Reclaiming Hard Rock Mines:

An In Depth Look at Vegetation, Soil, and Water on the Bullion Mine Site, Basin, Montana

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Introduction

Mining originated in Montana with the discovery of gold in the 1860's. The gold and silver boom continued through 1950, leading to Montana's reputation as the Treasure State. Once viable metals were depleted, these mines were abandoned, leaving environmental issues including degraded water, soil, and vegetative communities.

The Environmental Protection Agency (EPA), the United States Forest Service (USFS), the Bureau of Land Management (BLM) along with other state and federal agencies are reclaiming abandoned mine sites throughout the western United States. This report focuses on the Bullion Mine, just one of 20,000 inactive mines in Montana (Durkin and Herrmann 1994). Located on the eastern slope of the Continental Divide, nine miles north of Basin, Montana, the hard rock Bullion Mine produced gold, silver, lead, zinc, and copper through the 1950's (Nimick 1999).

Figure 1. Waste rock at the Bullion Mine Site.

Figure 2. Iron precipitate in Jill Creek.

The abandoned Bullion Mine contained an unstable hillslope with tailings piles, waste rock and acid mine drainage (AMD; Figure 1). Waste rock, the soil and rock material removed with ore extraction, and tailings, which are created during ore processing, are sources of contamination on abandoned mine sites. One of the most difficult problems to address in mine reclamation is AMD, which occurs when pyrite is exposed to water and oxygen resulting in the formation of sulfuric acid and iron hydroxide (Durkin and Herrmann 1994). Acid mine drainage can result in the acidification of ground and surface waters, increasing the availability of arsenic and metals for plant and animal uptake.

The source of AMD at the Bullion Mine surfaces at the adit, the opening to the mineshaft used to remove the ore, and flows into Jill Creek, an unofficially named tributary to Jack Creek (Figures

2 and 3). Jack and Jill Creek converge one mile downstream from the mine site, and Jack Creek flows into Basin Creek which flows through the town of Basin. The Bullion Mine site is approximately eight acres, with the majority of the mine and mill located on private property, while Jill Creek, two tailings deposits, and additional waste materials were on the Beaverhead-Deerlodge National Forest (Maxim 2003).

In a joint effort, the EPA and the USFS began reclamation of the Bullion Mine site in the spring of 2001 and completed the project in the fall of 2002. The reclamation goal was to reduce heavy metal contamination associated with soil erosion and sedimentation, thereby reducing human health and safety hazards (Maxim 2003). Treatment of AMD was not included in the reclamation goals or the work plan.

Reclamation started with the removal of 27,238 cubic yards of mine waste, which was transported to the Luttrell Repository, at the headwaters of Ten Mile Creek on the Continental Divide. Lime gravel (3 t/a) and triple super phosphate (250 lbs/a) were incorporated into the subsoil by a backhoe excavator and covered with 18 inches of subsoil taken from a nearby borrow site to serve as coversoil (Figure 3). Composted manure (20 t/a) and Biosol Mix fertilizer (approximately 1 t/a) were incorporated into the coversoil. After fertilization, weed-free straw (approximately 1.5 t/a) was scattered over the entire site. A seed mixture was applied along with 6,000 transplanted shrubs and trees (Table 4).

In August 2002, a rhyolite drainage channel with a plastic PVC liner was installed to capture and divert adit discharge into Jill Creek. Various sized rocks, boulders and woody debris were used to reconstruct 500 feet of Jill Creek. Reclamation was completed in October 2002 (Figure 3; Maxim 2003).

During the fall of 2003, one-year after reclamation, the Montana State University Land Resources and Environmental Sciences capstone class assessed the current condition of the Bullion Mine site and developed a monitoring plan to guide future management decisions. Soil characteristics, including nutrient and metal/metalloid concentrations, were measured spatially across the site and through soil profiles. Vegetation cover and density were recorded and compared to soil characteristics. Water quality parameters, including metal concentrations, were measured both on site and up to one mile downstream. This data was then used to create a monitoring plan. Although designed specifically for the Bullion site, this plan could also serve as a monitoring template for other reclaimed mine sites.

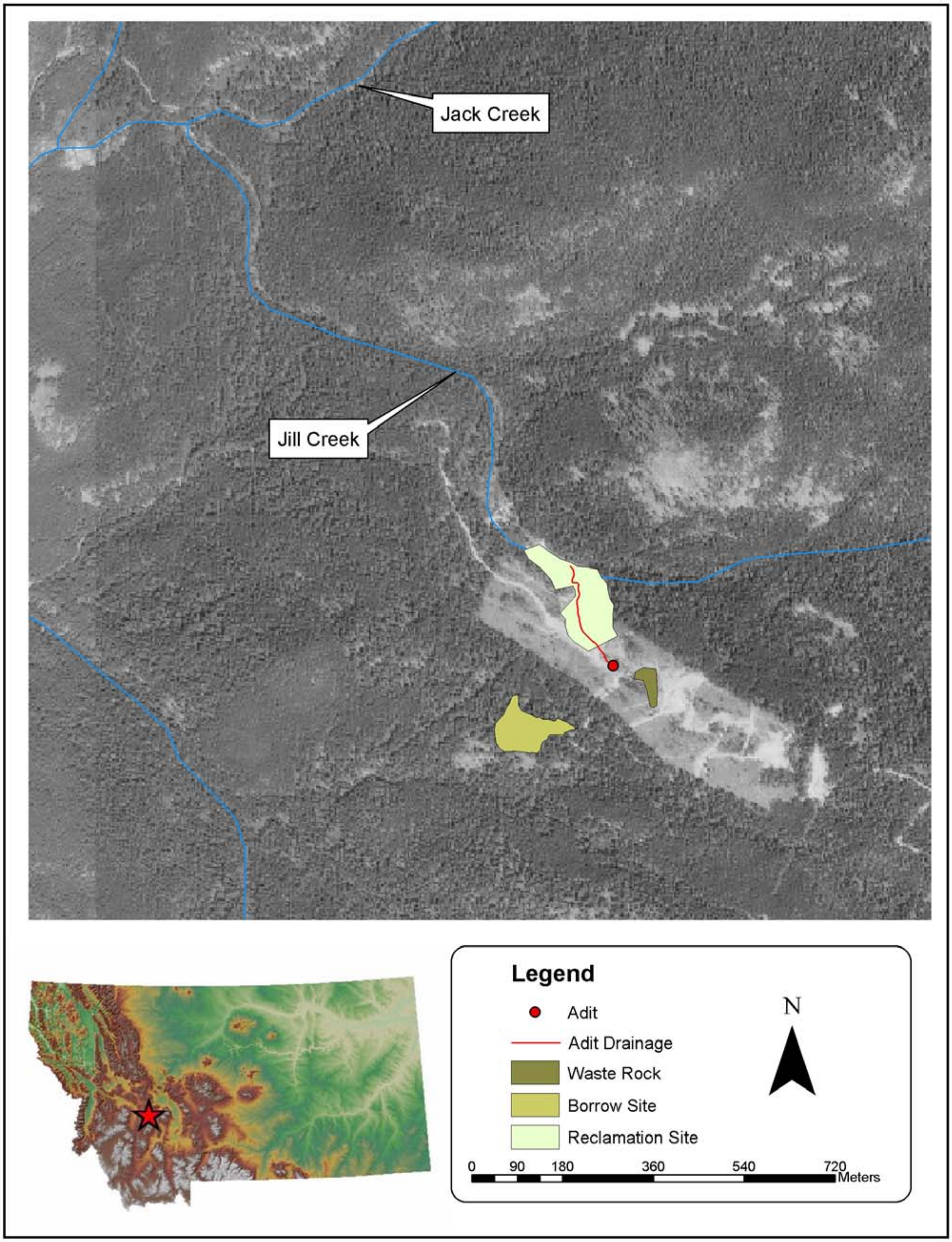
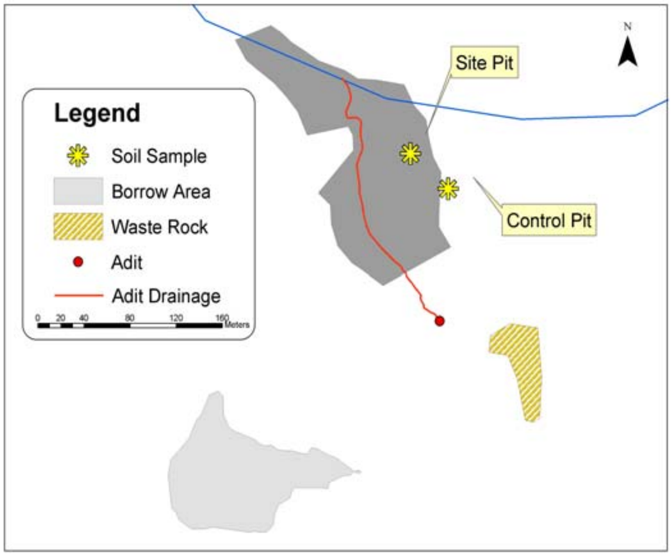


Figure 3. Bullion Mine site located on the Beaverhead-Deerlodge National Forest.

Soil Analysis

Previous mine soil research compares the efficacy of reclamation strategies to maximize site productivity for the least cost (Bendfelt et al. 2001). This study determined the extent to which reclamation goals set by the USFS and EPA for soil quality at the Bullion Mine were achieved. Detailed analysis was completed for two soil profiles, while extensive sampling across the reclamation site was utilized for coversoil analysis. The analysis of soil profiles was designed to identify sources of recontamination and assess the suitability of the coversoil in preventing metal migration into the rooting zone. Spatially extensive sampling quantified metal availabilities across the site and compared those levels to other environmental variables. The objectives for soil analysis were: 1) to determine success of reclamation of the Bullion Mine soils through coversoil analysis; 2) to identify possible sources of on-site contamination and the vectors through which re-contamination may occur; and 3) to compare arsenic and metal levels to environmental parameters to better understand mechanisms affecting metal availability across the site.



Methods

Two soil sampling pits were excavated and characterized at the Bullion Mine (Figure 4). Site one was located in an undisturbed area just outside the perimeter of the Bullion Mine and is the control or reference area, consistent with the approach advocated by Wood and Buchanan (2000). Site two was located within the Forest Service reclamation boundary, but away from potential influences of adit discharge. Soil samples taken from the control site were separated on the basis of horizon delineations. Samples were taken from site two at 15 cm depth increments since horizons has not developed in the coversoil. All samples were collected using stainless steel shovel and trowel blades which were rinsed with water between samples.

Seventeen transects were placed across the slope of the hill at 15 m intervals (Figure 5). Two 1-m² quadrats per transect were chosen, selecting 1 wet and 1 dry quadrat from each transect when possible, to assess differences between wet and dry soils. Three samples of approximately one kilogram each were scooped from seven different locations within each quadrat to an approximate depth of 15 cm. Shovel and trowel blades were rinsed with deionized water between quadrats.

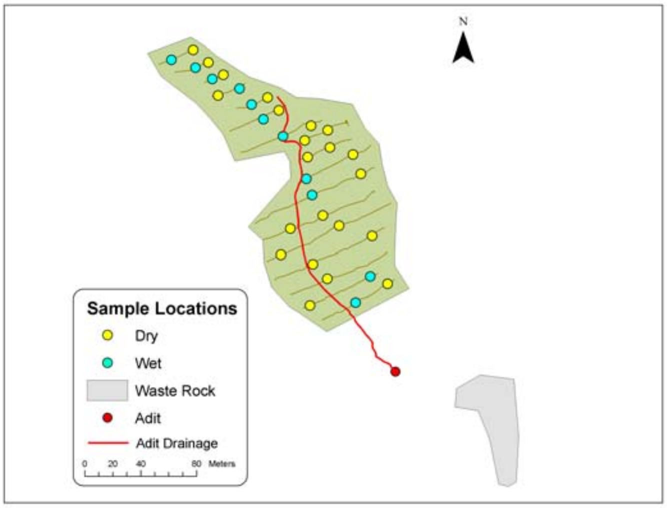


Figure 5. Wet and dry soil quadrat locations.

Soils were dried at ~40°C to a constant mass. Samples were weighed for water content, by calculating mass lost after drying. For other analyses, soils were passed through a 2 mm sieve. Transect samples were analyzed for total arsenic, aluminum, lead, and zinc from 8 representative quadrats on the Bullion Mine site (Alpine Analytical 2003); whereas 34 quadrat samples were analyzed for available arsenic, metals, and nutrients (Mg, Ca, S, Zn, Mn, Cu, Fe, B, Na, NO_3^-, P, and K), and soil characteristics including percent organic matter, pH, electrical conductivity, soluble salts, and cation exchange capacity. Soil pH and soluble salts were measured with a 1:1 soil/water slurry (Page et al. 1982). Cations (Ca, Mg, K and Na) were measured using ammonium acetate extraction. Phosphorous was determined using Bray I extraction and Olsen extraction. Nitrate-N was measured by cadmium reduction and total nitrogen was measured by Kjeldahl digestion. Citric acid digestion was used to measure soluble P_2O_5 and ammonium oxalate was used to find soluble K_2O. Organic matter was determined by loss on ignition. Zinc, manganese, iron and copper were evaluated using the DTPA extractable method and measured with ICP (Page et al. 1982). In addition to these analyses, soil samples were analyzed for particle size distribution using the pipette method with 5 mg/L sodium-hexametaphosphate (Dane and Topp 2002). Sulfur contents were determined by monocalcium phosphate ICP method (Page et al. 1982).

