WATER COVER ON ACID GENERATING URANIUM TAILINGS - LABORATORY AND FIELD STUDIES[1]

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Abstract: Under the Mine Environmental Neutral Drainage (MEND) program, a joint research project between CANMET, Elliot Lake Laboratory and Rio Algom Limited, Elliot Lake, Ontario, Canada, was established to investigate the feasibility of establishing a shallow water cover on pyritic uranium tailings as a close-out option for controlling acid generation and release of contaminants. The program consisted of: 1) laboratory lysimeter studies to investigate oxidation and leaching characteristics of coarse and homogenized total mill tailing with and without a water cover, 2) field evaluation of a partially submerged wetland tailings basin for its geochemical and biological controls on acid generation, and 3) establishment of a 65 ha flooded field demonstration site, and evaluations of its hydrological and geochemical control parameters. The laboratory lysimeter studies indicated that both control tailings without a water cover oxidized rapidly producing acidic drainage. However, the oxidation rate for the well drained coarse tailings was approximately two orders of magnitude higher than that for the homogenized total mill tailings which retained high degree of moisture saturation. Coarse tailings with a shallow water cover had a near neutral drainage effluent for a period of three years. Dissolved iron concentrations in the effluent were either below detection or less than 1 mg/L for the initial three year period and increased slightly thereafter. Results from the partially submerged tailings basin showed that the overall wetland/water cover system was effective in controlling acidic drainage from this site with effluent pH>7 and dissolved iron concentrations ~ 0.1 mg/L. A description of the 65 ha flooded field test program is presented including some initial water quality data. The results indicated that acid generation could effectively be controlled using a shallow water cover (0.5- 1.0 m in depth).

Additional Key Words: acid mine drainage, uranium mine/mill tailings, uranium wastes.

Introduction

Water with its low oxygen diffusion coefficient ($2x10^{-9}$ m^2/s) and low oxygen solubility (8.6 g/m at 25° C), is probably the most cost effective and readily available oxygen- limiting cover for controlling acid generation in reactive wastes. In the absence of convective transport, the rate of oxygen diffusion through water is too slow to be significant (Davé 1992). A water cover on reactive wastes: 1) limits available oxygen and hence controls acid generation, 2) eliminates surface erosion by wind and water action, and 3) creates a reducing environment for bacterial reductions of nitrates and sulphates.

Under the Canadian Mine Environmental Neutral Drainage (MEND) program, a joint research project entitled "Development of wet barriers on pyritic uranium tailings" was undertaken by the Elliot Lake Laboratory, CANMET, Energy, Mines and Resources Canada and Rio Algom Limited, Elliot Lake, Ontario. The objective of the study was to evaluate the feasibility of establishing a shallow water cover on pyritic uranium tailings, as a decommissioning option, for controlling acid generation and release of contaminants.

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The uranium mill tailings in the Elliot lake region are acid generating, low level radioactive wastes, containing approximately 5 to 7% pyrite and low concentrations (10 to 15 Bq/g) of uranium decay series radionuclides. The tailings were discharged at neutral to alkaline pH's but have low buffering capacity because of an acid leach process used in uranium extraction.

With water cover as an emerging technology for controlling acid generation, Rio Algom Limited, for their Elliot Lake operations, has proposed decommissioning two inactive tailings sites at Quirke and Panel Mines by large scale flooding and an in situ water cover. These sites are ideally situated in valleys with cross-valley engineered dams and favourable topography for flooding and maintenance of a water cover. At the Quirke site, an experimental 65 ha test site has been developed for a large scale flooding demonstration.

The present study was initiated in 1989 to evaluate the performance of a water cover on pyritic uranium tailings, both under laboratory controlled conditions and in the field. Preliminary results of this study were reported in 1990 by Davé et al. (1990).

Experimental Study

The experimental study consisted of three parts: 1) laboratory lysimeter column tests, 2) field evaluation of a wetland basin containing partially submerged pyritic uranium tailings, and 3) establishment of a 65 ha flooded field demonstration site.

Column Leaching Tests

Column lysimeter leaching tests were conducted to determine oxidation and leaching characteristics of pyritic uranium tailings under unsaturated (control) and flooded conditions. For these tests, two types of tailings were chosen. The first one consisted of fresh and homogenized total mill tailings (control-1, approximately 50% less than 74 µm or -200 mesh), obtained from the tailings filtration circuit of Rio Algom's Quirke mill. The second consisted of fresh and predominantly coarse tailings (94% greater than 74 µm or +200 mesh), obtained from the Quirke tailings area. For flooded conditions, only coarse tailings were used representing a worst case scenario. Tests were also conducted for evaluating the effects of coarse and fine grained limestone mixed with the two types of tailings.

