NARRATIVE REPORT

THE RESTORATION
OF
SOUTH BAY MINE SITE

July 2003

The Restoration of South Bay Mine Site

By

M. Kalin

Boojum Research Limited

468 Queen St. E Toronto M5A 1T7

There are an estimated 5000 abandoned mine sites in Ontario, many of them generating acidic run-off. They are the legacy of an era in which few constraints governed the search for minerals and little thought was given to site restoration. They are now the property, by default, of Ontario taxpayers. The passage of the Ontario Mining Act in 1991, and amended in 2000, marked the formal recognition in Ontario of the longevity and complexity of mine-related environmental problems. The only mine site that has ever been returned to the Ontario government, having undergone a process of remediation, is the South Bay Mine in Northwestern Ontario.

The rehabilitation of the South Bay Mine has restored aesthetic values to the site and has attacked acid mine drainage at its source. The clean up has contributed substantially to the growing body of knowledge about the nature and treatment of AMD as reported in numerous government reports, conference papers, refereed journals and book chapters. Much of the work was funded by Canmet, the Biotechnology Strategy Fund, and the Industrial Research Assistance Program of the National Research Council of Canada. And all of it was unconditionally supported by BP Selco and its successor on the site Talisman Energy Inc. The work at South Bay has set a benchmark for mine site restoration.

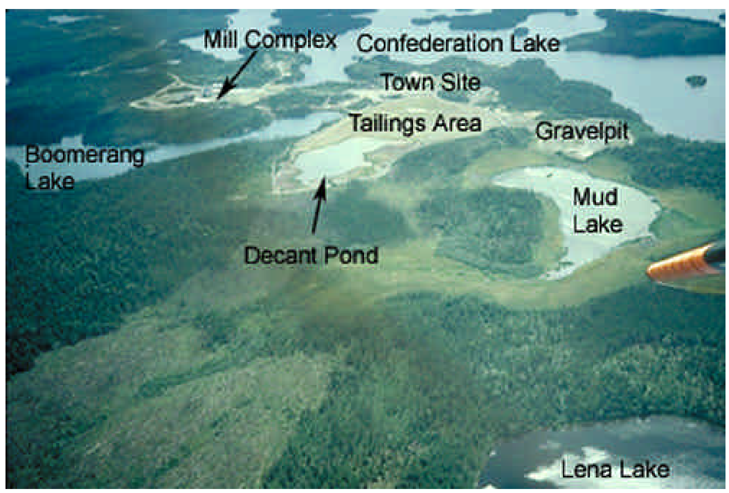
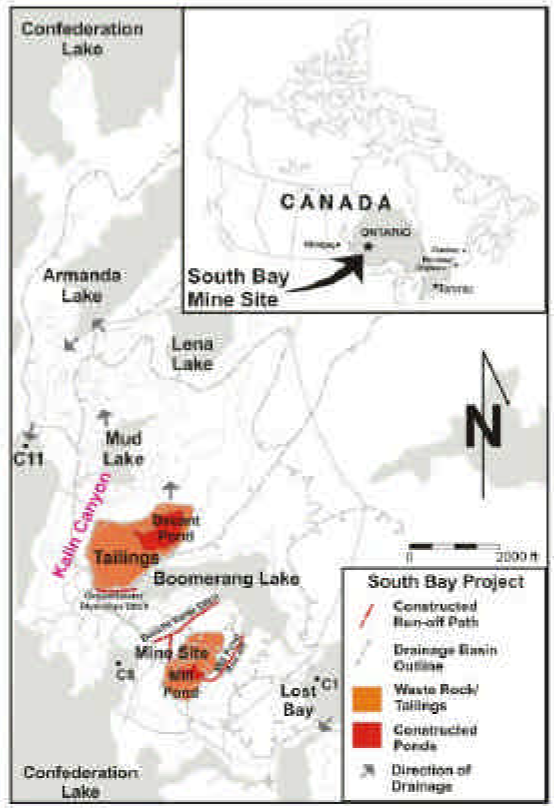


Plate 1: Aerial view of the South Bay min site

The South Bay mine is virtually surrounded either by Confederation Lake, an important sport fishery and tourist destination, or by two tributaries of Confederation Lake, both now included in the South Bay Waste Management Area (SBWMA) (Plate 1). While the pH of those tributary lakes is very low, the enhanced, self-sustaining, biological treatments systems in them have ensured that that the water quality in Confederation Lake has remained within Ontario Water Quality Objectives.

Underground plumes of contaminated water that reached Confederation Lake in 1992 were quickly diverted into Boomerang Lake, which had become the main engine on the site of biological remediation. In 1996, a contaminated plume reached Mud Lake just to the north of the site and also a tributary of Confederation Lake. This inspired a round of research into the treatment of ground-water in-situ, a world-leading innovation. Experiments into possible treatment methodologies for Mud Lake are complete and now await regulatory approval.

Not every experiment conducted at South Bay was a success, and not every turn of events was anticipated but the most important initiatives undertaken there performed as well or better than predicted. The ground water regime is now well understood. The site has been stabilized by vegetation. Sulphate-reducing organisms are well established in newly developed wetlands and in Boomerang Lake. Most importantly, contaminants are not leaving the waste management area.



Map 1: South bay location and overview of the SBWMA

Mining, milling and decommissioning: state of the art 1985

The South Bay Mine was operated for ten years, from 1971 until May 1981, during which time it yielded 1,395,000 tons of ore (001/5) mostly copper and zinc and some silver (Table 1).

Table 1: Mining, milling and decommissioning 1970-1985.

Item	Description
PROPERTY & LOCATION	South Bay Mine: located on Confederation Lake, 85 km east of Red Lake, northwestern Ontario, Canada. (Longitude 92° 40’ Latitude 51° 08’)
METALS RECOVERED	Copper and zinc concentrates, minor silver
HISTORY OF MINE DEVELOPMENT AND OPERATION	1968 May Orebody was located by Questor Survey. 1970 Feb Started construction a concentrator. Apr Started sinking a vertical shaft 1971 Mar Concentrator went into production at a nominal rate of 450 t/d Concentrate shipped to Val D’Or for smelting 1974 Shaft deepened from 236 m to 555 m 1979 Started using tailings for backfill early in the year 1980 The mine operated continuous ly until May 1981 when reserves were depleted

Table 1 continued……..

Table 1 continued: Mining, milling and decommissioning 1970-1985.

<table>
<tr><td>GEOLOGY AND MINERALOGY</td><td>The ore bodies occur in volcanic rocks generally of granitic composition. Ore occurs in a series of steeply dipping lenses which are spatially related to altered felsic tuffs. The tuffs and ore lenses occur within an embayment in a quartz-feldspar porphyry with a fine granular siliceous matrix. The feldspar (Plagioclase) is commonly altered to fine-grained sericite in the immediate vicinity of the ore bodies.</td></tr>
<tr><td>MINING METHODS</td><td>Mostly cut and fill stopping using mine waste and sand for fill. Starting around January 1979, about half the tailings was recovered to mix with sand fill. Cement was used with sand fill. Ammonium nitrate and fuel oil (ANFO) blasting agent at a rate of 0.28 kg/t ore</td></tr>
<tr><td>MILLING PROCESS</td><td>1,675,000 tonnes of mill feed - estimated. Conventional crushing and grinding to 68% minus 41 microns. Selective flotation to produce a copper concentrate and a zinc concentrate. Copper was floated first at pH 8.5; concentrate was reground and cleaned at pH 11.0 - 11.8. Zinc was recovered from the copper tailings at a final pH of 11.6 - 12.0. Concentrates were dewatered and dried in an oil-fired dryer to 6% moisture. Concentrates stored outdoors on concrete pads and shipped out by truck.</td></tr>
<tr><td>MILLING REAGENTS</td><td><table>
<tr><td>Reagent</td><td>kg/t</td><td>Reagent</td><td>kg/t</td><td>Product</td><td>Assays %</td><td></td><td>Distribution %</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td><u>Cu</u></td><td><u>Zn</u></td><td><u>Cu</u></td><td><u>Zn</u></td></tr>
<tr><td>NaCN</td><td>0.045</td><td>Steel</td><td>1.68</td><td>Mill Head</td><td>1.67</td><td>9.11</td><td>100</td><td>100</td></tr>
<tr><td>Na_2Cr_2O</td><td>0.19</td><td>$ZnSO_4$</td><td>0.17</td><td>Copper Conc</td><td>27</td><td>3.63</td><td>89.4</td><td>2.2</td></tr>
<tr><td>Z-200</td><td>0.08</td><td>$CuSo_4$</td><td>0.58</td><td>Zinc Conc.</td><td>0.4</td><td>53.73</td><td>3.8</td><td>92.3</td></tr>
<tr><td>MIBC</td><td>0.015</td><td>$Ca(OH)_2$</td><td>1.38</td><td>Tailings</td><td>0.14</td><td>0.63</td><td>6.8</td><td>5.5</td></tr>
</table></td></tr>
<tr><td>MILL WASTE</td><td>Mill waste in 1976 was reported to contain 0.14% Cu and 0.63% Zn. Estimate 19% sulphur. Approximate composition of tailings: chalcopyrite 0.14%; sphalerite 0.6%; pyrrhotite 4%; pyrite 41%; balance - light coloured silicates. Preproduction waste may have been used for fill, roads, etc. After this the waste was used for mine backfill. The mine and mill site covers a 15 ha area between Confederation L. and Boomerang L. The tailings cover 27 ha, of which 14 ha are dry, and 13 ha make up Decant Pond.</td></tr>
<tr><td>MILL WASTE DISPOSAL AND WATER TREATMENT</td><td>Mill tailings were pumped 0.4 km to a 25 hectare swampy basin enclosed by a peripheral dyke. Two concrete dams built directly on bedrock adjacent to Boomerang L. Other dams constructed from waste rock and gravel. About 50% of tailings (sand portion) were recovered and used as mine fill, starting January 1979. Estimate 1,010,000 tonnes to tailings pond and 115,000 tonnes to mine. Most tailings discharged into southern portion of tailings basin. Final tailings discharged were slimes (80%< 15 um) into northern points of tailings area.</td></tr>
<tr><td>POST-MINING REMEDIATION</td><td>Neutralizing potential in the tailings probably very small, AGP estimates 580 acid / t of tailings,
Mill Pond and Backfill Raise tailings spill area were periodically limed during operations. Decant Pond was not limed during operations, but received 2.7 t of lime each year between 1981 and 1985.Revegetation of tailings completed in 1982, following placement of a 0.3 to 0.5 m layer of gravel overburden plus fertilizer and seeds. Shallow piezometers installed in tailings by Hanna October 25-28,1985.</td></tr>
<tr><td>REFERENCES</td><td>(1) Mallory, G.A. Selco Mining Corporation - South Bay Division, Milling Practice in Canada, CIM, Sp. Vol. 16, 1978, pp. 187-189; (2) Corkery, M. Timothy. A study of the geology of the sulphide ore bodies at South Bay Mines, Northwestern Ontario. A thesis, 1977. Chapt. 2, pp.6-16; (3) Fotheringham, W.J. Cut and fill stopping at Selco's South Bay Mine. 5th Annual District 4 Meeting, C.I.M., Flin Flon, Sept. 19, 1980; (4) Canadian Mines Handbook, 1973-74 to 1982-83, and (5) J.E. Hanna Assoc. Inc. A Water Management Plan for South Bay Mines. Feb. 1986.</td></tr>
</table>

