95-185

Environment Canada
Water Science and Technology Directorate

Direction générale des sciences et de la technologie, eau
Environnement Canada

Uptake of Trace Elements by Plants Growing in Abandoned Mine Sites

By:
J. M. Azcue and A. Mudroch

95-185

Management Perspective

UPTAKE OF TRACE ELEMENTS BY PLANTS GROWING IN ABANDONED MINE SITES

by Jose M. Azcue and Alena Mudroch

In Canada there are approximately 12,500 hectares of acid drainage generating tailings with the possibility for mobilization of toxic elements and their subsequent transport into aquatic ecosystems. Natural revegetation of abandoned mine areas is considered one of the ideal remediation alternatives from the aesthethical point of view. However, little information exists on the capacity of plants colonizing wastes at abandoned mine sites to accumulate trace elements. This study was designed to determine the uptake of different trace elements by plants colonizing tailings at two different abandoned mine sites. The first site was a gold mine in British Columbia, Canada, the other a base metal mine accompanied by a cobalt ore smelter in Ontario, Canada.

Some plants, representing higher and lower vegetation, growing on the tailings in Wells, B.C. and Cobalt mining area, Ontario, have shown to be resistant to elevated concentrations of trace elements. Some plants, such as Engelman spruce and beaked sedge, have shown preferential accumulation of trace elements, particularly As. The results of the study indicated that willow has been able to grow on gold mine tailings without considerable uptake of trace elements. The results showed that leaves of Douglas maple act as a plant organ for the preferential accumulation of trace elements and can act as a detoxification mechanism for the plant. The results of the study indicated the need for development of a list of plant species occupying abandoned mine tailings, and assessment of the uptake of toxic trace elements by individual plant species. However, the bioavailability of the trace elements in the plants also needs to be assessed to evaluate the impact on wildlife consuming the plants occupying the tailings.

UPTAKE OF TRACE ELEMENTS BY PLANTS GROWING IN ABANDONED MINE SITES

Jose M. Azcue and Alena Mudroch

National Water Research Institute
P.O.Box 5050, Burlington, ON
Canada L7R 4A6

ABSTRACT

There are approximately 12,500 hectares of acid generating tailings in Canada. Acid mine drainage and dust emission can cause mobilization and subsequent transport of trace elements into aquatic ecosystems. The main objective of this study was to determine the uptake of different trace elements by plants colonizing tailings at two different abandoned gold and base metal mine sites. Several plants, higher and lower vegetation, can grow on abandoned mine tailing substrates with elevated concentrations of trace elements. Some plants, such as Engelman spruce and beaked sedge, have shown preferential accumulation of trace elements, particularly As and Pb. The results of this study indicated that willow trees can grow on gold mine tailings without considerable uptake of trace elements. The results showed that leaves of Douglas maple act as a detoxification mechanism for the plant. In the two study areas, capping with clean material and/or revegetation of the abandoned mine tailings, though not a final solution, can be recommended to minimize erosion of the tailings by water and wind with subsequent transport of toxic trace elements into the surrounding environment.

INTRODUCTION

Metal mining has been one of the major industries in Canada for more than a century. Mining activities are spread over 115 communities, representing approximately 36 billion dollars of the national economy (Feasby and Tremblay, 1995). Acid mine drainage and dust emission are the main problems in on-land disposal of mine tailings and waste rock. In Canada, there are approximately 12,500 hectares and 750 million tonnes of acid drainage generating tailings and waste rock, respectively (Feasby and Tremblay, 1995). Improper treatment, disposal, and storage of the mine wastes can bring about mobilization of toxic metals and trace elements and their subsequent transport into aquatic ecosystems.

At present, a safe disposal of wastes from active mines is a high priority to the mining companies in Canada. However, there are many abandoned mine sites in Canada with existing mobilization of different metals and trace elements. Remediation of these sites has been considered costly and difficult. Natural revegetation of acidic metal contaminated soils and new techniques for establishing vegetation covers to remediate the above problems at abandoned mine areas have been extensively studied (Winterhalder, 1983, 1995; Helm, 1991; Peters, 1995). The main objective of these studies has been the aestethical appearance, such as the establishment of a permanently stable landscape at the abandoned mine sites. However, limited information exists on the capacity of plants colonizing wastes at the abandoned mine sites to accumulate trace elements. The accumulation of the trace elements by the plants depends on several factors, such as plant species; plant parts and soil conditions (Kabata-Pendias and Pendias, 1986). Plant analysis provides a direct means of integrating some of the complicated soil-plant mechanisms which govern the uptake of trace elements from soils (Richards, 1993).

This study was designed to determine the uptake of different trace elements by plants colonizing tailings at two abandoned mine sites in Canada. The first site was a gold mine in British Columbia, the other a base metal mine with a cobalt ore smelter in Ontario.

MATERIALS AND METHODS

Study Areas

Plants collected at two different mining areas, Wells, Cariboo Region, British Columbia, and Cobalt, Ontario, were analyzed in this study. In the Cariboo region, gold had been extensively mined from the 1800's to 1960 (Andrews, 1989). The region, in the Barkerville Terrane, is underlain mostly by clastic sedimentary rocks, principally Precambrian and Palaeozoic sandstone, greywacke, and black and green pelite, with minor proportions of limestone and mafic volcanic rocks (Struik, 1988). In Wells the abandoned tailings from the milling and gold extraction process were discharged into the northeast end of Jack of Clubs Lake, changing its original morphometry (Galbraith, 1991). At present, approximately 25 ha of land adjacent to the lake are covered with the gold mine tailings to a maximum thickness of about 4.5 m. The mines in the Cobalt region were spread over a large area. By 1911 the Cobalt area was the biggest producer of silver in the world. Mining activities continued until the 1950's, and there are currently no operating mines in the vicinity. The oldest rocks in the Cobalt area are Archean volcanics and interflow sediments containing pyrite, pyrrhotite, chalcopyrite, sphalerite and galena. The silver deposits occur in fractures, faults and joints which vary in width from a few millimetres to as much as 1.2 m (Dumaresq, 1993).

