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Development of a Wetland Treatment System at United Keno Hill Mines, Eisa, Yukon Territory

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ABSTRACT

An adit on the United Keno Hill property discharges water at 1-10 L/sec with 20-30 mg/L (ppm) zinc. This paper describes how a wetland treatment system was developed to passively treat this discharge.

Adit water was supplied to a 180 m^2 pilot-scale wetland at a rate of 18 L/min. The wetland reduced zinc concentrations from 25 ppm to approximately 3 pprn. However, water in parts of the wetland had 0.3 ppm zinc. Microcosms established within the wetland reduced zinc concentrations to <0.2 ppm. Cobalt, iron, manganese, and nickel were also removed in the wetland and the microcosms. Finally, a natural wetland receiving water with 3 ppm zinc produced a discharge of 0.3 ppm zinc. Taken together, these results suggest that a constructed wetland can, in principle, reduce zinc below the permitted discharge limit of 0.5 ppm .

Zinc appeared to be retained in the pilot wetland by reacting with hydrogen sulphide, generated in sediments by sulphate-reducing bacteria. Metals accumulating in natural wetlands receiving mine-impacted water were primarily retained with iron and/or manganese oxides, or as sulphides. These metals were not taken up by wetland plants.

INTRODUCTION

United Keno Hill Mines Ltd. (UKHM) owns several small mines in the Keno Hill area. Mining in this region has been active since the discovery of silver in 1906. Total silver production from over 30 different mines in the area has exceeded 6.4 billion grams. Active mining on the property ceased in 1989, but UKHM plans to resume mining. The company has recently submitted a permit application, which includes an abandonment plan. The work reported herein represents is one of its components.

One problem requiring attention at UKHM is an adit discharge which flows at a rate of up to 10 L/sec and contains up to 30 mg/L (ppm) zinc. Since this discharge is believed to require treatment for several decades, a technology capable of providing long term treatment at low-cost is required. Conventional lime treatment is arguably inappropriate in this circumstance, and the feasibility of using a wetland treatment system was assessed. In 1995, Microbial Technologies was retained to determine whether a wetland could reduce zinc concentrations from the adit discharge to acceptable levels. The following account summarizes results from the 1995 field program which led to the design of a full-scale treatment system.

SITE CHARACTERISTICS AND STUDY APPROACH

Site Location and characteristics of the Galkeno 900 adit

The United Keno Hill Mine camp is located by the hamlet of Eisa, in Central Yukon, 450 km north of Whitehorse. The Keno Hill-Galena Hill area is underlain by Yukon Group metasedimentary rocks (Boyle, 1965).

The Galkeno 900 adit was excavated in 1959, supplying ore to nearby Galkeno mill. When the mine was last abandoned in 1989, this adit was left discharging water with the composition shown in Table 1. Historically, the water pH has ranged from 6.6 to 8.1, but it measured 6.5 at the time of the study. An earlier attempt to plug the adit was unsuccessful, and water has since been discharging at 1-10 L/sec.

Table 1. Comparison between CCREM Water Qmality Guidelines and Galkeno 900 discharge.

	CCREM[1]	Galkeno 900 adit
	(hardness >180 mg/L)	(mean diss. conc. for 1994-95)
Cadmium	1.8	15
Copper	4	< 2
Iron	300	2,105
Lead	7	<10
Nickel	150	506
Zinc	30	25,000

[1] Metal concentrations expressed in μg/L.

Pilot Wetland

An area measuring 9 x 18.5 x 0.5 metres was excavated in May 1995 on a bare, exposed, South-facing plot below the Galkeno 900 adit. This area was fertilized and planted with sedges *(Carex aquatilis;* Taylor, 1983, or *C. Stems,* Porsild, 1973) collected from a nearby stand receiving uncontaminated water. Water from a settling pond receiving lime-treated Galkeno 900 water was used to irrigate the wetland after planting. Plants in the wetland soon grew at a rate comparable to that from those at the donour site.

By the end of June, water from the Galkeno 900 adit was piped first into a plastic-lined 7.6 x 7.0 x 2.0 m pond, thence into the pilot wetland. Metal removal was initially very poor. A site visit in mid-August revealed that this was due to channelized flow in the wetland. Plywood baffles were installed in the wetland to obtain a more even distribution of the flow, as shown in Figure 1. The results presented in this paper are for the period after these baffles were installed.

