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CONSTRUCTED WETLAND EXPERIMENT FOR TREATING AMD AT BELL COPPER

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Constructed wetlands have been used to remove iron from coal mine acid mine drainage and have been proposed for removal *of* other heavy metals and acid. The authors are conducting a constructed wetland experiment to treat AMD seepage at Bell Mine. Feed copper concentration and flow rate can be varied, and effects on the disposition of deposited metals will be measured, statistically evaluated, and related to season and meteorology. Vegetation metal uptake and sulphate reducing bacterial activity in the sediments will be assessed for a four year period. The results should enable the mining industry to better assess the role for constructed and natural wetlands in AMD treatment.

Sedge and cat-tail have been transplanted from nearby Newman Lake into test ponds, and baseline evaluation work is in progress. Loading of the ponds with AMD is expected in mid-1991. The paper will present a status report on progress of the experiment at Bell Mine.

L'aménagement de terres humides pour le traitement des écoulements acides de mine à la Bell Copper

Les terres humides ont été utilisées pour éliminer le fer des écoulements acides de mine au charbon et il a été proposé de les utiliser pour éliminer d'autres métaux lourds ainsi que des acides. Les auteurs effectuent une expérience portant sur la construction d'un site de terres humides pour traiter les écoulements acides à la mine Bell. La concentration en cuivre des affluents ainsi que le taux d'écoulement peuvent être variés. Les effets de la disposition des métaux déposés seront mesurés, statistiquement évalués et étudiés en fonction de la saison ainsi que de la météorologie. L'assimilation des métaux par la végétation et l'activité des bactéries réductrices dans les sédiments seront évalués pendant quatre ans. Les résultats devraient permettre à l'industrie minière de mieux évaluer le rôle des terres humides, naturelles et artificielles, dans le traitement des écoulements acides miniers.

Des souchets et des quenouilles ont été transplantés du lac Newman, situé à proximité, dans des cellules d'essai et le travail d'évaluation préliminaire se poursuit. Des écoulements acides miniers seront ajoutés aux cellules vers la mi-1991. La communication présentera un rapport sur la progression de l'expérience entreprise à la mine Bell.

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BACKGROUND

Acid Mine Drainage at Bell Copper

The Bell Mine is an open pit copper mine located on Newman Peninsula, Babine Lake, approximately 65 km northeast of Smithers, B.C. Pit development began in 1970, and a mill was commissioned to produce a copper concentrate with significant gold content.

Waste rock removed *as* part of the mining operation is stockpiled in dumps near the pit perimeter or used as structural fill for tailings dams. To date, approximately 66 million tonnes of waste rock and 56 million tonnes of tailings have been deposited on site. Some of the waste materials have potential to generate acid solution containing dissolved heavy metals.

Wetlands for Waste Treatment

The background leading to the Bell Wetlands experiment has been provided previously (Gormely et al., 1990). Wetlands are defined as "land where the water surface is near the ground surface long enough each year to maintain saturated soil conditions, along with related vegetation" (Reed et al., 1988). The mechanisms operating in wetlands are not well understood, and further work is needed to better define these. Hammer (1990) considers that wetlands provide a suitable environment for microorganisms that conduct useful transformations on contaminants entering the system.

The removal of dissolved metals in wetlands is mediated through a variety of processes, including direct uptake by plants, ion exchange or adsorption on clays or organic macromolecules in the root zone, uptake by microorganisms, and precipitation with metabolically-produced sulfides in anaerobic sediments. The first three mechanisms provide for short-term, temporary immobilization within the wetland, whereas the precipitation of metal sulfides represents a potentially long-term deposition form.

The anaerobic environment in sediments generated by a high level of microbial activity is critical for the promotion of sulfate reducing conditions and the production of sulfides. It is hypothesized that the sulfides react with dissolved copper to produce highly insoluble copper sulfide. Anaerobic sulfate reduction is an acid consuming process, so that a biologically induced rise in pH is noted, without need for reagent addition.

To foster the required high level of anaerobic bacterial activity, a source of organic material is required. Above- and belowground particulate and dissolved organic matter originating from plant detritus and leachates serves as a source of this needed reducing power.

Two design concepts for a constructed wetland can be considered: the conventional wetland with an exposed free water surface, and the more recently developed root zone system or vegetated submerged bed (VSB). In the latter, subsurface flow through a permeable medium is induced; the treatment occurs as a result of microbiological growth and root systems of emergent aquatic vegetation in the permeable medium.