Plant collection, preparation and analysis

Ten species of lower vegetation and leaves, needles and branches of ten species of trees (Tables 2 and 3) were collected at the tailings and along creeks and lakes at different distances from the tailings in Wells, B.C., in August, 1992 (Azcue and Mudroch, 1993). At the Cobalt area, dominant species growing on the tailings were collected in August 1994. The selection of all vegetation samples followed a random sampling pattern with the objective to collect representative samples of the plant species and their organs.

Concentrations of trace elements in tailings and soils were generally several orders of magnitude greater than in the plants. Therefore, the risk of potential contamination is very high when determining concentrations of trace elements in plants and the cleaning stage become critical (Azcue, 1995; Azcue and Mudroch, 1994). Consequently, immediately following collection, all plants were washed with lake water, placed in plastic bags and transported to the laboratory. Once in the laboratory, plant roots were separated from the above-ground biomass (i.e., stems and leaves). To obtain maximum homogenization, plant materials were cut into small pieces which were thoroughly mixed and dried to a constant weight at 70°C in an oven. Dried samples were homogenized and pulverized to approximately 177 μm in a Wiley mill equipped with stainless steel blades. The digestion of the samples was carried out by acid digestion with concentrated $HCl:HNO_3$ (1:3) (Azcue and Mudroch, 1994). The acids were added to Teflon beakers containing 0.2 to 0.5 g samples with subsequent mixing. All samples were allowed to degas at room temperature overnight to prevent a vigorous reaction during heating. The Teflon beakers were covered with Teflon lids to protect the sample from contamination while allowing gas to escape. The samples were digested in a microwave oven (Floyd, Inc. Model RMS 150). The microwave digestions followed a four-stage scheme: a) 3 min. at 25 psi, b) 3 min. at 50 psi, c) 3 min. at 75 psi, d) 5 min. at 100 psi, and d) 5 min. at 130 psi.

Blanks were collected from the final rinse of the plants, and analyzed simultaneously with the samples to detect any possible remaining contamination or leaching of soluble elements during washing. The presence of titanium was used as a control of the cleaning procedure. Titanium, although present in the soils, is known not to be assimilated by plants to any great extent. Levels of Ti in the plant samples were used as a control of the cleaning procedures. The Ti concentration in all the subsamples was less than the levels in the tailing samples (average 1,440 $\mu g.g^{-1}$).

Soil and tailings analysis

Soil and tailing samples (at approximately 15 cm depth) were collected within the plants sampling sites. Five to ten samples were collected at each plant sampling site. The samples were thoroughly mixed, placed in plastic containers, transported to the laboratory, and freeze-dried. The total concentration of trace elements in the sediments was determined by acid digestion (*agua regia* + HF) in a microwave oven.

Determination of the trace elements (Al, Ba, Ca, Cr, Cu, Fe, K, Mn, Pb, Si, Sr, Ti, and Zn) in both plants and soils, was carried out by inductively coupled plasma atomic emission spectroscopy (ICP-AES) using a Jobin Yvon Model 74. The standard solutions consisted of high purity concentrations of 0.5 and 5 $mg.L^{-1}$ of the trace elements in a solution of 2% HNO_3 (Delta Scientific Laboratory Products, Canada). To avoid clogging problems with the ICP-AES, all samples were centrifuged at 5,000 rpm for 20 min, prior to analysis. Certified reference materials of the National Institute of Standards and Technology [apple leaves - SRM

1515; citrus leaves - SRM 1572; and orchard leaves SRM 1571] and Buffalo River sediment [SRM 2704] were used in the quality control. Subsamples of the certified reference material were digested with the same acid mixtures used for the samples.

RESULTS AND DISCUSSION

The chemical composition of the tailings and other growing substrates is fundamental to evaluate the uptake of trace elements by the local vegetation. Leachates from both tailings (i.e., Wells, B.C. and Cobalt, Ontario) were slightly acidic. The pH of the leachate from the tailings from Wells, B.C. was 5.5, and that from the tailings from the Cobalt area 6.8. Table 1 summarizes the total concentration of the trace elements in the tailings and soils from the Cariboo region and Cobalt area. The concentrations of most trace elements in the tailings in both study areas were elevated and similar to those from other mine-impacted areas (Salomons and Förstner, 1988). The tailings from the Cariboo region are the product of gold milling and extraction. Therefore, they contain elevated concentrations of As and Hg (Table 1). On the other hand, the tailings of the Cobalt area are the product of mining and production of different metals, such Co, Ag, Ni, etc. Therefore, the tailings in the Cobalt area have typically elevated concentrations of Cd, Co, Cr, Cu, Mg, Pb and Zn (Table 1).

