ABANDONED MINE SITE INVESTIGATION
OF THE
BULLION MINE SITE ALONG
JACK AND JILL CREEKS,
MONTANA

Prepared for:
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EXECUTIVE SUMMARY

In the fall of 2002, Bitterroot Restoration, Inc. (BRI) completed fieldwork for a site characterization of the Bullion Mine project site along Jack and Jill Creeks, which are located on Federal lands within the Basin Mining District, Montana. The purpose of the site assessment was to determine the nature and extent of potential contamination on the site, to broadly assess possible impacts to human health and the environment, and to recommend whether or not affected materials should be removed. The findings of this site investigation will help guide future efforts to manage contaminated materials in the watershed and to restore the Jack and Jill Creek drainages.

The Bullion Mine project site is located on a half-mile stretch of two tributaries, known locally as Jack and Jill Creeks. Jill Creek is a tributary to Jack Creek, while Jack Creek subsequently leads to Basin Creek, a major tributary of the Boulder River. The Basin Creek Drainage contains mining and milling waste associated with numerous historic mining and milling sites. On October 22, 1999, United States Environmental Protection Agency added the Basin Creek Drainage, including the Bullion Mine and Milling Complex, to the National Priorities List. Currently, the United States Forest Service and United States Environmental Protection Agency (EPA) are partners in a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) response action at the mine and mill site. The Jack and Jill Creek project site contains eroded tailings that have re-deposited downstream from the mine and mill site.

This characterization occurred from July 2002 through March 2003. The field investigation took place over six days, from September 23 through September 28, 2002. Fieldwork was conducted by Bitterroot Restoration, Inc. and EMC². A topographic/site features survey of the mine-waste impacted area was completed by Territorial Engineering and Surveying, a licensed professional surveying company. Data analysis and reporting occurred from March 15 to March 21, 2003.

The field initiative involved: 1) collecting nine mine waste samples and nine soil samples, as well as the field analysis of 45 mine waste samples and 46 soil samples by X-ray fluorescence (XRF); 2) collecting surface water and sediment samples from seven stream cross-sections; 3) gathering stream hydrological information; 4) estimating the volume of contaminated soils; and 5) assessing the riparian health, including the types, health, and density of riparian vegetation, as well as geomorphic features, of the injured area.

The results from this site investigation indicate that the levels of contamination in and around Jack and Jill Creeks exceed established protective limits for recreational populations. Arsenic is the major chemical of potential concern (COPC) in the system. Chemicals of potential concern are those metals present at concentrations elevated with respect to local conditions. They are determined by comparing concentrations of metals at the site to a body of data representative of local conditions unaffected by site activities (Human and Ecological Risk Division, Dept. of Toxic Substances Control, California EPA, 1997).

Seventy-two percent of soil and mine waste samples contained arsenic concentrations above chemical of potential concern limits of recreational visitors, and the average arsenic concentration in these samples was over three times higher than the concentration limits for
recreational populations. In addition, all streambed sediments collected exceeded Montana’s chemicals of potential concern soil arsenic exposure limit for recreational users of 700 parts per million. Lead concentrations are also of concern with 39 percent of soil and mine waste samples containing concentrations above chemicals of potential concern limits for recreational visitor concentrations. The surface water in Jack and Jill Creeks also shows elevated levels of chemicals of potential concern. This is the likely cause of the complete absence of observed aquatic life in the injured area on Jack and Jill Creeks. Jill Creek is more impacted than Jack Creek. Water samples from Jill Creek display concentrations of arsenic, cadmium, zinc, and lead above the Montana water quality standards for human health concentrations.

Additionally, the surface water was acidic (5.81 pH) on Jill Creek, reflecting both its closer proximity to the acid mine drainage of the Bullion Mine site, as well as the slight dilution effect occurring below the confluence with Jack Creek.

The riparian health assessments also indicate that the ecological integrity of the system is compromised. Many parts of the flood-prone zone are devoid of vegetation, likely due to the high concentrations of metals in the floodplain soils. In addition, the channels of both Jill and Jack Creeks are moderately to significantly entrenched, reflecting probable historic changes in the hydrology of the system.

Based upon the results of the site investigation, Jack and Jill Creek are significantly impacted, with levels of chemicals of potential concern in the floodplain materials, streambed sediments and water exceeding the limits for recreational exposure and human health. It is recommended that approximately 284,157 cubic feet of contaminated tailings materials be removed, the impacted stream channel and floodplain areas be reconstructed, and the impacted riparian zone be restored.
1.0 PROJECT GOALS AND OBJECTIVES

The fieldwork for a site characterization of the Bullion Mine project site along Jack and Jill Creeks, which are located on Federal lands within the Basin Mining District, Montana, was completed in the fall of 2002. The purpose of the assessment was to determine the nature and extent of potential contamination, to broadly assess possible impacts to human health and the environment, and to recommend whether or not affected materials should be removed. The findings of this investigation will help guide future efforts to manage contaminated materials in the watershed and to restore the Jack and Jill Creek drainages.

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2.0 PROJECT SETTING

The Bullion Mine project site is located on a half-mile stretch of two tributaries, known as Jack and Jill Creeks. Jill Creek is a tributary to Jack Creek, while Jack Creek subsequently leads to Basin Creek, a major tributary of the Boulder River. The creeks are part of the Basin Creek Drainage, which is within the Beaverhead-Deerlodge National Forest approximately eight miles north of Basin, Montana in Section 13 and 14 Township 7 North, and Range 6 West, Montana Principle Meridian. The site location is illustrated in Figure 1.

Elevations at the Bullion Mine site span from 6,610 to 6,790 feet (2,015 to 2,070 meters). The surrounding vegetation is dominated by coniferous forest – predominately lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmannii*), and subalpine fir (*Abies lasiocarpa*) – with numerous shrub species, including grouse whortleberry (*Vaccinium scoparium*), Labrador tea (*Ledum glandulosum*) and mountain alder (*Alnus incana*), in the understory. Drummond’s willow (*Salix drummondii*), bluejoint reedgrass (*Calamagrostis canadensis*), water sedge (*Carex aquatilis*), and field horsetail (*Equisetum arvense*) are the principal species in the wide marshy floodplains.

Average temperatures in this region range from a minimum of 8.9° F (-12.8° C) in January to a maximum of 82.2° F (27.9° C) in July. The annual average precipitation is less than 12 inches (30.5 cm) and the average annual total snowfall is between 2 and 3 feet (61 to 91 cm) (Western Regional Climate Center 2002).

Forest riparian area in Reference Reach
3.0 PROJECT BACKGROUND

The Basin Creek Drainage contains mining and milling waste associated with numerous historical mining and milling sites. On October 22, 1999, United States Environmental Protection Agency (EPA) added the Basin Creek Drainage, including the Bullion Mine and Milling Complex, to the National Priorities List. Currently, the United States Forest Service and United States EPA are partners in a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) response action at the mine and mill site. The Jack and Jill Creeks project site contains eroded tailings that have re-deposited downstream from the Bullion mine and mill. The re-deposition of eroded tailings are highly visible on the privately owned riparian corridor directly downstream of the Jack and Jill Creek project site. It is beyond the scope of this project, however, to address historic mining impacts outside of USFS boundaries.

4.0 SITE ASSESSMENT METHODS

4.1 Project Planning

The Standard Operating Procedures (SOPs), outlined in the Restoration of Abandoned Mine Sites Final Workplan (U.S. Army Corps of Engineers, Omaha District, 2002), were adhered to during the course of this field investigation: A1 (Surface Soil/Rock Sampling Equipment and Procedures); A3 (Subsurface Soil/Rock Sampling Equipment and Procedures); A4 (Soil/Rock Homogenization Equipment and Procedures); A7 (Investigative Derived Waste Procedures); A11 (Surface Water and Sediment Sampling Equipment and Procedures), A12 (Equipment Decontamination Procedures); A13 (Sample Handling, Documentation, and Tracking Procedures); and A14 (Field Documentation).

4.1.1 Health and Safety Plans

Prior to conducting fieldwork, BRI developed a health and safety plan for the Bullion project. Information on health and safety issues associated with this field effort may be found in the Bullion Site Safety and Health Plan (SSHP), Sept. 2002.

4.1.2 Sampling Methodology

Sampling plans were developed for the collection of surface water, sediment, soil, and mine waste material. Information on sampling methods followed is found in The Standard Operating Procedures (SOPs), Surface Soil/Rock Sampling Equipment and Procedures (U.S. Army Corps of Engineers, Omaha District, 2002).
4.1.3 Sample Identification Scheme

The sample identification (ID) scheme for soil and mine waste samples, described in *The Standard Operating Procedures (SOPs)* (U.S. Army Corps of Engineers, Omaha District, 2002) used the following designation.

**AB-CC-DD-EEE** where:

- **A** = Designation of sampling area location – B (For Bullion)
- **B** = T for mine tailings sample; S for soil sample
- **CC** = A numerical digit that indicates if the sample is normal, a duplicate, or a confirmation. 01 = Normal; 02 = Duplicate; 04 = Confirmation (analyzed by XRF and at the laboratory)
- **DD** = A numerical digit that indicates the depth from which the sample is extracted. 01 = between 0 and 1 foot; 02 = greater than 1 foot to 2 feet; 03 = greater than 2 feet to 3 feet; 04 = greater than 3 feet to 4 feet;
- **EEE** = two or three digit sample identification number

For example, a confirmation soil sample collected from a depth of 1.5 feet at the Bullion Mine site would be coded B-S-0402100. The last three digits (100) are the sample identification number.

The sample ID scheme for water and stream sediment samples used the designation below.

**AA-CSB-CCC** where:

- **AA** = Designation of sampling area location – MT (For Bullion, in Montana)
- **CSB** = Three character identification code that identifies the sample with the subreach where it was collected. CS stands for “Cross-Section.”
- **CCC** = Identifies if the sample is water (H2O) or sediment (SED)

For example, a sediment sample collected from Subreach C at the Bullion Mine site in Montana would be coded MT-CSC-SED.

4.2 Field Investigation Activities

This investigation occurred from July 2002 through March 2003. The field investigation, described in the *Site Specific Addendum to RAMS General Work Plan and Safety and Health Plan for Bullion Mine* (Bitterroot Restoration, Inc. [BRI], 2002), took place over six days, from September 23 through September 28, 2002. The first project task involved developing sampling and safety plans in mid-summer 2002. Fieldwork was conducted by BRI and EMC². A topographic/site features survey of the mine waste impacted area was completed by Territorial Engineering and Surveying, Inc., a licensed professional surveying company. Data analysis and reporting occurred from March 15 to March 21, 2003.

Upon arrival at the project site, the field team first delineated the boundary of the injured area. The field team then collected mine waste, soil, surface water, and sediment data; estimated the depth and extent of contaminated material; and completed riparian health assessments. Finally, Territorial Engineering and Surveying, Inc. created a topographic site map on one-foot contours,
delineated areas of interest, and surveyed all sampling locations (See Appendix B). Field notes from the field investigation are contained in Appendix A.

4.3 Boundary Delineation

Delineating the project boundary first involved a physical examination of the project site. Boundary limits were based upon visual clues regarding the extent of contamination including: the absence of ground cover; type, quantity, and diversity of plant species; the location of the flood plain; old stream channels; tailings/waste materials; and erosion features on either side of the stream. Boundaries were subsequently confirmed or relocated according to contamination levels recorded with X-ray Fluorescence (XRF). White flags were placed every 100 feet along the border of the project site. Boundaries were used to determine the extent of the survey, to delineate the riparian assessment survey subreaches, and to provide XRF sampling boundaries. Sampling location coordinates, obtained from a hand-held Garmin Etrex Global Positioning System (GPS) device with an accuracy of 15 meters, were recorded in the field logbook. The boundaries and sampling locations were also mapped by Territorial Engineering and Surveying, Inc. The survey met minimum conventional theodolite traverse control standards (third order geodetic control and 1:5000 accuracy).

In addition to boundary determinations, the project area was divided into seven subreaches, which are displayed in Figure 2. Subreach boundaries were based on hydrologic and geomorphic changes within the stream channel, distinct changes in mine waste deposition, and by vegetation characteristics within the riparian zone. Subreaches are described below sequentially from the top (highest elevation) boundary on Jill Creek to the lower boundary on Jack Creek at the USFS property line.

**Subreach A** is located at the top boundary of the injured area on Jill Creek. This short segment ranges from 6774 feet to 6790 feet in elevation. It is characterized as a boulder/step pool stream sequence with a steep incline and a narrow floodplain. The riparian zone associated with this subreach should be lush and somewhat impenetrable. Instead, it is sparsely vegetated, consisting of bare ground and numerous dead lodgepole pine, Engelmann spruce, and subalpine fir. The large, woody debris is making its way to the channel area.

**Subreach B**, located on Jill Creek directly below Subreach A, is characterized as a boulder/log cascade sequence with a very steep incline. Elevations range from 6714 to 6774 feet. The vegetation types and characteristics are similar to those described in Subreach A.

**Subreach C** is characterized as a woody debris stream sequence with a moderate incline. With elevations ranging from 6664 to 6714 feet, this subreach is located on Jill Creek directly below Subreach B. The floodplain in this subreach widens dramatically to encompass extensive woody debris stream sequence, Subreach C
overflow channels on the right side of the stream.

**Subreach D** runs from a logjam on Jill Creek below Subreach C to the confluence of Jack and Jill Creeks. With elevations ranging from 6645 to 6664 feet, it is characterized as a boulder/step pool stream sequence with a steep incline and moderate floodplain width. It is braided with a side channel on the right (looking downstream), and an inundated zone on the left (looking downstream) that is composed of wetland graminoids. Similar to Subreaches A, B, and C, Subreach D is sparsely vegetated.

**Subreach E** starts at the confluence of Jack and Jill Creeks. The highest elevation on this subreach is 6664 feet, while the lowest is 6622 feet. It is characterized as a flat, moderately wide, highly braided stream delta. The additional discharge from Jack Creek has flushed the floodplain relatively free of tailings.

**Subreach F**, situated directly below Subreach E, is characterized as a slow-moving logjam stream sequence with a moderate incline. The elevation ranges from 6616 to 6622 feet. The surrounding floodplain zone is wide and contains a historic beaver dam complex. Large tailings piles exist here, and the current system has cut back down to an equilibrium channel elevation.