In Situ Microcosms

Microcosms were established in the pilot wetland to obtain additional data on metal removal and to determine the process responsible for this. Six *in situ* microcosms were set up on August 18 within the pilot wetland. They consisted of translucent plastic cylinders (13.1 cm inner diameter x 25 cm height) containing plant and sediment cores. The cores were drained, sealed at the bottom, and replenished with 1.4 Litres of Galkeno 900 water (Columns 4, 5, and 6) or Galkeno 900 water diluted 1:2 with freshwater collected from nearby South McQuesten river (Columns 1, 2, and 3). Microcosms thus prepared were re-introduced in the wetland exactly were they were originally collected. Water from the columns was sampled at regular interval and analyzed in the field for pH, Eh, alkalinity, or shipped to a commercial laboratory for analysis of metals and sulphate.

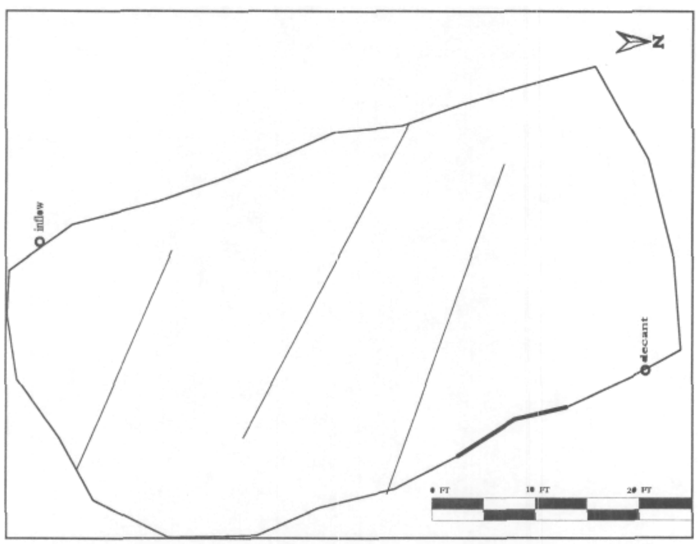

Figure 1. Layout of the UKHM pilot wetland, including inlet, outlet, and position of baffles.

Natural Wetlands

Two natural wetlands located on the property were investigated in this study. The Galkeno swamp, located near the pilot wetland, measured approximately 3.5 x 11.5 m. A spring of pH 6.6 with 3 ppm zinc flowed through this wetland. The second swamp was fed by No Cash Creek, which had a circumneutral pH and contained 5 ppm zinc. This wetland also received waiter from another source, precluding any assessment of its effectiveness in removing metals. Both wetlands were vegetated by unidentified sedges. The Galkeno swamp was sampled for water quality and for metal concentrations in plants and sediments, whereas the No Cash swamp was only sampled for metal concentrations in plants and sediments.

Sampling and Analytical Methods

Water samples were collected by mine staff at the inlet and decant of the pilot wetland and from the microcosms, acidified and shipped for analysis in a commercial laboratory. Sample filtration was unnecessary since filtered and unfiltered samples had essentially the same metal concentrations. Plants were clipped above ground and placed in clean, individual plastic bags and shipped to a commercial laboratory for metal analysis. Sediment sampled were collected in Whirlpak bags where the plants were collected and shipped for metal analysis.

Metal species present in sediment samples from the two natural wetlands were quantified by a sequential leach procedures, using the previously described conditions shown in Table 2 (Sobolewski, 1996).

Table 2. List of reagents and conditions used in a sequential leach of UKHM wetland sediment samples.

EXTRACTANT	PROCEDURE	PHASE DISSOLVED
Wash	4 column volumes	Pore water metal concentrations
0.1 M $Na_5O_{10}P_3$, pH 10	8 hour leach @ 25° C	Soluble organic complexes
1 M NaOAc/HOAc, pH 5	16 hour leach @ 25° C	Adsorbed and exchangeable metals, carbonates
1 M NH_2OH/HCl in 0.25% HOAc	4 hour leach @ 90° C	Amorphous and crystalline iron oxides
$KClO_3$/HCl; ± 4 M HNO_3	2 leaches @ 90° C; 1st without, 2nd with HNO_3	Sulphides
HF-$HClO_4$-HNO_3-HCl	Total digest	Silicates, residual crystalline fraction

RESULTS

Performance of the Pilot Wetland

Mine water was introduced at a rate of 18 L/min. from the end of August, when baffles were installed in the pilot wetland, until the end of September, when snow began to fall (Figure 2). Zinc concentrations in the inlet were fairly constant at 25 ppm, except in early September when a transient decrease was caused by dilution from rainfall 1. Zinc concentrations in the decant initially levelling off at approximately 3 ppm, until some event upset the system around the 8th of !September (Figure 2). Zinc concentrations decreased thereafter, but never reached less than 5 ppm.