During the past decade natural vegetation has started to colonize one part of the exposed surface area of the tailings in Wells, B.C. The other part of the tailings surface was covered with approximately 30 cm of fill material, including sand, gravel, and glacial till to prevent generation of dust and transport of contaminated tailing particles. The untreated zones have been colonized mainly by metal-tolerant plants such as tufted hairgrass and beaked sedge. However, there is a noticeable colonization by many other grasses and higher vegetation species on the treated area. Ten different plant species of lower vegetation collected from the surface of the mine tailings and along surrounding creeks and lakes were analyzed for major and trace elements (Table 2). The concentrations of Cu, Cr, and Zn in the sampled vegetation were similar to reported typical values for terrestrial vegetation (Adriano, 1986; Thompson and Walsh, 1988; Market, 1992). These elements are called "enzymatic elements" because they contribute in building up specific physiological potentials, and are responsible for the maintenance of definitive osmotic relations within the cell metabolism (Market, 1992). The concentrations of Co were above the typical natural concentrations in some of the analyzed plant species, such as horsetails, beaked sedge and tufted hairgrass.

The elements considered non-essential or toxic to the plants, particularly As, Cd, and Pb, were present in considerably greater concentrations than natural levels. Arsenic was present at relatively high concentrations in all plant species of lower vegetation, reaching 36.8 $\mu g.g^{-1}$ in beaked sedge plants, which represents 360 times greater concentrations than the typical natural levels. The concentrations of trace elements in some of the plant species showed a relationship with those in the tailings and soils. For example, concentrations of trace elements in red clover were one order of magnitude greater in plants growing on the tailings, than those in plants found on the shore of Jack of Clubs Lake. The concentrations of metals in some of the plant species suggested preferential accumulation of certain trace elements. In beaked sedge, the concentrations of As, Fe and Pb were considerably greater in the plants growing on the tailings than in those growing on the shore of the lake and on the banks of the surrounding creeks at the study area in Wells, B.C. (Table 2). However, the concentrations of the other trace elements in the same plant species did not show any relationship with those in the tailings in which they were growing.

Table 3 summarizes the concentrations of major and trace elements in higher vegetation growing on the tailings and adjacent areas of the abandoned gold mine in Wells, B.C. and the Cobalt mining area. The concentrations of Hg (not shown in the table) were below the detection limit in all collected plant material. The only exception was 0.5 $\mu g\ Hg.g^{-1}$ in the bark of Engelman spruce growing on the tailings at Wells, B.C. The same spruce specimen contained the greatest concentration of Au, with maximum concentrations of 103 $ng.g^{-1}$ in the bark. Mean concentrations in twig samples collected in areas where the concentrations of Au were elevated in surface waters, was 1.5 $ng.g^{-1}$. The greatest concentrations of As was found in the Engelman spruce tree growing on the tailings. Bark and twig samples from the spruce contained over 40 $\mu g.g^{-1}$ As, and those in the twigs of the same species growing on the shores of Jack of Clubs Lake and Willow River ranged from 0.1 to 0.9 $\mu g.g^{-1}$. Further, the twigs of a nearby fir tree contained up to 10 $\mu g.g^{-1}$ As (Table 3). The relatively large ranges in the concentrations of As in the trees growing in the tailings most likely reflected the heterogeneous distributions of As in the tailings and the physical properties of the tree roots. The concentrations of Cr, Cu, Ni, and Zn were similar in the Engelman spruce twigs collected at all locations (ranges from 0.1 to 1.5 $\mu g.g^{-1}$ Cr, <0.3 to 2.8 $\mu g.g^{-1}$ Cu, <2 to 5 $\mu g.g^{-1}$ Ni, and 58 to 100 $\mu g.g^{-1}$ Zn). Generally, the samples of the willow trees showed very low uptake of the trace elements. Cadmium and Co levels were considerably elevated in all plants species collected in the Cobalt mining area, reaching 20.6 $\mu g.g^{-1}$ of Cd in the twigs of European white and 26 $\mu g.g^{-1}$ in the leaves of Douglas maple (Table 3). The results indicated the uptake of trace elements by Douglas maple trees. Further, the leaves of the tree appeared to be an excretory pathway of toxic elements, with trace element concentrations being up to 17 times greater in the leaves than in the other parts of the tree.

In addition to the aesthetical advantages and minimization of erosion and dust transport, the vegetation cover on the surface of the tailings has proved to minimize acid drainage and seepage. The vegetation removes water from the tailings by intercepting precipitation and adsorption by the root system. It has been calculated, for instance, that to produce 1 kg of dry matter, an alfalfa (*Medigo sativa*) plant transpires more than 800 kg of water (Northen, 1958). The accumulation factors, expressed as the average ratios of trace elements in plants and growing substrates are summarized in Table 4. Calculated accumulation factors >1 were found for Cd and Cr in some of the plant species, including both higher and lower vegetation. Lower plants accumulated greater concentrations of Cr, Cu, and Ni than the higher plants (Table 4). Accumulation factors of As >0.1 were found for fuzzy-spiked and tufted hairgrass. As indicated above, the results suggested that the leaves of Douglas maple acted as a detoxification organ of the plant. In general, deep rooted plants (beaked sedge) accumulated greater concentrations of trace elements. Decomposition of plant residues enhances the development of an oxygen-consuming barrier and formation of new soil. Labine (1971) showed that approximately 10 years after revegetation, a 2- to 3-cm organic horizon was formed and a podzolic profile started to develop in treated tailing areas.