Samples of tailings and waste rock were analyzed for Shoemaker-McLean-Pratt (SMP) lime requirement and acid base account to determine the concentrations of sulfide compounds and minerals. The SMP lime requirement is the amount of lime required to neutralize acid in solution, and was evaluated using ASA Method 12-3 (Page et al. 1982), a single buffer extraction, while the Sobek (1987) method was used for acid base accounting. Samples were analyzed at Energy Laboratories, Billings, MT. The acid base account is used to determine the potential acidity produced from weathering and oxidation of sulfide minerals and biological reactions (Sobek et al. 1987). Potential acidity is the lime required to neutralize acid produced over time. The equation for calculating potential acidity is:

Potential Acidity = [HNO_3 extractable sulfur + residual Sulfur] (31.25) + [HCl extractable Sulfur] (23.44). (Montana DEQ et al. 1999). (1)

To allow for complete neutralization, lime that passes a 60 mesh screen and has 90% calcium carbonate equivalence was assumed in calculations. Potential acidity was multiplied by 1.25 to calculate the total lime requirement and accounts for complete incorporation. The tonnage of lime was divided by lime purity to obtain the application rate (Montana DEQ et al. 1999).

To determine the accuracy of laboratory data, relative percent differences were calculated for all lab data, excluding SMP lime requirement and acid base account (Appendix 1; Table 1). Data from field split samples were compared and relative percent difference was calculated as follows:

$$\mathrm{RPD} = [(X - Y) / ((X + Y)/2)] * 100 \tag{2}$$

where X is the known sample value and Y is the replicate sample value. If the relative percent difference is greater than 25%, data are not in control and should not be used for decision making. Relative percent difference values for available sulfur were 66% and 15% respectively, suggesting these data were not in control (Appendix 1; Table 1). Relative percent difference values for all other metals were in control.

Results

The control pit was characterized to determine undisturbed soil conditions. The profile exhibited characteristics of a typical coniferous forest. Six horizons were delineated in the profile including O, A, E, Bt1, Bt2 and CB (Figure 6). Applied coversoil from the borrow area was comprised of mixed Bt1, Bt2, and CB horizons. At the control site, the highest available metal levels were found in the top 15 cm due to the acidic nature of the litter layer (Figures 7a-e). The A horizon of the control site was strongly acidic (pH 5.5, Figure 8). The available zinc concentration of the A horizon was 2.1 ppm, iron was 106.8 ppm, aluminum was 19 ppm, copper was 1.7 ppm, and sulfur was 4 ppm. Due to the dominance of sand in the coversoil (66%), there may be problems with nutrient and water retention associated with the low chemical activity of sand (Brady and Weil 1999). Nutrient analysis across the site served as an indicator of coversoil suitability. Nitrate levels at the site averaged 13.8 ppm, with an approximate agricultural standard for nitrate at 12.5 ppm. Nitrate levels are probably higher than 13.8 ppm during most of the growing season, and our samples were collected at the end of the growing season when values are lowest (Vaughan et al. 2000). Phosphorus levels averaged 29.8 ppm with an agricultural standard of 13 ppm (Table 1). High phosphorous levels are favorable in areas where plant exposure to arsenic is possible, because plants do not differentiate between arsenate and phosphate. Therefore, higher phosphate levels can reduce arsenate uptake (Lambkin and Alloway 2003). The similarity between arsenic and phosphorus also confounds soil phosphorous measurements. Arsenic was not precipitated out of soil samples before testing for phosphorus, which may in part explain the high concentration of phosphate. Potassium levels on the site were an average of 162.5 ppm compared to an agricultural standard of 81 ppm.

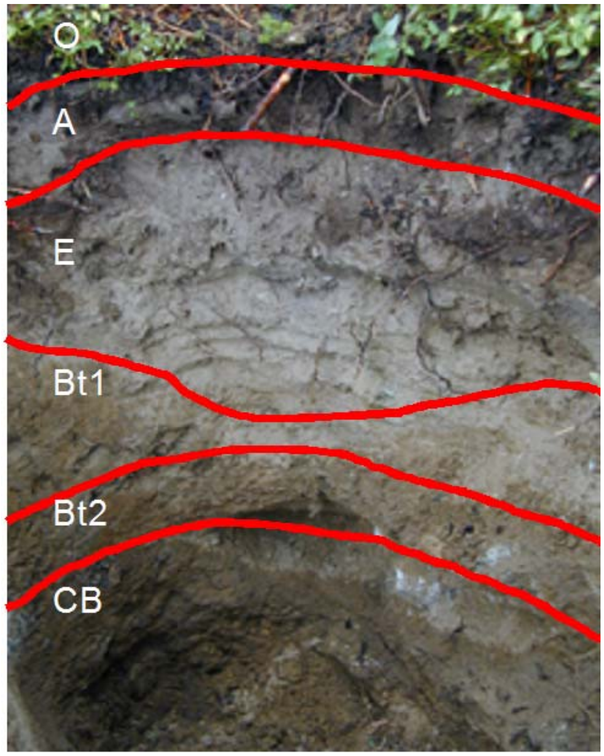


Figure 6. Control pit.

Interactions of contaminants and the applied coversoil were also considered. Acidic abandoned mine waste materials typically will not support plant life (Harwood 1979), therefore concentrations of metals across a mine site soil profile were measured. The onsite pit was

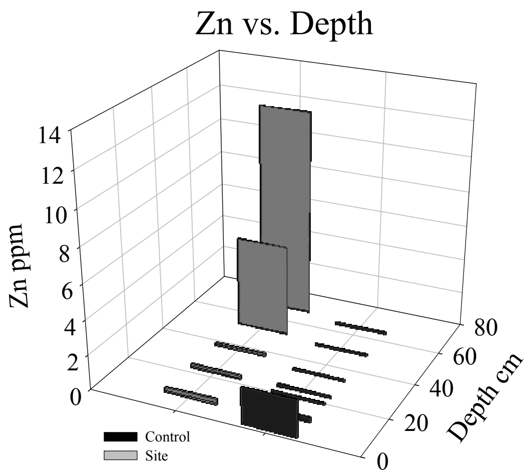


Figure 7a. Zinc vs. depth.

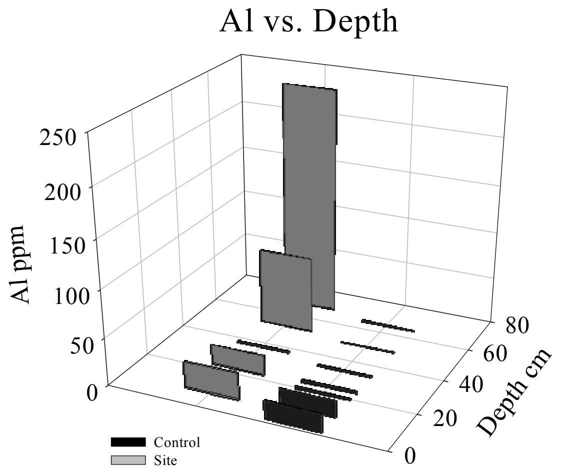


Figure 7b. Aluminum vs. depth.

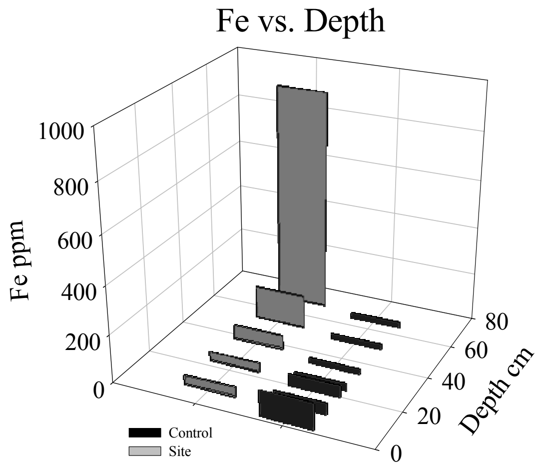


Figure 7c. Iron vs. depth.

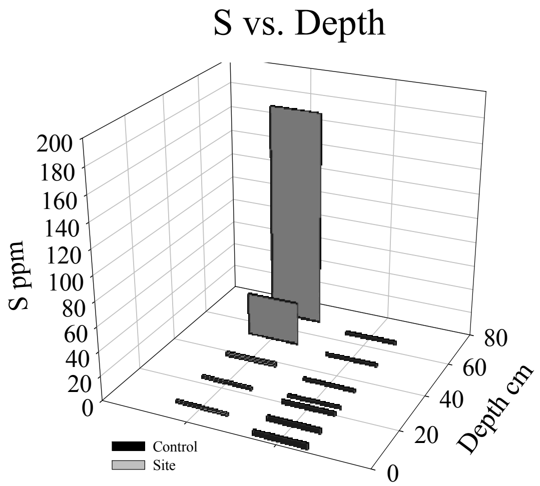


Figure 7d. Sulfur vs. depth.

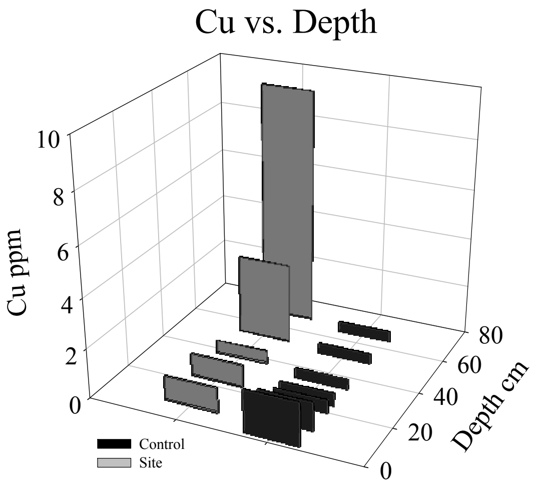


Figure 7e. Copper vs. depth.

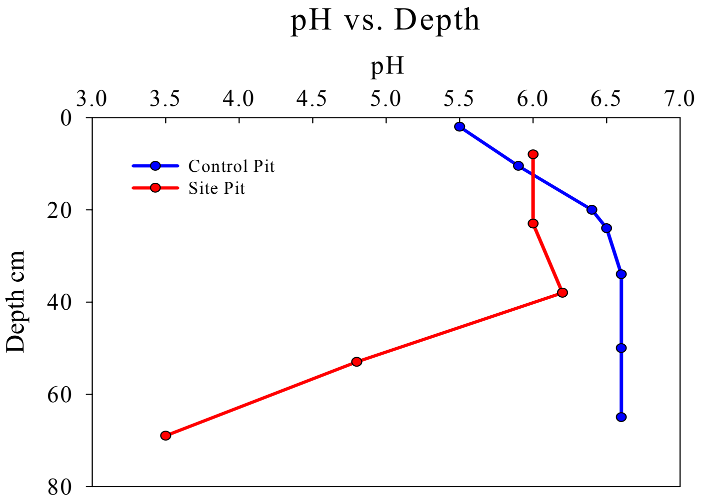


Figure 8. Soil pH vs. depth.

Table 1. Nutrient levels.

	Mean ± Std. Dev.	**Range**	**Sufficiency Level** (Crop lands)
Nitrate	13.8 ppm ± 21.5	1 – 108 ppm	12.5 ppm[1]
Phosphorus*	29.8 ppm ± 20.4	12 – 97 ppm	13 ppm[2]
Potassium*	162.5 ppm ± 113.8	58 – 544 ppm	81 ppm[2]

*Relative Percent Difference >25%

[1] Source : Jacobsen et al. 2003.
[2] Source : Havlin et al. 1999.

excavated to observe the coversoil and underlying metaliferous waste. A broken layer of gravelly limestone was noted in the profile at 40 cm (Figure 9).

Coversoil at the site pit had low available metal concentrations with zinc at 3 ppm, iron at 41.7 ppm, aluminum at 1 ppm, copper at 1.9 ppm, and sulfur at 45 ppm. The pH of the cover soil was 5.8, and potential acidity calculations showed a low lime requirement. Available metal concentrations increase substantially at the boundary of the coversoil and the metaliferous waste at about 40 cm deep. Available metal concentrations for the metaliferous waste were zinc, 32.1 ppm; iron, 888.4 ppm; aluminum, 142 ppm; sulfur, 319 ppm; and copper, 8.8 ppm (Figures 7a-e).