Vegetated Submerged Bed Wetland

In the VSB wetland, careful hydraulic design is required to ensure the flow passes through the root zone. Periodic maintenance is required to ensure permeability and balanced utilization of the entire design area. Neglect of this maintenance can result in process failure as solution bypasses the active treatment zone, and such failure might not be detected for some time, and could be difficult to correct without reconstructing portions of the wetland.

Winter and Kickuth (1989) are exponents of this system, and have published details of its use to promote sulfate reduction in a textile plant effluent in Germany.

Free Water Surface Wetland

The free water surface wetland is the system used as an inexpensive method of treating acid mine drainage resulting from eastern coal mines (Brodie et al., 1989). This, however, is an oxidative system rather than a reductive one. Constructed wetlands of this type typically consist of basins or channels with a subsurface barrier to prevent seepage, a medium to support the vegetation, and water at a shallow depth flowing through the unit.

Objectives of the Project

The purpose of the proposed test at Bell Copper is to develop an experimental engineered wetland which can be used to investigate and demonstrate the efficiency of metals removal from contaminated seepage with this technology. As well, the work has a research objective to develop a better understanding of the mechanisms of treatment and the operating limitations set by these. Specific objectives are:

1. To determine the performance and capacity of the experimental wetland system to remove metals under different seasonal conditions and varying flows and metal concentrations in the waste stream in a northern climate and a mine environment;

2. To relate the performance and capacity measurements to underlying mechanisms of metal fixation in the sediments, with particular reference to sulphate reducing bacteria;

3. To study changes in plant species composition and growth in the experimental ponds;

4. To determine metal tissue concentrations in the transplanted vegetation;

5. To develop improved design criteria and demonstration data that will permit a technical and economic assessment of the process as a means of acid mine drainage treatment.

DESCRIPTION OF THE BELL PROJECT

Cell Design

The concept at Bell is to establish a test cell, together with a smaller control cell for comparison. A mixing pond will be used to mix AMD with fresh water to make one week's feed at 1 ppm copper. Metering pumps will transfer this material at a constant rate into the test and control ponds. A plan and cross section of the test plot are shown in Figure 1 and Figure 2.

A 5 by 60 m test pond and a 2.5 by 30 m control pond have been constructed and lined, together with a batch mixing pond. The ponds are 1.3 m deep, lined with high density polyethylene membrane to prevent seepage. Initial inflow will be 8 1/min for the test cell and *2* 1/min for the control. Originally, the concept was to provide a layer of soil over a gravel base to permit flow both above and below the root zone. The control cell was to remain unplanted.

Information collected by Noranda Research on research activities in the Eastern U.S. suggested that the free water surface concept may not be satisfactory, and that greatest success was being achieved when the entire flow was through the root *zone.* To achieve this, the surface of the planting must slope at the hydraulic gradient in the soil. This gradient probably varies with the season and maturity of the wetland, and thus, the design concept is difficult to implement. The test cell was constructed with a difference in elevation of the invert over its length of about 300 mm, but the actual slope requirement remains to be determined, and will depend on the nature of the vegetation root mass together with its supporting peat substrate. This will probably change over the duration of the project.

The Bell design does not provide for any oxidation for iron control prior to the anaerobic cell. Given the low level of iron in the feed, this is felt to be satisfactory. Iron not precipitated by oxidation is not removed by the anaerobic treatment in some circumstances.

