Compendium of metal uptake data for plants growing on mine sites in Yukon

YUKON RESEARCH CENTRE
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Recommended citation:

Soprovich and Janin, 2017. Compendium of metal uptake data for plants growing on mine sites in Yukon. Yukon Research Centre, Yukon College. September 2017.

FOREWORD

This document is meant as a report on, and a supplement to the Metals Uptake Database (www.yukoncollege.yk.ca/research), completed in the summer of 2017. It acts to summarize and report on certain aspects of the data contained within the database, and highlight the literature from which data in the database was retrieved.

The general purpose of this project was to compile information on the uptake of metals by different plant species in the North, specifically on mine-impacted sites, in order to compare this data to the scientific literature on species specific metal uptake. To this end, literature of this type was gathered from a number of sources for both the Yukon and Alaska.

The document is organized with the compendium of literature as the first section of the report, containing written summaries regarding the main trends of the metal uptake data within each piece of literature. The executive summaries or abstracts of the literature were included in the compendium, and where no such section existed in the particular document, an attempt was made to concisely summarize the findings of the literature, denoted with an asterisk. Note that these summaries are in no way reflections of the views or opinions of the original authors. Following the compendium is a written summary of the main trends of the data in the database, as well as summary data tables.

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August 2017

GLOSSARY OF TERMS

Shoots: In botany, this refers to the plants stems and associated appendages, including, buds, leaves, flowers, and fruits.

Bioconcentration factor: The ratio of the concentration of metals found in the shoots of a plant relative to the concentration of metals of the soil. In this report, we have also included the "root bioconcentration factor", which we report as the concentration of metals in the roots of a plant relative to the concentration of metals in the soils.

Translocation factor: The ratio of the concentration of metals found in the shoots of a plant relative to the concentration of metals found within the same plant's roots.

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1 COMPENDIUM OF STUDIES PRESENTING METAL UPTAKE DATA IN YUKON

1.1 BREWERY CREEK MINE 2009 REVEGETATION ASSESSMENT

Research Location: Brewery Creek mine, YT

Publication Type: Technical report

Publication Year: 2009

Summary of Report*: The Brewery Creek Mine is a gold mine located 50km due East of Dawson City, YT. A revegetation program has been ongoing at this site since 1997, using a variety of seed mixes. Monitoring metals uptake in the seeded vegetation is a part of the current revegetation program, occurring at three separate sites. These sites consist of two purported mine-impacted sites, the Blue Zone Waste Rock Storage Area (BZWRSA) and the Leach Pad, and one control area outside of impacted sites. The monitoring plots for this study were 5m x 5m, and the species included in the database are slender wheatgrass (*Agropyron trachycaulus*), Kentucky bluegrass (*Poa pratensis*), Red fescue (*Festuca rubra*), and alfalfa (*Medicago sativa*). Both soil and plants were analyzed for metal content using standard ICP-MS analyses.

Summary of metals uptake data: The highest bioconcentration factor of any species included in the database was for Cd uptake in alfalfa, at 1.48. However, this was based on a single data point with a concentration of Cd in the soil of only 0.60 ppm, so it is difficult to say what the bioconcentration factor would be at higher concentrations of Cd. Surprisingly, alfalfa had a bioconcentration factor of 0.00 for As given concentrations of As in the soil at 309.00 ppm. Cu, Pb, Zn, and Se all had bioconcentration factors at or below 0.35 in alfalfa, given substrate concentrations of 36.10 ppm for Cu, 15.8 ppm for Pb, 1.3 ppm for Se, and 111.0 ppm for Zn.

Kentucky bluegrass exhibited higher bioconcentration for Cd and Se relative to the other metals with average bioconcentration factors of 0.77 and 0.65 respectively, given metal content in soils at 0.61 and 0.80 ppm respectively. This is however based on a single sample. Zn bioconcentration was, on average fairly low in Kentucky bluegrass at a factor of 0.17, given a high substrate concentration of 111.0 ppm. Cu and Pb bioconcentration was at a factor of 0.11 for Cu and 0.004 for Pb, where the concentration of metals in the soils was 30.3 ppm for Cu and 16.0 ppm for Pb.

Red Fescue had low bioconcentration of all metals species, at 0.001 for As, 0.17 for Cd, 0.08 for Cu, 0.13 for Zn, 0.005 for Pb, and 0.18 for Se. This corresponds to metals concentrations in the soils of 203.44 ppm for As, 0.96 ppm for Cd, 36.6 ppm for Cu, 132.84 ppm for Zn, 16.07 ppm for Pb, and 1.33 ppm for Se. These data are based on 6 different samples, 3 at each of the BZWRSA and the Leach Pad.

Slender wheatgrass was sampled in duplicate at the Leach Pad, and in triplicate at the BZWRSA. The results suggest that bioconcentrations of all metals in the scope of our work are also low in slender wheatgrass, with average bioconcentrations of 0.01, 0.18, 0.06, 0.01, 0.22, and 0.16 for As, Cd, Cu, Pb, Se, and Zn respectively. The range of metals concentrations for the soils these plants were sampled in are 70.2 – 336.67 ppm for As, 0.85 – 1.07 ppm for Cd, 34.7 – 38.5 ppm for Cu, 15.73 – 16.4 ppm for Pb, 1.17 – 1.5 ppm for Se, and 119.67 – 146 ppm for Zn.

Species included: Slender wheatgrass (*Agropyron trachycaulus*), Kentucky bluegrass (*Poa pratensis*), red fescue (*Festuca rubra*), alfalfa (*Medicago sativa*)

Metals included: As, Cd, Cu, Pb, Se, Zn

Citation: Laberge Environmental Services. (2009). Brewery Creek Mine 2008 Revegetation Assessment. Site Assessment Report Prepared for Alexco Resources Corp

1.2 DESIGN OF A PASSIVE SYSTEM FOR TREATMENT OF DISCHARGES FROM THE GALKENO 900 ADIT AT THE UNITED KENO HILL MINE CAMP

Research Location: United Keno Hills Mining District, YT

Publication Type: Technical report

Publication Year: 1995

Executive summary: Considerable anecdotal information indicates that wetlands can effectively neutralize and remove metals from contaminated mine drainage. As far back as 1965, Boyle (1965) noted that “(a bog) into which the mine water from the Hector Calumet mine flows, effectively removes all of the zinc (40 ppm) in less than 2,000 feet.” A review of the technical literature corroborates this view: natural wetlands have been documented to neutralize acidic discharge and remove metals and metalloids such as aluminum, arsenic, copper, iron, lead, manganese, radium, and zinc.

It is generally recognized that wetland plants play a supportive role in metal removal by providing the environment favouring important chemical and microbial processes. Thus, they produce detritus which can adsorb and retain certain metals. This organic matter also sustains microbial activity which injects alkalinity into the water. Microbes catalyze oxidation and hydrolysis reactions causing iron and manganese to precipitate. These oxides provide surfaces which interact with dissolved metal, leading to their removal from mine water. Finally, anaerobic microbes respiring on sulphate produce hydrogen sulphide, consume acidity, and raise water pH. The sulphide ion reacts with many metals, including cadmium, copper, iron, lead, nickel, and zinc, forming insoluble precipitates that remain buried in the anaerobic sediments.

The use of wetlands to treat mine drainage has been exploited since the early 80's in North America. Initial successes with wetlands treating coal-generated acid mine drainage in the Eastern States has resulted in the construction of over 300 wetland treatment systems (WTS). These systems treat water on a year-round basis, neutralizing water with pH as low as 2.5, flows as high as 35 L/sec., and reducing aluminum, iron and manganese from initial concentrations as high as 100, 300, and 100 mg/L, respectively (R.P.L. Kleinmann and D. Kepler, personal communication). Extensive monitoring experience has resulted in the derivation of standardized design criteria (Hedin et al., 1994):

Net acid mine drainage is pre-treated with an anoxic limestone drain (at 7,800 kg/L/min of flow), followed by an aerobic wetland, or is treated in a compost-based wetland [minimum size (m^2) = acidity loading (g/day)/7].

Net alkaline mine drainages is treated to remove iron at a rate of 20 g/m^2/day and manganese at a rate of 0.5 g/m^2/day.