This is a concern as the pH of the waste materials decreased with depth in the profile, ranging from 6.0 at the surface to 3.5 at ~80 cm (Figure 8). At low pH, the availability and mobility of metals are greatly enhanced (Truog 1946), increasing the likelihood of migration of solubilized metals. Similar problems could result if metaliferous waste were exposed through down slope coversoil movement, as is present on the site one year after reclamation, with gullying and slope movement.

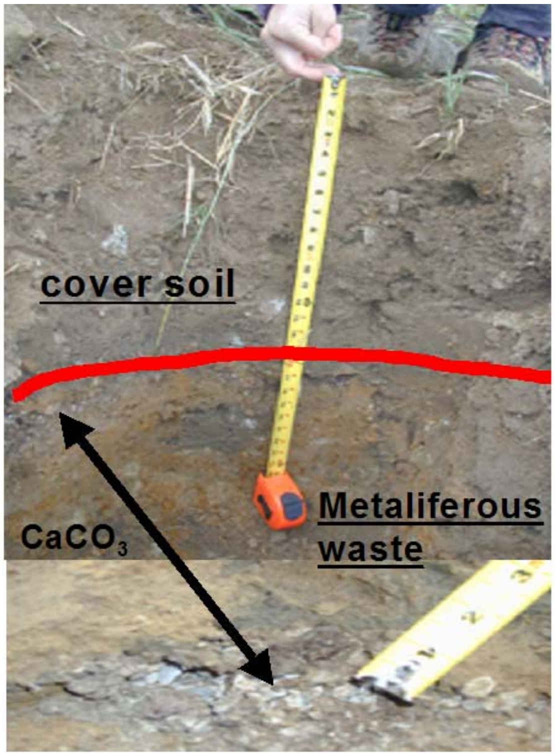


Figure 9. Site pit.

Total metal and arsenic values in cover soil collected at 8 quadrats are below human health guideline levels set in the Bullion Mine Site Final Report, and show a wide range across the site (Table 2; Maxim 2003). Given this, the reclamation effort can be considered successful in its goal of meeting recreational health safety standards on the site.

Table 2. Total metal concentrations.

	Mean ± Std. Dev.	**Range**	**Project Human Health Guideline**
Total As	49.4 ppm ± 57.5	5.7-178.0 ppm	700 ppm
Total Al	725.8 ppm ± 122.2	436-812 ppm	--
Total Pb	24.4 ppm ± 15.7	11-60 ppm	1,100 ppm
Total Zn	183.6 ppm ± 156.1	25-367 ppm	220,000 ppm

However the estimated 2,300 tons of waste rock above the reclaimed site has an acid load that would require 0.86 tons of calcium carbonate per kiloton of waste rock to be neutralized, posing a substantial re-contamination threat. An estimated 19.3 tons of lime would be required to neutralize the waste rock. The total lime requirement was calculated from the potential acidity and SMP lime requirement. The waste rock is of additional concern as it is not supporting plant life and is extremely acidic, pH 4.2 (Appendix 1; Table2).

Contamination of the reclaimed area could occur through water infiltration of the waste rock resulting in oxidation of sulfide-rich materials. Likewise, slope failure could permit upslope waste rock to slide onto the reclaimed area. Failure of the adit drainage armoring and conditions resulting in interflow or throughflow of acidified waters are additional sources of contamination. Conditions resulting in seasonal soil saturation may result in vertical migration of contaminants through the applied topsoil (Jianmin and Bradshaw 1995). Hydrogeologic characterization of the site would be necessary to draw specific conclusions about these issues.

Table 3. Coversoil parameters.

	Mean	**Std. Dev.**	**Range**
% OM	2.1	0.7	1.2-4.7
Mg (ppm)	240.5	81.6	84.0-428.0
Ca (ppm)	2177.9	837.4	421.0-5533.0
S (ppm)	200.2	228.1	5.0-999.0
Zn (ppm)	51.1	81.9	1.1-337.0
Mn (ppm)	74.8	70.0	17.7-268.0
Cu (ppm)	12.9	18.1	1.0-85.9
Fe (ppm)	83.6	92.2	26.6-392.2
B (ppm)	0.6	0.2	0.4-1.0
pH	5.7	0.8	4.0-7.0

The range and standard deviation of coversoil parameters across the site were high for most elements measured (Table 3). Soil pH, for example, varied from 4.0 to 7.0, and changed with position on slope across the Bullion Mine site (Figure 10). Transect 1 is at the top of the hill and transect 17 at the bottom. There was a positive correlation between pH and slope position (r = 0.51, p = 0.02), with more acidic pH values at the top of the hill, adjacent to remaining waste rock. Arsenic was more available at the top of the hill slope (r = -0.37, p = 0.03); while copper and zinc availabilities were not correlated to position on slope (Cu: r = 0.07, p = 0.69; Zn: r = -0.11, p = 0.53).

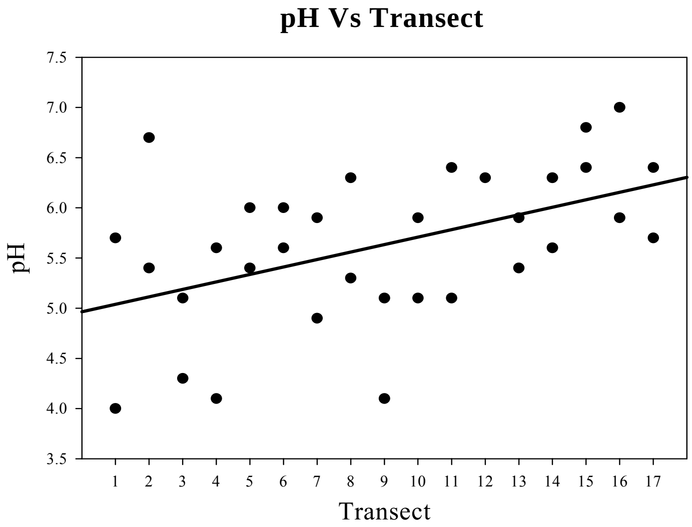


Figure 10. Soil pH vs. transect.

Although there was no conclusive evidence of upward migration of metals and metalloids in the dry soil profile (Figures 7a-e), there were higher metal and arsenic concentrations in wet areas. Several areas across the Bullion Mine site contained standing water (Figures 5 and 11). Wet and dry sites were compared to see whether available metal and arsenic levels were elevated in wet sites, the result of contaminated groundwater surfacing.

Figure 11. Standing water sites.

There was significantly higher cation exchange capacity (CEC) in wet quadrats (T_{14} =2.15, p=0.05; Figure 12). Higher CEC levels indicate a higher affinity to chelate cations. These cations are bound by the soil, yet they can be easily removed and assimilated by plants.

Levels of available zinc were significantly higher in wet soils (T_{14} =2.58, p=0.02; Figure 13), perhaps due to upward migration and/or lateral movement of zinc (Maeda and Bergstrom 2000). Upward migration is a result of capillary action causing groundwater to rise and contaminate the cover soil. Lateral movement is caused by horizontal movement of groundwater through the soil originating deeper in the hill slope, reaching the surface, and contaminating the cover soil. The contaminated groundwater could be a result of a heterogeneous mix of inputs originating from a ground water source also contributing to the adit drainage (Nakayama et al. 2002; Elzahabi and Yong 2001). Though it is difficult to quantify these water inputs, it is important to know they exist and pose a threat to the coversoil.

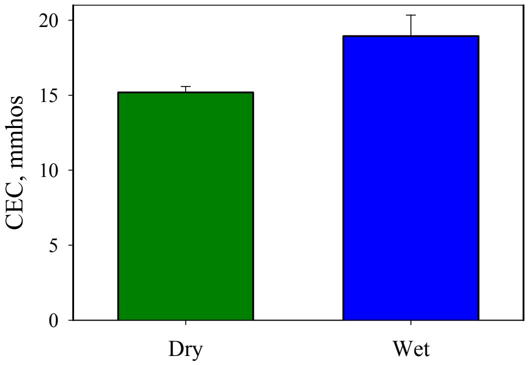


Figure 12. CEC in wet and dry quadrats.

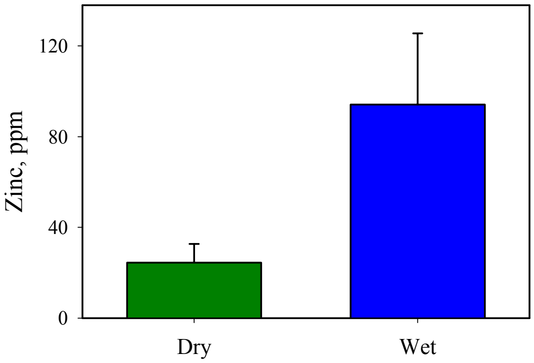


Figure 13. Zinc in wet and dry quadrats.

Zinc is more available to plants in wet areas and has the potential to be phytotoxic. Phytotoxicity occurs between 50-125 ppm (Munshower 1994). Available zinc levels average

51.1 ppm on the site with a standard deviation of 81.9 (Table 3). Levels range as high as 337 ppm, so zinc phytotoxicity may be a problem, although there was no correlation between zinc availabilities and vegetation cover.

Availabilities of arsenic and metals are determined by four soil components: pH, CEC, percent organic matter, and soil texture (Barona et al 1999; Nakayma et al. 2002; Maeda and Bergstrom 2000). Soil pH most significantly affects the availability of arsenic, copper, and zinc. Only arsenic availability correlated with position on slope, with higher levels of available arsenic at the top of the hill. Cation exchange capacity was higher in wet soils (Figure 12), as was zinc availability. Arsenic and zinc availabilities were positively correlated with CEC, similar to work done by Barona et al. (1999). Metal and arsenic availabilities did not correlate with percent organic matter or soil texture; in contrast to results of Barona et al. (1999) and Nakayama et al. (2002).

Conclusions

Several key soil parameters appear to be determining reclamation success. At the Bullion Mine site, pH levels increased down the slope, which corresponded with decreasing arsenic levels. None of the available metal concentrations varied with position on the hill slope. Zinc levels varied widely, some exceeding phytotoxic levels, in the wet areas. There was little correlation with spikes in available zinc and decreased vegetation cover, so we were unable to detect evidence of zinc phytotoxicity on the site.

Characterization of the soils and their relationships to chemical parameters present three sources of concern. Although total metal level concentrations do not exceed human health standards in the cover soil, available metal concentrations in the covered metaliferous waste are high. Low pH values in the metaliferous waste create a situation where metals are available, mobile, and potentially phytotoxic. Phytotoxic levels are a site and plant species-specific issue. Erosion of the coversoil could lead to exposure of metaliferous waste, reducing the buffering capacity of the coversoil.

Remaining upslope waste rock poses additional contamination issues. Residual waste rock is acid-producing and has the potential to contaminate the reclaimed site through acid leaching, or erosion. Possible contamination of coversoil could also occur via upward and lateral movement of metal contaminated water and adit drainage. The coversoil is acting as a barrier to site contamination. Although the coversoil is comprised primarily of compost-amended sandy materials, it has low concentrations of available metals and there is no evidence of upward metal migration after one year. Below 40 cm, available metal concentrations increase, posing concerns about upward migration through the coversoil and potential contamination in the future.

Because soil forming factors are measured on a geologic time scale, characterization one year post reclamation is not indicative of future conditions, but provides a basis for understanding the constructed soil of the Bullion site. Overall success of the Bullion Mine reclamation will be determined by what happens over the next decades. Water movement and coversoil stability will play the largest roles in sustaining the reclamation of the Bullion mine.

Vegetation Analysis

Revegetation of mine sites stabilizes soil, captures resources, and serves as the basis of community food webs. While vegetation can be one indicator of ecosystem function, the presence of dense vegetation cover alone may not indicate a contaminant-free environment. Soil characteristics play a large role in determining plant type and density. Many abandoned, unreclaimed mines have very acidic soils that can support some metal-tolerant plant species. Although this could lead to high plant cover, metal movement off site is still possible through water runoff, soil erosion, sediment loading, and animal consumption of contaminated plants. . Establishing baseline vegetation data is important for future monitoring of the Bullion Mine. Our three objectives related to vegetation were: 1) to quantify the amount and type of vegetation; 2) to evaluate the extent of the cover crop and 3) to investigate correlations between plant growth and soil parameters.