CONCLUSIONS

Several plants of the higher and lower vegetation, have shown to be resistant to elevated concentrations of trace elements. Therefore, they can successfully grow on abandoned mine tailing substrates. Some plants, such as Engelman spruce and beaked sedge, have shown preferential accumulation of trace elements, particularly As. The results of the study indicated that willow has been able to grow on gold mine tailings without considerable uptake of trace elements. The results showed that the leaves of Douglas maple act as an organ of preferential accumulation of trace elements and may act as a detoxification mechanism for the plant. Elevated concentrations of some non-essential elements in vegetation growing on the tailings in Wells, B.C. and the Cobalt mining area in Ontario, indicated that terrestrial vegetation can play an important role in the mobilization and transport of trace elements into the surrounding ecosystems.

In summary, the main advantages of revegetation of abandoned mine areas are:

- aesthetical, establishment of a permanently stable landscape;
- minimization of erosion and dust emission from tailings;
- minimization of acid drainage and seepage by intercepting precipitation and water absorption by the roots;
- formation of an oxygen-consuming barrier by decomposing plant residues which prevents oxidation and solubilization of trace elements present in the tailings.

The disadvantage of growing plants on the tailings may be the accumulation of toxic trace elements in different plant organs, as shown in this study, and their potential effects on wildlife consuming the plants. Consequently, the bioavailability of trace elements in the plants needs to be assessed. On the other hand, the selection of plants which do not accumulate trace elements and can be planted on the tailings should be considered. The results of the study indicated the need for the development of a list of plant species occupying abandoned mine tailings, and assessment of the uptake of trace elements by individual plant species.

Acknowledgments

The authors would like to thank Dr. Jeanne Percival, Geological Survey of Canada, for providing tailing and plant samples from the Cobalt mining area; Dr. Gwendy Hall, Geological Survey of Canada; and Mr. Jerry Rajkumar, National Water Research Institute, for their collaboration in the analysis of the collected samples.

References

Adriano, D.G. 1986. Trace elements in the Terrestrial Environment. Springer-Verlag, Berlin.

Andrews, K.I., 1989. *A Preliminary Investigation of Public Health and Environmental Impacts of Abandoned Mine Tailings at Wells, B.C.* Williams Lake, Ministry of the Environment, Province of British Columbia.

Azcue, J.M. 1995. Comparison of different cleaning procedures of root material for analysis of trace elements. *Intern. J. Environ. Anal. Chem.* (in press).

Azcue, J.M. and Mudroch, A., 1993. Metal concentration in the vegetation of an abandoned mine in Wells, B.C. (Canada). Proceedings of First SETAC World Congress Ecotoxicology and Environmental Chemistry, Lisbon, Portugal. pp: 49-50.

Azcue, J.M. and Mudroch, A. 1994. Comparison of different washing, ashing, and digestion methods for the analysis of trace elements in vegetation. *Intern. J. Environ. Anal. Chem.* **57**: 151-162.

Azcue, J.M., Mudroch, A., Rosa, F. and Hall, G.E.M. 1994. Effects of abandoned gold mine tailings on the arsenic concentrations in water and sediments of Jack of Clubs Lake, British Columbia. *Environ. Technol.* **15**: 669-678.

Azcue, J.M. and Nriagu, J.O. 1993. Arsenic forms in mine-polluted sediments of Moira Lake, Ont.*Environ. International* **19**: 405-415.

Dumaresq, C.G. 1993. The occurrence of arsenic and heavy metal contamination from natural and anthropogenic sources in the Cobalt area of Ontario. MS Thesis, Carleton University, Ottawa, ON. 210pp.

Feasby, D.G. and Tremblay, G.A. 1995. New technologies to reduce environmental liability from acid generating mine wastes. In Proc. Conf. on Mining and the Environment, Sudbury. pp:643-647.

Galbraith, D.M. 1991. Reclamation assessment - Wells tailings. MEMPR, Resources Management Branch.

Helm, D.J. 1991. From boreal to reclaimed site: revegetation at the Usibelli coal mine. *Agroborealis* **23(1)**: 45-50.

Kabata-Pendias, A. and Pendias, H. 1986. *Trace Elements in Soils and Plants* (CRC Press, Inc., Boca Raton, 1986).

Labine, C.L. 1971. The influence of certain seeded grasses on the evolution of mine tailings. B.Sc Thesis, Biology Department, Laurentian University, Sudbury, Ontario.

Market, B. 1992. Aspects of cleaning environmental materials for multi element analysis, e.g. plant samples. *Fresenius J. Anal. Chem*. **342**: 409-412.

Mudroch, A., Hall, G.E.M., Azcue, J.M., Jackson, T.A., Reynoldson, T. and Rosa, F. 1993. Preliminary report on the effects of abandoned mine tailings at Wells, B.C., on the aquatic ecosystem of Jack of Clubs Lake. National Water Research Institute Contribution N° 93-23.

Northen, H.T. 1958. *Introductory Plant Science*. Ronald Press, Co., New York.

Peters, T.H. 1995. Revegetation of the Copper Cliff tailings area. In: Restoration and Recovery of an Industrial Region. Ed. by J.M. Gunn. Springer-Verlag, pp.123-133.

Richards, J.E. 1993. Soil Sampling and Methods of Analysis, M.R. Carter, Ed., Lewis Publisher, Florida, pp.115-139.

Salomons, W. and U. Förstner. 1988. *Chemistry and Biology of Solid Waste*. Springer-Verlag, 305pp.

Struik, L.C. 1988. Structural Geology of the Cariboo Gold Mining District, East-central British Columbia, Geological Survey of Canada, Memoir 421, 100 pp.