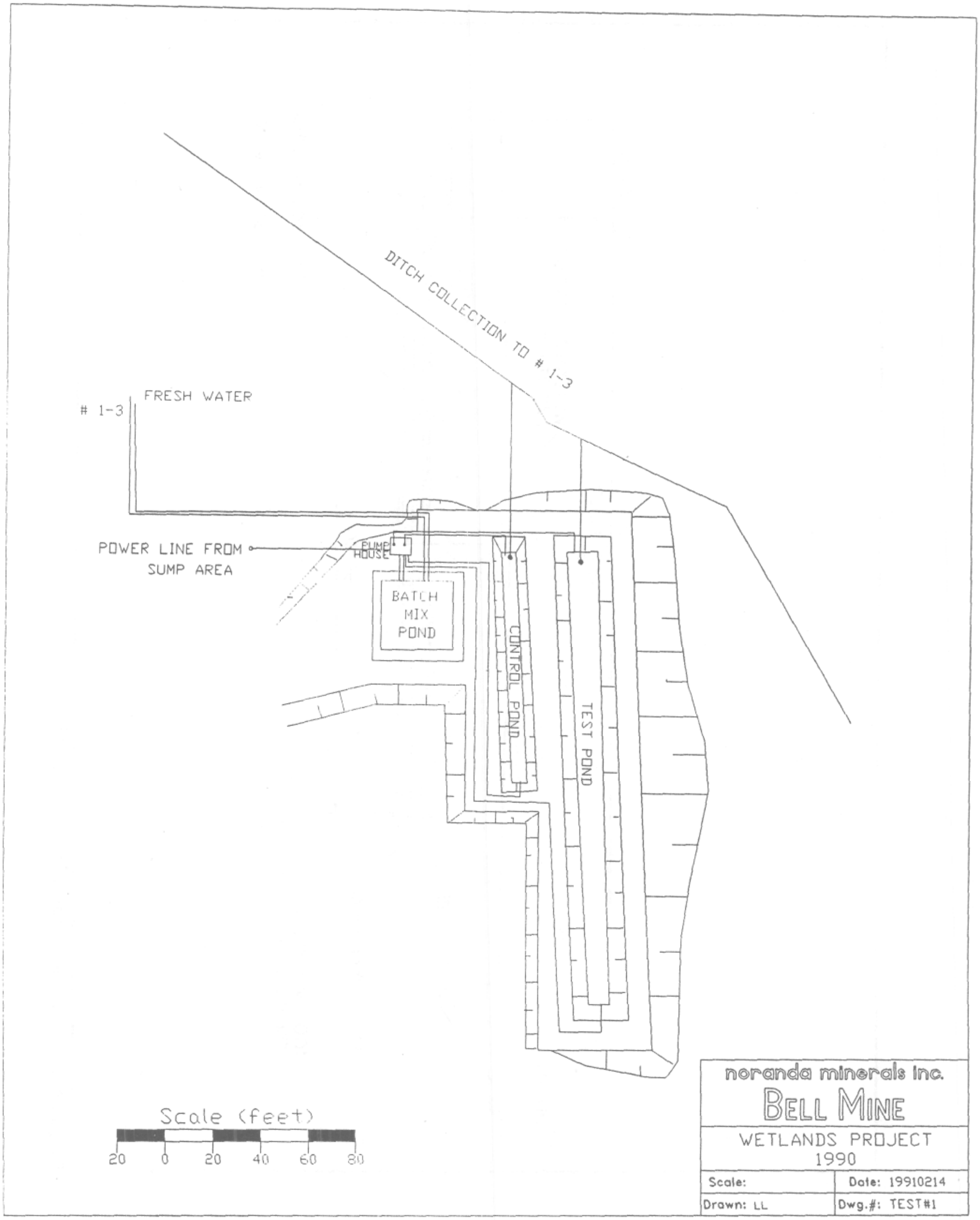

Figure 1. Plan View of Mixing Pond, Test and Control Cells.