Additional criteria have been developed for aluminum or for water containing a combination of contaminants to be treated, based on consideration of metal geochemistry and on knowledge of wetland processes. Similar design criteria are unavailable for mine drainage other than from coal mines. Therefore, data necessary for their design must be generated through field studies. Such a field program was instituted in the summer of 1995.

Investigations of natural wetlands in the vicinity of the United Keno Hill camp revealed that they are able to improve the quality of contaminated mine drainage. One small swamp near the Husky adit was shown to increase water pH from 1.06 to 6.56 within a distance of fifteen feet! Another swamp was shown to reduce zinc concentrations from 3 mg/L to 0.3 mg/L.

Plants from two wetlands receiving contaminated mine drainage did not take up metals accumulated in sediments. An analysis of the metal species retained in these sediments revealed that metals were largely retained by sorption onto iron and manganese oxides, and by precipitation as sulphides. These metals resisted leaching by low pH water (pH 4), indicating that they were stably retained in these sediments.

A 9 x 18.5 metre pilot wetland was constructed in May 1995 near the Galkeno 900 adit to determine whether it could improve the quality of its discharge. Zinc was shown to be removed by the wetland from an initial concentration of 25 mg/L to 4-5 mg/L, on flows of 3 L/min. A concurrent study using in situ microcosms indicated that zinc concentrations could be reduced to less than 0.3 mg/L. The rate of zinc removal calculated from the in situ microcosms data was in good agreement with rates estimated for the Galkeno constructed wetland and a natural wetland. Cadmium, manganese and nickel were also reduced to low concentrations. Sulphate reduction in sediments and formation of insoluble metal sulphides appeared to be the primary process responsible for their removal.

These data provide the basis for designing a wetland system to treat the discharge from the Galkeno 900 adit. For the past 10 years, this discharge has averaged 29 ppm zinc and flows of 7.4 L/sec. For design purposes, flows of 10 L/sec containing 33 ppm were assumed. While discharges limits in the water license are set to 0.5 mg/L, the design objective has been set at 0.25 mg/L. Using the above rate equation and design criteria, a retention time of 26 days will be required to treat a discharge of 864 m^3/d. This necessitates building a series of wetlands averaging approximately 450 x 20 x 0.5 metre. A gently sloping area downgradient of the Galkeno 900 adit could accommodate these wetlands. This design assumes that treatment would be provided on a year-round basis. An alternative option would be to store water in the adit during the winter months and release it for treatment during the summer. Regardless of the option eventually selected, the current treatment with lime will need to be continued for the next 3-4 years to give time for the wetlands to be constructed, planted, and for biomass to accumulate sufficiently for effective treatment.

Summary of metals uptake data: To support the decision of implementing constructed wetlands at the Galkeno 900 adit, Microbial Technologies investigated bioremediation in four wetlands around the site: the South McQuesten swamp (control), the No Cash swamp, the Gallekeno swamp, and the Galkeno tailings in Christal Lake. *Carex aquatilis* was the species of study for these wetlands, and the researchers found that metals uptake was very low for each of these sites despite high metals concentrations in the substrates. For all of the mine-impacted sites, the maximum bioconcentration factors were 0.01, 0.03, 0.06, and 0.02 for Cd, Cu, Pb, and Zn respectively. The range of metals concentrations in the shoots of the sedges were 0.5 – 3.1 ppm, 2.81 – 3.42 ppm, 2.5 – 34 ppm, and 102 – 237 ppm for Cd, Cu, Pb, and Zn respectively. This in comparison to metals concentrations in the wetland soils with ranges of 66 – 2140 ppm, 110 – 251 ppm, 98 – 1,760 ppm, and 10,345 – 12,3000 ppm for Cd, Cu, Pb, and Zn respectively. These data corroborate the suggestions made by the researchers that wetland plant species do not actively uptake metals.

Species included: Water sedge (*Carex aquatilis*)

Metals included: Cd, Cu, Pb, Zn

Citation: Microbial Technologies. (1996) Report No. UKH/96/01 United Keno Hill Mines Limited Site Characterization. Technical Appendix II: Design of a passive system for treatment of discharges from the Galkeno 900 Adit at the United Keno Hill Mine Camp. Submitted for Access Consulting Limited.

1.3 ARSENIC IN PLANTS IMPORTANT TO TWO YUKON FIRST NATIONS: IMPACTS OF GOLD MINING AND RECLAMATION PRACTICES

Research Location: Mt. Nansen, YT; Venus Mine, YT; Arctic Gold and Silver Mine, YT

Publication Type: Masters thesis

Publication Year: 2002

Executive summary: This project examines arsenic in plants growing near closed or reclaimed gold mines located in the traditional territories of two Yukon First Nations. A total of 238 soil and plant samples (comprising 9 different species) were collected from Mt. Nansen, Arctic Gold and Silver, and Venus Mine tailing properties. At each property, samples were collected near the suspected point source of contamination, approximately 1-3 km away, and from background sites. Species were chosen for their ethnobotanical significance to the Little Salmon/Carmacks and the Carcross/Tagish First Nations, based on interviews with Elders and other knowledgeable people. Total and inorganic arsenic concentrations were determined using ICP-MS and AAS instrumentation, and organic arsenic concentrations were calculated from the difference. Uptake of arsenic by plants was low compared to soil arsenic concentrations. In both plants and soil, the arsenic form was predominantly inorganic. Concentrations in berries at all three sites were low or undetectable, and are therefore considered safe to eat under Health Canada tolerable daily intake guidelines for inorganic arsenic. At Mt. Nansen, the lichen "caribou moss" (*Cetraria/Cladina spp*.), Bolete mushrooms (*Leccinum spp*.), and the medicinal shrubs willow (Salix spp.) and Labrador tea (*Ledum groenIandicum/L decumbens spp*.) had high mean arsenic concentrations around point sources or at sites up to 1.5 km away. These localized high concentrations will not likely affect foraging animals, given their constant movement. However, Carmacks residents could avoid gathering all species with elevated arsenic around the Mt. Nansen mining property until reclamation is complete.

Summary of metals uptake data: A total of nine different species were sampled for Arsenic content in this study: willow (*Salix spp*.), mushrooms (*Leccinum spp*.), blueberry (*Vaccinium uliginosum*), caribou moss (*Cladina/Cetraria spp*.), lowbush cranberry (*Vaccinium vitis-idaea*), crowberry (*Empetrum nigrum*), Labrador tea (*Ledum spp*.), soapberry (*Shepherdia Canadensis*), and raspberry (*Rubeus ideaus*). 197 samples were taken at Mt Nansen, 20 at Arctic Gold and Silver, and 21 at Venus Mine. These samples were taken at various locations around each mine site, outlined in the paper. Average bioconcentration factors for As at mine-impacted sample sites (N1&N2, A1&A2, V1&V2) were 0.06 for willow, 0.01 for mushrooms, 0.001 for blueberry, 0.36 for caribou moss, 0.005 for lowbush cranberry, 0.001 for crowberry, and 0.19 for Labrador tea. Raspberry and soapberry had As concentrations below the detection limit of analysis of 1.3 ppm. Of the species most actively bioconcentrating Arsenic, concentrations in the plant tissues range from 0.07 – 5.69 ppm for willow, 8.87 – 31.14 for caribou moss, and 0.30 – 5.69 ppm for mushroom species. The highest As concentrations correspond to samples taken directly at the mine tailings.

Species included: Willow (*Salix spp.*), mushrooms (*Leccinum spp.*), blueberry (*Vaccinium uliginosum*), caribou moss (*Cladina/Cetraria spp.*), lowbush cranberry (*Vaccinium vitis-idaea*), crowberry (*Empetrum nigrum*), Labrador tea (*Ledum spp.*), soapberry (*Shepherdia Canadensis*), raspberry (*Rubeus ideaus*)

Metals included: As

Citation: Nicholson, H.C. 2002. Arsenic in plants important to two Yukon First Nations: impacts of gold mining and reclamation practices [masters thesis]. [Vancouver (BC)]: University of British Columbia.