Figure 1 shows a typical experimental arrangement of a column leaching lysimeter with a water cover. The column, 122 cm in height and 15.2 cm nominal diameter (I.D. 14.5 cm), was made from a schedule 80 (thickness 1.25 cm) PVC pipe. In total, 24 columns were filled with tailings or tailings and limestone mixtures and each column contained approximately 14.3 kg of material. Columns 1 to 15 consisted of five sets, all in triplicates. Set 1 contained only total mill tailings and was used as a first control (control-1). The other four sets contained total mill tailings mixed with 7.5% (by weight) limestone of grain sizes -6.3 mm (-4 mesh), -2.4 mm (-8 mesh), -0.84 mm (-20 mesh) and wet ground limestone, respectively. The amount of limestone added was approximately equivalent to the net acid generation potential of the tailings.

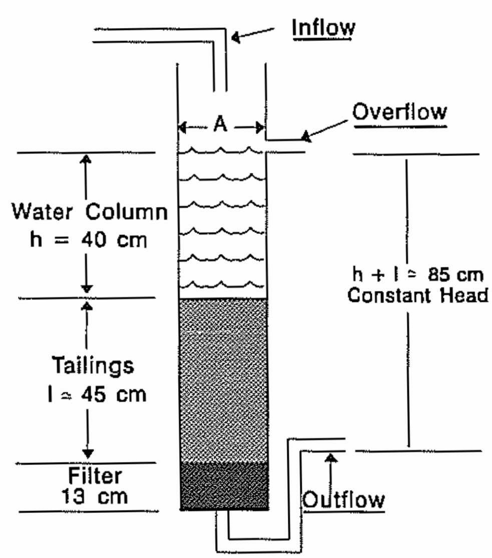

Figure 1. Experimental arrangement of a flooded leaching column.

Columns 16 to 21 consisted of three duplicate sets which contained coarse tailings as a second control

(control-2). The first set (columns 16 and 17), contained coarse tailings, while the other two sets contained coarse tailings mixed with 7.5% (by weight) of coarse grain size 6.3 mm (-4 mesh) or wet ground limestone, respectively.

Columns 22 to 24 contained only coarse tailings with no limestone and were filled with distilled water to a height of 40 cm above the tailings, providing a shallow water cover.

Initially, all the columns were inoculated with 100 mL of acidic leaching solution obtained from an underground leaching stope of the Quirke Mine. The columns were then allowed to acclimatize for a few days. All columns from 1 to 21 were batch leached under unsaturated conditions by adding, every two weeks, 1 L of well aerated natural lake water collected from Gravel Pit Lake near the Quirke tailings. For each column, the effluent sample was collected every two weeks and its volume and primary water quality parameters: pH, redox potential (Eh), electrical conductance (Ec), acidity, alkalinity were measured. On a monthly basis, individual column samples were composited and analyzed for total dissolved Al, Ca, Fe, Mg, Mn, Ra-226, Th, U and SO_4^{-2} concentrations. Initially for the first year, the columns were leached by adding 100 mL of the lake water daily and the samples were composited weekly for analysis.

Column 22 to 24 with a water cover were leached with distilled water under flooded conditions. Distilled water was continuously added at the top of each column at a sufficient flow rate to maintain the water cover and allow pore water drainage of approximately 1L per day for the first two years and then to 1 L per week. Over a four year period, approximately 250 pore water volumes were exchanged. The initial high ground water flow was simulated to rapidly leach and remove soluble minerals like gypsum to further study the oxidation and leaching characteristics of other residual minerals and radionuclides.

Partially Submerged Tailings and Wetland Basin: Field Evaluations

This study consisted of an extensive environmental monitoring survey of an existing natural wetland basin, called Panel wetland, containing partially submerged pyritic uranium tailings. It was undertaken to establish whether the existing natural wetland and water cover system was providing any treatment to acid mine drainage, and to evaluate its hydrologeochemical and biological controls on acid generation and migration of contaminants associated with the oxidation process.

The survey included: determination of the site hydrology and its flow conditions, measurements of surface and ground water quality parameters and their seasonal fluctuations, characterization of substrate solid/tailings and sediment for oxidation- reduction profiles, bacterial enumeration, and vegetation uptake of metals and radionuclides.

The Panel wetland site is a small basin located in a bedrock valley containing partially submerged pyritic uranium tailings. It has a total area of 14.5 ha and contains approximately 236,000 tonnes of tailings spread over 12.9 ha. Approximately 88% of the total tailings area is under water, leaving 1.6 ha in the western part of the basin where the tailings are exposed. The average thickness of the tailings in the basin is 0.92 m. The depth of water cover varies from shallow, 0.1 to 0.5 m, in the western and central parts to slightly deeper ponded water, 0.4 to 1.4 m in depth, in the east. The basin supports a dense vegetation cover consisting of cattails, marshland grasses, sedges, sphagnum and other acidophilic mosses. The deep ponded water contained submergent vegetation such as pond weeds.

