Case Study Assessment – Subaqueous Tailings Disposal in Mandy Lake Flin Flon, Manitoba

MEND Report 9.2b

This work was done on behalf of MEND and sponsored by Environment Canada

November 2006

SNC·LAVALIN

Case Study Assessment – Subaqueous Tailings Disposal in Mandy Lake Flin Flon, Manitoba

FINAL Report

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EXECUTIVE SUMMARY

Mandy Lake is a small and inactive lacustrine subaqueous tailings disposal site located near the town of Flin Flon, Manitoba, Canada. During 1943-1944, 73,000 metric tonnes of high-sulphur base metal tailings from the nearby Mandy Mine were discharged into the lake.

The Mandy Lake site has been the object of two monitoring campaigns since it ceased its activities. The first one, in 1975-1976, focused on characterizing tailings material, water and vegetation. The second investigation, in 1989-1990, addressed in detail water quality, sediments composition and biota. It also emphasized the geochemistry of tailings and tailings interstitial water.

Both studies arrived at similar conclusions, namely that despite high sulphide and metal contents in the tailings, water quality in the lake is good and there is diverse and abundant aquatic life. The lake has rehabilitated naturally and will probably continue to do so.

Reclamation works at Mandy Mine were restricted to the former pit, buildings and causeway. No reclamation was carried out on the lake.

A comparison with other Canadian lakes used as tailings disposal sites reveals that the major impact from this practice occurs during the actual depositional stage; once discharge has stopped, the ecosystems gradually recover. Future investigations should therefore pay special attention to the recovery rate of lacustrine ecosystems so as to fully document the return of such disposal facilities to natural conditions.

Key words: Subaqueous tailings disposal, acidic drainage, Mandy Lake, sulphidic tailings, oxidation, mine reclamation.

SOMMAIRE

Le lac Mandy est un petit site lacustre d'immersion de résidus miniers inactif situé près de la municipalité de Flin Flon (Manitoba), au Canada. Entre 1943 et 1944, 73 000 tonnes métriques de résidus miniers à forte teneur en sulfure, provenant de la mine Mandy à proximité, ont été déversées dans le lac.

Le site du lac Mandy a fait l'objet de deux campagnes de suivi depuis la fin des activités. La première, réalisée en 1975-1976, portait principalement sur la caractérisation des résidus, de l'eau et de la végétation. La deuxième, menée en 1989-1990, a étudié en détail la qualité de l'eau, la composition des sédiments et le biote. Elle a aussi mis l'accent sur la géochimie des résidus et l'eau interstitielle des résidus miniers.

Les deux études ont abouti aux mêmes conclusions, c'est-à-dire que malgré la haute teneur en sulfure et en métaux des résidus, la qualité de l'eau du lac est bonne et la vie aquatique y est abondante et diversifiée. Le lac s'est rétabli naturellement et il continuera probablement de le faire.

Les travaux de remise en état de la mine Mandy se sont limités à l'ancienne fosse, aux bâtiments et au pont-jetée. Le lac n'a pas été remis en état.

Une comparaison avec d'autres lacs canadiens utilisés comme parc à résidus révèle que les principales répercussions de cette pratique ont lieu durant l'immersion elle-même; une fois l'élimination des résidus terminée, les écosystèmes se rétablissent peu à peu. Ainsi, les futures études devraient s'attarder au taux de récupération des écosystèmes lacustres de façon à bien documenter le processus de rétablissement de tels sites.

Mots clés : disposition subaquatique, drainage acide, Lac Mandy, résidus sulfurés, oxydation, restauration des sites miniers.

The case study for Mandy Lake was completed in 2004; with the report finalized in 2006. It was part of a series of case studies that were to be compiled and released on CD-ROM. Approval for publication was not obtained for some of the case studies, and in 2010 the MEND Steering Committee recommended posting the completed studies on the MEND web site.

As such, the data for this case study was collected up to 2003 from Hudson Bay Mining & Smelting Co, Ltd. Even though this case study is somewhat dated, it provides relevant and useful information on subaqueous tailings disposal and ecosystem recovery.

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1. INTRODUCTION

Natural Resources Canada (NRCan) has commissioned GEOCON, a wholly-owned subsidiary of SNC-LAVALIN ENVIRONMENT INC., to perform a series of case studies on 5 different reclaimed mine sites specially selected because of the reclamation technologies applied.

This study addresses the subaqueous disposal of high-sulphur-base metal tailings into Mandy Lake (Manitoba, Canada) during 1943-1944. Although it was likely that the deposition of sulphide-rich tailings under water at the time was mainly for convenient reasons and not for controlling acid generation (little, if anything, was known about acid mine drainage (AMD) in 1943), the site provides valuable information regarding the long-term performance of underwater deposited reactive tailings in natural lakes.

After a thorough description of the existing biological, chemical and physical conditions prevailing at the site 60 years after the last tailings were deposited in Mandy Lake, the discussion will focus on identifying the performance highlights and selecting the preferred orientations for further monitoring and studies, in order to fully evaluate the impact of this technology on natural eco-systems and to potentially make it more environmentally and socially acceptable.

2. SITE CHARACTERISTICS

Most of the description that follows has been taken from the historic site description by Hamilton and Fraser (1978) dealing with vegetation cover of the underwater deposited tailings in Mandy Lake.

2.1 Location

Mandy Lake, an inactive subaqueous tailings disposal, is located in central Manitoba, 5.5 km south of the town of Flin Flon and less than 1 km from the border with the Province of Saskatchewan (Figure 2-1). The site is owned by Hudson Bay Mining and Smelting Co. Ltd. The abandoned Mandy Mine site is located on what used to be a peninsula in the northwest arm of Schist Lake. At present there is a causeway between the tip of the peninsula and shore, creating Mandy Lake, a small lake where tailings were deposited and impounded (Figure 2-2). The water level in Mandy Lake is slightly above that of

Schist Lake, into which it drains. Mandy Lake receives drainage from Phantom Lake to the west, as well as spring water.