Of more immediate concern, the operation also generated waste rock and about 785,000 tons of tailings. During the lifetime of the mine acid run-off had affected the water quality of Boomerang Lake but was generally controlled by lime scattered throughout the site and occasionally in the lake. The remediation of the site was governed by two severe restraints. Firstly, the property is essentially a peninsula, almost completely surrounded by Confederation, Mud and Boomerang Lakes. (Map 1) Secondly, like most active and retired mines in Canada, the site was remote, accessible only by a seasonal road, and far removed from the power grid. So the costs of building a conventional treatment plant on-site, and of providing it with power and lime, would have been prohibitive. Moreover, the site was too small and too close to water to provide a secure landfill site for the disposal of the contaminated lime sludge that it would have generated. One consultant proposed that the water quality of Boomerang Lake, a tributary of Confederation Lake, which was adversely affected by the mine, could be restored by regular applications of calcite dispersed from small boats every ten to fifteen years. BP Selco rightly dismissed the suggestion as simplistic.

Acid mine drainage is a particularly insidious, self-perpetuating problem that is produced in three distinct phases: when sulphide minerals are allowed to weather, through exposure to oxygen and moisture, sulphuric acid is produced; the acid dissolves metals and sulphides, which exposes new surfaces to weathering, and attracts acidophilic bacteria; the bacteria feed upon the energy released when molecules of sulphide minerals are torn apart and extrude enzymes to hasten the process. This cycle plays itself out in mines, waste rock piles, and particularly in tailings deposits, which form an ideal habitat for the acidophiles. Different groups of these bacteria specialize in breaking down particular minerals; the most notorious of them – though not necessarily the most widespread - is Thiobacillus ferrooxidans, which converts ferrous iron into ferric iron, an oxidizing agent of pyrite. Unless the process is interrupted, old mine sites will generate AMD so long as iron is available.

The most obvious source of the AMD that was getting into Boomerang Lake was Mill Pond, which drained into the lake by way of a wide, shallow valley. During the life of the mine the pond had been a catchment lagoon for water used in the operations. It continued to receive acidic seepage from a nearby waste rock pile, and run-off from the mine and mill compound which was built upon waste rock, used as fill, and which was further contaminated by concentrates (Plate 2).

Plate 2: Lime application on the mill site.

Previously, the pH of the pond had fluctuated erratically, from a low of 2.5 to neutral, in response to broadcast applications of lime (Figure 1).Since the closure, the pH of the pond had plunged to 2.9 while concentrations of zinc and copper soared. Early in 1986 BP Selco awarded a contract to Boojum Research Ltd, a Toronto-based, mine site remediation specialist, to clean up the pond.

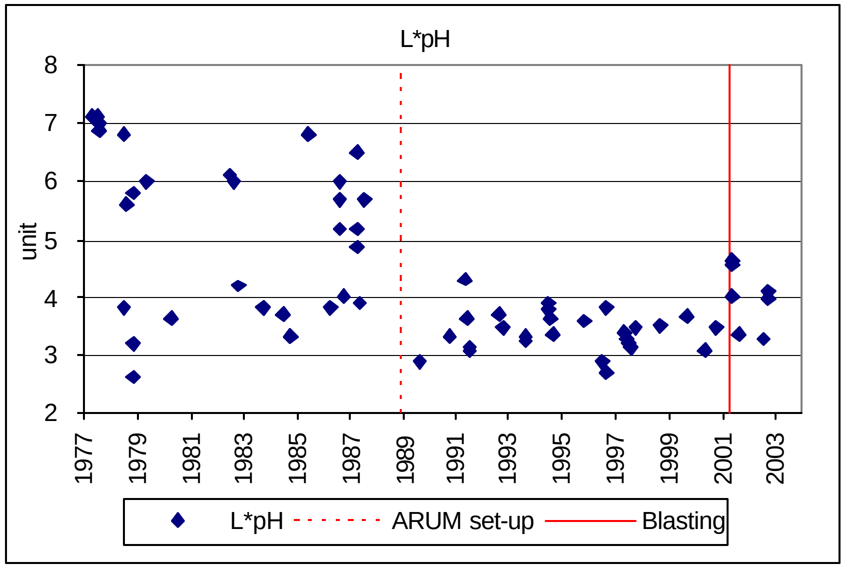


Figure 1: Mill Pond Outflow pH 1977 –2003

Ecological Engineering Considered

Boojum was one of the first proponents in Canada of ecological engineering, a discipline built around the idea that natural systems, if well enough understood, can be manipulated by the addition of small, precise amounts of energy to achieve desired benefits. Applying the theory to acid mine drainage, the company had developed a variety of techniques to stimulate the growth of organisms that can balance the pH of soil and water, take metals out of solution and suppress the activity of acidophilic bacteria. For example, Boojum utilized algae and other acid-tolerant plants to bind metals by adsorption, stabilize sediments and to enrich sediments with organic matter as nourishment for bacteria such as Desulfovibrio that reduce iron and sulphate. This raises the ambient pH and precipitates metals in the sediments.

Ecological engineering, in effect, was put on trial in Mill Pond. Boojum staff and summer students dropped 20 loader buckets of sawdust into an outflow channel from the pond to stimulate blooms of algae and to begin the formation of sediment – habitat for sulphate-reducing bacteria - on the rocky bottom. Cattails were planted around the edges. BP Selco staff also built a series of containment dams in the drainage valley below the pond, now known as Mill Pond Run-Off, to create habitat for algae. Within weeks, algae in Mill Pond, and below it in the newly created wetland, were thriving. The pH in Mill Pond, although still low, had stabilized (Plate 3). The concentrations of copper dropped from 109 mg/l to 16 mg/l and zinc from 390 mg/l to 173 mg/l.

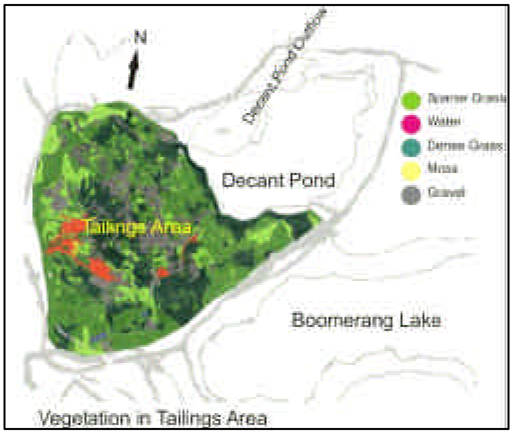
Encouraged by those results, BP Selco commissioned Boojum to survey the entire site and to prescribe an abandonment strategy. In September 1986, Geoffrey MacDonald and Glen Mallory both with BP Selco's environmental affairs group, and Margarete Kalin, president of Boojum met with representatives of the Ministry of the Environment, Northwest Region, Kenora to present the results of that survey, to describe the experiments and restoration effort that were underway and to offer a close-out scenario for the site.