The surface water hydrology and chemistry of the basin were studied for three seasons, spring, summer and fall. Water samples were collected along selected transects throughout the basin and at various depths. For ground water monitoring, the site was instrumented with a series of multi-level piezometers along selected transects parallel to surface and ground water flow regimes and at shallow depths of 0.3, 1.0, 1.5 m at each location. The ground water hydrology and chemistry was only determined for summer and fall seasons.

The water samples were analyzed for pH, redox potential (Eh), electrical conductance (Ec), dissolved oxygen, acidity, alkalinity, total dissolved solids, SO_4^{-2}, and total dissolved metal concentrations for Al, Ca, Cu, Fe, Mg, Mn, Ni, Pb, Th, U, Zn and Ra-226.

Soil/tailings substrate and sediment samples were collected from shallow depths (up to 0.3 m) for solid phase characterization of metals and radionuclides, sulphur speciation and bacterial enumeration for Thiobacillus ferrooxidans (TF) and Sulphate Reducing Bacteria (SRB). Composite vegetation samples were also collected for individual plant species. All substrate, sediment and vegetation samples were analyzed for total Al, Ca, Cu, Fe, Mg, Mn, Ni, Pb, Th, U, Zn and Ra-226 contents.

Field Demonstration and Flooded Test Site: Quirke Tailings Concept

A large scale flooded test site, 65 ha in area, has been developed at the Quirke Mine tailings site to demonstrate flooding of tailings using a terraced cell concept, and to evaluate its performance based on the site hydrological and geochemical monitoring results. Figure 2 shows a general plan of the flooding concept at the Quirke mine waste management area.

The tailings basin contains approximately 48 million tonnes of uranium mine tailings and waste rock and covers an area of 190 ha with a drainage basin of 275 ha. There is a 15 m elevation difference between the west end of the Quirke tailings and the east end effluent discharge area. To enable covering the tailings with water, the basin was developed in a terraced manner by construction of four internal dykes and dividing the basin into a series of internal cells (14 to 18) which effectively dealt with a drop in tailings surface elevation from west to east. This represented an overall average gradient of about 0.5%. The drop in elevation from cell to cell is about 4 m. These internal cells are retained by dykes constructed of mine waste rock, tailings and glacial till. Figure 3 shows a typical cross-section of the tailings basin, internal dykes and external dams. The overall basin hydrology is such that a minimum of 0.6 m water cover could be maintained over the tailings in each cell. Detailed design concepts and geotechnical aspects of the Quirke tailings site are given by Balins et at. (1991).

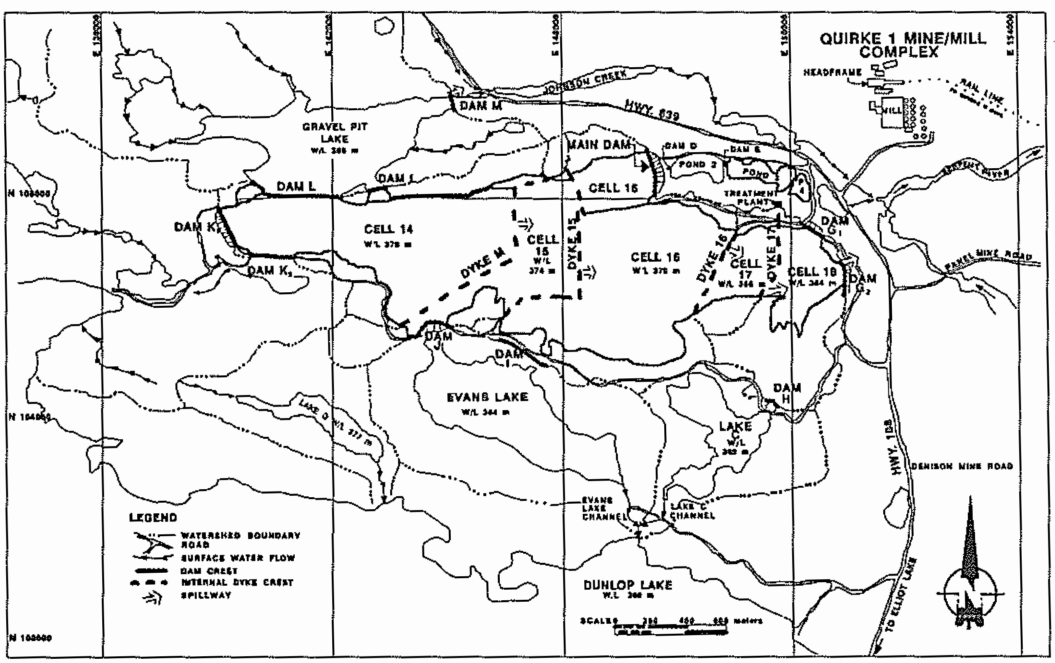

Figure 2. General plan of flooding concept at the Quirke mine waste management area.