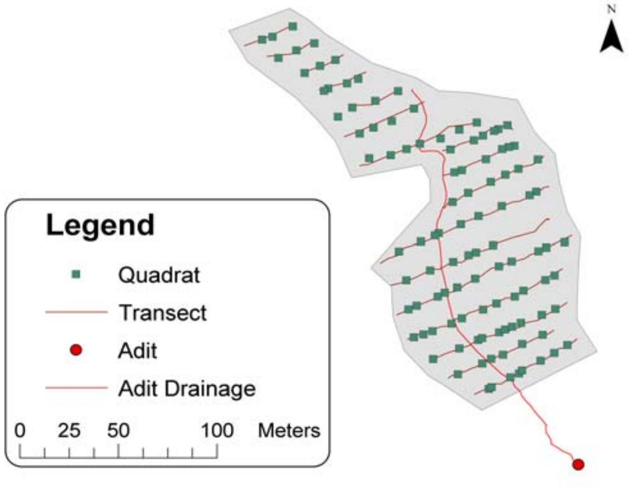


Figure 14. Vegetation quadrats.

Methods

Vegetation was measured using stratified random sampling, across the 17 transects used in soil analysis. One m^2 quadrats were randomly located along the transects (Figure 14). Parameters measured within each quadrat were: species density, percent vegetation cover (canopy) by species, bare ground, rock, and litter. Plants were excluded if 50% of their base was not included in the quadrat. Data was analyzed using Excel and SPSS (version 11.5) *Secale cereale* seeds were collected from plants growing on the site and grown under greenhouse conditions to determine seed viability.

Results

Fifteen species of grasses and forbs were included in the seed mix planted at the Bullion Mine (Table 4). All the species seeded were found in the quadrats except for two species, a grass, *Bromus cerintus* and a forb, *Monarda fistulosa*. Eight species of trees and shrubs were transplanted onto the site, for a total number of 4280 transplants.

Table 4. Species list.

Species List					
Graminoids		**Forbs**		**Shrubs**	
Agrostis scabra	V	*Achillea millefolium*	S	*Alnus viridis*	T
Bromus cerintus	S	*Aquilegia brevistyla*	S	*Rosa woodsii*	T
Bromus techtorum	V	*Asteraceae sp.*	V	*Rubus idaeus*	T
Calamagrostis canadensis	S	*Brassicaceae sp,*	V	*Salix exigua*	T
Carex sp.	V	*Capsella bursa*	V	*Shepherdia canadensis*	T
Deschampsia caespitosa	S	*Chenopodium album*	V	*Spiraea betulifolia*	T
Festuca idahoensis	S	*Elymus elymoides*	S		
Festuca longifolia	S	*Lupinus argenteus*	S	**Trees**	
Festuca sp.	V	*Lotus corniculatus*	S	*Abies lasiocarpa*	V
Glyceria grandis	S	*Monarda fistulosa*	S	*Picea engelmanii*	T
Poa canbyi	S	*Polygonum aviculare*	V	*Pinus contorta*	T
Poa secunda	S	*Saxifragacae sp.*	V	*Pseudotsuga menziesii*	V
Secale cereale	S	*Vicia sp.*	V		
Unknown Grass 1	V	Clover sp.	V	**Bryophyte**	
		Unknown Forb 1	V	Moss sp.	V
		Unknown Forb 2	V		

S=seed-mix T=transplanted V=volunteering

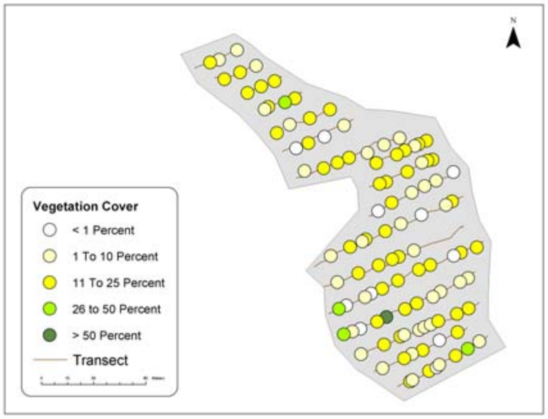


Figure 15. Map 4. Vegetation cover.

Forty-one species of plants were found across the entire site. Eighteen species were not seeded or transplanted. These species may have been present in the coversoil, brought to the site by the reclamation equipment, or their seeds may have been wind transported. Volunteer species may have significant impacts on the future vegetation of the Bullion Mine site, especially invaders such as *Bromus tectorum* (Booth et al. 2003) and *Chenopodium album.* These species could quickly out-compete native species, decreasing the diversity of native species on the site (Sheley and Petroff 1999). The surrounding forest also contributes volunteer tree species, which could have significant positive effects on the site.

Vegetation at the Bullion Mine had a canopy cover of a 13%, with a standard deviation of 10% and a range of 0 to 60% (Figure 15). The plant density in each quadrat ranged from 0 to 114 plants, with an average of 27 plants and a standard deviation of 22. Some quadrats were located in the adit drainage or on building structures resulting in no plant establishment.

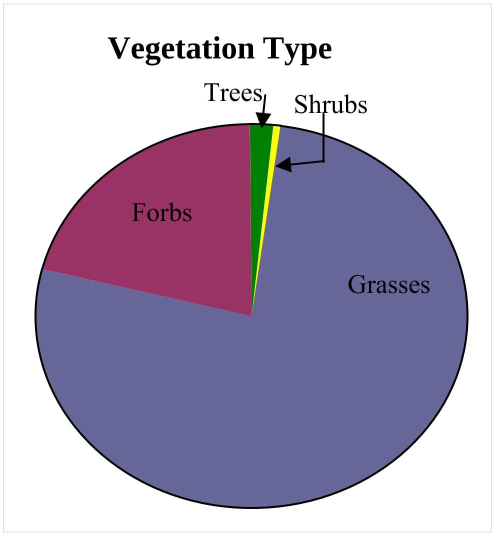


Figure 16. Vegetation type percentages.

The dominant plant types on the site were grasses, comprising 76% of the vegetation (Figure 16). The dominant grass was *Secale cereale*, which made up one-third of the grass cover and one-quarter of all vegetation. Forbs (21%), shrubs (1%), and trees (2%) were also identified throughout the quadrats. *Chenopodium album* was the dominant forb found on the site. There was a trend of increasing species diversity down slope. Mesic species such as *Alnus viridis* and *Sheperdia canadensis* were found at the bottom of the slope, near Jill Creek.

Cover crops are used in reclamation to reduce bare ground, limit soil and nutrient loss, supply organic matter, and check weed growth (Chambliss 2003). The coversoil of the Bullion Mine site is approximately 50% sand and contains an average of 2.1% organic matter. By planting *Secale cereale,* a rapidly growing cover crop with high biomass production, organic matter is increased through root growth and aboveground litter deposition.

Secale species are planted as cover crops because, in general, these plants thrive at high altitudes, have a high winter hardiness, germinate at soil temperatures around 0°C, and produce large quantities of above ground biomass (National Grain and Feed Association). Specifically, S*ecale cereale* is a winter annual that has an excellent winter hardiness, quick germination and growth rate (Chambliss 2003), and tolerates low fertility, low pH, and either wet or dry conditions (Kluchinski 2002).

Secale cereale produced a large amount of plant biomass and initiated a root system that could stabilize soil at the Bullion. Seeds of *S. cereale* that were produced this year on the site are germinated in the greenhouse, suggesting that if seeds successfully over-winter, *S. cereale* could impact future vegetation at the Bullion Mine site. Positive effects include acting as a nurse plant and protecting native plant seedlings, and negative effects could be out competing native species.

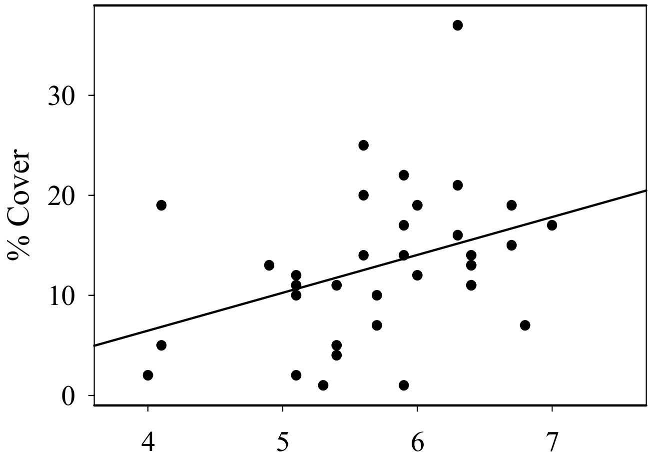


Figure 17. pH vs. % cover.

There was a positive correlation (p = 0.034) between pH and vegetation cover (Figure 17). Lower pH values increase metal availability to plants. When soil pH values are higher, metals are bound to the organic and inorganic components in the soil, reducing phytotoxicity (Dunn et al. 2002). Positive correlations were found between nitrogen, phosphorus, and potassium levels and vegetation cover at the Bullion Mine (Table 5).

Table 5. Correlation coefficients between vegetation cover and soil nutrients.

	r	**p**
Nitrate	0.4	0.02
Phosphorus	0.5	0.004
Potassium	0.41	0.02

Conclusions

The vegetation inventory of this site shows good representation of seeded and planted species, with an almost equal abundance of volunteer species. Several of the volunteer species are potentially invasive species, and their populations should be monitored yearly and controlled if necessary. Both the transplanted and volunteer conifers are beneficial, if they persist and increase in abundance. The cover crop was well established and appeared to be providing moderate soil stabilization, vegetative cover and organic matter inputs. This species should also be monitored for the next few years to estimate its long-term contributions to site stability, and to provide more information about its efficacy as a cover crop for future projects.

Water Analysis

Acid mine drainage (AMD) is a persistent environmental problem around the world, forming when mining activities expose sulfide minerals to the near-surface environment and oxygen-rich water. The result is the aqueous transfer of metals (e.g, Fe, Al, and As) and low pH water ($pH < 4$) to ground and surface waters, having detrimental effects on aquatic habitat and organisms.

Pyrite (iron disulfide) is commonly associated with metal ore deposits. The oxidation of pyrite involves a combination of biotic and abiotic processes and reactions. In the presence of oxygen and water, pyrite oxidizes to form insoluble ferric hydroxide, sulfate, and hydrogen ions. The acid-generating chemical reaction is:

$$FeS_2 + 15/4\ O_2 + 7/2H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+ \qquad (3)$$

These reduction-oxidation (redox) reactions along with microbial catalysis control the oxidation of pyrite in aqueous systems. Although the presence of oxygen is the driving force behind oxidation, the major rate-determining step may not involve oxygen at all (Evangelou and Zhang 1995). The oxidation of pyrite can be influenced by temperature, pH, and the presence of iron and sulfur-oxidizing bacteria. For example, the growth of *Thiobacillus ferrooxidan* provides the necessary catalyst to increase the ferrous oxidation rate by five to six orders of magnitude. Subsequently, pyrite is both directly and inorganically oxidized by ferric iron, removing the bottleneck at the ferric ion production level (Nordstrom 1982).

The oxidation of sulfur and the liberation of hydrogen ions further increases mine drainage acidity (every mole of pyrite yields four moles of acidity, eq. 4).

$$S_2° + 3O_2 + 2H_2O \rightarrow 2SO_4^{2-} + 4H^+ \quad (4)$$

As the acidity drops below pH ~4.5, the oxidation of Fe(II) or ferrous iron via abiotic pathways slows considerably. Lower pH also increases the solubility of ferric hydroxides. The primary oxidizer of pyrite then becomes ferric iron as the pH drops below 3.0 (eq. 5). The oxidation rate of pyrite by ferric iron is not affected by the presence or absence of oxygen.

$$FeS_2 + 14Fe^{3+} + 8H_2O \leftrightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (5)$$

Ferric iron is reduced to ferrous iron by pyrite faster than ferric can be oxidized by oxygen, consequently, the ferrous to ferric oxidation of Fe(II) to Fe(III) becomes the most important rate-limiting step in the oxidation of pyrite at a low pH. The ferrous oxidation rate constant is slow, (eq. 6), limiting the amount of ferric iron provided to oxidize pyrite (Evangelou and Zhang 1995).

$$Fe^{2+} + 1/4O_2 + H^+ \rightarrow Fe^{3+} + 1/2H_2O \quad (6)$$

The oxidation of Fe(II) to Fe(III) generally leads to the precipitation of poorly-ordered iron oxy-hydroxides. In AMD, oxidation of Fe(II) to Fe(III) and progressive neutralization of acid waters frequently leads to the precipitation of Fe sulfates and oxy-hydroxides as a function of rising pH (Morin et al. 2003).These oxy-hydroxides can incorporate toxic elements within their structure (chelate) or adsorb them at their surface. Such reactions may strongly limit the mobility of trace elements such as arsenic in AMD. Arsenic is scavenged by structural incorporation in some of these minerals and adsorbed onto their surfaces (Morin et al. 2003).

As pH drops below 3.0, ferric iron continues to play a role in the oxidation of pyrite. More importantly, the oxidation rate of pyrite depends upon factors affecting the growth of Fe(II) oxidizing microorganisms such as *Thiobacillus ferrooxidan* (Nordstrom 1982). Ultimately, these growth factors can be linked to the availability of electron donors/acceptors, carbon source and energy, which become important in determining the rates of aqueous pyrite oxidation. *Thiobacillus ferrooxidan* can increase rates of Fe(II) oxidation by providing rapid regeneration of ferric ions in acid solutions. Lastly, another component of AMD is diel cycling, the temporal variability of pH, temperature, and dissolved oxygen, over a 24-hour period (Nagorski et al. 2003, Sullivan et al. 1998).

