ECOLOGICAL ENGINEERING MEASURES DEVELOPED FOR ACID GENERATING WASTE

Biological Polishing for Acidified Lakes

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Abstract.A copper/zinc concentrator located in the Red Lake area, northern Ontario, was shut down in 1981. In an area of 25 hectares, 760,000 tonnes of tailings are contained within low dams. The tailings contain about 41% pyrite and 4.1% pyrrhotite. The 75 hectare mine site, including the town site and mill, is surrounded by recreational fishing lakes of the English River drainage basin. Decommisioning procedures include those steps which will assure acceptable surface water quality in the long term. As Ecological Engineering appeared suitable in providing such a solution to acid generating wastes on this site, efforts were directed towards development of measures using this approach. An acidic ground water plume generated by the tailings was intercepted with ditching and a polishing pond was created. The biological polishing capacity of endemic biological polishing agents, identified as algal complexes dominated by *Achnanthes* and *Mougeotia* spps. in acidic (pH 3.5) water, are evaluated after 2 years' growing seasons. An acid-tolerant aquatic moss was introduced in the polishing system. The moss carpets cover the sediment surface, providing a permanent sink for metals removed by the polishing agents. This paper provides a description of this Ecologically Engineered system and its expected long term performance.

ADDITIONAL KEY WORDS: Acid mine drainage; biological waste water treatment; close-out; Ontario, Canada

Introduction

The Ecological Engineering methods which are being developed are based on the results of ecological studies carried out on the natural recovery process which takes place on tailings sites. The

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principles of this technology have been presented in detail by Kalin and van Everdingen (1988).

It is intended that these Ecological Engineering systems will be self-sustaining in the long term, as well as being maintenance- free. The measures are being tested on a tailings site from a copper/zinc concentrator in Northern Ontario, Canada. A feasibility study was initiated in 1986 and the close-out measures applicable to the site conditions are described by Kalin (1989).

This paper reports on the Ecological Engineering measures which have been implemented between 1986 and 1988 for a drainage basins containing 760,000 tonnes of acid-generating tailings containing 43% metal sulphides.

Site description

The waste-management area can be divided into three units - the tailings area with Decant Pond, the Boomerang Lake basin and the Mud Lake basin. Map 1 provides an overview of the site and identifies all major locations where remedial measures have taken place. The South Bay site is surrounded by Confederation Lake which is part of the English River drainage basin. The tailings, located close to Boomerang Lake, provide the main source of acid generation. Boomerang Lake has acidified (pH 3.5) over the life of the mill and displays increasing concentrations of zinc.

Contaminated water arises from the tailings area at a total of about 30,000 m^3 per annum. This water leaves the basin in four directions, two of which reach Confederation Lake directly and two indirectly through Mud Lake and Boomerang Lake. The annual flow volume estimates and the flow directions were determined based a hydrological investigation. On an annual basis, a total water volume of about 335,000 m^3 can be expected to move through the Boomerang Lake drainage basin.

Tailings and contaminant production

The elemental concentrations in the water collected from within the tailings exhibited large ranges. Therefore, to estimate the acid mine drainage production which takes place annually, a range of the concentrations of oxidation products was used (minimum and maximum values) along with an average. Table 1 gives the results of the calculations of the oxidation and precipitation products which can be expected to form from the tailings pile of 760,000 tonnes.

The tailings have an average 43% Fe + Cu + Pb + Zn + S content. The tailings exhibit a relatively high ratio of metals to sulphur (0.6 to