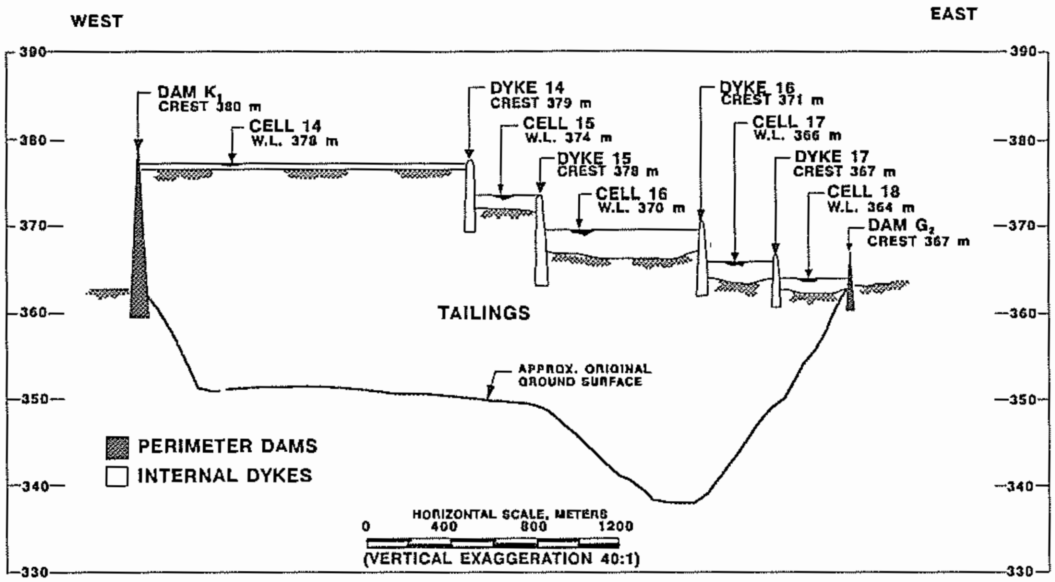

Figure 3. Schematic profile of flooding concept, Quirke mine waste management area.

The initial decommissioning and flooding concept is being tested at Cell #14 located at the highest elevation in the west end of the basin. The cell has an area of approximately 65 ha. An internal dyke #14, together with other containment dams completes the field demonstration test site. Water from a nearby Gravel Pit Lake is used for initial flooding.

The monitoring program for cell #14 consisted of obtaining a water balance for evaluating seepage losses through the site, measurements of piezometric pressure heads across the dyke for calculating seepage losses through the dyke and monitoring of surface and ground water quality parameters.

Results and Discussion

Column Leaching Tests

The column leaching results for unsaturated coarse tailings (control-2, column 16 and 17), unsaturated coarse tailings with coarse limestone (column 18 and 19), unsaturated total mill tailings (control-1, column 1 to 3) and flooded coarse tailings (column 22 to 24) are shown, respectively, in figures 4 to 7 for pH, SO_4^{-2}, and Fe. The results are presented in decreasing order of acidic drainage from the columns.

Initially for the first year, when the leaching scheme consisted of daily additions of 100 mL of natural lake water to the columns, no acidic drainage was observed from any of the columns. Although the tailings in columns 16 and 21 were coarse grained, they appeared to retain appreciable amounts of moisture to maintain near saturation conditions due to a shallow

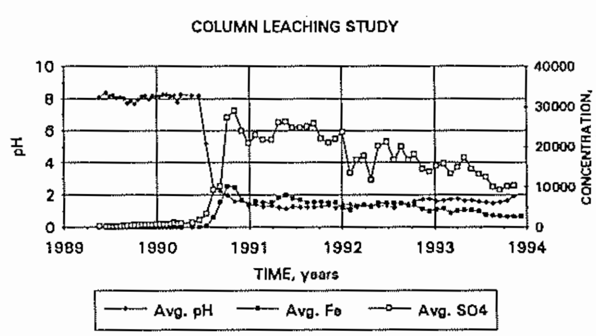

Figure 4. Leaching profiles of coarse pyritic uranium tailings, columns 16 and 17 (control-2), variations of pH, Fe and SO_4^{-2} with time.

water table and frequent water additions. This condition was altered by modifying the leaching scheme in June 1990 to batch additions of 1L of water every two weeks.

The control-2, columns 16 and 17, were first to show acidic drainage, 1 to 2 months after the new leaching scheme was implemented. The pH of the effluent dropped from 8 to 2 during this short interval and continued to fall slowly to pH 1.2 over a two year period. It recovered slowly to 1.8 afterward. All other parameters also indicated severe oxidation with peak Fe and SO_4^{-2} concentrations of approximately 10,000 and 28,000 mg/L, respectively (Fig. 4). From the water quality data and mass balance for the initial three year leaching period, it was estimated that approximately 275 to 300 g or 70 to 75% of the total Fe contained in the tailings was oxidized and removed. This corresponded to an average iron oxidation and removal rate of approximately 18.3 mg Fe per kg tailings per day.