Precambrian shield formations underlie most of the area, with rock formations largely controlling drainage. There are numerous moraines and eskers from glaciation. Many wetlands such as bogs, fens, swamps and marshes occur in this region. The dominant tree species are spruce, jack pine, poplar and birch. Common wildlife includes moose, black bear, beaver and spruce grouse. Most people make their living by hunting, trapping, fishing, lumbering or mining.

2.2 History

The Mandy Mine site was one of the first mineral claims to be worked in the Flin Flon area. The ore vein, comprised of solid chalcopyrite averaging 20% copper with significant amounts of gold and silver and surrounded by lower grade sulphides, was mined from 1917 to 1920, and the ore was transported to Trail, British Columbia. In 1920, the richest veins were exhausted and the mine closed. The deposit was again mined between April 1943 and December 1944. The ore was milled on site, and the tailings were deposited into the shallow, semi-confined Mandy Lake adjacent to the property. It is estimated that approximately 73,000 metric tonnes of high-sulphur base metal tailings were discharged into the lake.

The majority of the tailings material has been underwater for 60 years, where it was placed in a fan-shaped deposit from a single launder. Some tailings were spilled along the shore where they remained. The deposited tailings feature a gradual slope away from the shore ranging from 30 to 107 cm below the water surface, then drop off abruptly into 5 m deep water. Below the drop-off point, tailings are covered in soft black sediment with a slightly septic odor.

Little data is available on the tailings at the time of their deposition, except that the sulphide tailings mineral was predominantly pyrite, sulphur content was in the 15-17 percent range and appreciable levels of zinc and copper remained in the material.

2.3 Climate

The average temperature at the site in January is -17 degrees Celsius, while the temperature averages 24 degrees Celsius in July. Total annual precipitation averages 480 mm, with 343 mm of rainfall per year and 137 mm (water equivalent) snowfall precipitation, occurring mostly from November through March.

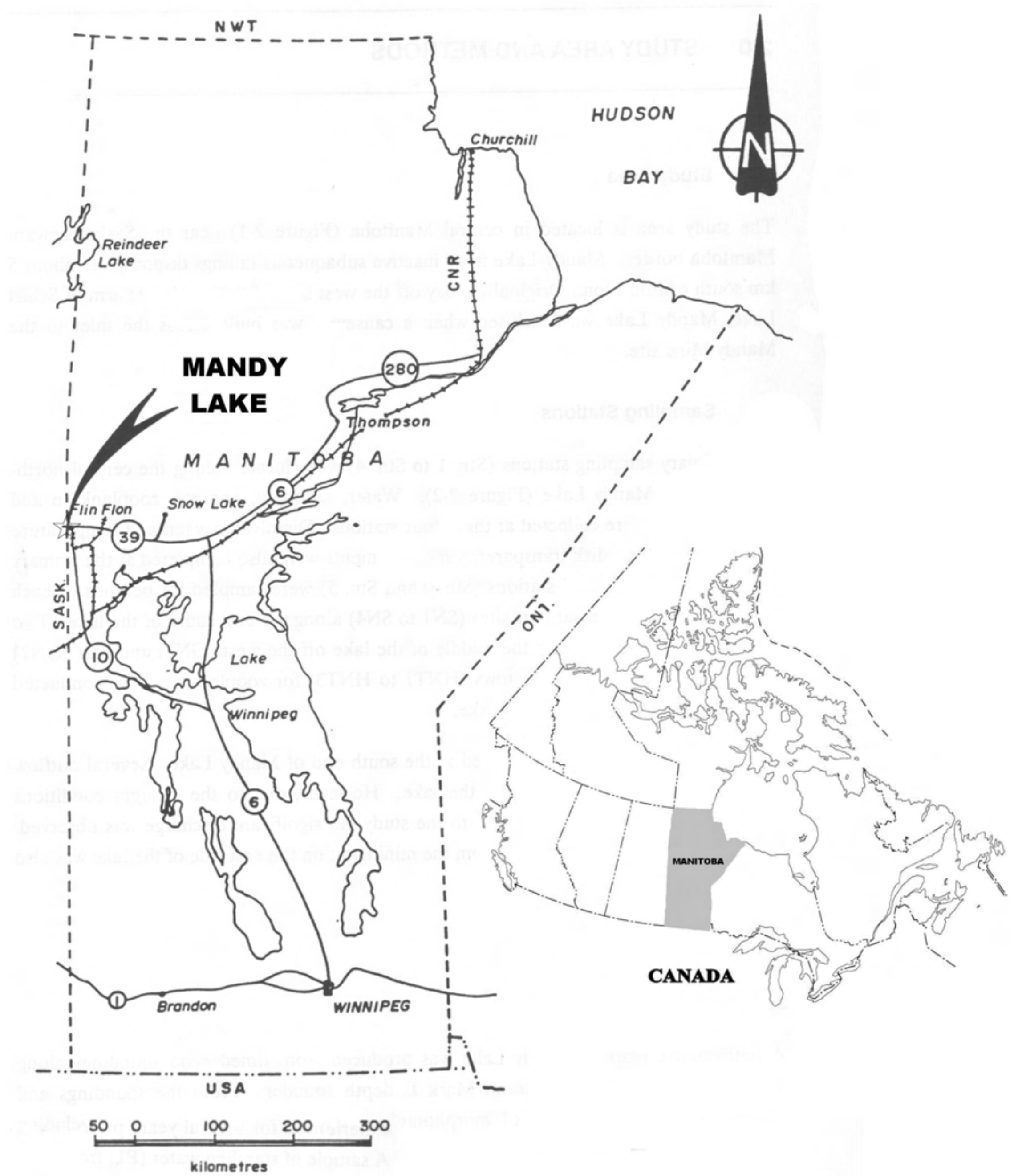


Figure 2-1 - Location Map

(Modified from Rescan,1990a)