Plate 3: Algae in Mill Pond 1986

Kalin described five distinct areas of concern, each of which would require a particular suite of ecological remedies: the tailings basin; Decant Pond; tailing spills outside the basin; the mine/mill compound which included the mine shaft; and Mill Pond and Boomerang Lake.

The Tailings Basin

The South Bay tailings basin covers an area of about 25 hectares of which about 5 hectares are underwater. The basin originally held a peat bog that drained into Boomerang Lake. The sides of the basin had been augmented with berms and concrete dams poured into trenches to bedrock, to retain the tailings. When the mine closed, about 300,000 tons of tailings were returned to the mine workings leaving about 785,000 tons in the basin. The dry tailings were covered with gravel to a depth of 30 to 40 cm, hydro mulched and seeded with a mix of birds-foot, trefoil and tall-fescue. Those measures represented the state-of-the-art in mine site remediation in 1981. They were intended primarily to hold down dust although it was also hoped they would exclude moisture and oxygen. Boojum's survey of the tailings vegetation revealed that the introduced species had not done well (Schematic 1). On a more positive note, several indigenous species had invaded the tailings, especially acid-tolerant mosses that had taken hold wherever the tailings retained water after rainfall l (Plate 4).

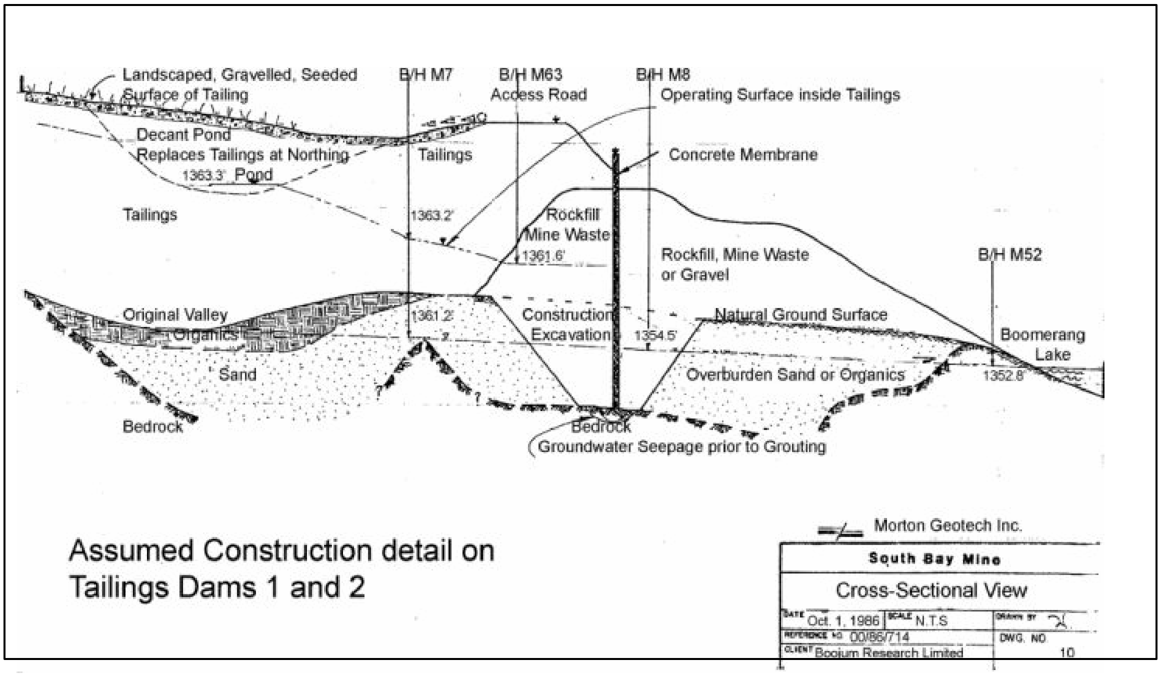


Schematic 1: Tailings vegetation survey 1986

Plate 4: The sparse grass cover l986

Boojum recommended that the vegetation on the tailings be left undisturbed so the colonizing species would continue to proliferate. Since little was known about the movement of ground water out of the basin, or anywhere else on the site, the company also recommended that a comprehensive hydro-geological survey be undertaken. Signs that a considerable hydrological head had built up in the tailings was evident in the form of seepages, emerging from the rubble below Dams #1 and #2 and trickling into Boomerang Lake (Plate 5). BP Selco undertook to seal the leaks with grout. (Schematic 2).

Plate 5: Seepage into Boomerang Lake



Schematic 2: Reconstructed cross section of Dams #1 and #2

Decant Pond

Situated in the southeast and lowest corner of the tailings, Decant Pond contained about 42,900 m^3 of water covering about 5 ha to a mean depth of 0.8 m. Overflow from the pond drained into a broad belt of muskeg, which surrounded Mud Lake, a small, shallow lake to the north. It was believed that the muskeg was polishing the overflow since there was no evidence of contamination in the lake. Here too pH had been controlled with lime, so the pond water was near neutral and relatively free of contaminants. But the pond bottom had been covered with a layer of lime sludge containing zinc concentrations as high as 3%. Vigorous growths of moss, cattails and dense mats of periphytic algae covered the shores while algae floated thickly on the surface (Plate 6). At the request of Boojum, the liming was discontinued in 1986 so that the inherent dynamics of the pond and its biota could be studied.

Analysis showed that the dry weight of the algae in the pond consisted of 5.3% zinc, 6.7% iron, 0.6% copper and 0.07% lead. Boojum proposed to stimulate growth in the pond and to further research the growth characteristics of the algal mats to optimize biological polishing.

Plate 6: Decant pond algae mats

Tailing spills

During the life of the mine the 800-meter pipeline, which had carried the tailings slurry from the mill to the tailings basin, had breached leaving two spills large enough to generate an unacceptable level of contaminants. Spill Area #1 contained about 200 m³ of tailings and drained into Boomerang Lake. Spill Area #2 consisted of 709 cubic meters and drained into a large seasonal puddle at the foot of the Backfill Raise (Plate 7). The puddle, in turn, drained into Confederation Lake.

Plate 7: The backfill raise puddle

Boojum proposed to contour Spill Area #1 into a series of small terraces to retain rainwater until it evaporated and to add organic matter to encourage plant growth (Plate 8).

Spill Area #2 was filled with paper waste from the mill and warehouse and then buried with waste rock and sand. Leftover lime was scattered in both spill areas.

Plate 8: Puddle Confinement in Spill Area 1

Mine / Mill complex

The mine complex, a 15-hectare compound, contained the mineshaft housing, mill, concentrator, machine shop, warehouse, and powerhouse all of which were to be demolished within two years. The complex stood on ground that had been leveled in part with acid-generating waste rock (Plate 9). The Mine Shaft, the Backfill Raise and the Portal Raise had been topped with rubble and capped with concrete.

Plate 9: Mill complex overview

The mine workings were not force-flooded but had been left to fill on their own. A previous study had concluded, erroneously, that since the entrance to the mine and the portal raise were near the top of a local watershed that they would not overflow. Run-off from the concentrate pads and the compound flowed into Mill Pond. Work already begun in the pond would continue.

Boomerang Lake

Boomerang is a long narrow lake, covering about 24 hectares to a maximum depth of 5.2 meters with a volume of about 1 million m^3. It forms the southeastern boundary of the mine site and intrudes into the site, forming a partial barrier between the tailings and the mine/mill compound. It drains to the south into Lost Bay, an extension of Confederation Lake. The turnover time of water in the lake is about 3 years.

The lake is well mixed, so measured values of pH and electrical conductivity were consistent; the mean pH was 4.3 while electrical conductivity was typically close to 325 uS/cm^2. Copper, iron and lead were present in the water although not at elevated levels; zinc however was detected at levels ranging from 6.90 to 9.4 mg/L and was also present in elevated concentrations in the sediment. The sediment also contained extremely high levels, up to 23 per cent, of iron.

Biota in the lake was already actively isolating contaminants. Periphytic algae, dried, ground and analyzed for elemental content, consisted of 0.6 % copper, 6.7 % iron lead, 0.07% lead, and 0.5% zinc. Since the lake was already contaminated, Boojum proposed that it be utilized as a large-scale biological polishing pond in which a variety of biota could be stimulated to remove metals and raise the pH before it reached Lost Bay.

Approval in Principle

The close out scenario jointly presented by BP Selco and Boojum Research was approved in principle at the meeting in Kenora with the MOE with the understanding that:

1. A hydrological survey of the tailings area would be carried out to determine groundwater flow and acid loading to Decant Pond and Boomerang Lake
2. Efforts would be made to seal the leaking dams adjacent to Boomerang Lake
3. Wetland areas would be developed in Mill Pond, Decant Pond and in the tailings spill areas
4. The mill site would be contoured to ensure that run-off flowed away from Confederation Lake and into Boomerang Lake where it could be treated. Boomerang was designated a part of the waste management area.
5. A possible final, close out scenario be determined, depending on the results of the work, by the fall of 1988.

