SUBAQUEOUS DISPOSAL OF REACTIVE MINE WASTE: AN OVERVIEW AND UPDATE OF CASE STUDIES - MEND/CANADA[1]

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Abstract: A study of subaqueous disposal of reactive tailings started in 1988 with an initial overview of all known Canadian sites. A work plan was developed in 1989, which consisted of evaluating four lakes (Buttle and Benson Lakes, BC, Anderson and Mandy Lakes, MB) over 2-year periods for each lake. The initial year consisted of evaluating the biophysical features of each lake as a preliminary exercise in preparation for the second year of work. The second year consisted of performing detailed geochemical work on interstitial water at two or three sites in each lake. Each phase resulted in the preparation of a separate report.

At the request of MEND, a scientific and technical peer review of all work was done in 1992. This and presentations made to regulatory agencies provided feedback on the merits of use of subaqueous disposal to control reactive materials. Information deficiencies were also documented. Additional research work was undertaken to address these and support application of this method. A planning team of technical and scientific experts met in January 1993 and outlined a program which incorporated the peer review recommendations. Two lakes were selected to continue the field program and work has been undertaken to obtain additional data. Companion studies include technical literature reviews, comparison of field techniques, and the establishment of quality assurance and quality control programs.

A planned outcome is a manual on how to employ the technique for final disposal of reactive tailings.

Introduction

Worldwide research is in progress to find an economic and effective solution to acid mine drainage (AMD). Two coordinated programs have been initiated in Canada: the National Mine Environment Neutral Drainage (MEND) program and the British Columbia Mine Acid Drainage Task Force.

Disposal of tailings materials under a water barrier, such as in a lake, is thought to be one way to prevent acid generation, by preventing oxygen and bacterial action on the sulfide surfaces. Similar disposal may offer benefits in the handling of potentially acid-generating waste rock, although studies to date have not addressed this.

Random deposition of reactive tailings under water has been used at various mines in Canada. However, a thorough review has not been done of long-and short-term impacts at these historic sites, which could provide an understanding of the physical, chemical, and biological processes taking place.

This paper provides an overview of studies conducted and general results from each of four studied lakes, major collective results, and additional work required to develop criteria for applying this technology. Perhaps

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as important, the paper outlines the planning process used to ensure that the concepts are properly understood and fairly reviewed by all those involved.

Public Policy Issues

The concept of disposing of tailings materials in lakes is controversial and in the past has generally not been acceptable to regulatory agencies or the public. Consequently, this study was initiated with the recognition that the possible scenarios for the application of subaqueous disposal were: not being acceptable in any lake, being of limited application in biologically barren (low productivity) lakes, or being applicable to biologically productive lakes under rigorous conditions. These scenarios are still valid. However, the policy that sets acceptable scenarios is only partly determined by technical and scientific evidence. The need for a comprehensive review program and consequent endorsement from regulators and other sectors was recognized in the original planning of this project.

Project Evolution and Study Schedule

The subaqueous study started in 1988 with an initial overview report, consisting of a literature review and case histories of historic mining activities in Canada where subaqueous disposal had been used for tailings materials (Rescan, June 1989). The intention was to identify and assess sites where detailed studies could help develop complete case histories. This report provided a basis for subsequent work planned in 1989 and performed from 1989-92 on four lakes. Buttle and Benson Lakes in British Columbia and Mandy and Anderson Lakes in Manitoba. (Figure 1) Information on mine history and tailings characteristics were reported as part of each of these investigations (Rescan, March 1990a,b,c,d).

Table 1. Subaqueous tailings disposal project study lakes.