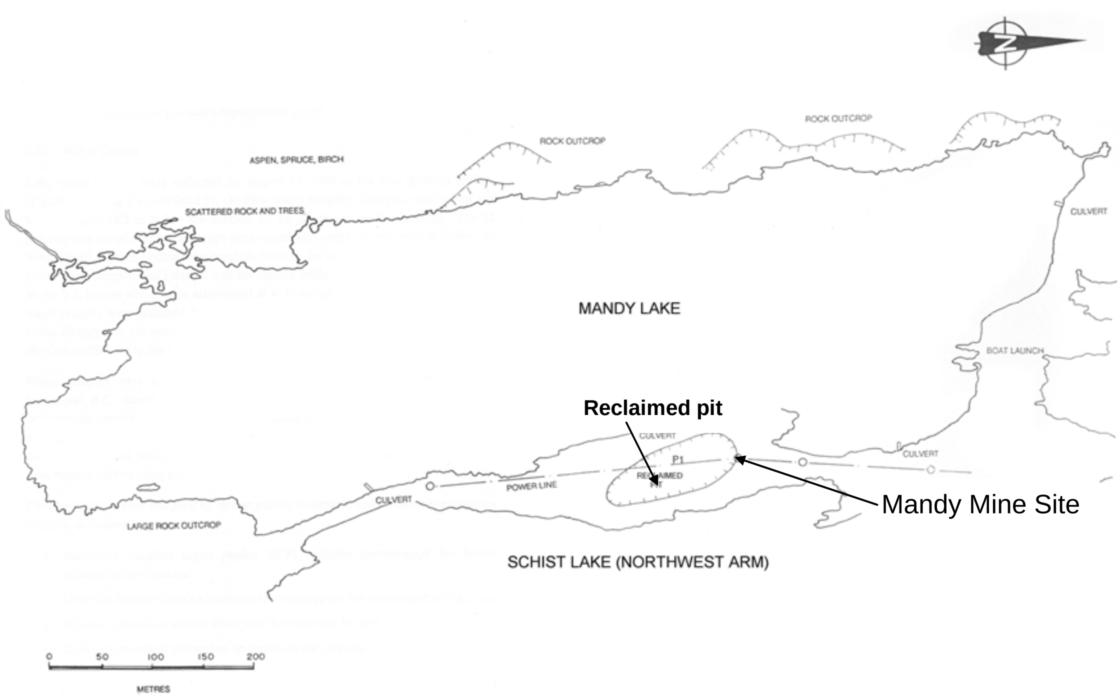


Figure 2-2 - Mandy Lake Site

(Modified from Rescan 1990a)

3. CONCEPTUAL CONSIDERATIONS OF SUBAQUEOUS DISPOSAL OF REACTIVE MINE WASTES

Disposal of tailings materials under a water cover, such as in a lake, is thought to be a way to minimize acid generation, by reducing oxygen diffusion and bacterial action on the sulphide surfaces.

The problem with most base-metal mine tailings is the high sulphur content. In these materials, acid production is the major detrimental factor that has to be controlled before a rehabilitation scheme is effective. The reaction involved in acid production is the well-known oxidation of sulphidic material to form sulphuric acid (Equation 3-1), hydrous iron oxides and related sulphate salts (Equation 3-2).

Equation 3-1
Pyrite Oxidation

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4$$

Equation 3-2
Oxidation of Ferrous Sulphate through Bacterial Action

$$4FeSO_4 + 2H_2SO_4 + O_2 \rightarrow 2Fe_2(SO_4)_3 + 2H_2O$$

Thiobacillus ferrooxidans

As shown in Equation 3-1, oxygen and water are required for the reaction to take place; if oxygen is unavailable, the sulphidic materials should remain in an unaltered state with no decrease in pH or increase in soluble constituents.

Theoretically, underwater deposition of tailings minimizes oxygen ingress to the bulk tailings. However, there is always some dissolved oxygen present in the well mixed water cover, especially near the air/water interface (MEND, 2002). Climatic factors, namely wind speed, precipitation and temperature, will also influence how much and at what depth oxygen is present in the lake (Figure 3-1). Wind-induced and thermal currents dominate oxygen transport within the water cover as oxygen molecular diffusion is an extremely slow process. Wind also plays an important role in the potential resuspension of tailings, exposing them to oxidation in the upper section of the water column (Yanful, Verma, 1999). Oxygen is also present in groundwater and may be carried into the tailings through groundwater pathways.