Ecological Engineering Implemented

Boojum had correctly identified the major problem areas on the site but, in retrospect, may have under-estimated the diversity of the challenges it faced. Over the next 17 years each sector of the site was to become a discreet zone of operations within which AMD, the common enemy, demonstrated a seemingly endless capacity to reinvent itself. The task compelled Boojum to enlarge its ecological toolkit. With the support of research grants issued jointly by industry and the federal government through the Reactive Acid Tailings Study (RATS) and later through the Mine Environment Neutral Drainage (MEND) Programs, Boojum began to intensively research the bacterial reduction of sulphates, and gave the process a formal name, Acid Reduction Using Microbiology (ARUM). The company researched the process in its own laboratories and kept apace of a growing body of knowledge generated by academics in Europe and North America. And it was learning on the job, as it fulfilled remediation contracts at other sites in Ontario, Saskatchewan and Newfoundland.

All of the innovations applied at South Bay were first tested in the laboratory, then in a small-scale pilot project on site and finally introduced in stages, with regulatory approval. Groundwater diversions were constructed, only after clear patterns were demonstrated by one or more years of monitoring data. When ground water data was inadequate, large-scale experiments were conducted so that existing piezometers could measure the impact on the water table. In Appendix 1, all activities at the site are categorized chronologically by location.

Decant Pond

The liming of Decant Pond was discontinued in 1986 with a resulting drop in pH. Cattails had colonized the north shore of the pond, where it extended beyond the tailings into muskeg and grew abundantly in the pond shallows. But they were unable to take hold on the south shore, which consisted of exposed tailings. Since the saturated beach seemed to be a major source of the pond's acidification, efforts were made beginning in 1986, to transplant cattails onto the beach, both with a front-end loader and by hand. Cattails are an important component of the ecological toolbox because they extrude polysaccharides through their roots, which stimulate the ARUM process. But they made no headway at all on the beach, which was high in acid and low in nutrients. In 1988 the ARUM effect was induced when 120 bales of straw were scattered on the beach (Plate 10). Analysis of samples that collected and analyzed in 1989 showed that the straw had been colonized by sulphate reducing bacteria.

Plate 10: Addition of straw bales to Decant pond beach 1988

Cattails, planted on rafts and set adrift on the pond were much more successful (Plate 11). Cattails growing under natural conditions will sometimes form floating islands, supported by gases trapped in their root mass. This effectively creates a secondary habitat for sulphate reducers, as well as providing a supply of organic matter that falls to the sediment below. Moreover, they effectively put a lid on the water surface, protecting it from wind-blown agitation, which reduces oxygen levels in the water. Boojum tried to induce the same effect at Decant Pond by setting cattails adrift in wood and wire rafts. The floating cattails thrived… at least until the winter of 1990 when muskrats moved into the pond and devoured their roots. The presence of the muskrats was at least testimony to the fact that Decant was returning to a natural state.

Plate 11: Floating Cattail Raft For Decant Pond

The pH of the pond was also affected by heavy rainfall in 1991 and 1992, which created acidic puddles on the tailings and which eventually found their way into the pond. Moreover, the intermittent flooding of the tailings beach accelerated the precipitation of iron, which built up dramatically on the straw and reduced the effects of ARUM. The straw was augmented, in July 1992, with 30 truck loads of decomposed bark, forestry wastes, after laboratory experiments confirmed that it would stimulate ARUM (Plate 12). This resulted in an almost immediate increase in pH.

Plate 12: Forestry wood waste addition in l992 to Decant pond beach.

Mill Pond

In 1986 summer students working for Boojum unloaded more than a truckload of sawdust into Mill Pond. It was believed that this would provide adsorption sites for metals. Two more loads were added in 1987 but analysis subsequently showed that the sawdust contained only slightly elevated levels of zinc, copper, sulphur iron and lead. Another disappointment in Mill Pond was the poor survival rate of cattails, both transplanted onto the shore and floating in rafts, apparently because of persistently high levels of copper. When it was determined that the organics in straw were more degradable, 25 bales were added in 1987, 70 bales in 1988 and several truckloads in 1989 (Plate 13). By 1990 the algal population in the pond was booming (Plate 14). Algae also thrived in the wetlands that were created in Mill Pond Run-Off.

Plate 13: Summer students adding straw to Mill Pond 1986.

Plate 14: Algae blooming in Mill Pond 1990

By the summer of 1988 the various buildings on the mine and mill compound had been demolished. After experiments showed that wood, insulation and general rubble provided an excellent substrate for periphytic algae, the demolition materials were deposited into Decant Pond. Materials that were contaminated with metals were buried behind a diversion ditch, where the flow of groundwater was considered to be minimal.

Ground Water Concerns

A hydro-geological survey of the tailings area and the mine and mill compound was begun in September 1986 and completed the following summer. Morton Geotech Incorporated did the work. Initially, only 12 boreholes were to be drilled in and around the tailings basin but when existing hydro-geological data on the site proved unreliable, the project was expanded to 30 boreholes. These revealed that the bedrock beneath the site was irregular and that the overburden was extremely varied. Both factors complicated the flow of ground water. Ultimately, 54 borings were equipped with at least one piezometer in each, and in some cases two or three installed at varying depths. A final report was submitted in August 1987.

Based on the rate of rain and snowfall, it was estimated that about 30,000 m^3 of contaminated ground water flowed out of the tailings basin every year. The hydro-geological survey showed that the water was moving in four distinct plumes; a very small plume north which was expected to emerge in the muskeg that surrounded Mud Lake, and larger plumes to the northwest, the west and the southwest, all apparently heading towards Confederation Lake. The northwest and west plumes were expected to be so diluted before they arrived at the lake that they would pose no problem, but the southwest plume was expected to reach the lake in as little as 2.7 years. A piezometer installed on Mill Complex Beach was already recording slightly elevated levels of zinc.

Early in 1987, to capture the southwest plume, work crews excavated an interceptor ditch that extended in a broad arc from the southwest corner of the tailings basin back to Boomerang Lake. The Groundwater Diversion Ditch was about 500 meters long and about three metres deep, with a bottom elevation of 1,365 feet above sea level (Plates 15 and 16).

Plate 15: Ground Water Diversion Ditch at an early stage of construction

Plate 16: The ground water plume in the Diversion Ditch

A polishing pond was excavated at the end of the arc to begin the remediation of the water before it entered the lake. Chara, commonly known as stonewort for its ability to accumulate calcium and magnesium carbonates in a sheath around its stem, was introduced to the pond. Efforts to stem the seepage of contaminated water from beneath the concrete dams with grout were unsuccessful but this was not a major concern as the run-off moved directly into Boomerang Lake.

The hydro-geological survey also revealed that two contaminated plumes were moving out of the Mine and Mill Compound. One flowed northwest past Piezometer M18, near the Backfill Raise, the other almost due west past Piezometer M38, not far from an inlet of Confederation Lake. The estimated time of arrival of the flow past M38 to the lake was 21 to 40 years. It was believed that the plumes were driven by the hydraulic head in Mill Pond. Steps were immediately taken to contour the mine/mill compound to divert uncontaminated surface waters directly into the Run-Off valley, where more retention dams had been built to further polish the run-off (Plate 17). As a further precaution, in November 1992, a new diversion ditch was built extending about 500 m from the Backfill Raise towards Boomerang Lake.

Plate 17: Dave's dam and lower dam 1987

By 1991, ARUM had begun to significantly change the water chemistry of Mill Pond. And yet… samples collected from the plumes passing Piezometers M18 and M32 showed no change in chemistry at all. Instead, geochemical interpretations suggested that they weren't coming from Mill Pond. In March, an electromagnetic survey of the mill complex, sensitive to the increased electrical conductivity of contaminated water, revealed that the probable source was the rising water in the underground workings. Another EM survey, a few months later found high zinc concentrations in Confederation Lake near the bottom of the lake just off the mill complex beach. But higher in the water column, zinc was at acceptable levels indicating that the contaminated plume from the mine workings was welling up from below.

The Backfill Raise Diversion Ditch was extended and deepened which successfully intercepted the plume and carried it to Boomerang Lake (Plate 18). Much of the ditch was dug through waste rock, used as fill, and through Tailings Spill #2 so the sides were particularly inhospitable to vegetation. In the summer of 2000, 4 tonnes of wood ash, another waste product of the forestry industry, were dispersed onto the slopes of the ditch, which raised the pH of the waste materials and provided nutrients for plant growth. By the end of the summer, a thick carpet of moss had begun to cover the ditch, reducing infiltration into the waste rock.

Plate 18: Extending and deepening the Backfill Raise ditch

Ultimately it was concluded that while Mill Pond was not driving groundwater plumes, it was responsible for highly contaminated seeps in the mill complex. The outflow channel was enlarged which drained the pond to the level of original bog. The seeps have been reduced substantially. In 2001, in light of the success of wood ash treatments in the Backfill Raise Diversion Ditch, the exposed pond bottom, and the entire Mine/Mill Complex were covered with approximately 100 tonnes of wood ash and are now being colonized by moss.

Boomerang Lake

The diversion of more contaminants into Boomerang added urgency to the search for ways to immobilize them. In 1987, Boojum staff dropped 600 cuttings, mostly spruce trees and roadside brush into the shallow waters along the edges of the lake or within logs booms anchored wherever influxes delivered contaminants (Plate 19).