1.4 THE BERRIES ARE SAFE TO EAT: RESULTS OF THE 2001 STUDY OF ARSENIC IN PLANTS COLLECTED FROM MONTANA MOUNTAIN

Research Location: Venus Mine, YT; Arctic Gold and Silver Mine, YT

Publication Type: Non-technical summary

Publication Year: 2002

Executive summary: The Venus Mine tailings and the Arctic Gold and Silver tailings are situated on Montana Mountain, south of Carcross in the Yukon. Both mining properties are located in the traditional territory of the Carcross Tagish First Nation (CTFN), who still actively hunt and gather in this area. The mines operated at a time when proper environmental management was not required. Tailings produced during this period were not properly stored, and before recent clean-up programs took place, they affected the surrounding environment. At both the Venus and Arctic Gold and Silver sites, windblown tailings accumulated on nearby shrubs such that the Carcross/Tagish First Nation was warned away from certain traditional berry-picking areas. The problem had to do with the high arsenic levels in the tailings. The tailings have now been capped, and recent questions have been raised about whether people can return to picking at these sites. This led to the current study looking at arsenic concentrations in berries from both tailing sites in order to see how arsenic concentrations have changed since the caps were constructed.

Summary of metals uptake data: The data used from this study consisted of one sample location where dwarf raspberry was picked. The raspberry fruit had a concentration of 1.25 ppm As, despite a soil concentration of 11,373 ppm As, indicating minimal As uptake by dwarf raspberry. However, the sample size for this conclusion is small, consisting of only 3 separate samples.

Species included: Dwarf raspberry (*Rubus acaulis*)

Metals included: As

Citation: Nicholson, H.C. (2002). University of British Columbia. The Berries are safe to eat! Results of the 2001 study of arsenic in plants collected from Montana Mountain.

1.5 BASELINE STUDIES ON SELENIUM CYCLING IN THE EARN LAKE ENVIRONMENT

Research Location: Earn Lake, YT

Publication Type: Technical report

Publication Year: 2005

Executive summary: Selenium ecotoxicology has been the subject of a number of recent reviews, although much of the data has focused on species endemic to temperate and sub-tropical aquatic systems. This has resulted in various recommendations regarding appropriate criteria for protecting aquatic life. The Yukon uses the CCME guideline of 1 ug/L, which is more stringent than the USEPA criterion of 5 ug/L. These recommendations were based primarily on data from two sites in the southern United States where significant selenium toxicity was observed due to effluent from coal fly-ash ponds.

These sites are characterized with warm waters, organic rich sediments, and high biological productions containing higher trophic level species exotic to the north. The characteristics of most of the water bodies in the Yukon are very dissimilar to this scenario, and the current selenium guideline for the protection of aquatic biota may be far too conservative.

The geology of parts of the Yukon contains high baseline levels of selenium, magnesium and arsenic and has been attributed to the black shales (argillites) of the "Earn Group". There is currently active exploration at some of these locales, with a strong possibility for future mining. The mining and milling of ores within these areas has the potential to release selenium to the environment.

Biogeochemical cycling of selenium in the water column and sediments, as well as accumulation of selenium in the food web, was studied at a remote lake in central Yukon in June 2004. Earn Lake was chosen as the study site as routine testing discovered high levels of selenium (concentrations of 3 ppm) in whitefish tissue in 2002. These concentrations were generally an order of magnitude greater than the concentrations documented in whitefish tissues from other local lakes. The natural high levels of selenium in this system allowed it to be an excellent candidate for cycling studies.

Water testing determined that waterborne selenium is entering Earn Lake via Dromedary Creek draining Dromedary Mountain to the north and via Two Moose Creek draining the Earn Hills from the south. Selenium concentrations exceeded the CCME guideline at these sites as well as down lake. Lake bottom sediments did not contain excessive amounts of selenium. Sequential leach analysis determined that 10 to 25% of total selenium in the sediments was organic. Levels of body burden selenium in the invertebrate tissues appear to be in range with other limited Yukon data. Milk vetch is a plant known to accumulate selenium from the soil, and several specimens were analyzed. The relative low concentrations present in the vetch samples would tend to indicate that the soils were not seleniferous at the collection locations. Mice tissues were analyzed and levels of

selenium were within range for other documented wildlife. Concentrations of selenium in the fish tissues were generally greater for all species when compared to fish tissues collected from other non-impacted sites. Studies have suggested that cold water fish species are more tolerant of selenium than warm water fish.

Selenium is a micronutrient essential for animal life although there is a very narrow range between essential and toxic amounts. Due to the small sample size of fish utilized in this study, no assumptions can be made on whether the amounts documented in the fish tissues are healthy or detrimental in any way. Further assessments should be conducted at Earn Lake.

Future guidelines (in water and/or sediment) for the protection of aquatic life should generally be site specific and should consider the nature of the water (stream or lake), the degree of organic-rich sediments, the dominant species of selenium present in the water column and in the sediments, and the productivity of the water.

Summary of metals uptake data: The sampled species in the Earn Lake study site included felt-leafed willow (*Salix alaxensis*), milk vetch (*Astragalus alpinus*), and water sedge (*Carex aquatilis*). Willow had highest bioconcentration of Cd and Zn for these species, with factors of 0.48 for Cd and 0.5 for Zn. The bioconcentration factors for Cu and Se in willow were still appreciable, at 0.1 and 0.09 respectively, and also Pb and As had bioconcentration factors of 0.00 and 0.01 respectively. Milk vetch had very low bioconcentration for the metals analyzed and Se had the highest bioconcentration factor for milk vetch at 0.08. Interestingly, water sedge had appreciable bioconcentration factors with Cd at 0.28, Cu at 0.38, Pb at 0.29, Se at 0.11, and Zn at 0.16. It is important to note that these bioconcentration factors are based off of one soil sample and one plant sample for each species. Of note, for the substrate of the willow sample, Cd concentrations were only 0.62 ppm, whereas Zn concentrations were at 77.70 ppm and yet the bioconcentration factors for the two metals were almost equal. The substrate for the milk vetch sample was higher in metal content at 2.03 ppm, 39.6 ppm, 214, 11.1 ppm, 3.7 ppm, and 22.3 ppm for Cd, Cu, Zn, Pb, Se, and As respectively. The sediment for the water sedge had similar metal content at 1.32, 26.6, 270, 10.4, 1.8, and 14 ppm for Cd, Cu, Zn, Pb, Se, and As respectively.

Species included: Felt-leafed willow (*Salix alaxensis*), milk vetch (*Astragalus alpinus*), water sedge (*Carex aquatilis*)

Metals included: As, Cd, Cu, Pb, Se, Zn

Citation: Burns, Bonnie E. (2005). Baseline studies on selenium cycling in the Earn Lake environment. Whitehorse (YT): Laberge Environmental Services for Mining Environment Research Group. 40p.

1.6 CADMIUM GEOCHEMISTRY OF SOILS AND WILLOW IN A METAMORPHIC BEDROCK TERRAIN AND ITS POSSIBLE RELATION TO MOOSE HEALTH, SEWARD PENINSULA, ALASKA

Research Location: Quarry Prospect & Big Hurrah transects, Seward Peninsula AK

Publication Type: Journal Article

Publication Year: 2013

Abstract: The regional geochemistry of soil and willow over Paleozoic metamorphic rocks in the Seward Peninsula, Alaska is potentially high in cadmium (Cd), and willow, a preferred browse of moose, bioaccumulates Cd. Local moose show clinical signs of tooth wear and breakage and have been declining in population for unknown reasons. Willow leaves (all variants of *Salix pulchra*) and A-, B-, and C-horizon soils were sampled near 2 mining prospects suspected to be high in Cd. Although Al, Cd, Co, Cu, Fe, Mo, Ni, Pb, and Zn were examined, our focus in this exploratory study was on the level of Cd in the 3 soil horizons and willow between and within the 2 prospects and their vicinity. We used an unbalanced, one-way, hierarchical analysis of variance (ANOVA) to investigate the geochemistry of soils and willow at various distance scales across the 2 prospect areas that were separated by ~80 km; sites within a location were approximately 0.5 km apart and replicate samples were separated by ~0.05 km. Cd concentration was significantly different in willow between and within sites, and within sites for all soil horizons. Specifically, this exploratory study identified highly elevated levels of Cd in willow growing over Paleozoic bedrock in the Seward Peninsula at both prospects and over the Paleozoic geologic unit in general. Potential negative effects for moose are discussed.

