BIOAVAILABILITY OF METALS FROM SPENT HEAP LEACH ORE: A GREENHOUSE STUDY[1]

Heidi M. Hoven[2] and Robert E. Long

Abstract. Rubber rabbitbrush (*Chrysothamnus nauseosus*) and fourwing saltbush (*Atriplex canescens*), representative of anticipated climax cover species for the heap leach pad of gold mining company in northern Nevada, were grown in crushed ore that had been accelerated through the leaching process. Accelerated leaching was done to mimic metal concentrations at closure of the mine. Plants were acquired from a distant nursery and grown in a 2 x 3 factorial greenhouse design, using three soil types, to assess the bioavailability and potential for bioaccumulation of metals in above ground tissues. Plants were transplanted into upwind native soils and two crushed ore composites with moderate and high concentrations of metals, respectively, in March, 2002. Plants were grown at an accelerated rate by keeping soil moisture content just below field capacity. Methods and the potential for risk to grazing livestock and wildlife will be discussed.

Additional Key Words: Arsenic, bioaccumulation, fourwing saltbush (*Atriplex canescens*), heavy metals, metal uptake, mine closure, risk of trophic transfer, Rubber rabbitbrush (*Chrysothamnus nauseosus*), selenium

Introduction

Trophic transfer due to exposure to mine-associated vegetation, and the accompanying risks to the environment, has been relatively overlooked in the attempt to regulate heavy metal levels in the environment. As is often the case, established wildlife risk management criteria indicate the need for assessing bioavailability of heavy metals to plants that are eaten by the affected wildlife (Ford 1996). It is only recently that a shift in regulatory focus (from federal and state standards for allowable heavy metal levels in waters and soils towards ecological risks associated with abandoned mines and mine closures) has occurred; yet allowable heavy metal levels in vegetation

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grazed by livestock and wildlife are not well established. Furthermore, the bioavailability of heavy metals at closed or closing mine sites has not been investigated extensively.

The underlying basis of this study is to determine whether or not vegetation growing on the reclaimed heap leach pad will bioaccumulate heavy metals and thereby pose a risk to grazing wildlife and livestock. Metals of primary concern at this time are antimony, arsenic, boron, molybdenum, lead, selenium, and thallium.

Bioaccumulation is the ability of a living organism to accumulate toxins during its life span. For example, if metal concentrations in an organism become elevated to levels that are higher than concentrations found in the source, the organisms are said to bioconcentrate the metals. One important point to note is that different species of plants show different affinities for metal uptake. For example, some species will readily uptake a metal, while others will compartmentalize or even block its uptake. Therefore, metal uptake mechanisms do not apply to all species of plants universally. The mechanisms of uptake and transport for each species are of major importance in determining where metals will accumulate in the plant (i.e., roots, stems, or leaves), particularly when determining the potential risks to grazing wildlife and livestock. Additionally, in organic soils, it is believed that increasing the pH reduces mobilization of inorganic compounds; however, studies have shown that movement of heavy metals through mineral soils to the groundwater (thereby being possibly available for uptake by plants) may not be affected by raising the pH (Khan et al. 2000, Turpeinen et al. 2000). This could be the case for the spent leach material at the mine where pH values are elevated.

In order for a living organism to accumulate metals, metals must be in soluble form. Once soluble, metals (and organic compounds) are available for uptake and called bioavailable. Both biological and physiochemical factors can affect the bioavailability of any given metal which, in turn, affects the amount of metal able to be taken up by the organism. With respect to plants, microbial influence, plant and soil interactions, the amount of organic material in the soil, redox potential of the soil, soil pH, pH of interstitial water, and salinity are the major factors that determine the bioavailability of metals.

In evaluating the bioavailability of metals in the spent heap leach ore, there are three general questions to address:

1. What is the bioavailability of metals occurring in the native soils to native vegetation (i.e., what is the background level of metals accumulated by native vegetation)?

2. If metals from spent heap leach ore are bioavailable, are they translocated to edible parts of the plants?
3. If metals from the spent heap leach ore accumulate in edible parts of the plants, what concentrations can be expected?

Plants were selected for this study based on three criteria. First, the species must be one of the dominant perennial shrubs resident at the mine. At undisturbed areas adjacent to the mine, the mature plant community was primarily composed of shrubs with very little understory of grass and forbs. Second, the species must be palatable by livestock and wildlife. Third, the species must be commercially available as one-gallon individuals from one nursery. The two species that met all three criteria were fourwing saltbush *(Atriplex canescens)* and rubber rabbitbrush *(Chrysothamnus nauseosus)*.