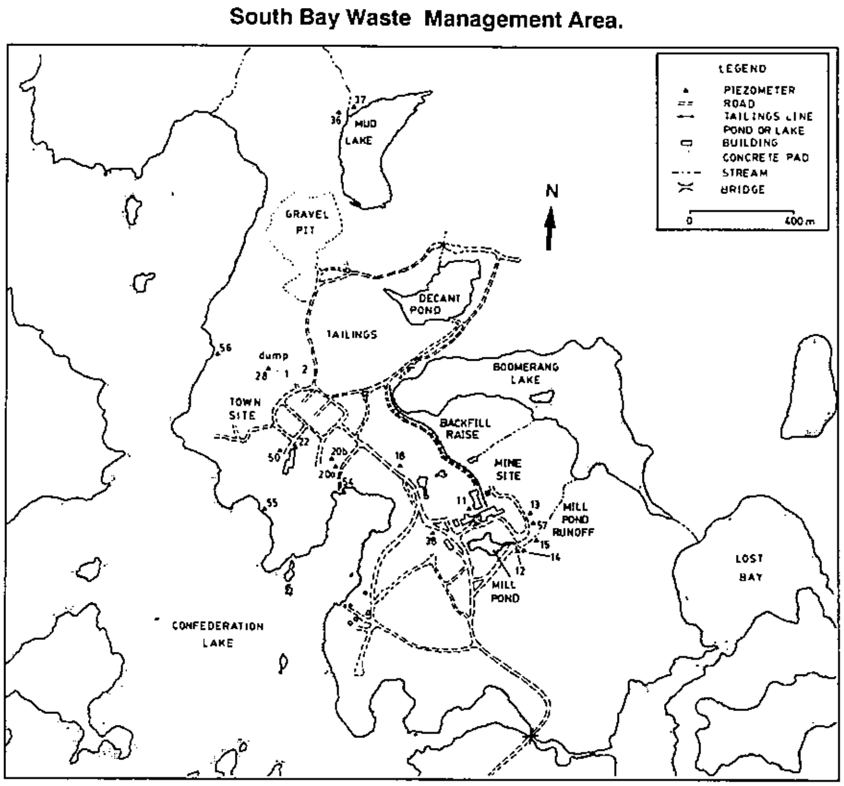


Figure 1: Overview of South Bay Waste Management Area.

0.75), which no doubt reflects the presence of pyrrhotite, although some iron may be present in silicate minerals in the tailings.

The acid-generation potential of the tailings is considered with respect to pyrite and pyrrhotite content. The rate at which pyrite is depleted from the tailings deposit, based on the minimum sulphur concentrations in the water, is estimated to take approximately 35,700 years. Based on the highest concentrations in the water, this process is estimated to take 1,100 years. The acidity which can be produced ranges from 530 to 16 tonnes of $CaCO_3$ equivalent per year. These tonnages can be produced and are potentially discharged with a delay ranging from 0.45 years to 3.2 years. Precipitation of iron hydroxide is expected to occur with an estimated annual volume of sludge produced ranging from 80 to 2,576 m^3.

From these estimates of annual contaminant generation, one important point emerges and that is the need for a self-sustaining treatment system, as

Table 1: Calculating the potential acid production

PARAMETER	MINIMUM	AVERAGE	MAXIMUM
Tailings, tonnes	760,000	760,000	760,000
Average density of material, t/m^3	3.65	3.65	3.65
Average bulk porosity, fraction (est.)	0.30	0.30	0.30
Volume, m^3	297,353	297,353	297,353
Surface Area, m^2	200,000	200,000	200,000
Average thickness, m	1.5	1.5	1.5
Initial FeS2 + FeS, mass fraction	0.45	0.45	0.45
Initial pyrite + pyrrhotite, tonnes	342,000	342,000	342,000
Initial pyrite + pyrrhotite, moles	2.94E+09	2.94E+09	2.94E+09
Initial neutr. cap., mass fraction (CaCO3)	0	0	0
Initial neutralizing capacity, tonnes CaCO3	0	0	0
Net mean annual infiltration, m/yr	0.15	0.15	0.15
Average thickness saturated, m	0.94	0.94	0.94
S concentration, mg/L	176	1,669	5.668
SO4 concentration, millimoles/L	5.5	52.1	176.8
Acidity, mg/L	133	9,191	30,120
Fe concentration, mg/L	31	2.328	9,857
Initial SO4 flux, mol/m^2.yr	0.82	7.81	26.52
Pyrite depletion rate, mol/yr	82,346	780,880	2,651,903
Minimum depletion time, yr	35,742	3.769	1,110
Acid production rate, tonnes/yr (CaCO3)	16	156	531
Neutralizing capacity exhaustion period, yr	0	0	0
Acid storage capacity, tonnes (CaCO3)	7.5	516	1.692
Potential discharge delay, yr	0.45	3.30	3.19
PRECIPITATES:			
Maximum Fe(OH)3 quantity, tonnes	314,537	314,537	314.537
Fe(OH)3 production, t/yr (if all from FeS2)	9	83	283
Fe(OH)3 production, t/yr (if all from FeS)	18	167	567
Potential sludge volume at 10% solids, m^3	2,859,424	2,859,424	2.859,424
Annual sludge volume, m^3/yr	80	759	2,576

