zinc. Field measurements of pH were also made. Load profiles for the metals were determined by multiplying the discharge at each site by the concentration.

Metal loads along the primary study reach increased substantially. The largest increases occurred along a 60-meter reach bounded upstream by site WF_802m and downstream by site WF_862m. Metal loads for all five metals of concern increased anywhere from 5 to 130 times along this reach. The reach lies to the north of the North Waste Dump and is downgradient from spring and seep flow along the northern toe of the waste dump and generally corresponds to a region of radial faults. Metal loading from just 60 meters of the 1,748-meter reach was equivalent to 50 percent or more of the dissolved aluminum, copper, iron, manganese, and zinc load at the downstream end of the primary study reach (table 5). It also could be inferred that metal loads from this reach were equivalent to about 10 percent of the iron load, 16 percent of the copper load, 19 percent of the manganese load, 33 percent of the zinc load, and 51 percent of the aluminum load leaving the secondary study area (table 5).

Overall, sources along the primary study reach were equivalent to 15 percent of the iron, 33 percent of the copper and manganese, 58 percent of the zinc, and 66 percent of the aluminum load leaving the mine site (table 5). In general, metal loads continued to increase downstream from the primary study reach; however, aluminum and zinc loads initially decreased downstream from the outfall from the Summitville Water Treatment Facility and discharge from the Pump House Fault. Alkaline effluent from the treatment facility caused aluminum and zinc to precipitate from the water column. Copper and iron loads increased substantially along this reach as discharge from the Pump House Fault entered Wightman Fork (table 5). The largest increases in metal loading to Wightman Fork occurred as a result of inflow from Cropsy Creek. Aluminum and iron loads in Wightman Fork increased by about 85 percent while manganese and zinc loads increased by more than 65 percent. Aluminum, iron, manganese, and zinc loads from Cropsy Creek were equivalent to about 40 percent of the specific metal load at the end of the study reach (table 5). Copper, iron, and manganese loads from Cropsy Creek were nearly as large or larger than the load from the primary study reach; aluminum and zinc loads were about 20 percent smaller.

Table 5. Summary of dissolved metal loading for selected source areas along Wightman Fork to downstream end of primary and secondary study reaches, September 18 and 19, 1997

Source area delineated by site identification number(s)	Source of load	Equivalent percentage of dissolved metal at the downstream end of the study reach				
		Aluminum	Iron	Copper	Manganese	Zinc
	Primary study reach (0 to 1,748 meters)					
WF_802m to WF_862m	Area corresponding to region of radial faults and downgradient from spring and seep inflows from the toe of the North Waste Dump	78	50	70	58	57
	Secondary study reach (1,748 to 2,815 meters)					
WF_0m to WF_1,748m	All loads from primary study reach	66	33	15	33	58
WF_802m to WF_862m	Area corresponding to region of radial faults and downgradient from spring and seep inflows from the toe of the North Waste Dump	51	16	10	19	33
WF_1,748m to WF_1,807m	Pump House Fault and outfall from Summitville Water Treatment Facility	losses occurred	23	25	2	losses occurred
WF_2,755m to WF_2,815m	Cropsy Creek	46	27	46	39	41

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APPENDIX

Table 6. Site locations, specific conductance, and pH for inflows to Wightman Fork during tracer-injection and synoptic-sampling study, September 18 and 19, 1997

[m, meters; µS/cm; microsiemens per centimeter at 25 degrees Celsius; USEPA, U.S. Environmental Protection Agency; SWTF, Summitville Water Treatment Facility; shaded area denotes secondary study reach]