Plate 19: Log Booms in Boomerang Lake Outflow

Later analysis indicated that within a year each cutting was supporting about 8 kg of algal growth and within two years 20 kg; dried, the algae consisted of 4.24 per cent iron, 0.02 per cent copper, 0 .003 per cent lead and about 0.05 per cent zinc. This meant that each brush cutting added to the lake removed about 4 to 10 grams of zinc. The algal mass continued to grow after the second year but quantification of growth rates became problematic because the mass of algae had increased to the point that it was sloughing off and dropping to the bottom bearing its burden of precipitated metals. There too the algae performed a benign function, adding to the organic matter in the sediment and creating a habitat for sulphate-reducing bacteria.

Working at another mine site, Kalin had shown that aquatic mosses stabilize lake sediments and capture falling debris by growing up, around and through it, adsorb zinc and iron precipitates and consume oxygen at the lake bottom, further inhibiting activity of acidophilic bacteria. Since the bottom of Boomerang was almost completely devoid of vegetation Boojum technicians gathered 200 bags of moss, collected in the run-off from the tailings spill and in similarly acidic waters in Elliot Lake. These were anchored to the bottom of Boomerang, beneath the log booms filled with brush. Water with a low pH does not draw carbon from the atmosphere which is why phytoplankton will not grow well in acidic lakes. But aquatic moss extracts inorganic carbon from the degradation of organic material in the sediment. The moss in Boomerang thrived. (Plate 20).

Plate 20: Boomerang Lake Outflow, moss and brush cuttings 1991.

Precipitate with Phosphate

While the measures employed in Boomerang prevented the severe contamination of Confederation Lake, the ability of the lake to remediate AMD was stretched to capacity by the steadily increasing flow of contaminants. By 1992, surface run-off from the mill complex and the flow from the Ground Water Diversion Ditch were delivering an estimated 16 tonnes of sulphur to the lake every year; pH in the lake was down to 3.54, very nearly to the level that ferrous iron, held in the sediment, would be remobilized. The construction of the Backfill Raise Ditch promised to bring an even higher loading.

The lake was in a need of a one-time fix to at least stabilize the falling pH. Lime additions would have raised the pH, but only briefly; in the past, before the closure of the mine, applications of lime raised the pH of the lake to neutral but within a year, it was down again to 2.7 (Figure 2). Apart from being ineffective over the long term, lime would have bound up the phytoplankton in the lake as well as low-level nutrients, phosphates and bacteria, pulling them out of the water column. Moreover, lime sludge would have smothered the sediments. In other words, lime would sterilize the lake and disrupt the ARUM process.

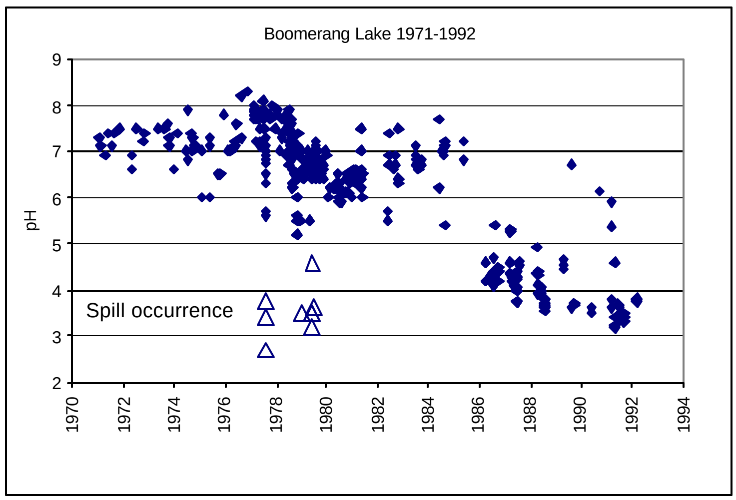


Figure 2: Early pH trends in Boomerang Lake

Boojum had already begun to research phosphate as a possible precipitator of iron. Phosphate rock was being used in Pennsylvania to remediate acid mine drainage from coal wastes. Boojum's experiments over the winter 1991 had shown that phosphate could raise the pH in bodies of water to 4.5, reduce iron cycling and stimulate biological activity in and on the sediment. In short, phosphate was an ideal amendment for Boomerang. Ultimately, 80 tonnes of phosphate were added to Boomerang Lake resulting in a dense, uniform growth of moss.

In the spring of 1993, 300 kg of phosphate sands were added to Mill Pond, 20 kg were broadcast in the outfall area of the pond, five tons were scatted in the small AMD ponds created by precipitation on the tailings, and 9 tons were dropped into Boomerang.

Wherever phosphate was used, the results were encouraging (Plate 21). Water quality in Boomerang was immediately improved. It was estimated that the 9 tonnes of phosphates added to Boomerang had taken 330 kg of zinc out of solution, 1.35 tonnes of iron and 276 kilograms of aluminum. This represented an almost immediate decrease of 6 per cent of the dissolved zinc in the lake, 74 per cent of the iron and 10 percent of aluminum.

Plate 21: Moss growth Boomerang Lake 2000.

But the flow of contaminants continued to increase, year by year. ARUM, with a boost from the phosphate additions, held the pH above 3.5 but zinc concentrations increased from about 5 to 30 mg/l. Phytoplankton, the free-swimming algae which carry zinc down to the sediment, were not growing abundantly in the lake, because of the absence of inorganic carbon. If the pH in the lake could be raised to about 4.5, so that carbon would be made available, phytoplankton would thrive. Presently, zinc reductions in Boomerang Lake are primarily the work of ARUM installations at the lake outflow. Discharge values during the summer are generally around 1 mg/l of zinc or less to Lost Bay.

New Groundwater Concerns

By 1993 it was obvious that the hydro-geological regime beneath and around the tailings basin was changing. The 1986 hydro-geological survey had concluded that most of the groundwater leaving the tailings flowed in three plumes to the northwest, west and southwest. The Groundwater Diversion Ditch, excavated from the southwest corner of the tailings to Boomerang Lake, was expected to collect much as 10,000 m^3 a year but in 1993 captured only 4700 m^3. A reassessment of the water balance of the tailings revealed that while the flow to the west and southwest had decreased, the northwest plume had increased from an estimated 7,437 m^3 annually to 13,642 m^3.

This posed the urgent question, ‘where was the ground water going?’ The most likely explanation seemed to be Mud Lake, the small water body separated from the tailings by a broad belt of muskeg. The lake was outside the SBWMA but its sediments and water were monitored periodically for contaminants and had always remained in pristine conditions. Nonetheless, in light of concerns about the missing ground water, the monitoring program was stepped up. Samples taken through the ice in March 1994 revealed that, in fact, the plume had arrived.

So far, the pH of the water had dropped to 5.3 but the conductivity had risen to 1,430 uS.cm-1 indicating a further drop was imminent. By April as the ice broke, the pH of the lake water reached 3.1, due to iron oxidation.

So why had the plume changed direction? Predictions based on ground water investigations rely on extensive interpolation from point source data leading to assumptions about the underlying bedrock. A new drilling program, in the summer of 1994, revealed the presence of a bedrock canyon, dubbed Kalin Canyon in tribute to the Boojum president, that was intercepting the ground water flow out of the tailings and diverting it north. One of the insights to come out of the work at South Bay, never previously reported, was that AMD is heavier than clean water so may travel through the ground in a separate layer; this has great implications for the assumption that AMD will be diluted to acceptable levels by ground water.

Mud Lake was incorporated into the SBWMA and efforts were made to stimulate ARUM in it. Potato wastes were scattered on the sediments in the discharge zone of the groundwater, and floating cattails were introduced. Within a year, however, the cattails failed, because the floating structures that supported them became saturated with iron and sank (Plate 22 and Plate 23). In 1997, 60 tonnes of phosphate were added to precipitate iron from the lake water onto the sediment.

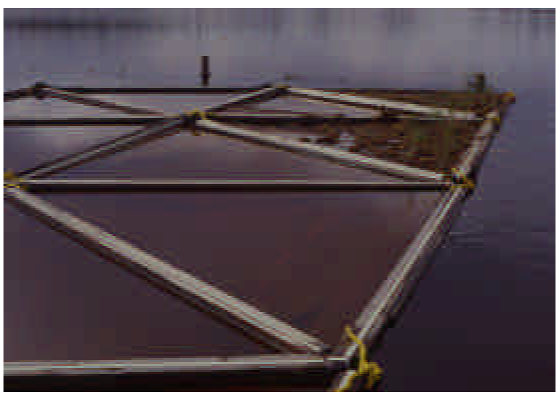


Plate 22: Arum cover installation in Mud Lake

Plate 23: Iron precipitate on the Arum cover

Concurrent with terrestrial experiments, that preceded applications of wood ash on the Backfill Raise Diversion Ditch in 2000, and the application of ash on the Mine/Mill Complex in 2001, Boojum tested applications of wood ash, within an enclosure, onto sediments in Mud Lake. Composed primarily of calcium and potassium-oxides, wood ash contains major and minor elements common in the environment and yet essential to plant growth. Field and greenhouse research have shown that it has a liming effect of up to 90% of the total neutralizing power of lime. And almost by definition, since ash is derived from the combustion of clean and virgin woods it is not offensive to the environment. Sitting on and in the sediment, it intercepts the up-welling plume of contaminated groundwater and precipitates up to 80 per cent of metal contaminants. It has great promise, in short, as a mediating agent in the lake sediments. Lacking regulatory approval, however, it has not yet been introduced.