**Subreach G** has a moderate incline, with elevations ranging from 6607 to 6616 feet. The lower boundary of this subreach is defined by the USFS property line, and the upper boundary is immediately below the main beaver complex (Subreach F). This subreach has healthier, denser plant life and a more typical stream morphology than the subreaches described above. The surrounding floodplain zone is wide and marshy.
4.4 Mine Waste and Soil Sampling

The field investigation involved the collection of nine mine waste samples and nine soil samples, as well as the field analysis of 45 mine waste samples and 46 soil samples by XRF following EPA Method 6200. Sample locations are displayed and numbered on the map in Figure 3. The field distinction between “mine wastes” and “soils” was based upon a cursory field assessment of textural and color properties. The mine waste sampling locations were located on and around mine waste tailings piles, while the soil samples were collected from soils underlying or adjacent to mine waste materials. These areas included surface soils in places exposed to runoff/erosion from waste areas and/or soils beneath waste piles. The sampling sites, located at cross-sections along the contaminated stream, were designed to determine the types and amounts of contamination. For the most part, sampling locations were evenly distributed throughout the site. The exception was that representative mine waste piles were sampled. Composite samples were extracted to a maximum depth of one meter (39.4 inches). The samples were composited by mixing them in a clean container (a new heavy gauge plastic “trash compactor” bag for each sample, lining a five-gallon plastic bucket).

All samples were analyzed for total metals concentration using a Spectrace 9000 portable XRF, which allows for an on-site rapid assessment of the elemental spectrum. The XRF’s detection limits, precision, and accuracy are provided in Appendix F. Additionally, a subset of 18 confirmation samples, co-located with the XRF sampling sites, was analyzed for total metals. (Laboratory analyses for chemicals of potential concern (COPC) concentrations occurred via atomic emission spectrometry (EPA Methods 200.2 series)).

Field analysis for total metals concentration using an XRF

water extractable metals, pH, electrical conductivity and Acid-Base Accounting (ABA). Total metal concentration results from the 18 co-located sites were used for confirmatory analysis and to calibrate the XRF against the more accurate laboratory-analyzed samples. Following collection, laboratory samples, each weighing approximately one kilogram, were stored in individually sealed containers and shipped on ice to SVL Analytic in Kellogg, Idaho for analysis. Standard Chain of Custody (COC) procedures were followed to track and identify the individual samples. COC procedures are described in SOP A13 – Sample Handling, Documentation, and Tracking Procedures.

4.5 Surface Water Sampling

A total of seven representative sites, located along cross-sections within each subreach, were sampled within the area of potential mine waste impact. Cross-section locations are displayed and numbered on the map in Figure 2. Surface water sampling was performed to monitor stream water volumes, flows, and analyte concentrations. Surface water quality analyses included total
metals concentrations, hardness, temperature, and pH. Laboratory analyses for COPC concentrations occurred via atomic emission spectrometry (EPA Methods 200.7 series).

At each cross-section, the stream channel was subdivided into one to 10 segments of equal length depending on the width of the channel. The depth of the stream was measured in the middle of each segment. Velocity measurements were obtained from each stream segment using an FP201 Global Flow Probe hand-held flow meter with a five- to 15-foot expandable handle. Velocity readings were measured in feet per second with accuracies of plus-or-minus 0.1 feet per second for instantaneous velocity and plus-or-minus 0.01 feet per second for average and maximum velocity.

Velocity readings were determined by extending the flow meter handle to the appropriate length and placing the probe in the center of the channel of each stream segment within the respective cross-sections. The flow probe was moved slowly back and forth from the top of the water surface to the bottom of the channel for a minimum of one-minute to obtain a vertical flow profile. The average flow velocity for the stream cross-section, along with the date and time was recorded in the field logbook. The stream discharge was calculated by first determining the cross-sectional area of each stream channel segment, then multiplying the average velocity by the cross-sectional area, and finally averaging together the discharge of each segment to obtain a total stream discharge. Where flows are below the instrument’s Limit of Detection (LOD) of 0.3 feet per second, flows are estimated as half the difference between zero and the LOD (e.g., 0.15 feet per second).

Stream temperature and pH measurements were collected using a waterproof Hanna instruments HI-9023 microcomputer pH and temperature meter. The pH meter is accuracy to 0.01 units and its collection capabilities range from 0.00 to 14.00 pH. The temperature meter can record temperatures ranging from 32 to 212 degrees Fahrenheit. It is accurate to 0.7 degrees Fahrenheit. The instrument was calibrated before each set of samples was obtained. To use the instrument, the probe was placed in the stream at the cross-section. Keeping the probe submerged, it was moved it slowly back and forth across the stream until the pH and temperature readings stabilized (approximately 2 minutes). The results were recorded into a permanent notebook.

Surface water samples were collected at each of the seven cross-sections with a depth-integrated wading device and were placed in sample containers supplied by SVL. To operate the wading device, it was moved up and down through the water column at set locations across the stream for a predetermined timeframe that depended on the stream size. The device was calibrated to collect equal amounts of water through the water column and across the stream. All excess water was disposed of by pouring gently out on the stream bank adjacent to the sampling location.

Once collected, the water samples were immediately preserved with nitric acid. The filled sample bottles and jars were labeled as specified in the The Standard Operating Procedures.
(SOPs), (U.S. Army Corps of Engineers, Omaha District, 2002). The labeled bottles were placed in ice chests and cooled to approximately 4°C with the appropriate chain-of-custody paperwork. The cooler was shipped by overnight mail to SVL Analytic in Kellogg, Idaho.

4.6 Sediment Samples

Seven streambed sediment samples were collected from the streambed directly under the surface water sampling location. Samples, gathered at depths ranging from one-half inch to four inches, were collected in the interstices of cobbles with a stainless steel spoon. The samples were labeled and stored in one-liter sample containers provided by SVL Analytical with the appropriate chain-of-custody paperwork. The samples were shipped by overnight mail to SVL Analytic in Kellogg, Idaho. Laboratory analyses followed EPA Method 200.7.

4.7 Riparian Health Assessment

Riparian assessments were conducted with a focus on vegetative health. The rationale for looking at vegetation data is that the condition of plants in the riparian zone is a major component in determining the vigor of riparian ecosystems (Hansen, et al., 1995).

Riparian health assessments were conducted along four stream reaches in the injured area and one Reference Reach upstream of the injured area. Each Riparian Reach was representative of unique stream and vegetation characteristics found on Jack and Jill Creeks. The riparian vegetation is uniform over the entire length of the injured area on Jill Creek, thus, it was classified in the field as a single Riparian Reach. The hydrologic characteristics differ from the top to the bottom of the creek. Ultimately, Jill Creek was merged into one Riparian Reach, corresponding with Subreaches A through D, which are described in Section 4.3 Boundary Delineation of this report. Riparian Reach E, located at the confluence of Jack and Jill Creeks, corresponds with Subreach E. Riparian Reaches F and G correspond with Subreaches F and G, respectively.

Detailed vegetation data, physical site data, some wildlife data, trend commentary, and photograph were collected. The vegetation data gathered included species identification and canopy cover estimations, as well as age class breakdowns for each tree and shrub species. Physical site data included channel morphology and condition, substrate composition, disturbance degree and kind, amount and cause of bare ground, and commentary. Wildlife data included details of beaver activity and observations of fishery, amphibian, and reptile data.

The riparian inventory data collected for this project was originally gathered on the entire riparian zone, which extends laterally out to the valley toe slope foot. This area includes both the near-channel zone of mine tailing deposits, and a wide outer band on both sides unimpacted by these tailings contaminants. Subsequently, the width dimension was adjusted to reflect only the narrower floodplain impacted by deposition of mine tailings. The species data was also adjusted by eliminating those species found only under the forest canopy at the outer edge of the riparian zone. These steps were undertaken to reflect conditions within the narrower impacted zone, as opposed to the entire riparian habitat area.
The assessment used was developed by Dr. Paul Hansen and his team at the Riparian and Wetland Research Program, University of Montana at Missoula. Refer to Bitterroot Restoration’s riparian and wetland website (http://bitterrootrestoration.com/index.html) for more information on the methodology used to conduct the riparian health assessments.

4.8 Rosgen Stream Classification—Level II

Reaches of stream channel may be classified according to morphological characteristics that reflect the stream’s capacity to store/transport sediment. The relevant parameters, in order of importance, are channel slope, channel pattern, channel material size, the ratio of channel width to depth, the entrenchment ratio, and channel sinuosity (Rosgen 1996).

The bankfull channel width, flood prone width, the maximum and mean stream depths at bankfull stage, and the average channel material size were measured at a representative cross section within each subreach. These measurements were used to determine the width-to-depth ratio (bankfull width divided by bankfull mean depth), the width of the flood prone area (the flood prone area is defined as the area of floodplain inundated by a flood that reaches a depth twice the maximum bankfull stage depth), and the entrenchment ratio (entrenchment is the ratio of width of the channel at bankfull stage and that of the flood prone area). The channel material size was visually estimated within each subreach.

The channel slope and channel pattern data were derived in Geographic Information System (GIS) from the one-foot contour survey map. For each subreach of stream classified, average channel slope was determined as the percent drop (rise/run). The change in elevation and the segment length were used for this calculation. Channel pattern refers to sinuosity and number of threads (split around islands or a single stream body). Sinuosity was calculated as the ratio of channel length to valley length for the reach. These parameters are described by Rosgen (1996) and the calculations are in Appendix C.

4.9 Volume of Contaminated Material

The thickness and the extent of mine wastes were determined through soil core sampling. These calculations were used to estimate the volume of impacted floodplain materials. The soil depth/characteristics were examined at 100 sampling locations that were taken along 24 transects that intersected with mine waste and/or soil testing sites. Each transect ran from the stream edge to the site boundary. Sample locations are portrayed on Figure 4. To obtain representative depths of mine tailings across the cross section, sample locations were spaced apart 15 to 20 feet. Soil core samples were obtained with a soil auger. Soil was examined to a maximum depth of 3 feet. In many cases, water or river cobbles above 3 feet were encountered. Soil cores were divided into sections determined by variations in color and composition. The depth of each section to either cobbles or the water table was then measured and recorded. Data supporting the mine waste volume estimates are contained in Appendix D.

To obtain volume measurements, the soil depth for each sample was entered into GIS and interpolated across the injured area. When analyzing the field data, it was found that the
FIGURE 4
Soil Core Sampling Locations
Bullion Mine Site

Used to Estimate the Volume of Contaminated Soil

Scale 1 : 1,700
sampling density was insufficient for GIS interpolation, so the density of points was increased using ArcView 3.2, a GIS software, following the assumptions listed below:

- All locations in the streambed equal zero. In other words, no materials would be excavated from the actual streambed and no material would be removed below groundwater level.
- For a given contour line, the removal depths are equal at the site boundary on stream right and stream left.
- No material would be excavated from sampling locations with COPC levels below the recreation levels described in Table 6-1.

4.10 Topographic/Site Features Survey

A Topographic/Site Features Survey of the mine-waste impacted area was completed by Territorial Engineering and Surveying, Inc. and is found in Appendix B. The site was mapped on a local coordinate system using traditional surveying methods. Key points were mapped in latitude/longitude using a survey grade (sub-centimeter accurate) Global Positioning System (GPS) unit. The survey met minimum conventional theodolite traverse control standards (third order geodetic control and 1:5000 accuracy). In addition to constructing a survey with one-foot contours of the injured area, the surveying team mapped features of interest (old beaver dams, for example), stream cross-sections, and mine waste and soil sampling locations.

4.11 Quality Assurance and Control

Quality Control (QC) procedures used for mine wastes, soil, and water testing were consistent with methods described by the EPA and the *The Standard Operating Procedures (SOPs)* (U.S. Army Corps of Engineers, Omaha District, 2002). All samples collected in the field were prepared with appropriate COC documentation, including sample logs, sample identification (ID) numbers, and appropriate seals.

All samples were individually sealed in plastic bags prior to shipment. Mine waste and soil sample containers were wrapped in bubble wrap or other protective wrapping and stored in plastic boxes. Upon collection, nitric acid (reagent grade) was added to all water samples. The samples were immediately placed in ice chests and cooled to 4°C or less. Boxes and ice chests were taped shut and sealed with custody seals. COC forms were signed as relinquished and sealed in bags and taped inside each box. COC forms were reviewed and signed by the laboratory upon receipt. The laboratory sent the final analytical results to BRI.

Field notes were kept in bound, waterproof notebooks. Notes were written in waterproof ink or pencil. Sample numbers were transferred to COC forms.

QC of the XRF analysis followed EPA Standard Operating Procedure No. 1713 (1995). The XRF calibration procedures included verification of potential multiple soil matrix types. Matrix differences, such as large variations in calcium or iron content, may affect XRF measurements.
5.0 LABORATORY ANALYSIS

5.1 Mine Waste and Soil Analysis

Eighteen confirmation samples, co-located with the XRF sampling sites, were analyzed for total metals. Data from the 18 co-located sites were used to calibrate the XRF against the more accurate laboratory-analyzed samples. Samples were analyzed in a laboratory via atomic emission spectrometry (see Table 5.1 below). In addition, the confirmation samples were assessed for acid generating potential (Acid-Base accounting).

<table>
<thead>
<tr>
<th>Target Constituent</th>
<th>Analytical Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>EPA M200.2 ICP-Total metals</td>
</tr>
<tr>
<td>Cadmium</td>
<td>EPA M200.2 ICP-Total metals</td>
</tr>
<tr>
<td>Copper</td>
<td>EPA M200.2 ICP-Total metals</td>
</tr>
<tr>
<td>Lead</td>
<td>EPA M200.2 ICP-Total metals</td>
</tr>
<tr>
<td>Zinc</td>
<td>EPA M200.2 ICP-Total metals</td>
</tr>
</tbody>
</table>

In addition, six mine waste samples (surface rock/soil samples) were analyzed for water extractable metals (Table 5.2).

<table>
<thead>
<tr>
<th>Target Constituent</th>
<th>Analytical Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>EPA M200.7 ICP-water-extractable</td>
</tr>
<tr>
<td>Cadmium</td>
<td>EPA M200.7 ICP-water-extractable</td>
</tr>
<tr>
<td>Copper</td>
<td>EPA M200.7 ICP-water-extractable</td>
</tr>
<tr>
<td>Lead</td>
<td>EPA M200.2 ICP-water-extractable</td>
</tr>
<tr>
<td>Zinc</td>
<td>EPA M200.7 ICP-water-extractable</td>
</tr>
</tbody>
</table>

5.2 Surface Water and Sediment Analysis

Table 5.3 presents target metals for the surface water and streambed sediment samples.

<table>
<thead>
<tr>
<th>Target Constituent</th>
<th>Analytical Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>EPA M200.2 ICP-Total metals</td>
</tr>
<tr>
<td>Cadmium</td>
<td>EPA M200.2 ICP-Total metals</td>
</tr>
<tr>
<td>Copper</td>
<td>EPA M200.2 ICP-Total metals</td>
</tr>
<tr>
<td>Lead</td>
<td>EPA M200.2 ICP-Total metals</td>
</tr>
<tr>
<td>Zinc</td>
<td>EPA M200.2 ICP-Total metals</td>
</tr>
<tr>
<td>pH</td>
<td>EPA M150.1</td>
</tr>
<tr>
<td>Conductivity</td>
<td>EPA M120.1</td>
</tr>
</tbody>
</table>
Sample analysis followed the quality control criteria set by the Environmental Chemistry Branch Laboratory and/or as per the Final Work Plan, Restoration of Abandoned Mine Sites, June 2002. Laboratory QC data are included with the raw analytic results in Appendix E.

