10/16/96

PHASE I

FEASIBILITY STUDY
WATER AND SEDIMENT SAMPLING AND HYDROLOGIC MEASUREMENT PROGRAM
RESULTS AND FINDINGS
1995 SPRING RUNOFF
FOR
OPERABLE UNIT 6
CALIFORNIA GULCH NPL SITE
LEADVILLE, COLORADO

OCTOBER 1996

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1. INTRODUCTION

1.1 *PURPOSE OF STUDY:*

The purpose of this Phase 1 investigation was to characterize and assess the contribution of contaminant metals from the various sources of tailings, mine waste and waste rock piles to the surface water drainages during seasonal snowmelt runoff in Operable Unit 6 (OU6) of the California Gulch NPL Site (Site) in Leadville, Colorado. Two drainages in OU6 contribute flow to the Arkansas River via Evans Gulch and California Gulch. Because some (most?) of the drainages in OU6 are intermitant streams, the majority of runoff occurs during the spring snow melt period. This program of field sampling was carried out by the Bureau of Reclamation (Reclamation) for USEPA Region VIII under Inter-Agency Agreement (IAG) No. DW14953658. Laboratory analysis of the water and sediment samples was performed by Reclamation's Research Chemistry Laboratory under IAG No. DW14953680-01. This report quantifies and evaluates chemical concentrations in water and stream bed sediments in several drainage basins during the 1995 spring snowmelt runoff.

Cal Gulch is not in OU6)

1.2 OBJECTIVE:

The objectives of this report are to present the findings of ~~the USBR~~ Reclamation's 1995 Phase I Sampling and Hydrologic Measurement Program and to evaluate the findings of the sampling program. The evaluation of these findings identifies which areas within OU6 are in need of remediation and provides a basis for the selection of remedial alternative designs in OU6. The objectives for this report included:

alternatives for design and construction in OU6.

instead ??

1. ~~Providing~~ To provide a detailed chemical and hydrologic description of a single season snowmelt runoff event based on weekly sampling from May through July, 1995 for characterization of OU6 surface water.

2. To assess chemical, streamflow, and mineralogical data from ~~4~~ four OU6 sub-basins to identify possible geochemical processes, to quantify trace element mass loading into California Gulch and Evans Gulch drainages, and to provide supporting data to help identify potential ~~tailings~~ contaminant metals source areas.

is there a better word phrase? i.e "contaminant metals" - "trace" might lead one to believe we're only talking about small amounts.

1.3 PREVIOUS STUDIES:

A number of previous Remedial Investigation (RI) studies have been conducted on the California Gulch NPL Site, including the "Surface Water Remedial Investigation Report, California Gulch Site, Leadville Colorado," draft dated March 1993 [1]. This report and other RI reports address general site-wide water quality and other issues. After a review of the existing data reports, Reclamation recommended that a more detailed sampling and investigation program be carried out in OU6 to address its water quality issues ~~in OU6~~ and to attempt to identify sources or source areas of trace metal contamination to the surface water. Previous studies had not attempted to address possible contamination sources or provide enough data to characterize water quality and possible contamination from the majority of mine waste piles in OU6. Where feasible, sampling locations were chosen to coincide with previous study locations. The previous sample location designation was used at these four locations in Evans Gulch.

1.4 *GENERAL STUDY LOCATION:*

The OU6 site is located in Lake County, Colorado, approximately 100 miles southwest of Denver, Colorado. OU6 is comprised of approximately 2,200 acres of the 16.5 square miles of the California Gulch NPL Site. OU6 includes the drainage areas east of Leadville, outside of the populated area, see figure 1. ~~and approximately defined by the drainage divides of Stray Horse Gulch on the north and California Gulch on the south.~~ The OU6 boundary includes the upper end of Evans Gulch on the east and the lower portion of Evans Gulch near US Highway 24 and State Highway 91, north of Leadville on the northwest. Elevation ranges from approximately 10,000 feet above mean sea level (MSL) to 12,500, on the eastern limit below Mosquito Pass.

1.5 *WATERSHED BASINS : General*

There are two watersheds within OU6 which contribute surface runoff to the Arkansas River. These watersheds are the Evans Gulch (EG) drainage and the Stray Horse Gulch (SHG) drainage. Surface water runoff in the Stray Horse Gulch drainage flows into the Starr Ditch which contributes flow to California Gulch, a tributary to the Arkansas River. The small drainage called Little Stray Horse Gulch (LSHG), also contributes runoff through ~~various ditches in~~ Leadville to California Gulch. Two smaller sub-drainage basins are also tributary to Evans Gulch. These are the South Evans Gulch and Lincoln Gulch. The area of the South Evans Gulch basin has extensive mine-workings and mine-waste and waste rock piles. Lincoln Gulch drains a significant portion of the area known as Breece Hill. All of the outflow from OU6 is received by the Arkansas River via Evans Gulch and California Gulch. Evans Gulch serves as the water supply source for the city of Leadville and is managed by the Parkville Water District. The Leadville Mine Drainage Tunnel (LMDT) was constructed during World War II and the Korean War by the U.S. Bureau of

Mines, to drain the mine workings east of the city of Leadville. The tunnel extends under the OU6 area and probably drains a significant portion of the groundwater and infiltration from the surface. Effluent from the LMDT is treated at the Leadville Mine Drainage Tunnel Treatment Plant (LMDTTP), operated by Reclamation. The locations of drainages and drainage basins in OU6 are shown on Figure 1.

Mention that Yak Tunnel underlies Breece Hill, South Evans Gulch, and Evans Gulch ?? - relates to groundwater just like LMDT,

1.6 *GENERAL GEOLOGY:*

The geology of Leadville and the history of the Leadville Mining District are described in detail in various reports. The primary reference used in this study is the "Geology and Ore Deposits of the Leadville Mining District, Colorado," by Emmons, et. al., published by the U.S. Geological Survey as Professional Paper No. 148 [2].

too wordy for the public)

The bedrock formations which underlie OU6 are a series of sedimentary strata that range in age from Cambrian (years bp) to Pennsylvanian (years bp) and consist of quartzite, limestone, dolomite, and shale. These Paleozoic (dates?) sedimentary formations were intruded during the late Cretaceous (dates) or early Tertiary (dates) in several episodes by porphory in "blanket" sills and dikes. These porphyry intrusions created the major portion of the mineralized zones and ore deposits.

The entire sequence of intruded sedimentary formations and pre-Cambrian granitic bedrock was uplifted and faulted into a series of discrete bedrock blocks by north-south trending normal faults that step downward in elevation from Mosquito Pass on the east to Leadville and the Arkansas River Valley on the west. This series of faults largely controlled the distribution and depth of the ore bodies, as well as groundwater which entered the mines in large quantities prior to the drainage tunnels. Note the drainage tunnels (LMDT and Yak) affected certain levels - pumping was required to dewater the lower ore body levels throughout the area.

Over a period of 130 years, the sedimentary bedrock units and intrusive ore deposits were mined, and wastes were deposited on the surface after grading and processing. These waste materials are now subject to weathering processes which oxidize, break down, and release remaining trace metals into the surface water drainages. The distribution and areal extent of these mine waste and waste rock deposits are still related to the formations and type of ore deposits from which they originated; and, therefore, the quality of the surface runoff water that enters the drainages of the Arkansas River reflect these sources of the ore. Several different types of ore bodies were mined, including both sulphide and oxide carbonate ores.

see note on pg. 1 - word "trace" needs a better word used. - "contamin" ??

Of particular significance are the mines that worked the sulphide ore bodies. When the sulphide ore waste material are exposed to weathering processess on the surface, the breakdown and alteration of the sulphide minerals generates low pH levels in surface water, which can dissolve remaining trace metals and

is

acidic

contaminant ??

lead to significant dissolved trace metal concentrations in the water and suspended sediment particles in the total water column. This type of runoff is generally refered to as acid mine drainage (AMD) or ~~as~~ Acid Rock Drainage (ARD). Trace metals associated with other types of ore bodies may still be of environmental significance because of their availability to the environment ~~from~~ via erosion, ~~airborne by~~ both water and wind, or through direct contact with people.

Throughout much of the OU6 area, the bedrock is overlain with glacial deposits associated with the Evans Gulch glacier, which moved down the Evans valley depositing lateral moraines on both sides of the valley and a thin cover of ground moraine in the valley bottom. Geologic maps by Emmons show the Evans valley to be bedrock; however, this mapping may have ignored the thin soil cover present on a photograph from the period. Today, the valley is densely vegetated with willow. wetlands ?? On the hills adjacent to the south side of Stray Horse Gulch there was a very thin cover of unconsolidated glacial or other soils left before mining activity totally removed or dirupted the original ground. Glacial lake deposits are found in the upper end of the Stray Horse Gulch drainage in Adelaide Park, which supports a small area of wetlands.

South Evans also has a glacial

hills on north side are covered with glacial deposits.

1.6.1 *Ore Body Geology and Acid Rock Dainage:*

The metal ores that were mined in the Leadville Mining District were mapped and divided into five different ore body types by Emmons. Because these ore bodies were intruded along and through sedimentary lithologies in lacotlith or tabular-shaped bodies, the classification of three of the ores was related to the stratigraphic position relative to the "Blue Limestone, White Limestone, Gray and White Porphyry and 'Parting' Quartzite." In addition there were two ores of more limited extent referred to as "Stockworks and blankets in siliceous ore, and Magnetite-quartz-pyrite-gold' ore." Because the present day mine waste ~~tailing~~ and waste rock piles in OU6 are the product of the mining of these ore bodies, their composition relfects to some extent the lithologies and mineralogy of the bedrock that was mined and processed.

The mineralogy and lithology of the metal ores was divided between two primary types; the sulphide ore and oxide ore minerals. Because of the capacity to generate acid through oxidation processes, the distribution of the sulphide ores ~~are~~ is of particular interest in order to determine possible sources of acid rock drainage in OU6. The sulphide ores were grouped by their metallic content as follows:

"1. Massive sulphide ores, consisting of preponderating amounts of metallic sulphides:
   a. Pyritic or iron ores.
   b. Galena or lead ores.
   c. Sphalerite or zinc ores.
   d. Chalcopyrite-bearing mixed sulphides or copper ores.

e. Mixed sulphides.
f. Argentite-bismuthinite, or silver-bismuth ores.

2. Carbonate sulphide ores, consisting of mixtures of sulphides and large amounts of manganosiderite.

3. Siliceous sulphide ores, consisting of mixtures of sulphides with large amounts of quartz or jasperoid:

a. Pyritic gold ores
b. Chalcopyritic gold ores"

The most abundant pyritic iron ores are described as "often extremely pure aggregates of pyrite with relatively small quantities of other sulphides." The distribution of these sulphide ore bodies included a number of the major producing mines that were located in OU6 as described below :

> "Bodies of nearly pure pyrite are found in the mines of Iron Hill, Carbonate Hill, Graham Park, Breece Hill, and Evans Gulch...In some places the relatively pure pyrite forms the entire sulphide body, as in certain stopes of the Maid, R.A.M., Greenback, Mahala, Tucson, Moyer, Wolftone, Ibex, and other properties." (p. ??)

The mineral composition of pyrite ore from the Henriett-Maid mine, which is located along the south side of Stray Horse Gulch, was given as "Pyrite, 99.27 percent; chalcopyrite, 0.02 percent; arsenopyrite, 0.02 per cent; argenite, 0.02 percent (or 5 ounces of silver to the ton of ore)." It was noted that the arsenopyrite "...indicates the source of the minute quantities of arsenic found in the flue dust of the smelter."
The pyritic ore bodies in some of these mines can be described as massive. An appreciation for this adjective can be found in the description of the Henriette-Maid mine:

> "In this mine a body of sulphides extended from the Parting quartzite through the White limestone as far down as the Lower or Cambrian quartzite. The upper 30 feet consisted of a mixture of sphalerite and pyrite. The next 10 to 12 feet consisted of pyrite containing about 30 ounces of silver to the ton. The third layer, 20 feet thick, consisted of pyrite containing 15 ounces of silver to the ton. Beneath this was a mass of solid pyrite 80 feet thick containing streaks of chalcopyrite and a higher silver content than either of the two layers above." (p.165)

Do you want to conclude anything as a result of this Emmons ore body information ?? ie ground surface located above these ore bodies is where we expect AMD /ARD source area.

1.7 *SAMPLE COLLECTION SITES:*

surface ??

During the 1995 spring runoff, water and sediment samples were collected over a period of 10 weeks from the 15 sites in OU6. The collection sites were located in order to sample and quantify surface water flow, water chemistry and sediment chemistry along the drainage path of each basin and sub-basin in OU6 as decribed below in Table 1.5.1. The locations allow for the possible characterization and identification of source areas within each drainage basin. Sampling site locations are shown on Figure 1.7. 2 ??

which ?

Table 1.7: Operable Unit 6 - Phase I - Water and Sediment Sampling Sites.

BASIN	Station ID	Site Description
Evans Gulch	WE01	Evans Gulch most upstream location on east side of Evans Gulch Road, near Tailings Area #2 and the Luema and Silver Spoon Mines. Receives drainage from the Resurrection #2 and Diamond Mines. Approximate elevation 3,~~3~~63 m (11,035 ft.). Previously sampled by Weston Inc. why metric ?
	EG03	Evans Gulch on west side of Evans Gulch Road at confluence from drainage south of Famous Mine. Almost directly south of station WE01, this site collects drainage from the New Monarch, Famous, Fortune, and Resurrection #1 Mines. Approximate elevation 3,3~~3~~8 m (11,050 ft.).
	WE02	Evans Gulch, 5~~50~~ m (1,800 ft.) downstream of confluence with South Evans Gulch, and 500 ft. downstream from the Lincoln Gulch confluence. Receives drainage from Lincoln Gulch, South Evans Gulch, and the sub-basin drainage associated with site EG03. Approximate elevation 3,2~~9~~5 m (10,810 ft.). Previously sampled by Weston Inc. don't believe it's that for D/S - ? - 100 ft ?
	EG01	Evans Gulch ~~a~~ 5~~50~~ m (1800 ft.) upstream of confluence with Little Evans Gulch (Creek) at Poverty Flat, and ~~1~~5.~~3~~ km (3.3 mi.) downstream from station WE02. Approximate elevation 3,~~1~~27 m (10,260 ft.).
	EG02	Evans Gulch downstream of confluence with Little Evans Gulch (Creek), north of Leadville and immediately west of ~~State~~ US Highway 24. Approximate elevation 3,0~~7~~8 m (10,100 ft.).
South Evans Gulch	SEG01	South Evans Gulch at head of basin where access road crosses drainage. Approximate elevation 3,45~~6~~ m (11,340 ft.).

	SEG02	South Evans Gulch where access road crosses drainage above confluence with Alps Gulch, near Nome Mine. Approximate elevation 3,426 m (11,240 ft.).
	SEG03	South Evans Gulch below confluence of Alps Gulch drainage, near Favorite Mine. Receives drainage from Breece Hill and Ibex #1 Mine. Approximate elevation 3,406 m (11,175 ft.).
	SEG04	South Evans Gulch midway between SEG-03 and confluence with Evans Gulch. Collects drainage from the Winnie, Ollie Reed, Big Four, Ibex #1, and Erie Mines. Approximate elevation 3,378 m (11,075 ft.).
	SEG05	South Evans Gulch ~~1~~ 180 m (600 ft.) above confluence with Evans Gulch. Approximate elevation 3,338 m (10,950 ft.).
Lincoln Gulch	LG01	Lincoln Gulch ~~1~~ 90 m (300 ft.) above confluence with Evans Gulch. Collects drainage from the Ibex and Silver King Mines and associated ~~tailings~~ piles. Approximate elevation 3,307 m (10,850 ft.)
Stray Horse Gulch	SHG07	Upper Parshall Flume on Stray Horse Gulch located immediately north of the Dolomite Mine and downstream from Adelaide Park. Collects drainage from the Penn #1, #2, and #3 Mines and the ~~nearby Humboldt, Ward, and Dolomite Mines.~~ Approximate elevation 3,295 m (10,810 ft.).
	SHG08	Middle Parshall Flume on Stray Horse Gulch located ~~1~~ 120 m (400 ft.) downstream from the Old Mikato Mine and ~~910 m~~ (3,000 ft.) downstream from SHG07. Collects drainage from the Old Mikato and New Mikato Mines to the south, and the ~~McCormick~~ Mine to the north. Approximate elevation 3,219 m (10,560 ft.).
	SHG09	Lower Parshall Flume on Stray Horse Gulch, located ~~1~~ 730 m (2,400 ft.) downstream of SHG08 and ~~1~~ 140 m (450 ft.) upstream of the Hamm's ~~Mine~~ pile area. Collects drainage from Greenback and Wolftone and Asarco Mines on the south, and the Result and Emmet Mine on the north. Approximate elevation 3,170 m (10,400 ft.).
	SHG10	Sampling site in Leadville at 5th Avenue where Stray Horse Gulch joins Starr Ditch. Collects drainage from the Hamm's ~~Mine~~ pile area ~~as well as~~ some drainage from Little Stray Horse Gulch and its associated mines and ~~tailings~~ piles. Approximate elevation 3,103 m (10,180 ft.).

Breece Hill and

waste rock

(Hamm's and Res. No. 1 are the only tailing areas up there.)

Park No. 4 Mine.

flume is at this waste pile

runoff goes d/s of flume

waste pile

east

Emmons spells it "Mikado"

located above McCormick runoff

Highland Mary No. 1 and No. 2

Tailing

from Greenback, Mahala, RAM, Wolftone, Maid of Erin, and Adams Mines on the south, and

Robert

McCormick

piped

flow

Tailing

and possibly

waste rock

2. METHODOLOGY:

2.1

line start location ??

2.1 ~~1~~ *FIELD AND LABORATORY PROCEDURES AND PROJECT QUALITY ASSURANCE:*

?

2.1.1 Program Accomplishments:

This sampling program established a consistent and prolonged evaluation of the drainages in OU6 from the beginning of the snowmelt cycle, through the peak of the runoff season, and culminating with drainages returning to normal flow patterns in July. There were 13 new sample locations established to supplement the 4 existing locations to better understand the dynamics of surface water flow and sediment transport within Evans Gulch, South Evans Gulch, Lincoln Gulch, Little Stray Horse Gulch, and Stray Horse Gulch. Although there were a total of 17 sampling locations identified in the Phase 1 Sampling Plan, only 15 were sampled. No samples were collected from the 2 sites on Little Stray Horse Gulch due to the lack of runoff water. Water samples were collected over a period of 10 weeks beginning May 10, 1995, and ending July 26, 1995. Because the samples were usually collected over a 2-day period on a weekly frequency, each weeks set of samples ~~were~~ was termed a Sample Event group. This allows for grouping and data base queries by sample event number and, therefore, would not miss individual dates. Because the snowmelt runoff progresses up in altitude, not all stations were sampled during all 10 event weeks. Higher altitude sites on South Evans Gulch were not sampled until Events 3 and 4. Following several sampling events, it was decided by the sampling team and the EPA-RPM Remedial Project Manager (RPM) not to collect sediment samples, partly due to the heavy flow conditions which made it impossible to safely sample sediment, scouring of the sediment in Evans Gulch and ~~partly because~~ other drainages, and it was felt that an adequate amount of sediment sample data had been collected by early July. Measurements of associated environmental parameters such as pH, conductivity, and temperature aided in evaluation of potential contaminates. minants

Three Parshall flumes were installed in ~~the winter of 1995~~ December 1994 in Stray Horse Gulch (SHG-07, SHG-08, SHG-09) to provide accurate flow data for the evaluation of surface runoff infiltration to groundwater and the environmental effects of wetland areas such as Adelaide Park on existing water quality. Previous hydrologic flow measurements in Stray Horse Gulch indicated a possible significant loss of surface runoff to the subsurface groundwater. Water flow characteristics for all other sites were measured with a portable velocity flow meter. At a number of the sites, flow was not measured until Event No. 4, May 30, due to the difficulties associated with low flows, deep snow pack at the sampling sites, and problems with the velocity flow meter.

the flumes didn't help on this - rewrit ??

area of water flow was estimated

2.1.2 Sampling Methodology:

It is believed that contaminant metals are primarily transported by the finer suspended sediments within the surface water column. This concern ~~has been~~ was addressed by obtaining two 500-ml water samples, one for analysis of total metals

and one for analysis of dissolved metals. A detailed description of this sampling procedure is provided in Standard Operating Procedure (SOP) No. 2A-9 [3].

better phrasing as to "trace" and contam. metals ??

A separate potential source for trace element and contaminant metals transport ~~has been~~ was addressed by obtaining a 250-ml bedload composite sample in a glass jar. This sample was taken from across the central two-thirds of stream channel area, so as not to include bank sluff. The sampling procedure used was outlined in SOP No. 3A [4].

usually spelled slough ??

Water samples were collected directly into the sample bottle, eliminating the need for decontamination procedures and potenitial cross-contamination. Sediment samples were normally collected using a white hard plastic scoop, spatula, and quart-sized mixing bowl. This equipment was decontaminated at the vehicle before leaving each site.

Inorganic constituents carried within the water column are addressed by collecting a 1,000-ml unfiltered and non-preserved sample, as outlined in SOP No. 2A-9.

This process avoided cross-contamination concerns by collecting water samples first and then bedload sediment, always standing downstream while obtaining a sample and moving upstream between water and bedload sample collection. Duplicate samples, field blanks, and equipment rinsate samples were also collected during each sampling event for quality assurance and quality control (QA/QC) purposes and to insure reproducibility of results.

Infiltration of surface water to groundwater, and effects on metals loading related to flow quantity, have been evaluated using three Parshall flumes located in Stray Horse Gulch between Adelaide Park and Hamm's Tailing Impoundment. A hand-held flow-velocity meter was used for all other sampling sites to evaluate similar criteria.

As each sampling site was established, a description of that location was written into the field notebook; and any subsequent deviations from that first site were recorded in the field notebook. At non-flume sites, a flow measurement location was established ~~at each site~~ by placing a sturdy string with calibrated foot markers across the creek spanning from bank to bank. This maintained consistency for each location and was expandable as flows changed at each site.

At the end of each sampling day, all samples were taken to the LMDTTP for processing. Appropriate samples were filtered and/or acidified in accordance with SOP No. 10 [5]. Calibration of field equipment was rechecked, and deviations were recorded in the field notebook. All sample labels were checked and clear taped to prevent smudging and tampering, EPA Sample Identification Tags were completed and secured to the sample containers, and chain of custody seals were placed over the capped opening. The chain of custody form was completed and signed. Each sample container was placed in a separate zip-lock plastic bag to prevent leakage and cross contamination during transport. For the first day of the sampling event, all samples were locked in cold storage.

When samples from all sites had been collected and processed, each analysis group (total metals, dissolved metals, inorganic, and sediment) was loaded into separate iced coolers. The appropriate chain of custody paperwork was placed in a sealed zip-lock plastic bag and placed inside the coolers, and custody seals were positioned across the cooler openings. All samples were then transported to Denver, Colorado, via Government vehicle for laboratory analyses.

— which one? Reclamation??

The samples were relinquished to the receiving laboratory where sample identification was checked against the chain of custody form, appropriate signatures were collected, and the samples were placed in secured refrigerated coolers .