CONSTANTS USED:	
mol. weight SO4	96.06
mol. weight FeS2	119.9
mol. weight FeS	87.90
mol. weight CaCO3	100.0
mol. weight Fe(OH)3	106.8
mol. weight CaSO4.2H2O	172.1
Conversion factor, g/tonne	1E+06
Conversion factor, tonne/g	1E-06
Stoichiometric ratio, 2 SO4 -> 1 FeS2	0.5
Stoichiometric ratio, 1 FeS2 -> 2CaCO3	2

even with maximum oxidation rates, treatment of the contaminants will be required for at least 1,100 years.

Ecological Engineering measures

It has to be recognized that water must be brought to the surface before its quality can be addressed with Ecological Engineering measures. The contaminant loadings to Boomerang Lake are the sum of contributions from allochthonous sources (run-off from the mine site and spill areas, and ground water discharge from the tailings) and autochthonous sources (metal flux from the sediments). Processes relevant to the removal of these contaminant sources are, sedimentation of particulate matter, contaminant flux from the sediment and dissolution of contaminants.

The suspended solids loading received by Boomerang Lake is small, due to the fact that no direct fresh water input exists to the lake. The processes which will drive zinc removal from the water column are adsorption on and co-precipitation with manganese oxides as well as with amorphous iron oxides, and adsorption on organic matter. The adsorption affinities of zinc, however, are affected by pH, Eh, mineralogy and organic acids. The natural removal processes for zinc vary, therefore, depending on local conditions. In order to enhance these natural removal processes, conditions have to be created which support those processes, for example the production of organic matter.

Periphytic algal growth on suspended branches in the lake could contribute significantly to zinc removal if submerged surface areas were provided on which extensive growth could occur. Therefore, log booms have been installed, behind which brush has been placed. The biological polishing capacity which has developed on this brush consists mainly of an algal complex dominated by _Achnanthes_ and _Mougeotia_ spps.

The concentrations of iron, copper, sulphur and zinc contained in this algal material after two growing seasons and those for an undetermined length of time suggest that one of the major processes of removal will be the co-precipitation of metals with iron hydroxides.

Although the increase of iron content from one growing season to the second is notable (20 g/kg increasing to 40 g biomass /kg substrate), the metal concentrations in the algal mat do not increase proportionally. The concentrations of iron and zinc in algal mats collected from those branches where the time of suspension is unknown were one order of magnitude higher (166 g/kg and 6 g/kg,), compared to two years' growth

(40 g/kg and 0.5 g/kg) respectively.

The algal growth on the branches of the brush will be relegated to the bottom sediments after sloughing, a process promoted by wave action. The sediments in the lake will be enriched with the metals adsorbed by the algal complex. Therefore, a reducing environment has to be maintained over the sediments to prevent resolubilization of the metals.