**6.0 DATA SCREENING CRITERIA**

### 6.1 Mine Waste and Soil Standards

This report concentrates on five COPCs for recreational users: Arsenic, Cadmium, Copper, Lead, and Zinc. These COPCs are the standard suite of contaminants investigated on minelands in western Montana and northern Idaho. The remoteness of the site suggests that recreationists will be the population most likely to visit. The EPA’s exposure limits for recreational users, presented in Table 6.1, govern contact to the COPCs in soil material. The primary exposure pathways are soil contact, inhalation and water ingestion. The standards assume that potential carcinogenic and non-carcinogenic health risks vary between recreational populations. The cleanup guidelines used in this report are based on a Hazard Index of 0.5 or an increased cancer risk of $5 \times 10^{-4}$. The latter is the carcinogenic risk for the gold panner/rock hound recreational population (Tetra Tech, 1996).

**TABLE 6.1 EPA CLEANUP GUIDELINES FOR FIVE CHEMICALS OF POTENTIAL CONCERN FOR RECREATIONAL VISITORS**

<table>
<thead>
<tr>
<th>COPC</th>
<th>Arsenic</th>
<th>Cadmium</th>
<th>Copper</th>
<th>Lead</th>
<th>Zinc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Ingestion/Inhalation Cleanup Guideline (mg/kg)*</td>
<td>700</td>
<td>19,500</td>
<td>27,100</td>
<td>1,100</td>
<td>220,000</td>
</tr>
</tbody>
</table>

* Concentrations for Arsenic and Cadmium are based on an increased cancer risk of $5 \times 10^{-4}$, while Copper, Lead, and Zinc are based on a Hazard Index of 0.5.

### 6.2 Surface and Groundwater Standards

Table 6.2 presents water quality guidelines for the COPCs for this study. These standards govern exposure to COPCs by water ingestion.

**TABLE 6.2  WATER QUALITY GUIDELINES**

<table>
<thead>
<tr>
<th>COPC</th>
<th>Montana DEQ Water Quality Standards Aquatic Life</th>
<th>Montana DEQ Water Quality Standards Human Health</th>
<th>Required Reporting Value</th>
<th>EPA National Primary Drinking Water Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acute</td>
<td>Chronic</td>
<td>Surface Water</td>
<td>Groundwater</td>
</tr>
<tr>
<td>Arsenic</td>
<td>340</td>
<td>150</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>Cadmium</td>
<td>1.05*</td>
<td>0.16*</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Copper</td>
<td>7.3</td>
<td>5.2</td>
<td>1,300</td>
<td>1,300</td>
</tr>
<tr>
<td>Lead</td>
<td>82**</td>
<td>3.2**</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Zinc</td>
<td>67*</td>
<td>67*</td>
<td>2,000</td>
<td>2,000</td>
</tr>
</tbody>
</table>

All values stated as micrograms/liter (µg/L)

* @ 50 mg/L hardness
** @ 100 mg/L hardness
7.0 RESULTS AND DISCUSSION

7.1 Mine Waste and Soil Results and Discussion

This investigation resulted in the collection of nine soil and nine mine waste samples, which were analyzed for total metals via ICP, water extractable metals, pH, conductivity and Acid-Base Accounting. In addition, 91 soil and mine waste samples were analyzed for total metals concentrations via XRF. Data for all lab analyses are in Appendix E, and XRF field analyses data are included in Appendix F.

An initial review of the results of the analysis, presented in Table 7.1, suggested little to no difference between the soil and mine waste samples. A Student’s t-Test was utilized to examine whether this observation was statistically relevant (see Appendix G). As also shown in Table 7.1, there was no significant difference in analytic values between the soil and mine waste samples at alpha = 0.05. This is likely due to the mixing of materials as a result of the disturbance ecology of the creek systems as well as to leaching of COPCs from mine wastes into pre-disturbance substrates. For the purpose of the remainder of the analyses, analytic results from the soil and mine waste samples were condensed into a single data set.

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Soil*</th>
<th>Mine Waste*</th>
<th>t-Value</th>
<th>p-Value**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic (total mg/kg by ICP)</td>
<td>1,609 (2,015)</td>
<td>2,941 (2,247)</td>
<td>-1.32</td>
<td>0.20</td>
</tr>
<tr>
<td>Cadmium (total mg/kg by ICP)</td>
<td>5 (8)</td>
<td>1 (1)</td>
<td>1.53</td>
<td>0.15</td>
</tr>
<tr>
<td>Copper (total mg/kg by ICP)</td>
<td>464 (471)</td>
<td>178 (160)</td>
<td>1.73</td>
<td>0.10</td>
</tr>
<tr>
<td>Lead (total mg/kg by ICP)</td>
<td>887 (1,433)</td>
<td>1,526 (1,193)</td>
<td>-1.03</td>
<td>0.32</td>
</tr>
<tr>
<td>Zinc (total mg/kg by ICP)</td>
<td>429 (508)</td>
<td>157 (91)</td>
<td>1.59</td>
<td>0.13</td>
</tr>
<tr>
<td>Arsenic (total mg/kg by XRF)</td>
<td>1,978 (2,676)</td>
<td>2,866 (3,056)</td>
<td>-0.66</td>
<td>0.52</td>
</tr>
<tr>
<td>Cadmium (total mg/kg by XRF)</td>
<td>152 (122)</td>
<td>102 (37)</td>
<td>1.18</td>
<td>0.26</td>
</tr>
<tr>
<td>Copper (total mg/kg by XRF)</td>
<td>233 (177)</td>
<td>314 (268)</td>
<td>-0.76</td>
<td>0.46</td>
</tr>
<tr>
<td>Lead (total mg/kg by XRF)</td>
<td>867 (1,370)</td>
<td>1,101 (1,107)</td>
<td>-0.40</td>
<td>0.70</td>
</tr>
<tr>
<td>Zinc (total mg/kg by XRF)</td>
<td>316 (270)</td>
<td>194 (109)</td>
<td>1.26</td>
<td>0.23</td>
</tr>
<tr>
<td>Arsenic (mg/kg water extractable by ICP)</td>
<td>1 (2)</td>
<td>0 (0)</td>
<td>0.72</td>
<td>0.51</td>
</tr>
<tr>
<td>Cadmium (mg/kg water extractable by ICP)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>1.08</td>
<td>0.34</td>
</tr>
<tr>
<td>Copper (mg/kg water extractable by ICP)</td>
<td>1 (1)</td>
<td>0 (0)</td>
<td>1.00</td>
<td>0.38</td>
</tr>
<tr>
<td>Lead (mg/kg water extractable by ICP)</td>
<td>1 (1)</td>
<td>0 (0)</td>
<td>0.87</td>
<td>0.44</td>
</tr>
<tr>
<td>Zinc (mg/kg water extractable by ICP)</td>
<td>12 (19)</td>
<td>0 (0)</td>
<td>1.04</td>
<td>0.36</td>
</tr>
<tr>
<td>pH (standard units)</td>
<td>4 (0)</td>
<td>4 (0)</td>
<td>2.04</td>
<td>0.06</td>
</tr>
<tr>
<td>Conductivity</td>
<td>381 (738)</td>
<td>115 (65)</td>
<td>1.08</td>
<td>0.30</td>
</tr>
<tr>
<td>Total Sulfur (total mg/kg)</td>
<td>0 (1)</td>
<td>0 (0)</td>
<td>0.62</td>
<td>0.54</td>
</tr>
<tr>
<td>Pyritic Sulfur (total mg/kg)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0.85</td>
<td>0.41</td>
</tr>
<tr>
<td>Sulfate Sulfur (total mg/kg)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0.37</td>
<td>0.71</td>
</tr>
<tr>
<td>Non-extractable Sulfur (total mg/kg)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>1.30</td>
<td>0.21</td>
</tr>
<tr>
<td>Acid generating potential</td>
<td>4 (9)</td>
<td>1 (1)</td>
<td>0.84</td>
<td>0.41</td>
</tr>
<tr>
<td>Acid neutralizing potential</td>
<td>5 (3)</td>
<td>4 (3)</td>
<td>0.82</td>
<td>0.43</td>
</tr>
<tr>
<td>Acid-Base potential</td>
<td>1 (10)</td>
<td>3 (4)</td>
<td>-0.37</td>
<td>0.71</td>
</tr>
</tbody>
</table>

* Mean and standard deviation are reported as #(#)
** Significant difference at alpha = 0.05
7.1.1 Total Metals from Field XRF Results

Table 7.2 presents total metal concentrations statistics for the soil and mine waste samples collected from Jack and Jill Creeks as analyzed by field XRF. In general, the XRF trends for these elements tend to follow the results of the laboratory analyses, although cadmium concentrations via XRF are an order of magnitude higher than the laboratory results.

| COPCs | Average Sample Concentration from Jack and Jill Creeks (mg/kg)* | Minimum Sample Concentration from Jack and Jill Creeks (mg/kg) | Maximum Sample Concentration from Jack and Jill Creeks (mg/kg) | Screening Criteria for Recreational Visitors (mg/kg) | Percent of 18 samples above COPC limits for Recreational Visitors
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>2,422 (2,823)</td>
<td>104</td>
<td>9240</td>
<td>700</td>
<td>56 percent</td>
</tr>
<tr>
<td>Cadmium</td>
<td>127 (91)</td>
<td>90</td>
<td>458</td>
<td>19,500</td>
<td>0 percent</td>
</tr>
<tr>
<td>Copper</td>
<td>274 (224)</td>
<td>36</td>
<td>680</td>
<td>27,100</td>
<td>0 percent</td>
</tr>
<tr>
<td>Lead</td>
<td>984 (1,214)</td>
<td>15</td>
<td>4191</td>
<td>1,100</td>
<td>28 percent</td>
</tr>
<tr>
<td>Zinc</td>
<td>255 (209)</td>
<td>35</td>
<td>882</td>
<td>220,000</td>
<td>0 percent</td>
</tr>
</tbody>
</table>

* Mean and standard deviation are reported as #(##)
** Shading indicates exceedance of screening criteria.

7.1.2 Total Metals from Laboratory Results

Table 7.3 presents mean total metal concentrations for the soil and mine waste samples collected from Jack and Jill Creeks. The results indicate that while arsenic and lead are significant metals of concern, arsenic is the major contributor in this system. In all cases where lead exceeds recreational exposure limits, arsenic is also exceeded, but arsenic levels may exceed exposure limits without a simultaneous exceedance in lead concentrations (Figures 4 and 5).

<table>
<thead>
<tr>
<th>COPCs</th>
<th>Average Sample Concentration from Jack and Jill Creeks (mg/kg)</th>
<th>Minimum Sample Concentration from Jack and Jill Creeks (mg/kg)</th>
<th>Maximum Sample Concentration from Jack and Jill Creeks (mg/kg)</th>
<th>Screening Criteria for Recreational Visitors (mg/kg)</th>
<th>Percent of 18 samples above COPC limits for Recreational Visitors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>2,275 (2,181)</td>
<td>82.2</td>
<td>6220</td>
<td>700</td>
<td>72 percent</td>
</tr>
<tr>
<td>Cadmium</td>
<td>3 (6)</td>
<td>0.2</td>
<td>24.7</td>
<td>19,500</td>
<td>0 percent</td>
</tr>
<tr>
<td>Copper</td>
<td>321 (372)</td>
<td>42.1</td>
<td>1280</td>
<td>27,100</td>
<td>0 percent</td>
</tr>
<tr>
<td>Lead</td>
<td>1,207 (1,321)</td>
<td>50.9</td>
<td>4620</td>
<td>1,100</td>
<td>39 percent</td>
</tr>
<tr>
<td>Zinc</td>
<td>293 (380)</td>
<td>43.4</td>
<td>1750</td>
<td>220,000</td>
<td>0 percent</td>
</tr>
</tbody>
</table>

* Shading indicates exceedance of screening criteria.

7.1.3 Statistical Comparison of XRF Results and Laboratory Results

A least squares regression analysis was utilized to determine whether the apparent trend is statistically significant. EPA Method 6200 stipulates that the correlation coefficient (R-squared) between ICP and XRF data needs to be greater than 0.7 for the XRF data to be considered
Abandoned Mine Site Investigation – Bullion Mine, Jack & Jill Creeks, Montana 7/28/03

**FIGURE 5**
Arsenic Concentration at Soil Sampling Locations
Bullion Mine Site

Scale 1: 1,700
Abandoned Mine Site Investigation – Bullion Mine, Jack & Jill Creeks, Montana 7/28/03

FIGURE 6
Lead Concentration at Soil Sampling Locations
Bullion Mine Site

Scale 1 : 1,700
screening level data. The method also stipulates that if the data range spans greater than one magnitude, a log scale shall be used for analysis. As both data sets for all elements range across multiple magnitudes, a log-log correction was utilized. Least squares regression analysis, which was utilized to determine whether the apparent trend is statistically significant, is described in Appendix G. As shown in Table 7.4, a comparison of the two log-corrected data sets via least squares regression analysis indicates a poor relationship between results obtained by the two methods.

<table>
<thead>
<tr>
<th>COPCs</th>
<th>R² for regression line</th>
<th>p-Value of regression line</th>
<th>R for regression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>0.338</td>
<td>0.01*</td>
<td>0.58</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.116</td>
<td>0.17</td>
<td>0.34</td>
</tr>
<tr>
<td>Copper</td>
<td>0.200</td>
<td>0.06</td>
<td>0.45</td>
</tr>
<tr>
<td>Lead</td>
<td>0.374</td>
<td>0.007*</td>
<td>0.61</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.631</td>
<td>&lt;0.0001*</td>
<td>0.79</td>
</tr>
</tbody>
</table>

*Statistical significance at alpha = 0.05

While three of five regression analyses are statistically significant at alpha = 0.05, in no case is the correlation coefficient sufficiently strong to permit the analytic results via XRF to be used as screening level data. Nonetheless, the moderately strong correlations (0.25 < R < 0.8) for all elements, and particularly for zinc, lead and arsenic, indicate that the XRF data supports the more limited laboratory results data set and suggests that the Jack and Jill Creek floodplains contain significantly elevated levels of arsenic and lead.

### 7.1.4 Water-Extractable Metals Results for Soils and Mine Wastes

Table 7.5 presents water-extractable metal concentrations statistics for the soil and mine waste samples collected from Jack and Jill Creeks, as analyzed by EPA Method 200.7. Zinc has the highest concentration, which is to be expected given that it is among the most soluble of trace elements. All samples fell below Montana Department of Environmental Quality’s water quality standards for human health.