In addition to the mobilization of iron and sulphate, the acidification of these columns also mobilized other metals, e.g., Al, Ca, Mg, Mn, Th, U and rare earths Y and Ce, etc. The control-2 tailings also contained some residual limestone and gypsum precipitate following limestone neutralization of leached tailings in the mill. With the onset of acid generation, all the available alkalinity was consumed and Ca leached out within the first year and a half. After approximately four years of leaching, the columns are still producing very acidic leachates with Fe and SO_4^{-2} concentrations on the order of 4,000 and 15,000 mg/ L, respectively.

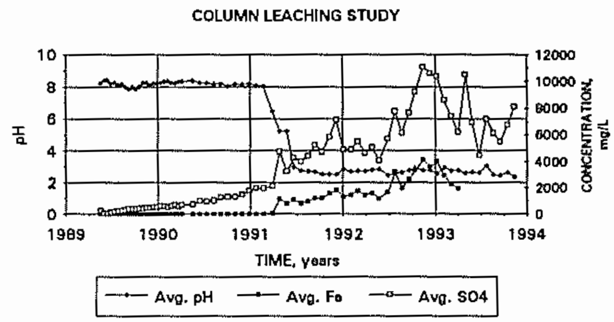

Figure 5. Leaching profiles of coarse pyritic uranium tailings mixed with 7.5% +6.5 mm size limestone (columns 18 and 19), variations of pH, Fe and SO_4^{-2} with time.

Columns 18 and 19, which contained coarse tailings and 7.5% limestone, also produced acidic drainage, but its onset was delayed for a period of one year from the start of acidic drainage from control-2 columns (Fig. 5). The acidic discharge rates were also lower for these columns than control-2 columns. Although sufficient limestone alkalinity was present in these columns, the data showed that it was not readily available for total acid neutralization probably because of its coarse grain size and surface armouring. The leachates were also saturated with respect to gypsum (Ca concentrations ~600 mg/L).

For the entire leaching period, no acidic drainages were observed from columns 3 to 15 which contained total mill tailings mixed with 7.5% limestone and columns 20 and 21 which contained coarse tailings and 7.5% wet ground limestone. The leachates were slightly alkaline (pH ~ 8) and saturated with respect to gypsum, indicating that acid generation and its neutralization were active processes in these columns. Wet ground limestone, because of its particle size, provided sufficient alkalinity or high neutralization potential in preventing acidic drainage.

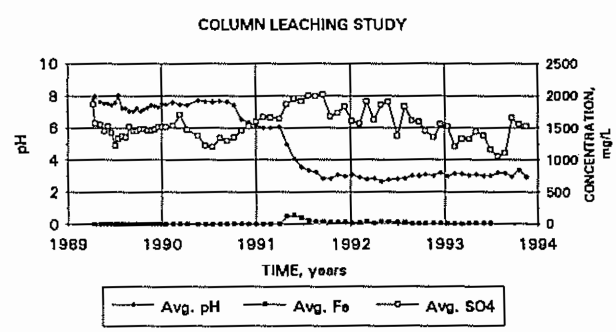

Figure 6. Leaching profiles of homogenized pyritic uranium total mill tailings , columns 1, 2 and 3 (control-1), variations of pH, Fe and SO_4^{-2} with time.

The control-1, columns 1 to 3, which contained homogenized total mill tailings also produced acidic drainages but at pH's ~ 3 containing lower concentrations of Fe and SO_4^{-2} than those for the control-2 columns (Fig. 6). The maximum Fe and SO_4^{-2} concentrations of the leachates were in the ranges of

50 to 400 mg/L and 1400 to 2800 mg/L, respectively. These values were significantly lower than corresponding concentrations of 10,000 to 12,000 mg/ L for Fe and 25,000 to 32,000 mg/L for SO_4^{-2} in control-2 column leachates. From the leachate Fe concentrations, it was calculated that for the homogenized total mill tailings (control-1), on an average a total of approximately 2.5 g or less than 0.7% of the total Fe contained in the tailings was oxidized and mobilized over the entire leaching period.

These tailings had a permeability on the order of $1x10^{-7}$ m/s and were characterized by a high capillary suction which, under the present water table configuration, maintained them near complete saturation conditions. The acid generation and metal migration rates for such tailings were thus low. Deposition of well mixed and homogenized total mill tailings without further segregation of its particle distribution could significantly reduce total acid generation and metal loadings.

In columns 22 to 24, which contained coarse tailings under water, soluble sulphates of Ca, Mg and trace amounts Mn leached out rapidly with approximately 50 L of water applied over an initial period of three months. The drainage from these columns remained at near neutral pH for a period of over three years and thereafter the pH dropped slightly to ~ 6.5 (Fig. 7).