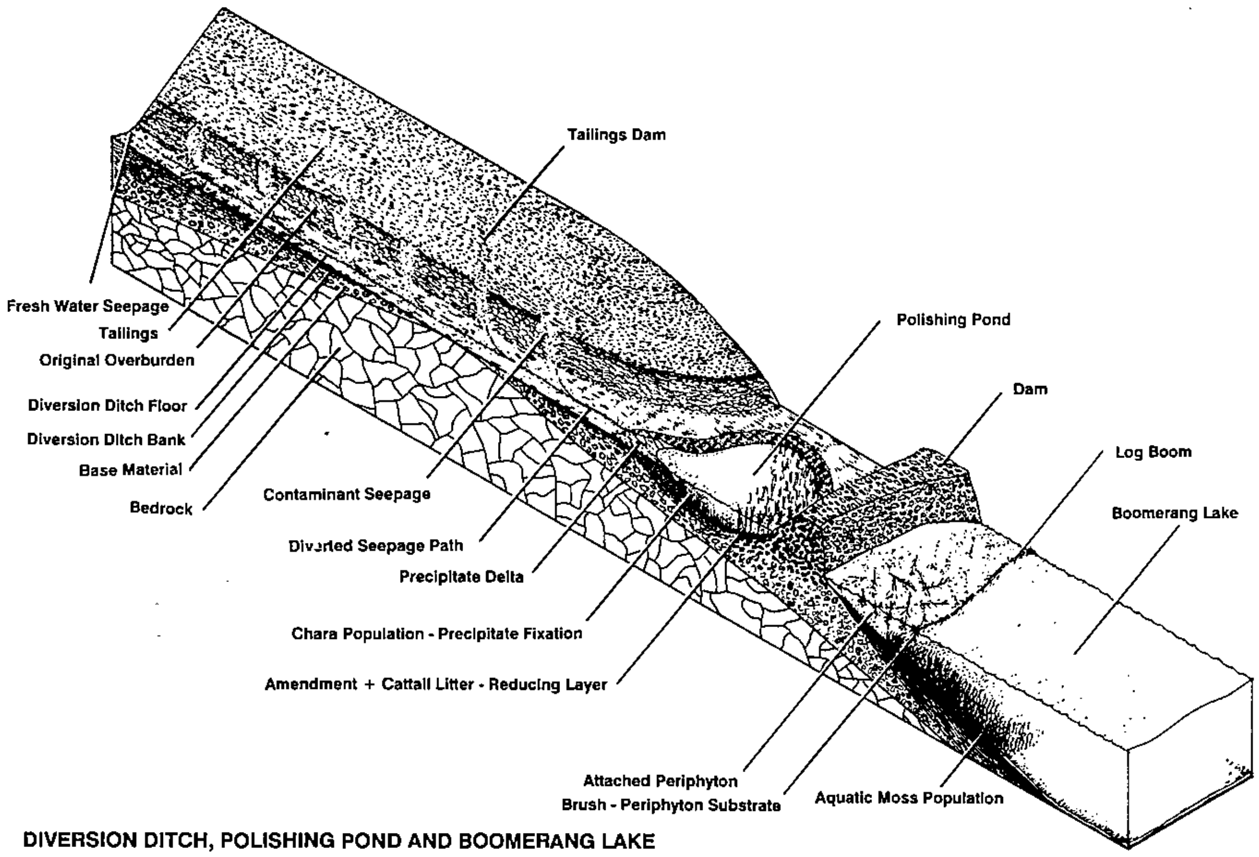
For this purpose, within areas enclosed by log booms, submerged aquatic moss has been introduced, where decaying basal portions serve to consume oxygen above the sediments. From the investigation of a lake (pH 3.5) in Northern Saskatchewan which received tailings, it was found that this species of moss covered the entire lake bottom and provided an effective barrier to oxygen over the sediment (Kalin, 1985). Its ability as a cation-exchange medium was found to be limited in the presence of concentrations of iron greater than 35 mg/l in acidic waters (Buggeln and Kalin, 1986). However, the moss surface functions as an adsorption and precipitation site, as well as providing filtration capacity for particulates.

The components described above, algal biomass and moss-covered sediment, constitute the biological polishing system in Boomerang Lake for the removal of zinc. Thus, it will be important to provide sufficient surface area for algal growth and to develop an extensive cover of submerged aquatic moss. It is expected that, before too much longer, such a system will be established in the shallow part of Boomerang Lake near the outflow, since the most extensive growth of moss and algal material has been noted in this area after the first year of placement of the brush.