<table>
<thead>
<tr>
<th>COPCs</th>
<th>Average Sample Concentration from Jack and Jill Creeks (mg/kg)*</th>
<th>Minimum Sample Concentration from Jack and Jill Creeks (mg/kg)</th>
<th>Maximum Sample Concentration from Jack and Jill Creeks (mg/kg)</th>
<th>Surface Water Threshold Concentration (mg/kg) for Human Health Concerns (MT DEQ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>0.7 (1.3)</td>
<td>0.005</td>
<td>3.4</td>
<td>18</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.1 (0.2)</td>
<td>0.001</td>
<td>0.4</td>
<td>5</td>
</tr>
<tr>
<td>Copper</td>
<td>0.4 (0.5)</td>
<td>0.035</td>
<td>1.3</td>
<td>1,300</td>
</tr>
<tr>
<td>Lead</td>
<td>0.3 (0.7)</td>
<td>0.003</td>
<td>1.6</td>
<td>15</td>
</tr>
<tr>
<td>Zinc</td>
<td>6.0 (13.2)</td>
<td>0.124</td>
<td>33.0</td>
<td>2,000</td>
</tr>
</tbody>
</table>

* Mean and standard deviation are reported as #(#)

---

**TABLE 7.4 LEAST SQUARES COMPARISON OF LOG-CORRECTED METAL CONCENTRATIONS VIA ICP AND FIELD XRF**

**TABLE 7.5 WATER-EXTRACTABLE METAL CONCENTRATIONS OF SOILS AND MINE WASTES VIA ICP**
7.1.5 pH and Conductivity Results for Soils and Mine Wastes

Table 7.6 presents pH and conductivity statistics for the soil and mine waste samples collected from Jack and Jill Creeks. All samples had highly acidic values. Five of the 18 samples had values less than 3.5 standard units, a level of extreme acidity where acid sulfates can be readily present (see 7.1.6 Acid-Base Accounting Results for Soils and Mine Wastes below). Twelve of the samples had pH values between 3.5 and 4.5, a level of high acidity at which exchangeable aluminum can be significantly phytotoxic.

**TABLE 7.6 pH AND CONDUCTIVITY VALUES OF SOILS AND MINE WASTES**

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Average Sample Values from Jack and Jill Creeks*</th>
<th>Minimum Average Sample Values from Jack and Jill Creeks</th>
<th>Maximum Average Sample Values from Jack and Jill Creeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (standard units)</td>
<td>3.82 (0.48)</td>
<td>2.98</td>
<td>4.74</td>
</tr>
<tr>
<td>Conductivity (µmho/cm)</td>
<td>248 (526)</td>
<td>54.2</td>
<td>2340</td>
</tr>
</tbody>
</table>

* Mean and standard deviation are reported as #(#)

There are two major diagnostic thresholds that use soil electrical conductivity as a prime measure. Conductivity of greater than 2,000 µmho/cm @ 25°C is one of the indications of an Aridisol, while conductivity of greater than 4,000 µmho/cm @ 25°C defines a saline soil (Boul and others 1989). Only one sample from Jack and Jill Creek exceeds the 2,000 µmho/cm threshold. Soil salinity is not a significant problem in these soils.

7.1.6 Acid-Base Accounting Results for Soils and Mine Wastes

Table 7.7 presents Acid-Base Accounting results for the soils and mine wastes from Jack and Jill Creeks. The most significant results are the Acid-Base Potential values. Three of 18 samples displayed negative Acid-Base Potential values, indicating that they are acid generating. While the floodplain materials are strongly acidic, the acid generating potential of these materials is being exhausted.

**TABLE 7.7 ACID-BASE ACCOUNTING RESULTS FOR SOILS AND MINE WASTES**

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Average Sample Values from Jack and Jill Creeks*</th>
<th>Average Sample Values from Jack and Jill Creeks</th>
<th>Maximum Average Sample Values from Jack and Jill Creeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total sulfur (mg/kg)</td>
<td>0.15 (0.38)</td>
<td>0.01</td>
<td>1.67</td>
</tr>
<tr>
<td>Pyritic sulfur (mg/kg)</td>
<td>0.08 (0.20)</td>
<td>0.01</td>
<td>0.86</td>
</tr>
<tr>
<td>Sulfate sulfur (mg/kg)</td>
<td>0.07 (0.18)</td>
<td>0.005</td>
<td>0.75</td>
</tr>
<tr>
<td>Non-extractable sulfur (mg/kg)</td>
<td>0.01 (0.01)</td>
<td>0.005</td>
<td>0.06</td>
</tr>
<tr>
<td>Acid generating potential (TCaCO₃/1000T)</td>
<td>2.4 (6.2)</td>
<td>0.15</td>
<td>26.9</td>
</tr>
<tr>
<td>Acid neutralizing potential (TCaCO₃/1000T)</td>
<td>4.3 (2.9)</td>
<td>1.08</td>
<td>9.29</td>
</tr>
<tr>
<td>Acid-Base potential (TCaCO₃/1000T)</td>
<td>2.0 (7.3)</td>
<td>-24.3</td>
<td>8.67</td>
</tr>
</tbody>
</table>

* Mean and standard deviation are reported as #(#)
7.2 Surface Water Quality Results and Discussion

Seven water quality samples were collected and analyzed for total metals, pH, temperature, and hardness. The results of these analyses are shown in Table 7.8 and Figure 6. A review of the results suggested that there was a significant difference between values for Jack Creek and Jill Creek.

**TABLE 7.8 WATER SAMPLE RESULTS**

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Average Sample Values from Jack and Jill Creeks*</th>
<th>Minimum Sample Values from Jack and Jill Creeks</th>
<th>Maximum Sample Values from Jack and Jill Creeks</th>
<th>Average Sample Values from Jack Creek*</th>
<th>Average Sample Values from Jill Creek*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic (dissolved metal mg/L)</td>
<td>30 (43)</td>
<td>5</td>
<td>126</td>
<td>8 (5)</td>
<td>47 (53)</td>
</tr>
<tr>
<td>Cadmium (dissolved metal mg/L)</td>
<td>29 (18)</td>
<td>8</td>
<td>44</td>
<td>10 (1)</td>
<td>43 (2)</td>
</tr>
<tr>
<td>Copper (dissolved metal mg/L)</td>
<td>480 (314)</td>
<td>121</td>
<td>798</td>
<td>149 (25)</td>
<td>729 (67)</td>
</tr>
<tr>
<td>Lead (dissolved metal mg/L)</td>
<td>10 (13)</td>
<td>3</td>
<td>39</td>
<td>3 (0)</td>
<td>16 (15)</td>
</tr>
<tr>
<td>Zinc (dissolved metal mg/L)</td>
<td>3,066 (1,880)</td>
<td>869</td>
<td>4680</td>
<td>1,060 (167)</td>
<td>4,570 (100)</td>
</tr>
<tr>
<td>pH (standard units)</td>
<td>6.5 (0.9)</td>
<td>5.61</td>
<td>7.48</td>
<td>7.4 (0.05)</td>
<td>5.81 (0.2)</td>
</tr>
<tr>
<td>Temperature (° F)</td>
<td>44.3 (4.5)</td>
<td>40.5</td>
<td>49.1</td>
<td>43.6 (4.8)</td>
<td>44.75 (4.9)</td>
</tr>
<tr>
<td>Hardness (mg/L)</td>
<td>79.9 (23.8)</td>
<td>51.3</td>
<td>99.7</td>
<td>54.6 (2.8)</td>
<td>98.90 (0.9)</td>
</tr>
</tbody>
</table>

* Mean and standard deviation are reported as #(#)

A Student’s t-Test was utilized to examine whether the apparent differences were statistically relevant (See Appendix G). Also shown in Table 7.9, there was a significant difference in all analytic values between most sediment analytic results at alpha = 0.05 except for total arsenic and lead concentrations and water temperature.

**TABLE 7.9 COMPARISON OF WATER SAMPLE RESULTS JACK CREEK VERSUS JILL CREEK**

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Average Sample Values from Jack Creek*</th>
<th>Average Sample Values from Jill Creek*</th>
<th>t-Value</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic (dissolved metal mg/L)</td>
<td>8 (5)</td>
<td>47 (53)</td>
<td>-1.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Cadmium (dissolved metal mg/L)</td>
<td>10 (1)</td>
<td>43 (2)</td>
<td>-28.5</td>
<td>&lt;0.0001**</td>
</tr>
<tr>
<td>Copper (dissolved metal mg/L)</td>
<td>149 (25)</td>
<td>729 (67)</td>
<td>-13.9</td>
<td>&lt;0.0001**</td>
</tr>
<tr>
<td>Lead (dissolved metal mg/L)</td>
<td>3 (0)</td>
<td>16 (15)</td>
<td>-1.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Zinc (dissolved metal mg/L)</td>
<td>1,060 (167)</td>
<td>4,570 (100)</td>
<td>-35.0</td>
<td>&lt;0.0001**</td>
</tr>
<tr>
<td>pH (standard units)</td>
<td>7.4 (0.05)</td>
<td>5.8 (0.2)</td>
<td>16.3</td>
<td>&lt;0.0001**</td>
</tr>
<tr>
<td>Temperature (° F)</td>
<td>43.6 (4.8)</td>
<td>44.8 (4.9)</td>
<td>-0.3</td>
<td>0.8</td>
</tr>
<tr>
<td>Hardness (mg/L)</td>
<td>54.6 (2.8)</td>
<td>98.9 (0.9)</td>
<td>-30.2</td>
<td>&lt;0.0001**</td>
</tr>
</tbody>
</table>

* Mean and standard deviation are reported as #(#)

**Statistically significant difference at alpha = 0.05**

Jill Creek lies upstream of Jack Creek and therefore closer to the source of mine wastes and acid mine drainage from the Bullion Mine Adit and has a significantly lower pH and higher concentration of metals than Jack Creek. The probable cause for this trend is that the metals under consideration generally show greater solubility at lower pH levels. Arsenic, a metalloid,
has the reverse relationship, with its solubility increasing as pH increases. Increases of arsenic solubility are not as significant until pH values increase above the ranges measured in the two drainages. This last factor is a likely explanation for no significant change in dissolved arsenic concentration between Jack and Jill Creek.

While Jill Creek exceeds Jack Creek in percent of water samples above water quality standards for human health, all water samples exceeded cadmium standards (Table 7.10).

**TABLE 7.10 WATER QUALITY SAMPLE COMPLIANCE WITH HUMAN HEALTH STANDARDS**

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Montana DEQ Water Quality Standards for Human Health</th>
<th>Percent of Samples Above MT DEQ Water Quality Standards for Human Health: Jack Creek</th>
<th>Percent of Samples Above MT DEQ Water Quality Standards for Human Health: Jill Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic (dissolved metal mg/L)</td>
<td>0.018</td>
<td>29</td>
<td>50</td>
</tr>
<tr>
<td>Cadmium (dissolved metal mg/L)</td>
<td>0.005</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Copper (dissolved metal mg/L)</td>
<td>1.300</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lead (dissolved metal mg/L)</td>
<td>0.015</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Zinc (dissolved metal mg/L)</td>
<td>2.000</td>
<td>57</td>
<td>100</td>
</tr>
</tbody>
</table>

With the exception of arsenic, all of the COPC values from the Jack and Jill Creeks water samples exceeded the chronic values recommended in the Montana DEQ aquatic life water quality standards. Cadmium, copper, and zinc concentrations exceeded the aquatic life criterion acute values (Table 7.11).

**TABLE 7.11 WATER QUALITY SAMPLE COMPLIANCE WITH AQUATIC LIFE STANDARDS**

<table>
<thead>
<tr>
<th>Analyses</th>
<th>MT DEQ Water Quality Standards for Aquatic Life</th>
<th>Percent of Samples Above MT DEQ Water Quality Standards for Aquatic Life: Jack Creek</th>
<th>Percent of Samples Above MT DEQ Water Quality Standards for Aquatic Life: Jill Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic (dissolved metal mg/L)</td>
<td>0.340</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cadmium (dissolved metal mg/L)</td>
<td>0.00105*</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Copper (dissolved metal mg/L)</td>
<td>0.0073</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Lead (dissolved metal mg/L)</td>
<td>0.082**</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Zinc (dissolved metal mg/L)</td>
<td>0.067*</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

* @ 50 mg/L hardness  
** @ 100 mg/L hardness
7.3 Streambed Sediment Results and Discussion

Seven sediment samples were collected and analyzed for total metals, pH and conductivity. The results of these analyses, shown in Table 7.12, indicated that there was a significant difference in sediment samples between Jack and Jill Creeks.

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Average Sample Values from Jack and Jill Creeks*</th>
<th>Minimum Sample Values from Jack and Jill Creeks</th>
<th>Maximum Sample Values from Jack and Jill Creeks</th>
<th>Average Sample Values from Jack Creek*</th>
<th>Average Sample Values from Jill Creek*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic (total metal mg/kg)</td>
<td>1,804 (483)</td>
<td>1180</td>
<td>2480</td>
<td>1,367 (306)</td>
<td>2,133 (262)</td>
</tr>
<tr>
<td>Cadmium (total metal mg/kg)</td>
<td>27 (14)</td>
<td>13.6</td>
<td>51.6</td>
<td>40 (10)</td>
<td>16 (2)</td>
</tr>
<tr>
<td>Copper (total metal mg/kg)</td>
<td>1,051 (375)</td>
<td>653</td>
<td>1790</td>
<td>1,093 (610)</td>
<td>1,020 (171)</td>
</tr>
<tr>
<td>Lead (total metal mg/kg)</td>
<td>673 (160)</td>
<td>466</td>
<td>876</td>
<td>514 (57)</td>
<td>793 (68)</td>
</tr>
<tr>
<td>Zinc (total metal mg/kg)</td>
<td>2,021 (1,070)</td>
<td>1110</td>
<td>4060</td>
<td>3,000 (927)</td>
<td>1,288 (200)</td>
</tr>
<tr>
<td>pH (standard units)</td>
<td>6 (1)</td>
<td>5.83</td>
<td>6.94</td>
<td>7 (0.1)</td>
<td>6 (0.1)</td>
</tr>
<tr>
<td>Conductivity (µmho/cm)</td>
<td>390 (55)</td>
<td>317</td>
<td>445</td>
<td>366 (63)</td>
<td>409 (48)</td>
</tr>
</tbody>
</table>

* Mean and standard deviation are reported as #(#)

A Student’s t-Test was utilized to examine whether the apparent differences were statistically relevant. Also shown in Table 7.13, there was a significant difference in all analytic values between most sediment analytic results at alpha = 0.05, except for total copper concentration and conductivity.