2.1.3 Opportunistic sampling:

For three separate dates during the runoff cycle, composite water samples were collected outside of the normal sampling routine. These samples were obtained from some of the designated sample sites, by acquiring approximately 250 ml of water at four different times of day within the same 1000-ml sample bottle. The data generated from these composites were compared to all other data from each equivalent site to determine if variability may occur at a site related to time of day sampled. Several of these composite samples were obtained on July ?, when heavy runoff flows in Evans Gulch eroded out a road crossing culvert pipe at W/E-02. The erosion caused large amounts of sediment to be deposited further downstream at Big Evans Reservoir, causing concern for water quality. The Parkville Water District advised residents to boil their water for a ? period of time after this event. Analyses of these samples indicates much higher concentrations of trace metals due to the heavy suspended loads and are not included in the discussions and findings later in this report. So as not to bias or skew analyses, the interpretation of the data only considered results from the primary grab samples collected within the 'normal' runoff event schedule.

— Need to note that no thunderstorm events were sampled, which had been intended in the original program??

2.1.4 Decontamination:

The overall objective of the decontamination (decon) procedure is to eliminate cross-contamination of samples leading to a false positive analytical result. Decon procedures used throughout the sampling program are documented in SOP No. 1 [6].

2.2 Data Base & Geographic Information Systems (GIS) Management:

The Phase I water sampling data were loaded into the Reclamation Geotechnical Services Intergraph Environmental Resource Management Applications (ERMA) which is supported by an Oracle relational database.

Existing data have been through a Quality Assurance process which means the data have been validated for completeness, accuracy, precision, and quality conformance by the lab before being delivered to Geotechnical Services. The chemistry lab data are reformatted using Excel 5.0 to fit the ERMA data model and loaded into the Oracle data base. To ensure no corruption of the data takes place while manipulating data from the existing format into a format compatible with the database, the following checks are made:

number them ??

In the spread sheet, the number of analytes are multiplied by the number of samples to determine the total number of database entries there should be.

?

A visual spot check is made to ensure the spreadsheet rows and database columns match.

Three to five percent of the analytical values in the database table are compared with the corresponding original data entries to ensure an accurate translation.

No manipulation of the analytical values and corresponding units is ~~be~~ performed; only the format of the data is changed. Data that ~~was~~ were defined as empty cell in spread sheet format will be changed to NULL for entry into Oracle.

No new data ~~is~~ are added to the data received. If the "sample_id" is not defined in the spreadsheet, it will be generated by joining together into one column the various columns that define the sample_id (concatenating the appropriate columns).

new word! - I had to look it up!

A functional Oracle database is the final product populated with the applicable data. The ERMA suite of products provides GIS and CADD capabilities to preform the required site analysis.

2.2 *Laboratory Analyses*

2.2.1 **METHODOLOGY:** The following sections describe the analytical chemistry methods, quality control procedures and documentation, and the data analysis methods applied in this study.

REQUESTED ANALYTES: Chemical analyses for this study were performed by the Bureau of Reclamation, Technical Service Center (TSC), Environmental Research Chemistry Laboraotory, D-8240 (the Lab). The Lab performed the analyses through an interagency agreement with the Region VIII office of the Environmental Protection Agency (EPA). All analytical data quality control and reporting requirements were defined in several Unique Laboratory Sample Analyses (ULSA) Client Request Forms negotiated with the Region VIII EPA Field Quality Assurance Officer, Tina Diebold, and the Region VIII Sample Broker, Jim Gindleberger. The ULSA forms defined the required analytes, methods, required limits of detection (LOD), reporting limits, Lab quality control requirements, and reporting requirements for sample delivery group (SDG) reports, and the ULSA requests were included in the project Quality Assurance Project Plan (QAPP) [7]. All samples, organized into discrete SDGs, were received from Reclamation field crews under appropriate chain of custody procedures. The following analyses and quality control checks were requested:

DISSOLVED and TOTAL Trace Metals in water samples were analyzed using Inductively-Coupled Plasma Emission Spectroscopy (ICP-ES, or ICP), and Graphite Furnace Atomic Absorption Spectrophotometry (GFAA). Samples labeled as "Total Metals" were received *unfiltered* and *acidified* and were digested using microwave-assisted acid digestion, EPA Method 3015A, prior to analysis. Samples ~~called~~ labeled as "Dissolved Metals" were received *filtered* and *acidified* and were analyzed without performing digestion. The following methods, detection limits, and reporting limits were requested:

TABLE 2.1

Element	EPA Method	Requested Technique	Laboratory LOD, mg/L	Requested Reporting Limit,mg/L
Calcium	200.7	ICP	0.050	0.067
Magnesium	200.7	ICP	0.05	0.033
Sodium	200.7	ICP	0.050	0.100
Potassium	200.7	ICP	1.00	3.3
Aluminium	200.7	ICP	0.030	0.100
Silicon	200.7	ICP	0.020	0.070
Copper	200.7	ICP	0.005	0.017
Iron	200.7	ICP	0.004	0.070
Manganese	200.7	ICP	0.004	0.017
Zinc	200.7	ICP	0.005	0.017
Arsenic	206.2	GFAA	0.001	0.003
Silver	272.2	GFAA	0.0005	0.002
Cadmium	213.2	GFAA	0.0001	0.0005

Lead	239.2	GFAA	0.00139	0.003

LOD represents Limit of Detection, as defined by J.K Taylor's Quality Assurance of Chemical Measurements [8]. LOD is defined as 3 times the standard deviation, s_0, estimated from repeated measurements of a standard or sample. Standard deviation, s_0, was determined for each analyte by 15 replicate measurements of an inter-laboratory performance evaluation sample standard, performed under identical instrument conditions used for analysis of environmental samples. Requested reporting limits represent the LOQ, or limit of quantitation, defined by Taylor to be 10 times s_0. Silicon was analyzed as dissolved only.

Matrix problems encountered during GFAA analyses were resolved using simple method of standard additions, as described in EPA SW-846 Method [9] 7000A.

2.2.2 **General Water Chemistry Analyses***:* The following general chemistry analyses were requested for filtered, unpreserved water samples. The following methods and requested detection and reporting limits were used (IC = ion chromatograph):

Table 2.2.2

Element	EPA Method	Requested Technique	Laboratory LOD, mg/L	Requested Reporting Limit,mg/L
Sulfate	300	IC	3.00	10.0
Chloride	300	IC	1.00	3.3
pH	150.1	Electrometric	n/a	n/a
Alkalinity	310.1	Titrimetric	1.0	3.3
Residue	160.1	Gravimetric	5.00	16.7
Conductance	120.1	Electrometric	n/a	n/a

Requested LOD and reporting limits (LOQ) are defined as above.

2.2.3 **Trace Metal Analyses for Sediments:** Sediment samples were digested using EPA Method 3051 Microwave Assisted Digestion and analyzed for the following elements:

Table 2.2.3

Element	EPA Method	Requested Technique	Requested LOD, mg/kg	Requested Reporting Limit,mg/kg
Aluminium	6010A	ICP	6.00	6.0
Copper	6010A	ICP	1.00	1.0
Iron	6010A	ICP	4.00	4.0
Manganese	6010A	ICP	1.00	1.0
Zinc	6010A	ICP	1.00	1.0
Arsenic	7060A	GFAA	0.200	0.5
Silver	7761	GFAA	0.100	1.0
Cadmium	7131A	GFAA	0.020	0.5
Lead	7421	GFAA	0.100	0.1

Requested LOD and reporting limits (LOQ) are defined as above.

Samples were blended (stirred) prior to subsampling for Method 3051 microwave assisted digestion. Since many samples were wet sediment-water slurries, grab sub-samples were used.

2.3 *LABORATORY QUALITY CONTROL*:

Lab QC checks, acceptance and corrective action criteria, and the contents of reporting packages were defined in detail by the ULSA request forms mentioned above in section b.2. Data for each SDG were summarized in separate data delivery packages which provided a standard EPA checklist cover, a case narrative describing potential data quality problems, a data table listing final results, Laboratory QC reports, detection limits reports, several Contract laboraotory Program (CLP) forms for the ICP, and appropriate raw data for each requested analyte. The following QC checks and documentation were provided for each SDG (TV = true value):

2.3.1 Method 200.7 ICP Analysis for Waters and Sediments:

CALIBRATION STANDARDS SUMMARY: Instrument calibration was performed and documented according to the requirements in the EPA Region VIII - BOR IAG #DW14953680-01 before any environmental samples were analyzed. Reclamation ??

PREPARATION (REAGENT) and DIGESTION (METHOD) BLANKS (1 per SDG, for each type of run - total, dissolved, or sediment - non-detect at requested LOD). For total and sediment trace elements, digested (method) blank and reagent blank was run. For DISSOLVED metals, reagent blank only was run.

- INITIAL CALIBRATION BLANK (ICB) was a reagent blank run after the ICV standard.

- CONTINUING CALIBRATION BLANK (CCB) was a reagent blank run after the CCV standard.

- PREPARATION BLANK (PB) was run after the ICB only for total metals and sediments and was a digested reagent blank.

ICV - INITIAL CALIBRATION VERIFICATION: (1 per run after calibration standards and blank, prior to samples, ± 10% of TV).

DUPLICATE SAMPLE RPD (1 set per SDG, RPD 20%): RPD calculated as indicated in the EPA Contract Laboratory Program (CLP) *Inorganic Statement of Work, ILMO3.0.*

SPIKED SAMPLE RECOVERY (1 per SDG, each analyte, 75% to 125% as percent recovery). Spike was added to digestion for TOTAL metals and sediments.

QC CHECK SAMPLE (1 per SDG, 80% - 120% of TV). The QC check standard for total metals was digested using Method 3015A, the check sample for sediments was digested using Method 3051A.

CCV - CONTINUING CALIBRATION VERIFICATION (1 per SDG at end of run, each analyte, ± 10% of TV).

ICS STANDARD - INTERFERENCE CHECK SAMPLE (2 per SDG - after ICV and at end of run, TV ± 20% for each analyte): The ICS standard was applied as defined in the current CLP *Statement of Work for Inorganic Analysis, Multi-Media, Multi-Concentration.*

STATISTICAL DETECTION LIMIT REPORT (run quarterly, attached to QC report package). Detection limits are described in section b.2 above.

2.3.2 **GFAA Analyses:** The same QC checks as were used for ICP were applied to GFAA analyses. Refer to the above section for details.

2.3.3 **Sulfate and Chloride by Method 300 Ion Chromatography:** QC checks for these analytes included the following:

CALIBRATION STANDARDS SUMMARY: (similar to ICP and GFAA above).

PREPARATION (REAGENT) BLANK (1 per SDG - non-detect at requested detection limit).

ICV - INITIAL CALIBRATION VERIFICATION: (1 per run after calibration standards and blank, prior to samples, ± 10% of TV).

??

DUPLICATE SAMPLE RPD (1 set per SDG, RPD [illegible] 20%).

QC CHECK SAMPLE (1 per SDG, 80% - 120% of TV).

CCV - CONTINUING CALIBRATION VERIFICATION (1 per SDG at end of run, each analyte, ± 10% of TV).

STATISTICAL DETECTION LIMIT REPORT (run quarterly, attached to QC report package).

2.3.4 **pH and Alkalinity by Method 310.1:** QC checks for this analyte included the following:

pH METER CALIBRATION SUMMARY: (similar to ICP and GFAA above).

??

DUPLICATE SAMPLE RPD (1 set per SDG [illegible] 20%).

QC CHECK SAMPLE (1 per SDG, 80% - 120% of TV).

2.3.5 **Filterable Residue by Method 160.1:** QC checks for this analyte included the following:

BALANCE CALIBRATION CHECK: Balance calibration check sequence number from balance calibration logbook is included in QC report..

PREPARATION (REAGENT) BLANK (1 per SDG - non-detect at requested detection limit).

??

DUPLICATE SAMPLE RPD (1 set per SDG, RPD ≤ 20%).

QC CHECK SAMPLE (1 per SDG, 80% - 120% of TV).

2.3.6 **Conductivity (Conductance) by Method 120.1:** QC checks for this analyte included the following:

ICV - INITIAL CALIBRATION VERIFICATION: (1 per run after calibration standards and blank, prior to samples, ± 10% of TV).

??

DUPLICATE SAMPLE RPD (1 set per SDG, RPD ≤ 20%).

QC CHECK SAMPLE (1 per SDG, 80% - 120% of TV).

2.4 *LABORATORY DATA REVIEW and EVALUATION*:

There were several layers of inspection and review of analytical data. Within the TSC Lab, each analyst involved with this project was required to review the calibration, precision, and accuracy QC checks immediately following each SDG run, and to re-run and take appropriate corrective actions for QC requirement exceedances. Analysis concentration data and QC information were then transferred to appropriate forms and data tables which were checked for transcription errors. Data delivery packages were then assembled and checked against ULSA agreement requirements and then forwarded to the Lab QC Officer. The QC Officer then checked and reviewed the assembled data packages, wrote the case narrative, and forwarded the final data packages to the EPA Sample Broker and Reclamation clients. Formal data validation for each SDG was performed by the EPA Region VIII data validation staff.

The QA samples submitted to the Lab as blinds (coded with an -02- or -03- in the middle of the sample identifier) were audited by Reclamation project staff to check for transcription errors, and to evaluate field sampling procedures and laboratory performance on blind field duplicates and blanks. These results are summarized in a TSC QA review memorandum [10].

Primary sample data (coded with an -01- in the middle of the sample identifier, were also reviewed prior to data analysis and plotting by the project chemist. Primary data were checked for instances where dissolved concentrations were greater than total concentrations, and major ions data sets were evaluated using cation-anion balance. Major ion data for samples from Stray Horse and Lincoln Gulches were not

evaluated using ion balance since a large portion of ionic activity in these samples is from elevated trace element concentrations.

Data for dissolved and total trace element concentrations were reviewed to identify anomalous data where dissolved were greater than total concentrations. This resulted in three possible quality decisions based on the magnitude of the difference observed for dissolved greater than total anomalies. These decisions depended on whether the sample's measured values were near the limit of detection (LOD), greater than the LOD, or if all the elements for a sample had dissolved trace element values greater than total values, indicating switched sample analysis (suggesting possible labeling error). The following table lists (containing 24 anomalous data observations) was compiled for all dissolved and total trace element samples:

Table 2.4.1 - Summary of anomalous trace element data results for the 1995 data set.

Station	Date	Element(s)	Observation
EG01	6/28/95	As	Near limit of detection (LOD)
EG02	6/13/95	Cd	Possible contamination of dissolved sample
SEG01	6/14/95	Zn	Near limit of detection (LOD)
SEG01	6/27/95	Zn	Possible contamination of dissolved sample
SEG01	7/27/95	Mg, Zn	Possible contamination of dissolved sample
SEG02	6/20/95	Zn	Near limit of detection (LOD)
SEG02	6/27/95	Zn	Near limit of detection (LOD)
SEG02	7/27/95	Mg, Zn	Possible contamination of dissolved sample
SEG03	7/11/95	Zn	Possible contamination of dissolved sample
SEG03	7/27/95	Zn	Possible contamination of dissolved sample
SHG07	5/25/95	Al,Cu,Fe,Mn,Zn,As,Cd	Possible label switch
SHG07	5/30/95	Mn, Zn	Possible contamination of dissolved sample
SHG07	7/26/95	Al,Fe,Mn,Zn,Cd	Possible label switch
SHG09	6/07/95	As	Possible contamination of dissolved sample
SHG10	7/10/95	As	Near limit of detection (LOD)
WE01	5/16/95	As	Near limit of detection (LOD)
WE01	5/30/95	As	Near limit of detection (LOD)
WE01	5/30/95	Mg, Zn	Possible contamination of dissolved sample
WE01	6/27/95	Zn	Possible contamination of dissolved sample
WE01	7/10/95	Mg, Zn	Possible contamination of dissolved sample
WE02	5/10/95	As	Near limit of detection (LOD)
WE02	5/10/95	Al, Zn	Possible contamination of dissolved sample
WE02	5/30/95	Zn	Possible contamination of dissolved sample
WE02	7/10/95	Zn	Possible contamination of dissolved sample

Near limit of detection (LOD) - dissolved ≈ total (concentration within 1/3 of LOD)

Possible contamination of dissolved sample - dissolved > total (concentration > 1/3 of LOD)

Possible label switch - all dissolved > total (many elements)

The results of this analysis of the anomalous data observations indicate 8 out of 1,000 analytes (0.8%) were found to have dissolved greater than totals, five occurrences for As and three for Zn; however, the concentrations were near 1/3 of the LOD. Dissolved greater than total anomalies are not unusual in the lower concentration ranges due to greater variability relative to the absolute measured concentrations. For dissolved greater than total differences greater than expected variability where contamination is suspected, anomalies occurred in 18 of the 1000 analytes (1.8%); 12 occurrence for Zn, 4 for Mg, and 1 each for Cd, Mn, As, and Al. Two out of the 100 samples (2%) indicate a possible label switch since so many trace elements showed dissolved greater than total anomalies. These quality problems are well within reasonable expectation for a study of this size and complexity, and thus do not affect interpretative conclusions made in the following sections.

2.5 *DATA HANDLING AND ANALYSIS*:

Original data tables for each SDG were electronically provided by way of Microsoft Excel® for Windows, version 5.0, spreadsheet files. These spreadsheets were combined into a master spreadsheet that was archived as an Oracle® relational database running on a UNIX server.

The project chemist used Microsoft Access® for Windows, version 2.0, to create a database from data in the master Excel® 5.0 spreadsheet. Access query tables were created for dissolved trace elements, total trace elements, sediment trace elements, major cations, and anions, which were then exported as Excel® for Windows, version 3.0, spreadsheets.

Appropriately paired Excel® 3.0 spreadsheets were then combined, and the sample ID fields (included in each spreadsheet) were used to confirm that the data and samples were correctly matched. Total and dissolved trace elements were combined into a single metals spreadsheet, and major cations and anions were similarly combined into an ions spreadsheet. Combined spreadsheets and the sediment trace elements spreadsheet were then edited to remove text annotations from numeric data, and to change all non-detect (ND and less than ###) analyte data cells to one-half the LOD for each analyte (to allow for a more unbiased statistical analysis of the data).

The edited Excel® 3.0 spreadsheets were then converted to SPSS® for Windows, version 6.0, (Statistical Package for the Social Sciences, SPSS, Inc.) data files using DBMS/Copy Plus™, version 4.0 (SPSS, Inc), an MS-DOS file conversion program. SPSS® was used for all subsequent statistical analysis and data plotting. Any further adjustments or editing of data were performed in the SPSS® environment.

Trace element data from this study were plotted on normal probablility scale plots; and almost all variables are non-normally distributed, both with respect to the entire data set and subsets based on basin and station. Because of the non-normality of data, the median was used to estimate the central tendency of each data set examined. Since the median is a rank-based statistic representing the 50th percentile, 50 percent of the data will be equal to or greater than the median value. Thus, if a water quality regulation is exceeded by the median concentration, it is safe to conclude that at least half of the data also exceed the regulated concentration. In cases where data sets were normally distributed, the median and mean coincide.

Flow-weighted metal loading in kg/wk was calculated using the following formula:

$$\frac{(\text{flow, ft}^3/\text{s}) \times (28.3168\ \text{L/ft}^3) \times (6.048 \times 10^5\ \text{s/wk}) \times (\text{metal conc, } \mu\text{g/L})}{(1.0 \times 10^9\ \mu\text{g/kg})}$$

3.

3.~~0~~ *Geochemical Modeling of Snowmelt Runoff Water:*

In order to assess and characterize the changes in dissolved minerals with flow and chemistry, modeling of the Phase 1 runoff chemistry data was performed using the EPA MINTEQA2 model [11].

3.1 ***MINTEQ MODELING***: The MINTEQA2 chemical equilibrium computer model was used to calculate the expected equilibrium chemical speciation (the concentration, as activity, of all the different chemical compounds that will form with each component) and mineral saturation indices (calculated for all minerals potentially involved in weathering to produce the sample water chemistry) for samples having major ions and dissolved trace element data.

MINTEQA2 data files were created using the PRODEFA2 data entry program. Non-detect elements data were not entered into the model data sets. The samples were assumed to be in equilibrium with atmospheric gases: the partial pressure of carbon dioxide gas, pCO_2, was fixed at 0.000224 atm, and the partial pressure of oxygen, pO_2, was fixed at 0.1421 atm. These partial pressures correspond to expected values at elevation 3,170 m (10,400 ft.). Field pH and temperature data were entered as the sample equilibrium values. Arsenic data, reported as µg/L elemental As, were gravimetrically converted and entered as MINTEQA2 component #061, H_3AsO_4. Silicon data, reported as mg/L elemental Si, were gravimetricaly converted and entered as MINTEQA2 component #770, H_4SiO_4. Iron was entered as Fe^{+3}, component #281, while all

other cationic elements were entered as divalent (+2 charge) components, except for silver, entered as monovalent Ag^+, component #020.

MINTEQA2 runs were performed for individual sample data sets, as well as median values data sets for each sampling station. Individual sample speciation and mineral saturation index data were then entered into the trace elements SPSS® data file for plotting and analysis. Median values station summaries output are summarized in the following sections numbered 3.X.5 and 3.X.6. Output files were saved in ASCII text format.

The reader is cautioned that the results calculated by the MINTEQA2 model depend on the assumption that the data represents a water that is at chemical equilibrium. In flowing systems such as snowmelt runoff, the assumption of equilibrium conditions may be violated, and modeling results may be less quantitative. Thus, the more specific and detailed the interpretation derived from MINTEQA2 results, the more important assumption violations become. Here are some examples where the assumption of equilibrium may be violated:

Dynamic Inflow/Outflow Conditions: Adsorption to suspended particulates is a dynamic process where fresh sediment and dissolved inputs from feeder streams are mixing in complex and chaotic ways. Suspended sediments are also simultaneously settling out of the water column. With changing influent and effluent mass loading and depletion occurring along a drainage path, the reactants and products are constantly changing; and the water cannot be considered at equilibrium.

Reaction Kinetics: While many mineral weathering reactions and chemical solution reactions that form trace element complexes occur quickly (on the order of seconds), some occur more slowly (on the order of hours or days). The kinetics of a particular reaction may be slower than the runoff flow residence time will allow, and this represents non-equilibrium condition.

Mixing and Turbulent Flow: Sediments and dissolved constituents may mix at drainage basin confluences; however, they may not mix in a homogeneous manner. Colder or higher salinity waters will exhibit density gradients that resist mixing, and the mixing process does take time (that is, lateral distance along the stream). A collected sample that does not represent a fully mixed system will produce measured analytical data that do not represent a fully mixed system, and this is a non-equilibrium condition.

The mineral saturation index, log(AP/KT), is the log of the equilibrum solution activity product divided by the equilibrium constant, K, for the mineral dissolution reaction, times the °K temperature. The saturation index is an indicator of whether a given water is oversaturated (positive values) or undersaturated (negative values) with respect to a given mineral, and MINTEQA2 calculates saturation indices for all minerals whose weathering or dissolution may have potentially contributed to the final equilibrium concentrations (expressed as thermodynamic *activity*).