In-Situ Remediation

In March 1996, an EM survey and an assessment of the elemental mass balance of Mud Lake determined that the flow through Kalin Canyon reported entirely to Mud Lake at a rate of about 1 l/s. To whatever degree ARUM could be increased in the lake, it would always be limited by the size of the lake and its rapid turnover rate of three times a year. There was simply no room to maneuver… not unless contaminants in the ground water could be treated in situ, that is in the plume itself, before they reached the lake.

Late in the year Boojum issued a subcontract with Biotechnology Research Institute (BRI) to look for anaerobic respiratory bacteria (ARBs) that might be resident in the plume moving through Kalin Canyon. ARBs are microorganisms, which utilize transition metals as alternate terminal electron acceptors for anaerobic respiration and in so doing raise the alkalinity of contaminated ed waters. BRI used rRNA techniques to find 18 bacterial species in samples from the canyon, among them, of course, the ubiquitous culprits T. ferrooxidans and Acidophilum but also the sulphate-reducer Desulfobacterium. In April 1987, Kalin and Grant Ferris, a professor with the geology department at the University of Toronto, designed a research program to determine through laboratory and geochemical evaluations, if ARUM could be triggered by the direct injection of nutrients into the groundwater plume. The National Research Council, IRAP Program, supported the research.

Field tests were conducted, just outside the tailings, in contaminated ground water trapped on a layer of clay in a sandy overburden (Plate 24). In 1998, urea was added at a depth of one-meter in the sand. Urea is converted by ureolytic bacteria to ammonia, which raises pH and leads to the precipitation of metals below ground; the degradation of sugar assists in the formation of metal carbonates and, of course, stimulates the sulphate reducers. Within a year, the urea reduced zinc from 1000 to 200 ml/l but no further. The addition of sugar, a year later, resulted in a further reduction virtually to zero (Figure 3). and an increase in pH from 3.5 to 7.

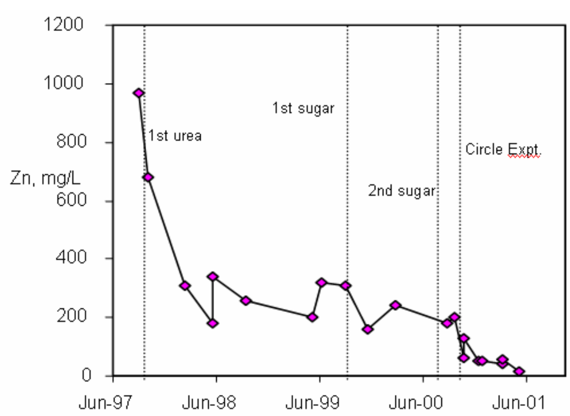


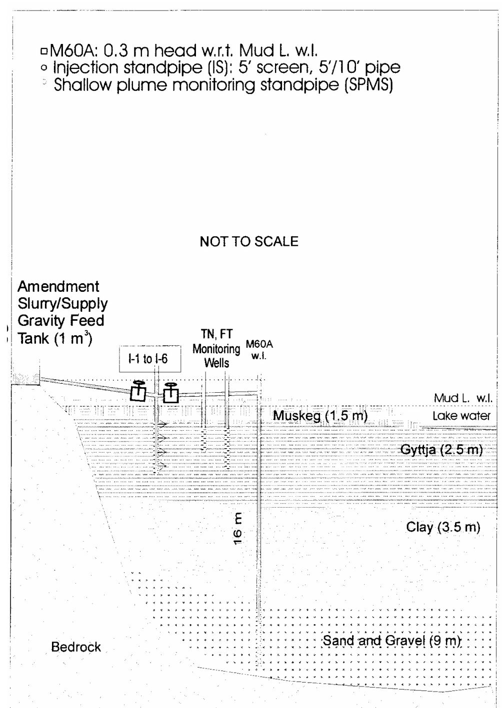
Figure 3: Zinc concentration decreases with sugar and urea

Plate 24: Setup of 1st urea experiment

Based on those results, along with the results of laboratory work at University of Toronto and geochemical simulations of ureolytic bacteria, a large pilot test area was selected on the shores of Mud Lake (Plate 25). In that test, begun in 2000, ground water is drawn from the Kalin Canyon plume from a depth of 16 m, enriched with urea and sugar and re-injected at 6 m with a passive drip system as shown in its initial stages in Plate 26 and Schematic 3. It is carried from there to Mud Lake. Preliminary data suggests that alkalinity is being generated in the plume. The study continues.

Plate 25: Monitoring wells for in-situ ARUM

Plate 26: Setup of feeder tank to drip system



Schematic 3: Lay out of injection system installed in July 2000 for pilot test.

PHITO and PET

At other Ontario projects, at Stanrock, Elliot Lake and at INCO's Copper Cliff tailings, Boojum plowed a mixture of phosphate rock and horse manure into tailings just before they were re-vegetated. The organic horse manure supported heterotrophic bacteria, which consume oxygen while the phosphate precipitated iron to form a layer of hardpan, which substantially reduced porosity. The process is know as PHITO (Phosphate Heterotroph Inhibition of Tailings Oxidation). It is believed that PHITO will substantially reduce the flow of groundwater out of the South Bay tailings. A groundwater model at South Bay predicted a 30 to 40 per cent reduction in the flow out of the tailings if they could be covered with a watertight membrane. PHITO won't seal the tailings perfectly, but will reduce the flow substantially. The concept has been tested and is being gradually implemented on and in the tailings.

. Experiments are also ongoing into ways in which the pH in Boomerang Lake can by increased through the use of metallic magnesium, a process know as Passive Electrochemical Treatment (PET) (Plate 27). Submerged in acid waters, magnesium consumes hydrogen ions, thereby increasing pH. Tests in the effluents from the Backfill Raise, in the seeps on the Mill Site and in Boomerang Lake have been promising. A full application to raise the pH to a target level is under consideration.

Plate 27: Magnesium scrap metal pieces in Boomerang lake

Conclusion

The South Bay Waste Management Area will generate AMD for the foreseeable future. But the volumes of waste generated have been reduced, and will be reduced much more when phosphates, applied to the tailings, form hardpan. The wastes that are generated are contained within the site, which is effectively protecting Confederation Lake. When the work at Mud Lake is complete the SBWMA will have become, in effect, a self-sustaining, self-renewing waste treatment system. Moreover, based on well-documented research from South Bay, similar systems can be applied at acid generating sites throughout Ontario and, for that matter, the world.

Like any system, the measures introduced at South Bay will require periodic monitoring and occasional inputs of energy to perform at peak capacity, services that Boojum Research Ltd is prepared to provide and/or supervise. But no treatment system comes without a manual. The components of the South Bay Waste Treatment System are no more complex, considerably less fallible and far less costly to maintain than the pumps, regulators and transformers that constitute a conventional plant. Fundamentally, AMD is a natural process, accelerated by human activities to a state of ecological imbalance. At South Bay, natural processes, cultivated by human activity, are counteracting AMD and, with time, will restore balance to the site.

Appendix 1: Remediation activities at the SBWMA

Biological Polishing (BP), Cementation Experiment (CEM), Decommisioning (D), GW-ARUM (GWA), Monitoring (M), Passive Electrochemical Treatment (PET), Precipitate With Phosphate (PWP), Phosphate-Heterotroph Inhibition of Tailings oxidation (PHITO), Surface ARUM (S-A), Wood Ash (W-A).