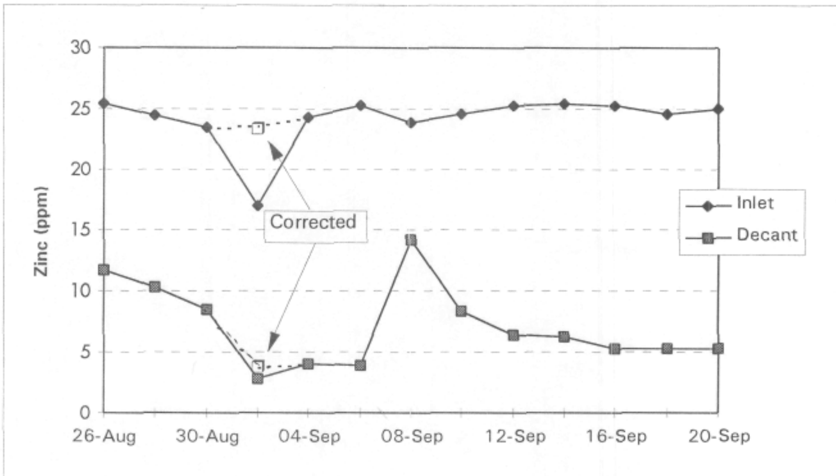

Figure 2. Inlet and decant concentrations of zinc for the pilot wetland.

While a removal rate of close to 90% is relatively good, a discharge of 3 ppm still exceeds the 0.5 ppm permitted limit. The hydraulic retention time of mine water in the pilot wetland might have been too short to reduce zinc below this limit. This view is supported by the observation that zinc concentrations in an area of stagnant water within the wetland decreased to 0.3 ppm. Zinc concentrations were also decreased to 0.3 ppm in a nearby natural wetland (the Galkeno swamp) receiving water containing 3 ppm zinc.

Although other metals were at environmentally acceptable concentrations in the mine water, it is worth noting that several of them, particularly cobalt, manganese, and nickel, were effectively removed in the pilot wetland.

Metal Removal from In Situ Microcosms

To supplement the above work, zinc removal was measured in six (6) columns containing plants and sediment cores filled with 1.4 Litres mine water (3 undiluted, 3 diluted 2:1 with freshwater) and re-inserted

[1] Figure 2 shows both the original zinc concentrations and concentrations corrected for dilution due to rainfall.

into the wetland. These *in situ* microcosms experienced the same temperature and sunlight regime as the pilot wetland, and are believed to correctly replicate the processes occurring within it.

Zinc concentrations decreased to less than 0.2 ppm in these microcosms (Figure 3). A regression on the combined data from all the columns revealed that zinc concentrations decreased exponentially. Using this regression, it was calculated that a constructed wetland with a hydraulic retention time of 26 days would adequately treat the discharge from the Galkeno 900 adit.