In Figure 2, an overall representation of the combination of the measures described previously, together with the precipitation and neutralization systems is made. The polishing system in the acidic lake is complemented by precipitation/neutralization which is expected to occur in a groundwater-interceptor ditch and a polishing pond which have been constructed. Their location was determined by the topography of the tailings and the prevailing groundwater flows.

Although data with respect to the quantification of the expected function of the interceptor ditch are not available at this stage, it is reasonable to expect that precipitation of iron hydroxide will occur as the tailings seepage is exposed to the air. The precipitation process will be further enhanced by the mixing of the seepage water

Figure 2: Conceptual representation of the Ecological Engineering measures for an acidified lake



with uncontaminated ground water drawn into the ditch from the other side. Some neutralization can also be expected to occur through the addition of this uncontaminated water.

The settling pond at the lower end of the interceptor ditch will facilitate completion of the precipitation step, allowing settling of the precipitate. A neutralizing buffer can be established through the introduction of a *Chara* population. Such a population has colonized a seepage path leaving the tailings in the northern direction. *Chara* populations accumulate calcium and magnesium carbonate on the outside of their cell walls during growth, and in this way serve as a buffer to the expected acidification (Kalin & Smith, 1986; Smith & Kalin, 1988).

Assessment of the implemented measures

At this early stage of the implementation, i.e. at a time when the system is only beginning to function, it is not possible to quantify its effectiveness. Some discussion can be had, however, addressing the qualitative effectiveness of the measures implemented to date.

The metal and sulphate removal capacity of the system will depend on the rates at which the processes employed occur. Those are: the growth rates of the biological agents, the rate of sulphate reduction, the rates of adsorption, co-precipitation and precipitation of metals, and the rate at which the contaminants are produced in the three drainage basins. To enable a determination of some of these rates, data have been collected.

Quantification of biomass of the polishing agents has been carried out for the algal material growing on the brush cuttings from Boomerang Lake. The results are presented in Figure 3, expressed as algal biomass weight per kg of growth substrate versus the number of days the material was suspended.

Absolute growth rates cannot be obtained from the accumulation of biomass, as wave action continuously strips biomass which settles to the sediments. The assumption is made that the amount of biomass relegated to the sediment is, on average, the same throughout the year. However, the quantities of biomass determined per kg of substrate suspended (both air dried in an oven at 60°C) indicate that an incremental increase in biomass is noted after about 180 days of suspension from 200 g/kg to 500 g/kg (Figure 3).

An estimate was made with respect to the total growth substrate which might be provided by a spruce tree of dimensions similar to those used as part of the brush suspended in Boomerang Lake. One tree can be expected to produce about 40 kg of growth substrate in addition to the trunk and can therefore be estimated to provide substrate for about 8 kg to 20 kg of algal biomass /unit tree. On the average this biomass contains 4.2% Fe, 0.02% Cu, 0.003% Pb, and about 0.05% Zn after two years of growth. These concentrations increase with time to 16% Fe, 0.1% Cu, 0.02% Pb, and 0.6% Zn based on concentrations determined in biomass suspended for an undefined period of time. Therefore using a unit tree to evaluate the polishing capacity for the removal of Zn in Boomerang Lake, where the annual loading ranges from 1.4 tonnes to 2.5 tonnes, results in a requirement of 10 to 15,000 trees, or the equivalent quantity of brush.

In Figure 3, the biomass quantities of moss which has been growing for different lengths of time are presented. Again the biomass quantity determined after two growing seasons is significantly higher than that obtained within one growing season. It is likely that this increase is due to the adhered material on the non-growing parts of the moss strands. The rate of growth the first year following introduction of the moss was about 0.4 to 0.8 $g/m^2/day$ and, in the second growing season, about 1.5 $g/m^2/day$, due primarily to the higher biomass weights. Moss bags which were harvested in spring after overwintering displayed no growth during the winter as expected, with a negative growth rate of 0.02 $g/m^2/day$. Through continued apical growth a thick carpet of moss is attained, ensuring a reducing environment in the sediments below.