Summary of metals uptake data: In this study, 10 plant and soil samples were taken at the Quarry Prospect transect, and 11 were taken at the Big Hurrah transect. Plant samples were the leaves of the tealeaf willow, *Salix pulchra*. For the metals of interest to this compendium, the Quarry Prospect transect had soil metals concentrations of 1.20, 21.93, and 278.61 ppm for Cd, Cu, and Zn respectively. The Big Hurrah transect had soil concentrations of 1.36, 50.35, and 148.94 ppm for Cd, Cu, and Zn respectively. These values are for the A-horizon of soil at the sample sites. The data from this study suggests that this species of willow actively accumulates both Cd and Zn in its leaves, as the bioconcentration factors averaged to 2.5 and 0.88 for Cd and Zn respectively at the Quarry Prospect transect. The Big Hurrah transect had similar results, with bioconcentration factors of 11.32 and 1.09 for Cd and Zn respectively. Cu bioconcentration was lower, with factors of 0.39 and 0.13 for the Quarry Prospect and Big Hurrah transect respectively.

Species included: Tealeaf willow (*Salix pulchra*)

Metals included: Cd, Cu, Zn

Citation: Gough, L.P., Lamothe, P.J., Sanzalone, R.F., Drew, L.J., Maier, J.A.K., Schuenemeyer, J.K. (2013). Cadmium geochemistry of soils and willow in a metamorphic bedrock terrain and its possible relation to moose health, Seward Peninsula, Alaska. Alces 49: 99-111

1.7 METAL UPTAKE IN NORTHERN CONSTRUCTED WETLANDS

Research Location: Yukon Research Centre Lab, YT

Publication Type: Technical report

Publication Year: 2015

Executive Summary: Constructed wetlands (CWs) have been employed as passive treatment systems for metal contaminated mine drainage in Canada. However, relatively few CWs have been documented in northern environments and further studies are needed to understand the metal removal mechanisms in wetlands operating under cold climates, with short growing seasons. The goal of this study was to evaluate the performance of laboratory-scale CWs for the removal of Cd, Cu, Se and Zn, as well as, to evaluate Cu and Se uptake in two northern plant species (*Carex aquatilis* and *Juncus balticus*). Eight laboratory-scale wetlands were constructed using local materials, including locally harvested plant species and microorganisms and operated under northern summer conditions for 10 weeks. The CWs were fed continuously with synthetic influent containing Cd, Cu, Fe, Se and Zn at concentrations predicted at mine closure. Average removal efficiencies of 96%, 99%, 79% and 97% were observed for Cd, Cu, Se and Zn respectively. There were no significant differences in plant establishment or growth between our CW treatments, or any evidence of increasing Cu uptake with increasing contaminant availability in either northern plant species. Increased belowground uptake of Se was observed at the higher influent concentration in the Pit treatment. However, overall our study suggests that uptake of contaminants by these two northern species is very minor (<0.06% Cu and <0.11% Se, except for *C. aquatilis* in one treatment <0.2% Cu and <0.4 % Se) and likely does not pose a risk to the surrounding environment. We conclude that CWs could operate as successful passive treatment solutions in a northern environment, at least during the summer months, pending further studies on winter treatment. Further studies are required to examine seasonal metal removal rates in relation to rates of sulfate reduction, carbon consumption, metal precipitation and sorption. In addition, potential contaminant uptake and the influence of functional plant characteristics on metal removal in a suite of northern plant species would further assist in the development of large-scale long-term northern CWs.

Summary of metals uptake data: This laboratory study involved the creation of small-scale constructed wetlands containing the species *Carex aquatilis* and *Juncus balticus* to treat mine water effluent from an open pit overflow, and effluent downstream of a tailings management facility. The control was not included in this database as it does not represent a mine-impacted environment.

For the three treatments recorded (pit overflow, pit overflow with carbon-source addition, tailings management facility effluent) the range of Cu and Se content in the substrate of the constructed wetlands containing *Carex* were 18.53 – 38.27 ppm and 0.81 – 1.50 ppm respectively. For the wetlands containing *Juncus* the range of metals concentration in the substrate for Cu and Se was 19.95 – 42.03 ppm and 0.28 – 0.60 ppm respectively. *Carex* saw shoot bioconcentration factors in the range of 0.19 – 0.36 and 0.17 – 0.21 for Cu and Se respectively corresponding to metals concentrations in the shoots of 6.62 – 7.33 ppm and 0.17 – 0.25 ppm for Cu and Se. This data corresponded to translocation factors for *Carex* in the range of 0.5 – 1.29 and 0.12 – 0.58 for Cu and Se respectively. *Juncus* had similar results, with shoot bioconcentration factors of 0.13 – 0.34 and 0.45 – 1.73 for Cu and Se respectively, and ranges of shoot metals concentrations for Cu and Se of 5.31 – 6.70 ppm and 0.27 – 0.75 ppm. The translocation factors for *Juncus* were 0.94 – 1.28 for Cu, and 0.42 – 1.43 for Se. These measurements were made in triplicate.

Species included: Water sedge (*Carex aquatilis*), Baltic rush (*Juncus balticus*)

Metals included: Cu, Se

Citation: Stewart K. and Janin A. (2015). Metal Uptake in Northern Constructed Wetlands, March 2015, 32 p.

1.8 SA DENA HES MINE: DATA REPORT IN SUPPORT OF THE HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENTS (HHERA)

Research Location: Sa Dena Hes Mine, YT

Publication Type: Technical report

Publication Year: 2014

Executive summary: In June and August 2013, Azimuth undertook a multi-disciplinary field investigation of the Sä Dena Hes Mine Site with the objective of defining the concentration and spatial distribution of metals in a wide range of environmental including soil, water, sediment, vegetation, berries and medicinal plants, ground invertebrates, flying invertebrates, small mammals and feces from snowshoe hare and moose. This Data Report document compiles all 2013 field data and is the common source for raw data to support the terrestrial Ecological (ERA) and Human Health Risk Assessments (HHRA).

The Data Report has four main objectives:

1. Describe patterns in metal concentrations in environmental media from at least two areas that are located away from influence of the mine, yet still within the local region that might be representative of the mineralization features of the soil.

2. Distinguish/determine what may be considered as 'exposed' versus 'background' conditions within the Mine Site boundaries. This was accomplished by comparing metals concentrations across all environmental media between reference areas and areas within the Mine Site.

3. Determine site-wide metals contamination patterns within and between various environmental media on- and off-site to characterize the degree of metals 'exposure' for ecological receptors.

4. Determine if there has been uptake and accumulation of metals from the soil into biota tissue – such as vegetation, ground invertebrates, and small mammals and explore relationships between metal concentrations in soil and higher trophic levels of the food web.

This report has a terrestrial ecological focus, with an emphasis on organic and near-surface inorganic soils and other media (e.g., ground invertebrates, berries) that are important from a wildlife dietary exposure perspective. Screening of contaminants of potential concern (COPC) within discrete Areas of

Environmental Concern (AEC) was the responsibility of the ERA. Fourteen areas were investigated, two off-site reference areas and one internal reference area, areas with known contamination (Burnick, Main Zone, Jewelbox, Mill Site, 1380 Gully) and several on-site areas with no known source of contamination that are peripheral to the Tailings Management Facility (e.g., north, east and west of the Tailings Ponds) and Reclaim Pond. The ERA identified 10 COPC metals in soils using the screening criteria that are laid out in the ERA and include arsenic, antimony, cadmium, copper, lead, molybdenum, selenium, silver, vanadium and zinc. The Data Report does not assess potential effects to ecological receptors or human health, which are addressed by the ERA and HHRA respectively. An aquatic ERA is planned for 2014, with emphasis on the Camp Creek receiving environment.