Methods

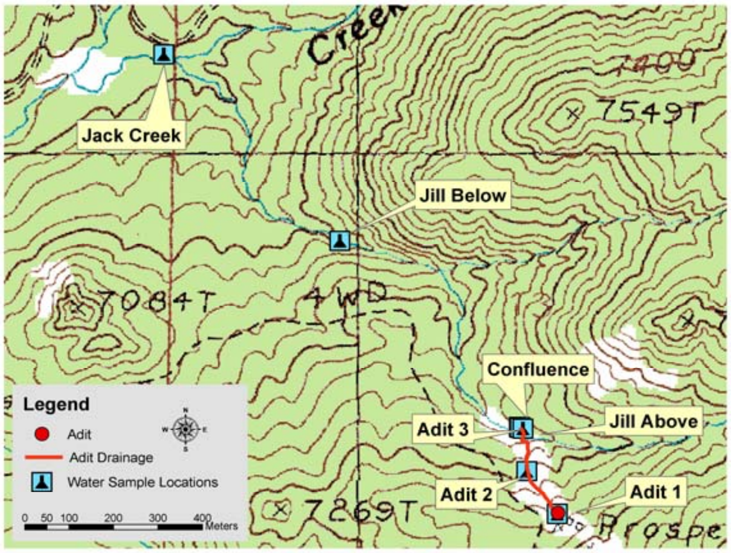


Figure 18. Water sample locations.

Water was collected at seven sites, based on downstream proximity to the adit source (Figure 18). Aqueous samples were collected three times at each site. Sample sites included three locations within the adit drainage (Adit 1, 2, and 3) and four sites down gradient. Jill above, located upstream of any acid drainage influence; Confluence, at the point were the adit drainage entered Jill Creek; Jill Below, located approximately ½ mile downstream, midway between confluence and Jack Creek; and Jack Creek, located just downstream of Jill/Jack Confluence. The diurnal properties of metals and aqueous solutions (Sullivan et al. 1998) justified three sample times of 8 am and 4 pm on August 26th, and 8 am August 27, 2003. A total of 43 samples were analyzed for total metals, dissolved metals, total arsenic, As(III), As(V), total Iron, Fe(II) and Fe(III). Six 125mL-samples were collected from seven sites using a 20mL syringe (42 total). All HDPE 125mL bottles contained an acidified (5% in dilution) solution of nitric acid (HNO_3). Three samples were used to measure total metals (TM) and three for dissolved metals (DM). The DM samples were filtered with a 0.22µm glass filter (Osmonics Inc.). Samples were analyzed at the Montana State University Soil and Water Analytical Laboratory. DM and TM samples were analyzed for Cu, Fe, S, Zn, Pb, Al, Cd and As using inductively coupled plasma emission spectrometry (ICP-ES).

Additional samples were obtained in September 2003 to examine arsenic and iron speciation. These samples were drawn from each site using a 20-mL syringe and divided into 3 subsamples. The samples were filtered (0.22-µm) into 15-mL HDPE plastic bottles containing 0.25-mL of 6.0M HCL, and immediately shaken for 5 min to remove dissolved sulfide.

One subsample was analyzed for total soluble Fe (Fe(ts)) and Fe(II) using the colorimetric FerroZine method (Bangthanh et al. 1999). A second aliquot was further diluted. Eight columns were used for As(III) analysis, using strong anion-exchange cartridges (Supelclean LC-SAX SPE tubes, 3-ml, Supelco) to retain As(V). A new cartridge was used for each sample, and each cartridge was conditioned prior to use with a 2-mL methanol bath and rinsed with 2-mL of deionized water.

The diluted samples (i.e., solvents) were eluted at 2-mL/min using positive pressure (syringe piston). The As sample (0.01-mL) was passed through the conditioned cartridge at 2-mL/min. The column was eluted with 2.50-mL of deionized H_20 at 2-mL/min, which was collected with the sample. The combined elutes were weighed to calculate the dilution factor. The concentration of As(III) in the eluted sample was determined by hydride generation atomic absorption spectrometry (HG-AAS) (Langner et al. 2001).

Concentrations of total dissolved As and Fe in the acidified ICP samples were approximately equal to the levels of As and Fe analyzed using the As Column method and colorimetric FerroZine method respectively (Langner et al. 2001). Concentrations of As(V) were determined by calculating the difference between As(ts) and As(III) concentrations based on previously reported analytical protocols for determining As(ts) and As(III) (Langner et al. 2001). Dissolved oxygen and pH were measured at the same times aqueous samples were taken using YSI 63 (pH, salinity, conductivity) and YSI 85 (oxygen, conductivity, salinity, temperature) handheld meters.

Results

At the adit source and until the AMD reaches Jill Creek (Figure 18), concentrations for all metals analyzed exceeded Montana’s Department of Environmental Quality (DEQ) published numeric water quality standards for these metals (DEQ 2002**)**. The samples taken above the confluence in Jill Creek also had high levels of Al, Cu, Zn, As, and Pb (Figure 19b, -19e).

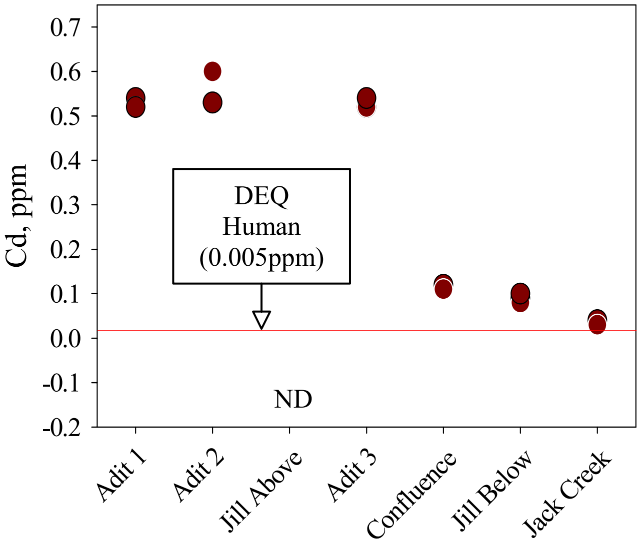


Figure 19a. Aqueous cadmium concentrations.

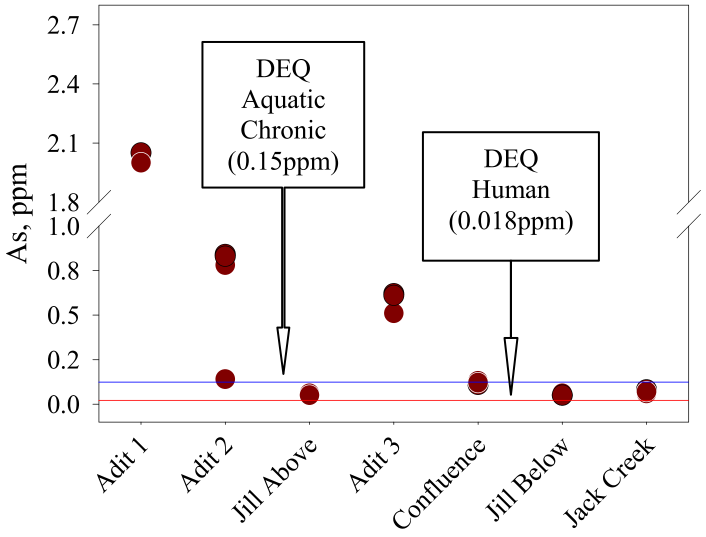


Figure 19b. Aqueous arsenic concentrations.

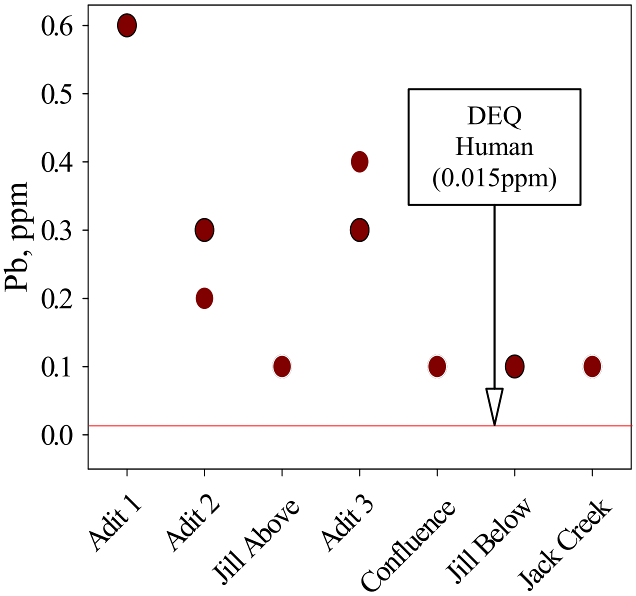


Figure 19c. Aqueous lead concentrations.

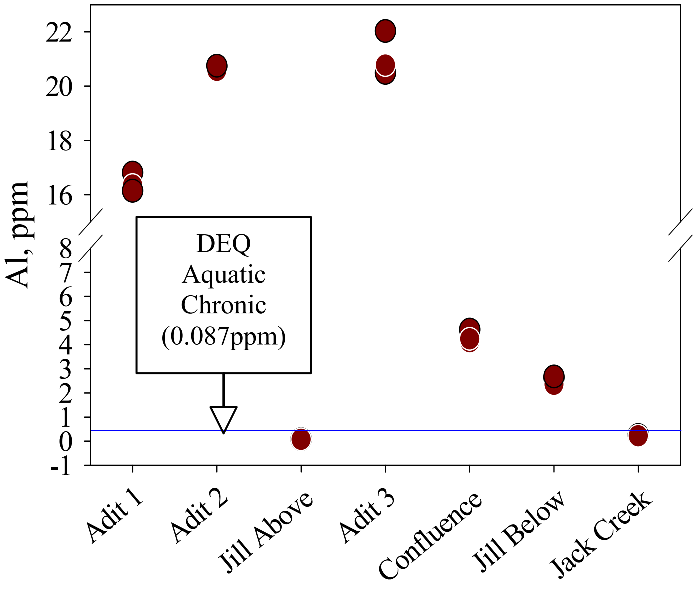


Figure 19d. Aqueous aluminum concentrations.

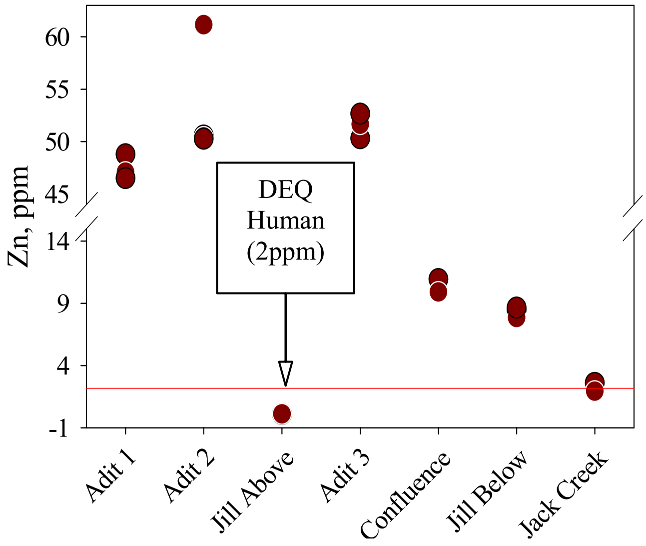


Figure 19e. Aqueous zinc concentrations.

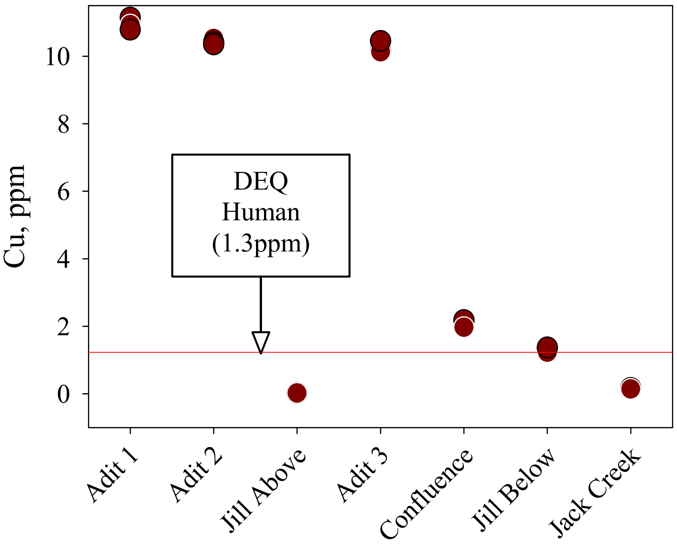


Figure 19f. Aqueous copper concentrations.