Lake	Mineral mined	Tailings deposited (mt)	Tailings minerals and metals	Tailings discharge
Mandy, MB	copper,zinc.	73,000	pyrite, chalcopyrite, sphalerite.	1943-45
Anderson, MB	copper,lead, zinc.	7,300,000	pyrite, pyrrhotite, galena, sphalerite, chalcopyrite, arsenopyrite.	1979-present
Buttle, BC	copper,lead, zinc.	5,000,000	chalcopyrite, pyrite, galena, sphalerite.	1966-84
Benson, BC	N/A	N/A	chalcopyrite, pyrite.	1962-73

N/A not available

Study consisted of two phases conducted over two consecutive years for each lake. The first phase consisted of a preliminary surveillance of the biophysical conditions in each. It was recognized that, to withstand rigorous scientific scrutiny, more comprehensive studies of the chemical and physical lake dynamics would ultimately be required. The second phase was a detailed sampling program to core sediments under controlled conditions that prevented the oxidation and changes in the chemistry of the pore water. These geochemistry studies were to determine the general reactivity of tailings materials at the sediment/water interface, as determined by the chemistry profiles through the upper sediment layers. If initial results indicated that the tailings had been rendered unreactive, it could be concluded that this disposal method had high potential for control of reactive tailings. Additional work would then be warranted to provide technical understanding of the overall natural system, and design and operating criteria for application of this methodology. The schedule for the studies is shown in Table 2.

Table 2. Study schedule

Topic	Phase	Year of Study	Phase	Year of Study
General overview of Canadian mines.	Planning	1988		
Buttle Lake.	Biophysics	pre 1989	Geochemistry	1989
Mandy Lake.	Biophysics	1989	Geochemistry	1990
Anderson Lake.	Biophysics	1989	Geochemistry	1990
Benson Lake.	Biophysics	1990	Geochemistry	1991

Study Results

Study results have been compiled (Rescan March 1990a,b,c,d) and summarized (Pederson et al. 1991).

Mandy Lake Studies

The preliminary studies (Rescan March 1990a) provided numerous observations:

- Mandy Lake is a small meso-eutrophic lake (area 239,000 m^2) with a mean depth of 3.6 m.
- Water quality in the lake was good and metals release from sediments appears to be minimal.
- Mandy Lake has diverse and abundant biota.
- Metals do not appear to be bioaccumulating in fish.
- Although metal levels are elevated in sediments in areas where tailings were deposited, an organic layer covering these sediments appears to reduce oxygen concentrations at the water-sediment interface and provide a barrier to metal release.
- Mandy Lake has rehabilitated naturally and speculation is that this will continue to do so.

The detailed geochemical studies (Rescan September 1990b) revealed the following:

- Despite the cessation of mining many years previous, tailings are widely distributed (possibly owing to slumping of the tailings fan) in modern sediments on the lake floor.
- Natural sediments underlying the tailings are organic-rich.
- The tailings-bearing deposits are suboxic or anoxic at very shallow depth below the sediment/water interface. Near shore, oxic conditions are indicated in at least the upper 5 mm.
- Concentrations of Zn, Cu and Pb in pore waters are very low. There is no apparent outflow of metals from the mixed tailings and natural organic-rich sediments.
- Tailings on the lake floor show little or no evidence of chemical reaction 46 yr after discharge.

Anderson Lake Studies

The preliminary studies (Rescan March 1990b) showed the following:

- Anderson Lake is a small biologically productive (meso-eutrophic) lake with a mean depth of 2.1 m.
- Present tailings discharges are adversely affecting water quality near the outfall and to a lesser extent in the whole lake. Drainage from exposed tailings (access roads) adjacent to the lake probably contributes to deterioration of water quality, as do hydroxide salts suspended in the water used to transport tailings to the lake. The relative contribution of these factors has not been determined.
- Petrographic and mineralogical examination of submerged and fresh tailings indicated a high sulfide content, mainly pyrite, and little oxidation of the sulfides.
- Benthic invertebrate densities were generally lowest near the tailings discharge point but comparable to those observed prior to tailings deposition. Although natural sediments near the outfall are initially buried by the tailings discharge, a veneer of organic material is deposited over time allowing benthic communities to re-establish.
- Fisheries resources in the lake have always been limited, possibly owing to winter kills or restricted stream access to the lake. Metal levels were higher in fish near the tailings outfall, particularly for Cu, Pb and Zn. High Zn in the fish correspond to high levels in the sediments.