Summary of metals uptake data: Both alder (*Alnus spp.*) and willow (*Salix spp.*) were sampled in this study, and these were the species included in the database. For alder, Zn was the most heavily bioconcentrated metal, with an average bioconcentration factor of 0.64, and a large range of bioconcentration factors from 0.06 – 3.16. The ranges of bioconcentration factors in alder for the other metals were 0.00 – 0.01, 0.01 – 0.05, 0.22 – 0.65, 0.02 – 0.1, and 0.02 – 0.04 for As, Cd, Cu, Pb, and Se respectively. The concentrations of metals in the soil where alder was sampled had ranges of 2.50 – 193.50 ppm for As, 1.50 – 17.00 ppm for Cd, 6.00 – 16.75 ppm for Cu, 21.00 – 662.50 ppm for Pb, 1.25 – 2.90 ppm for Se, and 14.00 – 1,520.00 ppm for Zn. In willow, Cd was the most heavily bioconcentrated metal, with an average bioconcentration factor across all samples of 2.79, and again a large range of values for bioconcentration factors from 0.21 – 9.60 ppm. This corresponds to a range of Cd concentration in the soils where willow was sampled from 0.25 – 25.0 ppm. The ranges of bioconcentration factors found in *Salix* for the other metals were measured at 0.00 – 0.01, 0.05 – 0.41, 0.00 – 0.03, 0.02 – 0.84, 0.07 – 0.8 ppm for As, Cu, Pb, Se, and Zn respectively. These correspond to metals concentrations in the soils at *Salix* sampling sites in ranges of 2.50 – 141.0, 0.25 – 25.0, 8.25 – 97.0, 21.0 – 4981.0, 0.25 – 2.90, 105.25 – 5223.0 ppm for As, Cd, Cu, Pb, Se, and Zn respectively.

Species included: Alder (*Alnus spp.*), willow (*Salix spp.*)

Metals included: As, Cd, Cu, Pb, Se, Zn

Citation: Azimuth Consulting Group Partnership (2014). Sa Den Hes Mine: data report in support of the human health and ecological risk assessments (HHERA). 131p.

1.9 MINTO MINE CONSTRUCTED WETLAND TREATMENT RESEARCH PROGRAM – DEMONSTRATION SCALE

Research Location: Minto Mine, YT

Publication Type: Technical Report

Publication Year: 2015

Summary of report*: The Minto Mine, located 240 km North of Whitehorse, in the Dawson mountain range, has been tasked with implementing the construction of a constructed wetland treatment system as a part of their Reclamation Closure Plan. This paper outlines the first reported results of the demonstration scale wetland constructed on mine site. The purpose of the demonstration scale wetland is to optimize local design so that implementation will be more successful for the full-scale constructed wetland upon mine closure. The wetland design involves a 2x2 grid of wetland cells, with two cells connected in series running parallel to the other two cells. Influent from mill-associated activities is used as the influent for each line of 2 cells, and both *Carex aquatilis* and Sphagnum moss (*Sphagnum spp.*) were planted in the wetland cells. Substrate consisted of mostly sand, with ~2-7% organic matter added in the form of wood chips and peat in order to facilitate microbial growth and metabolism. Leachable metal concentrations in the CWTS soils were measured, as well as total metal content in water within the CWTS and in its effluent by ICP-MS. Total metals in plant tissues was also measured using ICP-MS.

Summary of metals uptake data: The influent for this constructed wetland is associated with mill activities on site. The species placed in the wetland for the remediation study were *Carex aquatilis* and *Sphagnum spp.* For *Carex*, Cu concentrations were the highest of any metal found in plant samples, at 51.93 ppm in the roots, and 16.40 ppm in the shoots, implying a translocation factor 0.32. The other translocation factors in *Carex* were 0.82 for Zn, 0.43 for Pb, and 0.19 for As. Cd concentrations were below the detection limit of analysis in the shoots of plants, and only at an average of 0.02 ppm in the roots of plants. Concentrations of As in the shoots and roots of *Carex* plants was 0.20 ppm and 1.03 ppm respectively; for Pb it was 0.16 ppm in the roots and 0.07 ppm in the shoots; for Zn the concentration was 7.33 ppm in the roots and 6.0 ppm in the shoots. All plant samples were made in triplicate.

For sphagnum moss average concentrations from samples were 0.15 ppm for As, 0.01 ppm for Cd, 14.43 ppm for Cu, 0.04 ppm for Pb, and 3.67 ppm for Pb. As with *Carex*, sphagnum moss had high levels of Cu relative to the other metals. Sample consisted of the whole plant, and were made in triplicate.

Species included: Water sedge (*Carex aquatilis*), sphagnum moss (*Sphagnum spp.*)

Metals included: As, Cd, Cu, Pb, Se, Zn

Citation: Contango Strategies Ltd. (2015). Minto Mine Constructed Wetland Treatment Research Program - Demonstration Scale. Prepared for Capstone Mining Corp. 22p. Document – 011_0315_01A

1.10 VEGETATION METAL UPTAKE MONITORING PLAN FOR MINTO MINE

Research Location: Minto Mine, YT

Publication Type: Technical Report

Publication Year: 2015

Summary of paper*: The vegetation monitoring uptake plan at Minto Mine aims to monitor data on metals uptake in plants on mine site in order to assess the potential risk of consumption of these metals by humans or wildlife. This is a part of the revised Minto Phase V/VI Environmental, Monitoring, Surveillance and Reporting Plan (EMSRP). Sampling sites were chosen to represent both mine-impacted areas (example at the tailings) and non-impacted or control areas. Both soil and vegetation samples were taken at each site to give an idea of the amount of uptake of metals in plants. Vegetation species were chosen so as to represent vegetation which may actually be consumed by humans or wildlife. For example, willow leaves, horsetail shoots, and grasses were sampled due to their potential to be consumed from browsing moose. Soapberry and blueberry were chosen as vegetation samples for their potential to be consumed by humans or bears. Metals analysis was performed via standard ICP-MS analysis.

Summary of metals uptake data: Of the vegetation samples recorded in the report, metals content in both the vegetation and soil for individual sampling sites were present for two species of violet wheatgrass (*Agropyron trachycaulus* and *Agropyron violaceum*), tufted hairgrass (*Deschampsia cespitosa*), sheep fescue (*Festuca ovina*), rocky mountain fescue (*Festuca saximontana*), glaucous bluegrass (*Poa glauca*), and grey leaf willow (*Salix glauca*). All species of grasses were sampled from the shoots up, and grey leaf willow samples consisted of just the leaves of the plant. Across all of the sampling sites, the metals content in the soils were very similar, having concentrations ranging from 3.7 – 6.5 ppm for As, 0.09 – 0.46 ppm for Cd, 23.6 – 687 ppm for Cu, 4.2 – 7.5 ppm for Pb, 0.5 – 1.0 ppm for Se, and 58 – 71 ppm for Zn. Cd, Cu, and Zn were consistently the metals that were taken up most actively by the plants.

Agropyron trachycaulus exhibited relatively high bioconcentration of Cd and Cu with a factor ranging from 0.31 to 1.13 for Cd and 0.48 to 1.09 for Cu. The range of bioconcentration factors for As was 0.02 – 0.05, and for Pb it was 0.05 – 0.09, and Se 0.19 – 0.40, and for Zn a range of 0.23 – 0.28. *Agropyron violaceum* had similar bioconcentrations, with only a single data point in the data set – As had 0.04, Cd had 0.35, Cu had 0.05, Pb had 0.03, Se had 0.27, and Zn had 0.11. Tufted hairgrass again had higher bioconcentrations for Cd and Cu with a range of 0.28 – 1.73 for Cd and 0.81 – 1.91 for Cu. The range of bioconcentration factors spanned 0.03 – 0.07 for As, 0.08 – 0.12 for Pb, 0.24 – 0.40 for Se, and 0.37 – 0.78 for Zn. Rocky mountain fescue had higher bioconcentration of Zn, with a range of 0.32 – 1.29. Cu also had relatively high bioconcentrations, with a range of 0.41 – 1.43. Glaucous bluegrass had bioconcentration ranges of 0.73 -1.21 for Cd, 0.66 – 0.69 for Cu, and 1.69 – 1.78 for Zn across all the plants sampled. Finally, grey leaf willow showed similar trends with only one data point for the species, very actively taking up Cd, with a bioconcentration factor of 7.22, and bioconcentration factors for Cu and Zn of 1.67 and 1.87 respectively.