Code	Year	Location	Activity	Details
D	1993	Backfill Raise	Construction	Hole excavated
D	1993	Backfill Raise	Construction	New Warehouse seep ditch dug.
M	1993	Backfill Raise	Surveying	Survey following excavation
PWP	1994	Backfill Raise	Ammendment	Seep edge of stream: NPR code 30, 5.5 t
CEM	1996	Backfill Raise	Construction	WHS, BRC reconfigured for cementation exp'ts.
PET	1999	Backfill Raise	Ammendment	Magnesium Installation
D	2000	Backfill Raise	Construction	Planting Willow along BRC Ditch
D	2000	Backfill Raise	Ammendment	Test Plot Vegetation Growth
D	2000	Backfill Raise	Construction	Pipes put into erroded area road down toward BR2.5
D	2000	Backfill Raise	Construction	Culvert Installed BRC Ditch
D	2000	Backfill Raise	Construction	Dredging
M	2001	Backfill Raise	Monitoring	5 Run Off culverts sampled
BP	1986	Boomerang Lake	Construction	Log Boom Installation in Lake B2 Area in winter
S-A	1986	Boomerang Lake	Construction	Cattails transplanted in hydroponic: rafts
S-A	1986	Boomerang Lake	Construction	Berms
BP	1987	Boomerang Lake	Brush	260 cut brushes distributed over four areas
BP	1987	Boomerang Lake	Construction	200 moss bags introduced.
BP	1987	Boomerang Lake	Construction	Log boom and brush installation at B2, B8, B9 & B11
S-A	1988	Boomerang Lake	Amendment	Straw placed in Harold's Dam area.
BP	1988	Boomerang Lake	Construction	Brush distributed over B2 area
BP	1991	Boomerang Lake	Construction	30 truckloads of trees distributed over B8 area.
M	1992	Boomerang Lake	EM Survey	March EM survey of Tailings Dams 1 and 2:EM 31
PWP	1992	Boomerang Lake	Amendment	NPR Code 31:B9-B10:5.5 t; B7:0.5 t, B11 to B2: 3 t
M	1993	Boomerang Lake	EM Survey	Sep.; EM31 survey of Tailings Dams 1 and 2
PWP	1993	Boomerang Lake	Amendment	NPR: Code 30: B10: 9.3 t, B9: 15.6 t, Backfill Bay 3.9 t; Code 132: B9: 7.9 t; B8 - island, 15.7 t, Backfill Bay 3.9 t
PWP	1994	Boomerang Lake	Amendment	NPR: lower third of B.L. 16.5 t code 132
BP	1995	Boomerang Lake	Amendment	Brush Placement, 100 truckloads ~127 t
PWP	1995	Boomerang Lake	Amendment	Whole lake, 80 t code 31 using barge
BP	1996	Boomerang Lake	Amendment	Miscellaneous Fertilizer Addition ~ 294 kg
M	1997	Boomerang Lake	Monitoring	O2 profiles
BP	1997	Boomerang Lake	Amendment	1 t CaNO3 addition
PET	1998	Boomerang Lake	Construction	B11 bay and BR Bay Boom Curtains installed
PET	1998	Boomerang Lake	Amendment	Magnesium Experiment in 1 m 3 tanks on shore
PET	2001	Boomerang Lake	Monitoring	The new raft in the middle of BR Enclosure examined and Mg samplescollected, Phytoplankton collected
S-A	1986	Confederation Lake	Ammentment	Cattails transplanted by front end loader in June
M	1986	Confederation Lake	Elev. Survey	Lake levels monitored.
M	1986	Confederation Lake	Monitoring	Water bodies secchi depths measured.

Code	Year	Location	Activity	Details
M	1986	Confederation Lake	Monitoring	Sediment samples collected.
M	1986	Confederation Lake	Monitoring	Integrated phytoplankton samples 2.5 m sampled.
M	1993	Confederation Lake	Cond Survey	Conductivity survey along C8 shore
M	1995	Confederation Lake	Monitoring	Salmo Consulting Site Visit, Toxicology assessment
M	1996	Confederation Lake	EM Survey	EM47 Survey in C8 area
M	1998	Confederation Lake	EM Survey	EM survey along shore
M	2001	Confederation Lake	Monitoring	Phytoplankton in C8 Bay off a bedrock face between CS13 and M54
S-A	1986	Decant Pond	Construction	Cattails transplanted by front end loader.
BP	1986	Decant Pond	Construction	Cattails transplanted in hydroponic raft, netting
S-A	1986	Decant Pond	Construction	Cattails transplanted by hand
S-A	1986	Decant Pond	Construction	Two Cattail Rafts installed in June.
BP	1986	Decant Pond	Monitoring	Periphyton growth noted in shores.
BP	1987	Decant Pond	Construction	Gravel building materials as surface area for periphyton
S-A	1987	Decant Pond	Construction	26 cattail rafts installed.
S-A	1988	Decant Pond	Amendment	Straw replaced in cattail rafts, June.
S-A	1988	Decant Pond	Amendment	120 bales of straw placed on DP beach.
BP	1988	Decant Pond	Construction	Log boom installation in spring.
BP	1991	Decant Pond	Amendment	5 t NPR distributed from TRO to Decant Pond beach.
S-A	1992	Decant Pond	Amendment	30 truckloads of wood waste added to ARUM Beach
BP	1994	Decant Pond	Amendment	NPR: TRO to Decant Pond beach: 1.5 t code 132
PWP	2000	Decant Pond	Amendment	Putting NPR on Beach
PWP	2000	Decant Pond	Amendment	NPR: 4 bags (3.6 t) slurried and pumped onto beach.
M	2001	Decant Pond	Monitoring	Extensive Survey
S-A	1986	Mill Complex	Amendment	Mill Pond 1 truckload of sawdust added at outflow in June.
S-A	1986	Mill Complex	Construction	Cattails transplanted in Mill Pond in June.
S-A	1986	Mill Complex	Amendment	Mill pond outflow Sawdust 4 m3 placed after removing lime sludge in June. Liming of Decant Pond stopped.
S-A	1986	Mill Complex	Construction	Cattails transplanted by hand in Mill Pond.
S-A	1986	Mill Complex	Construction	Cattails transplanted in hydroponic set-ups: rafts, netting
BP	1987	Mill Complex	Amendment	Fertilizer added to in July.
S-A	1987	Mill Complex	Amendment	3 truckloads of sawdust distributed over pond bottom.
BP	1988	Mill Complex	Amendment	250 lb of 6:27:27 NPK added (Dryden supplier)
BP	1988	Mill Complex	Construction	Construction of Upper and Lower Dams
S-A	1988	Mill Complex	Amendment	60 bales of straw added for ARUM, Mill Pond
M	1992	Mill Complex	EM Survey	EM 31 survey of town site in March
BP	1992	Mill Complex	Amendment	Fertilizer Application: 18-6-12 Fert 55 kg Osmocote
PWP	1992	Mill Complex	Amendment	Mill Pond NPR Application: 0.75 t code 30 middle,shore

Code	Year	Location	Activity	Details
M	1993	Mill Complex	EM Survey	September, 1993 EM survey of Town Site:EM 31
BP	1994	Mill Complex	Amendment	Mill Pond NPR: 16.5 t code 30, 5.5 t code 132
PWP	1994	Mill Complex	Amendment	WHS edge of stream: 4.1 t of code 30, NPR
D	1998	Mill Complex	Construction	Build siphon, pipes to drain Mill Pond
D	1998	Mill Complex	Amendment	Draining of Mill Pond
D	1998	Mill Complex	Construction	Digging ditch in Mill Pond
D	1998	Mill Complex	Construction	Damage to siphon
PET	1999	Mill Complex	Amendment	Magnesium Installation at BFR + WHS
D	1999	Mill Complex	Construction	Drilling, Preparation for blasting
D	1999	Mill Complex	Construction	First, Second and Third Blast
M	2000	Mill Complex	Construction	Shallow Standpipes MS-MP-1, MS-MP-2, MS-MP-3
PET	2000	Mill Complex	Amendment	Reinstallation of Magnesium (weighing), WHS1
W-A	2001	Mill Complex	Amendment	Wood Ash Experiment, 0.5L to 18 L bucket.
M	2001	Mill Complex	Monitoring	Mill Pond Outfow Old and New Sampled
M	2001	Mill Complex	Monitoring	Water Levels: MS-MP-1, MS-MP-2, MS-MP-3, M38, M18
M	2001	Mill Complex	Construction	Sample from M55, M50. Two new shallow piezos (MS-55A, MS-55b) were installed in the muskeg area apox. Half way between M55 and M50. Samples form new piezos collected
W-A	2001	Mill Complex	Reveg Exper.	Fertilizer, Wood ash, seeds planted on exposed MP sediment
D	2002	Mill Complex	Concrete concentrate	Leach experiment for concrete concentrate in Confederation Lake water
BP	1986	Mill Complex	Amendment	Drepanocladis from Spill Area #2 transplanted to MPO.
BP	1986	Mill Complex	Construction	Dave's Dam constructed.
BP	1986	Mill Complex	Construction	Mill Pond Outflow Dam built.
M	2001	Mill Complex	Monitoring	Sample collected from Lower Dam & Upper Dam
M	1992	Mine Complex	EM Survey	March 1992 EM survey of Mine Site:EM 31, 34
D	1993	Mine Complex	Construction	Opening of BRC at base
D	1993	Mine Complex	Construction	New New Ditch Excavation
M	1993	Mine Complex	EM Survey	Sep., 1993 Re-do of EM survey of Mine Site, EM-31
M	1995	Mine Complex	EM Survey	EM Survey of Mine Site, February, 1995
D	1995	Mine Complex	Construction	Freshwater Diversion Ditch complete
M	1998	Mine Complex	EM Survey	Veryfication of high readings of previous EM survey
D	2000	Mine Complex	Construction	Planting Cattails, Willows poplar & oats
M	2001	Mine Complex	Survey	Collar elevation of MS-MP-1, MS-MP-2, MS-MP-3 in respect to M18. Base line stablished M38, M13, MS-MP1,2,3
M	1994	Mud Lake	Operation	Confirmation of Mud Lake Contaminated by Tailings Groundwater
S-A	1995	Mud Lake	Cattails	Cattail rafts Installed
S-A	1995	Mud Lake	Construction	ARUM Curtain Installed enclosing 2500 m2