The detailed geochemical studies (Rescan September 1990a) revealed:

- Mine tailings are widely distributed on the floor of Anderson Lake, not only near the discharge outfall but also in distal regions some 2 km from the discharge.
- Natural sediments underlying the tailings are extremely organic-rich.
- Tailings and sediments are suboxic or anoxic at very shallow depths below the sediment-water interface.
- Dissolved metals and sulfate are high in Anderson Lake, reflecting contamination from tailings slurry water and non-tailings sources.
- Despite high metal levels in lake water, metals in pore waters of both tailings and natural sediments are extremely low. This depletion must reflect continuous removal of metals from interstitial solution at very shallow depths at all sites.
- There is no evidence that tailings on the lake floor are releasing Zn, Cu or Pb to the overlying water. In fact, metals may be diffusing into the tailings and natural sediments from metal-rich bottom water.
- Once tailings discharge to Anderson Lake stops, organic-rich deposits will likely progressively blanket the tailings, ensuring that they remain stored in an anoxic state.

Buttle Lake Studies

A preliminary information base on Buttle Lake (Rescan March 1990a), compiled prior to 1988, allowed immediate planning for geochemistry work which was conducted in 1989. The results were:

- Buttle Lake is oligotrophic and is 35 km long. The tailings deposit is in the south basin (7 km long with maximum depth of 87 m), separate and effectively confined from the north basin by a shallow sill.
- Tailings are widely distributed across the south basin, and are being covered with a veneer of organic-rich sediments at a rate of about 4 mm $year^{-1}$. High solid-phase metal concentrations are still observed in the upper 5 mm, which presumably reflects upward mixing of tailings by burrowing infauna.
- The deposits are anoxic below depths of about 2 or 3 cm.
- Dissolved metals levels in pore waters in methane-bearing natural sediments underlying the tailings are extremely low, probably due to precipitation of authigenic sulfide minerals.

- Dissolution of Fe oxyhydroxides may be releasing heavy metals to interstitial waters at shallow depths. However, an Fe and Mn oxide-rich veneer at the core top is providing an absorbent veil which reduces upward diffusion of dissolved heavy metals from enriched zones below.
- In south basin deep water, metals are diffusing into the tailings; at other locations, there are very small effluxes of metals in most cases. The largest efflux - Zn - could increase the steady-state Zn content in deep water by <0.2 parts per trillion.
- Now-buried tailings in the south basin had a negligible impact on water quality.

Benson Lake Studies

Background studies (Rescan March 1990c) characterized the lake adequately for additional geochemistry studies. The results of this work were:

- Benson Lake is a reasonably small, deep (mean depth 25.5 m) soft-water oligotrophic coastal lake.
- Studies in 1967 and 1973 found the lake bottom covered by tailings and devoid of benthic life. The outlet river had a fine sediment bottom layer and was populated by turbid-water benthic invertebrates.
- The lake supports some fish, which feed on drift organisms carried by lake inlet streams. The fish have high zinc in their tissues; equally high concentrations were found in a nearby control lake (Keogh Lake).

Benson Lake studies (Rescan June 1992) followed the format of the other studies. Conclusions were:

- Pyrite-rich mine tailings were discharged into Benson Lake from 1962 to 1973.
- A thin veneer of manganese and iron oxyhydroxide-rich material mantles the deposits; natural sediments are suboxic or anoxic at very shallow depths below lake bottom.
- Dissolved metals are low in bottom waters; there is no evidence of efflux to overlying water.

Summary of Results

The following basic conclusions were developed from the initial studies of the four lakes:

- Reactivity of the tailing materials is low as illustrated by extremely low dissolved metals in interstitial pore water. This verifies the hypothesis of reduced reactivity due to submerged conditions.
- Preliminary estimates of metal flux rates from the sediments indicate that these are low and should have no significant impact on overall metal balances within the lakes.
- Basic physical conditions detected in each lake have allowed estimates of the chemical mechanisms acting to maintain low-reactivity in and around the tailings deposits.
- Biological communities exist in some of the lakes.
- Metal levels in water and fish are variable and depend on the history of the lake (active or abandoned). Some levels appear to be elevated while others are typical of background levels.

Scientific, Regulatory and Public Review; Planning Group

A strategy was evidently needed to review the results of studies. Elements were determined to include scientific peer review of completed and proposed work, government regulatory agency review of work and final reports, and public review of the overall concept and scientific database.