Species included: Violet wheatgrass (*Agropyron trachycaulus* and *Agropyron violaceum*), tufted hairgrass (*Deschampsia cespitosa*), sheep fescue (*Festuca ovina*), rocky mountain fescue (*Festuca saximontana*), glaucous bluegrass (*Poa glauca*), grey leaf willow (*Salix glauca*)

Metals included: As, Cd, Cu, Pb, Se, Zn

Citation: Access Consulting. (2015). Vegetation metal uptake monitoring plan. Prepared for Minto Explorations ltd.

1.11 WOLVERINE PROJECT WILDLIFE PROTECTION PLAN 2010 ANNUAL MONITORING REPORT

Research Location: Minto Mine, YT

Publication Type: Technical Report

Publication Year: 2011

Summary of paper*: The Wolverine Mine, owned and operated by Yukon Zinc, is a zinc-silver-copper-lead-gold mine located within the Kaska First Nations traditional territory. In 2009, a wildlife protection plan was implemented as part of the agreement made in the Quartz Mining License. This plan involved wildlife monitoring research, wildlife encounters training, and quantification of metals uptake in certain plant species to provide information on the possibility of transport of metals up the food chain via these vectors. Comparing sampling areas on mine site versus reference areas off of the site, bird surveys carried out under this wildlife protection plan found there to be significantly fewer birds on mine site relative to off site. Various wildlife encounters were reported including multiple interactions with fox and ravens on site, as well as an incident of a flock of swans landing in the site tailings pond. Certain measures were proposed and implemented to deal with these occurrences. ICP-MS analysis was used to determine metals content in sampled plants. Statistical analysis of metals content in the plants recorded in this study indicate that certain differences do exist between the off mine-site sampling area for these studies (Money Creek area), relative to the two sampling areas located on the mine site (Putt Creek and Mine Site), and differences were also found between the two on-site sampling areas. The species sampled in this vegetation survey were diamondleaf willow (*Salix planifolia*), horsetail (*Equisetum arvense*), and reindeer lichen (*Cladina stellaris*).

Summary of metals uptake data: While no data was collected on metals content in soils, the work done in the 2010 annual report for wildlife monitoring contains a large data set on metals content in plant tissues of the three studied species, and so is included in the database. The data for the purported reference area, Money Creek, was not included in the database as it was deemed that it should not be affected by mine activities. Diamondleaf willow samples consisted of shoots and leaves of the plants. For diamondleaf willow, metals concentrations in plant tissues on the Mine Site and Putt Creek sample areas ranged from 0.01 – 0.29 ppm for As, 0.02 – 12.0 ppm for Cd, 1.4 – 9.20 ppm for Cu, 0.06 – 2.07 ppm for Pb, 0.01 – 1.46 ppm for Se, and 20.2 – 391.0 ppm for Zn. Horsetail samples consisted of only the shoots of the plants. For horsetail, metals content in plant tissues ranged in concentration from 0.01 – 0.61 ppm for As, 0.01 – 1.91 ppm for Cd, 2.0 – 7.60 ppm for Cu, 0.04 – 0.96 ppm for Pb, 0.01 – 45.3 ppm for Se, and 12.9 – 201.0 ppm for Zn. Finally, for reindeer lichen, metals content in the tissue of the whole organism were in the range of 0.04 – 0.35 ppm for As, 0.04 – 0.87 ppm for Cd, 0.1 – 4.50 ppm for Cu, 0.18 – 2.85 ppm for Pb, 0.02 – 0.26 ppm for Se, and 12.6 – 74.1 ppm for Zn.

Species included: Diamondleaf willow (*Salix planifolia*), horsetail (*Equisetum arvense*), reindeer lichen (*Cladina stellaris*)

Metals included: As, Cd, Cu, Pb, Se, Zn

Citation: Yukon Zinc. (2011). Wolverine project wildlife protection plan 2010 annual monitoring report. 37p. QML – 0006

1.12 WOLVERINE PROJECT WILDLIFE PROTECTION PLAN 2011 ANNUAL MONITORING REPORT

Research Location: Minto Mine, YT

Publication Type: Technical Report

Publication Year: 2012

Summary of paper*: The 2011 Wolverine project wildlife protection plan activities were very similar to those undertaken in 2010. Wildlife encounters reporting continued in 2011 and included the trapping and relocation of a fox which was deemed to be a nuisance, and mallard ducks sighted on the tailings pond which then flew away after deterred with air horns. For metals uptake monitoring, statistical analyses were performed to determine the difference in metals content in the sampled plant species between 2010 data and 2011 data. The same plant species sampled in 2010 were used in 2011 to ensure relevant results -- diamondleaf willow (*Salix planifolia*), horsetail (*Equisetum arvense*), and reindeer lichen (*Cladina stellaris*). This comparison was made to see if heightened mining activities would cause an increase in metals content in plants on site. Interestingly, for both As and Cu, the concentration of metals in all three plant species studied were higher in 2011 than in 2010 at the control site for the study, Money Creek. This could reflect either that the control site is actually affected by mine activity, or natural attenuation of bioavailable metals in this area is normal, or this may simply be an artifact of sampling procedure. For the sampling site at Putt Creek where mine activities were ongoing in 2011, As was found to be higher in 2011 than 2010 in all three plant species, Pb concentrations in all three species were higher in 2011, and Zn conventrations were higher in 2011, but only in lichen samples. For the Mine Site sampling area, Cu concentrations were higher in all three sampled species in 2011 relative to 2010, Pb concentrations were higher in 2011 for both horsetail and lichen, and Se levels were higher in lichen at the Mine Site Study Area in 2011 relative to 2010. Cd concentrations were not found to be any different between years for any of the species at any of the sampling sites.

Summary of metals uptake data: Concentration ranges in plant tissues were similar between the 2011 and 2010 sampling years, however the upper ends of concentration ranges tended to be slightly higher in the 2011 sampling year. Lichen in particular saw elevated upper limits to the concentration range for all metals focused on in our database. This may be due at least in part to dust deposition, which hasn't been controlled for in the monitoring program, as any wildlife browsing on these species would also ingest deposited metals dust. This is a caveat when considering this data for strictly metals uptake purposes. Metals data in *Salix planifolia* for 2011 gave a range of As in samples of 0.05 – 0.16 ppm, for Cd 0.04 – 23.40 ppm, for Cu 2.15 – 11.50 ppm, for Pb 0.10 – 6.18 ppm, for Se 0.05 – 10.30 ppm, and for Zn 53.30 -795.0 ppm. Reindeer lichen had concentration ranges for the 2011 data of 0.06 – 1.68 ppm for As, 0.06 – 1.29 ppm for Cd, 1.04 – 29.0 ppm for Cu, 0.37 – 19.30 ppm for Pb, 0.05 – 1.32 ppm for Se, and 10.70 – 148.0 ppm for Zn. Horsetail data for 2011 had very similar ranges to the 2010 data with a concentration range of 0.05 – 0.85 ppm for As, 0.03. – 1.21 ppm for Cd, 2.10 – 8.69 ppm for Cu, 0.11 – 1.59 ppm for Pb, 0.07 – 40.4 ppm for Se, and 14.0 – 226.0 ppm for Zn.

Species included: Diamondleaf willow (*Salix planifolia*), horsetail (*Equisetum arvense*), reindeer lichen (*Cladina stellaris*)

Metals included: As, Cd, Cu, Pb, Se, Zn

Citaton: Yukon Zinc. (2012). Wolverine project wildlife protection plan 2011 annual monitoring report. 47p. QML – 0006

2 SUMMARY OF DATA

2.1 CONTEXT

While this data outlines cases of different species growing in mine-impacted soils, it is important to understand that the trends outlined here are a representation of possible values for metals uptake data in the species studied. Metals content in plant tissues is highly variable and impacted by numerous factors, such as the soil chemistry and the particular biochemistry of an individual plant , which is in turn influenced by the underlying genetics of the individual (Luo et al 2016, Tangahu 2011). While this compendium is meant to serve as a guide for understanding metals uptake in different species, it shouldn't be expected that species at different sites and under different conditions should have the same metals uptake characteristics. It is also important to note that the averages and ranges included in this report are based on a limited amount of data, sometimes from just a single study; it shouldn't be assumed that the values of these data are representative of the species as a whole, especially when considering the variety of environments any such species may inhabit.