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Average sample value from Jack Creek*</th>
<th>Average sample value from Jill Creek*</th>
<th>t-Value</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic (total metal mg/kg)</td>
<td>1,367 (306)</td>
<td>2,133 (262)</td>
<td>-3.6</td>
<td>0.02*</td>
</tr>
<tr>
<td>Cadmium (total metal mg/kg)</td>
<td>40 (10)</td>
<td>16 (2)</td>
<td>4.8</td>
<td>0.01*</td>
</tr>
<tr>
<td>Copper (total metal mg/kg)</td>
<td>1,093 (610)</td>
<td>1,020 (171)</td>
<td>0.2</td>
<td>0.82</td>
</tr>
<tr>
<td>Lead (total metal mg/kg)</td>
<td>514 (57)</td>
<td>793 (68)</td>
<td>-5.8</td>
<td>0.002*</td>
</tr>
<tr>
<td>Zinc (total metal mg/kg)</td>
<td>3,000 (927)</td>
<td>1,288 (200)</td>
<td>3.7</td>
<td>0.01*</td>
</tr>
<tr>
<td>pH (standard units)</td>
<td>7 (0.1)</td>
<td>6 (0.1)</td>
<td>14.5</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>Conductivity (µmho/cm)</td>
<td>366 (63)</td>
<td>409 (48)</td>
<td>-1.0</td>
<td>0.35</td>
</tr>
</tbody>
</table>

* Mean and standard deviation are reported as #(#)

These trends in sediment do not parallel those from the surface water results. While Jill Creek exhibits more acidic sediments and higher lead concentrations than Jack Creek, Jill Creek has higher arsenic concentrations but lower cadmium and zinc concentrations than Jack Creek. As pH increases downstream, metals such as cadmium and zinc may become less mobile and precipitate, while arsenic may become more mobile and therefore may be reduced in relative concentration along Jack Creek.

Exhibited in Table 7.14, all sediment samples from both Jack and Jill Creeks exceed Montana’s 700 ppm soil arsenic concentration limits for recreational visitors. The remaining COPCs
examined for this investigation were in compliance with EPA cleanup guidelines for recreationalists.

**TABLE 7.14 COMPLIANCE WITH EPA CLEANUP GUIDELINES FOR RECREATIONALISTS**

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Soil Ingestion/Inhalation Cleanup Guidelines (mg/kg)</th>
<th>Percent of Samples Above EPA Soil Ingestion/Inhalation Guidelines: Jack and Jill Creeks</th>
<th>Percent of Samples Above EPA Soil Ingestion/Inhalation Guidelines: Jack Creek</th>
<th>Percent of Samples Above EPA Soil Ingestion/Inhalation Guidelines: Jill Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>700</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Cadmium</td>
<td>19,500</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Copper</td>
<td>27,100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lead</td>
<td>1,100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Zinc</td>
<td>220,000</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

7.4 Riparian Health Assessment

Table 7.15 illustrates the functional scores and habitat/community types found on the project site. Functional scores, ranging from zero to 100 percent, were derived by rating riparian vegetation and soil/hydrology conditions. A stream that scores between 100 and 80 percent is considered in proper functioning condition (healthy). Scores between 79 and 60 percent indicate that the stream is functional, but at-risk of degradation (healthy, but with problems). Nonfunctioning (unhealthy) streams score below 60 percent. The vegetation and soil/hydrology factors assessed included diversity, cover, and regeneration of vegetation, as well as the amount of bare ground present, and the condition of the stream banks. A healthy stream system supports dense vegetation that is regenerating and has little to no exposed ground. The stream banks do not experience much erosion due to armoring from large rocks and binding root mass. This assessment/scoring system, developed by Dr. Paul Hansen, is thoroughly described on BRI’s riparian and wetland website ([http://bitterrootrestoration.com/index.html](http://bitterrootrestoration.com/index.html)).

The vegetation within the project site scored between 63 and 70 percent, which is considered functional, but at-risk of further degradation. The soils and hydrology, with scores between 73 and 87 percent, is also functional, but at-risk of further degradation. In contrast, the reference reach, located approximately one-half mile above the Jack and Jill Creek confluence, scored 93 percent for vegetation health and 90 percent for soil/hydrology health. The Reference Reach is therefore considered as functional and healthy.

The most common vegetation community type identified across the Reference Reach, the four Riparian Reaches on Jill Creek, and one Riparian Reach on Jack Creek consists of Engelmann Spruce (*Picea engelmannii*) (overstory) and Bluejoint Reedgrass (*Calamagrostis canadensis*) (understory). Significant portions of Riparian Reaches A through D and Riparian Reach E are unvegetated. These bare areas are categorized as an “Unclassified” habitat/community type. Riparian Reaches F and G, located on slower moving, meandering stream sections of Jack Creek, are dominated by the Subalpine Fir (*Abies lasiocarpa*) (overstory) and Bluejoint Reedgrass (*Calamagrostis canadensis*) (understory) habitat type. Both Riparian Reaches host a second habitat type – Drummond Willow (*Salix drummondiana*) (overstory), and Beaked Sedge (*Carex*...
rostrata) (understory) for Riparian Reach 5 and Planeleaf Willow (*Salix planifolia*) (overstory), Water Sedge (*Carex aquatilis*) (understory) for Riparian Reach G. The riparian health assessments for the Bullion project are provided in Appendix C.

### TABLE 7.15 RIPARIAN HEALTH ASSESSMENT RESULTS, FUNCTIONAL SCORES, & HABITAT TYPES

<table>
<thead>
<tr>
<th>Location</th>
<th>Vegetation</th>
<th>Soil/Hydrology</th>
<th>Overall Health</th>
<th>Habitat/Community Type 1</th>
<th>Habitat/Community Type 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Reach</td>
<td>93</td>
<td>90</td>
<td>91</td>
<td>Engelmann Spruce/Bluejoint Reedgrass</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Jill Creek</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riparian Reach A</td>
<td>70</td>
<td>73</td>
<td>72</td>
<td>Engelmann Spruce/Bluejoint Reedgrass</td>
<td>Unclassified</td>
</tr>
<tr>
<td>Riparian Reach B</td>
<td>70</td>
<td>73</td>
<td>72</td>
<td>Engelmann Spruce/Bluejoint Reedgrass</td>
<td>Unclassified</td>
</tr>
<tr>
<td>Riparian Reach C</td>
<td>70</td>
<td>73</td>
<td>72</td>
<td>Engelmann Spruce/Bluejoint Reedgrass</td>
<td>Unclassified</td>
</tr>
<tr>
<td>Riparian Reach D</td>
<td>70</td>
<td>73</td>
<td>72</td>
<td>Engelmann Spruce/Bluejoint Reedgrass</td>
<td>Unclassified</td>
</tr>
<tr>
<td><strong>Jack Creek</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riparian Reach E</td>
<td>63</td>
<td>80</td>
<td>72</td>
<td>Engelmann Spruce/Bluejoint Reedgrass</td>
<td>N/A</td>
</tr>
<tr>
<td>Riparian Reach F</td>
<td>70</td>
<td>60</td>
<td>65</td>
<td>Subalpine Fir/Bluejoint Reedgrass</td>
<td>Drummond’s Willow/Beaked Sedge</td>
</tr>
<tr>
<td>Riparian Reach G</td>
<td>70</td>
<td>87</td>
<td>79</td>
<td>Subalpine Fir/Bluejoint Reedgrass</td>
<td>Planeleaf Willow/Water Sedge</td>
</tr>
</tbody>
</table>

#### 7.5 Hydrologic and Geomorphic Characteristics (Rosgen Stream Classification—Level II)

From a topographic and geomorphic perspective, Jill and Jack Creeks are very different. Jill Creek, a tributary of Jack Creek flows down a steep mountainside. Jack Creek flows through a valley with moderate to gentle slopes and a fairly wide floodplain. These differences are reflected in the hydrologic measurements described below. Riparian Reaches A through C on Jill Creek exhibit very low discharges. The rate increases significantly on Riparian Reach D, probably due to a series of springs toward the bottom of this section. Discharge is at its highest, 1.86 cubic feet per second (cfs), at the confluence of Jack and Jill Creeks (Riparian Reach E). It steadily declines thereafter. Water diffusion into the broad hydrology of the beaver dam complex may account for the decline.

The stream gradient decreases as one moves downstream, from an average of 8.5 percent on Jill Creek to 2.3 percent on Jack Creek. Sinuosity scores also reflect the topographic differences.
between Jack and Jill. The average sinuosity of Jill is 1.07; it increases to 1.23 on Jack Creek where the stream has room to meander. The flood-prone width widens from an average of 46 feet on Jill to 69 feet on Jack Creek.

The Rosgen stream typing method was used to characterize stream Riparian Reach morphology on Jack and Jill Creeks.

- **Rosgen Stream Types A4/A4+:** Riparian Reaches A through D on Jill Creek were rated as A4 or A4a+. Briefly described, an A4 and A4a+ streams are cascading step/pool sequences that are steep, confined, and entrenched. These high-energy systems with low sinuosity are capable of heavy debris transport. The substrate materials are mainly composed of gravel.

- **Rosgen Stream Type B:** Riparian Reach E at the top of Jack Creek, is a B3 Rosgen stream type. It has a moderate gradient with moderate entrenchment, and moderate to high sinuosity. It is dominated by riffles with infrequently spaced pools. The substrate material is principally cobbles. Riparian Reach F, located directly below Riparian Reach E, is a B4 Rosgen stream type. It has a moderate gradient with moderate entrenchment, and moderate to high sinuosity. It is dominated by riffles with infrequently spaced pools. The substrate material is principally gravel.

- **Rosgen Stream Type C:** Riparian Reach G at the bottom of the injured area on Jack Creek is classified as a C3 Rosgen stream type. C3 stream reaches tend to reside in broad valley with floodplains and alluvial soils. These moderately sloped, meandering reaches have moderate to high sinuosity, and are associated with riffle/pool bed morphology. Cobbles are the main substrate material.

Analytical data are presented in Table 7.16 below.

**TABLE 7.16 HYDROLOGIC AND GEOMORPHIC CHARACTERISTICS**

<table>
<thead>
<tr>
<th>Location</th>
<th>Discharge (ft³/sec)</th>
<th>Flood prone Width (ft)</th>
<th>Slope (%)</th>
<th>Sinuosity</th>
<th>Rosgen Stream Type</th>
<th>Channel Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jill Creek averages</td>
<td>0.41</td>
<td>46</td>
<td>8.5</td>
<td>1.07</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Riparian Reach A</td>
<td>0.12</td>
<td>17.6</td>
<td>8</td>
<td>1.12</td>
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<td>Gravel</td>
</tr>
<tr>
<td>Riparian Reach B</td>
<td>0.19</td>
<td>48.50</td>
<td>12</td>
<td>1.09</td>
<td>A4a+</td>
<td>Gravel</td>
</tr>
<tr>
<td>Riparian Reach C</td>
<td>0.03</td>
<td>81.2</td>
<td>8</td>
<td>1.04</td>
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<td>Gravel</td>
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<tr>
<td>Riparian Reach D</td>
<td>1.32</td>
<td>36.3</td>
<td>6</td>
<td>1.05</td>
<td>A4</td>
<td>Gravel</td>
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<tr>
<td>Jack Creek averages</td>
<td>1.21</td>
<td>69</td>
<td>2.3</td>
<td>1.23</td>
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<td>N/A</td>
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<td>Riparian Reach E</td>
<td>1.86</td>
<td>42.7</td>
<td>3</td>
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<td>Cobbles</td>
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<td>2</td>
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<td>Riparian Reach G</td>
<td>0.93</td>
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7.6 Volume Estimate of Contaminated Materials

Based upon methods previously discussed, the following field estimate of contaminated materials recommended for removal was developed for the Bullion site. These figures were not calculated using formal engineering tools and are not intended to take the place of a thorough engineering estimate and cost analysis. They are presented to give stakeholders a general idea of the volume of contaminated materials present at the Bullion project site.

As Table 7.17 portrays, the materials exceeding screening criteria are spread fairly evenly across the site. With the exception of subreaches A and D, approximately 50,000 cubic feet of mine waste and soils are recommended for removal in each subreach. The total amount of contaminated materials is estimated at 284,157 cubic feet.

<table>
<thead>
<tr>
<th>Volume (ft.$^3$)</th>
<th>Subreach A</th>
<th>Subreach B</th>
<th>Subreach C</th>
<th>Subreach D</th>
<th>Subreach E</th>
<th>Subreach F</th>
<th>Subreach G</th>
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<tr>
<td>7,610</td>
<td>48,914</td>
<td>53,109</td>
<td>15,876</td>
<td>50,428</td>
<td>56,896</td>
<td>51,324</td>
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8.0 CONCLUSIONS

The results from this site investigation indicate that the levels of contamination in and around Jack and Jill Creeks exceed established protective limits for recreational populations. Arsenic is the major COPC in the system. Seventy-two percent of soil and mine waste samples contained arsenic concentrations above screening criteria for recreational visitors, and the average arsenic concentration in these samples was over 3 times higher than the limits. In addition, all streambed sediments collected exceeded Montana’s soil arsenic exposure limit of 700 ppm. Lead concentrations for 39 percent of soil and mine waste samples exceeded the screening criteria for recreational visitors.

The surface water in Jack and Jill Creeks also shows elevated levels of metals. This is the likely cause of the complete absence of observed aquatic life in the injured area on Jack and Jill Creeks. Jill Creek is more heavily impacted than Jack Creek. Water samples from Jill Creek display concentrations of arsenic, cadmium, zinc, and lead above the Montana water quality standards for human health. Additionally, the surface water was acidic on Jill Creek, reflecting both its closer proximity to the acid mine drainage of the Bullion Mine site, as well as the slight dilution effect occurring below the confluence with Jack Creek.

The riparian health assessments also indicate that the ecological integrity of the system is compromised. Many parts of the flood-prone zone are devoid of vegetation, likely due to the high concentrations of metals in the floodplain soils. In addition, the channels of both Jill and Jack Creeks are moderately to significantly entrenched, reflecting probable historic changes in the hydrology of the system.