Following completion of work through 1991, the MEND Board of Directors requested a peer review of all work. Clearly, if subaqueous disposal is to be used, it has to be scientifically sound and well justified.

The Rawson Academy of Aquatic Science, an independent consulting group, was chosen to do the review. They, in turn, chose an expert panel (Appendix A). The objectives of the review were to conduct a technical and scientific review of all of the MEND studies on subaqueous disposal of tailings and to define additional requirements to establish the scientific credibility of the approach.

A scope for the review was developed (Rescan July 1992); the review established a number of key points.

- Subaqueous disposal of tailings appears to offer physico-chemical advantages over terrestrial disposal, particularly in preventing and/or controlling sulphide oxidation and generation of acid waters.
- The process of tailings disposal is potentially highly disruptive of lake ecosystems. Natural sedimentation would take decades to insulate the ecosystem from the potential influence of the tailings. However, remedial measures could perhaps limit the extent of impact and accelerate recovery.
- The MEND literature review of geochemical processes was comprehensive through 1992, but was inadequate on toxic effects, particle behaviour, field and analytical techniques, biological indices of whole lake effects, and the role of wetlands in metal stabilization.
- Background limnologies of the case-study lakes were adequate for gross comparisons but did not support clear interpretation of cause and effect.
- Data were sufficient to assess whether reactivity of tailings disposed under water remained low; the data were insufficient to address effects during disposal and long term ecosystem adjustment.
- Methods used for porewater extractions from the cores, and quality assurance/quality control (QA/QC) were of concern.
- More detailed studies of metal fluxes, rates of accumulation, whole lake response and seasonal variations should be done.
- Preferences for subaqueous tailings disposal would be, in order, infilling a small headwater lake, disposal in a manmade structure, and in-lake disposal where tailings represent a small part of total lake volume.

Following the peer review, presentations on the studies were made at a meeting of representatives of various federal and provincial agencies. No "fatal" technical flaw was identified by the representatives. Consequently, it was felt additional research work could proceed to address peer recommendations.

Future information sessions involving regulators will be held when enough new information is available to present. Meetings with the public and other interest groups are felt to be premature at this time.

A Planning Group of technical and scientific experts (Appendix B) has been assembled to ensure that the objectives of the program are being met. This group is not to be concerned about program costs or the sources of finances while developing a sound and complete program.

The planning team has focused on field and analytical techniques to improve measurement of metal fluxes at the sediment/water interface, and selected two lakes for continuing study: Buttle as a deep lake and Anderson as an active, relatively shallow site. The group planned a program to clarify understanding of the reactivity of the substrate, and to study the seasonal spectrum. Improved techniques to estimates metal flux, involving use of small dialysis chambers, or peepers, located at the water/tailings interface. The group also recommended at least three locations would be sampled in each lake for each sampling campaign, and duplicates of all cores and peepers would be required.

1993 Field Program

As recommended in the peer review, a literature review on metal toxicology was completed. (INRS-EAU March 1993).

Based on the Planning Group directions, detailed design was done for the 1993 field and laboratory programs. Formal documents for each study campaign were reviewed and signed-off by each group member. Through this, consensus on campaign strategy and technical details was achieved prior to field work. Each work plan had a detailed work scope and methods manual for field work (Rescan February 1993, Rescan et al. July 1993, Rescan October 1993) and QA/QC procedures for field methods. An equally detailed lab QA/QC manual (ASL and U BC March 1993) was prepared; this is the subject of a separate paper (Maynard April 1994).

Three major campaigns were conducted in 1993 - two on Anderson Lake and one on Buttle Lake. Timing of the Anderson campaigns was critical in that the metallurgical operation using the site, the only active disposal site available for study, was scheduled for shutdown in late 1993/early 1994. A further post-production campaign will be performed after operations cease. For Buttle, a fall 1993 study was conducted and a spring 1994 program is scheduled. Another - probably during winter 1994-95 - will complete seasonal gaps.