Dissolved iron concentrations were either below detection or less than 1 mg/L for these columns for the initial three year period, then increased slowly to 1 to 2 mg/L for columns 22 and 23 and between 5 to 20 mg/L for column 24. Occasionally there have been flow control and drainage problems with the last column, which at times resulted in an excessive drainage, and hence, a drop in the water cover height over the tailings. The effluent concentrations of other metals during that period were less than 1 mg/L.

Because of its continuous flow, the water column above the tailings was well oxygenated (~ 8 to 10 mg/L of dissolved oxygen). In the drainage effluent, the dissolved oxygen concentrations were depleted to 2 to 4 mg/L. Consumption of oxygen by tailings and/or by other oxygen-consuming micro-organisms may lead to oxidation of tailings. The observed increase in the effluent Fe concentration could indicate the start of such a process which can only be verified by further monitoring.

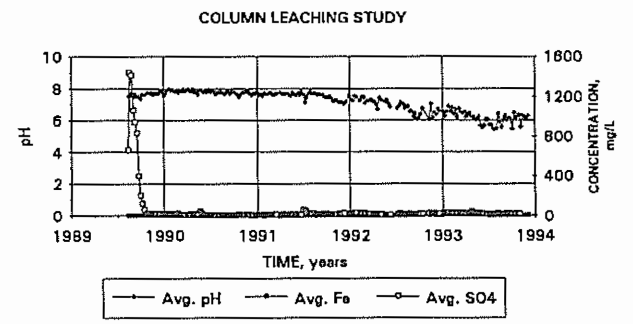

Figure 7. Leaching profiles of coarse pyritic uranium tailings under flooded conditions (columns 22,23 and 24), variations of pH, Fe and SO_4^{-2} with time.

With the depletion of dissolved Ca and Mg sulphates, the flooded columns also started to release increased concentrations of Ra-226, increasing from 1000 mBq/L to approximately 5,000 mBq/L.

Partially Submerged Tailings and Wetland Basin

Figure 8 shows the surface water quality profiles for pH, and dissolved Fe and SO_4^{-2} concentration for the Panel wetland basin along its length. The surface water in the basin was slightly to moderately acidic in the exposed and vegetated part of the basin with low to medium concentrations of dissolved solids (600 to 2000 mg/L), Fe (1 to 80 mg/L), Ca (150-500 mg/L) and SO_4^{-2} (50 to 1000 mg/L).

In the central and eastern parts of the basin, where a permanent water body existed, the surface water was near neutral to moderately alkaline, pH (6.2 to 9.8), with low concentrations of dissolved solids (100 to 300 mg/L), Fe (0.1

to 0.4 mg/L), Ca (30 to 50 mg/L), and SO_4^{-2} (50 to 100 mg/L). The surface water quality of the basin was seasonally independent except for pH in the central and eastern parts of the basin, which increased from 7.5 to 9.8 in the summer. The drainage water volume was estimated to be six times the volume of the water contained in the basin which represented a dilution factor of 6.

Figure 9 shows the ground water quality profiles for pH, and dissolved Fe and SO_4^{-2} concentrations at 1 m below the tailings/sediment surface. The ground water at shallow depths in the basin was mostly tailings derived pore water with slightly acidic to near neutral pH (5.7 to 7.8), low to moderate acidity (10 to 200 mg $CaCO_3$/L), low to high alkalinity (0 to 1400 mg $CaCO_3$/L), low to moderate Fe (0.5 to 70 mg/L), high Ca (400 to 800 mg/L), high SO_4^{-2} (800 to 1500 mg/L), and high Ra-226 (280 to 10,900 mBq/L). There was no seasonal dependence except for dissolved Fe concentrations, which were variable.

The soil substrate in the basin consisted mainly of tailings except near the far east end where the original peat sediment existed. The paste pH of the substrate varied from highly acidic to near neutral, 2.1 to 7.5. TF were present in all soil substrate and sediment samples from exposed and shallow water cover sites in the western part of the basin. At deep water sites near the center and towards the east, the bacterial counts for TF reduced drastically to insignificant numbers (0 to 100 MNP). Sulphate Reducing Bacteria (SRB) populations at these sites exceeded those for TF. Sulphate reduction was clearly evidenced by a strong smell of H_2S gas in the ground water at these locations.

Tailings were oxidizing in the exposed and shallow water covered and vegetated part of the basin. In exposed areas, oxidation was taking place near the surface in the unsaturated zone and in the vicinity of the water table. In vegetated areas, oxidation of both organic matter and tailings was taking place from surface to the root zone of the substrate. The tailings in the basin were fine grained and retained high degree of moisture saturation. The exposed tailings were thus oxidizing slowly producing moderately low pH (3.4 to 5.5) surface drainage and sub-surface water.