Based upon its site investigation, BRI therefore concludes that Jack and Jill Creek are significantly impacted, with levels of COPCs in the floodplain materials, streambed sediments and water exceeding the limits for recreational exposure and human health. The removal of
approximately 284,157 cubic feet of contaminated tailings materials, the reconstruction of the impacted stream channel and floodplain areas, and the restoration of the impacted riparian zone are recommended.
9.0 REFERENCES


APPENDICES

For

ABANDONED MINE SITE INVESTIGATION
OF THE
BULLION MINE SITE ALONG
JACK AND JILL CREEKS,
MONTANA

Prepared for:
U.S. Army Corps of Engineers, Sacramento District and
U.S. Army Corps of Engineers, Omaha District

Prepared By:
Bitterroot Restoration, Inc.
445 Quast Lane
Corvallis, MONTANA  59828

July 7, 2003
Appendix A.
Bullion Investigative Field Notes
Appendix B.
Topographic/Site Features Survey of the Impacted Area at Bullion Mine
Appendix C.
Riparian Assessment Data
and
Rosgen Stream Classification Calculations
### SUMMARY OF CROSS SECTION DATA
**Bullion Mine Site**

<table>
<thead>
<tr>
<th>Cross-Section</th>
<th>Channel Area (ft²)</th>
<th>Discharge (cfs)</th>
<th>Floodplain width (ft)</th>
<th>pH</th>
<th>Temperature</th>
<th>Gradient</th>
<th>Sinuosity</th>
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<td>64.92</td>
<td>7.4</td>
<td>41.18</td>
<td>2%</td>
<td>1.46</td>
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<td>Variable</td>
<td>Cross Section A</td>
<td>Cross Section B</td>
<td>Cross Section C</td>
<td>Cross Section D</td>
<td>Cross Section E</td>
<td>Cross Section F</td>
<td>Cross Section G</td>
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<td>---------------------------</td>
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<td>-----------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>bankfull width (ft)</td>
<td>8.66</td>
<td>9.78</td>
<td>12.00</td>
<td>9.50</td>
<td>12.50</td>
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<td>11.42</td>
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<td>bankfull mean depth (ft)</td>
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<td>0.81</td>
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<td>10.23</td>
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<td>0.6 - 2.5 in. (coarse gravel)</td>
<td>0.6 - 2.5 in. (coarse gravel)</td>
<td>0.6 - 2.5 in. (coarse gravel)</td>
<td>2.5 - 5 (small cobbles)</td>
<td>0.6 - 2.5 in. (coarse gravel)</td>
<td>2.5 - 5 (small cobbles)</td>
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<td>water surface slope (rise/run)</td>
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<td>12%</td>
<td>8%</td>
<td>6%</td>
<td>3%</td>
<td>2%</td>
<td>2%</td>
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<td>channel sinuosity</td>
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<td>1.04</td>
<td>1.05</td>
<td>1.03</td>
<td>1.21</td>
<td>1.46</td>
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Appendix D.
Volume of Contaminated Material Calculations
Soil Core Sampling Locations
Bullion Mine Site

Used to Estimate the Volume of Contaminated Soil

- Volume Transects
- Jack & Jill Creeks
- Contours (1 ft.)
- Subreach boundaries
- Control points
- Stream cross-sections

Bitterroot Restoration
Soil Core Sampling Locations
Bullion Mine Site
Used to Estimate the Volume of Contaminated Soil

Interpolated Depth of Contaminated Soil

- 0.00
- 0.15
- 0.30
- 0.50
- 0.70
- 0.90
- 1.15
- 1.45
- 1.75
- 2.05
- 2.35
- 2.65
- 2.90

Volume Transects
Jack & Jill Creeks
Contours (1 ft.)
Subreach boundaries
Control points
Stream cross-sections

0 200 400 600 Feet

Bitterroot Restoration
<table>
<thead>
<tr>
<th>DEPTH (FT)</th>
<th>AREA (SQ_FT)</th>
<th>VOLUME(CU FT)</th>
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<td><strong>TOTAL</strong></td>
<td></td>
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Note: Calculations are based on the estimated amounts of contaminated material that are recommended for removal at given depths.
Appendix E.
SVL Laboratory Raw Analytic Results
### Appendix E. SVL Laboratory Raw Analytic Results for the Bullion Mine Site

#### Soil Analysis for Acid-Base Accounting and Soil/Mine Waste Results

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Sample Date</th>
<th>Comments</th>
<th>Job_Id</th>
<th>Arsenic (mg/kg)</th>
<th>Cadmium (mg/kg)</th>
<th>Copper (mg/kg)</th>
<th>Lead (mg/kg)</th>
<th>Zinc (mg/kg)</th>
<th>Ph</th>
<th>Conductivity (umhos/cm)</th>
<th>S-Total (%)</th>
<th>S-Pyritic (%)</th>
<th>S-Sulfate (%)</th>
<th>S-Non-Extractable (%)</th>
<th>AGP (TCaCO$_3$/1000T)</th>
<th>ANP (TCaCO$_3$/1000T)</th>
<th>ABP (TCaCO$_3$/1000T)</th>
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</thead>
<tbody>
<tr>
<td>BS-04-02-131</td>
<td>9/25/02</td>
<td>-80 SIEVE</td>
<td>105123</td>
<td>6210</td>
<td>24.7</td>
<td>1190</td>
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<td>0.86</td>
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<td>0.13</td>
<td>0.05</td>
<td>0.08</td>
<td>&lt;0.01</td>
<td>1.56</td>
<td>2.62</td>
<td>1.06</td>
</tr>
<tr>
<td>BT-04-00-250</td>
<td>9/26/02</td>
<td>-80 SIEVE</td>
<td>105123</td>
<td>5090</td>
<td>&lt;0.2</td>
<td>155</td>
<td>3700</td>
<td>54.8</td>
<td>6.11</td>
<td>59.9</td>
<td>0.23</td>
<td>0.06</td>
<td>0.17</td>
<td>&lt;0.01</td>
<td>1.88</td>
<td>1.08</td>
<td>-0.8</td>
</tr>
<tr>
<td>BT-04-00-270</td>
<td>9/26/02</td>
<td>-80 SIEVE</td>
<td>105123</td>
<td>82.2</td>
<td>&lt;0.2</td>
<td>42.1</td>
<td>50.9</td>
<td>119</td>
<td>4.18</td>
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<td>0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.3</td>
<td>8.27</td>
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<tr>
<td>BT-04-00-290</td>
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<td>-80 SIEVE</td>
<td>105123</td>
<td>142</td>
<td>1.2</td>
<td>65.9</td>
<td>110</td>
<td>225</td>
<td>4.46</td>
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<td>0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.3</td>
<td>8.01</td>
<td>8.01</td>
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</table>
### Appendix E. SVL Laboratory Raw Analytic Results for the Bullion Mine Site Water Extractable Analysis

<table>
<thead>
<tr>
<th>Sample 1.1. Number</th>
<th>Sample Date</th>
<th>Comments</th>
<th>Job_Id</th>
<th>Arsenic (mg/L)</th>
<th>Cadmium (mg/L)</th>
<th>Copper (mg/L)</th>
<th>Lead (mg/L)</th>
<th>Zinc (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS-04-02-131</td>
<td>9/25/02</td>
<td>EXTRACTION 1:10 RATIO</td>
<td>105126</td>
<td>3.41</td>
<td>0.414</td>
<td>0.456</td>
<td>1.63</td>
<td>33</td>
</tr>
<tr>
<td>BS-04-00-191</td>
<td>9/26/02</td>
<td>EXTRACTION 1:10 RATIO</td>
<td>105126</td>
<td>0.037</td>
<td>0.0028</td>
<td>0.0347</td>
<td>&lt;0.005</td>
<td>0.124</td>
</tr>
<tr>
<td>BS-04-00-231</td>
<td>9/26/02</td>
<td>EXTRACTION 1:10 RATIO</td>
<td>105126</td>
<td>&lt;0.010</td>
<td>0.0267</td>
<td>1.3</td>
<td>&lt;0.005</td>
<td>1.64</td>
</tr>
<tr>
<td>BT-04-01-130</td>
<td>9/25/02</td>
<td>EXTRACTION 1:10 RATIO</td>
<td>105126</td>
<td>0.761</td>
<td>0.0051</td>
<td>0.266</td>
<td>0.185</td>
<td>0.385</td>
</tr>
<tr>
<td>BT-04-00-170</td>
<td>9/25/02</td>
<td>EXTRACTION 1:10 RATIO</td>
<td>105126</td>
<td>0.116</td>
<td>&lt;0.002</td>
<td>0.287</td>
<td>0.0148</td>
<td>0.2</td>
</tr>
<tr>
<td>BT-04-00-210</td>
<td>9/26/02</td>
<td>EXTRACTION 1:10 RATIO</td>
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<td>0.104</td>
<td>0.0069</td>
<td>0.115</td>
<td>0.0194</td>
<td>0.637</td>
</tr>
</tbody>
</table>
### Appendix E. SVL Laboratory Raw Analytic Results
for the Bullion Mine Site
**Surface Water Sample Results**

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Sample Date</th>
<th>Comments</th>
<th>Job Id</th>
<th>Calcium (mg/L)</th>
<th>Magnesium (mg/L)</th>
<th>Hardness (mg/L)</th>
<th>Arsenic (mg/L)</th>
<th>Cadmium (mg/L)</th>
<th>Copper (mg/L)</th>
<th>Lead (mg/L)</th>
<th>Zinc (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT-CSA-H2O</td>
<td>9/27/02</td>
<td>AS VALUES &lt; 0.033MG/L ARE ESTIMATED.</td>
<td>105127</td>
<td>28.9</td>
<td>6.59</td>
<td>99.4</td>
<td>0.026</td>
<td>0.0444</td>
<td>0.771</td>
<td>0.0115</td>
<td>4.68</td>
</tr>
<tr>
<td>MT-CSB-H2O</td>
<td>9/27/02</td>
<td>AS VALUES &lt; 0.033MG/L ARE ESTIMATED.</td>
<td>105127</td>
<td>28.9</td>
<td>6.68</td>
<td>99.7</td>
<td>0.126</td>
<td>0.044</td>
<td>0.798</td>
<td>0.039</td>
<td>4.63</td>
</tr>
<tr>
<td>MT-CSC-H2O</td>
<td>9/27/02</td>
<td>AS VALUES &lt; 0.033MG/L ARE ESTIMATED.</td>
<td>105127</td>
<td>28.7</td>
<td>6.58</td>
<td>98.8</td>
<td>0.014</td>
<td>0.0419</td>
<td>0.691</td>
<td>0.0069</td>
<td>4.48</td>
</tr>
<tr>
<td>MT-CSD-H2O</td>
<td>9/27/02</td>
<td>AS VALUES &lt; 0.033MG/L ARE ESTIMATED.</td>
<td>105127</td>
<td>28.4</td>
<td>6.49</td>
<td>97.7</td>
<td>0.02</td>
<td>0.0411</td>
<td>0.654</td>
<td>0.0084</td>
<td>4.49</td>
</tr>
<tr>
<td>MT-CSE-H2O</td>
<td>9/27/02</td>
<td>AS VALUES &lt;0.033 MG/L ARE ESTIMATED.</td>
<td>105127</td>
<td>16.4</td>
<td>3.64</td>
<td>55.9</td>
<td>0.014</td>
<td>0.0105</td>
<td>0.167</td>
<td>&lt;0.005</td>
<td>1.18</td>
</tr>
<tr>
<td>MT-CSF-H2O</td>
<td>9/27/02</td>
<td>AS VALUES &lt;0.033 MG/L ARE ESTIMATED.</td>
<td>105127</td>
<td>16.5</td>
<td>3.71</td>
<td>56.5</td>
<td>&lt;0.01</td>
<td>0.0102</td>
<td>0.159</td>
<td>&lt;0.005</td>
<td>1.13</td>
</tr>
<tr>
<td>MT-CSG-H2O</td>
<td>9/27/02</td>
<td>AS VALUES &lt;0.033 MG/L ARE ESTIMATED.</td>
<td>105127</td>
<td>14.9</td>
<td>3.43</td>
<td>51.3</td>
<td>&lt;0.01</td>
<td>0.0079</td>
<td>0.121</td>
<td>&lt;0.005</td>
<td>0.869</td>
</tr>
</tbody>
</table>

**NOTE:** Sample numbers are labeled as follows in the field notes and in the SVL analytical reports:
- MT-CSA-H2O = CS1
- MT-CSB-H2O = CS2
- MT-CSC-H2O = CS3
- MT-CSD-H2O = CS4
- MT-CSE-H2O = CS7
- MT-CSF-H2O = CS5
- MT-CSG-H2O = CS6
## Appendix E. SVL Laboratory Raw Analytic Results for the Bullion Mine Site

### Stream Sediment Sample Results

<table>
<thead>
<tr>
<th>Sample 1.3. Number</th>
<th>Sample Date</th>
<th>Comments</th>
<th>Job Id</th>
<th>Arsenic (mg/kg)</th>
<th>Cadmium (mg/kg)</th>
<th>Copper (mg/kg)</th>
<th>Lead (mg/kg)</th>
<th>Zinc (mg/kg)</th>
<th>Ph</th>
<th>Conductivity (umhos/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT-CSA-SED</td>
<td>9/27/02</td>
<td>NONE</td>
<td>105124</td>
<td>2170</td>
<td>13.6</td>
<td>911</td>
<td>818</td>
<td>1120</td>
<td>6.06</td>
<td>445</td>
</tr>
<tr>
<td>MT-CSB-SED</td>
<td>9/27/02</td>
<td>NONE</td>
<td>105124</td>
<td>1870</td>
<td>16.3</td>
<td>838</td>
<td>724</td>
<td>1110</td>
<td>5.94</td>
<td>410</td>
</tr>
<tr>
<td>MT-CSC-SED</td>
<td>9/27/02</td>
<td>NONE</td>
<td>105124</td>
<td>2480</td>
<td>18.1</td>
<td>1180</td>
<td>876</td>
<td>1480</td>
<td>5.95</td>
<td>439</td>
</tr>
<tr>
<td>MT-CSD-SED</td>
<td>9/27/02</td>
<td>NONE</td>
<td>105124</td>
<td>2010</td>
<td>17.6</td>
<td>1150</td>
<td>755</td>
<td>1440</td>
<td>5.83</td>
<td>341</td>
</tr>
<tr>
<td>MT-CSE-SED</td>
<td>9/27/02</td>
<td>NONE</td>
<td>105124</td>
<td>1720</td>
<td>51.6</td>
<td>1790</td>
<td>577</td>
<td>4060</td>
<td>6.92</td>
<td>437</td>
</tr>
<tr>
<td>MT-CSF-SED</td>
<td>9/27/02</td>
<td>NONE</td>
<td>105124</td>
<td>1200</td>
<td>31.6</td>
<td>653</td>
<td>466</td>
<td>2340</td>
<td>6.81</td>
<td>317</td>
</tr>
<tr>
<td>MT-CSG-SED</td>
<td>9/27/02</td>
<td>NONE</td>
<td>105124</td>
<td>1180</td>
<td>38.2</td>
<td>837</td>
<td>498</td>
<td>2600</td>
<td>6.94</td>
<td>344</td>
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</table>

**NOTE:** Sample numbers are labeled as follows in the field notes and in the SVL analytical reports:

- MT-CSA-SED = CS1
- MT-CSB-SED = CS2
- MT-CSC-SED = CS3
- MT-CSD-SED = CS4
- MT-CSE-SED = CS7
- MT-CSF-SED = CS5
- MT-CSG-SED = CS6
SVL QUALITY CONTROL INFORMATION
### Quality Control Report: Part I Prep Blank and Laboratory Control Sample