The various campaigns include water column sampling, sediment cores, and peepers, as well as measurement of field parameters. A special water column sampler was designed and applied to the winter and summer campaigns at Anderson Lake. A group of special studies is being run as well. At Anderson, manual diurnal temperature profiles are being obtained, and in-situ recording termister strings will provide a full data set of water column temperature profiles with changing seasons. Two weather stations erected to obtain temperature, wind and precipitation data, will assist in interpreting the other data and in developing future generic application criteria. For both the Buttle and Anderson programs, a cross-comparison is being done of two methods of handling samples from the peepers: under inert atmosphere or sample extraction under normal atmosphere. Preliminary results from the 1993 programs, particularly the high-resolution water column sampling, confirm the tentative findings from earlier studies (Pederson et al. April 1994).

Budget

Due to the duplicity of data collection required for QA/QC, recent campaigns cost approximately $0.25 million (Canadian) each. The completed program will, in total, cost $1.5 to $2.0 million (Canadian).

Proposed Additional Future Work

The basic elements of the original hypothesis have been successfully addressed, as the reactivity of the tailings studied has been demonstrated to be low. In addition, biological communities have been demonstrated to be present in the adjacent environment in some of the lakes studied. To more fully understand these systems, and to develop case history information that will withstand scientific, regulatory and public scrutiny, additional extensive technical supportive work is underway. Ideally, additional disposal lakes in other geographical and geological settings and operating mines utilizing a biological-active lake could be studied. Appropriate sites have not been found, and are not part of current planning.

Design and operating criteria for an application manual is also required. With continuing positive results from recent study campaigns, work on this should commence in 1994 in parallel with ongoing studies.

Conclusions

Completed work has demonstrated that subaqueous disposal has technical justification. Additional work requirements have been outlined, and are underway. Additional case histories would be useful to extend the findings geologically and geographically, but candidate lakes for study have not been found.

Scientific and regulatory review and planning is a major part of the program, and is assisting in achieving a fair and objective study of the concept and methodology for subaqueous disposal of reactive tailings in lakes. Though complex, it is as important as the technical study for the acceptance and application of this promising method of acid drainage control, and will continue over the entire program to the final objective of a design and application manual.

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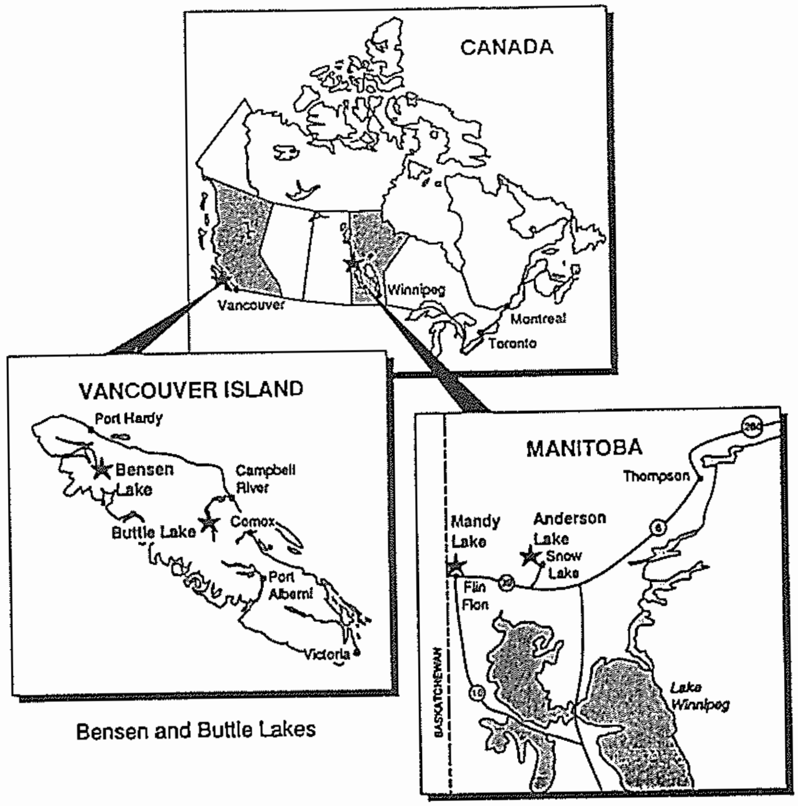

Figure 1. Location of project sites

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