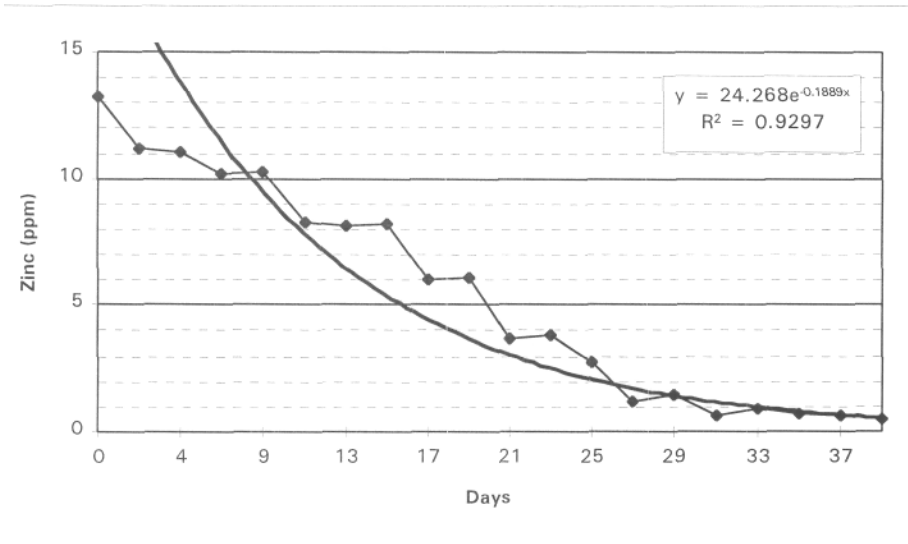

Figure 3. Zinc concentrations in mine water incubated in microcosms.

The gradual decrease in sulphate concentrations in the microcosms indicated that sulphate reduction occurred in sediments (Figure 4) at a rate of approximately 25 mmol/m^2/day. This process was probably responsible for much of the metal removal observed in the wetland.

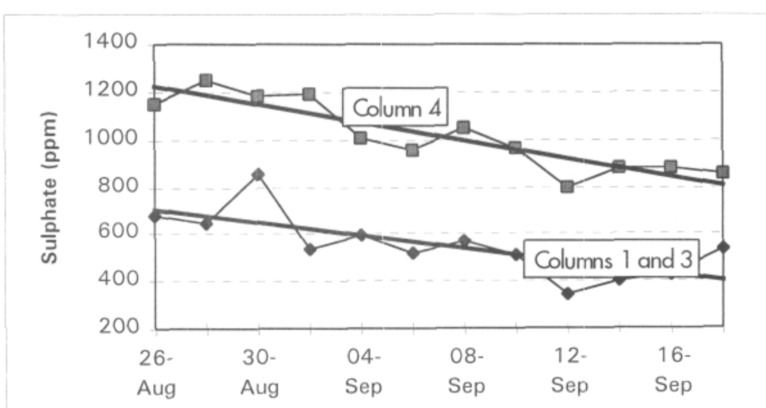

Figure 4. Sulphate concentrations in mine water incubated in microcosms.

Metal Distribution in Natural Wetlands

The pilot wetland could not provide data on the long-term consequences of metal removal. One concern is that plants might accumulate metals, thus providing a point of entry into the food chain. Another concern is that treatment effectiveness might decrease over time, due to some finite capacity to remove metals.

To answer these questions, two natural wetlands (the Galkeno swamp, mentioned above, and the No Cash swamp) receiving contaminated mine drainage and an uncontaminated wetland (the South McQuesten swamp, donour site for the pilot wetland) were sampled. Plants in these wetlands were examined to determine whether they accumulate metals. In addition, the speciation of metals (e.g., organically-bound, as insoluble sulphides, etc) retained in sediments was determined.

Potentially toxic metals retained in the sediments of natural wetlands included cadmium, copper, lead, and zinc. However, plants did not take up these metals, despite 1-2 orders of magnitude enrichments in sediments (Table 3).

Table 3. Metal concentrations in wetland sediments and plants in the Keno Hill area[a].

	S. McQuesten swamp	No Cash swamp	Galkeno natural swamp	Non-impacted[b] sites	Non-impacted sites
Metal	Sediments/Plants *n=2*	Sediments/Plants *n=1*	Sediments/Plants *n=2*	Plant tissues Range	Plant tissues Mean
Cadmium	23/<0.50	227/0.78	66/<0.50	2.6-28	8.0
Copper	46/4.27	238/3.19	110/2.81	2.5-243	48
Lead	<50/4.7	1,760/7.2	98/<2.5	2.0-53	11
Zinc	1,114/132	12,200/185	10,345/102	26.5-1,000	143

[a]Data expressed as mg/dry kg

[b] Ranges and means of concentrations of metals in aquatic grasses and forbs and sediments from non-impacted wetlands, as reported by Hutchinson, 1975

The metal species present in sediments from the Galkeno and No Cash swamps were determined through a sequential leach analysis. Data presented in Table 4 indicate that cadmium, iron, lead, manganese and zinc were predominantly (>80%) retained as iron and/or manganese oxides or as sulphides. Metals in the Galkeno swamp were mostly associated with iron and manganese oxides, whereas those in the No Cash swamp were mostly retained as sulphides.