Methods

A temporary greenhouse was constructed outside McClelland Laboratories in Sparks, Nevada, to conduct a 2 x 3 factorial design bioavailability study. Two plant species from Mountain States Nursery in Arizona (i.e., fourwing saltbush and rubber rabbitbrush) and three soil types (i.e., native upwind soil of the mine, and crushed ore from two locations, namely RHP2 and RHP4, which were rinsed heap residue samples from an accelerated leach column study that was conducted to determine the final chemical and physical characteristics of the spent heap leach ore) were used. RHP2 and RHP4 were chosen based on moderate and high metal concentrations, respectively, in comparison to the other RHP soils of the column study.

The native topsoil was collected at an upwind location near the mine for use as the control. Fourwing saltbush and rubber rabbitbrush grew well in the locations where the upwind topsoil was collected. The depth of topsoil collection (the upper 5-8 inches of the soil profile) was determined by similarity of soil texture and coarse fragment content. The RHP soils were selected for use as growth media based on their anticipated similarity to the final graded surface of the heap leach and their concentrations of metals.

Temperatures inside the greenhouse were controlled to simulate spring growing conditions at the mine. Spring is the period of time when temperatures and moisture conditions are normally optimal for plant growth at the mine location. Figure 1 shows the average monthly maximum and minimum temperatures at the mine between 1999 and 2000. A comparison of average precipitations (mm) at the mine and at an experimental station in the nearest town, Fallon, Nevada, indicates that the highest levels of moisture occur during the spring (Figure 2).

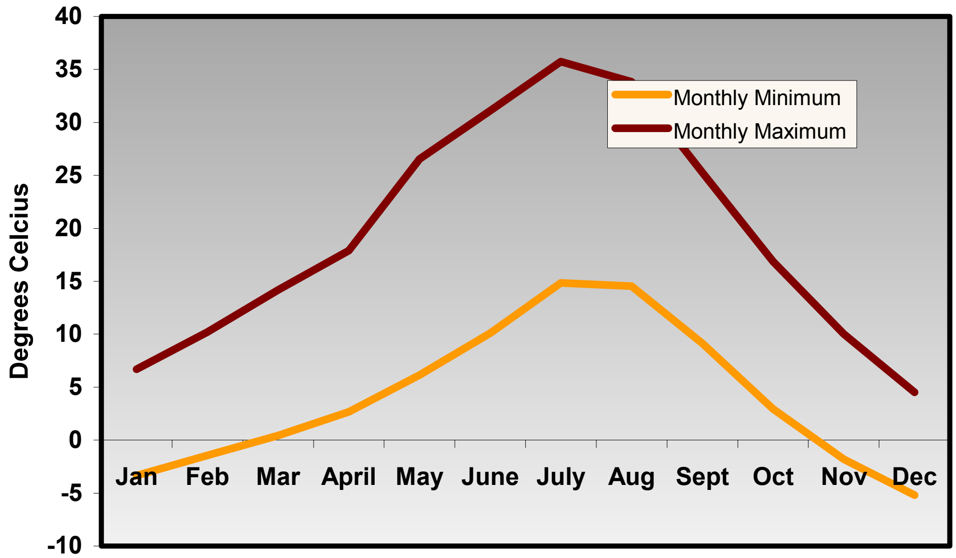

Figure 1. Average monthly temperature at the mine and Fallon Experimental Station.