MINTEQA2 saturation indices (SI's) that are near zero suggest that the particular water is at or near equilibrium with the given mineral and that the dissolution and precipitation of the mineral will have a *regulating* effect on the water chemistry. SI values greater than ± 1 suggest that these minerals are not near equilibrium for the particular water chemistry. If the SI is negative, the water will tend to *dissolve* that particular mineral and may mobilize any toxic metals associated with the mineral. Positive SI's suggest that the water will tend to *precipitate* the mineral in question (or at least that there are favorable conditions for the mineral formation reaction to occur) . The following minerals are in the MINTEQA2 mineral data base and they have either been observed in and around California Gulch or are similar to minerals observed in the local geology:

Table 3.1 - Minerals observed or potentially present in the California Gulch/Leadville geology, that are also in the MINTEQA2 mineral reactions data base.

Mineral	Class	Chemical Formula
Calcite	carbonate	$CaCO_3$
Dolomite	carbonate	$CaMg(CO_3)_2$
Rhodochrosite	carbonate	$MnCO_3$
Smithsonite	carbonate	$ZnCO_3$
Hematite	oxide	α-Fe_2O_3
Goethite	oxide-hydroxide	α-$FeO(OH)$
Ferrihydrite	hydroxide	$Fe(OH)_3 \cdot 3H_2O$
Jarosite NA	hydroxide-sulfate	$NaFe_3(OH)_6(SO_4)_2 \cdot 6H_2O$
Langite	hydroxide-sulfate	$Cu_4(OH)_6SO_4 \cdot 7H_2O$
Anhydrite	sulfate	$CaSO_4$
Gypsum	sulfate	$CaSO_4 \cdot 2H_2O$
Anglesite	sulfate	$PbSO_4$
Quartz	crystalline silica	SiO_2

SiO2, (A, GL) amorphous silica SiO_2

4.0 Results and Evaluation:

The data from this study suggest that there are two different geochemical regimes in the OU6 study area. Evans Gulch and South Evans Gulch represent similar calcium-bicarbonate waters with neutral pH, approximately 1 meq/L (61 mg/L) bicarbonate buffering capacity, and generally low trace element concentrations. These two drainages are actually connected and are indicative of carbonate mineral-influenced chemistry. Lincoln Gulch and Stray Horse Gulch, on the other hand, are low pH, high sulfate, and elevated trace element concentration waters indicative of pyrite mineral oxidation processes associated with mine tailings. A significant observation for all OU6 basins is the consistent presence of elevated concentrations of Zinc in runoff samples, which is related to the observed wide distribution of zinc-containing minerals in the overall watershed and the high solubility of zinc.

do I not understand why "tailings" is used instead of "waste rock"?

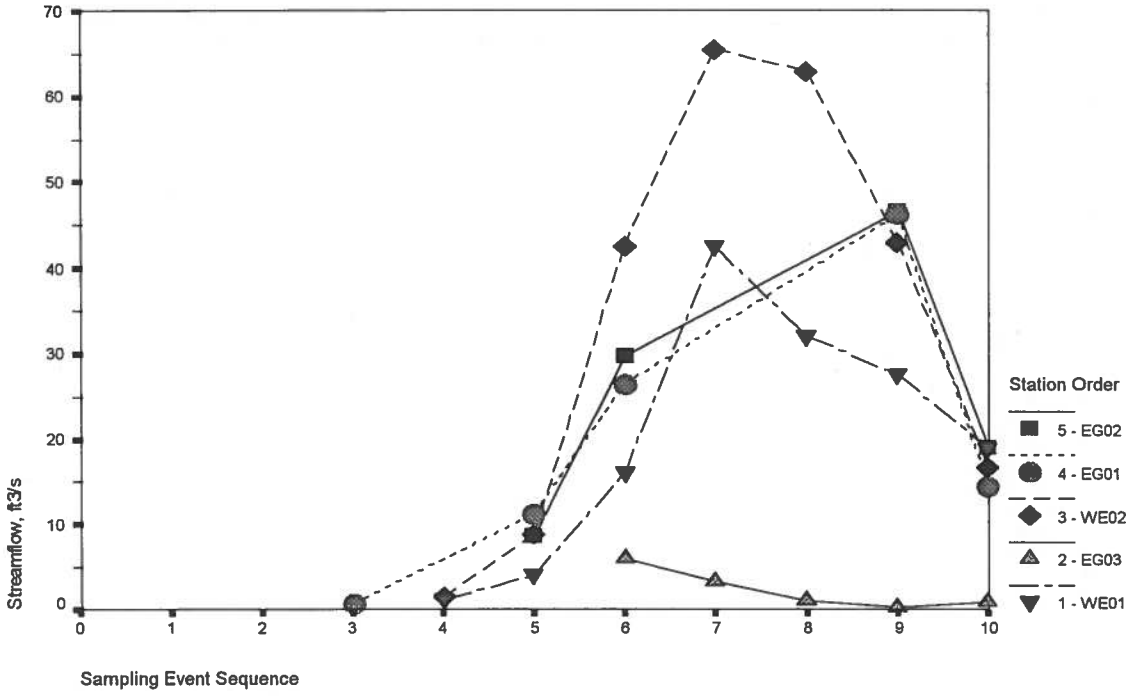
Runoff volumes during this study are different in each drainage basin, primarily related to the available drainage area, local snow accumulation, and elevation gradients; however, almost all stations showed a flow maximum on or about June 20 (Sampling Event No. 7). The highest runoff flows occured in Evans Gulch, up to 60-70 ft^3/s around the runoff maximum, and 40-50 ft^3/s as late as July 11. South Evans Gulch runoff flows were 20-30 ft^3/s at maximum, while acidic and contaminated Stray Horse Gulch and Lincoln Gulch exhibited runoff maximums of 3-4 ft^3/s, an order of magnitude less than the relatively clean Evans Gulch basin. Hydrographs of the flow measurements at each basin are plotted by Sample Event No. on

— where's the rest of this page? → "figures 3 to 5."?

I thought Lincoln G. had a peak flow at ~20 cfs not 3-4 cfs

California Gulch 1995 Streamflow

Evans Gulch Stations



figures 3 to 5. .FIG. 3

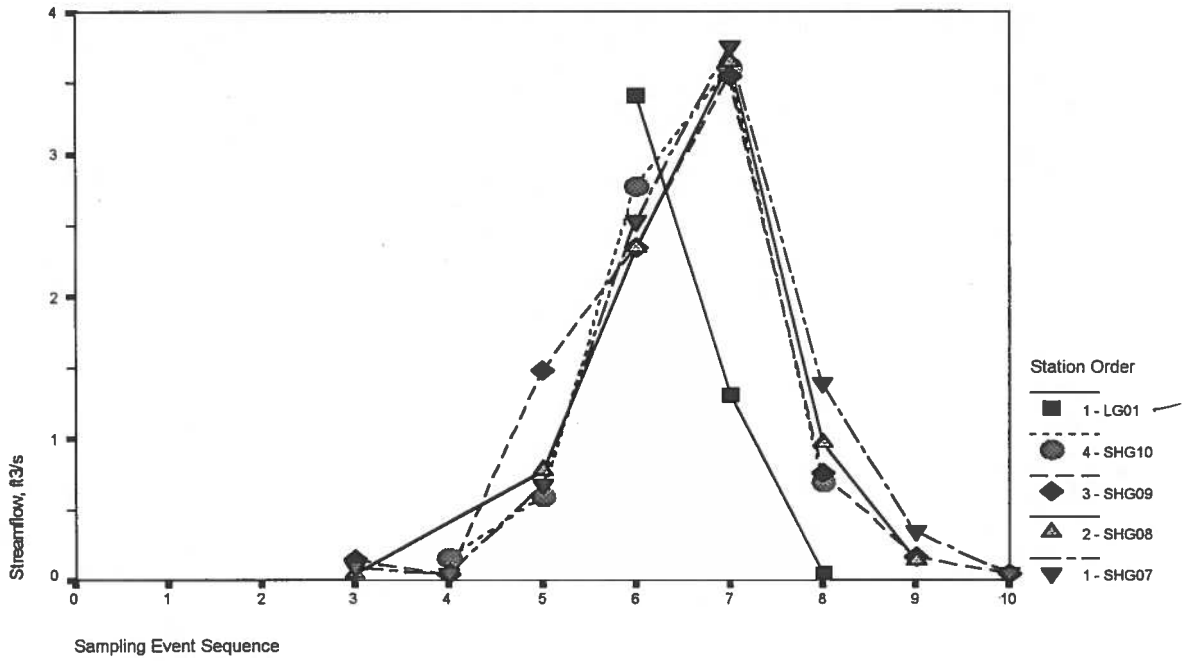
looks like this line from pg. 23 ended up here.

Fig ??

fIG. 4

California Gulch 1995 Streamflow

Stray Horse and Lincoln Gulch Stations



See my question on LG-01 flows on pg. 48

California Gulch 1995 Streamflow

South Evans Gulch Stations

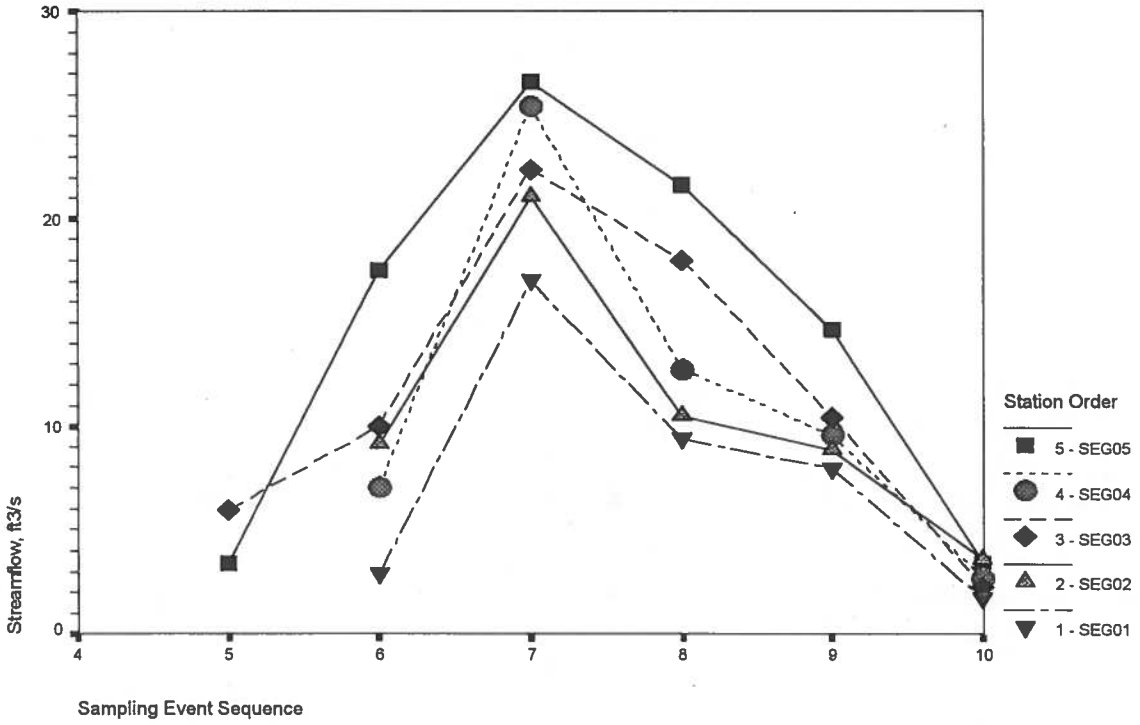


Fig. 5

FIG. 5

Anything on this page?
- Fig. 6 ?? - there is one
in the first edition you gave me.

on Fig 6, title at top says
"All DM @ SHG-09" -
spell out "Dissolved Metals"
instead of "DM" ??

Where is this?

At each station in every basin, there was a response to the runoff flow maximum that is seen as a reduction in all measured chemical concentrations, probably due to dilution and the rapid turbulent flow. This relationship is shown on fig.6. However, no clear overall statistical relation between concentration and flow was observed. Variability even within a single basin makes simple correlations between flow and concentration difficult to observe. In lower Stray Horse Gulch the highest concentrations of dissolved and total metals were seen at the start of the runoff and towards the end of runoff, probably due to flushing of metals and highly acidic soils in the channel as the flow began and the redeposition of suspended metals towards the end of the flow.

The trace element data can be treated as two distinct groups: the ***suspended elements***, Iron, Aluminum, and Manganese, which are primarily associated with suspended sediments in the water samples; and the ***toxic elements***, Zinc, Copper, Lead, Arsenic, Cadmium, and Silver. The suspended elements tended to be much higher in concentration relative to the toxic elements and to have a generally lower percentage of concentration in the dissolved fraction. Zinc is usually thought of as an essential trace element; however, it is a nuisance contaminant in drinking waters above 5 mg/L (as seen in Stray Horse and Lincoln Gulch median concentrations), and is potentially toxic to aquatic life at Colorado state water quality regulation levels of 90-100 µg/L (exceeded by Evans Gulch median zinc concentrations). Because zinc concentrations in OU6 waters were often observed above regulated concentrations, zinc is called a toxic element in this report.

The toxic elements were generally much lower in concentration; and, except for Lead, they showed higher proportions of concentration in the dissolved fraction. The trace metal concentrations, pH, and flow data from Sampling Events No. 3, 7, and 10 were plotted on a series of map pairs using the GIS database to show these relationships from the start of the runoff cycle, at its peak, and at the end. The sample data are shown for all collections sites in OU6 on Figures 7 through 14. Sample data values were rounded to the nearest whole number for display purposes. The GIS data maps are differentiated by Toxic and NonToxic, Total and Dissolved trace metal fractions. Zinc values were plotted as a Non-Toxic trace metal on these maps for display purposes and it occurs in roughly equal portions in the total and dissolved samples.

Silver(Ag) was not included in the GIS plots of the data because of its low values, at or below detection limits, in most samples . Locations of the drainages and mine waste and waste rock piles in OU6 are shown on these maps in order to indicate possible source locations between sampling stations on each drainage.

4.1 Summary of Sampling Data and MINEQA2 Analyses by Basin:

next sentence

The following sections compare each basin's trace element data using median values to summarize statistically the changes in concentrations, MINTEQA2 analyses differentiate what form the metals are in and a comparison is made to water quality standards applicable to the OU6 watershed.

Summary results will be presented for each of the four OU6 basins investigated during this study. In order to minimize confusion, tables and figures are numbered according to the applicable paragraph section number. The following data topics will be described in section 4 using the following format:

4.X Drainage basin physical summary and general comments.

- 4.X.1 Snowmelt runoff flow summary and maximum flow table.
- 4.X.2 Major ions chemistry summary table summary of median major cation and anion concentrations and pertinent comments.
- 4.X.3 Dissolved and total trace elements summary table and comments.
- 4.X.4 Water quality standards summary of potential violations by element.
- 4.X.5 MINTEQA2 model speciation summary on median data from each station with table.
- 4X.6 MINTEQA2 mineral saturation index summary table and comments.
- 4.X.7 Flow-weighted Trace Element Loading summary table and comments.
- 4.X.8 Trace Elements in stream bed sediments summary table and comments.

pg. 37 says "Flow-weighted metal" loading - this term needs to be defined somewhere!

4.1.1 ? ***Comparison to Water Quality Standards:***

The following table lists the primary and secondary maximum concentration limits (MCL's) defined under the federal Safe Drinking Water Act (SWDA) - amended 1986, (National Primary Drinking Water Standards - 40 CFR 141, and the National Secondary Drinking Water Standards - 40 CFR 143); and the table value standards (TVS) implemented by the State of Colorado, Department of Health, Water Quality Control Commission, for Evans Gulch, Upper Arkansas River Basin, Stream Segment 7. Colorado TVS values were calculated from Evans Gulch hardness data using the lower 95% confidence interval of 84 mg/L as $CaCO_3$, determined from a statistical analysis of available Evans Gulch calcium and magnesium data.

Table 4.1: Water quality standards applicable to OU6 samples. All values in µg/L unless noted. MCL = maximum concentration level, TVS = table value standard, na = not applicable.

Analyte	SWDA Primary MCL	SWDA Secondary MCL	Colorado TVS Acute	Chronic
Aluminum	none	50-200	none	none
Arsenic	50	none	50	none
Cadmium	5	none	3.22	0.989
Copper	1,300	1,000	15.0	10.2
Iron	none	300	none	300 dissolved 1000 total ??
Lead	15	none	72.3	3.04
Manganese	none	50	none	50 dissolved
Silver	none	100	1.51	na
Zinc	none	5,000	101	91.4
Sulfate	none	250 mg/L	250 mg/L	na
Chloride	none	250 mg/L	250 mg/L	na
pH	none	6.5 - 8.5	6.5 - 9.0	na
TDS	none	500 mg/L	none	none

4.2 *EVANS GULCH (EG):*

This drainage flows east to west along the south side of a lateral moraine that divides Evans Gulch from the Little Evans Creek drainage. EG is the longest continuous drainage in OU6, with EG sampling stations covering a distance of 5.9 km (3.6 mi.). Station elevations range from 3,400 m (11,050 ft.) at EG03, to 3,100 m (10,100 ft.) at EG02, producing an elevation change of 290 m (950 ft) between top and bottom stations. The EG03 sub-basin collects drainage from elevations as high as 3,540 m (11,600 ft.) while the main stem drainage extends laterally well beyond the WE01 station to elevations > 3,500 m (11,400 ft.). The elevation gradient from WE01 to EG02 is 49 m/km, the lowest gradient observed for OU6 in this study. what's the max.?

why in metric?

see english unit vs. metric questions on pg. 39

4.2.1 **Runoff Flow:** EG stations exhibited the highest runoff stream flow volumes in OU6, up to 65.5 ft^3/s during peak observed flows on 06-19-95. EG03 showed more aqueous metals than the main stem stations, but flows were low (5-6 ft^3/s) due to limited drainage sub-basin area, local snow depth, and melting rate during this study. No flow was observed at

EG01 and EG02 during the first 3 sampling events, as the creek was dry due to diversion and storage of water into Big Evans Reservoir by the Parkville Water District.

Table 4.2.1: Maximum stream flows observed at Evans Gulch sampling stations during the 1995 OU6 runoff event

Station	Maximum Flow, ft^3/s	Date Observed
WE01	42.5	06-19-95
EG03	5.99	06-14-95
WE02	65.5	06-19-95
EG01	46.3*	07-10-95
EG02	46.6*	07-11-95

* = flow not measured during 06-19 to 06-27 flow maximum. for safety reasons ??

4.2.2 **Major Ions Chemistry:** The principal EG runoff water cations were calcium and magnesium, and the principal anion was bicarbonate. The exception was station EG03, which showed elevated sulfate, calcium, and magnesium relative to the other EG stations, suggestive of pyrite oxidation processes and contact with tailings and mine waste. Median sodium, potassium, and chloride concentrations were less than 0.1 meq/L (Na less than 2.3 mg/L, K less than 3.9 mg/L, Cl less than 2.5 mg/L) at all stations. The pH of EG water was near neutral during runoff and contained acid-neutralizing capacity in the form of bicarbonate at median concentrations around 1.2 meq/L (70-80 mg/L). EG showed generally good water quality; however, it does collect trace element-contaminated effluent from the EG03 sub-basin and Lincoln Gulch.

they are due to Rec. Tailing imp.

Interestingly, station WE02, directly downstream from LG01 did not show a strong major ions or pH response to Lincoln Gulch inflows around the runoff maximum. WE02 has elevated ions relative to WE01, EG01, and EG02, but still lower than EG03, the sub-basin in EG most affected by mining activities. These results suggest that the much higher runoff flows observed in the main stem of Evans Gulch exerts a dominating dilution influence compared to the smaller influent side stream basins of EG03 and LG01. All stations showed a dilution response to observed high runoff flow with lower ions concentrations on or about the 06-19-95 sampling event.

I would say the LG sub basin was more affected by mining activities than EG03 was.

Table 4.2.2: Median major ions concentrations, in mg/L, for Evans Gulch sampling stations: (from u/s to d/s)

Analyte	WE01	EG03	WE02	EG01	EG02
Field pH	7.47	7.45	7.64	7.89	7.65
Calcium	13.1	40.2	16.8	15.9	15.9
Magnesium	5.97	20.8	8.99	7.43	7.42
Sodium	0.410	0.900	0.450	0.460	0.494
Potassium	< 1	< 1	< 1	< 1	< 1
Sulfate	12.9	127	21.1	15.5	14.4
Chloride	1.34	1.09	< 1	1.62	1.29
Bicarbonate	71.1	75.0	74.7	71.4	66.3

4.2.3 **Dissolved and total trace elements:** Refer to Figures 7 through 13 for plots of trace elements vs. sampling date for each EG station. Table 4.2.3 summarizes median total and dissolved trace element concentrations from samples collected during the 1995 runoff episode. Median total and dissolved trace element concentrations are repeated in Table 4.2.5 which summarizes MINTEQA2 speciation data for median EG station data. Trace element concentrations in EG were low relative to mine tailings influenced basins, and the concentrations appear to have fluctuated in a more complex manner compared to the major ions. In general, all trace elements showed a maximum concentration peak around the runoff flow maximum, with a subsequent concentration minima and then a suggested increase as flows subsided.

or waste rock ??

confusing – max. concentration peak at flow max. does not agree with statement at top of pg. 27 that "response to the runoff flow maximum that is seen as a reduction in all measured chemical concentrations" – which one do you agree with ??? (I thought concentration decreases with higher flows in EG)

what's really the story here?

Upper EG stations showed very low concentrations of lead and copper, and no median dissolved concentration of these elements was seen until station WE02. There was no detectable silver in any EG station; however, readily measurable concentrations of zinc, arsenic, and cadmium were found at all stations. All elements showed a general increase in concentration as station elevation decreases, probably caused by interaction with a greater watershed area. The apparently abrupt concentration increases seen in the lower EG01 and EG02 stations were probably due to the physical distance downstream of these stations from WE02.

how effects conc.??

or inflow from sub-basins with greater mining activity like SEG and LG ??

or some other source of contamination may exist in lower EG ??

Table 4.2.3: Median total (method 3015A digestion), dissolved, and free ion (where applicable) trace element concentrations, in µg/L, for Evans Gulch sampling stations (ND = not detected, NC = not calculated, NU = not used):

Analyte		WE01	EG03	WE02	EG01	EG02
Iron, Fe						
	Total	332	36.4	182	503	497
	Dissolved	38.5	<20	24.1	<20	106
Aluminum, Al						
	Total	195	46.3	165	298	250
	Dissolved	<30	<30	<30	<30	<30
Manganese, Mn						
	Total	25.0	8.47	41.3	95.8	61.5
	Dissolved	22.5	<5	35.1	4.67	16.2
Silicon, Si						
	Dissolved	1,720	2,010	1,690	1,570	1,630
Zinc, Zn						
	Total	70.6	289	232	469	474
	Dissolved	103	262	238	301	262
Copper, Cu						
	Total	ND	3.86	8.95	21.9	27.9
	Dissolved	<5	<5	<5	7.53	13.4
Lead, Pb						
	Total	2.74	2.74	8.42	25.1	27.6
	Dissolved	<1.4	<1.4	<1.4	1.70	3.44
Arsenic, As						
	Total	1.29	3.34	1.44	3.03	3.25
	Dissolved	<1	1.21	1.12	1.08	1.25
Cadmium, Cd						
	Total	0.275	0.820	1.27	1.95	1.36
	Dissolved	0.130	0.745	1.23	1.77	1.64
Silver, Ag						
	Total	<0.500	<0.500	<0.500	<0.500	<0.500
	Dissolved	<0.500	<0.500	<0.500	<0.500	<0.500

4.2.4 **Water Quality Standards:** Despite lower trace element concentrations, neutral pH, and bicarbonate buffering capacity observed in EG, the following water quality standard exceedances apply to calculated median concentrations. If median concentrations for a given analyte exceed water quality standards, it is safe to assume that half the individual sample concentrations will also exceed standards:

Iron: Median total Fe > Federal secondary MCL 300 µg/L at stations WE01, EG01, EG02 (Colorado TVS OK).