Thompson, M. and Walsh, J.N. 1989. Handbook of Inductively Coupled Plasma Spectrometry. Blackie and Son, Ltd., London, pp 319.

Winterhalder, K. 1995. Approaches to engendering biodiversity in tailings revegetation. Proc. Conf. on Mining and the Environment, Sudbury. pp: 1239-1248.

Winterhalder, K. 1983. The use of manual surface seeding, liming, and fertilization in the reclamation of acid metal contaminated land in the Sudbury, Ontario mining and smelting region of Canada. *Environ. Technol. Lett*. **4**: 209-216.

Table 1. Concentrations of major and trace elements in tailings and soils from Cobalt area and Cariboo region

	As (µg/g)	Ca (%)	Cd (µg/g)	Co (µg/g)	Cr (µg/g)	Cu (µg/g)	Fe (%)	Hg (µg/g)	K (%)	Mg (%)	Mn (%)	Na (%)	Ni (µg/g)	Pb (µg/g)	Zn (µg/g)
Cobalt area:															
Nipissing Tailings	n.a.	2.1	10.5	982	133	644	4.3	n.a.	0.16	1.9	0.07	0.06	754	343	300
Buffalo Tailings-1	n.a.	1.4	10.4	367	110	513	4.0	n.a.	0.08	1.6	0.07	0.04	177	374	390
Buffalo Tailings-2	n.a.	1.1	11.5	351	133	444	4.5	n.a.	0.10	1.7	0.07	0.02	178	392	372
Buffalo Tailings-3	n.a.	0.7	5.2	142	82	248	2.8	n.a.	0.11	1.1	0.04	0.03	73	178	198
Cart Lake Tailings-1	n.a.	1.4	11.2	233	128	105	4.1	n.a.	0.23	1.7	0.07	0.05	99	303	327
Cart Lake Tailings-2	n.a.	1.3	10.4	213	117	78	3.8	n.a.	0.19	1.7	0.07	0.03	120	206	125
Cariboo region:															
Tailings-1	1184	0.7	4.5	24	16	15	>10	0.03	0.25	0.2	0.04	0.07	32	144	138
Tailings-2	>2000	0.2	12	20	11	26	>10	0.07	0.12	0.1	0.08	0.06	29	965	165
Tailings-3	903	1.0	3.9	36	27	29	>10	0.15	0.15	0.2	1.17	0.06	43	467	303
Tailings-4	1009	0.1	2.6	19	11	11	9.7	0.07	0.29	0.3	0.08	0.06	18	434	208
Lowhee Creek -1	30	0.3	0.9	21	23	40	4.0	0.02	0.28	0.3	0.09	0.08	52	29	109
Lowhee Creek -2	26	0.5	0.2	19	26	39	>10	0.02	0.36	0.3	0.08	0.08	48	30	102
Lowhee Creek -3	396	0.5	2.4	19	29	48	>10	0.32	0.13	0.2	0.07	0.07	43	224	216
Willow River	599	0.6	2.2	20	20	24	8.3	0.04	0.22	0.3	0.08	0.06	33	135	127
Jack of Clubs Lake	411	0.8	2.2	32	41	62	7.5	0.10	0.23	0.7	0.33	0.06	85	164	351
Barkerville	39	1.1	2.1	45	52	109	7.6	0.26	0.34	0.8	0.16	0.07	104	102	213
Bowron Lake	21	0.4	1.4	34	54	47	8.9	0.12	0.25	1.0	0.64	0.07	66	37	137
Shepard Creek	28	1.9	1.1	35	71	92	5.9	0.15	0.17	1.4	0.13	0.07	92	49	256
Eight Mile Lake	<5	5.1	0.6	18	47	37	3.4	0.04	0.15	1.2	0.07	0.08	50	26	122
Nine Mile Lake	<5	0.7	0.5	11	41	26	2.3	0.08	0.12	0.5	0.03	0.07	27	30	84

Table 2. Major and trace element concentrations (ug/g dry weight) in lower vegetation at the tailings and adjacent areas in Wells, B.C.