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Method</th>
<th>Matrix</th>
<th>Units</th>
<th>Prep Blank</th>
<th>True LCS</th>
<th>Found LCS</th>
<th>LCS %</th>
<th>Analysis Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>60108</td>
<td>SOIL</td>
<td>mg/kg</td>
<td>&lt;1.0</td>
<td>283</td>
<td>213</td>
<td>100.0</td>
<td>3/16/03</td>
</tr>
<tr>
<td>Cadmium</td>
<td>60108</td>
<td>SOIL</td>
<td>mg/kg</td>
<td>&lt;0.20</td>
<td>30.7</td>
<td>49.4</td>
<td>97.4</td>
<td>3/16/03</td>
</tr>
<tr>
<td>Copper</td>
<td>60108</td>
<td>SOIL</td>
<td>mg/kg</td>
<td>0.43</td>
<td>169</td>
<td>176</td>
<td>105.3</td>
<td>3/16/03</td>
</tr>
<tr>
<td>Lead</td>
<td>60108</td>
<td>SOIL</td>
<td>mg/kg</td>
<td>&lt;0.50</td>
<td>84.7</td>
<td>86.9</td>
<td>102.6</td>
<td>3/16/03</td>
</tr>
<tr>
<td>Zinc</td>
<td>60108</td>
<td>SOIL</td>
<td>mg/kg</td>
<td>&lt;0.50</td>
<td>149</td>
<td>142</td>
<td>95.3</td>
<td>3/16/03</td>
</tr>
<tr>
<td>pH</td>
<td>9045</td>
<td>SOIL</td>
<td></td>
<td></td>
<td>N/A</td>
<td>9.07</td>
<td>94.4</td>
<td>3/16/03</td>
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<td>Spec. Cond.</td>
<td>120.1</td>
<td>SOIL</td>
<td>umhos/cm</td>
<td></td>
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<td>460</td>
<td>103.3</td>
<td>3/16/03</td>
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<tr>
<td>ABF</td>
<td>EPAX600</td>
<td>SOIL</td>
<td>TCaCO3/k</td>
<td>N/A</td>
<td>42.0</td>
<td>40.5</td>
<td>96.4</td>
<td>3/15/03</td>
</tr>
<tr>
<td>Acid Generating</td>
<td>EPAX600</td>
<td>SOIL</td>
<td>TCaCO3/k</td>
<td>N/A</td>
<td>9.31</td>
<td>9.37</td>
<td>100.6</td>
<td>3/15/03</td>
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<tr>
<td>Acid Neut. Pot.</td>
<td>EPAX600</td>
<td>SOIL</td>
<td>TCaCO3/k</td>
<td>N/A</td>
<td>52.0</td>
<td>49.9</td>
<td>96.0</td>
<td>3/15/03</td>
</tr>
<tr>
<td>Non-Ext Sulfur, S</td>
<td>LECO</td>
<td>SOIL</td>
<td>%</td>
<td>&lt;0.010</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>3/15/03</td>
</tr>
<tr>
<td>Pyritic Sulfur, S</td>
<td>LECO</td>
<td>SOIL</td>
<td>%</td>
<td>&lt;0.010</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>2/12/03</td>
</tr>
<tr>
<td>Sulfate Sulfur, S</td>
<td>LECO</td>
<td>SOIL</td>
<td>%</td>
<td>&lt;0.010</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>3/15/03</td>
</tr>
<tr>
<td>Total Sulfur, S</td>
<td>LECO</td>
<td>SOIL</td>
<td>%</td>
<td>&lt;0.010</td>
<td>0.298</td>
<td>0.300</td>
<td>100.7</td>
<td>3/15/03</td>
</tr>
</tbody>
</table>

**Legend:**
- LCS = Laboratory Control Sample
- LCS % = LCS Percent Recovery
- N/A = Not Applicable
### SVL ANALYTICAL, INC.

#### Quality Control Report

**Test Method Matrix**

<table>
<thead>
<tr>
<th>Client: BITTERROOT RESTORATION INC</th>
<th>QC SAMPLE ID</th>
<th>Duplicate or MSD</th>
<th>Spike Result</th>
<th>Spike Add</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>As</strong> 6010B SOIL 1 mg/kg</td>
<td>6210</td>
<td>5630 M</td>
<td>3.8</td>
<td>6450 100</td>
</tr>
<tr>
<td>As 6010B SOIL 2 mg/kg</td>
<td>2570</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Cd 6010B SOIL 1 mg/kg</td>
<td>24.7</td>
<td>119 M</td>
<td>6.0</td>
<td>119 100</td>
</tr>
<tr>
<td>Cd 6010B SOIL 2 mg/kg</td>
<td>&lt;0.20</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Cu 6010B SOIL 1 mg/kg</td>
<td>1190</td>
<td>1330 M</td>
<td>2.8</td>
<td>1330 100</td>
</tr>
<tr>
<td>Cu 6010B SOIL 2 mg/kg</td>
<td>53.6</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Pb 6010B SOIL 1 mg/kg</td>
<td>4620</td>
<td>4780 M</td>
<td>0.8</td>
<td>4820 100</td>
</tr>
<tr>
<td>Pb 6010B SOIL 2 mg/kg</td>
<td>1500</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Zn 6010B SOIL 1 mg/kg</td>
<td>1750</td>
<td>1910 M</td>
<td>6.0</td>
<td>1910 100</td>
</tr>
<tr>
<td>Zn 6010B SOIL 2 mg/kg</td>
<td>43.4</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>pH 9045 SOIL 1</td>
<td>3.70</td>
<td>3.65</td>
<td>1.4</td>
<td>N/A</td>
</tr>
<tr>
<td>COD 120.1 SOIL 1 umpos/c</td>
<td>2340</td>
<td>2330</td>
<td>6.4</td>
<td>N/A</td>
</tr>
<tr>
<td>ABP EPA600 SOIL 1 TCA/C3/</td>
<td>24.3</td>
<td>26.9</td>
<td>13.0</td>
<td>N/A</td>
</tr>
<tr>
<td>ADF EPA600 SOIL 1 TCA/C3/</td>
<td>26.9</td>
<td>26.6</td>
<td>1.1</td>
<td>N/A</td>
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<tr>
<td>S-N-EX LECO SOIL 1</td>
<td>0.050</td>
<td>0.060</td>
<td>2.0</td>
<td>N/A</td>
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<tr>
<td>S-PYR LECO SOIL 1</td>
<td>0.060</td>
<td>0.060</td>
<td>2.0</td>
<td>N/A</td>
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<tr>
<td>S-TOX LECO SOIL 1</td>
<td>0.750</td>
<td>0.740</td>
<td>1.3</td>
<td>N/A</td>
</tr>
<tr>
<td>S-TOT LECO SOIL 1</td>
<td>1.92</td>
<td>1.91</td>
<td>1.3</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Legend:**

- **R** = Result or *Found: Interference required dilution.
- **U** = Unsatisfactory.
- **N/A** = Not Analyzed.
- **R > 40** = Results more than 40 times the spike added.

QC Sample 1: SVL SAM No.: 326240 Client Sample ID: BULL-XT-04-02-131
QC Sample 2: SVL SAM No.: 326250 Client Sample ID: BULL-XT-04-01-150

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3/17/03 11:22
<table>
<thead>
<tr>
<th>Analyte</th>
<th>Method</th>
<th>Matrix</th>
<th>Units</th>
<th>Prep Blank</th>
<th>True LCS</th>
<th>LCS #R</th>
<th>Analysis Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>200.1%</td>
<td>ESOIL</td>
<td>mg/L Ext</td>
<td>&lt;0.010</td>
<td>1.00</td>
<td>1.07</td>
<td>107.0</td>
</tr>
<tr>
<td>Cadmium</td>
<td>200.1%</td>
<td>ESOIL</td>
<td>mg/L Ext</td>
<td>&lt;0.0020</td>
<td>1.00</td>
<td>1.04</td>
<td>104.0</td>
</tr>
<tr>
<td>Copper</td>
<td>200.1%</td>
<td>ESOIL</td>
<td>mg/L Ext</td>
<td>&lt;0.0035</td>
<td>1.00</td>
<td>0.965</td>
<td>96.5</td>
</tr>
<tr>
<td>Lead</td>
<td>200.1%</td>
<td>ESOIL</td>
<td>mg/L Ext</td>
<td>&lt;0.0055</td>
<td>1.00</td>
<td>0.999</td>
<td>99.9</td>
</tr>
<tr>
<td>Zinc</td>
<td>200.1%</td>
<td>ESOIL</td>
<td>mg/L Ext</td>
<td>&lt;0.0055</td>
<td>1.00</td>
<td>1.02</td>
<td>102.0</td>
</tr>
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</table>

**LEGEND:**
- LCS = Laboratory Control Sample
- LCS #R = LCS Percent Recovery
- N/A = Not Applicable
### Quality Control Report

**Part II Duplicate and Spike Analysis**

<table>
<thead>
<tr>
<th>QC SAMPLE ID</th>
<th>Duplicate or MXD</th>
<th>Found</th>
<th>Matrix Spike</th>
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<tbody>
<tr>
<td></td>
<td>Result</td>
<td>%RPD</td>
<td>Result</td>
</tr>
<tr>
<td>As</td>
<td>0.161</td>
<td>12.6</td>
<td>1.82</td>
</tr>
<tr>
<td>Cd</td>
<td>0.0051</td>
<td>2.0</td>
<td>1.04</td>
</tr>
<tr>
<td>Cr</td>
<td>0.240</td>
<td>10.3</td>
<td>1.26</td>
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<tr>
<td>Pb</td>
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</tr>
<tr>
<td>Zn</td>
<td>0.388</td>
<td>0.3</td>
<td>1.42</td>
</tr>
</tbody>
</table>

**LEGEND:**
- UDL = Below Limit of Detection
- *Result or *Found = Interference required dilution
- %RDP = (%SAM - %DIP)/(%SAM + %DIP) / 100
- %M = Difference between duplicate/MXD column indicates MSB
- %SPK = (%SPK - %MSB)/(%SPK + %MSB) / 100
- MSB in duplicate/MSB column indicates MSB
- %R = %SPK - Results more than 5X the Spike Added

**QC Sample 1:** SVL SAM No.: 326275  
Client Sample ID: BULL-XT-04-01-110

---

**Notes:**
- 3/18/03 14:31
### SVL ANALYTICAL, INC.

#### Quality Control Report

**Part I Prep Blank and Laboratory Control Sample**

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<thead>
<tr>
<th>Analyte</th>
<th>Method</th>
<th>Matrix</th>
<th>Units</th>
<th>Prep. Blank</th>
<th>True—LCS—Found</th>
<th>LCS &amp;R</th>
<th>Analysis Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>200.7</td>
<td>WATER</td>
<td>mg/L</td>
<td>&lt;0.010</td>
<td>1.00</td>
<td>0.929</td>
<td>92.9</td>
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<tr>
<td>Calcium</td>
<td>200.7</td>
<td>WATER</td>
<td>mg/L</td>
<td>&lt;0.040</td>
<td>20.0</td>
<td>19.5</td>
<td>97.5</td>
</tr>
<tr>
<td>Cadmium</td>
<td>200.7</td>
<td>WATER</td>
<td>mg/L</td>
<td>&lt;0.0020</td>
<td>1.00</td>
<td>0.950</td>
<td>95.0</td>
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<tr>
<td>Copper</td>
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<td>WATER</td>
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<td>1.00</td>
<td>0.993</td>
<td>99.3</td>
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<tr>
<td>Hardness</td>
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<td>WATER</td>
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<td>&lt;0.265</td>
<td>122</td>
<td>126</td>
<td>99.5</td>
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<tr>
<td>Magnesium</td>
<td>200.7</td>
<td>WATER</td>
<td>mg/L</td>
<td>&lt;0.040</td>
<td>20.0</td>
<td>18.8</td>
<td>94.4</td>
</tr>
<tr>
<td>Lead</td>
<td>200.7</td>
<td>WATER</td>
<td>mg/L</td>
<td>&lt;0.0050</td>
<td>1.00</td>
<td>0.965</td>
<td>96.5</td>
</tr>
<tr>
<td>Zinc</td>
<td>200.7</td>
<td>WATER</td>
<td>mg/L</td>
<td>&lt;0.0050</td>
<td>1.00</td>
<td>0.926</td>
<td>92.6</td>
</tr>
</tbody>
</table>

**LEGEND:**
- LCS = Laboratory Control Sample
- LCS &R = LCS Percent Recovery
- N/A = Not Applicable
### SVL ANALYTICAL, INC.

#### Quality Control Report

<table>
<thead>
<tr>
<th>Client: BITTERROOT RESTORATION INC</th>
<th>SVL JOB No: 105127</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test Method Matrix</strong></td>
<td><strong>QC SAMPLE ID</strong></td>
</tr>
<tr>
<td><strong>Units</strong></td>
<td><strong>Result</strong></td>
</tr>
<tr>
<td>As 200.7 WATERS 1 mg/L</td>
<td>0.014</td>
</tr>
<tr>
<td>Ca 200.7 WATERS 1 mg/L</td>
<td>16.4</td>
</tr>
<tr>
<td>Cd 200.7 WATERS 1 mg/L</td>
<td>0.0105</td>
</tr>
<tr>
<td>Cu 200.7 WATERS 1 mg/L</td>
<td>0.167</td>
</tr>
<tr>
<td>Hg 200.7 WATERS 1 mg/L</td>
<td>55.9</td>
</tr>
<tr>
<td>Mg 200.7 WATERS 1 mg/L</td>
<td>3.64</td>
</tr>
<tr>
<td>Pb 200.7 WATERS 1 mg/L</td>
<td>&lt;0.0050</td>
</tr>
<tr>
<td>Zn 200.7 WATERS 1 mg/L</td>
<td>1.18</td>
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</table>

**LEGEND:**
- SPDQ: \( \frac{\text{SAM} - \text{DLQ}}{\left(\frac{\text{SAM} + \text{DLQ}}{2}\right) \times 100} \) UDL = Both SAM & DLQ not detected. *Result or *Found: Interference required dilution.
- SPDQ: \( \frac{\text{SPK} - \text{MDQ}}{\left(\frac{\text{SPK} + \text{MDQ}}{2}\right) \times 100} \) M in Duplicate/MSD column indicates MSD.
- SPIKE ADD column, A = Post Digest Spike; IR = Percent Recovery N/A = Not Analyzed; R > 4S = Result more than 4X the Spike Added