Aluminum: Median total Al > Federal secondary MCL 200 µg/L at all stations but EG03.

Manganese: Median total Mn > Federal secondary MCL 50 µg/L, at stations EG01 and EG02.

Zinc: Median dissolved Zn > Colorado TVS chronic 91.4 and acute 101 µg/L at all stations.

Copper: Median dissolved Cu > Colorado TVS chronic 10.2 µg/L at stations EG02, but less than acute TVS.

Lead: Median dissolved Pb > Colorado TVS chronic 3.04 µg/L at station EG02. Median total Pb > Federal primary MCL 15 µg/L at stations EG01 and EG02.

Cadmium: Median dissolved Cd > Colorado chronic TVS 0.989 µg/L at stations EG01 and EG02.

4.2.5 **MINTEQ speciation summary:** MINTEQA2 analysis results from median data sets for each EG sampling station are summarized in Table 4.2.5. Under each station heading are listed the measured total and dissolved trace element concentrations, followed by the calculated solid phase concentration (total - dissolved), and then the MINTEQA2 calculated species concentrations. "Solid phase" refers to the fraction that is bound to suspended sediment particles in the water column.

All concentrations are expressed in µg/L as the element. For example, all iron species are expressed as µg/L as Fe, rather than µg/L as $Fe(OH)_2^+$. To the immediate right of the concentration data is a summary of percentages for each species calculated based on the measured total concentration. Where total concentrations were below the detection limit (LOD), the element speciation calculations were omitted and are noted by the NC (not calculated) designator. In the case where dissolved concentrations are non detects, the solid phase was calculated as (total - LOD), and noted as "greater than" this difference. This difference was used to calculate a "greater than" percent as solid phase.

MINTEQA2 results suggest the following conclusions regarding the chemistry of EG waters:

Suspended elements (iron, aluminum, and manganese): Iron and aluminum were primarily associated with the solid phase at all stations except for EG03 where lower total concentrations relative to other EG stations made assessment of speciation difficult. Aluminum was almost entirely associated with the solid phase, suggestive of the aluminosilicate (probably feldspars and clays) character of the suspended material in EG. Manganese, on the other hand, appeared to be dominated by the free ion with minor amounts of the sulfate species; however, the solid phase dominates at the lower elevation stations. With EG station iron, there were only minor concentrations of free ion, and hydroxide complexes were the dominant dissolved species. These results were consistent with expected behavior for neutral pH waters containing bicarbonate.

Toxic Elements (zinc, copper, lead, arsenic, cadmium, and silver): MINTEQA2 results suggest the following regarding toxic element speciation:

> ***ZINC*** results suggest that the free ion was the major species with an apparent increase in solid phase (from 9 to 45 percent) towards lower elevation EG stations. Zn^{2+} appeared to be > 200 µg/L at all stations except WE01.

Table 4.2.5: MINTEQA2 calculated speciation distributions for Evans Gulch median concentration data sets. NC = not calculated; NU = not used (usually because dissolved > total).

	WE01		EG03		WE02		EG01		EG02	
	µg/L	% total	µg/L	% total	µg/L	% total	µg/L	% total	µg/L	% total
IRON, Fe										
Total	332		36.4		182		503		497	
Dissolved	38.5		<20		24.1		<20		106	
Solid Phase	294	88.4	>16.4	>45.1	158	86.8	>483	>96.0	391	78.7
Fe(OH)2 +	26.8	8.08	NC	NC	16.8	9.24	NC	NC	74.0	14.9
Fe(OH)3 aq	8.93	2.69	NC	NC	5.54	3.05	NC	NC	24.5	4.93
Fe(OH)4 -	2.73	0.820	NC	NC	1.71	0.940	NC	NC	7.53	1.51
Free Ion, Fe3+	0	0	NC	NC	0	0	NC	NC	0	0
ALUMINUM, Al										
Total	195		46.3		165		298		250	
Dissolved	<30		<30		<30		<30		<30	
Solid Phase	>165	>84.6	>16.3	>35.2	>135	>81.8	>268	>89.9	>220	>88.0
MANGANESE, Mn										
Total	25.0		8.47		41.3		95.8		61.5	
Dissolved	22.5		<5		35.1		4.67		16.2	
Solid Phase	2.50	10.0	>3.47	>41.0	6.20	15.0	91.1	95.1	45.3	73.7
Free Ion, Mn2+	22.2	88.7	NC	NC	34.4	83.2	4.59	4.79	15.9	25.9
MnSO4 aq	0.270	1.08	NC	NC	0.630	1.53	0.0700	0.0700	0.230	0.370
SILICON, Si										
Dissolved	1,720		2,010		1,690		1,570		1,630	
H4SiO4	1,718		2,008		1,688		1,568		1,628	
ZINC, Zn										
Total	70.6		289		232		469		474	
Dissolved	103		262		238		301		262	
Solid Phase	NC	NC	27.0	9.34	0	0	168	35.8	212	44.7
Free Ion, Zn2+	NC	NC	225	77.9	222	93.4	282	60.1	246	51.8
ZnCO3 aq	NC	NC	4.19	1.45	4.52	1.90	6.02	1.28	5.24	1.11
ZnSO4 aq	NC	NC	27.5	9.52	5.95	2.50	6.02	1.28	4.72	0.990
COPPER, Cu										
Total	<5		<5		8.95		21.9		27.9	
Dissolved	<5		<5		<5		7.53		13.4	
Solid Phase	NC	NC	NC	NC	>3.95	>44.1	14.4	65.6	14.5	52.0
Cu(OH)2 aq	NC	NC	NC	NC	NC	NC	6.69	30.6	11.9	42.7
CuCO3 aq	NC	NC	NC	NC	NC	NC	0.250	1.13	0.460	1.63
Free Ion, Cu2+	NC	NC	NC	NC	NC	NC	0.440	2.03	0.790	2.83
CuOH -	NC	NC	NC	NC	NC	NC	0.110	0.520	0.200	0.720
LEAD, Pb										
Total	2.74		2.74		8.42		25.1		27.6	
Dissolved	<1.4		<1.4		<1.4		1.70		3.44	
Solid Phase	>1.3	>47.4	>1.3	>47.4	>7.02	>83.3	23.4	93.2	24.2	87.7
PbCO3 aq	NC	NC	NC	NC	NC	NC	0.900	3.59	1.83	6.63
Free Ion, Pb2+	NC	NC	NC	NC	NC	NC	0.490	1.95	0.990	3.59
PbOH +	NC	NC	NC	NC	NC	NC	0.250	0.996	0.500	1.81
PbHCO3 +	NC	NC	NC	NC	NC	NC	0.0300	0.120	0.0600	0.217
PbSO4 aq	NC	NC	NC	NC	NC	NC	0.0300	0.120	0.0600	0.217
ARSENIC, As										
Total	1.29		3.34		1.44		3.03		3.25	
Dissolved	<1		1.21		1.12		1.08		1.25	
Solid Phase	>0.290	>22.5	2.13	63.8	0.320	22.2	1.95	64.4	2.00	61.5

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HAsO4 2-	NC	NC	1.04	31.0	0.940	65.6	0.910	30.1	1.06	32.5
H2AsO4 -	NC	NC	0.170	5.22	0.180	12.2	0.170	5.56	0.190	5.96
CADMIUM, Cd										
Total	0.275		0.820		1.27		1.95		1.36	
Dissolved	0.130		0.745		1.23		1.77		1.64	
Solid Phase	0.150	52.7	0.0800	9.15	0.0400	3.15	0.180	9.23	NC	NC
Free Ion, Cd2+	0.120	44.5	0.630	76.2	1.15	90.5	1.66	85.1	NC	NC
CdCO3 aq	0	1.18	0.0100	1.73	0.0300	2.32	0.0400	2.27	NC	NC
CdSO4 aq	0	0.990	0.100	11.8	0.0400	3.10	0.0400	2.27	NC	NC
SILVER, Ag										
Total	<0.500		<0.500		<0.500		<0.500		<0.500	
Dissolved	<0.500		<0.500		<0.500		<0.500		<0.500	
Solid Phase	NC		NC		NC		NC		NC	

COPPER, which was below detection above station EG01 for dissolved samples, appeared to be dominated by the uncharged di-hydroxy complex, with 45-65 percent associated with the solid phase. Free ion, Cu^{2+}, was present only in minor amounts.

LEAD: Dissolved Pb was below detection until station EG01. At the lower elevation EG stations, greater than 85 percent appeared to be associated with the solid phase, with the carbonate complex as the primary dissolved species. The free ion, Pb^{2+}, was estimated to be below the measurement detection limit at both EG01 and EG02.

ARSENIC was present in most EG waters as the arsenate anion and appeared to favor the solid phase (up to 65 percent). The primary solution species, consistent with the neutral pH of EG waters, was the mono-hydrogen $HAsO_4^{2-}$ species.

CADMIUM species were dominated by the free ion, with generally low solid phase association (except for WE01), and minor amounts of carbonate and sulfate species. The dominance of the free Cd^{2+} ion is significant with respect to aquatic toxicity.

4.2.6 **MINTEQ mineral saturation indices:** Saturation indices (SI's) suggest that EG waters were generally undersaturated with respect to carbonate and sulfate minerals, oversaturated with respect to oxides and oxide-hydroxides, undersaturated with respect to hydroxide-sulfates and sulfates, and probably near equilibrium with crystalline silica minerals, but undersaturated for amorphous

silica. The lower elevation stations appeared to be near equilibrium with quartz. These results are consistent with the overall neutral pH and Ca-Mg-bicarbonate chemistry of EG waters.

	Mineral Saturation Indices, log(AP/KT)				
Mineral	WE01	EG03	WE02	EG01	EG02
Calcite	-2.07	-1.68	-1.98	-1.99	-1.98
Dolomite	-4.53	-3.65	-4.28	-4.29	-4.25
Rhodochrosite	-3.08	NC	-2.90	-3.75	-3.19
Smithsonite	-3.05	-2.72	-2.70	-2.55	-2.59
Hematite	+15.9	NC	+15.4	NC	+17.1
Goethite	+5.48	NC	+5.27	NC	+6.10
Ferrihydrite	+1.91	NC	+1.71	NC	+2.35
Jarosite NA	-5.57	NC	-5.78	NC	-3.65
Langite	NC	NC	NC	-10.8	-9.62
Anhydrite	-3.11	-1.81	-2.83	-2.94	-2.96
Gypsum	-2.68	-1.39	-2.39	-2.53	-2.57
Anglesite	NC	NC	NC	-4.72	-4.45
Quartz	+0.147	+0.182	+0.143	+0.056	+0.046
SiO2, (A, GL)	-0.942	-0.898	-0.947	-1.02	-1.02

see comment about this title and term on pg. 28 - needs to be defined somewhere in report

4.2.7 **Flow-weighted metal loading**: Generally, EG median flow-weighted metal loading during the 1995 runoff ranks second lowest behind SEG. Despite the elevated aqueous concentrations in mine-influenced sub-basin EG03 samples, this station showed the overall lowest flow-weighted trace element metal ?? loading in EG. Highest loading was seen at station EG02, the lowest elevation station. Even though this loading for the 1995 snowmelt runoff was relatively low compared to SHG and LG loadings, EG probably showed greater continuous loading due to higher off-season flows. Within each EG station, median loading generally reached a maximum value for most trace elements the week before maximum observed runoff flow.

by this, you mean to say the total pounds of metal sent downstream over 12 months is greater for EG because it has a more lengthy runoff flow season ?? - Revise text?

Table 4.2.7: Median flow-weighted total trace element loading, kg/wk, in waters from Evans Gulch sampling stations: — defined?

Analyte	WE01	EG03	WE02	EG01	EG02
Iron, Fe	54.0	0.861	141	124	129
Aluminum, Al	70.7	0.810	74.4	103	105
Manganese, Mn	4.80	0.114	17.6	20.8	26.2

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Zinc, Zn	39.5	5.58	148	229	140
Copper, Cu	ND	0.119	8.19	5.40	6.71
Lead, Pb	1.08	0.091	4.99	5.72	10.8
Arsenic, As	0.642	0.048	0.668	0.715	1.68
Cadmium, Cd	0.174	0.015	0.863	0.626	0.596
Silver, Ag	0.081	0.004	0.184	0.062	0.104

4.2.8 **Sediment trace elements:** Stream bed sediments represent a sink for suspended solids and many trace elements associated with the solid phase. Median stream bed sediment trace element concentrations in EG rank second among the four basins in OU6, and all EG median trace elements except Fe and Al were greater than 1.5 times median SEG sediment concentrations. Highest sediment concentrations were in EG02, although the higher elevation and mine-influenced EG03 station showed concentrations approaching EG02. Most sediment median element concentrations showed an increase with lower elevation, consistent with exposure to greater watershed area runoff and settling of suspended solids.

uncertain what you mean here — "collector"?

at

in a stretch of EG with lower stream gradients ??

Table 4.2.8: Median trace element concentrations in stream bed sediments, mg/kg, (method 3051 digestion) for Evans Gulch sampling stations:

there sure is some change going on below here

Analyte	WE01	EG03	WE02	EG01	EG02
Iron, Fe	6,220	11,300	8,260	16,200	26,100
Aluminum, Al	1540	1,680	1,550	3,610	3,930
Manganese, Mn	281	2,240	1,320	2,020	1,120
Zinc, Zn	163	2,430	1,080	1,680	6,540
Copper, Cu	8.56	46.3	67.5	58.8	212
Lead, Pb	80.8	1,080	458	655	1,070
Arsenic, As	4.03	76.3	25.3	32.1	93.0
Cadmium, Cd	0.655	13.3	6.80	7.79	4.56
Silver, Ag *	0.135	3.26	2.09	3.79	0.610

* 3051 digestion not recommended for Ag

true at its outlet (SEG 05) or at its upper end (SEG 01)?

4.3 SOUTH EVANS GULCH (SEG):

- within the OU6 boundary ?? - actual EG elev. are just as high or higher

This drainage is the highest in initial elevation, and contains the best water quality of any of the sampled drainage basins in OU6. SEG station elevations range from 3500 m to 3300 m (11,340 to 10,950 ft.), and collects runoff from elevations up to 3,500 m (11,525 ft.). The runoff course extends ~~8~~ 1,900 m (6,200 ft.) from SEG01 to SEG05, and ~~8~~ 2,600 m (8,400 ft.) from SEG05 to the basin's upper reaches; producing elevation gradients of 62 m/km in-between sampling stations, and 63 m/km for the entire basin.

8,528 ft

within the OU6 boundary ?

need to relate more correctly somehow

Why metric units?

number rounding problems here - # sign. figures
3500 m = 11,480 ft
3300 m = 10,824 ft
11,340 ft = 3,457 m
10,950 ft = 3,338 m
etc.
11,525 ft = 3,514 m
⇒ Just do it in english units - skip the metric. ?
- Client and audience are more english-unit oriented if I had to judge.

4.3.1 **Runoff Flow:** Maximum runoff stream flow in SEG was observed at 26.6 ft³/s on 6-20-95. Progressively higher flow rates were observed from top to bottom of drainage, ranging from 17.0 to 26.6 ft³/s.

Table 4.3.1: Maximum stream flows observed at South Evans Gulch sampling stations during the 1995 OU6 runoff event from top to bottom

Station	Maximum Flow, ft³/s	Date Observed
SEG01	17.0	06-20-95
SEG02	21.1	06-20-95
SEG03	22.4	06-20-95
SEG04	25.5	06-20-95
SEG05	26.6	06-20-95

4.3.2 **Major Ions Chemistry:** The pH of SEG drainage was near neutral and median major ion concentrations were similar to EG stations. These waters were dominated by calcium, magnesium, and bicarbonate ions, indicative of a carbonate mineral origin for this chemistry. There was a trend towards higher sulfate concentrations in lower elevation stations, indicating contact with some pyrite oxidation from tailings in the lower basin reaches. The higher elevation stations SEG01 and SEG02 did not show a significant dilution response to runoff; however, the lower stations did appear to respond to higher flow.

mine waste rock

Want to note here that the SEG reach from SEG 02 to 03 overlies the yak tunnel and that some infiltration of surface water appears to be occurring ??
(see event No. 10) higher flows may mask water loss

Table 4.3.2: Median major ions concentrations, in mg/L, for South Evans Gulch sampling stations:

Analyte	SEG01	SEG02	SEG03	SEG04	SEG05
Field pH	7.57	7.28	7.84	7.43	7.61
Calcium	14.9	14.8	15.5	17.8	17.0
Magnesium	7.99	7.98	7.78	9.00	8.45
Sodium	0.370	0.390	0.428	0.465	0.467
Potassium	< 1	< 1	< 1	< 1	< 1
Sulfate	3.49	3.14	6.50	15.3	15.1
Chloride	< 1	< 1	< 1	< 1	< 1
Bicarbonate	82.5	82.8	79.8	79.8	80.8

4.3.3 **Dissolved and total trace elements:** Refer to Figures 7 through 14 for plots of trace elements vs. sampling date for each SEG station. Table 4.3.3 summarizes median total and dissolved trace element concentrations from samples collected during the 1995 runoff episode. Median total and dissolved trace element concentrations are repeated in Table 4.3.5 which summarizes MINTEQA2 speciation data for median SEG station data. SEG was very similar to EG, and is physically part of the same overall drainage. In general, trace metal concentrations were the lowest in SEG.

The available data suggest that SEG02 was the "cleanest" station and that runoff from mined areas is influencing SEG03 and SEG04. Trace element concentrations seem to follow an up-down-up-up-down pattern, suggesting that the runoff interaction with the SEG watershed is complex, with generally greater mining activity influence at lower elevations. There was no detectable zinc until station SEG03, and copper and cadmium were not observed until station SEG04. Median silver was also below detection in all SEG stations.

Table 4.3.3: Median total (method 3015A digestion), dissolved, and free ion (where applicable) trace element concentrations, in µg/L, for South Evans Gulch sampling stations (ND = not detected, NC = not calculated, NU = not used):

Analyte		SEG01	SEG02	SEG03	SEG04	SEG05
Iron, Fe						
	Total	171	105	244	344	201
	Dissolved	19.6	19.9	21.9	21.4	16.5
Aluminum, Al						
	Total	242	150	258	348	192
	Dissolved	<30	<30	<30	30.7	<30
Manganese, Mn						
	Total	5.69	<5	13.7	47.1	44.1
	Dissolved	<5	<5	8.31	34.9	22.8
Silicon, Si						
	Dissolved	1,420	1,490	1,570	1,690	1,550
Zinc, Zn						
	Total	<5	<5	22.3	418	424
	Dissolved	NU	NU	25.2	362	338
Copper, Cu						
	Total	<5	<5	<5	14.0	13.5
	Dissolved	<5	<5	<5	9.50	8.25
Lead, Pb						
	Total	<1.4	<1.4	6.22	27.7	11.0
	Dissolved	<1.4	<1.4	<1.4	<1.4	<1.4
Arsenic, As						
	Total	1.74	2.30	2.28	3.02	1.91
	Dissolved	1.29	1.29	1.33	1.56	1.46
Cadmium, Cd						
	Total	<0.1	<0.1	0.135	3.11	3.18
	Dissolved	<0.1	<0.1	<0.1	2.43	2.20
Silver, Ag						
	Total	<0.500	<0.500	<0.500	<0.500	<0.500
	Dissolved	<0.500	<0.500	<0.500	<0.500	<0.500

4.3.4 **Water Quality Standards:** SEG contained the cleanest waters sampled from OU6 in this study, and exhibited fewer exceedances of water quality standards compared to EG. If median concentrations for a given analyte exceed water quality standards, it is safe to assume that half the individual sample concentrations will also exceed standards:

Iron: Median total Fe > Federal secondary MCL 300 µg/L at station SEG04 (Colorado TVS OK).

Aluminum: Median total Al > Federal secondary MCL 200 µg/L at all stations but SEG02 and SEG05

Zinc: Median dissolved Zn > Colorado TVS 91.4 and 101 µg/L at stations SEG04 and SEG05.

Lead: Median total Pb > Federal primary MCL 15 µg/L at station SEG04.

Cadmium: Median dissolved Cd > Colorado TVS chronic 0.989 µg/L at stations SEG04 and SEG05

4.3.5 **MINTEQ speciation summary:** Refer to section 4.2 above for a general explanation of the MINTEQA2 speciation data for SEG seen in Table 4.3.5. SEG chemistry and speciation was similar to EG, with the exception that SEG exhibits lower total concentrations for all elements, especially in the higher elevation SEG01 - SEG03 stations. MINTEQA2 results suggest the following observations regarding the chemistry of median SEG data:

Suspended elements (iron, aluminum, and manganese): SEG MINTEQA2 results are similar to observed EG suspended elements chemistry.

IRON showed a consistent association with the solid phase with all stations greater than 80 percent. Like EG, free ion was very low and the mono-hydroxy species was the primary aqueous specie.

ALUMINUM was also primarily associated with the solid phase at all stations with below or near detection limit median concentrations for all stations.

MANGANESE was not detected until SEG03, and showed solid phase percentages ranging from 25-50 percent in the lower three stations. The free ion appeared to have been the primary solution form with minor amounts of the sulfate complex.

Toxic Elements (zinc, copper, lead, arsenic, cadmium, and silver): MINTEQA2 results suggest the following regarding toxic element speciation in SEG:

ZINC was not detected until SEG03. Like EG stations, MINTEQA2 results suggest that the free ion was the major species with an apparent increase in solid phase towards lower elevation SEG stations. Zn^{2+} appeared to be > 300 µg/L at SEG04 and SEG05, a significantly higher concentration compared to the lower EG stations.

COPPER, which was below detection above station SEG03 for total and dissolved samples, appeared to be dominated by the uncharged di-hydroxy complex, with 30-40 percent associated with the solid phase. Free ion, Cu^{2+}, was present only in minor amounts.

LEAD: Total Pb was not observed at SEG01 and SEG02, and dissolved Pb was below detection at all SEG stations. The strong implication is that SEG lead was primarily associated with the solid phase.

ARSENIC was present in SEG waters primarily as the mono-hydrogen arsenate species, $HAsO_4^{2-}$, similar to EG median output. The solid phase ranges from 25 to 50 percent of total concentration.

Move Cadmium from pg. 45 to here?

Table 4.3.5: MINTEQA2 calculated speciation distributions for South Evans Gulch median concentration data. NC = not calculated; NU = not used (usually because dissolved > total).