Species	Common name	Sampling Location	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Trifolium pratense	Red clover	Tailings	10.9	1.2	<0.1	2.8	12	1646	57	12.8	<0.1	41
Trifolium pratense	Red clover	J.C. Lake	1.9	0.2	<0.1	0.2	6	135	20	0.7	<0.1	12
Equisetum variegatum	Horsetails	Tailing	9.9	1.7	1.7	1.5	6	506	274	7.4	8.5	80
Equisetum variegatum	Horsetails	Willow R.	18.7	2.6	1.3	1.0	8	1478	87	4.6	16.3	58
Equisetum variegatum	Horsetails	Eight Mile L	8.4	1.7	1.0	1.1	7	414	479	6.3	6.9	31
Anaphalis margaritaceae	Pearly everlasting	Tailing	10.9	2.3	0.9	1.8	11	843	104	4.8	8.9	51
Anaphalis margaritaceae	Pearly everlasting	J.C. Lake	4.5	1.6	0.1	0.7	8	356	61	3.0	<0.1	38
Elymus innovatus	Fuzzy-spiked	Tailing	6.0	1.1	0.1	1.6	8	1371	376	3.7	3.3	39
Elymus innovatus	Fuzzy-spiked	Willow R.	7.1	1.5	0.5	1.0	5	1027	65	2.1	5.4	51
Elymus innovatus	Fuzzy-spiked	Lowhee C.	6.5	<0.1	<0.1	0.5	3	531	81	0.8	<0.1	33
Elymus innovatus	Fuzzy-spiked	Eight Mile L.	2.2	0.5	<0.1	2.4	4	638	287	8.4	<0.1	13
Elymus innovatus	Fuzzy-spiked	Nine Mile L.	5.5	1.1	0.6	0.5	5	477	154	2.3	4.1	20
Carex rostrata	Beaked sedge	Tailings	36.8	2.0	0.9	0.8	7	3249	107	4.5	15.3	20
Carex rostrata	Beaked sedge	Tailings	17.5	1.4	0.7	1.2	5	1224	229	5.2	14.8	27
Carex rostrata	Beaked sedge	Tailings	27.2	1.7	0.8	1.0	6	2236	168	4.8	15.0	24
Carex rostrata	Beaked sedge	J.C. Lake	2.7	1.2	0.3	1.5	5	237	118	4.1	2.6	22
Deschampsia caespitosa	Tufted hairgrass	Lowhee C.	3.7	0.8	0.2	5.0	6	416	32	16.0	1.1	25
Deschampsia caespitosa	Tufted hairgrass	Tailings	3.2	1.0	0.6	4.9	6	568	57	17.9	3.8	23
Deschampsia caespitosa	Tufted hairgrass	Barkerville	6.0	1.5	0.9	2.5	18	556	250	10.5	6.0	35
Castilleja miniata	Red paintbrush	Tailings	5.3	1.5	0.3	0.5	8	128	169	4.2	3.0	79
Aster modestus	Northern aster	Tailings	7.6	1.3	0.6	1.1	10	310	112	4.8	4.4	36
Mertensia paniculata	Tall blue bell	Tailings	2.2	0.3	<0.1	0.6	7	222	80	4.8	<0.1	35
Crysanthemum leucanthem	Sunflower	Tailings	10.3	1.4	0.6	1.5	8	456	26	4.3	4.7	17
Typical natural concentration (Market, 1992)			0.1	0.05	0.2	1.5	10	150	200	1.5	1	50

Table 3. Concentrations of trace elements (μg/g dry weight) in higher vegetation at the tailings and adjacent areas of Wells, B.C., and Cobalt Region, On.