Site identifier	Distance downstream from injection point (m)	Field value		Inflow type	Feature or description of inflow
		Specific conductance (µS/cm)	pH (standard units)		
WT_11m	11	187	5.6	Pit	Subsurface sampling pit near right bank
WT_25m	25	48	7.0	Tributary	Previously sampled as site USEPA WF1
WT_29m	29	300	6.6	Pit	Subsurface sampling pit near left bank
WT_43m	43	113	7.3	Tributary	Small unnamed tributary along left bank
WT_70m	70	54	6.3	Pit	Subsurface sampling pit near left bank
WT_79m	79	352	6.4	Pit	Subsurface sampling pit near right bank
WT_163m	163	53	6.0	Tributary	Small unnamed tributary along left bank
WT_258m	258	117	6.3	Pit	Subsurface sampling pit near right bank
WT_473m	473	573	3.8	Diffuse	Bog area along right bank
WT_596m	596	39	7.5	Tributary	Tributary flow from Pipeline Creek along left bank
WT_598m	598	1,203	3.9	Tributary	Small unnamed tributary along right bank
WT_807m	807	2,880	3.3	Pit	Subsurface sampling pit adjacent to ponded area along right bank
WT_829m	829	2,330	3.3	Diffuse	Seepage from arroyo cut along right bank downstream from bogs
WT_845m	845	2,400	2.8	Tributary	Tributary flow along right bank downstream from bog area
WT_868m	868	1,189	3.3	Pit	Subsurface sampling pit near right bank
WT_902m	902	1,887	3.2	Pit	Subsurface sampling pit near right bank
WT_912m	912	2,000	3.4	Pit	Subsurface sampling pit near right bank
WT_982m	982	805	3.3	Pit	Subsurface sampling pit near right bank
WT_985m	985	930	3.0	Pit	Subsurface sampling pit near right bank
WT_1,037m	1,037	829	3.0	Pit	Subsurface sampling pit near right bank
WT_1,075m	1,075	925	3.0	Tributary	Small unnamed tributary along right bank
WT_1,079m	1,079	760	3.0	Pit	Subsurface sampling pit near right bank
WT_1,089m	1,089	653	3.0	Pit	Subsurface sampling pit near right bank
WT_1,144m	1,144	355	5.7	Pit	Subsurface sampling pit along left bank of dam impoundment
WT_1,156m	1,156	2,410	3.4	Tributary	Small unnamed tributary along right bank downstream from dam
WT_1,267m	1,267	126	7.4	Tributary	Unnamed tributary along left bank near historic building
WT_1,283m	1,283	523	4.4	Tributary	Small unnamed tributary along right bank
WT_1,554m	1,554	1,455	3.2	Pit	Subsurface sampling pit near right bank
WT_1,560m	1,560	990	5.0	Pit	Subsurface sampling pit near right bank
WT_1,705m	1,705	2,170	4.5	Pit	Subsurface sampling pit near right bank
WT_1,752m	1,752	2,410	3.7	Pit	Subsurface sampling pit near right bank near pump house
WT_1,759m	1,759	1,570	3.6	Pipe	Pump House Fault discharge pipe
WT_1,774m	1,774	2,790	9.2	Pipe	SWTF discharge pipe
WT_1,777m	1,777	2,330	9.3	Pipe	SWTF discharge pipe
WT_1,983m	1,983	68	7.3	Tributary	Small unnamed tributary along left bank
WT_2,571m	2,571	2,330	3.9	Seepage	Seepage below Summitville Dam Impoundment structure
WT_2,573m	2,573	2,300	4.0	Seepage	Seepage below Summitville Dam Impoundment structure
WT_2,757m	2,757	814	3.5	Tributary	Inflow from Cropsy Creek along right bank

Table 7. Selected chemical data for synoptic samples collected from inflow sites to Wightman Fork during the tracer-injection and synoptic-sampling study on Wightman Fork, September 18 and 19, 1997

[Al, aluminum; Ca, calcium; Cd, cadmium; Co, cobalt, Cr, chromium; Cu, copper; Fe, iron; Li, lithium; Mg, magnesium; Mn, manganese; Ni, nickel; SiO_2, silica; Na, sodium; Sr, strontium; Zn, zinc; ND, not detected]