2.2 OVERVIEW OF BIOCONCENTRATION FACTORS

Table 1 represents a summary of the data included in the database, showing the average bioconcentration factor for each species and each metal for which data was found. Of the results in Table 1, the most striking trend is the high uptake of Cd by willow species. *Salix spp.* averaged a bioconcentration factor of 2.79, tealeaf willow (*Salix pulchra*) averaged a biococentration factor of 6.91, and grey leaf willow (*Salix glauca*) averaged a bioconcentration factor of 7.22. This trend is in agreement with the established literature, which suggests that willow in general actively uptakes Cd (Lewandowski et al 2006, Robinson et al 2000, Tangahu et al 2011).

There was also some moderate uptake of Cu in certain species. Grey leaf willow (*Salix glauca*) had an average bioconcentration factor of 1.67 averaged across all of the studies in the database, and tufted hairgrass (*Deschampsia cespitosa*) had a bioconcentration factor of 1.34 for Cu. These relatively high bioconcentration factors contrast with those for Pb, where the highest bioconcentration factor for any species included in the database was 0.09, and Se which had low bioconcentration factors for species across the board, except for in Baltic rush, where the bioconcentration factor was 1.30. This bioconcentration for Se was, however only based off of one study with 3 data points.

Zn actually seemed to have relatively high bioconcentration factors across all species seen in the database, suggesting it is a common metal for active uptake in plants, and the highest bioconcentration factors were in glaucous bluegrass (*Poa glauca*) with a bioconcentration factor of

1.74, grey leaf willow (*Salix glauca*) with a factor of 1.87, and tea leaf willow (*Salix pulchra*), with a bioconcentration factor of 0.99.

Water sedge was one species which consistently had low bioconcentration for the metals analyzed in different studies, supporting its use as a plant species for constructed wetlands. Despite this, the concentrations of metals actually found in the plant tissues had a large range for the studies included in the database, with some plants actually having relatively high concentrations of metals in their tissues. Milk vetch was another plant with very low bioconcentration, as well as low metals content within the tissues, however this is only based off of one data point from a single study included in this report (Burns, 2005).

Table 1. Average bioconcentration factors for the species and metals found in the database, organized by the plant part sampled for analyses. The number of samples (N) for these data are included in brackets for each average bioconcentration.

Plant common name	Plant Latin name	Plant part	As	Cd	Cu	Pb	Se	Zn
Alder	Alnus spp.	shoots	0.002 (4)	0.019 (8)	0.371 (8)	0.035 (8)	0.029 (2)	0.636 (8)
Alfalfa	Medicago sativa	shoots	0.003 (1)	1.483 (1)	0.172 (1)	0.004 (1)	0.162 (1)	0.351 (1)
Baltic rush	Juncus balticus	shoots	--	--	0.207 (9)	--	1.298 (9)	--
Blueberry	Vaccinium uliginosum	berries	0.001 (16)	--	--	--	--	--
Caribou moss	Cladina/Cetraria spp.	whole plant	0.362 (15)	--	--	--	--	--
Crowberry	Empetrum nigrum	berries	0 (16)	--	--	--	--	--
Diamondleaf willow	Salix planifolia	shoots	0 (52)	0 (52)	0 (52)	0 (52)	0 (52)	0 (52)
Dwarf raspberry	Rubus acaulis	berries	0 (4)	--	--	--	--	--
Felt-leafed willow	Salix alaxensis	leaves	0.005 (1)	0.484 (1)	0.098 (1)	0.003 (1)	0.091 (1)	0.499 (1)
Glaucous bluegrass	Poa glauca	whole plant	0.038 (2)	0.97 (2)	0.675 (2)	0.076 (2)	0.272 (2)	1.739 (2)
Grey leaf willow	Salix glauca	whole plant	0.016 (1)	7.222 (1)	1.669 (1)	0.031 (1)	0.12 (1)	1.87 (1)
Horsetail	Equisetum arvense	shoots	0.000 (52)	0.000 (52)	0.000 (50)	0.000 (52)	0.000 (52)	0.000 (50)
Kentucky bluegrass	Poa pratensis	shoots	0.013 (1)	0.77 (1)	0.106 (1)	0.004 (1)	0.65 (1)	0.17 (1)
Labrador tea	Ledum spp.	shoots	0.191 (15)	--	--	--	--	--
Lowbush cranberry	Vaccinium vitis-idaea	berries	0.001 (17)	--	--	--	--	--
Milk vetch	Astragalus alpinus	whole plant	0.004 (1)	0.01 (1)	0.028 (1)	0.009 (1)	0.081 (1)	0.031 (1)
Mushroom	Leccinum spp.	shoots	0.01 (15)	--	--	--	--	--

Table 1 Cont'd. Average bioconcentration factors for the species and metals found in the database, organized by the plant part sampled for analyses. The number of samples (N) for these data are included in brackets for each average bioconcentration.

Plant common name	Plant Latin name	Plant part	As	Cd	Cu	Pb	Se	Zn
Raspberry	Rubeus ideaus	berries	0 (8)	--	--	--	--	--
Red fescue	Festuca rubra	shoots	0.001 (3)	0.168 (6)	0.078 (6)	0.005 (6)	0.174 (6)	0.13 (6)
Reindeer Lichen	Cladina stellaris	whole plant	0 (44)	0 (44)	0 (44)	0 (44)	0 (44)	0 (44)
Rocky mountain fescue	Festuca saximontana	whole plant	0.038 (3)	0.365 (3)	0.752 (3)	0.076 (3)	0.206 (3)	0.652 (3)
Sheep fescue	Festuca ovina	whole plant	0.042 (4)	0.577 (4)	0.461 (4)	0.09 (4)	0.231 (4)	0.415 (4)
Slender wheatgrass	Agropyron trachycaulus	shoots	0.006 (5)	0.181 (5)	0.059 (5)	0.006 (5)	0.196 (5)	0.159 (5)
Soapberry	Shepherdia canadensis	berries	0.002 (7)	--	--	--	--	--
Tealeaf willow	Salix pulchra	leaves	--	6.912 (21)	0.263 (21)	--	--	0.986 (21)
Tufted hairgrass	Deschampsia cespitosa	whole plant	0.06 (3)	0.963 (3)	1.344 (3)	0.092 (3)	0.33 (3)	0.58 (3)
Violet wheatgrass	Agropyron trachycaulus	whole plant	0.035 (3)	0.601 (3)	0.794 (3)	0.071 (3)	0.28 (3)	0.26 (3)
Violet wheatgrass	Agropyron violaceum	whole plant	0.039 (1)	0.348 (1)	0.051 (1)	0.032 (1)	0.27 (1)	0.11 (1)
Water sedge	Carex aquatilis	shoots	0 (3)	0.004 (5)	0.138 (17)	0.03 (8)	0.198 (9)	0.009 (8)
Water sedge	Carex aquatilis	whole plant	0.021 (1)	0.28 (1)	0.376 (1)	0.288 (1)	0.111 (1)	0.157 (1)
Willow	Salix spp.	leaves	0.048 (16)	--	--	--	--	--

Table 1 Cont'd. Average bioconcentration factors for the species and metals found in the database, organized by the plant part sampled for analyses. The number of samples (N) for these data are included in brackets for each average bioconcentration.

Plant common name	Plant Latin name	Plant part	As	Cd	Cu	Pb	Se	Zn
Willow	Salix spp.	shoots	0.012 (26)	2.792 (10)	0.243 (10)	0.012 (10)	0.217 (10)	0.416 (10)

2.3 OVERVIEW OF METAL CONTENTS

Table 2 is another summary table of the data found in the database, showing the range of metals concentrations found for each species that is included in the database. Arsenic typically had low concentrations within plant tissues themselves, with some notable exceptions being samples taken from Mt. Nansen (Nicholson, 2002) including caribou moss (*Cladina/Cetraria spp.*) with a range of As in 8.87 – 31.14 ppm, labrador tea (*Ledum spp.*) with a range of 0.61 – 16.67 ppm, and mushroom species (*Leccinum spp.*), as well as willow (*Salix spp.*) samples from other projects with a range of As in the leaves of 0.3 – 4.19 ppm, and with the shoots in general a range of 0.01 – 5.69 ppm.