Al, Cu and, to a lesser degree, Zn levels return to those found in Jill Creek above the confluence with the adit drainage. Co-precipitation of As with Pb may affect As concentration levels, resulting in little variability of As concentrations from where the AMD enters Jill Creek to the down gradient site on Jack Creek.

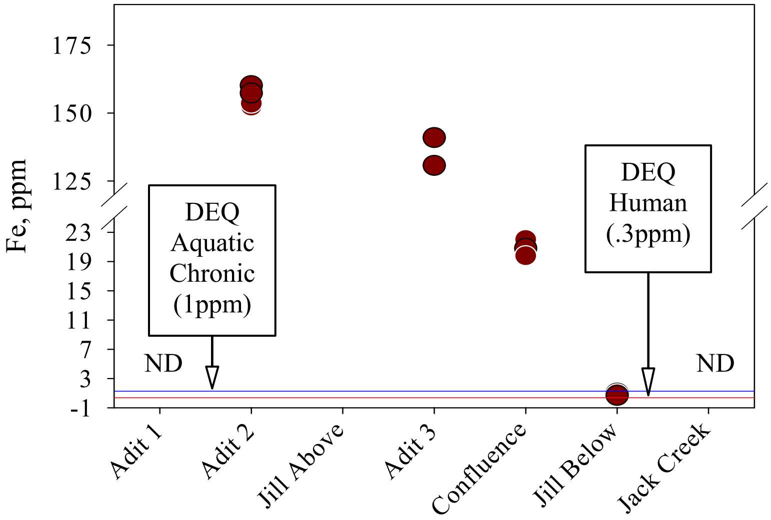


Figure 19g. Aqueous iron concentrations.

Cadmium and Fe levels in Jill Creek were below detection limits (Figures 19a, 19g). Cadmium levels at Jack Creek remain above DEQ's standards while Pb concentrations were undetectable. Cadmium may remain in solution more readily than Pb.

All metals analyzed exhibited variability of concentration levels from the adit source to Jack Creek. As, Cd, and Pb concentrations all exceed DEQ's standards even after mixing with Jill and Jack Creek. Concentrations of other metals (Al, Cu, Fe, and Zn) narrowly comply with DEQ's standards. Al and Zn exist very near the standard. It should be noted that slight diel variability of Al and Zn concentrations can affect whether compliance with DEQ's standards is met.

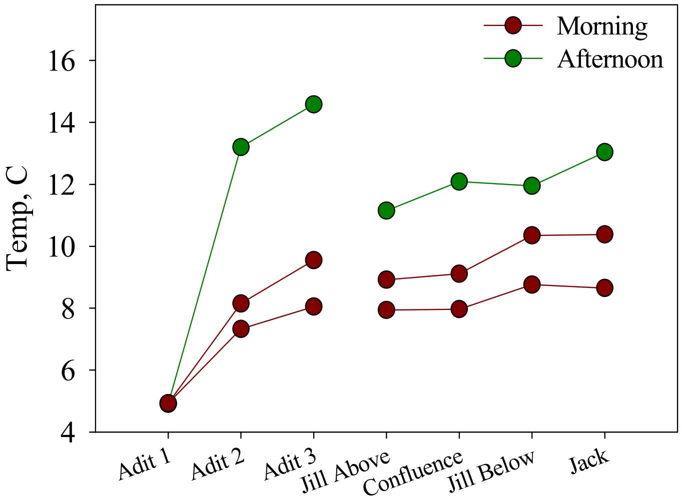


Figure 20. Aqueous temperatures.

Water temperature varied daily (Figure 20), affecting dissolved oxygen concentrations, which decreased with increasing temperature. Little diel metal concentrations were detected. With pronounced temperature change occurring over a 24-hour period other factors besides temperature may be controlling diel metal concentrations.

Adit drainage water had a pH that averaged 2.56 (Figure 21). At the confluence with Jill Creek the low pH adit water resulted in a decrease in the pH of Jill Creek from 5 above the confluence to 3 at the confluence, along with high concentrations of dissolved metals. The precipitation of Fe at the confluence is controlled by Jill Creek water increasing pH.

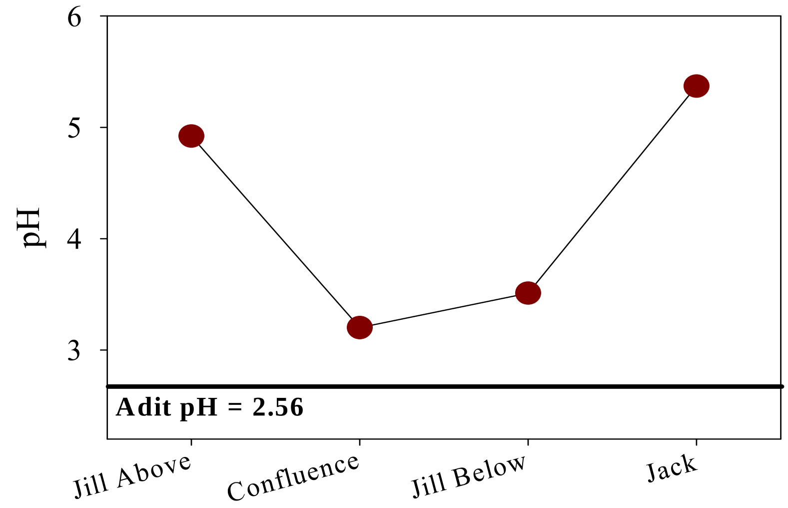


Figure 21. Aqueous pH levels.

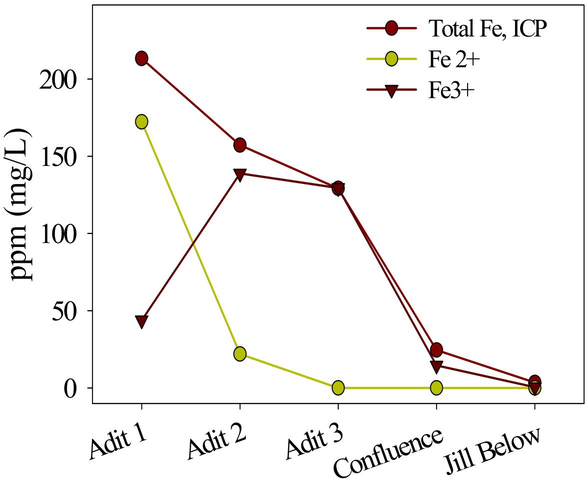


Figure 22. Speciated iron concentrations (aqueous).

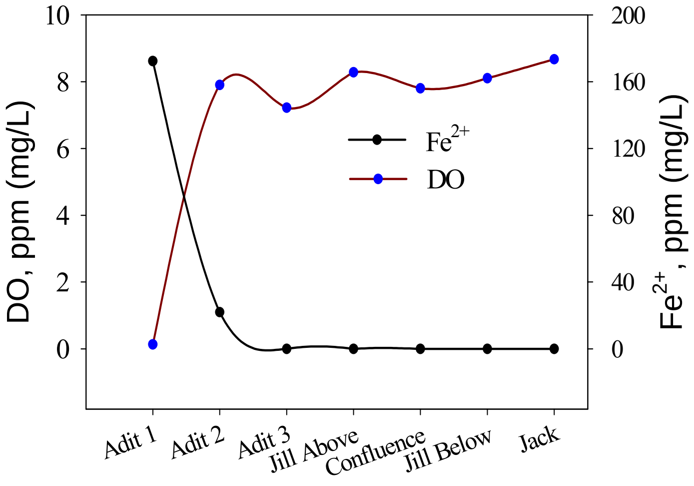


Figure 23. Dissolved oxygen concentrations (aqueous).

Total iron levels at the source (adit 1) were very high (210 ppm), and the majority occurs as Fe(II). As the water is exposed to atmospheric conditions, Fe(II) is oxidized to Fe(III) (Figures 22, 23). The low pH of the mine drainage results in Fe levels high in insoluble Fe(III) at the adit drainage. Acid mine drainage at the Bullion is supersaturated with respect to iron. Dissolved iron levels

Figure 24. Adit drainage confluence with Jill Creek.

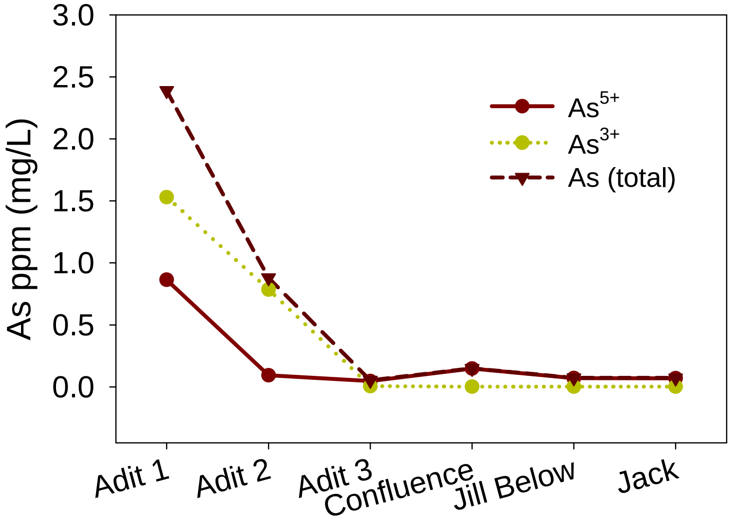


Figure 25. Aqueous arsenic concentrations.

drop drastically at the confluence with Jill Creek, due to increases in pH. This shows up visibly as the yellow-orange iron precipitate deposited along the bottom of Jill Creek (Figure 24).

Given that arsenite (As(III)) is more mobile and considered more toxic to microbiota and plants than arsenate (As(V)), the levels of arsenite can pose a significant health concern (Inskeep et al. 2001; Figure 25). Concentrations of arsenite at the source exceeded human health standards. However, due to the co-precipitation of As-Fe solid phases, As levels dropped to pre-confluence levels below the confluence with Jill Creek (Guillaume et al. 2003, Sasowsky et al. 2000).

Conclusions

Acid mine drainage affects chemical, physical, biological, and ecological properties of an ecosystem. Acid mine drainage can reduce biodiversity, altering and even eliminating living aquatic systems. The water flowing out of the adit contains metals in solution that are easily transported down gradient. Successful remediation would increase the pH, DO and temperature of the AMD, thereby decreasing metal concentrations and availabilities.

Monitoring

Developing a monitoring plan to recommend to the Forest Service was the final objective of the capstone class. This monitoring plan provides criteria to evaluate the direction of the reclamation work. Monitoring will provide consistent data to guide adaptive management on the Bullion site, indicating how well reclamation goals were met. This information can then be used to modify reclamation practices for future projects.

Vegetation Monitoring

Vegetation monitoring is essential for evaluating revegetation efforts of abandoned mine reclamation projects. Indicators are single parameters used to indicate success and, due to financial limitations and time constraints, should be easily measured (Ludwig et al. 2003). Vegetation is the primary indicator used in this monitoring plan.

Seventeen transects were marked at each end with iron rods to facilitate consistent sampling and monitoring across the site. Sampling should occur annually during the peak of the growing season with three $1m^2$ quadrats randomly located along each transect. The most commonly used parameters for monitoring vegetation include cover, species diversity, and density. Percent cover will be determined for both individual species and total vegetation. Sampling is recommended annually for the first three years, then every third year after until results indicate little change.

The *Secale cereale* that currently dominates the vegetative community is a hardy plant that may provide necessary cover and litter, or may out-compete more desirable species. We recommend closely monitoring *S. cereale* along with non-native invasive species such as *Bromus tectorum* and *Chenopodium album*. If invasive species cover and density increase dramatically, control of these species should be considered. Comparing annual results with 2003 data can suggest revegetation success or failure, as defined by the projects goals and objectives. These results can also be used to make inferences regarding other environmental parameters affecting vegetation, specifically soil and water influences.

Soil Monitoring

Vegetation success is highly dependent on soil characteristics. Soil traits including metal availabilities, pH, and soil erodibility should be monitored to ensure successful reclamation of the Bullion Mine site (Dale and Beyeler 2001). Because of its effects on plant nutrient and metal uptake, soil pH should be measured annually at the same time vegetation is sampled. Measuring pH is quick and inexpensive, and can be performed on site. It is also indicative of metal availabilities and possible plant phytotoxicities (Nakayama et al. 2002, Barona et al. 1999). Soil should be sampled at a depth of 0-15 cm in each vegetation quadrat by compositing seven subsamples within the quadrat. An on-site pH meter, testing a 1:1 soil to deionized water paste would be preferable to off-site analysis. Other options include litmus paper, pH indicator dyes, or analysis by a testing laboratory. A compilation of soil pH results will enable identification of possible areas of recontamination.