Site identifier	Sample		Element (milligrams per liter)						
	Date	Time	Al	Ca	Cd	Co	Cr	Cu	Fe
WT_11m	09–18–97	1520	0.24	15.1	ND	ND	ND	ND	12.7
WT_25m	09–18–97	1515	ND	5.6	ND	ND	ND	ND	.21
WT_29m	09–18–97	1505	ND	34.5	ND	0.01	0.08	ND	11.1
WT_43m	09–18–97	1500	ND	12.1	ND	ND	ND	ND	.15
WT_70m	09–18–97	1455	.08	5.7	ND	ND	ND	ND	2.3
WT_79m	09–18–97	1455	.55	21.0	ND	.01	.02	ND	89.5
WT_163m	09–18–97	1530	.14	6.0	ND	ND	ND	ND	.82
WT_258m	09–18–97	1430	.11	7.2	ND	ND	ND	ND	23.7
WT_473m	09–18–97	1410	.32	61.5	ND	ND	.05	ND	8.9
WT_596m	09–18–97	1350	ND	4.5	ND	ND	ND	ND	.21
WT_598m	09–18–97	1400	.79	164	ND	.01	.16	ND	16.7
WT_807m	09–18–97	1315	428	204	.13	1.1	.66	13.5	3.4
WT_829m	09–18–97	1305	303	121	.11	.96	.56	13.5	6.3
WT_845m	09–18–97	1255	260	85.1	.13	.90	.49	21.7	34.5
WT_868m	09–18–97	1250	117	46.3	.03	.39	.28	2.8	2.6
WT_902m	09–18–97	1225	231	70.6	ND	.82	.69	1.4	8.4
WT_912m	09–18–97	1210	252	69.2	.10	.98	.76	11.6	1.6
WT_982m	09–18–97	1150	52.8	21.4	ND	.08	.08	.42	17.0
WT_985m	09–18–97	1150	47.3	23.1	ND	.88	.09	.55	26.4
WT_1,037m	09–18–97	1140	76.1	28.8	.02	.17	.29	6.3	14.5
WT_1,075m	09–18–97	1130	58.5	24.4	.02	.13	.25	4.8	7.1
WT_1,079m	09–18–97	1130	26.6	15.4	ND	.06	.05	.85	4.2
WT_1,089m	09–18–97	1125	19.2	21.1	ND	.04	.13	.33	2.9
WT_1,144m	09–18–97	1050	ND	35.9	ND	ND	ND	.03	.19
WT_1,156m	09–18–97	1045	314	120	.14	1.1	.74	58.8	8.0
WT_1,267m	09–18–97	1015	ND	15.1	ND	ND	ND	ND	.41
WT_1,283m	09–18–97	1005	11.1	41.4	ND	.04	.12	1.9	.34
WT_1,554m	09–18–97	0955	35.6	158	.03	.20	.17	11.9	4.9
WT_1,560m	09–18–97	0940	.83	142	ND	.08	.01	.86	61.3
WT_1,705m	09–18–97	0925	13.6	357	.03	.24	.33	10.0	.18
WT_1,752m	09–19–97	1035	21.7	442	.03	.28	.56	11.3	1.0
WT_1,759m	09–19–97	1030	35.8	157	.03	.31	.17	75.5	106
WT_1,774m	09–19–97	1025	9.5	1,160	ND	ND	.02	.01	.02
WT_1,777m	09–19–97	1020	8.8	854	ND	ND	.02	ND	ND
WT_1,983m	09–19–97	1000	.02	14.9	ND	ND	ND	ND	.12
WT_2,571m	09–19–97	0940	98.6	457	.08	1.0	.85	24.6	39.7
WT_2,573m	09–19–97	0935	37.1	351	.04	.56	.71	11.3	5.3
WT_2,757m	09–19–97	0925	20.0	86.3	ND	.12	.15	2.0	11.3

Table 7. Selected chemical data for synoptic samples collected from inflow sites to Wightman Fork during the tracer-injection study on Wightman Fork, September 18-19, 1997—Continued

[Al, aluminum; Ca, calcium; Cd, cadmium; Co, cobalt, Cr, chromium; Cu, copper; Fe, iron; Li, lithium; Mg, magnesium; Mn, manganese; Ni, nickel; SiO_2, silica; Na, sodium; Sr, strontium; Zn, zinc; ND, not detected]