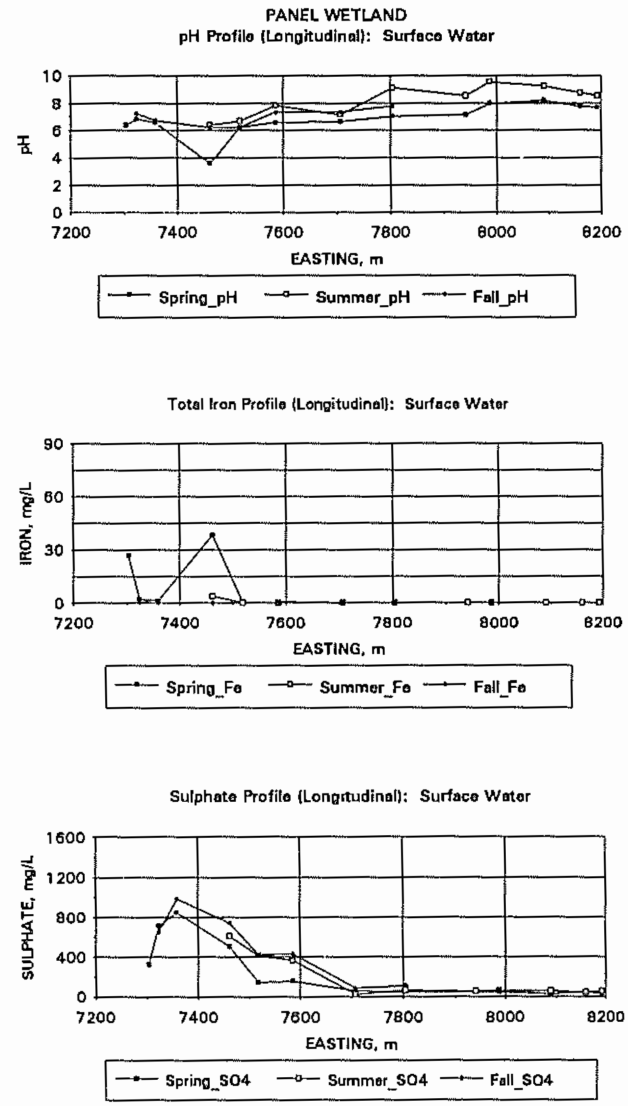

Figure 8. Panel wetland: surface water quality profiles and their seasonal variations for pH, Fe and SO_4^{-2}.

In the vegetated zone, no improvement in the quality of the surface water was noted as it drained from exposed areas towards the ponded water. Both the surface and ground water data indicated that the vegetation was associated with oxidation of the substrate rather than providing treatment for acid mine drainage. Some iron was precipitated and removed as ferric hydroxide in the vegetated zone.

The acidic surface drainage from exposed tailings and vegetated areas was diluted by a factor of 6 to 10 as it drained and mixed with the ponded water in the central part of the basin. The ground water from western and central sections of the basin also discharged in the ponded water where it neutralized the acidic surface water. Dissolved iron, aluminum and manganese were thus precipitated when the waters mixed.

The pH of the ponded water increased from 7.5 to 9.5 in the summer which was attributed to the bacterial reduction of nitrates in the organic sediments and photosynthetic process of some submergent vegetation (pond weeds) producing ammonia alkalinity and hydroxyl ions, respectively. This phenomenon needs to be further investigated.

From water quality data for surface drainage from exposed, shallow water cover and vegetated areas, and for pond water near the discharge end, the annual rates of total iron production, as a result of pyrite oxidation, and iron discharged from the system were calculated at 183.7 kg/y and 9 kg/y, respectively. These values corresponded to annual pyrite oxidation and iron discharge rates of 1.11 and 0.04 mg Fe per kg of tailings in the basin per year.

The existing wetlands system, because of its various physical , chemical and biological controls, retained or recycled approximately 96% of the total iron produced as a result of pyrite oxidation. It was estimated that at these rates, it will take approximately 31,700 years for all the pyrite to oxidize and 926,000 years for all the mobilized iron to leave the system. For calcium and Ra-226, the corresponding times for their complete removal from the system were calculated as approximately 708 and 40,000 years, respectively.

For cattails and grasses, the observed metal uptake levels were similar to those observed at other pyritic uranium tailings, base metal and gold tailings sites. High concentrations of Fe, Al, Ca and other heavy metals were observed in pond weeds and sphagnum moss, but their contribution to the total bio-mass production and metals retention and removal load was very small compared to cattails and grasses which were the most abundant species. In all vegetation species, the observed metal concentrations were below plant toxicity levels with little or no significant accumulation. There should, therefore, be little concern related to wind dispersion or animal forage. No symptoms of plant toxicity were observed in the basin.