Species	Common name	Parts of plant	Sampling location	Au	As	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn
Wells, B.C.:													
Abies lasiocarpa	Subalpine fir	twigs	Tailings	0.003	1.0	n.a.	0.3	0.8	n.a.	220	2	n.a.	37
Abies lasiocarpa	Subalpine fir	twigs	Tailings	0.005	2.2	n.a.	0.3	0.8	n.a.	320	<2	n.a.	34
Abies lasiocarpa	Subalpine fir	twigs	Tailings	0.024	10.0	n.a.	0.5	1.0	n.a.	1120	2	n.a.	32
Abies lasiocarpa	Subalpine fir	twigs	Lowhee Ck.	0.001	0.1	n.a.	0.2	0.4	n.a.	90	<2	n.a.	30
Abies lasiocarpa	Subalpine fir	twigs	Tailings	0.002	0.6	n.a.	0.5	1.3	n.a.	500	4	n.a.	50
Abies lasiocarpa	Subalpine fir	twigs	JCL shore	0.002	0.1	n.a.	0.2	0.3	n.a.	80	<2	n.a.	26
Abies lasiocarpa	Subalpine fir	twigs	JCL shore	0.001	0.0	n.a.	0.3	0.6	n.a.	80	<2	n.a.	33
Picea engelmannii	Engelman spruce	bark	Tailings	0.030	43.0	n.a.	1.5	1.6	n.a.	4950	<2	n.a.	54
Picea engelmannii	Engelman spruce	bark	Tailings	0.103	9.2	n.a.	0.5	1.6	n.a.	1430	<2	n.a.	80
Picea engelmannii	Engelman spruce	bark	Tailings	0.012	2.3	n.a.	1.0	2.9	n.a.	1270	<2	n.a.	54
Picea engelmannii	Engelman spruce	bark	JCL shore	0.018	0.3	n.a.	0.2	0.3	n.a.	100	<2	n.a.	56
Picea engelmannii	Engelman spruce	bark	JCL shore	0.008	0.3	n.a.	0.2	0.5	n.a.	180	<2	n.a.	44
Picea engelmannii	Engelman spruce	bark	JCL shore	0.012	1.8	n.a.	1.7	3.1	n.a.	1650	8	n.a.	97
Picea engelmannii	Engelman spruce	twigs	JCL shore	0.004	0.9	n.a.	1.5	2.8	n.a.	1380	9	n.a.	93
Picea engelmannii	Engelman spruce	twigs	JCL shore	0.001	0.1	n.a.	0.2	0.6	n.a.	130	<2	n.a.	64
Picea engelmannii	Engelman spruce	twigs	JCL shore	0.002	0.2	n.a.	0.2	0.7	n.a.	240	<2	n.a.	78
Picea engelmannii	Engelman spruce	twigs	Tailings	0.003	0.6	n.a.	0.7	1.9	n.a.	640	5	n.a.	100
Picea engelmannii	Engelman spruce	twigs	Tailings	0.006	2.7	n.a.	0.4	0.9	n.a.	460	3	n.a.	89
Picea engelmannii	Engelman spruce	twigs	Tailings	0.002	1.1	n.a.	1.0	2.2	n.a.	860	3	n.a.	87
Picea engelmannii	Engelman spruce	twigs	Tailings	0.002	0.5	n.a.	0.4	1.3	n.a.	420	2	n.a.	71
Picea engelmannii	Engelman spruce	twigs	Tailings	0.030	41.0	n.a.	1.7	2.4	n.a.	4460	4	n.a.	64
Picea engelmannii	Engelman spruce	twigs	Tailings	0.008	6.9	n.a.	0.4	0.6	n.a.	680	<2	n.a.	61
Picea engelmannii	Engelman spruce	twigs	Willow R.	0.004	0.2	n.a.	0.1	<0.3	n.a.	60	2	n.a.	58
Pinus contorta	Lodgepole pine	bark	Tailings	0.007	1.8	n.a.	0.8	3.1	n.a.	1510	<2	n.a.	32
Pinus contorta	Lodgepole pine	twigs	Tailings	0.001	0.6	n.a.	0.4	1.5	n.a.	430	2	n.a.	36
Pinus contorta	Lodgepole pine	twigs	Tailings	0.002	0.3	n.a.	0.2	0.8	n.a.	180	4	n.a.	30
Pinus contorta	Lodgepole pine	twigs	Tailings	0.001	0.2	n.a.	0.3	0.4	n.a.	80	3	n.a.	30
Pinus contorta	Lodgepole pine	twigs	Tailings	0.004	0.3	n.a.	0.5	1.3	n.a.	420	3	n.a.	30
Pinus contorta	Lodgepole pine	twigs	Willow R.	0.004	0.2	n.a.	0.3	0.8	n.a.	170	3	n.a.	25
Pinus contorta	Lodgepole pine	twigs	Willow R.	0.000	0.0	n.a.	0.2	0.3	n.a.	<50	<2	n.a.	17
Salix drummondian	Willow	twigs	Tailings	0.003	0.2	n.a.	0.8	0.7	n.a.	90	3	n.a.	120
Salix drummondian	Willow	twigs	Tailings	0.002	0.6	n.a.	0.2	<0.3	n.a.	90	<2	n.a.	33
Salix drummondian	Willow	twigs	Tailings	0.002	0.8	n.a.	0.3	0.5	n.a.	130	4	n.a.	67
Salix drummondian	Willow	twigs	Tailings	0.001	0.1	n.a.	0.3	<0.3	n.a.	<50	<2	n.a.	100
Salix drummondian	Willow	twigs	Tailings	0.001	0.2	n.a.	0.2	<0.3	n.a.	50	<2	n.a.	160
Salix drummondian	Willow	twigs	Tailings	0.001	0.1	n.a.	0.3	<0.3	n.a.	<50	<2	n.a.	48
Salix drummondian	Willow	twigs	Tailings	0.001	0.1	n.a.	0.3	<0.3	n.a.	100	<2	n.a.	75
Salix drummondian	Willow	twigs	Tailings	0.001	0.3	n.a.	0.2	<0.3	n.a.	80	2	n.a.	88
Salix drummondian	Willow	twigs	Tailings	0.001	0.1	n.a.	<0.1	<0.3	n.a.	70	<2	n.a.	95
Salix drummondian	Willow	twigs	JCL shore	0.002	0.0	n.a.	0.6	1.5	n.a.	60	<2	n.a.	105
Salix drummondian	Willow	twigs	JCL shore	0.001	0.0	n.a.	0.3	0.4	n.a.	<50	<2	n.a.	38
Salix drummondian	Willow	twigs	JCL shore	0.001	0.0	n.a.	0.2	<0.3	n.a.	50	<2	n.a.	130
Salix drummondian	Willow	twigs	Lowhee Ck.	0.002	0.0	n.a.	0.3	<0.3	n.a.	<50	<2	n.a.	120
Salix drummondian	Willow	twigs	Willow R.	0.001	-0.0	n.a.	0.2	<0.3	n.a.	<50	<2	n.a.	85
Salix drummondian	Willow	twigs	Williams Ck.	0.001	0.1	n.a.	<0.1	<0.3	n.a.	<50	<2	n.a.	67
Salix drummondian	Willow	twigs	Williams Ck.	0.001	0.0	n.a.	0.2	<0.3	n.a.	<50	<2	n.a.	46
Salix drummondian	Willow	twigs	Williams Ck.	0.004	0.1	n.a.	0.3	<0.3	n.a.	<50	2	n.a.	100
Cobalt Region, On.:													
Silver poplar	European white	leaves	Tailings	n.a.	n.a.	9.6	4.4	4.5	8.4	221	8.1	1.4	33
Silver poplar	European white	twigs	Tailings	n.a.	n.a.	20.6	6.1	4.8	9.7	171	3.6	1.8	35
Larix larchies	Tamarak	needles	Tailings	n.a.	n.a.	2.4	6.8	1.4	1.7	130	1.5	0.4	12
Larix larchies	Tamarak	twigs	Tailings	n.a.	n.a.	2.3	1.4	0.7	3.1	125	2.2	0.9	10
Prunus pensylvani	Pin. Cherry	leaves	Tailings	n.a.	n.a.	2.2	0.8	0.6	1.7	32	1.1	0.4	6
Prunus pensylvani	Pin. Cherry	twigs	Tailings	n.a.	n.a.	5.8	2.7	2.1	2.4	43	0.9	3.4	8
Viburnum edule	cranberry	leaves	Tailings	n.a.	n.a.	1.8	0.4	0.9	4.3	176	2.4	1.0	8
Viburnum edule	cranberry	twigs	Tailings	n.a.	n.a.	2.3	0.4	1.0	5.7	60	0.9	0.4	14
Viburnum edule	cranberry	berries	Tailings	n.a.	n.a.	1.8	0.5	0.6	4.2	29	1.1	0.2	5
Acer glabrum	Duglas mapple	leaves	Tailings	n.a.	n.a.	16.7	26.0	11.8	32.8	2652	15	27	65
Acer glabrum	Duglas mapple	twigs	Tailings	n.a.	n.a.	6.5	2.9	2.1	0.7	152	3.3	5.2	21
Festuca saximonta	Festuca		Tailings	n.a.	n.a.	10.6	16.0	7.4	13.0	1954	7.4	8.0	43