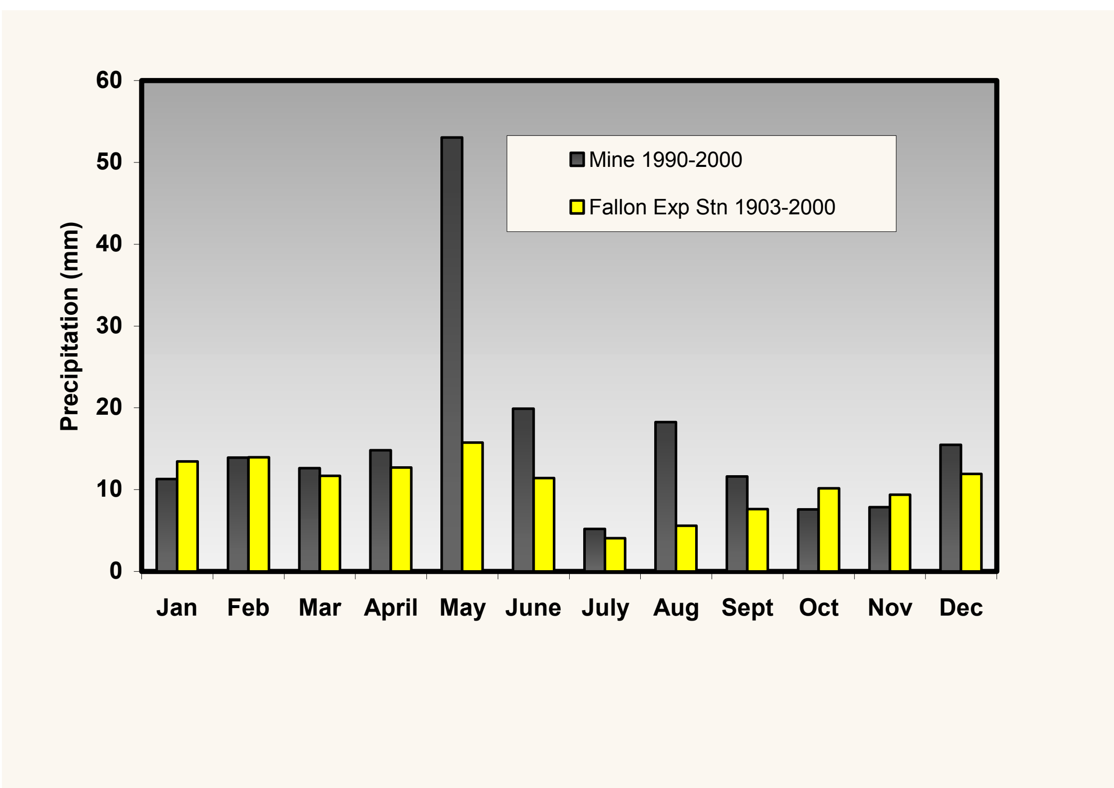

Figure 2. Average monthly precipitation at the mine and Fallon Experimental Station.

Seven replicates of each plant species were rinsed with deionized water and then transplanted into the three soil types. The soil was brought to field capacity and contained in clean five-gallon buckets rigged with drainage tubes. The drainage tubes were intended to allow for collection of effluent, which could then be recycled into the same bucket to minimize loss of metals from leaching during the first three weeks of the experiment while plants were acclimating. Once it was clear that low water holding capacity of RHP soils affected water retention (i.e., the soil dried quickly and formed cracks that allowed water to drain quickly), all drainage tubes were inverted and used as piezometers to record the level of free water within the buckets. The piezometer tubes also helped slow flow-through and made water available for uptake by the plants. Volume of water added and drained was recorded for each bucket.

By calculating water deficits after each watering, evaporation-transpiration (ET) rates were determined and monitored bi-weekly. In this study, ET is defined as evaporative loss of water from the soil in addition to evapotranspiration (evaporative losses from the plants during transpiration); evapotranspiration was not determined directly. ET was used to determine the amount of water necessary to keep the soils within 90% of field capacity, thereby extending the growing season under experimental conditions. By maintaining the soil moisture level within 90% of field capacity, optimal conditions for photosynthesis were maintained, and the potential for both plant growth and uptake of metals from soil was maximized. The assumption that accelerated growth rates were directly related to ET was based on the relationship between growth or yield and transpiration established by Hanks (1974):

$$Y/Yp = T/Tp \quad \textbf{(1)}$$

Where Y equals dry matter yield when conditions (e.g., water and soil chemistry) are limiting, Yp is potential yield when conditions are not limiting, T equals actual transpiration, and Tp is potential transpiration when conditions are not limiting.

Growth of the plants was measured in two ways. First, volume expansion/loss was determined by taking initial and subsequent measurements of height (H) and width from front to back (W1) and width from side to side (W2). All measurements were taken at maximum height and widths. Volumetric growth was calculated as:

$$(H \times W1 \times W2) / \# \text{ days} \quad \textbf{(2)}$$

Second, linear extension rates of stems were measured by marking three stems of each plant with a waterproof marker and tagged with brightly colored thread. The change in distance to the distal ends was recorded after a known period of growth. Linear extension growth rate was calculated as:

$$\text{Average extension (cm) / \# days} \quad \mathbf{(3)}$$

In addition to the nursery plants, in situ (upwind and downwind) specimens of each species were also used. Background metal concentrations of three upwind specimens of each species, three downwind specimens of each species, and three nursery specimens of each species were sampled. Plants were rinsed three times in deionized water and sorted by above- (leaves) and below-ground (secondary roots) tissue. Minimum samples of 3 g wet weight of tissue were collected by hand (i.e., no metal cutting implement was used) and individually frozen. Roots and leaves were analyzed for DPTA extractable antimony, arsenic, boron, molybdenum, lead, selenium, and thallium. Standard operating procedures prepared by the Wyoming State Subcommittee on Selenium in Soils, Vegetation, Overburden, and Wildlife were followed for selenium analysis (Steward et al. 1994). Above-ground tissue was sampled for metal accumulation during the first year, and above- and below-ground tissues will be analyzed at the termination of the experiment during 2003.

Additionally, four species occurring locally at the mine were assayed for germination potential in the three greenhouse soil types. Species were chosen relative to their distribution at the mine and their palatability to foraging stock and wildlife. Fourwing saltbush, rubber rabbitbrush, Nevada Mormon tea (*Ephedra nevadensis*), and spiny hopsage (*Grayia spinosa*) were selected. Ten replicate plantings of each species per soil type were planted and moderately watered. Percent germination by species per soil type has been determined for two trials thus far. A third trial will be conducted in the near future for statistical comparison.