	SEG01		SEG02		SEG03		SEG04		SEG05	
	µg/L	% total	µg/L	% total	µg/L	% total	µg/L	% total	µg/L	% total
IRON, Fe										
Total	171		105		244		344		201	
Dissolved	19.6		19.9		21.9		21.4		16.5	
Solid Phase	151	88.5	85.1	81.1	222	91.0	323	93.8	184	91.8
Fe(OH)2 +	13.7	7.99	13.9	13.2	15.3	6.26	14.9	4.34	11.5	5.73
Fe(OH)3 aq	4.55	2.66	4.62	4.40	5.06	2.07	4.94	1.44	3.81	1.90
Fe(OH)4 -	1.39	0.810	1.41	1.35	1.55	0.64	1.52	0.440	1.17	0.580
Free Ion, Fe3+	0	0	0	0	0	0	0	0	0	0
ALUMINUM, Al										
Total	242		150		258		348		192	
Dissolved	<30		<30		<30		30.7		<30	
Solid Phase	>212	>87.6	>120	>80.0	>228	>88.4	>317	>91.2	>162	>84.4
MANGANESE, Mn										
Total	5.69		<5		13.7		47.1		44.1	
Dissolved	<5		<5		8.31		34.9		22.8	
Solid Phase	NC		NC		5.39	39.3	12.2	25.9	21.3	48.3
Free Ion, Mn2+	NC		NC		8.24	60.2	34.3	72.9	22.4	50.9
MnSO4 aq	NC		NC		0.0700	0.490	0.490	1.04	0.300	0.670
SILICON, Si										
Dissolved	1,420		1,490		1,570		1,690		1,550	
H4SiO4	1,419		1,489		1,568		1,688		1,548	
ZINC, Zn										
Total	<5		<5		22.3		418		424	
Dissolved	NU		NU		25.2		362		338	
Solid Phase	NC		NC		0	0	56.0	13.4	86.0	20.3
Free Ion, Zn2+	NC		NC		23.9	94.9	340	81.4	318	74.9
ZnCO3 aq	NC		NC		0.500	2.00	7.24	1.73	6.76	1.59
ZnSO4 aq	NC		NC		0	0	6.52	1.56	6.08	1.43
COPPER, Cu										
Total	<5		<5		<5		14.0		13.5	
Dissolved	<5		<5		<5		9.50		8.25	
Solid Phase	NC		NC		NC		4.50	32.1	5.25	38.9
Cu(OH)2 aq	NC		NC		NC		8.45	60.3	7.34	54.4
CuCO3 aq	NC		NC		NC		0.310	2.24	0.270	2.02
Free Ion, Cu2+	NC		NC		NC		0.560	4.00	0.490	3.61
CuOH -	NC		NC		NC		0.140	1.02	0.120	0.920
LEAD, Pb										
Total	<1.4		<1.4		6.22		27.7		11.0	
Dissolved	<1.4		<1.4		<1.4		<1.4		<1.4	
Solid Phase	NC		NC		>4.82	>77.5	>26.3	>95.0	>9.60	>87.3
ARSENIC, As										
Total	1.74		2.30		2.28		3.02		1.91	

on same page

Dissolved	1.29		1.29		1.33		1.56		1.46	
Solid Phase	0.450	25.9	1.01	43.9	0.950	41.7	1.46	48.3	0.450	23.6
HAsO4 2-	1.08	62.3	1.08	47.2	1.12	49.1	1.32	43.6	1.23	64.4
H2AsO4 -	0.210	11.9	0.210	8.92	0.210	9.28	0.240	8.06	0.230	12.0
CADMIUM, Cd										
Total	<0.1		<0.1		0.14		3.11		3.18	
Dissolved	<0.1		<0.1		<0.1		2.43		2.20	
Solid Phase	NC		NC		>0.04	>25.9	0.680	21.9	0.980	30.82
Free Ion, Cd2+	NC		NC		NC	NC	2.29	73.6	2.07	65.17
CdCO3 aq	NC		NC		NC	NC	0.0600	1.95	0.0600	1.73
CdSO4 aq	NC		NC		NC	NC	0.0600	1.88	0.0500	1.59
SILVER, Ag										
Total	<0.5		0.500		<0.5		<0.5		<0.5	
Dissolved	<0.5		<0.5		<0.5		<0.5		<0.5	
Solid Phase	NC		NC		NC		NC		NC	

Move to pg. 43?

CADMIUM species were dominated by the free ion, with generally low solid phase association (20-30 percent) and minor amounts of carbonate and sulfate species.

4.3.6 **MINTEQ mineral saturation indices:** SI's for median SEG waters were generally undersaturated with respect to carbonate and simple sulfate minerals. Iron oxides and oxide-hydroxides, were clearly oversaturated. Jarosite was undersaturated at SEG01 and SEG02, but was oversaturated below these stations. SEG median water was undersaturated for cristobalite and amorphous silica. Except for quartz, SEG waters do not appear to be in equilibrium (near-0 SI's) with any of the table minerals. These results are consistent with the overall neutral pH and Ca-Mg-bicarbonate chemistry of SEG waters.

We know where it comes from too!

Why in a different order than for FG?

	Mineral Saturation Indices, log(AP/KT)				
Mineral	SEG01	SEG02	SEG03	SEG04	SEG05
Calcite	-2.02	-2.02	-2.00	-1.95	-1.97
Dolomite	-4.39	-4.36	-4.34	-4.22	-4.29
Rhodochrosite	NC	NC	-3.51	-2.89	-3.08
Smithsonite	NC	NC	-3.66	-2.51	-2.55
Ferrihydrite	+1.62	+1.63	+1.67	+1.66	+1.54
Hematite	+15.1	+15.2	+15.4	+15.4	+15.1
Goethite	+5.11	+5.16	+5.23	+5.26	+5.10
Jarosite NA	-7.84	-7.77	+6.90	+6.10	-6.54
Langite	NC	NC	NC	-10.6	-11.0
Anhydrite	-3.65	-3.69	-3.35	-2.93	-2.96

not the same sort of change at 2→3 we see for Jarosite but same sort of numbers we have in FG

Gypsum	-3.19	-3.24	-2.91	-2.50	-2.52
Anglesite	NC	NC	NC	NC	NC
Quartz	+0.098	+0.097	+0.107	+0.125	+0.105
SiO2, (A, GL)	-1.00	-0.996	-0.982	-0.960	-0.986

4.3.7 **Flow-weighted metal loading:** Median SEG flow-weighted metal loading during the 1995 snowmelt runoff was the lowest in OU6, due to lower aqueous trace element concentrations and flow relative to EG. The Table 4.3.7 data suggest that the loading increases significantly at SEG03 where mine-influenced runoff from Breece Hill increases. The upper two SEG stations were clearly different loading sources compared to downstream SEG stations and appear to be the lowest observed in OU6 during this study. As seen with EG loading, median metal loading generally reaches a maximum value for most trace elements the week before maximum observed runoff flow for each SEG station.

Table 4.3.7: Median flow-weighted total trace element loading, kg/wk, in waters from South Evans Gulch sampling stations (ND = element not detected in sample):

Analyte	SEG01	SEG02	SEG03	SEG04	SEG05
Iron, Fe	13.5	18.9	50.3	78.5	40.1
Aluminum, Al	23.5	27.0	50.2	90.8	51.0
Manganese, Mn	0.284	ND	3.79	5.95	8.83
Zinc, Zn	ND	ND	6.55	52.1	88.4
Copper, Cu	ND	ND	ND	1.96	3.08
Lead, Pb	ND	ND	1.34	3.75	1.88
Arsenic, As	0.146	0.181	0.364	0.448	0.260
Cadmium, Cd	<0.0100	<0.0100	0.047	0.361	0.558
Silver, Ag	ND	ND	ND	ND	ND

4.3.8 **Sediment trace elements:** SEG median stream bed sediment concentrations were the lowest in OU6. As seen with the metal loading data, there were clear sediment concentration increases with decreasing elevation stations, and the toxic metals showed a abrupt concentration jump (around 3-10 times greater compared to SEG03) beginning at SEG04. These results are consistent with known increasing mining activity and runoff below SEG03.

(metal loading sees the concentration jump below SEG 02 rather than SEG03)

Table 4.3.8: Median trace element concentrations in stream bed sediments, mg/kg, (method 3051 digestion) for South Evans Gulch sampling stations (<## = not detected at listed detection limit):

Analyte	SEG01	SEG02	SEG03	SEG04	SEG05
Iron, Fe	8,050	8,680	8,200	8,550	12,455
Aluminum, Al	2,530	2,750	2,590	1,535	3,730
Manganese, Mn	276	484	142	597	941
Zinc, Zn	42.8	162	207	876	1,960
Copper, Cu	4.41	7.45	5.07	52.1	74.4
Lead, Pb	41.2	228	147	848	725
Arsenic, As	9.22	18.6	10.9	50.3	27.2
Cadmium, Cd	0.300	0.875	1.45	6.80	9.57
Silver, Ag	<0.05	1.18	0.300	2.77	1.17

* 3051 digestion not recommended for Ag

4.4 *LINCOLN GULCH (LG):*

English and metric?

(from the top of Breece Hill to Evans Gulch)

Lincoln Gulch, a drainage path ~~X~~ 2,000 m (6,600 ft.) in length, contains contaminated drainage from several tailings areas and includes runoff originating from elevations as high as 3,600 m (11,675 ft.). This change produces an elevation gradient of 130 m/km, one of the steepest in OU6. Lincoln Gulch was sampled at only one location, station LG01. (just above its confluence with Evans Gulch)

mine waste rock

4.4.1 **Stream flow summary:** Lincoln Gulch exhibits relatively low flows for a very short period of time during the runoff. By the 6-27-95 sampling event, flow was below 0.1 ft^3/s. These data suggest that LG is not a large runoff volume source during snowmelt. Storm events, however, may play a role in contamination loading into Evans Gulch.

We may have start it too late

My old spreadsheet data show a LG01 sampling on 6/14/95 with a flow of 19.56 cfs and I have 6/19/95 with a flow of 1.06 cfs - did we somewhere change the data ????

Table 4.4.1: Maximum stream flows observed during the 1995 OU6 runoff event

Station	Maximum Flow, ft^3/s	Date Observed
LG01	3.41	06-14-95

4.4.2 **Major ions chemistry:** Only three samples were collected around the runoff maximum flow; however, it is clear from the available data that LG is an acidic water dominated by sulfate ion. pH never was higher than 5.1, and there was no detectable bicarbonate. This is suggestive of pyrite oxidation products and is consistent with the known source tailings areas in this basin. Elevated trace element data confirm what would be expected from water with such a low pH and lack of buffering. LG major ions do not, however, show a clear dilution response to flow.

a very acidic ??

mine waste rock

Table 4.4.2: Median major ions concentrations, in mg/L, for Lincoln Gulch sampling station~~s~~:

Analyte	LG01
Field pH	3.28
Calcium	49.2
Magnesium	39.4
Sodium	0.720
Potassium	1.54
Sulfate	662
Chloride	2.14
Bicarbonate	< 1

4.4.3 **Dissolved and total trace elements:** Refer to Figures 7 through 14 for plots of trace elements vs. sampling date for station LG01. Table 4.4.3 summarizes median total and dissolved trace element concentrations from samples collected during the 1995 runoff episode. Median total and dissolved trace element

concentrations are repeated in Table 4.4.5 which summarizes MINTEQA2 speciation data for median LG01 station data.

Table 4.4.3: Median total (method 3015A digestion), dissolved, and free ion (where applicable) trace element concentrations, in µg/L, for Lincoln Gulch.

Analyte		LG01
Iron, Fe		
	Total	185,000
	Dissolved	80,300
Aluminum, Al		
	Total	30,900
	Dissolved	10,000
Manganese, Mn		
	Total	17,600
	Dissolved	14,100
Silicon, Si		
	Dissolved	4,720
Zinc, Zn		
	Total	59,400
	Dissolved	53,700
Copper, Cu		
	Total	11,300
	Dissolved	8,440
Lead, Pb		
	Total	3,910
	Dissolved	381
Arsenic, As		
	Total	164
	Dissolved	9.81
Cadmium, Cd		
	Total	351
	Dissolved	298
Silver, Ag		
	Total	30.2
	Dissolved	0.750

4.4.4 **Water Quality Standards:** Lincoln Gulch (as well as Stray Horse Gulch) samples have regulated analyte concentrations significantly higher than both Federal and Colorado state standards. The following observations apply:

pH: Median pH < 6.5 Federal secondary MCL and Colorado TVS 6.5.

Sulfate: Median sulfate > 250 Federal secondary MCL and Colorado TVS.

Iron: Median total and dissolved Fe >> Federal secondary MCL 300 µg/L, and Colorado TVS chronic 1000 µg/L total TVS. Median dissolved Fe >> Colorado TVS chronic dissolved and federal secondary MCL 300 µg/L standards.

Aluminum: Median dissolved Al >> Federal secondary MCL 200 µg/L.

Manganese: Median total and dissolved Mn >> Federal secondary MCL 50 µg/L. Median dissolved Mn >> Colorado TVS chronic 50 µg/L dissolved standard.

Zinc: Median dissolved Zn and free ion >> Colorado TVS chronic 91.4 and acute 101 µg/L. Median dissolved and free ion Zn >> Federal secondary MCL 5000 µg/L.

Copper: Median dissolved and free ion Cu > Colorado TVS chronic 10.2 and acute 15 µg/L. Median dissolved and free ion Cu > federal primary MCL 1300 and Federal secondary MCL 1000 µg/L.

Lead: Median dissolved and free ion Pb > Colorado TVS chronic 3.04 and acute 72.3 µg/L standards. Median dissolved and free ion Pb > Federal primary MCL 15 µg/L.

Arsenic: Median total As > Federal primary MCL 50 µg/L, and Colorado TVS acute 50 µg/L.

Cadmium: Median dissolved and free ion Cd > Colorado TVS chronic 0.989 and acute 3.22 µg/L. Median dissolved and free ion Cd > Federal primary MCL 5 µg/L.

4.4.5 **MINTEQ speciation summary:** Refer to section c.1.5 above for a general explanation of the MINTEQA2 speciation data for LG seen in Table 4.4.5. LG

chemistry and speciation ~~was~~ were fundamentally different from the chemistry associated with EG and SEG. LG (and SHG) showed clear indications that pyrite mineral oxidation from runoff contact with exposed ~~tailings~~ mine waste rock has produced sulfuric acid (evidenced by elevated sulfate concentrations), lowered runoff pH, and mobilized significant concentrations of toxic metals. MINTEQA2 results suggest the following observations regarding the chemistry of median LG data:

Suspended elements (iron, aluminum, and manganese): LG MINTEQA2 results showed a clear departure from the species distributions associated with comparatively normal montane runoff chemistry seen in EG and SEG. Because of the low pH and high sulfate concentrations in LG runoff, most trace element species favor sulfate complexes over hydroxides or carbonates. MINTEQA2 results suggest the following:

> ***IRON*** species were all oxidized ferric forms. Despite the low pH of LG, the solid phase still accounts for more than 50 percent of total concentration. The primary aqueous form was the sulfate, $FeSO_4^+$, present at concentrations > 30 mg/L. There are also significant concentrations of hydroxide species that range from 1,000 to 20,000 µg/L. The free ion, while a minor percentage, was estimated to be >2,000 µg/L.
>
> ***ALUMINUM*** was similar to iron showing >60% (spell out "percent"?) solid phase, free ion > 4,000 µg/L, with sulfate complexes constituting the remaining aqueous species.
>
> ***MANGANESE*** results suggest a much lower percentage as solid phase (around 20%) (spell out) compared to Fe and Al. The free ion was the primary solution specie with minor amounts of the sulfate complex (still > 2,500 µg/L, however).

Table 4.4.5: MINTEQA2 calculated speciation distributions for Lincoln Gulch median LG01 concentration data. NC = not calculated; NU = not used (usually because dissolved > total).

		µg/L	% total
IRON, Fe			
	Total	185,000	
	Dissolved	80,300	
	Solid Phase	104,700	56.6
	Fe(OH)2 +	16,800	9.07
	FeOH 2+	16,000	8.64
	Fe2(OH)2 4+	1370	0.740
	FeSO4 +	36,400	19.7
	Fe(SO4)2 -	3050	1.65
	Free Ion, Fe3+	2410	1.30
ALUMINUM, Al			
	Total	30,900	
	Dissolved	10,000	
	Solid Phase	20,900	67.6
	Free Ion, Al3+	4,930	16.0
	AlSO4 +	4,160	13.5
	Al(SO4)2 -	890	2.88
MANGANESE, Mn			
	Total	17,600	
	Dissolved	14,100	
	Solid Phase	3,500	19.9
	Free Ion, Mn2+	11,300	64.1
	MnSO4 aq	2,810	15.9
SILICON, Si			
	Dissolved	4,720	
	H4SIO4	4,720	
ZINC, Zn			
	Total	59,400	
	Dissolved	53,700	
	Solid Phase	5,700	9.60
	Free Ion, Zn2+	39,500	66.5
	ZnSO4 aq	13,600	22.9
	Zn(SO4)2 2-	591	0.990
COPPER, Cu			
	Total	11,300	
	Dissolved	8,440	
	Solid Phase	2,860	25.3
	Free Ion, Cu2+	6,470	57.3
	CuSO4 aq	1,970	17.4
LEAD, Pb			
	Total	3,910	
	Dissolved	381	
	Solid Phase	3,530	90.3
	Free Ion, Pb2+	195	4.98
	PbSO4 aq	181	4.64
	Pb(SO4)2 2- 4.57	0.12	
ARSENIC, As			
	Total	164	

move to next page

	Dissolved	9.81	
	Solid Phase	154	94.0
	H2AsO4 -	9.17	5.59
	H3AsO4	0.630	0.380
CADMIUM, Cd			
	Total	351	
	Dissolved	298	
	Solid Phase	53.0	15.1
	Free Ion, Cd2+	204	58.0
	CdSO4 aq	88.5	25.2
	Cd(SO4)2 2- 5.36	1.53	
SILVER, Ag			
	Total	30.2	
	Dissolved	0.750	
	Solid Phase	29.5	97.5
	Free Ion, Ag+	0.650	2.15
	AgCl aq	0.0700	0.230
	AgSO4 -	0.0300	0.100

Toxic Elements (zinc, copper, lead, arsenic, cadmium, and silver): MINTEQA2 results support what is generally understood regarding elevated trace elements in mine tailing runoff.
waste rock

ZINC was significantly elevated in LG, and the free ion was the major species at >60 percent of total and >30 mg/L. The solid phase only accounts for approximately 10 percent of total, and there were significant concentrations of both Zn-sulfate complexes.

COPPER in LG showed a major departure from the species distributions seen in EG and SEG, where free ion represented <5 percent of total concentration. In LG, copper was primarily in the free ion form (>6,000 µg/L) with around 25 percent still in the solid phase. The only other significant form was the neutral sulfate, present at >1,500 µg/L.

LEAD: Despite significantly lower pH in LG, up to 90 percent of Total Pb remains associated with the solid phase. The remaining species were about evenly split between the free ion and the neutral sulfate complex.
space → ***ARSENIC*** was like Pb with respect to the proportion associated with the solid phase, >90 percent. Because of the much lower pH and consequent increase in H+, the primary aqueous form was the di-hydrogen arsenate, present at approximately 10 times the tri-hydrogen form.

CADMIUM species were dominated by the free ion at >50 percent of total; however, highly elevated sulfate favors a significant proportion (around 25 percent) of total concentration as the neutral sulfate complex. Solid phase Cd accounts for only around 15 percent of total.

SILVER was almost completely associated with the solid phase with only minor amounts of free monovalent Ag^+.

4.4.6 **MINTEQ mineral saturation indices:** LG SI's suggest that acidic LG median water ~~were~~ was highly undersaturated with respect to carbonate minerals. LG median water was oversaturated with respect to iron oxides, hydroxides, oxide-hydroxides, and jarosite, probably because of elevated dissolved Fe. Langite and the other simple sulfates were generally undersaturated despite elevated sulfate in LG water. LG median water was oversaturated for crystalline silica minerals, but probably near equilibrium for cristobalite, and undersaturated for amorphous silica.

	Mineral Saturation Indices, log(AP/KT)
Mineral	LG01
Calcite	-10.1
Dolomite	-20.2
Rhodochrosite	-8.86
Smithsonite	-8.89
Hematite	+13.6
Goethite	+4.32
Ferrihydrite	+0.480
Jarosite NA	+6.43
Langite	-18.1
Anhydrite	-1.31
Gypsum	-0.994
Anglesite	-0.933
Quartz	+0.472
SiO2, (A, GL)	-0.584

4.4.7 **Flow-weighted metal loading:** LG showed the highest median OU6 flow-weighted metal loading for all toxic trace elements, with values ranging from 2.3-times (Cd) to 40-times (Pb) median metal loading in SHG. While loading was high in LG relative to EG and SEG stations, this drainage does not flow for a long time period, a factor that may did ??

mitigate the highest observed OU6 loading. Median loading for all trace elements was at maximum the week before maximum observed runoff flow.

Space →

Table 4.4.7: Median flow-weighted total trace element loading, kg/wk, (method 3051 digestion) in waters from Lincoln Gulch:

Analyte	LG01
Iron, Fe	4,150
Aluminum, Al	693
Manganese, Mn	395
Zinc, Zn	1,332
Copper, Cu	253
Lead, Pb	87.7
Arsenic, As	3.68
Cadmium, Cd	7.88
Silver, Ag	0.678

4.4.8 **Sediment trace elements:** Median LG bed sediment concentrations, while high relative to EG and SEG, were generally lower than median SHG concentrations. LG sediments contain from 0.2-times (Cu and Zn) up to 0.75-times (Fe) median SHG concentrations. These lower median sediment concentrations may be related to the shorter period of flow during runoff experienced by LG relative to SHG.

Table 4.4.8: Median trace element concentrations in stream bed sediments, mg/kg, for Lincoln Gulch sampling stations:

Analyte	LG01
Iron, Fe	39,700
Aluminum, Al	3,930
Manganese, Mn	2,190
Zinc, Zn	1,110
Copper, Cu	485
Lead, Pb	2,150
Arsenic, As	78.0
Cadmium, Cd	4.13
Silver, Ag*	12.5

* 3051 digestion not recommended for Ag

4.5 *STRAY HORSE GULCH (SHG):*

side ??

Stray Horse Gulch runs approximately parallel to Evans Gulch along the southern end of OU6. SHG represents an important contaminant source for California Gulch. The entire drainage course is 3,750 m in length from Adelaide Park to SHG10 in Starr Ditch, located in Leadville. Elevation at the source of SHG is 3,400 m (11,175 ft.), resulting in a total elevation change of 300 m (1000 ft.), and an elevation gradient of 81 m/km for the entire SHG sub-basin. The lateral distance from SHG07 to SHG10 is 2,800 m (9,300 ft.) and is accompanied by a 190 m elevation drop for an elevation gradient of 68 m/km within sampling stations. SHG is an intermittant stream, only flowing during spring snowmelt runoff and thunderstorm events.

english units ??

SHG course goes from top of Breece Hill rather than adelaide

top ??

Breece Hill elev. ??

(623 ft)

horizontal ??

2,835

english units ??

EG and SEG flows don't go beneath hwy 24 = intermitent also ??

didn't give the SHG10 elev.

why metric units ?

4.5.1 **Stream flow summary:** While low pH and very high trace element concentrations were common in SHG, runoff flows were more than an order of magnitude less than those observed in Evans Gulch. Flow measurements confirmed that there is a significant loss of surface flow to the subsurface. As can be seen on hydrographs of SHG flow data, fig. 4, the majority of the loss occurs in the reach from SHG07 to SHG08. It should be noted that flow measurements at SHG10 may not be accurate enough to make significant judgements relative to the other SHG flumes, because of sediment and rock blockages at the discharge pipe at SHG10.