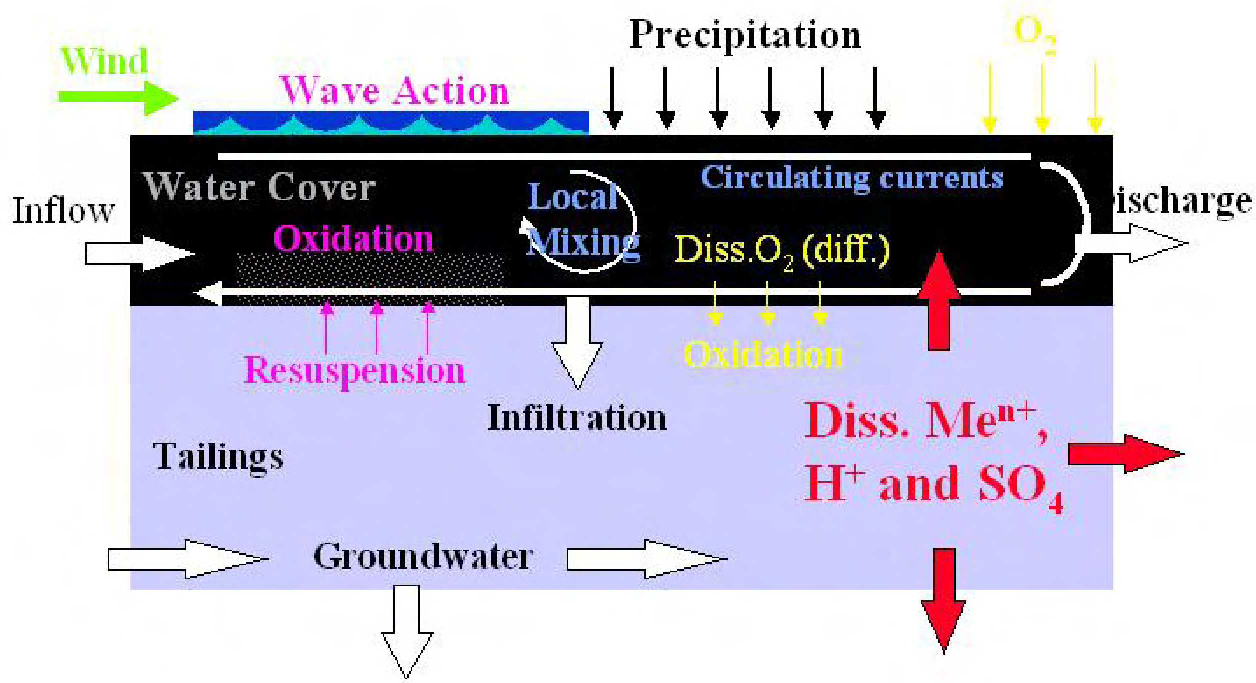
Oxygen availability to tailings is dependent on the oxygen concentration gradient across the water/tailings interface and within the tailings, the oxidation rate of sulphides, and the porosity and tortuosity of the tailings. The existence of an oxidized layer of tailings, other inert materials or organic deposits at this interface could significantly cut down the oxygen flux to the reactive tailings (Li *et al.*, 1997).

Therefore, if the availability of dissolved oxygen to the underwater deposited tailings can be minimized by means of a sufficiently deep-water cover, the amount of oxidation that will occur would be minimal and only at the surface of the tailings. The water quality would be greatly improved and aquatic vegetation and other biota would include species that are pollution intolerant (Fraser and Robertson, 1994).

The practice of underwater disposal of tailings in natural lakes is controversial and in the past has generally not been acceptable to regulatory agencies or the public (Fraser and Robertson, 1994). A major concern regarding subaqueous disposal of reactive tailings in natural lakes is the disruption of aquatic ecosystems during the deposition period and the time required for their recovery, if such a recovery can take place (Rawson Academy of Aquatic Sciences (RAAS), 1992). It might be unreasonable to expect a full retention of productive biological use during the initial deposition of tailings. On the other hand, it may be argued that using a natural lake might be preferable to a man-made water impoundment, owing to the necessary long term post-closure stability monitoring required by this type of facility (Vick, 2000).

Even if it is scientifically demonstrated that underwater disposal of mine tailings in natural water bodies is environmentally innocuous, it is doubtful that this tailings disposal technology (when applied to natural lakes) will become, in the short-term, a true option in the prevention of ARD from tailings. Public opposition to such a practice remains the main challenge to its broader application.

Figure 3-1
Processes Affecting Subaqueous Sulphide Oxidation and Water Quality
(After Li et al., 1997)



4. CHARACTERIZATION STUDIES

As expected, no characterization data on Mandy Mine tailings at the time of their deposition or later are available. In 1944, such characterization was probably not a usual practice in the mining industry. Environmental concerns were non-existent and acid rock drainage was not formally known. The decision to discharge the tailings into the nearby Mandy Lake was obviously made for reasons of convenience and economics common sense (at the time), because it obviated the need to construct tailings dams.

The only known information about the original tailings composition is derived from the gross ore composition and was described in section 2.

5. SELECTION AND IMPLEMENTATION OF THE REHABILITATION METHOD

Mandy Lake as a tailings disposal area has not undergone rehabilitation work. Following the 1975-1976 and 1989-1990 investigation programs (see section 6 below), which revealed that the lake's water quality is high and biota abundant, Hudson Bay Mining and Smelting Co. Ltd. proceeded to reclaim the Mandy Mine site. The open-pit water was treated with lime as the pit was being backfilled (using waste rock from nearby Schist Mine[1]). The pit was ultimately capped with a layer of clay. Foundations from the old mill were taken out and the causeway dyke was rebuilt and revegetated. No specific work was carried out on Mandy Lake tailings, studies having shown that underwater material had revegetated naturally (Hamilton and Fraser, 1978).

6. MONITORING PROGRAM AND PERFORMANCE TO DATE

The Mandy Lake site has been the object of two monitoring campaigns since it ceased its activities in 1944. The first investigation was carried out by Hudson Bay Mining and Smelting Co. Ltd., the owner of the site, in 1975-1976. That work focused on characterizing tailings material, water and aquatic vegetation (Hamilton and Fraser, 1978). Findings from this first investigation are described in section 6.1 below.

[1] Acid generation potential of Schist Mine waste rock is not known).

A second and more comprehensive study of Mandy Lake was undertaken in 1989 and 1990 by Rescan, as part of the Mine Environment Neutral Drainage (MEND) program. It assessed water quality, sediments composition and biota (benthos, phytoplankton, zooplankton, aquatic vegetation and fish). It also strongly emphasized the geochemistry of tailings and tailings interstitial water. Findings from this second investigation are described in section 6.2.