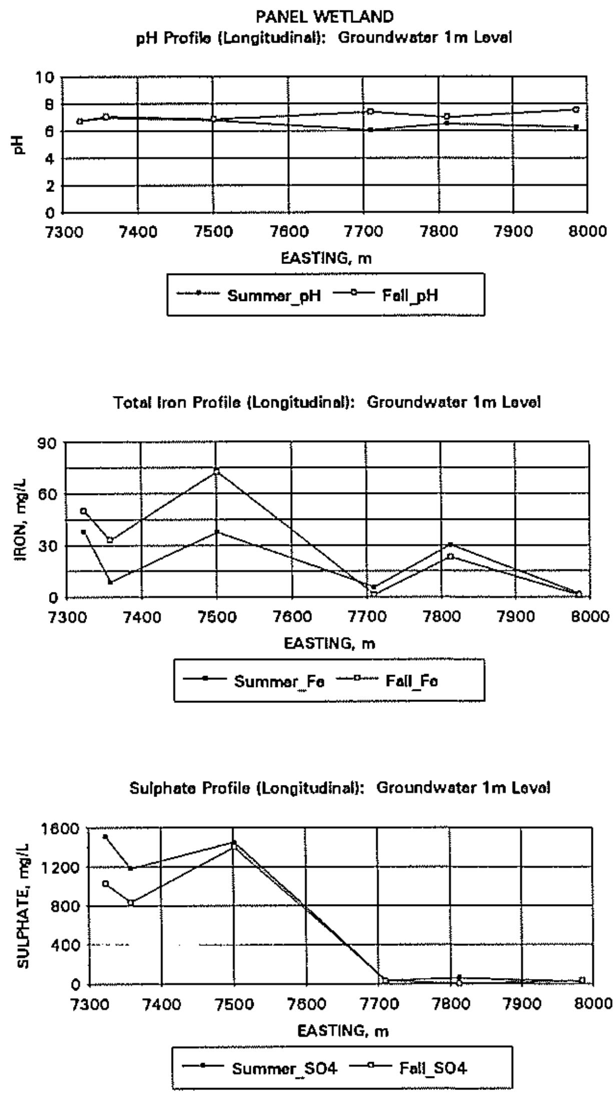

Figure 9. Panel wetland: ground water quality profiles and their seasonal variations for pH, Fe and SO_4^{-2}.

In general, the wetland/water system in the Panel wetland basin was effectively controlling the acidic drainage from partially submerged pyritic uranium tailings. The system should continue to function as long as the water cover is maintained. Its performance could be improved further if all the tailings were completely submerged.

Field Demonstration Test Site

Full scale flooding of the field demonstration test site, Cell #14, began in October 1992 using Gravel Pit Lake water. There was approximately 0.4 m of water cover over shallow areas at the end of flooding in 1992. In April 1993, the flooding of the cell resumed again. The site is being maintained at a constant water cover by periodically adding, when required, more water from Gravel Pit Lake. During 1993, a detailed water balance for the cell has been carried out and the site is being monitored continuously for its surface and ground water quality.

Figure 10 shows the surface water quality results for Cell #14 from October 1992 to September 1993. Previous to flooding in 1992, Cell #14 contained some water which had turned acidic with pH ~ 3.3 and acidity levels of 100 mg/L $CaCO_3$. The acidity was produced from exposed tailings in the basin which were not surface treated with limestone. Approximately 50% of the basin area had been leveled off and limestone was incorporated in the top 15 cm of the tailings to neutralize any acidity produced when exposed.

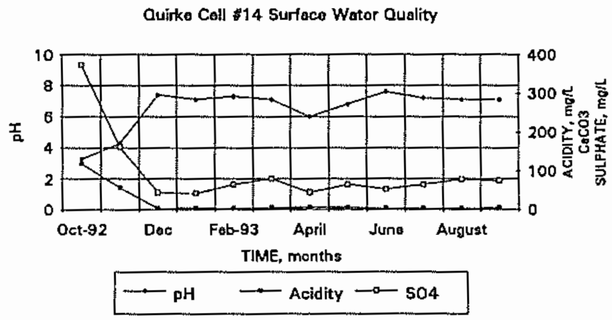

Figure 10. Surface water quality in the flooded Cell #14 at the Quirke mine tailings, variations of pH, acidity and SO_4^{-2}.

During the recent flooding, lime slurry was added to the inflow water for additional neutralization. At the end of flooding in December 1992, the surface water pH in the cell was 7.0 with acidity and alkalinity levels in the range of 6 to 8 mg/L $CaCO_3$. The water has maintained that general quality since. For comparison, the inflow water from Gravel Pit Lake had an average pH of 6.4, acidity of 5 mg/L $CaCO_3$, alkalinity of 4 mg/L $CaCO_3$, total dissolved solids at 40 mg/L and SO_4^{-2} concentration at 4 mg/L.

At the Quirke tailings site Cell #14, using a terraced cell concept, a shallow water cover has been successfully established and maintained for over a year. The site is being continuously monitored for its hydrological and water quality parameters throughout 1993.

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