Site identifier	Sample		Element (milligrams per liter)							
	Date	Time	Li	Mg	Mn	Ni	SiO_2	Na	Sr	Zn
WT_11m	09–18–97	1520	0.01	4.1	0.96	ND	19.8	3.3	0.26	0.16
WT_25m	09–18–97	1515	ND	1.5	.01	ND	19.1	2.4	.06	.01
WT_29m	09–18–97	1505	ND	9.0	5.5	ND	15.8	7.6	.62	ND
WT_43m	09–18–97	1500	ND	5.3	.04	ND	16.7	3.4	.17	ND
WT_70m	09–18–97	1455	ND	2.4	.46	ND	8.0	2.2	.07	ND
WT_79m	09–18–97	1455	ND	3.2	4.3	ND	19.0	3.0	.21	.04
WT_163m	09–18–97	1530	ND	1.2	.11	ND	23.0	3.3	.05	ND
WT_258m	09–18–97	1430	ND	1.6	.59	ND	21.8	3.8	.06	.03
WT_473m	09–18–97	1410	ND	17.1	1.2	ND	22.8	8.9	.65	.07
WT_596m	09–18–97	1350	ND	1.0	ND	ND	26.5	2.0	.04	ND
WT_598m	09–18–97	1400	ND	51.9	5.0	.01	18.5	11.0	1.1	.17
WT_807m	09–18–97	1315	.06	73.0	37.9	1.3	61.8	8.0	.83	22.1
WT_829m	09–18–97	1305	.03	50.0	30.8	1.0	64.8	6.9	.57	17.7
WT_845m	09–18–97	1255	.04	40.7	28.4	1.0	79.6	7.6	.36	17.8
WT_868m	09–18–97	1250	.02	16.8	14.7	.40	67.7	6.2	.23	6.9
WT_902m	09–18–97	1225	.02	34.4	31.7	.69	54.7	6.2	.43	10.3
WT_912m	09–18–97	1210	.03	37.2	34.1	.89	55.5	6.1	.44	17.4
WT_982m	09–18–97	1150	ND	7.5	5.6	.13	67.5	8.7	.16	3.0
WT_985m	09–18–97	1150	ND	8.8	6.4	.12	57.4	8.0	.16	2.3
WT_1,037m	09–18–97	1140	.01	9.7	7.2	.22	65.0	7.3	.15	6.4
WT_1,075m	09–18–97	1130	.01	8.0	5.7	.18	61.5	7.0	.15	5.3
WT_1,079m	09–18–97	1130	ND	4.8	3.3	.09	56.9	7.0	.13	2.8
WT_1,089m	09–18–97	1125	ND	5.0	3.2	.07	55.1	6.7	.16	2.3
WT_1,144m	09–18–97	1050	.01	9.4	.26	ND	17.5	4.0	.41	.11
WT_1,156m	09–18–97	1045	.05	45.3	39.7	1.1	96.8	7.0	.55	18.9
WT_1,267m	09–18–97	1015	ND	5.1	.17	ND	20.3	3.2	.21	ND
WT_1,283m	09–18–97	1005	.06	12.7	3.2	.07	21.9	7.6	.45	1.4
WT_1,554m	09–18–97	0955	.48	20.5	9.7	.24	44.0	12.5	.61	7.8
WT_1,560m	09–18–97	0940	ND	9.4	2.5	.04	22.1	18.9	.37	1.9
WT_1,705m	09–18–97	0925	.01	42.1	12.2	.47	34.1	28.3	1.5	7.0
WT_1,752m	09–19–97	1035	.02	45.9	12.3	.44	40.5	34.0	1.5	7.7
WT_1,759m	09–19–97	1030	ND	31.1	9.1	.34	35.9	6.2	2.4	7.5
WT_1,774m	09–19–97	1025	ND	18.4	.87	ND	.26	36.8	1.3	ND
WT_1,777m	09–19–97	1020	ND	17.3	.81	ND	.25	36.4	1.2	ND
WT_1,983m	09–19–97	1000	ND	2.4	.03	ND	17.0	1.9	.10	ND
WT_2,571m	09–19–97	0940	.03	62.1	50.7	.73	63.2	32.6	1.9	12.3
WT_2,573m	09–19–97	0935	.01	75.1	39.6	.50	40.9	22.4	2.0	8.0
WT_2,757m	09–19–97	0925	ND	15.5	9.0	.12	22.5	5.7	.63	2.6

Table 8. Selected chemical data for synoptic samples collected from Wightman Fork during the tracer-injection and synoptic-sampling study on Wightman Fork, September 18 and 19, 1997

[Ca, calcium; Cd, cadmium; Co, cobalt, Cr, chromium; Mg, magnesium; Ni, nickel; SiO_2, silica; Sr, strontium; ND, not detected]