QC Sample 1: SVL SAM No.: 326280 Client Sample ID: CS7

3/11/03 8:37
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<thead>
<tr>
<th>Analyte</th>
<th>Method</th>
<th>Matrix</th>
<th>Units</th>
<th>Prep Blank</th>
<th>True LCS Found</th>
<th>LCS %</th>
<th>Analysis Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>6010B</td>
<td>SOIL</td>
<td>mg/kg</td>
<td>&lt;1.0</td>
<td>283</td>
<td>280</td>
<td>98.9</td>
</tr>
<tr>
<td>Cadmium</td>
<td>6010B</td>
<td>SOIL</td>
<td>mg/kg</td>
<td>&lt;0.20</td>
<td>50.7</td>
<td>49.9</td>
<td>99.4</td>
</tr>
<tr>
<td>Copper</td>
<td>6010B</td>
<td>SOIL</td>
<td>mg/kg</td>
<td>&lt;0.30</td>
<td>160</td>
<td>75</td>
<td>101.6</td>
</tr>
<tr>
<td>Lead</td>
<td>6010B</td>
<td>SOIL</td>
<td>mg/kg</td>
<td>&lt;0.50</td>
<td>84.7</td>
<td>87.5</td>
<td>101.8</td>
</tr>
<tr>
<td>Zinc</td>
<td>6010B</td>
<td>SOIL</td>
<td>mg/kg</td>
<td>&lt;0.50</td>
<td>149</td>
<td>144</td>
<td>96.6</td>
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<tr>
<td>pH</td>
<td>9045</td>
<td>SOIL</td>
<td>unhrs/cm</td>
<td>N/A</td>
<td>8.60</td>
<td>8.53</td>
<td>99.2</td>
</tr>
<tr>
<td>Spec. Cond.</td>
<td>120.1</td>
<td>SOIL</td>
<td>unhrs/cm</td>
<td>0.010</td>
<td>468</td>
<td>439</td>
<td>94.4</td>
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</tbody>
</table>

**LEGEND:**
- LCS = Laboratory Control Sample
- LCS % = LCS Percent Recovery
- N/A = Not Applicable
<table>
<thead>
<tr>
<th>Test Method Matrix</th>
<th>QC SAMPLE ID</th>
<th>Result</th>
<th>Duplicate or MSD</th>
<th>RPD%</th>
<th>Matrix Spike</th>
<th>SVL JOB No: 105124</th>
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<tbody>
<tr>
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<td></td>
<td></td>
<td>Analysis</td>
</tr>
<tr>
<td></td>
<td>A5</td>
<td>6010B SOIL</td>
<td>2 mg/kg</td>
<td>2170</td>
<td>2420</td>
<td>M 0.6</td>
</tr>
<tr>
<td></td>
<td>C3</td>
<td>6010K SOIL</td>
<td>2 mg/kg</td>
<td>13.6</td>
<td>112</td>
<td>M 0.9</td>
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<tr>
<td></td>
<td>Cu</td>
<td>6010B SOIL</td>
<td>2 mg/kg</td>
<td>911</td>
<td>1100</td>
<td>M 0.0</td>
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<tr>
<td></td>
<td>Cd</td>
<td>6010B SOIL</td>
<td>2 mg/kg</td>
<td>818</td>
<td>961</td>
<td>M 2.1</td>
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<tr>
<td></td>
<td>Zn</td>
<td>6010B SOIL</td>
<td>2 mg/kg</td>
<td>1120</td>
<td>1440</td>
<td>M 3.5</td>
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</table>

**LEGEND:**

- RPD% = ((SAM - DUP)/((SAM + DUP)/2) * 100) U:L.D. = Both SAM & DUP not detected. *Result or "Found" interfered with matrix dilution.
- SPIKE ADD column, A = Post Digest Spike, X = Percent Recovery N/A = Not Analyzed, R >4X = Result more than 4X the Spike Added

QC Sample 2: SVL BAM No: 326266 Client Sample ID: C301
### SVL ANALYTICAL, INC.

**Quality Control Report**

<table>
<thead>
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<th>Client</th>
<th>BITTERROOT RESTORATION INC.</th>
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</thead>
<tbody>
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<td>Duplicate or MSD</td>
</tr>
<tr>
<td>QC SAMPLE ID</td>
<td>Units</td>
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<tr>
<td>COND 120.1 SOIL</td>
<td>umbos/c</td>
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<tr>
<td>pH 9045 SOIL</td>
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</table>

**LEGEND:**

- **RPD% = \( \frac{[\text{SAM} - \text{DUP}]}{[\text{SAM} + \text{DUP}]/2} \times 100 \)**: UDL = Both SAM & DUP not detected. *Result or *Found: Interference required dilution.
- **RPD% = \( \frac{[\text{SPK} - \text{MSD}]}{[\text{SPK} + \text{MSD}]/2} \times 100 \)**: M is Duplicate/MSD column indicates N/D.
- **SPK ADD column, A = Post Digest Spike; %R = Percent Recovery; N/A = Not Analyzed; \( R \times 10 \) - Results more than 10X the Spike Added**
- **QC Sample 1: SVL SAM No.: 325260 Client Sample ID: CS07**

---

3/17/03 13:16
CHAIN OF CUSTODY RECORDS
FOR
BULLION MINE
## COC RECORDS

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<th>Sample ID</th>
<th>Date</th>
<th>Time</th>
<th>Collection</th>
<th>Preservative(s)</th>
<th>Miscellaneous</th>
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<td>CS-02</td>
<td>11/27/02</td>
<td>10:30 AM</td>
<td>Surface Water</td>
<td>NaN</td>
<td>NaN</td>
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<td>CS-03</td>
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<td>Surface Water</td>
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<td>Sample ID</td>
<td>Date</td>
<td>Time</td>
<td>Value (ppm)</td>
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<tr>
<td>Bull-xt-04101-70</td>
<td>12/21/02</td>
<td>10:30 am</td>
<td>Pb: 20</td>
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<tr>
<td>Bull-xt-04101-70</td>
<td>12/21/02</td>
<td>11:30 am</td>
<td>Zn: 50, Cd: 5</td>
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<td>Bull-xt-04101-70</td>
<td>12/21/02</td>
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<td>As: 10</td>
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<td>12/21/02</td>
<td>2:00 pm</td>
<td>Total Metals</td>
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<tr>
<td>Sample ID</td>
<td>Date</td>
<td>Time</td>
<td>Matrix (Soil)</td>
<td>Analysis Required</td>
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<td>9/25/02</td>
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<td>16:30:00</td>
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</tbody>
</table>
Appendix F.
XRF Field Analytical Results for Total Metals
May 21, 2003

Ms. Clare Fitzgerald  
Bitterroot Restoration, Inc.  
445 Quast Lane  
Corvallis, Montana 59828

X-Ray Fluorescence (XRF) Instrument Details – Response to United States Forest Service (USFS) Comments for Bullion and Idora Site Characterization Reports

Dear Clare:

As discussed during our telephone conversation on Friday, May 9, 2003 the USFS commented on the Bullion and Idora Site Characterization Reports and requested additional information regarding the XRF instrument used in the field. Information regarding the USFS’ XRF comment, “To be consistent with the other sections below (e.g. pH, flow meters, etc.) this should state what type of XRF instrument was used, it’s approximate upper and lower detection limits, precision, accuracy and limitations,” is discussed below. I’ve included as attachments the XRF summary brief text for the Bullion and Idora sites submitted to BRI in March 2003 and EPA’s Method 6200 – ‘Field Portable X-Ray Fluorescence Spectrometry for the Determination of Elemental Concentration in Soil and Sediment’ for your reference.

- The type of XRF instrument used: Spectrace 9000 portable XRF

- The approximate upper detection limits or quantitation limits is determined as 10 times the sample result’s associated standard deviation, which is reported by the instrument. This quantitation limit varies from sample to sample. Typically, an average would be used to determine upper detection limits; however, because the XRF instrument was being used to characterize the site and site-specific characterization samples were not available the above method was employed.

- The approximate lower detection limits is determined as 3 times the sample result’s associated standard deviation, which is reported by the instrument. This detection limit varies from sample to sample. Typically, an average would be used to determine lower detection limits; however, because the XRF instrument was being used to characterize the
site and site-specific characterization samples were not available the above method was employed. Additionally, the EPA Method 6200 includes a guide for lower detection limits based on no interference, 600 counts per source and quartz soil, they are as follows:

- Arsenic (As) 40 ppm
- Lead (Pb) 20 ppm
- Copper (Cu) 50 ppm
- Cadmium (Cd) 100 ppm
- Zinc (Zn) 50 ppm

- Precision: The precision for the XRF instrument is based on site-specific conditions and is discussed in detail in the Quality Assurance/Quality Control section of the XRF summary briefs submitted to BRI for Bullion and Idora sites on March 20, 2003 and March 24, 2003, respectively.

- Accuracy: The accuracy for the XRF instrument is based on site-specific conditions and is discussed in detail in the Quality Assurance/Quality Control section of the XRF summary briefs submitted to BRI for Bullion and Idora sites on March 20, 2003 and March 24, 2003, respectively.

- Limitations: The XRF instrument limitations are discussed in detail in EPA’s Method 6200 Section 4.0 – ‘Interferences’.

Sincerely,
EMC

(sent via email)

Lisa N. Gonzales
Principal

Enclosures

cc: Joe Flynn, EMC²
Appendix G.
Statistical Procedures (Student’s t-Test, Least Squares Regressions)
Regression Summary
Log_XRF_Arsenic vs. Log_Arsenic

| Count | 18  |
| Num. Missing | 0  |
| R     | .581|
| R Squared | .338|
| Adjusted R Squared | .296|
| RMS Residual | .523|

ANOVA Table
Log_XRF_Arsenic vs. Log_Arsenic

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<thead>
<tr>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F-Value</th>
<th>P-Value</th>
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<td>2.231</td>
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<td>Residual</td>
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<tr>
<td>Total</td>
<td>17</td>
<td>6.608</td>
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</tr>
</tbody>
</table>

Regression Coefficients
Log_XRF_Arsenic vs. Log_Arsenic

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Std. Error</th>
<th>Std. Coeff.</th>
<th>t-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
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<td>.606</td>
<td>1.337</td>
<td>.208</td>
</tr>
<tr>
<td>Log_Arsenic</td>
<td>.558</td>
<td>.195</td>
<td>.581</td>
<td>.255</td>
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</tbody>
</table>

Regression Plot

\[ Y = 1.337 + .558 \cdot X; R^2 = .338 \]
Regression Summary

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Log_XRF_Cadmium vs. Log_CADMIUM</td>
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</tr>
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<td>Count</td>
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<td>Num. Missing</td>
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<tr>
<td>R</td>
<td>.341</td>
</tr>
<tr>
<td>R Squared</td>
<td>.116</td>
</tr>
<tr>
<td>Adjusted R Squared</td>
<td>.061</td>
</tr>
<tr>
<td>RMS Residual</td>
<td>.162</td>
</tr>
</tbody>
</table>

ANOVA Table

<table>
<thead>
<tr>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F-Value</th>
<th>P-Value</th>
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<tbody>
<tr>
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<td>.077</td>
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Regression Coefficients

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>Std. Coeff.</th>
<th>t-Value</th>
<th>P-Value</th>
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<tbody>
<tr>
<td>Intercept</td>
<td>2.034</td>
<td>.046</td>
<td>2.034</td>
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<td>.341</td>
<td>1.450</td>
<td>.1664</td>
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</table>

Regression Plot

\[ Y = 2.034 + 0.128 \times X; \text{ R}^2 = 0.116 \]
### Regression Summary

**Log XRF_Copper vs. Log COPPER**

<table>
<thead>
<tr>
<th>Count</th>
<th>Num. Missing</th>
<th>R</th>
<th>R Squared</th>
<th>Adjusted R Squared</th>
<th>RMS Residual</th>
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<tbody>
<tr>
<td>16</td>
<td>0</td>
<td>.447</td>
<td>.200</td>
<td>.150</td>
<td>.392</td>
</tr>
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</table>

### ANOVA Table

**Log XRF_Copper vs. Log COPPER**

<table>
<thead>
<tr>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
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<td>.612</td>
<td>3.990</td>
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<tr>
<td>Residual</td>
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<td>Total</td>
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</table>

### Regression Coefficients

**Log XRF_Copper vs. Log COPPER**

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Std. Error</th>
<th>Std. Coef.</th>
<th>t-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
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<td>1.306</td>
<td>2.653</td>
<td>.0174</td>
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<tr>
<td>Log COPPER</td>
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<td>.447</td>
<td>1.998</td>
<td>.0631</td>
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</table>

**Regression Plot**

\[ Y = 1.306 + .423 \times X; \text{ R}^2 = .2 \]
### Regression Summary

**Log\_XRF\_Lead vs. Log\_LEAD**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
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<tr>
<td>Num. Missing</td>
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<tr>
<td>R</td>
<td>.612</td>
</tr>
<tr>
<td>R Squared</td>
<td>.374</td>
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<tr>
<td>Adjusted R Squared</td>
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<tr>
<td>RMS Residual</td>
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### ANOVA Table

**Log\_XRF\_Lead vs. Log\_LEAD**

<table>
<thead>
<tr>
<th></th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
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<tr>
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<td>3.603</td>
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<tr>
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### Regression Coefficients

**Log\_XRF\_Lead vs. Log\_LEAD**

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>Std. Coeff.</th>
<th>t-Value</th>
<th>P-Value</th>
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<tbody>
<tr>
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<td>.593</td>
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</table>

### Regression Plot

Y = .593 + .705 * X, R^2 = .374
Regression Summary

Log_{XRF} Zinc vs. Log_{ZINC}

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
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<tbody>
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<tr>
<td>Num. Missing</td>
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</tr>
<tr>
<td>R</td>
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<tr>
<td>R Squared</td>
<td>.631</td>
</tr>
<tr>
<td>Adjusted R Squared</td>
<td>.608</td>
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<tr>
<td>RMS Residual</td>
<td>.229</td>
</tr>
</tbody>
</table>

ANOVA Table

Log_{XRF} Zinc vs. Log_{ZINC}

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F-Value</th>
<th>P-Value</th>
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<tbody>
<tr>
<td>Regression</td>
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<td>.052</td>
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</tbody>
</table>

Regression Coefficients

Log_{XRF} Zinc vs. Log_{ZINC}

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Std. Error</th>
<th>Std. Coeff.</th>
<th>t-Value</th>
<th>P-Value</th>
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<tbody>
<tr>
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<td>.815</td>
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<td>5.229</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Regression Plot

Y = .412 + .815 * X; R^2 = .631
t-STATISTIC & P-VALUE DESCRIPTION

The t statistic is used for small samples (less than 30 samples) to determine the probability whether a sample mean is not equal to the expected population mean. In general terms, the greater the value of a t statistic for a given sample size, the stronger the probability a sample mean does not follow the expected population mean (i.e., the sample and population means are different). The p-value indicates this probability. The small the p-value, the greater the likelihood that the sample mean does not follow the expected population mean.

LEAST SQUARES REGRESSION DESCRIPTION

Least squares regression describes how two measurement variables are related. Most importantly for the purpose of this exercise, the least squares regression method describes how accurately we can predict the value of one variable (the cause) if we know the value of another variable (the response). The coefficient of determination (R^2) is interpreted as the proportion of the total variation of the response that can be explained by the cause. The rule of thumb for interpreting the R^2 and the correlation coefficient (R) is that there is a strong relationship between the cause and effect if R^2 > 0.64 (|R| > 0.8), a moderate relationship if R^2 > 0.25 (|R| > 0.5), and a weak relationship if R^2 > 0.04 (|R| > 0.2). In this test, the p-value indicates the probability that the observed relationship between the two variables is not false or artificial. The smaller the p-value, the greater the likelihood that the observed relationship is not false.