6.1 Findings of the 1975-1976 investigation

A comparison between underwater tailings and those tailings that remained on the shore after spillage shows that both are net acid producers (Table 6-1). By the time the 1975-1976 investigation was carried out, the submerged Mandy Lake tailings had been underwater for 32 years. Despite these apparently unfavorable factors, and with no expenditures on rehabilitation or site maintenance, water quality was found to be good and aquatic animal and insect life had moved into the tailings area. Vegetation had colonized the area and produced a mat of organic matter that covered the entire surface of the tailings material.

Table 6-1
Acid Generating Potential of Mandy Mine Tailings
(Modified from Hamilton and Fraser, 1978)

Parameter	Underwater	Shore
Original pH	6.7	4.4
Total sulphur (kg/tonne)	156	158
Acid production potential (kg/tonne) AP	475	484
Acid consuming ability (kg/tonne) NP	52	4
Net acid production (kg/tonne) AP-NP	424	480

Analyses of the submerged tailings (Table 6-2) indicated that there were differences in the chemical composition. Some of these differences could be attributed to the original composition of the material and some to the chemical changes that had occurred. Under oxidizing conditions, one would have expected the iron sulphides to be partially depleted. However, analysis showed that minimal oxidation had occurred. The iron was present as iron sulphide and the percentage of iron oxide and sulphate present was low, with shore samples slightly higher (Table 6-2).

Table 6-2
Composition of Tailings from Mandy Mine
(Modified from Hamilton and Fraser, 1978)

Constituent (%)	Underwater	Shore
Total iron	17.4	19.8
Iron (Fe_2O_3)	0.8	2.9
Total sulphur	15.5	15.8
Sulphide sulphur	15.4	15.5
Sulphate sulphur	0.03	0.30
Aluminum (Al_2O_3)	8.4	6.7
Silica (SiO_2)	35.7	37.7
Copper	0.91	2.70
Zinc	4.70	1.60
Lead	0.13	0.12
Cadmium	0.01	$<$ 0.01
Calcium	1.04	0.51
Magnesium	1.75	1.03

Another feature that would be expected from the oxidation of sulphide tailings is the presence of soluble salts, with corresponding effects on water quality, including a decrease in pH and an increase in electrical conductivity resulting from solubility of heavy metals and sulphates. Analyses of a 1:5 distilled water extractions of the tailings (Table 6-3) indicated that the oxidized shore samples had a lower pH, higher concentration of soluble metals and consequently higher conductivity.

Water samples showed similar quality in both inflow and discharge waters of Mandy Lake (Table 6-4), with the lake discharge waters having higher pH and conductivity but less sulphate. Water collected above the tailings surface had higher conductivity and zinc concentrations than inflow waters and lower zinc concentration than discharge waters. The increase in constituents of the outlet waters does not appear to be related to tailings deposited underwater.

Table 6-3
Soluble Constituents in a 1:5 Distilled Water Extractions of Tailings from Mandy Lake
(Modified from Hamilton and Fraser, 1978)

Constituent (mg/kg tailings)	Underwater	Shore
Iron	0.9	84.3
Copper	0.25	6.23
Zinc	15.5	44
Lead	0.35	1.05
Cadmium	0.05	0.28
Calcium	145	2.59
Magnesium	18	121
Sulphate	240	7.34
pH	6.9	4.9
Conductivity (μS/cm)	400	2450

Table 6-4
Quality of Inlet and Outlet Water at Mandy Lake
(Modified from Hamilton and Fraser, 1978)

Parameter	Inflow	Outflow	Above tailings
pH	7.6	7.7	7.7
Conductivity (μS/cm)	200	390	260
Copper (mg/l)	0.01	0.02	0.01
Zinc	0.14	0.13	0.20
Lead	0.01	0.01	0.01
Cadmium	0.01	0.01	0.01
Iron	0.11	0.23	0.05
Calcium	22.0	22.5	21.0
Magnesium	5.3	5.5	5.6
Sulphate	28.8	21.7	-

Photo 6-1 - Mandy Lake Mine Site after Reclamation in the Early 90's (Looking West) (Source: HBMS)

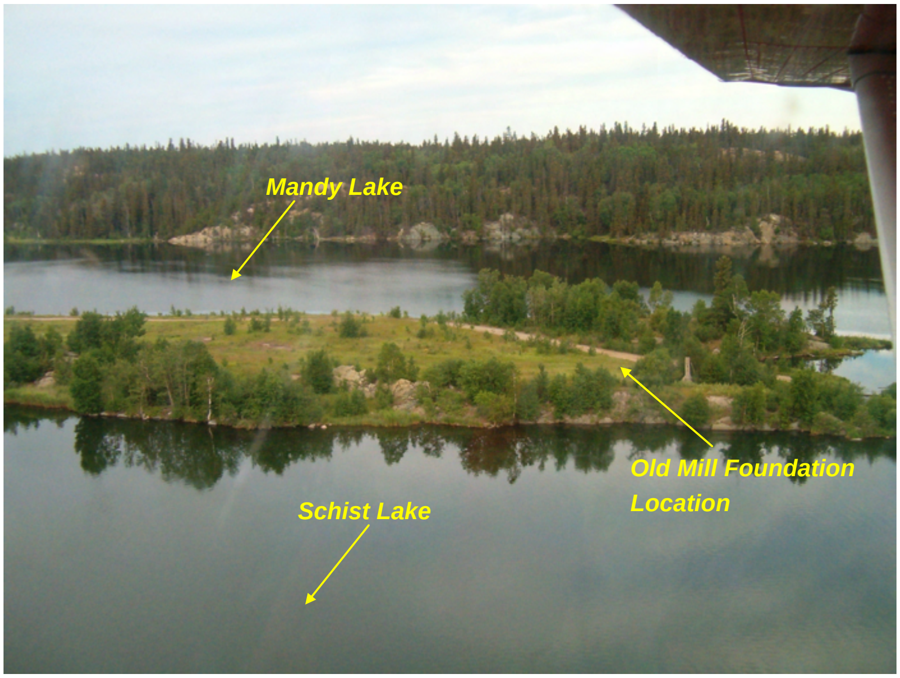


Photo 6-2 – Mandy Lake Mine after Reclamation in the Early 90's (Looking West) (Source: HBMS)