Results and Discussion

Background Soil Properties

The following data were collected from *in situ* soils at the mine (upwind and downwind locations) and from rinsed heap residue samples (RHP soils, Table 1). Sample designations of native soils are composed of the species code (ATCA for fourwing saltbush and CHNA for rubber rabbitbrush) and U (for upwind) or D (for downwind). Interpretations of suitable, marginal, and unsuitable are based on the Wyoming Division of Environmental Quality (WDEQ) Guideline I Topsoil and Overburden

Suitability where available, since an equivalent set of topsoil and overburden suitability limits has not been established for Nevada. Methods for determining soil properties can be found in *Diagnosis and Improvement of Saline and Alkali Soils* (U.S.D.A. Handbook 60, 1969).

Soil Texture. AMEC performed hydrometer and sieve analysis of the RHP soil materials. Percent passing particle size curves were supplied to SWCA by AMEC. USDA soil textures were determined based on interpretation of the particle size curves and USDA standards for particle sizes (U.S.D.A. Handbook 18, 1993). The USDA soil texture for all of the RHP samples is an *extremely medium gravelly coarse sandy loam* (U.S.D.A. Handbook 18, 1993).

Soil Paste pH. The soil paste pH (soil pH) of the native soils is alkaline but is within the suitable range for vegetation (5.50 to 8.50). The RHP soil pH ranges from 8.58 to 8.94, which is marginal for vegetation. The higher range of RHP soil pH values is most likely the result of the higher sodium contents.

Electrical Conductivity (EC). All of the soil conductivities range from 1.81 to 3.90 dS/cm. These values are within the non-saline and very slightly saline classes (0 to 4 dS/m) in the *Soil Survey Manual* (U.S.D.A. Handbook 18, 1993) and within the suitable range (0 to 8 dS/m) in the Wyoming's *Guideline I for Topsoil and Overburden* (WDEQ 1994).

Calcium Carbonate ($CaCO_3$). Calcium carbonate values are low, ranging from 0.49 to 1.70 percent $CaCO_3$ on a dry weight basis.

Sodium, Calcium, and Magnesium. These data were obtained for the purpose of calculating the SAR of each sample.

Sodium Absorption Ratios (SAR). SAR values were within the suitable range of 0 to 10 (WDEQ 1994). for all native soils, except one (ATCAD3). The sodium value for ATCAD3 is abnormally high for native topsoil supporting a good vegetative community as compared to the other 16 native soil SAR values and may be an anomaly. SAR values for the RHP soils were in the marginal level.

Table 1: Soil properties of native soils adjacent to the mine and rinsed heap (RHP) residue samples.[1]

Sample	Paste[2]	ECe[3]	$CaCO_3$[4]	ESP[5]	Sodium[6]	Calcium[6]	Magnesium[6]	SAR[7]	AGP[8]	ANP[9]	ABP[10]
Designation	pH	mS/cm	wt. pct.		meq/L	meq/L	meq/L				
ATCAU 1	7.77	3.16	1.86	ND	18.00	11.00	2.40	7.00	0.00	18.60	+18.60
ATCAU 2	7.59	2.07	1.76	ND	7.90	6.60	3.80	3.50	0.03	17.60	+17.57
ATCAU 3	7.85	1.32	1.37	ND	9.80	5.60	0.95	5.40	0.25	13.70	+13.45
CHNAU 1	7.91	1.53	1.27	ND	11.00	7.30	1.50	5.20	0.72	12.70	+11.98
CHNAU 2	7.85	1.28	1.57	ND	8.70	4.00	0.96	5.50	0.09	15.70	+15.61
CHNAU 3	7.61	1.50	1.18	ND	8.60	7.30	1.70	4.10	0.00	11.80	+11.80
Upwind Soils	7.76	1.81	1.50	ND	10.67	6.97	1.89	5.12	0.18	15.02	+14.84
ATCAD 1	7.65	3.75	1.47	ND	11.00	14.00	5.60	3.50	0.00	14.70	+14.70
ATCAD 2	7.99	1.92	1.37	ND	5.10	3.70	2.10	3.00	0.03	13.70	+13.67
ATCAD 3	8.29	13.80	2.06	ND	110.00	5.90	1.10	59.00	0.16	20.60	+20.44
CHNAD 1	7.94	1.01	1.37	ND	4.90	3.30	1.20	3.30	0.03	13.70	+13.67
CHNAD 2	7.81	1.00	1.47	ND	3.80	3.50	1.40	2.40	0.03	14.70	+14.67
CHNAD 3	7.30	1.93	2.45	ND	5.10	12.00	3.10	1.90	0.37	24.50	+24.13
Downwind Soils	7.83	3.90	1.70	ND	23.32	7.07	2.42	12.18	0.10	16.98	+16.88
RHP 2	8.58	2.52	0.49	0.00	21.00	3.50	0.53	15.00	0.72	4.90	+4.18
RHP 3	8.83	2.80	0.59	1.74	23.00	4.00	0.51	15.00	0.00	5.88	+5.88
RHP 4	8.94	3.43	0.69	2.14	24.00	11.00	0.76	9.90	0.00	6.86	+6.86
RHP 5	8.86	3.13	0.59	2.06	24.00	5.70	0.90	13.00	0.00	5.88	+5.88
RHP 6	8.78	3.08	0.69	1.13	23.00	5.80	0.88	13.00	0.00	6.86	+6.86
RHP 7	8.63	3.12	0.59	0.48	26.00	3.90	0.61	17.00	0.00	5.88	+5.88