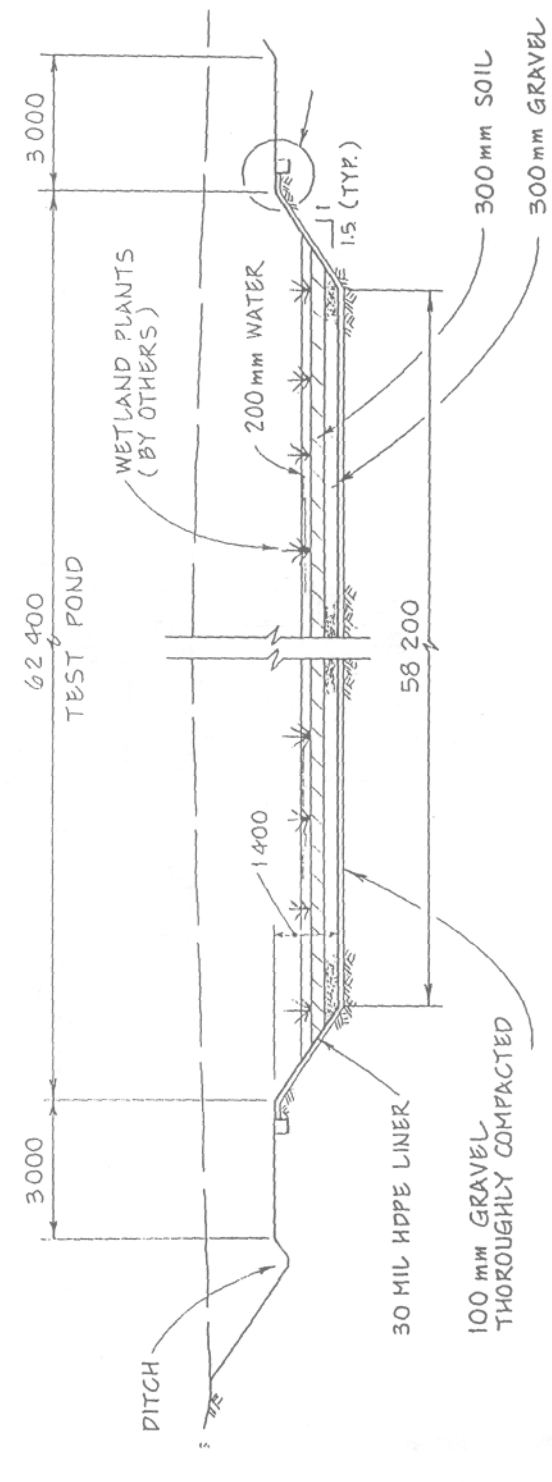

Figure 2. Cross-section of Test Cell.

Transplant Program

Transplanting was delayed in 1990 due to excessively wet conditions which prevented equipment access to the donor site. A floating sedge fen located on the shoreline of Newman Lake was ultimately selected as the main vegetation donor site. This donor site satisfied several practical and biological considerations. The location was relatively close to the experimental site, and was easily accessible. The vegetation was away from potential contamination sources of the mine operation. There was also more than enough vegetation available! for transplanting.

The donor site is comprised of a pure stand of the water sedge Carex aquatilis. The sedge community grows on a thick layer of floating peat and detritus in a dense arrangement of large clumps. Carex aquatilis has a substantial underground biomass comprised of horizontal, cord-like and scaly rhizomes along with a dense root mass.

Cat-tail (Typha latifolia) was another wetland species of choice. Its occurrence on Newman peninsula is sparse and scattered. Several small cat-tail colonies occur near the minesite; however, these plants are high in metals (especially copper) due to natural high metal levels in the soils, and from possible runoff from mining activities. A small isolated colony of cat-tail was found in a roadside ditch some distance away from the mine. Some of these plants were added to the transplanting operation.

Planting took place during the period July 11-13, 1990. Prior to commencing the planting, access to the donor site was developed. Bulldozer work was conducted to clear a causeway for access of a backhoe and a truck.

On July 11, the backhoe was moved out to Newman Lake to begin plant harvesting. The planting procedure was discussed with the operator, specifying that the vegetation sods remain small enough to handle by hand. The first load of material was transported on a flat-bed truck. Approximately 8-10 students were used to move the plant material into the ponds. The planting had to be labour intensive to ensure no damage to the liner, and maintain optimum plant placement and orientation.

Unloading the plants from the flat-bed truck proved to be very difficult. The pieces of plant material were cut into smaller portions so they could be moved. Usually, four workers were used to cut the plant material into smaller pieces, three workers moved these pieces along the ponds, while three workers placed the plants. Initially, the sods were too large, and extra time was used to cut the material into smaller chunks. Due to the labour intensity of unloading sod, cutting, and placing, only one-third of the large cell was completed on the first day. Water was added to the pond to keep the planted materials moist.

On the second day, a dump truck was used instead of the flat-bed truck. This proved more efficient, as many loads could be transported while planting could continue without waiting for additional loads. Keeping the ponds flooded aided in the planting process. The plant sods can float, so it was much easier to place the plants and move them into position.

Lack of space between the ponds was a major hinderance to planting. Plant material had to be transported by wheel barrow in order to be placed in the ponds. This contributed to the labour intensity of planting.

Barn manure was applied to the ponds after transplanting to fertilize the system.

Preloading Inspection and Baseline Sampling

Vegetation

On August 27, 1990, approximately six weeks after transplanting, the test ponds were inspected to determine the condition of the vegetation,.

The large test pond was filled with large clumps of sedge vegetation taken from the Newman lake floating fen. The small test pond was also filled with sedge vegetation from the Newman Lake donor site plus cat-tail plants which were intermingled with the sedge vegetation. The vegetation was found to be floating above the bottom of both ponds.