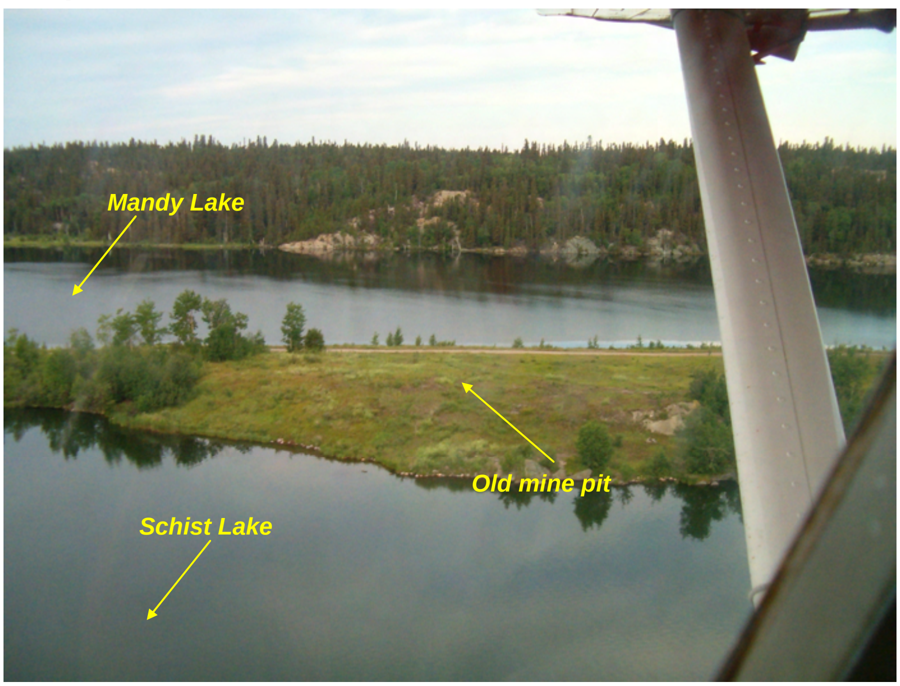


Photo 6-3 - Mandy Lake Mine After Reclamation in the Early 90's (Looking Northeast) (Source: HBMS)

Vegetation has established in the submerged tailings, but not on the tailings exposed to the atmosphere (on the shore). Commonly occurring species were sedges (*Carex* spp.), riverweed (*Podostemun ceratophyllum* Michx.) and spike rush (*Eleocharis* spp.). A layer of decaying organic material, up to 2.5 cm thick, underlaid the standing vegetation and covered 90-95% of the shallow sloping tailings area. In other areas of the lake, vegetation consisted of cattails (*Typha latifolia*), yellow pond lily (*Nuphar variegatum* Engelm), water smartweed (*Polygonum amphibium*), bulrushes (*Scirpus* spp.) and pondweeds (*Potamogeton* spp.).

Insects and other biota occurred universally through non-affected and tailings affected areas, and no distinction was determined between the two in terms of occurring species.

6.2 Findings of the 1989-1990 investigation

The 1989-1990 investigation on Mandy Lake can be divided into two (2) components:

- A preliminary study (Rescan 1990a).
- A detailed geochemical study on tailings and tailings interstitial water (Rescan 1990b).

Results from the 1989-1990 study provided more insight into the evolution of the Mandy Lake site but arrived at basically the same conclusions as the 1975-1976 investigation. The main observations are:

PRELIMINARY STUDY:

- 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 is good and metal release from sediments appears to be minimal.
- Mandy Lake has diverse and abundant biota.
- Metals do not appear to bioaccumulate in fish.
- Although sediment metal levels are elevated in areas where tailings were deposited, an organic layer covering these sediments appears to reduce oxygen concentrations at the water-sediment interface and provides a barrier to metal release.
- The elevated metal concentration in pondweed (*potamogeton* spp) collected over tailings sediments in the littoral zone of the lake indicates that some metal uptake is occurring in the vegetation.
- Mandy Lake has rehabilitated naturally and is expected to continue.

DETAILED GEOCHEMICAL STUDIES:

- Despite the cessation of mining 46 years earlier, mine 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 efflux of metals from the mixed tailings and natural organic-rich sediments.
- Tailings on the lake floor showed little or negligible evidence of chemical reaction 46 years after deposition.

6.3 Comparison with other subaqueous disposal sites

Despite the promising findings at Mandy Lake regarding the potential applicability of the technique, there was an obvious need for additional data from other tailings disposal lakes with different physical, chemical, biological and geographical characteristics. Mandy Lake is a small, shallow lake where a relatively small quantity of tailings (73,000 metric tonnes) was deposited. It was desirable to compare it with larger and deeper lakes and, if possible, a lake that was still active as a tailings disposal site.

As a first step, a MEND-funded literature review on the subaqueous disposal of reactive mine waste in a freshwater environment was conducted in 1988 (MEND Report 2.11.1a) to broaden the database of previous case studies (Rescan, 1989). The sites examined represented a range of ore types and receiving environments. Unfortunately, not all mines utilizing subaqueous disposal practices had water quality data available.