SHG10 was not a flume

Table 4.5.1: Maximum stream flows observed at Stray Horse Gulch sampling stations during the 1995 OU6 runoff event

Station	Maximum Flow, ft^3/s	Date Observed
SHG07	3.76	06-19-95
SHG08	3.65	06-19-95
SHG09	3.55	06-19-95
SHG10	3.61	06-19-95

4.5.2 **Major ions chemistry:** Like Lincoln Gulch, the major ion chemistry of SHG was dominated by acidic, sulfate rich water indicative of pyrite oxidation. The exception is the uppermost station SHG07, which has near-neutral pH and a small amount of bicarbonate ion (the 241 mg/L value for the 6-07-95 sample is thought to be a

transcription error). However, even SHG07 showed elevated sulfate, and appeared to be near the neutralizing capacity in this part of the SHG drainage. The downstream stations showed progressively lower pH, significantly higher sulfate, and elevated calcium and magnesium. SHG09 showed the highest median ion concentrations with magnesium apparently greater than calcium. The slightly lower concentrations compared to SHG09, seen in SHG10, were probably due to dilution with cleaner drainage from Little Stray Horse Gulch. The low pH and lack of bicarbonate seen in the lower SHG stations suggests that trace elements will be mobilized as more toxic species. Like most stations in OU6, all SHG major ions showed a dilution response to the maximum observed runoff flows on 6-19-95.

It's not connected - dilution from inflow below Hanna along 5th St more likely - revise

Table 4.5.2: Median major ions concentrations, in mg/L, for Stray Horse Gulch sampling stations:

Analyte	SHG07	SHG08	SHG09	SHG10
Field pH	6.51	3.64	3	2.99
Calcium	19.5	30.9	76.1	52.6
Magnesium	7.79	16.1	85.6	42.2
Sodium	1.60	1.62	2.55	2.12
Potassium	1.54	1.40	< 1	< 1
Sulfate	103	284	730	722
Chloride	1.35	< 1	2.16	1.27
Bicarbonate	5.82	< 1	< 1	< 1

4.5.3 **Dissolved and total trace elements:** Refer to Figures 7 through 14 for plots of trace elements vs. sampling date for each SHG station. Table 4.5.3 summarizes median total and dissolved trace element concentrations from samples collected during the 1995 runoff episode. Median total and dissolved trace element concentrations are repeated in Table c.4.5 which summarizes MINTEQA2 speciation data for median SHG station data.

Table 4.5.3: Median total (method 3015 digestion), dissolved, and free ion (where applicable) trace element concentrations, in µg/L, for Stray Horse Gulch sampling stations:

Analyte		SHG07	SHG08	SHG09	SHG10
Iron, Fe					
	Total	135	41,400	175,400	236,000
	Dissolved	130	21,700	131,000	49,100
Aluminum, Al					
	Total	553	5,830	42,300	41,400
	Dissolved	329	3,660	30,800	16,700
Manganese, Mn					
	Total	345	6,340	54,600	49,900
	Dissolved	409	5,240	43,000	18,300
Silica, Si					
	Dissolved	6,920	7,490	13,100	10,800
Zinc, Zn					
	Total	1,290	18,700	160,000	146,000
	Dissolved	1,360	16,100	127,000	61,300
Copper, Cu					
	Total	98.8	596	3,070	3,000
	Dissolved	94.2	470	2,280	1,150
Lead, Pb					
	Total	19.5	401	859	4,700 correct # ??
	Dissolved	8.22	119	371	329
Arsenic, As					
	Total	3.16	22.2	45.0	169
	Dissolved	1.27	4.93	16.4	8.14
Cadmium, Cd					
	Total	13.1	158	1,220	1,120
	Dissolved	13.5	127	1,040	467

Silver, Ag				
Total	<0.500	5.00	15.1	28.4
Dissolved	<0.500	<0.500	<0.500	<0.500

While SHG chemistry was similar to LG, there were differences in trace element concentrations worth comment. SHG07 was upstream of the majority of the SHG tailings, so the trace element and general chemistry concentrations for this station share more in common with the downstream *EG* and *SEG* stations than with LG or downstream SHG stations.

mine waste rock

Once SHG08 was reached, however, the trace elements and general chemistry begin to reflect increased interaction with SHG tailings with significant pH lowering and increases in Fe, Al, Mn,Cu, Pb, As, and Cd. By SHG09, several elements show another significant level of increase from SHG08. Median SHG09 Pb and As double, and Cu, Zn, Cd, Mn, Al, and Fe approach order of magnitude increases compared to SHG08 concentrations. Except for Pb, As, and Ag, median SHG09 concentrations were also much higher compared to LG01.

ditto

By SHG10, the lowest elevation station in this basin, median total concentrations compared to SHG09 have increased for Fe, Pb, As, and Ag, while actually declining for Al, Mn, Zn, and Cd. Dissolved concentrations show an even more dramatic decline for many elements. These changes are suggestive that total suspended elements were increasing and that mixing of SHG runoff with Starr Ditch water containing runoff from Little Stray Horse Gulch and other points north of Leadville, was perhaps altering the chemistry at SHG10 to favor precipitation and adsorption.

revise as noted on pg. 57 - Starr D. not connected w/ SHG flows

4.5.4 **Water Quality Standards:** Like Lincoln Gulch, all stations in Stray Horse Gulch except SHG07 have regulated analyte concentrations significantly higher than both Federal and Colorado state standards. The following observations apply:

pH: Median pH < 6.5 Federal secondary MCL and Colorado TVS 6.5 at all stations but SHG07.

Sulfate: Median sulfate > 250 Federal secondary MCL and Colorado TVS at all stations but SHG07.

Iron: Median total and dissolved Fe >> federal secondary MCL 300 µg/L, Colorado TVS chronic 1000 µg/L total standard at all stations but SHG07. Median dissolved Fe >> Colorado TVS chronic dissolved and Federal secondary MCL 300 µg/L at all stations but SHG07.

Aluminum: Median dissolved Al >> Federal secondary MCL 200 µg/L at all stations.

Manganese: Median total and dissolved Mn >> Federal secondary MCL 50 µg/L at all stations. Median dissolved Mn >> Colorado TVS chronic 50 µg/L dissolved standard at all stations.

Zinc: Median dissolved Zn and free ion >> Colorado TVS chronic 91.4 and acute 101 µg/L standards at all stations. Median dissolved and free ion Zn >> Federal secondary MCL 5000 µg/L at all stations but SHG07.

Copper: Median dissolved and free ion Cu > Colorado TVS chronic 10.2 and acute 15 µg/L standards at all stations. Median dissolved Cu > Federal primary MCL 1300 and Federal secondary MCL 1000 µg/L at stations SHG09 and SHG10.

Lead: Median dissolved and free ion Pb > Colorado TVS chronic 3.04 µg/L at all stations. Median dissolved Pb > Colorado TVS acute 72.3 µg/L at all stations but SHG07. Median dissolved Pb > PMCL 15 µg/L at all stations but SHG07. Median free ion Pb > PMCL 15 µg/L at all stations but SHG07.

Arsenic: Median total As > Federal primary MCL 50 µg/L, and Colorado TVS acute 50 µg/L at SHG10.

Cadmium: Median dissolved and free ion Cd > Colorado TVS chronic 0.989 and acute 3.22 µg/L at all stations. Median dissolved and free ion Cd > Federal primary MCL 5 µg/L at all stations.

okay here - Hanna

4.5.5 **MINTEQ speciation summary:** SHG chemistry was similar to LG in that both sub-basins experience mine waste- and tailings-influenced runoff producing low pH and elevated sulfate and trace elements. Because more sites were sampled; however, the description of SHG speciation chemistry is more complicated. Refer to section c.1.5 above for a general explanation of the MINTEQA2 speciation data for SHG seen in Table 4.5.5. MINTEQA2 results suggest the following observations regarding the implied chemistry of median SHG data:

Suspended elements (iron, aluminum, and manganese): SHG MINTEQA2 results were most similar to LG for station SHG09 and SHG10, while SHG07 showed speciation results very different from downstream SHG stations. SHG07 was the station least affected by mine waste rock and tailings oxidation effects in SHG.

IRON: While total concentrations show a clear increase with lower elevation, SHG07 showed significantly less solid phase (3-4 percent) and significantly more hydroxide species percentages (around 40 percent compared to <20 percent $Fe(OH)_2^+$) compared to the downstream SHG stations. SHG10 also showed a clear concentration reduction relative to upstream stations in dissolved Fe and Al, probably related to adsorption and precipitation processes at this station - another possible mechanism besides mixing that may be active at SHG10.

ALUMINUM showed a fairly consistent proportional split between solid phase, free ion, and the mono-sulfate complex across all SHG stations, this despite a trend towards increasing total Al with lower elevation. As with Fe, SHG10 Al showed a doubling of solid phase percentage compared to SHG09.

MANGANESE: Like LG, Mn showed lower solid phase percentages compared to Fe and Mn; however, by SHG10, solid phase Mn accounts for greater than 60 percent of total Mn. Free ion was the primary aqueous form for all but SHG10, where ongoing physiochemical processes appear to be forcing reactions toward the solid phase for all suspended elements.

Toxic Elements (zinc, copper, lead, arsenic, cadmium, and silver): Despite downstream increases in most toxic trace elements, solid phase percentages rise with a generally abrupt jump in solid phase percentage seen in SHG10. As with LG species, the lower pH favors increasing free ion concentrations for cationic elements; yet increases in suspended elements also forces a greater *percentage* of these elements towards the solid phase. Elevated sulfate concentrations in SHG also favor formation of sulfate complexes as the minor forms for the cationic elements. MINTEQA2 results suggest the following regarding toxic element speciation in SHG:

Table 4.5.5: MINTEQA2 calculated speciation distributions for Stray Horse Gulch median concentration data. NC = not calculated; NU = not used (usually because dissolved > total).

	SHG07		SHG08		SHG09		SHG10	
	µg/L	% total	µg/L	% total	µg/L	% total	µg/L	% total
IRON, Fe								
Total	135		41,400		175,400		236,000	
Dissolved	130		21,700		131,000		49,100	
Solid Phase	5	3.70	19,700	47.6	44,400	25.3	187,000	79.2
Fe(OH)2 +	55.6	41.2	6,530	15.8	27,100	15.5	10,360	4.39
FeOH 2+	33.0	24.5	5,060	12.2	29,600	16.9	8540	3.62
Fe2(OH)2 4+	0	0	0	0	5,630	3.21	0	0
Fe3(OH)4 5+	0	0	0	0	2,880	1.64	0	0
FeSO4 +	28.6	21.2	7790	18.8	49,650	28.3	23,500	9.94
Fe(SO4)2 -	0	0	369	0.890	3,540	2.02	2,160	0.920
Free Ion, Fe3+	12.1	8.96	1,820	4.40	12,700	7.24	4030	1.71
ALUMINUM, Al								
Total	553		5,830		42,300		41,400	
Dissolved	329		3,660		30,800		16,700	
Solid Phase	224	40.5	2,170	37.2	11,500	27.2	24,700	59.7
Free Ion, Al3+	238	43.0	2,130	36.5	18,400	43.5	8,000	19.3
AlSO4 +	85.9	15.5	1,360	23.3	10,500	24.8	7,030	17.0
Al(SO4)2 -	4.61	0.830	165	2.83	1,850	4.37	1,640	3.95
MANGANESE, Mn								
Total	345		6,340		54,600		49,900	
Dissolved	409		5,240		43,,000		18,300	
Solid Phase	0	0	1,100	17.4	11,600	21.3	31,600	63.3
Free Ion, Mn2+	378	92.4	4,510	71.1	36,200	66.3	14,500	29.0
MnSO4 aq	30.7	7.50	734	11.6	6,800	12.4	3,820	7.66
SILICA, Si								
Dissolved	6,920		7,490		13,100		10,800	
H4SiO4	6,920		7,490		13,100		10,800	
ZINC, Zn								
Total	12,900		18,700		160,000		146,000	
Dissolved	13,600		16,100		127,000		61,300	
Solid Phase	0	0	2,600	13.9	33,000	20.6	84,700	58.0
Free Ion, Zn2+	12,200	94.5	13,100	69.9	100,000	62.6	44,100	30.2
ZnSO4 aq	1,400	10.9	2,960	15.8	25,800	16.1	16,300	11.2
Zn(SO4)2 2-	0	0	0	0	0	0	858	0.590
COPPER, Cu								

to next page

Total	98.8		596		3,070		3,000	
Dissolved	94.2		470		2,280		1,150	
Solid Phase	4.60	4.66	126	21.1	790	25.7	1,850	61.7
Free Ion, Cu2+	85.5	86.6	392	65.7	1,860	60.5	867	28.9
CuSO4 aq	8.67	8.77	78.5	13.2	422	13.7	283	9.43
LEAD, Pb								
Total	19.5		401		859		4,700	
Dissolved	8.22		119		371		329	
Solid Phase	11.3	57.9	282	70.3	488	56.8	4,370	93.0
Free Ion, Pb2+	6.21	31.8	73.2	18.3	217	25.3	161	3.42
PbSO4 aq	2	10.2	45.2	11.3	150	17.5	164	3.48
Pb(SO4)2 2- 0	0	0	0	0	0	4.61	0.100	
ARSENIC, As								
Total	3.16		22.2		45		169	
Dissolved	1.27		4.93		16.4		8.14	
Solid Phase	1.89	59.8	17.3	77.8	28.6	63.6	161	95.2
H2AsO4 -	1.18	37.5	4.60	20.7	15.4	34.1	7.63	4.51
H3AsO4	0.0800	2.65	0.330	1.47	1.03	2.30	0.510	0.300
CADMIUM, Cd								
Total	13.1		158		1,220		1,120	
Dissolved	13.5		127		1,040		467	
Solid Phase	0	0	31.0	19.6	180	14.8	653	58.3
Free Ion, Cd2+	11.7	86.9	98.0	62.1	773	63.3	311	27.8
CdSO4 aq	1.71	12.7	28.1	17.8	251	20.5	145	13.0
Cd(SO4)2 2- 0	0	0	0	13.5	1.11	9.81	0.880	
SILVER, Ag								
Total	<0.500		5.00		15.1		28.4	
Dissolved	<0.500	NC	<0.500	<5.00	<0.500	<5.00	<0.500	<5.00
Solid Phase	<0.500	NC	>4.50	>95.0	>14.6	>95.0	>27.9	>95.0

guess it's correct - pretty large relative change - may be due to Hamma addition below SHG07

ZINC was present at SHG07 primarily as free ion, however, as total Zn concentrations clearly increase with lower elevation, the proportion of solid phase Zn show an opposite and steady increase, with a doubling at SHG10.

space → ***COPPER*** was half the maximum LG concentration at SHG maximums) is this all ??

LEAD: While total Pb continues to increase towards SHG10, dissolved Pb does not appear to increase, and perhaps even declines. The solid phase percentage increases as dissolved Pb decreases. Free ion changes from less than 30 percent at SHG07 to more than 5 percent at SHG10, with a maximum median free ion concentration >200 µg/L at SHG09.

ARSENIC total concentrations were comparable to LG01 at SHG10. The lower downstream pH also favors the dihydrogen arsenate form; however, there was once again a significant increase in solid phase As at SHG10.

CADMIUM free ion was at maximum concentration and percentage at SHG09. Despite the known preference for Cd to form the free ion, significantly higher suspended elements appear to be the factor that reduces the median free ion concentration at SHG10 to approximately one-half of SHG09 levels. The uncharged sulfate complex was also at maximum in SHG09, reaching >20 percent for a concentration of >250 µg/L.

SILVER was primarily bound to the solid phase in all SHG stations.

4.5.6 **MINTEQ mineral saturation indices:** SI's suggest that acidic SHG median waters were highly undersaturated with respect to carbonate minerals, oversaturated with respect to iron oxides and oxide-hydroxides because of elevated dissolved Fe. Jarosite and ferrihydrite were undersaturated at SHG07, but oversaturated in downstream SHG stations. Langite and the simple sulfates were undersaturated at SHG07, but show a clear trend approaching near-0 equilibrium SI values in downstream stations, probably due to elevated sulfate in runoff. SHG median waters were oversaturated for crystalline silica minerals, but undersaturated for amorphous silica. These results are consistent with the overall acidic pH and sulfate-dominated chemistry of SHG waters.

	Mineral Saturation Indices, log(AP/KT)			
Mineral	SHG07	SHG08	SHG09	SHG10
Calcite	-10.3	-10.2	-9.95	-10.1
Dolomite	-21.1	-20.7	-19.7	-20.3
Rhodochrosite	-10.2	-9.20	-8.39	-8.77
Smithsonite	-10.3	-9.32	-8.52	-8.88
Hematite	+8.33	+12.7	+14.0	+13.0
Goethite	+1.71	+3.87	+4.55	+4.01
Ferrihydrite	-1.97	+0.085	+0.676	+0.268
Jarosite NA	-2.11	+4.99	+7.48	+6.12
Langite	-26.1	-23.1	-20.4	-22.0
Anhydrite	-2.14	-1.67	-1.21	-1.27
Gypsum	-7.74	-1.29	-0.858	-0.882
Anglesite	-2.87	-1.53	-1.02	-0.964
Quartz	+0.705	+0.964	+0.902	+0.871
SiO2, (A, GL)	-0.371	-0.368	-0.150	-0.196

some order ??

4.5.7 **Flow-weighted metal loading:** Median ~~trace element~~ flow-weighted metal loading in SHG was lower compared to LG, but considerably higher compared to EG and SEG loading. Median metal loading for SHG07 was significantly lower compared to all other downstream SHG stations; and loading clearly increases towards lower elevation stations, reaching a maximum for all elements at SHG10. Despite having lower runoff loading compared to LG, the longer continuous flow period for SHG probably poses a greater water quality problem for downstream receiving waters. Like all basins in OU6, median metal loading generally reaches a maximum value for most trace elements the week before maximum observed runoff flow at each SHG station.

Table 4.5.7: Median flow-weighted total trace element loading, kg/wk, in waters from Stray Horse Gulch sampling stations:

Analyte	SHG07	SHG08	SHG09	SHG10
Iron, Fe	1.39	1,060	1,180	2,200
Aluminum, Al	3.69	108	284	419
Manganese, Mn	1.84	180	328	737
Zinc, Zn	7.84	569	960	1,820
Copper, Cu	0.882	14.3	18.1	31.1
Lead, Pb	0.174	11.1	20.2	43.6
Arsenic, As	0.033	0.563	0.678	1.10
Cadmium, Cd	0.100	4.86	7.42	12.8
Silver, Ag	ND	0.064	0.154	0.237

4.5.8 **Sediment trace elements:** Greater continuous flow in SHG may help explain why median sediment concentrations were higher than LG for almost all trace elements, ranging from 1.3-times (Fe) up to 6.2-times (Cu) greater than LG concentrations. As seen with the aqueous concentration data, SHG07 showed significantly lower sediment concentrations (especially for Pb, As, and Ag) for most elements compared to lower elevation SHG stations.

What about Al at 5200 at SHG07 vs 2470 to 2610 at lower stations? - effect of the wetlands between the Penn mines and SHG07 ??

Table 4.5.8: Median trace element concentrations in stream bed sediments, mg/kg, (method 3051 digestion) for Stray Horse Gulch sampling stations:

Analyte	SHG07	SHG08	SHG09	SHG10
Iron, Fe	9,510	70,300	50,500	52,400
Aluminum, Al	5,200	2,610	2,470	2,470
Manganese, Mn	491	607	1,320	5,620
Zinc, Zn	320	809	2,400	4,550
Copper, Cu	83.1	114	216	334
Lead, Pb	188	2,720	4,690	3,880
Arsenic, As	5.68	106	91.3	98.5
Cadmium, Cd	1.64	6.03	14.5	26.0
Silver, Ag*	1.06	44.5	16.4	18.8

* 3051 digestion not recommended for Ag

5.0 Summary and Conclusions:

This section summarizes the analyses of the Phase 1 OU6 sampling program and presents conclusions based on geochemical analyses by drainage basin and summarizes the results using statistical median values of the data.

Samples were collected from May through July 1995 at approximately weekly intervals in four drainage basins in OU6: Evans Gulch (EG), South Evans Gulch (SEG), Lincoln Gulch (LG), and Stray Horse Gulch (SHG). The purpose of the runoff sampling was to:

1) Provide a detailed chemical and hydrologic description of a single season snowmelt runoff event. Very few detailed studies of snowmelt runoff have been performed, and this annual seasonal event represents an unknown and potentially significant period for deleterious effects on downstream water quality, and

2) To assess chemical, streamflow, and mineralogical data from four OU6 sub-basins to identify possible geochemical processes, quantify trace element mass loading into

and the Arkansas River

mine waste rock and

California Gulch, and to provide supporting data to help identify potential tailings contaminant source areas.

5.1 Methodology:

Samples were collected according to the project quality assurance (QA) project plan following recommendations suggested by Region VIII Environmental Protection Agency (EPA) QA personnel. All chemical analyses were performed following current ?? EPA analytical methods. Water samples were analyzed for major ions, and dissolved (filtered at the time of collection) and total trace elements (digested using EPA Method 3015A prior to analysis). Stream bed sediments were digested using EPA Method 3051 and then analyzed for trace elements. Laboratory quality control (QC) and data reporting package requirements for these tests were defined by the Unique Laboratory Sample Analyses (ULSA) request form negotiated between the D-8240 Environmental Research Chemistry Laboratory (the Lab) and the Region VIII EPA Sample Broker.

Reclamation

The resulting analytical data were evaluated for quality problems and then entered into the SPSS statistics program for data manipulation, statistical analysis, and plotting. Data for analytes observed below the limit of detection (LOD) were coded as (0.5 X LOD), to prevent a more biased estimate of central tendency. Because most trace element data in this study were not normally (symmetrically) distributed, sub-basin and station data summaries used the median as the estimate of the central tendency of the data. If data for a particular analyte were normally distributed, the median and mean would be equal. The MINTEQA2 chemical equilibrium model was used to calculate mineral saturation indices and concentrations of the different forms or species that each element will form in a given water. MINTEQA2 runs were performed on individual sample data sets, as well as station median concentrations.

5.2 Data Quality:

Chemical analysis data quality was evaluated within the Lab by each responsible analyst performing tests and by the Lab QC Officer's routine review. The overall data quality was judged acceptable from the Lab QC perspective, with some problems noted on replicate sediment sample precision - partly caused by the lack of adequate mixing before grab subsampling in the Lab (which improved over the course of this study) and partly due to the coarse particle size distributions in some sediment samples. Samples from Lincoln and Stray Horse Gulches with elevated trace element concentrations sometimes exceeded QC limits for instrument-run spiked-sample percent recovery checks. This problem was often observed when the spiking standard solution concentration was low relative to the sample concentration, causing erratic and

unreliable percent recovery data. These problems were noted in the case narratives that accompanied each sample delivery package.

The overall quality of major ions data sets was evaluated using cation-anion balance (most natural waters are electroneutral and contain equal amounts of positive and negative ions). Almost all samples from Evans and South Evans Gulch, where pH was neutral and bicarbonate buffering was present, showed acceptable ion balance percentages of ± 5 percent. Major ion data for samples from Stray Horse and Lincoln Gulches were not evaluated using ion balance since a large portion of ionic activity in these samples is from elevated trace element concentrations.