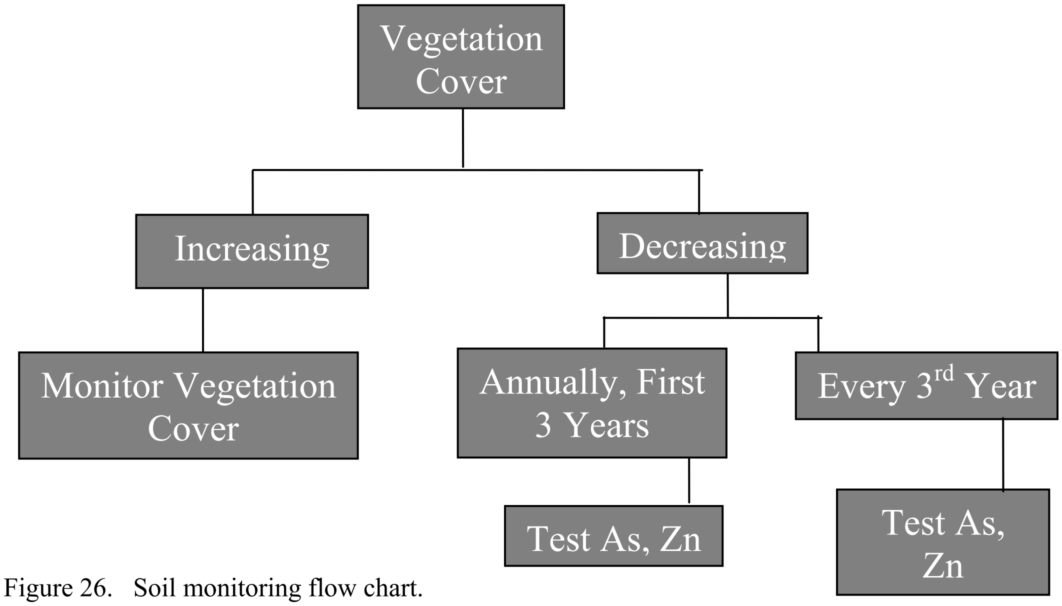


Figure 26. Soil monitoring flow chart.

Slope stability is a major concern on the Bullion Mine site. Currently, mass movement and gullying are taking place, reducing coversoil depth and potentially exposing waste materials. Hydrology, both above and below ground, is the main factor controlling these processes (Wu et al. 1996). Surface flow and a rising water table create unstable surfaces in sandy soils. Exposed metaliferous waste/waste-rock inhibits plant growth and increases contaminant transport off site. We suggest performing a yearly ocular evaluation of the site using established, permanent photopoints, of areas of concern (i.e. large gullies, exposed waste rock, areas of mass movement). A more in-depth method is adapted from the NRCS guideline <u>Rangeland Health Ecological Attributes Evaluation Matrix</u> (Appendix 2: Figures 1-2a,b). The matrix addresses several factors of slope stability including rills, water flow patterns, gullies, bare ground, soil surface characteristics and pedestals. Each characteristic is placed in a category and classified according to severity. A value is then assigned to each degree of severity and summed, producing long-term qualitative data indicative of slope stability on the site.

The need for measuring metal or nutrient availabilities will be determined by vegetation cover or persistent areas of bare ground identified during slope stability analysis. Composited soil samples from 0-15 cm will be collected directly from quadrats in areas identified previously as problems. For the first three years available (DTPA extractable) As and

Zn will be measured if vegetation cover (excluding *S. cereale*) decreases (Figure 26). As and Zn have been determined to be potentially mobile and phytotoxic on the site (Shu 1995). After three years, decreasing cover will suggest the need for testing As and Zn again, as well as N (NO_3^- and NH_4^+), P and K. Nutrient levels are currently sufficient, but may decrease over time. Exact nutrient sufficiency and metal phytotoxicity levels are plant dependent and need to be determined by a greenhouse study.

Water Monitoring

Until remediation of AMD on site occurs, several factors should be further quantified via monitoring. To test the integrity of the PVC lining, the adit discharge could be measured at two locations, at the source and before the AMD reaches Jill Creek. Adit discharge measures will also indicate fluctuations over time. Discharge measures can be done using standard flow meters or manually constructed weirs. Flow (or current) meters measure velocity, discharge (Q) would need to be calculated using the equation, Q = Width x Depth x Velocity. Construction of a weir would also allow for easy and consistent measurements. However, the material used to construct the weir, over time, may collect precipitate, eventually affecting discharge measures.

Water quality samples should be taken at the confluence of Jill Creek and the adit, and analyzed for metal concentrations, pH and dissolved oxygen. Metals to be considered for analysis should include, but not be limited to: As, Cd, Pb, and Zn. Future metal concentrations could then be compared to previous data (Appendix 3). Sample times should be consistent from year to year, collected in August in conjunction with vegetation monitoring.

Project Conclusions

Results one year after reclamation suggest that the objectives of the Bullion Mine reclamation may eventually be met. The coversoil is currently acting as a sufficient barrier to upward movement of metals and metalloids from the contaminated subsoil. The coversoil is supporting 41 species of plants with an average cover of 13% and a density of 27 plants/m^2. This vegetation is stabilizing the slope, reducing the potential for erosion.

There are four sources of possible contamination still remaining on the site: 1) the remaining upslope waste rock, 2) erosion of cover soil that could expose metaliferous wastes, 3) upward migration of metals in wet sites, and 4) AMD. Recontamination of the coversoil could have many serious effects. Phytotoxic metal levels will kill vegetation, possibly leading to increased erosion and contamination. It is essential that vegetation continue to stabilize the site. If monitoring of the site shows a decrease in vegetation or areas totally devoid of vegetation, additional fertilizer amendments and native seed may need to be applied.

Many things can be learned from the Bullion Mine, including both positive and negative reclamation practices. Positive aspects include waste removal, vegetation establishment, Jill Creek reconstruction, and decreased metal concentrations in the coversoil. Negative aspects include the major sources of contamination still remaining on the site. These sources will persist for decades to come, and need to be addressed if the site is to be totally reclaimed. The AMD is currently the single most important vector for movement of mining waster pollutants off site. The development of reasonable methods for AMD treatment will greatly increase success of future reclamation projects.

Appendix 1: Soil Data Tables

Table 1. Soil pit data.

	Horizon name	Horizon Depth	Soil	Zinc	Iron	Aluminum	Copper	Sulfur
			pH	ppm	ppm	ppm	ppm	ppm
Control	A	2-10 cm	5.5	2.1	106.8	19	1.7	4
	E	10-25 cm	5.9	0.2	44.4	17	1.1	3
	Bt1	25-46 cm	6.4	0.1	45.9	2	0.5	3
	Bt2	46-69 cm	6.5	0.1	29.1	2	0.5	2
	C	69-84 cm	6.6	0.1	20.1	1	0.4	2
Reclaimed	Coversoil	0-40 cm	5.8	3	41.7	1	1.9	45
	Metaliferous waste	> 40 cm	3.1	32.1	888.4	142	8.8	319
Waste Rock			4.2	49.8	198.1		64.8	97
Field Split X			6	0.3	35		0.9	4
Field Split Y			3.5	10.6	726		8.5	151
RPD X			0.00	0.00	11.57		10.53	66.67
RPD Y			0.00	11.56	23.02		11.11	15.29

Table 2. Acid base account data.

	Sulfur HCl % weight	Sulfur Res. % weight	Sulfur, HNO3 % weight	Potential Acidity t/kt	SMP Lime Requirement t/kt	Total Lime t/kt
Waste Rock	0.01	ND	0.02	0.86	5.4	8.69
Cover Soil	0.01	ND	ND	0.23	<.1	0.46

Appendix 2: Soil Monitoring Field Sheet

Rangeland Health Ecological Attributes Evaluation Matrix:

Attribute	Category I	Category II	Category III	Category IV	Category V
Rills	Rill formation is severe, well defined throughout most of the site are at close intervals.	Rill formation is moderately active, well defined throughout most of the area at close intervals.	Active rill formation is slight at infrequent intervals, mostly in exposed areas.	No recent formation of rills, some evidence of past rill formation, old rills are blunted or muted.	Minimal evidence of recent or past formation of rills
Water Flow Patterns	Flow patterns extensive and more numerous than expected; unstable with active erosion. Flow patterns connected.	Flow patterns more numerous than expected; deposition and cut areas common. Occasionally connected.	Flow patterns match what is expected for the site; erosion and deposition in flow pattern minor, but flow paths are not entirely stable.	Flow patterns match what is expected for the site. Little evidence of past erosion. Flow patterns are stable over the majority of the area.	Flow patterns are natural and stable and match what is expected for the site.
Pedestals caused by wind &/or water erosion	Abundant active pedestalling. Most rocks and plants are affected; exposed plant roots are common.	Moderate active pedestalling. Some rocks and plants are affected. Exposed plant roots are evident, but not common.	Slight active pedestalling, most pedestals in flow paths, interspaces and /or on exposed slopes.	No indications of active pedestalling; some evidence of past pedestal formation, especially in flow paths and/or on exposed slopes.	Minimal current or past evidence of pedestalled plants or rocks.
Bare Ground	Amount of bare ground much higher than expected for the site. Bare areas are large and are connected.	Amount of bare ground higher than expected for the site. Bare areas are large, but are not connected.	Amount of bare ground slightly higher than expected for the site. Bare areas moderate - small and clumped.	Amount of bare ground slightly higher than expected for the site. Size of bare areas is small.	Amount and distribution of bare areas matches that expected for the site.
Gullies	Present with active erosion, vegetation is intermittent on slopes and/or bed. Nick-points are present and new headcuts occurring. Down cutting channel is apparent.	Present with indications of active erosion, vegetations is intermittent on slopes and/or bed. Headcuts are active. Down cutting channel not apparent.	Present with few indications of active erosion, vegetation is intermittent on slopes and/or bed. Some headcutting is evident.	Present but stable; vegetation is well established on bed and slopes; not visual signs of active cutting, nickpoints, or bed erosion.	Drainage areas represented as natural stable channels.
Soil Surface	Surface organic layer rarely present, and then only in association with prominent plants or obstructions.	25-50% of the surface organic layer is no longer present. Variations in depth of the soil surface between vegetation and interspaces exceed 25%.	Not more than 25% of the surface organic layer is present. Variations in the depth of the soil surface between vegetation and interspaces are less than 25%.	Some evidence of past loss of surface organic layer. The soil surface is presently stable and no evidence of current surface organic layer loss.	Minimal evidence of surface organic layer loss. Variation between vegetation and interspaces matches that expected for the site.