Shaded areas denote soils used for greenhouse study. ND = No data

1. n=1 for all samples except Upwind and Downwind Soils values, which are the average of the preceding upwind and downwind soils (n=6), respectively. The first four letters of the sample designation are the abbreviation of the plant (e.g. ATCA is *Atriplex canescens* and CHNA is *Chrysothamnus nauseosus*). The final letter indicates whether the sample location was upwind (U) or downwind (D) of the mine heap leach pad.
2. Paste pH (USDA Handbook 60, method 21a, pg. 102).
3. ECe is the electrical conductivity of the extract from a saturated paste (USDA Handbook 60, method 3a, pg. 84)
4. Percent calcium carbonate on dry weight basis (USDA Handbook 60, method 23c, pg. 105).
5. ESP (exchangeable sodium percentage, ASA 15-2) was only analyzed on the RHP soils, because of the higher SAR levels on these soils.
6. Soluble sodium, calcium, magnesium (USDA Handbook 60, method3a, pg. 84).
7. SAR (sodium adsorption ratio) calculated by USDA Handbook 60, pg. 26.
8. AGP (acid generating potential) determined by EPA 600-2-78-054 SOBEC Documentation.
9. ANP (acid neutralization potential) determined by EPA 600-2-78-054 SOBEC Documentation.
10. ABP (acid base potential) calculated by: ABP = ANP – AGP

Exchangeable Sodium Percentage (ESP). These were determined because the SAR values for the RHP soils were in the marginal level. High RHP SAR values can be attributed to the leaching process. ESP values were within the normal range (0.00-2.14%).

Acid Generation Potential (AGP). The AGP indicates the potential of the soil to generate acidity when the material is placed on the surface and oxidation takes place.

Acid Neutralizing Potential (ANP). The ANP is the potential of the soil to neutralize acidity when oxidation of the soil occurs. All of the soil samples have a significant acid neutralizing potential (ANP) for reducing the effects of acid generation. This ANP capacity is the result of the amount of calcium carbonate (lime) that is present at 1-2 percent in the native soils and approximately 0.5 percent in the RHP soils.

Acid Base Potential (ABP). The ABP is the difference between ANP and AGP and indicates whether or not the soil has the ability to become more acid when and if oxidation occurs. Neither the native nor the RHP soils has any significant potential for producing acid soils when the material is oxidized. The ABP does not present a problem for reclamation until the value is less than -5.0 tons $CaCO_3$ per 1,000 tons of soil (WDEQ 1994). All ABP (NNP) values were in the positive range.

Background Soil Metal Concentrations

DTPA extractable metal concentrations determined in *in situ* mine soils (upwind and downwind locations) and RHP residue soil samples are listed in Table 2 and summarized below. Interpretations of suitable, marginal, and unsuitable are based on Wyoming Division of Environmental Quality (WDEQ 1994). Metal Suitability Limits, when these standards are available.

Antimony. Antimony levels in the native soils were below the detectable limit. RHP4, RHP5, and RHP6 had antimony levels above the 0.1 mg/kg detection limit.

Table 2: DPTA extractable metals results, native upwind soils and rinsed heap (RHP) residue samples.