Associated with the transplanted vegetation were several other wetland species such as:

Cinguefoil	(Potentilla)
Beggar-ticks	(Bidens)
Hornwort	(Ceratophyllum)
Horsetail	(Equisetum)
Willow	(Salix)
Spike Rush	(Eleocharis)
Water Starwort	(Callitriche)
Duckweed	(Lemna)

Among the fauna present in the test ponds were frogs, leeches, and voles. The vole population in the test ponds can be considered a nuisance. Because the voles were trapped and unable to climb up the plastic liner, they were exerting considerable grazing pressure on the sedge vegetation of the large pond.

Most of the sedge leaves in the large test pond died back as a result of the above-noted grazing pressure. The vegetation of the small test pond was in relatively good condition. Some new shoot growth was evident in the sedges of the large test pond.

The decision to postpone the loading of wetland ponds with copper-containing effluent was reached upon consideration of the stressed appearance of the transplanted stock and of the potential impact on the plants due to exposure to copper and sulfide (generated from the activity of SRBs) that would result.

Sedge and cat-tail plants were sampled at the donor sites and at both test ponds to obtain tissue samples from aboveground and belowground biomass. Samples were analyzed for Loss on Ignition, and 30 metals using I.C.P.

Results of Plant Tissue Analyses

The test results for copper are summarized in Table 1. Average copper levels (ppm dry weight) in tissues of sedge and cat-tail along with respective statistics of standard deviation (S.D.),

		DONOR SITE					
	Replicate:	1-1	1-2	2-1	2-2	3-1	3-2
Sedge	leaves	8.5	-	11.0	-	7.3	-
	roots	10.0	-	22.0	-	10.5	-
Cat-tail	leaves	8.2	7.4	6.3	-	7.7	7.0
	roots	26.9	-	23.2	22.0	50.2	-
		TEST PONDS					
Large Pond							
Sedge	leaves	14.0	12.0	9.4	-	9.1	8.3
	roots	35.9	-	36.8	-	27.5	-
Small Pond							
Cat-tail	leaves	6.7	-	5.9	-	8.7	-
	roots	19.0	21.2	18.0	-	24.9	-

Table 1 Results of Tissue Analyses for Copper (ppm dry weight) in Sedge and Cat-tail Leaves and Roots.

standard error (S.E.), and coefficient of variation (C.V.) are shown in Table 2.

The following significant trends are evident from the data shown in Table 2. Levels of copper were higher in all sedge leaf samples in comparison to copper levels found in cat-tail leaves. Copper levels in sedge roots were both above and below levels found in cat-tail roots. There was a significant difference between aboveground vs belowground copper levels in both tested species. Copper concentrations were from 2 to 4 times higher in belowground tissues. The range of the coefficient of variation for copper

Sample	Location	Mean	S.D.	S.E.	C.V.
Sedge leaves	donor site =	8.93	1.88	1.09	21%
Sedge leaves	test ponds =	10.56	2.37	1.06	22%
Sedge roots	donor site =	14.6	6.78	3.92	46%
Sedge roots	test ponds =	33.4	5.12	2.96	15%
Cat-tail leaves	donor site =	7.32	0.72	0.32	10%
Cat-tail leaves	test ponds =	7.1	1.44	0.83	20%
Cat-tail roots	donor site =	30.57	13.2	6.62	43%
Cat-tail roots	test ponds =	20.77	3.05	1.76	15%

Table 2 Statistical Summary of Copper Concentrations in Plant Tissue Samples.

levels in *roots* indicates a high degree of variability associated with this plant component.

The copper concentrations found in the sedge and cat-tail samples can be considered background levels assuming that there are

	Non-Enriched Sites		This Study	
Metal	Range	Mean	Range	Mean
Al	250-785	366	160-4190	1472
Cd	2.6-28	8.0	<0.1-0.66	0.2
Cu	2.5-243	48	5.9-36.8	16.5
Fe	70-31500	3170	130-18500	4255
Pb	2.0-53	11	<2-6	2.6
Mn	100-23000	2380	96.4-2640	582
Ni	1.1-44	--	2.5-18	5.3
Zn	26.5-1000	143	13.9-72.9	38.9

Table 3 Aboveground tissue concentration of eight metals measured in this study in comparison to metal levels of aquatic forbs and grasses in non-enriched environments as reported by Hutchinson (1975).

no anthropogenic sources of copper. Of the remaining 30 metals that were analyzed, only aluminum stands out as being considerably higher in the sampled plant tissues compared to background levels measured in other aquatic plants (Table 3).