Code	Year	Location	Activity	Details
S-A	1995	Mud Lake	Amendment	ARUM Potato Waste Added, 6,700 pounds (134 bags)
M	1996	Mud Lake	EM Survey	EM47 Survey
M	1996	Mud Lake	EM Survey	Gound Truthing North of Mud Lake
S-A	1996	Mud Lake	Construction	Dissasembly of Mud Lake ARUM Cover
PWP	1997	Mud Lake	Amendment	Mud Lake: NPR addition 60 t
PET	1998	Mud Lake	Amendment	Magnesium Experiment 1 m 3
D	1999	Mud Lake	Monitoring	Beaver Dam raising Mud L. water level
D	2000	Mud Lake	Construction	Covering Beaver Dam
GW-A	2000	Mud Lake	Construction	Injection System and Monitoring Piezometers installed
GW-A	2000	Mud Lake	Monitoring	FN and TN standpipes sampled ,TN3, 13, Assayer results
GW-A	2001	Mud Lake	Amendment	Injection run No. 1 (1.27 days)
W-A	2001	Mud Lake	Amendment	Wood Ash Experiment, 5L to 1 m 3, set up
GW-A	2001	Mud Lake	Monitoring	FN3,6,8 and TN2,6,8 sampled, No assayer results
GW-A	2001	Mud Lake	Construction	Hook Flow Meter in Injection System, Measure Flows
GW-A	2001	Mud Lake	Monitoring	I1-6, FN3-8, TN1-18 sampled, No assyer results
GW-A	2001	Mud Lake	Amendment	Injection run No. 2 (0.82 days)
GW-A	2001	Mud Lake	Rod Survey M60A	Conductivity Rod Survey A (Map 1, 14 measured points, Depth 10 ft,rod A)
GW-A	2001	Mud Lake	Rod Survey M60A	Conductivity Rod Survey B (Map 2, 14 measured points, Depth 10 ft,rod A)
GW-A	2001	Mud Lake	Amendment	Flow Tests Injection No. 3 (0.04 days)
W-A	2001	Mud Lake	Amendment	Samples (top and bottom) collected from Tank1 (orginally 2.5 L of wood ash) and Tank 2 (originally 5L of wood ash). Tank 2 was moved and positioned adjacent to Tank 1. Adding a new dose: Tank 1 - 7.5 L bringing the total to 10L. 10 L to Tank 2. Tank 2 had to be moved and contained no wood ash from previous application. Samples (top and bottom) were collected from each tank 10 min, 2, 6, 24, 48 h after wood ash addition.
GW-A	2001	Mud Lake	Monitoring	FN3-8 and TN1-18 sampled, No assayer results
M	2001	Mud Lake	Monitoring	A survey of water column and surface sediment pH, conductivity, temp along three east-west transcects at the northern one-third of the lake.
GW-A	2001	Mud Lake	Rod Survey M60A	M60 Injection Grid, Conductivity Rod Survey, Sampling of all TN and FT piezometers, Survey of collars of M60A, M60B with respect to the Mud Lake, Flow Volume Meter
GW-A	2001	Mud Lake	Rod Survey M60A	Conductivity Rod Survey C (Map 3, 129 measured points, Depth 10 ft,rod A)
GW-A	2002	Mud Lake	Amendment	Injection run No. 4 (0.49 days)
GW-A	2002	Mud Lake	Monitoring	FN4,6, TN1,4,6,9 sampled, Assayer resulrs
GW-A	2002	Mud Lake	Rod Survey M60A	Conductivity Rod Survey D (Map 4, 87 measured points, Depth 10 ft,rod A)
GW-A	2002	Mud Lake	Rod Survey M60A	Conductivity Rod Survey E (Map 5, 107 measured points, Depth 10 ft, rod A)

Code	Year	Location	Activity	Details
M	2002	Mud Lake	Survey	Assessment of the head in the vicinity of M58 and M59
GW-A	2002	Mud Lake	Amendment	Injection run No. 5 (20 days)
GW-A	2002	Mud Lake	Monitoring	FN4,6 and TN1,4,6,9 sampled, No assayer results
GW-A	2002	Mud Lake	Monitoring	I2,FN3-8 and TN-18 sampled, No assayer results
GW-A	2002	Mud Lake	Rod Survey M60A	Conductivity Rod Survey F (Map 6, 113 measured points, Depth 10 ft, rod A)
GW-A	2002	Mud Lake	Rod Survey M60A	Conductivity Rod Survey G (Map 7, 23 measured points, Depth 10 ft, rod A)
GW-A	2002	Mud Lake	Rod Survey M60A	Conductivity Rod Survey H (Map 8, 82 measured points, Depth <30 ft, rod B)
GW-A	2002	Mud Lake	Monitoring	I1-6 , Assayer results ,FN3-8 and TN-18 sampled, No assayer results
GW-A	2002	Mud Lake	Rod Survey M60A	Conductivity Rod Survey I (Map 9, 72 measured points, Depth <30 ft, rod B)
GW-A	2002	Mud Lake	Rod Survey M60A	Conductivity Rod Survey J (Map 10, 55 measured points, Depth <30 ft, rod B)
GW-A	2002	Mud Lake	Amendment	Injection run No. 6 (7 days)
GW-A	2002	Mud Lake	Monitoring	FN3-8 and TN-18 sampled, No assayer results
M	1986	Tailings	Piezometers	Installation and testing of Morton Piezometers M1-M57 completed in November
PH	1986	Tailings	Amendment	Tailings fertilzation plots set up and harvested.
PH	1986	Tailings	Monitoring	Terrestrial vegetation areas mapped.
PH	1986	Tailings	Soil Survey	Cond and pH measured on soil and tailings samples.
D	1987	Tailings	Construction	Tailings groundwater diversion ditch and polishing pond construction completed in May.
D	1987	Tailings	Construction	Grouting of tailings dams by Morton in October.
M	1994	Tailings	Survey	EM Survey between Tailings and Mud Lake #1
M	1994	Tailings	Survey	EM Survey between Tailings and Mud Lake #2
M	1994	Tailings	Construction	Installation of Vonhof Piezometers M58- M90
M	1995	Tailings	EM Survey	Completed 40 km of EM transects to define Kalin Canyon Plume
M	1995	Tailings	Construction	Piezometers M64 through M69 (ten) installed
M	1995	Tailings	Construction	Piezometers up to M90 (39) installed
M	1995	Tailings	Surveying	Total Survey Equipment Survey of Site: Hoey
M	1995	Tailings	GPS Survey	GPS Survey, Boojum
M	1996	Tailings	Microbiology	Installation of 4 slides: M60A, M60B, M62, M63
M	1996	Tailings	Microbiology	Installation of 2 slides: M34, M58
M	1996	Tailings	Microbiology	Installation of 14 slides: M7N, M7S, M18, M27C, M27N, M27S, M28, M38, M39, M39A, M57, M79, M81, M85
GW-A	1997	Tailings	Microbiology	Confirmation of presence of appropriate bacteria in tailings area groundwater Lau, Seepages collection
GW-A	1997	Tailings	Construction	Drilling to define the clay layer in Sandpit
GW-A	1997	Tailings	Amendment	Urea addition through stand pipes MSU-A and MSU-B

Code	Year	Location	Activity	Details
GW-A	1997	Tailings	Construction	Construction of Shallow Piezometers MSP1-MSP13
M	1997	Tailings	Microbiology	First time sampling and reinstalling: M7N, M7S, M18, M27C, M27S, M28, M34, M38, M39, M39A, M57, M58, M60A, M60B, M62, M63, M79, M81. Slide in M27N ruined, M85 out of water.
M	1998	Tailings	Microbiology	Removing of slides:M7N, M7S, M27C,N, S, M85
M	1998	Tailings	Microbiology	Reinstalling of five slides: M7N, M7S, M27C, N, S
PH	1998	Tailings	Amendment	Ground truthing across from M7, placement of new phosphate and new pipe
PH	1998	Tailings	Amendment	Placement of PHITO inside TRO and NPR
D	1998	Tailings	Construction	Ground truthing along concrete dam
M	1998	Tailings	Monitoring	Groundwater Modelling 3D version 1 A. Buchnea
GW-A	1999	Tailings	Amendment	2.5 kg of Redpath Brown Sugar added at each location around each piezometer. 250 g of Yeast extract added each location.
GW-A	1999	Tailings	Amendment	2.5 kg of Redpath Brown Sugar added at each location around each piezometer.
PH	1999	Tailings	Amendment	NPR
PH	1999	Tailings	Amendment	Fertilizer Test Plots, Set up NPR
PH	2000	Tailings	Amendment	1 bag = 909 kg. 13 bags(11.8 t) distributed around piezo M27. 2 bags (1.8 t) distributed in Upper TRO. 2 bags (1.8 t) in Lower TRO, Scal up of 1999 experiment
GW-A	2000	Tailings	Construction	Installation of shallow piezometers in circles
M	2001	Tailings	Monitoring	Water Levels measured , Piezometers sampled
M	2001	Tailings	Survey	Collar elevation of MSU-C, MSU-D and MSU-E
M	2002	Tailings	Construction	Cores, cuttings collected from drill holes close to M7N, M-PR-U, M-PR-L, H1, H2, M24N, M27N, TRO
M	2002	Tailings	Microbiology	Collecting the remaining slides (July 6,02: M27S,M27C,M7N,M7S; July 8: M60B, M81, M79, M39A,M39, M38, M63, M62, M57, M58; Missing Slides: M60A, M85, M27N, M18, M28) and water from the middle of the screen
M	2002	Tailings	Monitoring	Sampling all Tailings Piezometers before and after bailing, measure field chemistry before and after
PH	2002	Tailings	Survey	Map of phosphate rock distribution