Table 4. Accumulation of trace elements expressed as ratios (plant/soil)

Species	Common name	Parts of plan	As	Cd	Co	Cr	Cu	Ni	Pb	Zn
Abies lasiocarpa	Subalpine fir	Twigs	0.066	n.a.	0.014	0.03	n.a.	0.03	n.a.	0.21
Picea engelmannii	Engelman spruce	Twigs	0.011	n.a.	0.030	0.06	n.a.	0.02	n.a.	0.24
Picea engelmannii	Engelman spruce	bk	0.005	n.a.	0.025	0.07	n.a.	0.07	n.a.	0.35
Pinus contorta	Lodgepole pine	Twigs	0.000	n.a.	0.014	0.05	n.a.	0.08	n.a.	0.16
Pinus contorta	Lodgepole pine	Bk	0.002	n.a.	0.032	0.19	n.a.	0.00	n.a.	0.16
Salix drummondiana	Willow	Twigs	0.001	n.a.	0.011	0.01	n.a.	0.02	n.a.	0.41
Silver poplar	European white	twigs	n.a.	2.28	0.021	0.04	0.02	0.03	0.006	0.11
Silver poplar	European white	leaves	n.a.	1.06	0.015	0.04	0.02	0.06	0.004	0.10
Larix larchies	Tamarak	twigs	n.a.	0.26	0.005	0.01	0.01	0.02	0.003	0.03
Larix larchies	Tamarak	needles	n.a.	0.26	0.020	0.01	0.00	0.01	0.001	0.04
Prunus pensylvanica	Pin. Cherry	twigs	n.a.	0.64	0.010	0.02	0.01	0.01	0.011	0.03
Prunus pensylvanica	Pin. Cherry	leaves	n.a.	0.24	0.003	0.01	0.00	0.01	0.001	0.02
Viburnum edule	cramberry	twigs	n.a.	0.26	0.001	0.01	0.01	0.01	0.001	0.04
Viburnum edule	cramberry	leaves	n.a.	0.20	0.001	0.01	0.01	0.02	0.003	0.02
Viburnum edule	cramberry	berries	n.a.	0.20	0.002	0.01	0.01	0.01	0.001	0.02
Acer glabrum	Duglas mapple	twigs	n.a.	0.72	0.010	0.02	0.00	0.02	0.017	0.06
Acer glabrum	Duglas mapple	leaves	n.a.	1.85	0.091	0.11	0.08	0.11	0.087	0.20
Festuca saximontana	Festuca	whole	n.a.	1.16	0.056	0.07	0.03	0.05	0.026	0.13
Trifolium pratense	Red clover	whole	0.014	0.47	-0.011	0.94	0.38	0.26	-0.016	0.23
Equisetum variegatum	Horsetails	whole	0.033	0.81	0.059	0.73	0.28	0.19	0.060	0.35
Castilleja miniata	Red paintbrush	whole	0.007	0.57	0.018	0.36	0.47	0.16	0.020	0.49
Aster modestus	Northern aster	whole	0.013	0.60	0.028	0.54	0.40	0.15	0.030	0.28
Mertensia paniculata	Tall blue bell	whole	0.004	0.14	-0.044	0.32	0.30	0.14	-0.020	0.28
Crysanthemum leucanthem	Sunflower	whole	0.017	0.64	0.032	0.74	0.32	0.13	0.030	0.13
Anaphalis margaritaceae	Pearly everlasting	whole	0.021	0.47	0.028	0.82	0.38	0.12	0.021	0.27
Elymus innovatus	Fuzzy-spiked	whole	0.120	0.41	0.006	0.44	0.22	0.08	0.010	0.21
Carex rostrata	Beaked sedge	whole	0.028	0.32	0.023	0.57	0.17	0.11	0.030	0.11
Deschampsia caespitosa	Tufted hairgrass	whole	0.100	0.49	0.017	1.41	0.17	0.28	0.040	0.16

Environment Canada Environnement Canada

Canada

Canada Centre for Inland Waters
P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario
L7R 4A6 Canada

National Hydrology Research Centre
11 Innovation Boulevard
Saskatoon, Saskatchewan
S7N 3H5 Canada

St. Lawrence Centre
105 McGill Street
Montreal, Quebec
H2Y 2E7 Canada

Place Vincent Massey
351 St. Joseph Boulevard
Gatineau, Quebec
K1A 0H3 Canada

Centre canadien des eaux intérieures
Case postale 5050
867, chemin Lakeshore
Burlington (Ontario)
L7R 4A6 Canada

Centre national de recherche en hydrologie
11, boul. Innovation
Saskatoon (Saskatchewan)
S7N 3H5 Canada

Centre Saint-Laurent
105, rue McGill
Montréal (Québec)
H2Y 2E7 Canada

Place Vincent-Massey
351 boul. St-Joseph
Gatineau (Québec)
K1A 0H3 Canada