Site identifier	Sample		Element (milligrams per liter)							
	Date	Time	Ca	Cd	Co	Cr	Mg	Ni	SiO_2	Sr
WF_BG	09–18–97	1520	17.3	ND	ND	0.07	5.4	0.01	19.9	0.12
WF_13m	09–18–97	1515	18.2	ND	ND	.02	5.3	.02	19.0	.12
WF_31m	09–18–97	1505	14.9	ND	ND	.05	4.1	.01	20.2	.11
WF_54m	09–18–97	1500	16.3	ND	ND	.01	4.3	.01	20.0	.11
WF_145m	09–18–97	1445	16.0	ND	ND	.01	4.4	.01	20.1	.11
WF_265m	09–18–97	1435	13.2	ND	ND	.01	4.4	.01	20.2	.12
WF_445m	09–18–97	1425	19.9	ND	ND	.01	4.5	.01	19.7	.13
WF_592m	09–18–97	1355	15.4	ND	ND	.01	4.8	.01	19.9	.13
WF_622m	09–18–97	1345	12.1	ND	ND	ND	3.1	ND	20.9	.09
WF_682m	09–18–97	1340	14.2	ND	ND	ND	3.5	ND	22.6	.10
WF_742m	09–18–97	1330	12.7	ND	ND	.03	3.3	ND	21.3	.10
WF_802m	09–18–97	1320	14.7	ND	ND	ND	3.8	ND	22.8	.11
WF_817m	09–18–97	1310	20.1	ND	0.02	.03	4.9	.02	21.9	.11
WF_832m	09–18–97	1305	26.3	ND	.06	.06	7.0	.07	23.8	.13
WF_862m	09–18–97	1250	17.9	0.01	.10	.10	9.2	.11	27.8	.16
WF_890m	09–18–97	1245	21.9	.01	.09	.07	8.6	.11	26.8	.14
WF_922m	09–18–97	1205	23.0	.01	.10	.26	9.1	.11	27.6	.16
WF_954m	09–18–97	1200	24.2	.01	.09	.18	8.8	.11	27.4	.15
WF_993m	09–18–97	1145	23.6	.01	.10	.21	8.8	.11	27.3	.15
WF_1,042m	09–18–97	1135	21.7	.01	.10	.08	8.8	.11	27.3	.16
WF_1,083m	09–18–97	1130	20.8	.01	.10	.08	9.2	.12	28.3	.16
WF_1,102m	09–18–97	1100	19.7	.01	.11	.09	9.0	.13	28.1	.16
WF_1,131m	09–18–97	1055	19.0	.01	.11	.09	9.1	.13	28.3	.16
WF_1,163m	09–18–97	1045	22.4	.01	.11	.09	9.6	.13	29.1	.17
WF_1,214m	09–18–97	1040	28.4	.01	.12	.21	10.2	.13	30.8	.18
WF_1,259m	09–18–97	1017	25.2	.01	.10	.19	9.7	.12	28.5	.16
WF_1,274m	09–18–97	1010	22.6	.01	.11	.08	9.8	.13	28.8	.18
WF_1,332m	09–18–97	1000	21.3	.01	.11	.09	9.9	.13	28.7	.18
WF_1,392m	09–18–97	0955	27.3	.01	.11	.20	9.6	.12	28.4	.18
WF_1,485m	09–18–97	0950	24.7	.01	.11	.08	9.8	.12	28.3	.19
WF_1,599m	09–18–97	0935	28.1	.01	.10	.21	9.9	.12	28.7	.18
WF_1,645m	09–18–97	0930	28.4	.01	.10	.20	9.8	.11	28.5	.18
WF_1,748m	09–18–97	0920	18.0	.01	.12	.13	9.8	.13	29.7	.19
WF_1,748m	09–19–97	1040	141	ND	.08	.10	11.2	.09	20.8	.43
WF_1,807m	09–19–97	1020	923	ND	.04	.05	15.6	.04	13.2	.83
WF_1,964m	09–19–97	1005	484	ND	.04	.14	13.1	.04	11.8	.89
WF_2,384m	09–19–97	0950	368	ND	.04	.05	15.8	.04	12.7	.81
WF_2,755m	09–19–97	0930	409	ND	.06	.07	16.3	.06	14.0	.86
WF_2,815m	09–19–97	0920	478	ND	.07	.08	16.4	.07	15.5	.91