Primary trace element data were reviewed by the project chemist to identify instances where dissolved concentrations were greater than total concentrations. Eight out of 1,000 analytes (0.8%) were found to have dissolved > total, 5 occurrences for As (arsenic) and three for Zn (zinc). However, the concentration differences were near the observed standard deviation for the analysis (used to calculate the limit of detection - LOD), suggesting no significant statistical difference between total and dissolved. Dissolved > total anomalies are not unusual in the lower trace element concentration ranges due to greater variability relative to the absolute measured concentrations. For dissolved > total differences greater than expected variability where contamination is suspected, anomalies occurred in 18 of the 1000 analytes (1.8 percent); 12 occurrences for Zn, 4 for Mg, and 1 each for Cd (cadmium), Mn (manganese), As, and Al (aluminum). For 2 out of the 100 samples (2%) the dissolved > total anomalies were observed on 4 or more elements, suggesting a label switch.

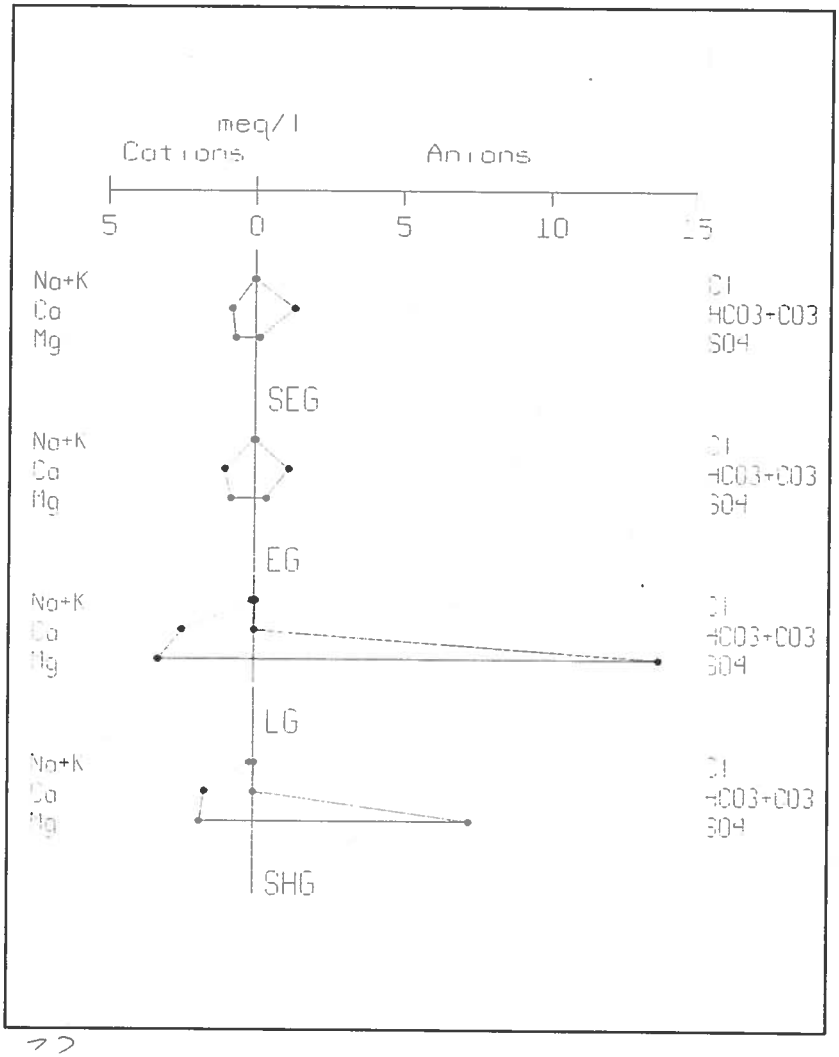
The quality problems mentioned here are well within reasonable expectation for a study of this size and complexity, and thus should not affect interpretative conclusions made in the body of this report.

5.3 Stream Flows:

Runoff volumes during this study are different in each drainage basin, primarily related to the available drainage area, local snow accumulation, and elevation gradients; however, almost all OU6 stations showed a flow maximum on or about June 20, 1995. Chemical concentrations in every sub-basin appeared to respond to flow, and almost all trace elements and major ions data show a dilution effect minimum concentration on or about maximum runoff flow. However, the relatively small sample sizes (less than or equal to 10 events) and natural variability did not produce any significant simple statistical correlations between flow and concentration. Highest flows were observed in Evans Gulch, up to 65.5 ft^3/s, and this drainage ~~is~~ was flowing at > 10 ft^3/s after the final 07-26-95 sampling event. Residual off-season flow in Evans Gulch is probably around 1 ft^3/s or less. Lincoln Gulch showed the lowest flows (maximum observed 3.4

ft^3/s) and the shortest duration runoff period (2-3 weeks) in OU6, with near-zero flow after 06-27-95. Stray Horse Gulch also shows maximum runoff flows in the 3-4 ft^3/s range, and the maximum flow shows a sharp clear peak with abrupt transitions to flows < 1 ft^3/s before and after runoff maximum.

5.4 Major Ions Chemistry:



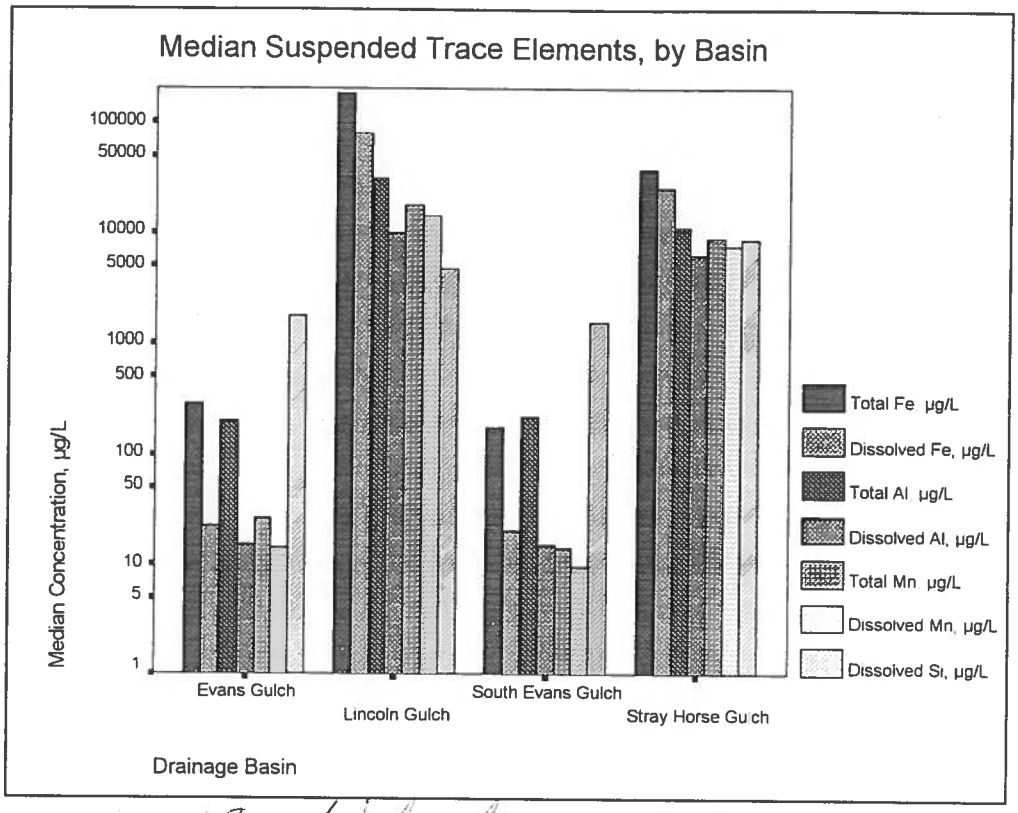
The data from this study suggest that there are 2 different geochemical regimes in the OU6 study area. Evans Gulch and South Evans Gulch represent similar calcium-bicarbonate waters with neutral pH, approximately 1 meq/L (61 mg/L) bicarbonate buffering capacity, and generally low dissolved solids and trace element concentrations. These 2 drainages are actually connected and are indicative of similar carbonate mineral-influenced chemistry. Lincoln Gulch and Stray Horse Gulch, on the other hand, are low pH, high sulfate, and elevated dissolved solids and trace element waters indicative of pyrite mineral oxidation processes associated with mine tailings. Figure 18 shows Stiff diagrams that plot sub-basin median major ions concentrations.

Figure 18 - Stiff diagrams for median major ions concentrations from each OU6 drainage sub-basin.

5.5 Dissolved and Total Trace Elements:

Evans and South Evans Gulches showed the lowest trace element concentrations, consistent with lesser mining influence and the neutral pH of the water. Many trace elements in these two basins (which are actually connected sub-basins) are below detection limits. Stray Horse and Lincoln Gulches, however, contained elevated concentration of all trace elements. Median trace element concentrations for each sub-basin are graphed in Figure 19, which shows the suspended elements Fe (iron), Al, and Mn, and Figure 20, which shows the toxic trace elements Zn, Cu (copper), Pb (lead), As, and Cd. Note that the concentration axes on both figures are log-scaled to accommodate the large range of observed concentrations. In general, all trace elements showed a maximum concentration peak prior to the runoff

flow maximum, with a subsequent concentration minima at the flow maximum and then a suggested increase as flows subsided. A significant observation for all OU6 basins is the consistent presence of elevated concentrations of Zn in runoff samples, probably related to the observed wide distribution of Zn-containing minerals in the watershed.



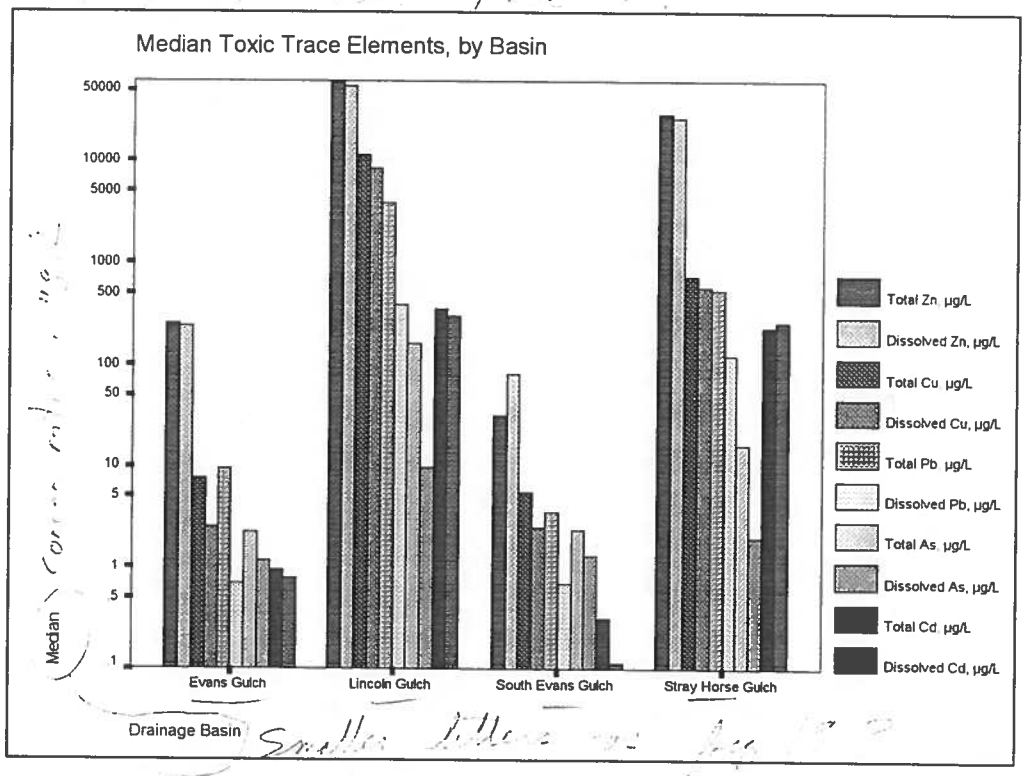


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Figure 20 - Median toxic trace elements in the 1995 spring snowmelt runoff for each of the OU6 sub-basins.

Upper elevation Evans Gulch stations showed very low concentrations of lead and copper, and no median dissolved concentration of these elements was seen until station WE02. There was no detectable Ag (silver) in any Evans Gulch station; however, readily measurable concentrations of Zn, As, and Cd were found at all stations. All elements showed a general increase in concentration as station elevation decreases, probably caused by interaction with a greater watershed area. The apparently abrupt concentration increases seen in the lower EG01 and EG02 stations were probably due to the physical distance downstream of these stations from WE02.

connected on this section — don't agree with this "reason" — maybe

The available data suggest that SEG02 was the "cleanest" station and that runoff from mined areas was influencing SEG03 and SEG04. Trace element concentrations seem to follow an up-down-up-up-down pattern during the runoff event, suggesting that the runoff interaction with the South Evans Gulch watershed is complex, with generally greater mining activity influence at lower elevations. There was no detectable zinc until station SEG03, and copper and cadmium were not observed until station SEG04. Median silver was also below detection in all South Evans Gulch stations.

While Stray Horse Gulch and Lincoln Gulch trace element concentrations were similar, Lincoln Gulch clearly showed much higher concentrations for most elements. Both of these acid mine drainage-influenced sub-basins contained low pH and elevated suspended and toxic trace elements. The higher concentrations observed in LG, however, are mitigated to some extend by the brevity of the runoff period.

SHG07 was upstream of the worst concentration of Stray Horse Gulch tailings, so the trace element and general chemistry concentrations for this station share more in common with the downstream Evans Gulch stations than with Lincoln Gulch or downstream Stray Horse Gulch stations. At the next downstream station, SHG08, however, the trace elements and general chemistry reflected increased ~~tailings~~ impacts with significant pH lowering and increases in Fe, Al, Mn,Cu, Pb, As, and Cd. At station SHG09, several elements showed another significant level of increase from SHG08. Median SHG09 Pb and As double; and Cu, Zn, Cd, Mn, Al, and Fe approach order of magnitude increases compared to SHG08 concentrations. Except for Pb, As, and Ag, median SHG09 concentrations were also much higher compared to the Lincoln Gulch station LG01.

At station SHG10, the lowest elevation station in this basin, median total concentrations compared to SHG09 have increased for Fe, Pb, As, and Ag, while actually declining for Al, Mn, Zn, and Cd. Dissolved concentrations show an even more dramatic decline for many elements. These changes ~~are~~ suggestive that total suspended elements were increasing, and mixing of Stray Horse Gulch runoff with Starr Ditch

Note previous discussion

probably caused by

water, containing runoff from Little Stray Horse Gulch and other points north of Leadville, was perhaps altering the chemistry at SHG10 to favor precipitation and adsorption.

Lamins added a load of silt and sand sized material to the SHG & Stars Gulch water.

5.6 Water Quality Regulations and Observed Exceedances:

Trace element data from each sampling station were evaluated by comparing station median concentrations to the water quality standards applicable to the OU6 watershed. Evans Gulch water is used as the drinking water supply for Leadville, Colorado. Table 1 lists the regulated analytes and the primary and secondary maximum concentration limits (MCL's) defined under the Federal Safe Drinking Water Act - amended 1986, (National Primary Drinking Water Standards - 40 CFR 141, the National Secondary Drinking Water Standards - 40 CFR 143); and the table value standards (TVS) implemented by the State of Colorado, Department of Health, Water Quality Control Commission, for Evans Gulch, Upper Arkansas River Basin, Stream Segment 7. Colorado TVS values were calculated based on Evans Gulch hardness data using the lower 95 percent confidence interval of 84 mg/L as $CaCO_3$, determined from a statistical analysis of Evans Gulch calcium and magnesium data from this study.

Table 5.6.1: Exceedances of Federal and Colorado State Water Quality Standards: This table shows the sampling stations where median concentrations during the 1995 California Gulch snowmelt runoff event exceeded either the Safe Drinking Water Act (SWDA) regulated levels, or Colorado acute and chronic water quality standards.

Standards			Stations Within Each Basin with Median Concentrations Exceeding	
Analyte	Regulatory Limit		EG	SEG
	LG	SHG		
pH				
	Federal SWDA Secondary, pH 6.5 - 8.5		none	none
	LG01	ALL but SHG07		
	Colorado Acute TVS, pH >6.5		none	none
	LG01	ALL but SHG07		
Sulfate:				
	Federal SWDA Secondary MCL, 250 mg/L		none	none
	LG01	ALL but SHG07		
	Colorado Acute TVS, 250 mg/L		none	none
	LG01	ALL but SHG07		
Iron:				
	Federal SWDA Secondary MCL, 300 µg/L		WE01 EG01 EG02	SEG04
	LG01	ALL STATIONS		
	Colorado Chronic Total TVS, 1,000 µg/L		none	none
	LG01	ALL but SHG07		

Colorado Chronic Dissolved TVS, 300 µg/L	none		SEG04	
LG01	ALL STATIONS			
Aluminum:				
Federal SWDA Secondary MCL, 200 µg/L	ALL but EG03		ALL but SEG02 SEG05	
LG01	ALL STATIONS			
Manganese:				
Federal SWDA Secondary MCL, 50 µg/L	EG01 EG02	none		LG01
ALL STATIONS				
Colorado Chronic Dissolved TVS, 50 µg/L	EG01 EG02	none		LG01
ALL STATIONS				
Zinc:				
Federal SWDA Secondary MCL, 5,000 µg/L	none		none	
LG01	ALL but SHG07			
Colorado Acute TVS, 101 µg/L	ALL STATIONS		SEG04 SEG05	LG01
ALL STATIONS				
Colorado Chronic TVS, 91.4 µg/L	ALL STATIONS		SEG04 SEG05	LG01
ALL STATIONS				
Copper:				
Federal SWDA Primary MCL, 1,300 µg/L	none		none	
LG01	SHG09 SHG10			
Federal SWDA Secondary MCL, 1,000 µg/L	none		none	
LG01	SHG09 SHG10			
Colorado Acute TVS, 15.0 µg/L	none		none	
LG01	ALL STATIONS			
Colorado Chronic TVS, 10.2 µg/L	EG02		none	
LG01	ALL STATIONS			
Lead:				
Federal SWDA Primary MCL, 15 µg/L	EG01 EG02		SEG04	
LG01	ALL but SHG07			
Colorado Acute TVS, 72.3 µg/L	none		none	
LG01	ALL but SHG07			
Colorado Chronic TVS, 3.04 µg/L	EG02		SEG04	
LG01	ALL STATIONS			
Arsenic:				
Federal SWDA Primary MCL, 50 µg/L	none		none	
LG01	SHG10			
Colorado Acute TVS, 50 µg/L	none		none	
LG01	SHG10			
Cadmium:				
Federal SWDA Primary MCL, 5 µg/L	none		none	
LG01	ALL STATIONS			
Colorado Acute TVS, 3.22 µg/L	none		none	
LG01	ALL STATIONS			
Colorado Chronic TVS, 0.989 µg/L	EG01 EG02		SEG04 SEG05	
LG01	ALL STATIONS			

MCL = Maximum Concentration Limit, TVS = Table Value Standard. Table 1 also identifies the sub-basin stations where median concentrations exceeded one or more of the applicable water quality regulations. If the median concentration for a given station is below the regulated concentration, one cannot be assured that all of the samples are below the limit. However, when median concentrations *exceed* a regulatory limit, it is safe to assume that half the samples will have concentrations equal to or greater than the regulated concentration. The reader is referred to the actual measured station concentrations, included in Appendix __, to gain a more complete knowledge of total exceedances, especially for those stations with non-exceedance median concentrations.

While Evans Gulch and South Evans Gulch represent the cleaner sub-basins sampled in this study, several notable exceedances were observed for the lower elevation station median concentrations in both sub-basins. In Evans Gulch, three stations exceeded standards for Fe, four stations exceeded standards for Al, two stations exceeded standards for Mn, one station exceeded standards for Cu, two stations exceeded standards for Pb, and two stations exceeded standards for Cd. Notably, all Evans Gulch stations exceeded Colorado standards for Zn. South Evans Gulch showed exceedances for the following station median concentrations: one station exceeded standards for Fe; three stations exceeded standards for Al; two stations exceeded standards for Zn; one station exceeded standards for Pb; and two stations exceeded standards for Cd.

The acidic sub-basins showed exceedances for all Table 1 elements and analytes. Lincoln Gulch showed the greatest number of exceedances, although almost all Stray Horse Gulch stations downstream of SHG07 also showed exceedances for Table 1 analytes.

5.7 Trace Element MINTEQ Model Speciation:

Speciation refers to the distribution of different forms and compounds that form in a given water with a specific element. For example, a dissolved trace element concentration is usually comprised of several different species, the free aquo ion which is unpaired with other inorganic constituents in the water; and compounds called complexes where the trace element is bound to carbonate, hydroxide, sulfate or other anions detected in the water. Speciation information has value to environmental researchers because some forms of a given trace element are much more toxic and bioavailable than others. In general, the free ion specie is the most toxic to aquatic life, while the portion adsorbed on suspended materials (the solid phase element) is least toxic. Table 5.7.1 summarizes the range of observed percentages for the primary species calculated by the MINTEQA2 model for each of the four OU6 sub-basins (see discussion in report body regarding MINTEQA2 model assumptions). The Table 5.7.1 percentages are based on the measured

total (3015A digestion) concentration. The ranges are based on individual sampling station median data MINTEQA2 results.

Within each sub-basin, a significant difference in the distribution of species between upper and lower elevation stations was observed, hence the wide range of percentages for some elements (for example Stray Horse Gulch Cd and Zn). In the cleaner sub-basins, there were often no detectable trace elements in the upper elevation stations, and thus these species distributions are largely unknown. In Stray Horse Gulch, there is a big difference between the relatively clean SHG07, which bears resemblance to the lower elevation Evans Gulch stations, EG02 and EG03, and the acidified downstream Stray Horse Gulch stations.

The following summarizes information for each element:

IRON, Fe

Fe is primarily associated with suspended materials in all OU6 stations, and even in the acidified stations, there is very little free ferric ion. The primary dissolved species in the cleaner sub-basins are hydroxides with insignificant amounts of sulfate complexes. In the acidified systems, hydroxides still constitute a significant proportion of species, but

Table 5.7.1- MINTEQA2 calculated speciation distributions for California Gulch OU6 sub-basins based on sampling station median concentrations. x = < 1% or insignificant.