A more comprehensive investigation was commissioned by MEND in 1988 (MEND Reports 2.11.1b, 2.11.3abc and 2.11.4a) and carried out by Rescan (1989, 1990a,b,c,d, 1995, and 1996) on four (4) different lakes between 1988-1995. These lakes were:

- Anderson Lake, in Manitoba (Rescan, 1990d and 1996).
- Buttle Lake, in British Columbia(Rescan, 1990b and 1995).
- Benson Lake, in British Columbia (Rescan, 1990c).
- Mandy Lake, in Manitoba (Rescan, 1990a)

(The findings for Mandy Lake have been cited at section 6-2 above).

A Peer Review of MEND studies conducted to 1991 on subaqueous disposal of tailings (RAAS,1992, MEND Report 2.11.1(d)) recommended more detailed work on some of the case studies and selected Anderson Lake and Buttle Lake for these studies. Proposed work included a mass balance of selected minerals and measurements of geochemical fluxes across the water/sediment interface. Results from these investigations can be found in MEND reports 2.11.3abc and 2.11.4a.

Highlights from the 1989-1995 studies and a 1994 update of case studies by Fraser and Robertson are summarized in table 6-5 and discussed briefly in section 7.

Table 6-5

Comparison of Case Studies of Subaqueous Tailings Disposal in Canadian Natural Lakes

(Compiled from Rescan, 1989,1990a,1990b,1990c,1990d,1990e, 1995, 1996 and Fraser and Robertson, 1994)

Lake	Location (province)	Mining Company (or Property)	Area (km^2)	Depth (deepest) (m)	Tailings deposited	Ore type	Main tailings minerals	Status as a tailings disposal site in 1989	Tailings discharge period	Water quality above tailings				Aquatic life	Impact on lake water quality and observations
										Mean pH	TSS (mg/L)	Diss. Metals (mg/L)	Sulphates (mg/L)		
Babine Lake	British Columbia	Noranda Inc (Granisle and Bell Koper mines)	N/A	N/A	N/A	Cu	N/A	Inactive	N/A	7.7[1]	1	< 0.01	3	N/A	Insignificant
Benson Lake	British Columbia	Cominco	0.773	54	3,600,000 T	Cu	Gt, Ep, Ca, Mt, Py, Po	Inactive	1962-1973	N/A	High during deposition but decreased after closure	Zn=0.06[2]	N/A	• Yes (high Zn content for at least one fish species). • No benthos	Major turbidity problems during actual discharge (inexistent prior to commencement of discharge)
Buttle Lake[5]	British Columbia	Westmin Resources	45	87 (south basin)	5,500,000 T	Cu, Pb, Zn	N/A	Inactive	1967-1984	7.03-7.3	N/A	Zn=0.007-0.025 Cu≤0.002	5.6-10.9	Zooplankton was absent during depositional years but reappeared to pre-1967 levels after discharge ceased	Insignificant
Kootenay Lake	British Columbia	Cominco's Bluebell Mine at Riondel (east bank)	N/A	N/A	• Undetermined quantity of waste rock, mill tailings and mine drainage up to 1952 • 4,800,000 T of tailings plus an undetermined quantity of waste rock during the Cominco period	Pb/Zn (Bluebell) Massive sulphides	Sp, Ga, Py	Inactive	1890-1952 (as small scale mining) 1952-1972 (as Cominco)	N/A	N/A	N/A Reported low (similar to background)	N/A	Metal concentrations in the flesh of fish from the lake were low. Test procedures regarding accumulation of heavy metals in the food chain were questioned	?
		Dragoon Resources at Ainsworth (west bank)	N/A	N/A	Undetermined quantity of tailings with a pH of 9.1 were dumped directly into the lake	Pb/Zn/Ag (Dragoon)	Ga,Sp	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	Liquid effluent quality guidelines were not met in 1982
Pinchi Lake	British Columbia	Cominco	N/A	N/A	Calcine from the roasting plant (tailings were impounded)	Hg	N/A	Inactive	World War II and 1964-1972	N/A	N/A	N/A	N/A	N/A Presence of Hg unlikely due to its low sublimation temperature	?
Summit Lake (ice-dammed glacial body of water)	British Columbia	Scottie Gold Mines	N/A	N/A	N/A	Au	Py, Po (acid generating)	inactive	N/A	7.1[3]	35,2	< 0,002	10,0	N/A	Low to insignificant

Table 6-5 (Cont'd)

Lake	Location (province)	Mining Company (or Property)	Area (km^2)	Depth (deepest) (m)	Tailings deposited	Ore type	Main tailings minerals	Status as a tailings disposal site in 1989	Tailings discharge period	Water quality above tailings				Aquatic life	Impact on lake water quality and observations
										Mean pH	TSS (mg/L)	Diss. Metals (mg/L)	Sulphates (mg/L)		
St.Mary's/Kootenay River	British Columbia	Sullivan Mine-Cominco	N/A (River)	N/A (River)	Iron and acid wastes from Kimberley Mine and gypsum from the Marysville fertilizer plant	Zn/Pb/Ag	N/A	Inactive	N/A	N/A	High[4]	High	N/A	Results from a 1965-1966 survey revealed an absence of benthic fauna in Mark Creek below the Sullivan operation. Populations of native species of fish greatly reduced as far as 15 km downstream of the confluence of Mark Creek with the St.Mary's River	The 1965-1966 survey showed high concentrations of lead, zinc and fluorides along with significant turbidity and discoloration in the St. Mary's River
Fox Lake	Manitoba	Farley and Sherridon Mine	N/A	N/A	Some tailings were submerged and others were deposited on land	Cu/Zn and Au/Ag (massive sulphides)	65-75% silicate minerals. Land tailings are more oxidized, than the submerged ones	Inactive	1949-1952	N/A	N/A	N/A	N/A	N/A	Insignificant In the submerged tailings, the degree of oxidation correlates with grain size. Oxidation was important in sandy-textured tailings and minor in the less porous silty fraction
Mandy Lake	Manitoba	Hudson Bay Mining and Smelting	0.239	5.5	73,000 T	Cu/Ag/Au	Py/Cpy/Sp (?)	Inactive	1943-1944	7.04	4.0	Zn=0.011 Cu=0.007	17.6	Diverse and abundant. No bioaccumulation of metals in fish	Insignificant
Anderson Lake[6]	Manitoba	Hudson Bay Mining and Smelting (Snow Lake Mill)	2.4	7.0	At least 7,500,000 T	Cu/Zn/Pb	Various (custom milling). Mainly Py	Active	1979-March1994 Aug. 1995-Nov. 1998 July 2000 to present	5	-	Zn=0.350-0,450 Cu=0.02-0.03	800	Low to moderate. Benthic invertebrate densities lowest near the tailings discharge point. Metal levels higher in fish near the tailings outfall	Moderate (adverse) for the whole lake but significant at the point of discharge
Garrow Lake	Little Cornwallis Island Northwest Territories	Polaris Mine (Cominco)	6	46	N/A	Pb/Zn	Py, Sp, Ga, Ma Ca, Do	Active	N/A	N/A	N/A	Zn< 0.02 Cu<0.008	N/A	N/A Garrow Lake is only 7 meters above sea level and is therefore saline at the bottom	Insignificant (at least for water quality)