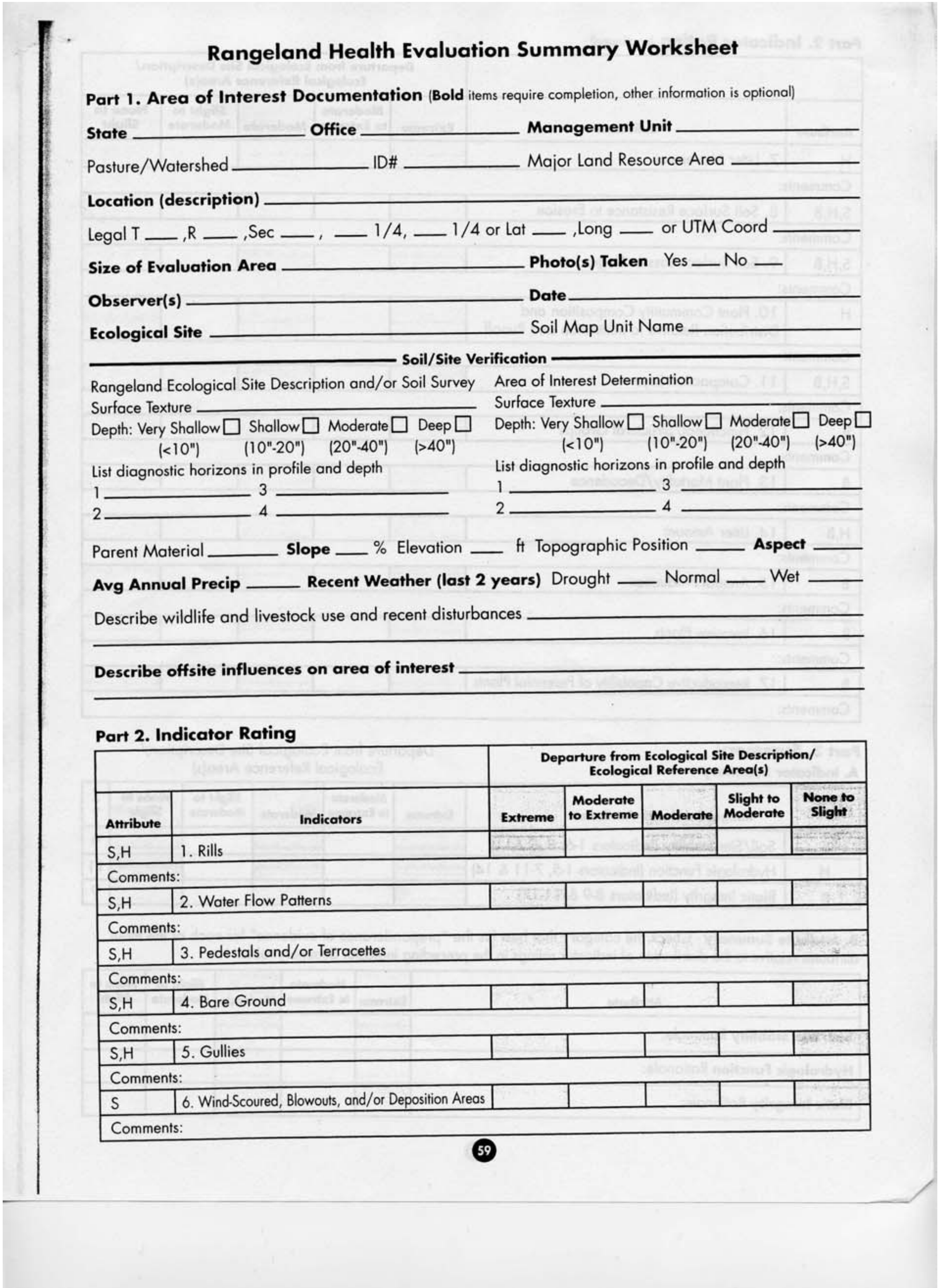
Appendix 3: Water Analysis Data

Sample #	Sample Location	Day in August	Time (am/pm)	pH	Temperature (c^{o})	Diss. Oxygen	Cu	Fe	Zn	Pb	Al	Cd	As
1	Adit 1	26	am	2.55	4.93	0.13	11.14	209.8	48.79	0.6	16.81	0.54	2.05
3	Adit 1	26	pm	2.6	4.91	0.02	10.93	211.7	47.08	0.6	16.35	0.52	2
5	Adit 1	27	am	2.46	4.93	0.08	10.78	212.9	46.5	0.6	16.14	0.52	2.86
8	Adit 2	27	am	ND	ND	ND	10.52	152.5	61.15	0.2	29.39	0.6	0.14
9	Adit 2	26	am	2.6	7.33	7.9	10.41	160.1	50.58	0.3	20.72	0.53	0.84
11	Adit 2	26	pm	2.67	13.2	6.52	10.34	153.6	50.43	0.3	20.58	0.53	0.78
13	Adit 2	27	am	2.62	8.15	7.87	10.35	157.4	50.27	0.3	20.75	0.53	0.83
15	Jill Above	26	am	4.93	7.94	7.22	0.03	ND	0.1	0.1	0.1	ND	0.06
17	Jill Above	26	pm	5.02	11.15	6.25	0.02	ND	0.1	0.1	0.08	ND	ND
19	Jill Above	27	am	4.83	8.92	7.89	0.02	ND	0.11	0.1	0.07	ND	0.05
21	Adit 3	26	am	2.55	8.05	8.28	10.15	141	50.3	0.3	20.48	0.52	0.62
23	Adit 3	26	pm	2.62	14.58	6.1	10.13	119.7	51.65	0.4	20.77	0.52	0.51
25	Adit 3	27	am	2.57	9.55	8.2	10.45	130.7	52.67	0.3	22.03	0.54	0.61
27	Confluence	26	am	3.22	7.97	8.09	1.97	22	9.92	0.1	4.12	0.11	0.13
29	Confluence	26	pm	3.31	12.09	7.25	2.18	20.8	10.94	0.1	4.62	0.12	0.11
31	Confluence	27	am	3.07	9.11	8.1	1.97	19.8	9.9	0.1	4.24	0.11	0.12
33	Jill Below	26	am	3.44	8.76	8.26	1.34	1	8.45	0.1	2.62	0.09	0.05
35	Jill Below	26	pm	3.61	11.95	6.5	1.23	0.9	7.85	0.1	2.36	0.08	0.06
38	Jill Below	27	am	3.52	10.35	7.95	1.37	0.7	8.65	0.1	2.68	0.1	0.05
39	Jack Creek	26	am	5.29	8.65	9.36	0.15	ND	1.85	0.1	0.26	0.03	0.06
41	Jack Creek	26	pm	5.22	13.04	2.33	0.17	ND	2.6	0.1	0.25	0.04	0.08
43	Jack Creek	27	am	5.6	10.38	7.97	0.14	ND	1.93	0.1	0.22	0.03	0.07
						Aquatic (chronic)	*	1	*	*	0.087	*	0.15
						Human Health (surface water)	1.3	0.3	2	0.015	n/a	0.005	0.018

ND = Not detected or No data

Note: All metal concentrations and Dissolved Oxygen are in ppm (mg/L).

*Concentration levels for these metals are determined in relation to water hardness



Rangeland Health Evaluation Summary Worksheet

Part 1. Area of Interest Documentation (**Bold** items require completion, other information is optional)

State ________ **Office** ________ **Management Unit** ________

Pasture/Watershed ________ ID# ________ Major Land Resource Area ________

Location (description) ________

Legal T ____ ,R ____ ,Sec ____ , ____ 1/4, ____ 1/4 or Lat ____ ,Long ____ or UTM Coord ________

Size of Evaluation Area ________ **Photo(s) Taken** Yes ____ No ____

Observer(s) ________ **Date** ________

Ecological Site ________ Soil Map Unit Name ________

Soil/Site Verification

Rangeland Ecological Site Description and/or Soil Survey	Area of Interest Determination
Surface Texture ________	Surface Texture ________
Depth: Very Shallow ☐ (<10") Shallow ☐ (10"-20") Moderate ☐ (20"-40") Deep ☐ (>40")	Depth: Very Shallow ☐ (<10") Shallow ☐ (10"-20") Moderate ☐ (20"-40") Deep ☐ (>40")
List diagnostic horizons in profile and depth	List diagnostic horizons in profile and depth
1 ________ 3 ________	1 ________ 3 ________
2 ________ 4 ________	2 ________ 4 ________

Parent Material ________ **Slope** ____ % Elevation ____ ft Topographic Position ____ **Aspect** ____

Avg Annual Precip ____ **Recent Weather (last 2 years)** Drought ____ Normal ____ Wet ____

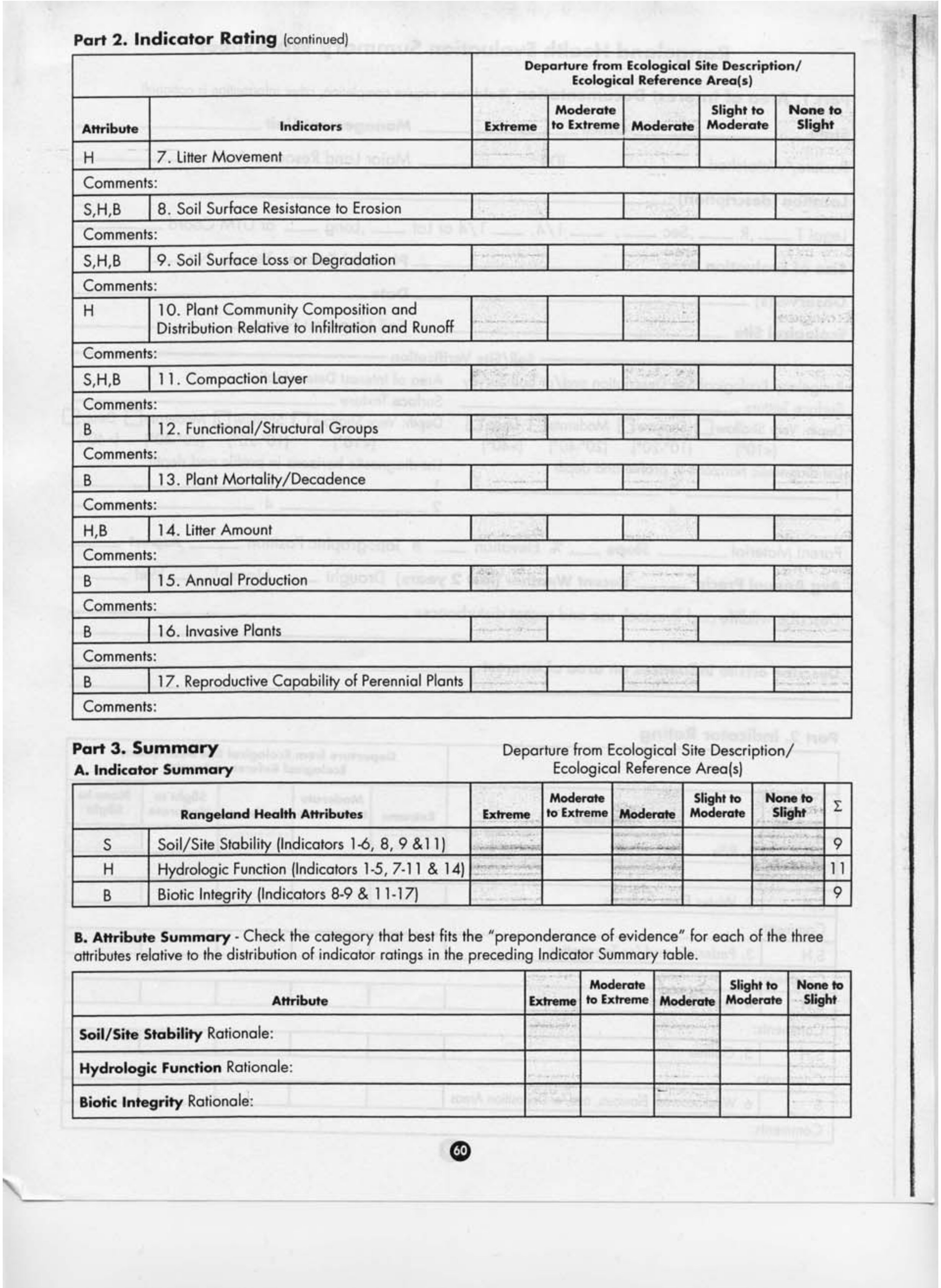
Describe wildlife and livestock use and recent disturbances ________

Describe offsite influences on area of interest ________

Part 2. Indicator Rating

		Departure from Ecological Site Description/ Ecological Reference Area(s)				
Attribute	**Indicators**	**Extreme**	**Moderate to Extreme**	**Moderate**	**Slight to Moderate**	**None to Slight**
S,H	1. Rills					
Comments:						
S,H	2. Water Flow Patterns					
Comments:						
S,H	3. Pedestals and/or Terracettes					
Comments:						
S,H	4. Bare Ground					
Comments:						
S,H	5. Gullies					
Comments:						
S	6. Wind-Scoured, Blowouts, and/or Deposition Areas					
Comments:						

Figure 2a. Soil monitoring evaluation matrix field sheet page 1.



Part 2. Indicator Rating (continued)

		Departure from Ecological Site Description/ Ecological Reference Area(s)				
Attribute	**Indicators**	**Extreme**	**Moderate to Extreme**	**Moderate**	**Slight to Moderate**	**None to Slight**
H	7. Litter Movement					
Comments:						
S,H,B	8. Soil Surface Resistance to Erosion					
Comments:						
S,H,B	9. Soil Surface Loss or Degradation					
Comments:						
H	10. Plant Community Composition and Distribution Relative to Infiltration and Runoff					
Comments:						
S,H,B	11. Compaction Layer					
Comments:						
B	12. Functional/Structural Groups					
Comments:						
B	13. Plant Mortality/Decadence					
Comments:						
H,B	14. Litter Amount					
Comments:						
B	15. Annual Production					
Comments:						
B	16. Invasive Plants					
Comments:						
B	17. Reproductive Capability of Perennial Plants					
Comments:						

Part 3. Summary

A. Indicator Summary

		Departure from Ecological Site Description/ Ecological Reference Area(s)					
	Rangeland Health Attributes	**Extreme**	**Moderate to Extreme**	**Moderate**	**Slight to Moderate**	**None to Slight**	Σ
S	Soil/Site Stability (Indicators 1-6, 8, 9 &11)						9
H	Hydrologic Function (Indicators 1-5, 7-11 & 14)						11
B	Biotic Integrity (Indicators 8-9 & 11-17)						9

B. Attribute Summary - Check the category that best fits the "preponderance of evidence" for each of the three attributes relative to the distribution of indicator ratings in the preceding Indicator Summary table.

Attribute	**Extreme**	**Moderate to Extreme**	**Moderate**	**Slight to Moderate**	**None to Slight**
Soil/Site Stability Rationale:					
Hydrologic Function Rationale:					
Biotic Integrity Rationale:					

60

Figure 2b. Soil monitoring evaluation matrix field sheet page 2.

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