Table 4. Concentrations of selected metal species in sediments of the Galkeno and No Cash swamps[a].

	Wash	Organic	Carbonates	Fe + Mn	Sulphides	Residue	Total
Galkeno							
Cd	<0.5	<0.5	<5	15.2	1.07	0.29	17
Cu	2.1	33	36	27	27	3.9	129
Fe	11	1394	630	10637	19862	3284	35818
Mn	3	491	259	4816	128	44	5741
Pb	<1	<27	<14	8.17	7.74	6.95	23
Zn	0.99	221	116	2,532	192	18	3080
No Cash							
Cd	<0.5	<0.5	<5	18.9	37.4	<0.5	56
Cu	1.9	55	9.5	19	103	1.7	190
Fe	2	1127	95	2712	16812	4115	24863
Mn	1	342	190	1530	1297	56	3416
Pb	<1	72.73	<10	193	567	8.42	841
Zn	0.86	209	314	2693	3290	39	6546

[a]Data are expressed as mg/dry kg

DISCUSSION

Results from the *in situ* microcosms and the Galkeno swamp suggest that a passive wetland treatment system treating water from the Galkeno adit can be designed to meet the 0.5 ppm permitted discharge limit for zinc. Results from the pilot wetland were more disappointing, showing that zinc was only reduced from 25 ppm to 3 ppm. However, some event appears to have upset treatment within the wetland, preventing it from further reducing zinc concentrations (Figure 2). Treatment efficiency would also be expected to improve when unvegetated area in the wetland (>35%) become fully vegetated. Therefore, it can be argued the data from the pilot wetland also support the passive wetland treatment concept.

The data available from this study indicate that a 26 days retention time would be adequate to treat the Galkeno 900 discharge. Given a discharge of 1-10 L/sec, it is calculated that a 45,000 m^2 wetland treatment system is required. This is based on water quality and removal rates measured during the summer, as no water quality or performance data are available for winter. Thus, it is presently unknown whether such a wetland would be entirely passive, or whether some active water management would be required.

The question of treatment effectiveness over the long-term was also addressed during the study. Long-term treatment would be expected if zinc was mostly removed in wetlands as insoluble sulphides, because sulphate reduction will proceed as long as organic matter and sulphate are supplied to sulphate-reducing bacteria in sediments. Analyses of sediments from two natural wetlands indicated that metals were either associated with iron or manganese oxides or as insoluble sulphides. Data from the *in situ* microcosms demonstrated that sulphate reduction occurred in the pilot wetland. Other measurements made in the field (data not shown) indicated that water in the wetland and in the microcosms became anoxic, precluding the formation of iron or manganese oxides. These results suggest that the pilot wetland probably operated anaerobically, with zinc being predominantly retained as insoluble sulphides. Therefore, a wetland treatment system treating the Galkeno adit discharge is likely to operate for many years, as long as the above conditions are met.

A concern expressed by members of local Native bands was that a wetland treatment system might concentrate metals in plants, leading to consumption of metal-contaminated plants by moose and water fowl. However, analysis of wetland plants and sediments indicated that metals were not taken up by plants, even when they were enriched by up to two orders of magnitude in sediments.

The rate of sulphate reduction measured in wetland sediments was calculated to be 25 mmol/m^2/day. The stoichiometrically for this bacterially catalyzed reaction is:

$$CH_3COO^- + SO_4^{2-} \rightarrow HS^- + 2\ HCO_3^-$$

According to this reaction, 2 moles of bicarbonate are produced for each mole of sulphate reduced. Therefore, the wetland sediments produce 50 mmol HCO_3^-, or 3 g HCO_3^-/m^2/day during the summer. Since bicarbonate neutralizes acidity in mine drainage, the above rate data could in principle be used to design a wetland treating acidic mine drainage. That is, it should be possible to size a wetland treatment system by matching the loading of acidity it receives with a loading of alkalinity (as bicarbonate) it produces from sediments. However, such a calculation is complicated by factors such as the effects of porewater pH and CO_2 (produced during plant decomposition) on the carbonate equilibrium and on the activity of sulphate-reducing bacteria, the kinetics of metal hydrolysis, etc. Nonetheless, the above concept appears to be fundamentally sound. Further research is required to validate this biogeochemical approach to wetland design.

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