Notes:
1) Data for water quality from 1976.
2) Data from 1971.
3) Data for water quality from 1979.
4) Data for water quality from 1965-1966.
5) Data for water quality from 1995.
6) Data for water quality from 1996 (except for TSS). The high level of dissolved metals is in part due to the tailings discharge, but also to 50,000 t of oxidized tailings backfill, Anderson mine operations, and the pipeline road constructed with tailings located near, and draining into the lake. Subsequent to 1996, the mine site, stock pile area, and road have all been reclaimed.

N/A: Not available.

7. CONCLUSION

7.1 Lessons learned

The physical and biological settings of Mandy Lake have apparently recovered well from the deposition, 60 years ago, of sulphides-rich tailings. Water quality is good, and aquatic life is diverse, abundant and relatively healthy. An organic layer of up to 2.5-cm, which acts as an oxygen sink, covers the shallower tailings and appears to reduce oxygen concentrations at the water-sediment interface despite high metal content in the tailings.

One of the most sensitive issues in subaqueous disposal of tailings is the recovery rate of a lacustrine ecosystem that undergoes discharge of large quantities of tailings over a long period. Mandy Lake is obviously doing well but how much is known about the conditions that prevailed prior to its use as a disposal site? Table 6-5 shows that, regardless of the lake, major disturbances are more likely to occur <u>during</u> actual discharge. The main impact is usually the turbidity-induced disappearance of biota. Minimal sulphides oxidation has occurred and consequently, low release of metals. The time required for recovery may become a key factor. An intra-generational time-frame (e.g. 10 years) may be deemed acceptable whereas an inter-generational one (e.g. 30 years) may not.

Subaqueous disposal of tailings in a natural water body is a controversial issue and generally not acceptable as a standard practice by Canadian regulatory agencies or the public (RAAS, 1992). Ultimate scenarios for its application would be (RAAS, 1992):

1) It is not acceptable in any lakes.
2) As much as possible, it should be restricted to biologically barren lakes.
3) If applied to biologically productive lakes, measures to minimize impact on the adjacent environment has to be taken.

Three (3) potentially acceptable options were identified by RAAS (1992):

- Disposal in and near-filling of a small headwater lake or depression having a limited catchment
- Disposal in a man-made structure
- Deep lake disposal

The Rawson Academy of Aquatic Sciences (RAAS 1992) noted that the current levels of scientific understanding and case-history study data are not sufficient to encourage the mining industry to seek approval for subaqueous disposal as a preferred option. Acceptability may become more feasible if a solid understanding of lake recovery time is known. The population may be more inclined to accept the short-term loss of a lake rather than the long-term hazards posed by other types of disposal such as a man-made water impoundment or a dry land conventional tailings pond.

Scientific and technical certainty about the relative innocuousness of subaqueous tailings disposal in natural lakes is certainly essential to determine its ultimate application scheme. Nevertheless, technical evidence alone might not be sufficient to overcome concerns in the general public. Perception of subaqueous tailings disposal can often be considerably distorted by very different but well publicized cases. Enlisting public support remains therefore the main challenge for the broader application of this method.

We have emphasized in this work the importance of determining the recovery rate of a lacustrine ecosystem following subaqueous disposal. One (or more) long-term pilot project on a selected lake, where appropriate baseline information has previously been collected, should be envisaged to provide insight into the processes that govern such a recovery and to precisely monitor its rate. All aspects, that is biological, chemical and physical recovery, should be addressed. This is one example of site-specific assessment required to effectively measure the cradle-to-grave effects of tailings disposal into natural aquatic environments (Sly, 1996). Other such site-specific assessments could deal with bioaccumulation of heavy metals by fish or metals uptake by aquatic vegetation, for example.

In its Review of 1993-1995 MEND Studies on the Subaqueous Disposal of Tailings, Sly (1996) proposes the development of a model assessment for comparison of the risks, costs and benefits of different means of disposal giving particular attention to long term stability and security of disposal systems. We share this view and strongly suggest such an analytical framework be developed to compare the disposal approaches.

8. ACKNOWLEDGEMENTS

The authors would like to thank Mr. Stephen West, Hudson Bay Mining and Smelting Co. Ltd, who provided valuable information for the case study.

Thanks also to Dr. Nand Davé, Natural Resources Canada, Mr. Gilles Tremblay, MEND Secretariat, and Mr. Stephen West, Hudson Bay Mining and Smelting Co, Ltd. for their comprehensive review of the report.

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