TABLE 5.7.1 - MINTEQA2 - SUMMARY OF MINERAL /TRACE METAL SPECIATION IN OU6 SURFACE WATER SNOWMELT RUNOFF BY DRAINAGE BASIN -

	Evans Gulch		South Evans Gulch		Lincoln Gulch		Stray Horse Gulch	
	Species	% Range	Species	% Range	Species	% Range	Species	% Range
IRON, Fe								
	Solid Phase	78-96	Solid Phase	81-94	Solid Phase	57	Solid Phase	3-80
	FeOH 2+	x	FeOH 2+	x	FeOH 2+	9	FeOH 2+	3-25
	Fe(OH)2 +	8-15	Fe(OH)2 +	4-13	Fe(OH)2 +	9	Fe(OH)2 +	4-42
	Fe(OH)3 aq	2-5	Fe(OH)3 aq	1-5	Fe(OH)3 aq	x	Fe(OH)3 aq	x
	FeSO4 +	x	FeSO4 +	x	FeSO4 +	20	FeSO4 +	10-29
	Fe(SO4)2 -	x	Fe(SO4)2 -	x	Fe(SO4)2 -	2	Fe(SO4)2 -	0-2
	Free Ion, Fe3+	x	Free Ion, Fe3+	x	Free Ion, Fe3+	1-2	Free Ion, Fe3+	2-9
ALUMINUM, Al								
	Solid Phase	>80	Solid Phase	80-92	Solid Phase	68	Solid Phase	27-60
	Free Ion, Al3+	x	Free Ion, Al3+	x	Free Ion, Al3+	16	Free Ion, Al3+	20-44
	AlSO4 +	x	AlSO4 +	x	AlSO4 +	14	AlSO4 +	15-25
	AlOH +	x	AlOH +	x	AlOH +	x	AlOH +	x
	Al(SO4)2 -	x	Al(SO4)2 -	x	Al(SO4)2 -	3	Al(SO4)2 -	1-5
MANGANESE, Mn								
	Solid Phase	10-95	Solid Phase	25-48	Solid Phase	20	Solid Phase	0-63
	Free Ion, Mn2+	5-89	Free Ion, Mn2+	51-73	Free Ion, Mn2+	64	Free Ion, Mn2+	30-95
	MnSO4 aq	1-2	MnSO4 aq	1-2	MnSO4 aq	16	MnSO4 aq	7-13
ZINC, Zn								
	Solid Phase	9-45	Solid Phase	0-21	Solid Phase	10	Solid Phase	0-58
	Free Ion, Zn2+	52-93	Free Ion, Zn2+	75-95	Free Ion, Zn2+	67	Free Ion, Zn2+	30-95
	ZnCO3 aq	1-2	ZnCO3 aq	1-2	ZnCO3 aq	x	ZnCO3 aq	x
	ZnSO4 aq	x	ZnSO4 aq	x	ZnSO4 aq	23	ZnSO4 aq	10-16
COPPER, Cu								
	Solid Phase	44-66	Solid Phase	32-39	Solid Phase	25	Solid Phase	4-62

(continued)**Table 5.7.1** - (Continued) MINTEQA2 calculated speciation distributions for California Gulch OU6 sub-basins based on sampling station median concentrations. x = < 1% or insignificant.

Evans Gulch		South Evans Gulch		Lincoln Gulch		Stray Horse Gulch	
Species	% Range	Species	% Range	Species	% Range	Species	% Range
Free Ion, Cu2+	2-3	Free Ion, Cu2+	3-4	Free Ion, Cu2+	57	Free Ion, Cu2+	29-87
Cu(OH)2 aq	30-43	Cu(OH)2 aq	54-61	Cu(OH)2 aq	x	Cu(OH)2 aq	x
CuCO3 aq	2-3	CuCO3 aq	2-3	CuCO3 aq	x	CuCO3 aq	x
CuSO4 aq	x	CuSO4 aq	x	CuSO4 aq	17	CuSO4 aq	8-14
LEAD, Pb							
Solid Phase	83-93	Solid Phase	>78	Solid Phase	90	Solid Phase	57-93
Free Ion, Pb2+	1-4	Free Ion, Pb2+	x	Free Ion, Pb2+	5	Free Ion, Pb2+	3-32
PbSO4 aq	x	PbSO4 aq	x	PbSO4 aq	5	PbSO4 aq	3-18
PbCO3 aq	3-7	PbCO3 aq	x	PbCO3 aq	x	PbCO3 aq	x
PbOH +	1-2	PbOH +	x	PbOH +	x	PbOH +	x
ARSENIC, As							
Solid Phase	22-65	Solid Phase	24-49	Solid Phase	94	Solid Phase	60-95
H2AsO4 -	31-66	H2AsO4 -	43-65	H2AsO4 -	6	H2AsO4 -	4-38
H3AsO4	5-13	H3AsO4	8-12	H3AsO4	<1	H3AsO4	<1-3
CADMIUM, Cd							
Solid Phase	3-53	Solid Phase	21-31	Solid Phase	15	Solid Phase	0-58
Free Ion, Cd2+	44-91	Free Ion, Cd2+	65-74	Free Ion, Cd2+	58	Free Ion, Cd2+	28-87
CdCO3 aq	1-3	CdCO3 aq	1.2	CdCO3 aq	x	CdCO3 aq	x
CdSO4 aq	x	CdSO4 aq	x	CdSO4 aq	25	CdSO4 aq	12-21
Cd(SO4)2 2-	x	Cd(SO4)2 2-	x	Cd(SO4)2 2-	2	Cd(SO4)2 2-	<1-2
SILVER, Ag							
Solid Phase	x	Solid Phase	x	Solid Phase	98	Solid Phase	>95
Free Ion, Ag+	x	Free Ion, Ag+	x	Free Ion, Ag+	2	Free Ion, Ag+	x

elevated sulfate from pyrite oxidation produces a larger proportion of sulfate complexes.

ALUMINUM, Al

Al is also strongly associated with the solid phase in OU6 waters. In Evans and South Evans Gulches, the solid phase is the dominant form. In the acidified sub-basins; however, significant portions of total Al becomes associated with the free ion and sulfate complexes.

MANGANESE, Mn

Mn, while usually associated with suspended sediments, shows slightly different behavior compared to Fe and Al. While Mn is associated with particulate matter, the free ion is clearly an important form in all OU6 drainages. In the acidified, sulfate rich stations, the sulfate almost reaches 20 percent.

ZINC, Zn

Zn, which is present in all OU6 sub-basins, shows consistently large proportions of free ion (lowest observed = 30%), with most of the remainder associated with the solid phase. Minor amounts of carbonate complex are present in Evans and South Evans Gulches; however, the sulfate complex is the other major specie in the acidified sub-basins.

COPPER, Cu

Cu in Evans and South Evans Gulch was primarily associated with the solid phase and the hydroxide complex, with minor amounts of the carbonate complex. Hydroxides. however, do not form in Lincoln and Stray Horse Gulches, where the free ion assumes a more dominant role and the sulfate complex represents up to 17 percent of total mass.

LEAD, Pb

The solid phase dominates the speciation of Pb in all OU6 sub-basins. The cleaner systems showed minor amounts of free ion, hydroxide, and carbonate complexes, while the free ion and sulfate complex are the minor components of the acidified systems

ARSENIC, As

Arsenic exists as an anion in almost all aqueous systems. In Evans and South Evans Gulches, the primary solution specie is the $H_2AsO_4^-$ anion, with a significant proportion associated with the solid phase. In the acidified sub-basins, an even greater proportion (up to 95%) is associated

with the solid phase, and the higher hydrogen ion activity produces a small amount of the uncharged hydrogen arsenate H_3AsO_4.

CADMIUM, Cd — Highly toxic Cd is dominated by the free ion in all OU6 sub-basins; however, the solid phase is also important. As with Zn, the cleaner neutral pH systems show low Cd concentrations relative to the acidified systems.

SILVER, Ag — Ag was only observed in the acidified sub-basins; and even in these systems, almost all the silver is associated with the solid phase.

5.8 MINTEQA2 Mineral Saturation Indices:

Mineral saturation indices (SI), calculated for sampling station median concentrations, are numbers that indicate whether a mineral is in equilibrium, oversaturated, or undersaturated with respect to the chemical concentration data entered into MINTEQA2 for a given water. SI values near 0 suggest that the mineral is near equilibrium and that this particular mineral dissolution reaction is possibly a factor regulating the concentrations of the product ions in the water. For example, if the SI for calcite, $CaCO_3$, is near 0, then this particular reaction may be influencing the concentrations of Ca^{2+} and CO_3^{2-} in the water. SI values greater than 0 suggest that the mineral is *oversaturated,* and thus it will tend to *precipitate* the ionic components out of the water to form the particular mineral. If the SI is negative, then the mineral is *undersaturated;* and the water will tend to *dissolve* the mineral and increase the concentrations of its component ions in the water.

The cleaner, neutral pH sub-basins (EG, SEG) were generally undersaturated with respect to carbonate and sulfate minerals, oversaturated with respect to oxides and oxide-hydroxides, undersaturated with respect to hydroxide-sulfates and sulfates, and probably near equilibrium with crystalline silica minerals, but undersaturated for amorphous silica. The lower elevation stations in both clean sub-basins appeared to be near equilibrium with quartz. Except for quartz, SEG waters do not appear to be in equilibrium (near-0 SI's) with any of the table minerals. These results are consistent with the overall neutral pH and Ca-Mg-bicarbonate chemistry of EG and SEG waters.

The SI's calculated for the mine-influenced acidified sub-basins (LG, SHG) suggest that these waters were highly undersaturated with respect to carbonate minerals. The exception is the near-neutral SHG07, which showed SI's more similar to lower elevation EG stations than LG or downstream SHG stations. The acidified stations were consistently oversaturated with respect to iron oxides, hydroxides, oxide-hydroxides, and jarosite, probably because of elevated dissolved Fe. Langite and the other simple sulfates were generally undersaturated despite elevated sulfate in LG water; however SHG stations showed a clear trend

approaching near-0 equilibrium SI values in downstream stations, probably due to elevated sulfate in runoff. Acidified waters were generally oversaturated for crystalline silica minerals, but undersaturated for amorphous silica. The SI results for these sub-basins are consistent with the overall acidic pH and sulfate-dominated chemistry of these waters.

5.9 Flow-Weighted Trace Metal Loading:

Flow-weighted trace metal

Loading was calculated by multiplying the measured concentrations of each trace element by the stream flow measured during sample collection. While loading is valuable information needed to assess trace element inputs into California Gulch and the Arkansas River, the *duration* of flow must also be considered. For example, LG showed the greatest overall trace element loading values; however, this particular drainage only flows for a brief period during the runoff. On the other hand, EG, which has low loading relative to the acidic sub-basins, also flows almost continuously and thus may be a larger overall loading source on a year-round basis. This factor should help the reader to balance the obviously much greater loading observed in the acidic sub-basins (two to three orders of magnitude greater in acidified systems) relative to the clean sub-basins.

In all sub-basins, median loading generally reaches a maximum value for most trace elements the week before maximum observed runoff flow. Loading is lowest in SEG, followed by EG, and then a large increase to SHG, and then finally reaching maximum observed values in LG. Greatest loading is observed at the lowest elevation stations in each of the sub-basins, an observation that would be expected given greater watershed contact and runoff volume collected by the lower stations. Given the more continuous flows and elevated trace element concentrations observed in SHG, this sub-basin is probably the most important loading source for California Gulch.

Figure 21: Flow-weighted total trace element loading for the 1995 spring snowmelt runoff in OU6.

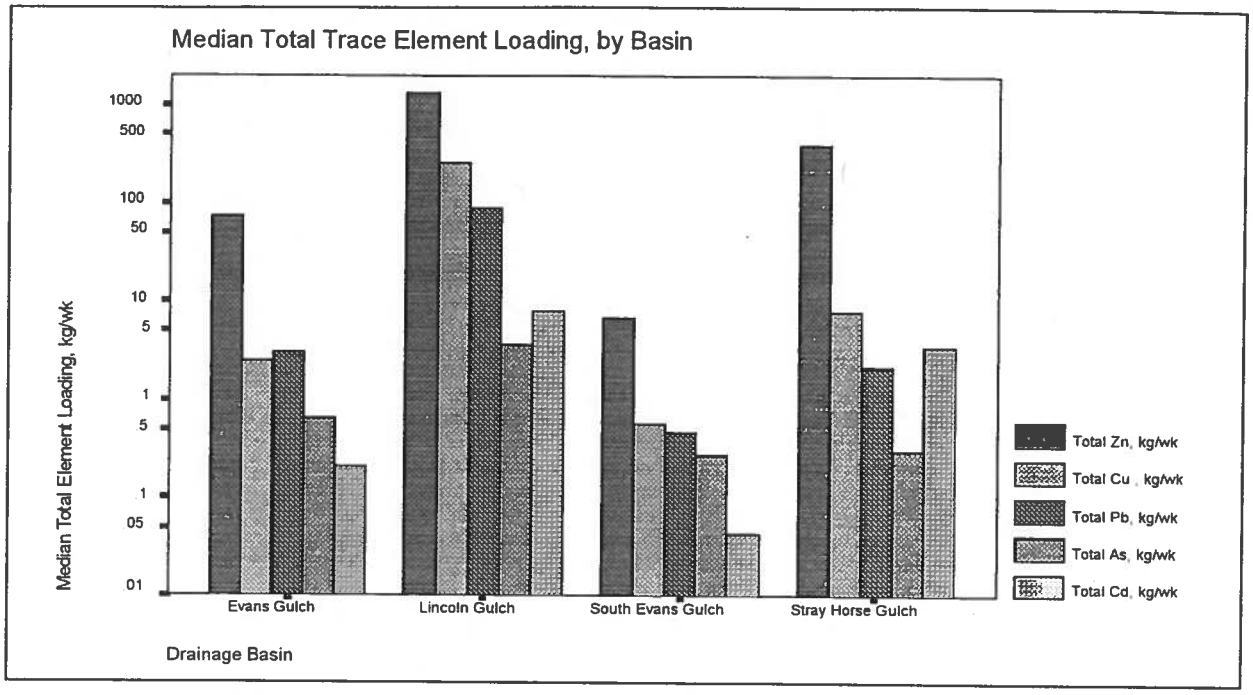
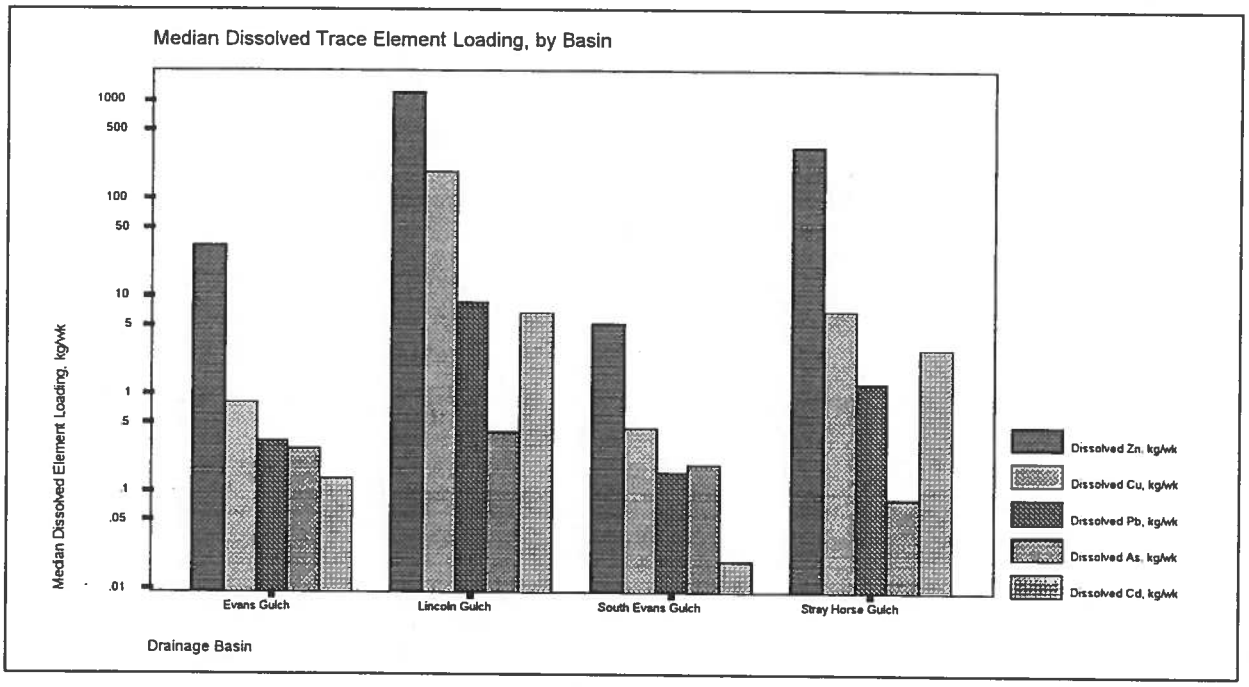
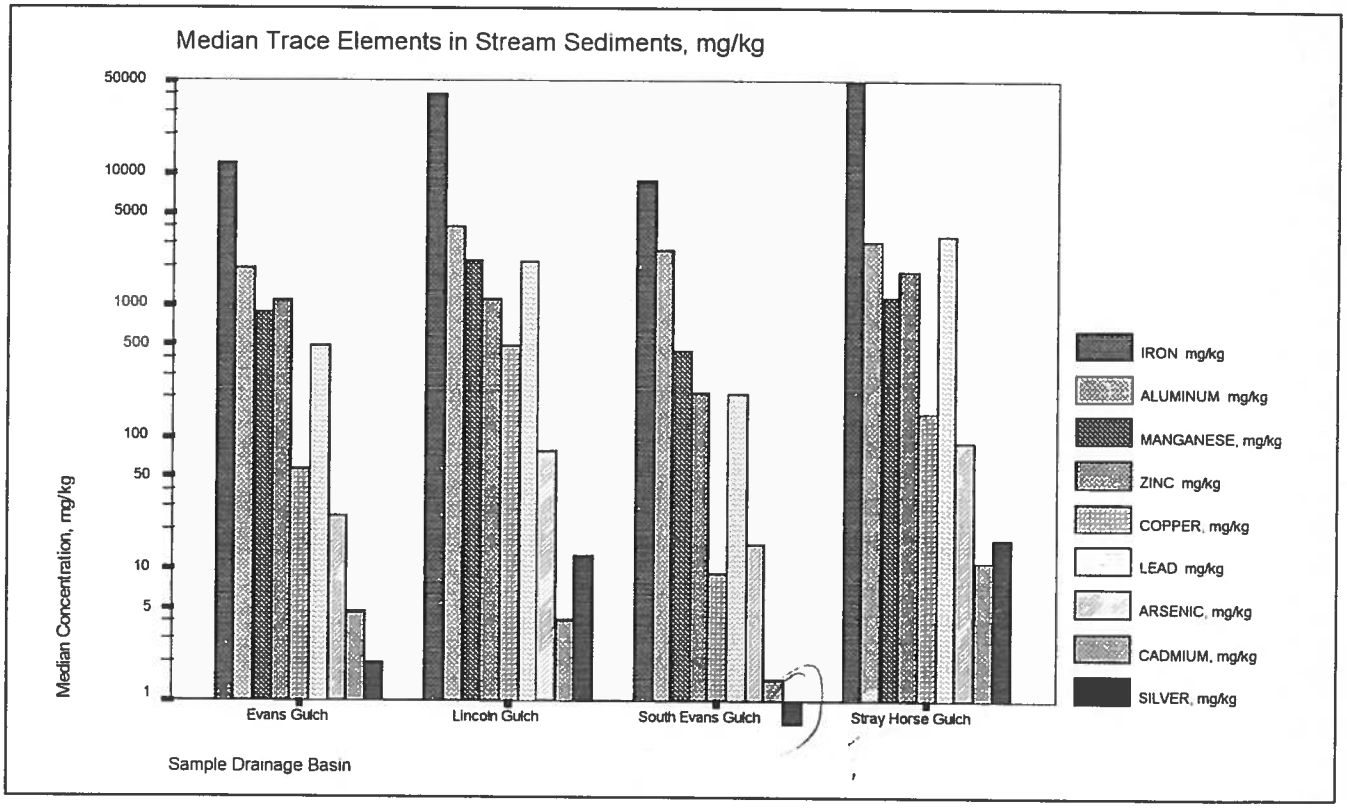


Figure 22: Flow-weighted dissolved trace element loading for the 1995 spring snowmelt runoff in OU6



5.10 Stream Bed Sediment Trace Elements:

Stream bed sediments represent a sink for suspended solids and many trace elements associated with the solid phase. Fe is known to adsorb onto suspended particulates as hydroxide complexes which then



become

effective adsorption surfaces for other trace elements.

Figure 23 -Median trace element concentrations in OU6 stream bed sediments.

Sediment concentrations appear to mirror concentrations in water with the notable exception of Pb, which shows median concentrations comparable to Zn in every sub-basin. This behavior may be explained by the observed affinity of Pb for the solid phase in water analysis results. Note that Ag concentrations are likely biased low, because the EPA Method 3051 digestion causes Ag volatilization losses.

Median stream bed sediment trace element concentrations were lowest in SEG, followed by EG, LG and then SHG. SHG shows generally greater median concentrations than LG - a reversal of the observed water analysis results - probably caused by greater runoff volumes and duration. All sub-basin sediment trace elements show a general trend towards greater concentration with lower station elevation, and this observation is consistent with exposure to greater watershed area runoff and settling of suspended solids. Stations in the vicinity of mining activity or waste piles also show increases in sediment concentrations, such as the concentration increases observed between SEG03 to SEG04 (3 to 10 times greater in SEG04), between SHG07 and SHG08, or the higher concentrations seen in EG03 relative to other upper elevation EG stations.

Table 5.10.1: Median trace element concentrations in stream bed sediments, mg/kg, (method 3051 digestion) for OU6 sub-basins.

Analyte	EG	SEG	LG	SHG
Iron, Fe	11,900	8,880	39,700	49,400
Aluminum, Al	1,890	2,590	3,930	3,090
Manganese, Mn	878	450	2,190	1,160
Zinc, Zn	1.080	217	1,110	1,840
Copper, Cu	57.2	9.30	485	149
Lead, Pb	491	212	2,150	3,360
Arsenic, As	25.1	15.4	78.0	90.5
Cadmium, Cd	4.70	1.50	4.10	11.2
Silver, Ag *	1.90	<1	12.5	16.7

* 3051 digestion not recommended for Ag

5.11 CONCLUSIONS:

Sampling of water and sediment in OU6 has identified three source areas of acid rock drainage. These are; Stray Horse Gulch, below Adelaide Park where a number of historic mines exist; Lincoln Gulch, which drains a portion of Breece Hill including the Ibex Mine complex; and a small sub-drainage entering Evans Gulch at the EG03 sampling site. This sub-drainage originates on the northwest slope of Little Ellen Hill and includes the Resurrection No. 1 and Fortune Mine waste piles and tailings. Both the Lincoln Gulch

drainage and EG03 drainages flow for a short duration during the peak of spring snowmelt and also, presumably, during large thunderstorm events. Because of dilution effects and buffering capacity of water in Evans creek, these drainages seem to have little impact on water quality in Evans. In general the drainages and source areas of acid rock drainage relflect those mine complexes identified and mapped by Emmons as mining the massive sulphide ore bodies.

Evans Gulch creek is the only perennial stream in OU6. Evans has relatively low trace metal content and a high pH. However, even in the upper reaches sampled, water in Evans does contain siginificant quantities of Zinc, Aluminum and Iron in both dissolved and suspended form. There also appears to be a significant increase in Lead in suspended form from site WE02 and EG01 below Big Evans Reservoir. There is also a significant increase in other trace metals between these two sampling sites.

Stray Horse Gulch is a significant acid rock drainage source area, carrying large quantities of dissolved and suspended trace metals in very low pH water. It is evident from the initially high concentrations during the early portion of the snowmelt runoff that the oxidation of sulphide minerals is ongoing throughout winter months in the minewaste soils of the gulch and that as snowmelt progresses the acid drainage runoff is diluted somewhat.

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