As expected from the bioconcentration factors, some very high concentrations of Cd were found in willow, with *Salix spp.* having a Cd concentration range of 0.94 – 25.37 ppm in the shoots, and tealeaf willow (*Salix pulchra*) having a concentration range in the leaves of 3.01 – 15.38 ppm, and diaomondleaf willow (*Salix planifolia*) having a range of Cd in tissues of 0.02 – 23.4 ppm. *Carex aquatilis* was the species that had the next highest concentrations of Cd in plant tissues, with a range of Cd at 0.5 – 3.1 ppm in the shoots. The highest levels of Cd found in the shoots for this species may be due to very high concentrations of Cd in the substrate, given that the bioconcentration factor for Cd in the shoots for *Carex* is averaged at 0.00.

Both Cu and Zn in general are in high concentration in plant tissues, as can be seen in Table 2, despite the suggestion by Table 1 that bioconcentration factors for these metals are not generally high. This is probably due to the sediment characteristics at the sample sites included in this database, which typically have elevated levels of Cu and Zn.

Both Pb, and in particular Se, are not as readily found in plant tissues at high concentrations, with a few exceptions of plants with high Se levels – horsetail (*Equisetum arvense*) with some samples at 45.3 ppm Se in the shoots, and diamondleaf willow (*Salix planifolia*) with a concentration of 10.3 ppm Se in its shoots.

Table 2. Concentration ranges (in ppm) of metals in plant tissues of species included in the database, organized by the plant part sampled for analyses. The number of samples (N) for these data are included in brackets for each concentration range.

Plant common name	Plant Latin name	Plant part	As	Cd	Cu	Pb	Se	Zn
Alder	Alnus spp.	shoots	0.01 (4)	0.02 - 0.14 (8)	3.55 - 5.03 (8)	1.08 - 12.74 (8)	0.05 - 0.06 (2)	41.08 - 103.98 (8)
Alfalfa	Medicago sativa	shoots	0.78 (1)	0.89 (1)	6.2 (1)	0.06 (1)	0.21 (1)	39 (1)
Baltic rush	Juncus balticus	shoots	--	--	5.31 - 6.7 (9)	--	0.27 - 0.75 (9)	--
Blueberry	Vaccinium uliginosum	berries	0.04 - 0.09 (16)	--	--	--	--	--
Caribou moss	Cladina/Cetraria spp.	whole	8.87 - 31.14 (15)	--	--	--	--	--
Crowberry	Empetrum nigrum	berries	0 - 0.17 (16)	--	--	--	--	--
Diamondleaf willow	Salix planifolia	shoots	0.01 - 0.36 (52)	0.02 - 23.4 (52)	1.4 - 11.5 (52)	0.06 - 6.18 (52)	0.01 - 10.3 (52)	20.2 - 795 (52)
Dwarf raspberry	Rubus acaulis	berries	1.25 (4)	--	--	--	--	--
Felt-leafed willow	Salix alaxensis	leaves	0.03 (1)	0.3 (1)	1.6 (1)	0.02 (1)	0.1 (1)	38.8 (1)
Glaucous bluegrass	Poa glauca	whole	0.22 - 0.27 (2)	0.11 - 0.35 (2)	39.1 - 113 (2)	0.43 - 0.47 (2)	0.2 - 0.21 (2)	98.3 - 123 (2)
Grey leaf willow	Salix glauca	whole	0.06 (1)	0.65 (1)	39.4 (1)	0.13 (1)	0.06 (1)	101 (1)
Horsetail	Equisetum arvense	shoots	0.01 - 0.85 (52)	0.01 - 1.91 (52)	2 - 8.69 (50)	0.04 - 1.59 (52)	0.01 - 45.3 (52)	12.9 - 226 (50)

Table 2 Cont'd. Concentration ranges (in ppm) of metals in plant tissues of species included in the database, organized by the plant part sampled for analyses. The number of samples (N) for these data are included in brackets for each concentration range.

Plant common name	Plant Latin name	Plant part	As	Cd	Cu	Pb	Se	Zn
Kentucky bluegrass	Poa pratensis	shoots	0.94 (1)	0.47 (1)	3.2 (1)	0.06 (1)	0.52 (1)	18.9 (1)
Labrador tea	Ledum spp.	shoots	0.61 - 16.67 (15)	--	--	--	--	--
Lowbush cranberry	Vaccinium vitis-idaea	berries	0.04 - 0.15 (17)	--	--	--	--	--
Milk vetch	Astragalus alpinus	whole	0.1 (1)	0.02 (1)	1.1 (1)	0.1 (1)	0.3 (1)	6.6 (1)
Mushroom	Leccinum spp.	shoots	0.59 - 5.19 (15)	--	--	--	--	--
Raspberry	Rubeus ideaus	berries	0.05 - 0.28 (8)	--	--	--	--	--
Red fescue	Festuca rubra	shoots	0.43 (3)	0.13 - 0.2 (6)	2.77 - 2.9 (6)	0.06 - 0.1 (6)	0.07 - 0.35 (6)	14.63 - 20 (6)
Reindeer Lichen	Cladina stellaris	whole	0.04 - 1.68 (44)	0.04 - 1.29 (44)	0.1 - 29 (44)	0.18 - 19.3 (44)	0.02 - 1.32 (44)	10.7 - 148 (44)
Rocky mountain fescue	Festuca saximontana	whole	0.16 - 0.35 (3)	0.03 - 0.19 (3)	25 - 233 (3)	0.2 - 0.88 (3)	0.07 - 0.3 (3)	18.8 - 89.3 (3)
Sheep fescue	Festuca ovina	whole	0.13 - 0.36 (4)	0.1 - 0.19 (4)	26.2 - 108 (4)	0.36 - 0.7 (4)	0.07 - 0.44 (4)	21 - 44 (4)

Table 2 Cont'd. Concentration ranges (in ppm) of metals in plant tissues of species included in the database, organized by the plant part sampled for analyses. The number of samples (N) for these data are included in brackets for each concentration range.

Plant common name	Plant Latin name	Plant part	As	Cd	Cu	Pb	Se	Zn
Slender wheatgrass	Agropyron trachycaulus	shoots	0.7 - 0.8 (5)	0.16 - 0.19 (5)	1.9 - 2.43 (5)	0.06 - 0.12 (5)	0.23 - 0.28 (5)	19.85 - 21.87 (5)
Soapberry	Shepherdia canadensis	berries	0.05 (7)	--	--	--	--	--
Tealeaf willow	Salix pulchra	leaves	--	3.01 - 15.38 (21)	6.7 - 8.61 (21)	--	--	162.55 - 245.47 (21)
Tufted hairgrass	Deschampsia cespitosa	whole	0.21 - 0.48 (3)	0.08 - 0.26 (3)	100 - 213 (3)	0.49 - 0.65 (3)	0.21 - 0.24 (3)	25.3 - 55.1 (3)
Violet wheatgrass	Agropyron trachycaulus	whole	0.16 - 0.32 (3)	0.09 - 0.17 (3)	58.5 - 133 (3)	0.32 - 0.52 (3)	0.15 - 0.24 (3)	13.6 - 19.8 (3)
Violet wheatgrass	Agropyron violaceum	whole	0.22 (1)	0.16 (1)	34.9 (1)	0.24 (1)	0.27 (1)	9.8 (1)
Water sedge	Carex aquatilis	shoots	0.2 (3)	0.5 - 3.1 (5)	2.81 - 16.4 (17)	0.07 - 34 (8)	0.17 - 0.25 (9)	6 - 237 (8)
Water sedge	Carex aquatilis	whole	0.3 (1)	0.37 (1)	10 (1)	3 (1)	0.2 (1)	42.4 (1)
Willow	Salix spp.	leaves	0.3 - 4.19 (16)	--	--	--	--	--
Willow	Salix spp.	shoots	0.01 - 5.69 (26)	0.94 - 25.37 (10)	1.95 - 4.88 (10)	0.2 - 146.19 (10)	0.04 - 0.61 (10)	67.05 - 387.8 (10)

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