Sediments and Microbiology

Several unanticipated problems were identified during the baseline sampling. The floating peat tussocks represented an unsuitable substrate for sampling with core samplers, and every attempt to obtain samples maintaining some spatial integrity of the material was unsuccessful. Only one grab sample was obtained to measure sediment pH.

General Observations

Profuse production of methane from the decaying peat was noted in both wetlands, which is indicative of an active methanogenic population and of the absence or low numbers of sulfate-reducing bacteria in this environment. This was expected because the influent was low in sulfate, and methanogens are not displaced by sulfate-reducers under those conditions. However, since methanogenic and sulfate-reducing bacteria have several other environmental requirements in common, it is anticipated that SRBs will become dominant once sulfate-containing influent is introduced.

Sampling of Peat Detritus

Peat detritus must be sampled to determine metal accumulation and sulfate-reducing activity. However, no acceptable sampling method was found during the initial sampling for baseline measurements. Although it was possible to tear off clumps of detritus by hand, this method and subsequent handling of the material were unsatisfactory. In future samplings, garden shears will be used to cut plant detritus underwater, and a high-speed blender will be used in an anaerobic atmosphere to produce a slurry from which levels of metals and sulfate-reducing bacteria can easily be determined.

Sulfate-reducing Bacteria (SRB) Enumeration

Enumeration of sulfate-reducing bacteria (SRB) was carried out in a general medium for SRB using either acetate or a mixture of lactate, propionate and butyrate as carbon sources (Widdel and Pfennig, 1981).

It was not possible to properly mix peat clumps with diluent, nor was it possible to determine the amount of material used for enumeration, since the sample was part peat and part water. In spite of these limitations, cell counts are provided in Table 4.

Source	Dilution Factor	Average Cell Number, Mixed Substrate	Average Cell Number, Acetate
Large wetland cell	1:100	1.3 colonies/tube	0.5 colonies/tube
	1:10	5.2 colonies/tube	0.75 colonies/tube
	1:1	57 colonies/tube	8 colonies/tube
Small cell, cattail-associated sediment	1:100	0 colonies/tube	0 colonies/tube
	1:10	0.7 colonies/tube	0 colonies/tube
	1:1	too much debris	1.3 colonies/tube
Small cell, sedge-associated sediment	1:100	0 colonies/tube	0 colonies/tube
	1:10	1.8 colonies/tube	2 colonies/tube
	1:1	16.7 colonies/tube	4 colonies/tube

Table 4 Cell Counts for SRB Enumeration in Wetland Sediments.

Discussion of Baseline SRB Enumeration Results

The data indicate the following:

a) Some SRB can be detected in all the samples, particularly in sedge-associated peat, even though no sulfate was added to the influent to the wetlands.
b) The samples taken from the large pond, particularly for the mixed substrate medium, show a **proportional decrease** in cell number with **increasing dilution**, suggesting that the technique is reliable.
c) Acetate did not support growth as well as the mixed substrate.
d) Excessive debris from the sample mask (are indistinguishable from) the SRB colonies at low (1:1) dilutions.

Sampling for Chemical Analysis

Samples for chemical analysis were collected on August 29th. The data indicate that the constructed wetlands peats have a metal content essentially identical with the peat in Newman Lake. Copper levels at these sites were measured at between 50 and 120 ppm, considerably less than the assay of over 8400 ppm in a sediment sample from a swamp on the mine site which directly receives AMD seepage. Expectedly, organic content was very high (approx. 36.6%).

CONCLUSION

Based on our experience to date and comments of others, a revised work program with improved sampling techniques for 1991 and beyond has been discussed and proposed for adoption. This program is intended to satisfy both the demonstration and research objectives of the project. The program will include more intensive sampling and analysis that will permit a statistical comparison of the baseline with results to be obtained over the next three years after loading.

Loading of the ponds with copper-containing feed will begin after satisfactory shoot production is observed this spring, indicating successful transplanting of the vegetation. Data on wetland performance will be collected over the summer and fall permitting an evaluation to be completed next winter which will provide the first comprehensive indication of the process effectiveness.

A multidisciplinary approach has resulted in the definition of a program that will enable the mining industry to draw conclusions regarding the potential effectiveness and feasibility of a wetland as an anaerobic treatment system for copper removal. At the same time, fundamental understanding of processes in these complex systems should be enhanced.

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