Sample	Antimony		Arsenic		Boron		Molybdenum		Lead		Selenium		Thallium	
Designation	mg/L	mg/kg	mg/L	mg/kg	mg/L	mg/kg	mg/L	mg/kg	mg/L	mg/kg	mg/L	mg/kg	mg/L	mg/kg
ATCAU 1	<0.05	<0.1	0.94	1.88	0.38	0.76	<0.1	<0.2	0.390	0.78	0.18	0.36	<0.25	<0.5
ATCAU 2	<0.05	<0.1	0.93	1.86	0.17	0.34	<0.2	<0.4	0.460	0.92	0.23	0.46	<0.25	<0.5
ATCAU 3	<0.05	<0.1	0.91	1.82	0.34	0.68	<0.1	<0.2	0.640	1.28	0.20	0.40	<0.25	<0.5
CHNAU 1	<0.05	<0.1	2.00	4.00	0.31	0.61	<0.1	<0.2	0.420	0.84	0.23	0.46	<0.25	<0.5
CHNAU 2	<0.05	<0.1	0.94	1.88	0.18	0.36	<0.1	<0.2	0.580	1.16	0.21	0.42	<0.25	<0.5
CHNAU 3	<0.05	<0.1	0.87	1.74	0.38	0.76	<0.2	<0.4	0.600	1.20	0.19	0.38	<0.25	<0.5
ATCAD 1	<0.05	<0.1	0.90	1.80	0.44	0.88	<0.1	<0.2	0.240	0.48	0.19	0.38	<0.25	<0.5
ATCAD 2	<0.05	<0.1	0.81	1.62	0.23	0.46	<0.2	<0.4	0.260	0.52	0.21	0.42	<0.25	<0.5
ATCAD 3	<0.05	<0.1	0.99	1.98	1.20	2.40	<0.05	<0.1	0.180	0.36	0.15	0.30	<0.25	<0.5
CHNAD 1	<0.05	<0.1	0.82	1.64	0.30	0.60	<0.1	<0.2	0.170	0.34	0.19	0.38	<0.25	<0.5
CHNAD 2	<0.05	<0.1	0.85	1.70	0.28	0.56	<0.1	<0.2	0.240	0.48	0.15	0.30	<0.25	<0.5
CHNAD 3	<0.05	<0.1	1.90	3.80	0.45	0.90	<0.05	<0.1	0.670	1.34	0.19	0.38	<0.25	<0.5
Upwind Soils	<0.05	<0.1	0.96	1.92	0.17	0.34	<0.1	<0.2	0.400	0.80	0.19	0.38	<0.25	<0.5
RHP 2	<0.05	<0.1	5.20	10.40	0.18	0.36	0.23	0.46	0.150	0.30	0.20	0.40	<0.25	<0.5
RHP 3	<0.05	<0.1	5.90	11.80	0.23	0.46	0.17	0.34	0.110	0.22	0.23	0.46	<0.25	<0.5
RHP 4	0.076	0.152	9.00	18.00	0.52	1.04	0.24	0.48	0.140	0.28	0.26	0.52	<0.25	<0.5
RHP 5	0.060	0.120	7.00	14.00	0.30	0.60	0.20	0.40	0.120	0.24	0.23	0.46	<0.25	<0.5
RHP 6	0.078	0.156	6.80	13.60	0.28	0.56	0.23	0.46	0.150	0.30	0.26	0.52	<0.25	<0.5
RHP 7	<0.050	<0.1	4.20	8.40	0.36	0.72	0.20	0.40	0.076	0.15	0.20	0.40	<0.25	<0.5

Shaded areas denote soils used for greenhouse study.

Note: WAD cyanide concentrations were less than 0.40 mg/kg for all 19 samples.

Arsenic. There is a full order of magnitude difference between the native soil arsenic levels and the RHP arsenic levels. Native soil arsenic levels range from 1.62 to 4.00 mg/kg, while the RHP levels range from 8.40 to 18.00 mg/kg. This difference can be attributed to the ore type and the leaching process. Most levels are at best marginal (greater than 2.0 mg/kg).

Boron. There is no appreciable difference between the native and RHP boron levels. However, only 6 samples exhibited levels within the WDEQ suitable range (less than 5.0 mg/kg).

Molybdenum. Native soil molybdenum levels are below the detectable limit. RHP molybdenum levels are detectable but less than 0.5 mg/kg, which is less than WDEQ suitability limit of 1.0 mg/kg.

Lead. Lead levels in the native topsoil are higher than in the RHP soils. Of the native soils, the upwind values are higher than the downwind values.

Selenium. Selenium values are similar for both the native and RHP soils. All levels are marginal (0.3-0.8 mg/kg in upland areas and ephemeral drainages).

Thallium. Thallium values are below the detection limit for both the native and RHP soils.

Background Plant Information

Reference or background levels of metal concentrations of *in situ* and nursery plants are listed in Tables 3 and 4. In general, antimony, arsenic, boron, molybdenum, and selenium levels appear elevated in the *in situ* plants compared to the nursery plants. Statistical analyses will be performed once a complete data set is available at the termination of the experiment.

Table 3. Average (n = 3) background metal concentrations of leaves and roots of *in situ* shrubs collected upwind and downwind of the mine on September 5, 2001.

Analyte:	Antimony	Arsenic	Boron	Lead	Molybdenum	Selenium	Thallium
Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
DL	0.05	0.05	5.00	0.05	0.05	0.05	0.05
4WU-L	0.29	2.05	47.67	0.20	1.60	0.36	<0.05
4WU-R	0.42	12.33	0.21	0.64	0.05	<0.05	<0.05
RBU-L	0.10	0.47	60.00	0.17	0.74	0.06	<0.05
RBU-R	0.08	2.77	27.67	0.53	0.42	<0.05	<0.05
4WD-L	0.09	2.10	72.67	0.27	1.57	0.20	<0.05
4WD-R	0.10	0.45	28.33	0.22	0.86	0.06	<0.05
RBD-L	0.12	3.60	180.00	0.39	1.53	0.12	<0.05
RBD-R	0.11	0.66	22.33	0.16	0.53	0.05	<0.05

4W = fourwing saltbush; RB = rubber rabbitbrush; U = upwind; D = downwind; L = leaves; R = roots, DL=detection limit.

Table 4. Average (n = 3) background metal concentrations of leaves and roots of nursery shrubs prior to use in greenhouse experiment on March 1, 2002.

Analyte:	Antimony	Arsenic	Boron	Lead	Molybdenum	Selenium	Thallium
Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
DL	0.05	0.05	5.00	0.05	0.05	0.05	0.05
4WG-L	0.07	0.52	35.93	0.54	0.58	0.17	0.06
4WG-R	0.07	1.49	6.90	0.64	0.18	<0.05	0.08
RBG-L	0.17	8.02	46.27	1.58	0.47	<0.05	<0.05
RBG-R	0.16	4.35	18.33	1.29	0.25	<0.05	0.09

4W = fourwing saltbush; RB = rubber rabbitbrush; G = greenhouse; L = leaves; R = roots. DL=detection limit.

Volumetric growth rates of the greenhouse plants are shown in Figure 3. Generally, slower growth rates and loss of volume were observed during the first 2.5 months (data not presented). This is likely due to acclimatization of the plants to transplanting and adjustments of the watering schedule relative to environmental conditions within the greenhouse. Once plants were established, growth rates accelerated. Of note is that the plants continued to grow well into the summer, which is divergent from their natural growth pattern. Typically, these species will experience a growth spurt during the spring when water is most available and then slow their growth substantially during the summer when water is scarce and the climate is very hot and dry. If water is available during the summer, as in the greenhouse, these species show that they are capable of growing well. Figure 4 shows a linear measure of growth rates, which represents increased growth once the plants have established.

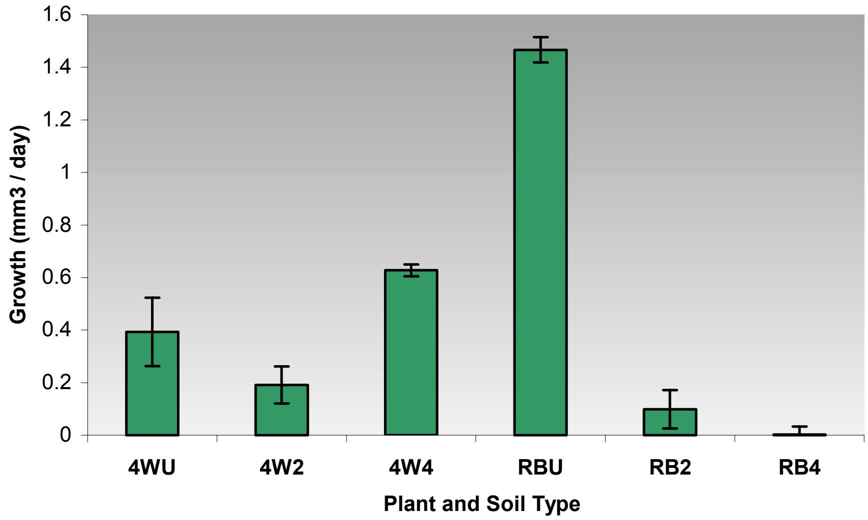

Figure 3. Average volumetric growth per day for fourwing saltbush (4W) and rubber rabbitbrush (RB) in upwind (U), RHP2 (2) and RHP4 (4) soils during 2002; (mean +/- se).

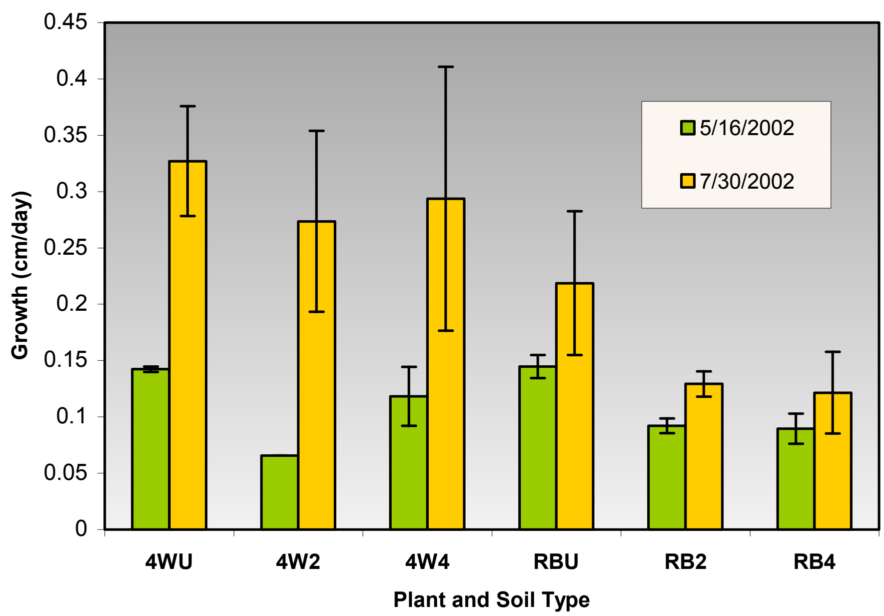

Figure 4. Average growth rates of stems for fourwing saltbush (4W) and rubber rabbitbrush (RB) in upwind (U), RHP2 (2) and RHP4 (4) soils. Growth measurements were taken on May 16th and July 30th, 2002; (mean +/- se).

When seeds from four perennial species known to grow near the mine site were tested for germination potential in the three soil types, seeds grown in native, upwind soils showed slightly higher germination success than RHP soils probably due to differences in organic and nutrient content (Table 5). However, statistical comparisons will be provided after the third trial is completed. Of note, though, is that all four species showed some measure of germination in at least one of the RHP soils, indicating the potential of these species for revegetation.

Table 5. Percent germination rate of four perennial shrubs in three soil types (Upwind, RHP2, and RHP4).

Soil Type:	Upwind		RHP2		RHP4	
Species	Trial 1 (%)	Trial 2 (%)	Trial 1 (%)	Trial 2 (%)	Trial 1 (%)	Trial 2 (%)
4W	50	10	20	20	0	0
RB	20	30	0	0	0	20
MT	40	100	20	10	0	20
SH	10	0	0	20	0	0

4W = fourwing saltbush; RB = rubber rabbitbrush; MT = Nevada Mormon tea; SH = spiny hopsage

Summary

One major observation in the greenhouse plant study was that ET rates are significantly lower for RHP soils than for native upwind soil. Table 6 compares the average ET rates by plant and soil type.

Table 6. Average ET rates in liters per day (L/day) for greenhouse plants during the week ending June 21, 2002.

Soil Type	Rubber Rabbitbrush		Fourwing Saltbush	
	ET Rates L/day	Percent of Upwind Rate (%)	ET Rates L/day	Percent of Upwind Rate (%)
Upwind soil	0.56		0.38	
RHP2 material	0.17	30	0.15	39
RHP4 material	0.19	34	0.25	66

If the upwind ET rates are assumed to be at or near potential for this study, then the ET rates for plants growing in the RHP heap leach materials are substantially less than potential. This relationship between yield (i.e., growth) and transpiration rate has been verified for several types of plants grown with saline water (Long 1983).

During the experiment, the lab staff has observed salts accumulating on the soil surface of the RHP buckets. This could be a sodium salt, since soluble sodium levels were higher in the RHP soils compared to the native upwind soil. The higher soluble sodium levels are not expected to have an adverse physical effect on the RHP soils since the exchangeable sodium percentages are very low, but the sodium could be having a specific ion effect on plant growth rates. If the sodium is not the cause of the decreased ET rates, then anions associated with the sodium (e.g., CN- or Cl-) might be. Analyzing the salt crust that has formed on the surface of the RHP soils could make this determination.

The cause for the lower ET rates of plants growing in the RHP materials has not been identified at this point in the study. Although not an initial objective of the study, its determination could have a significant impact on the potential for growing vegetation in the RHP material during reclamation of the heap leach pad at the mine.

Items to Evaluate During the Remainder of the Study

1. Differences in soil characteristics. A lack of native clays and silts in the RHP materials may result in water holding characteristics different from native soil, even though there are minus 200 mesh particle sizes in the RHP material.
2. Properties of water absorption of the RHP materials that differ from those of native soils and result in less water availability for plant uptake.
3. Presence of a salt that has a detrimental effect on plant growth rates. SAR levels were higher in the RHP materials than in the upwind soil, but the ESP were very low in the RHP materials since the cation exchange capacity (CEC) was very low (possibly due to lack of clays). Sodium levels should be evaluated more closely during the course of the study to determine if it is causing decreased ET rates and corresponding differences in growth rates.
4. Determination of bioavailability of metals associated with spent heap leach materials.
5. Determination of fate of metals taken up by plants grown in spent heap leach material.
6. Determination of whether a correlation exists between plant growth rates and metal accumulation.
7. Assessment of risk to livestock and wildlife that may forage on vegetation that establishes on the spent heap leach material.

Termination of this study is projected for the spring of 2003. At that time, final analysis of plant tissues will be conducted and assessment of bioavailability of metals in the heap leach ore will be assessed. Implications of this study could be precedent setting for the mining industry with respect to mine closure.

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