These estimates of polishing capacity are limited in their reflection of the real polishing capacity, for the following reasons: firstly, it is impossible to quantify the surface area provided by the brush placed behind the log booms, which may well be equivalent to the quantity required to remove the annual loadings of contaminants. Furthermore, these values were obtained during the establishment phase of the system, at a time when functioning at full capacity could not be expected. With progress of the populations, in terms of growth rates and lateral spread, increased polishing rates can be expected.

Thirdly, as the conditions in the lake improve, due to the reduction of contaminant loading which can be expected from the implementation of the measures at other locations on the site and through the

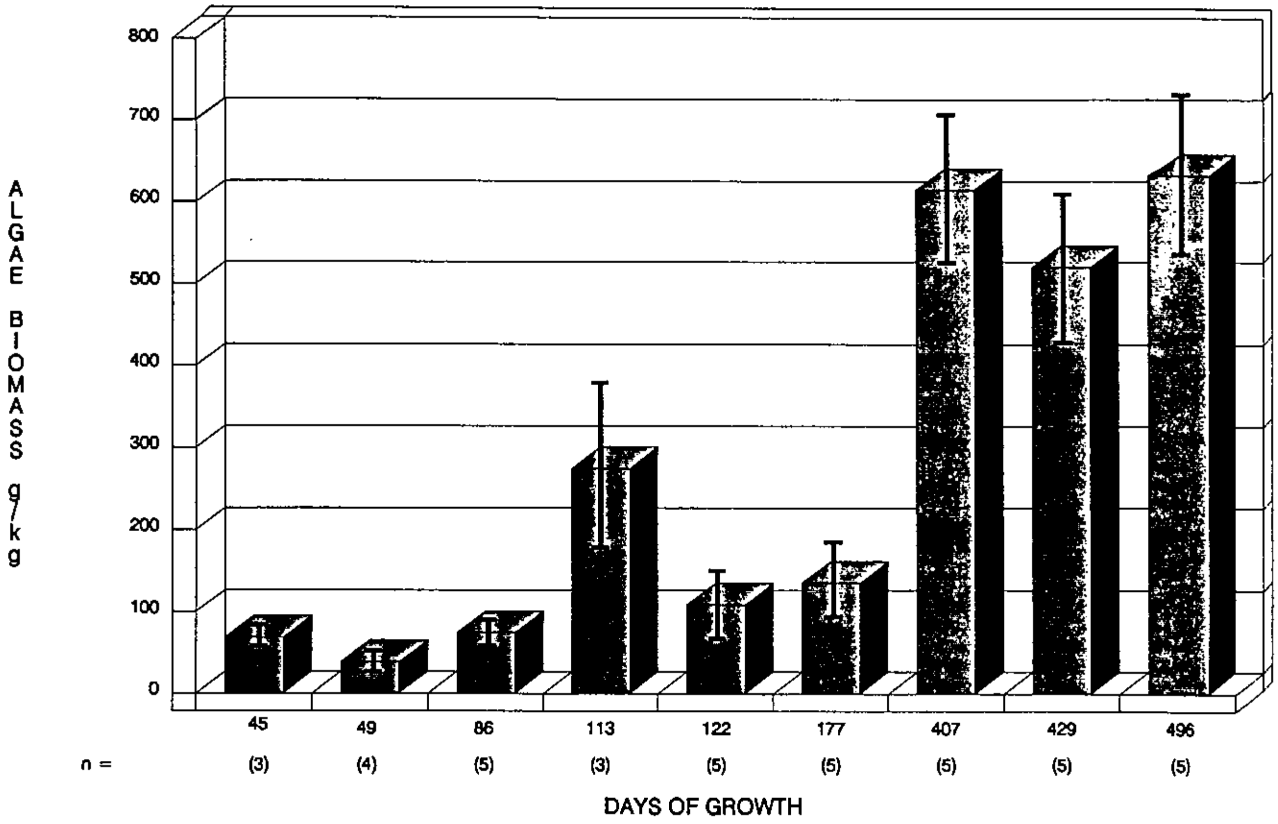


Figure 3: Biomass productivity of algal mats on cut brush

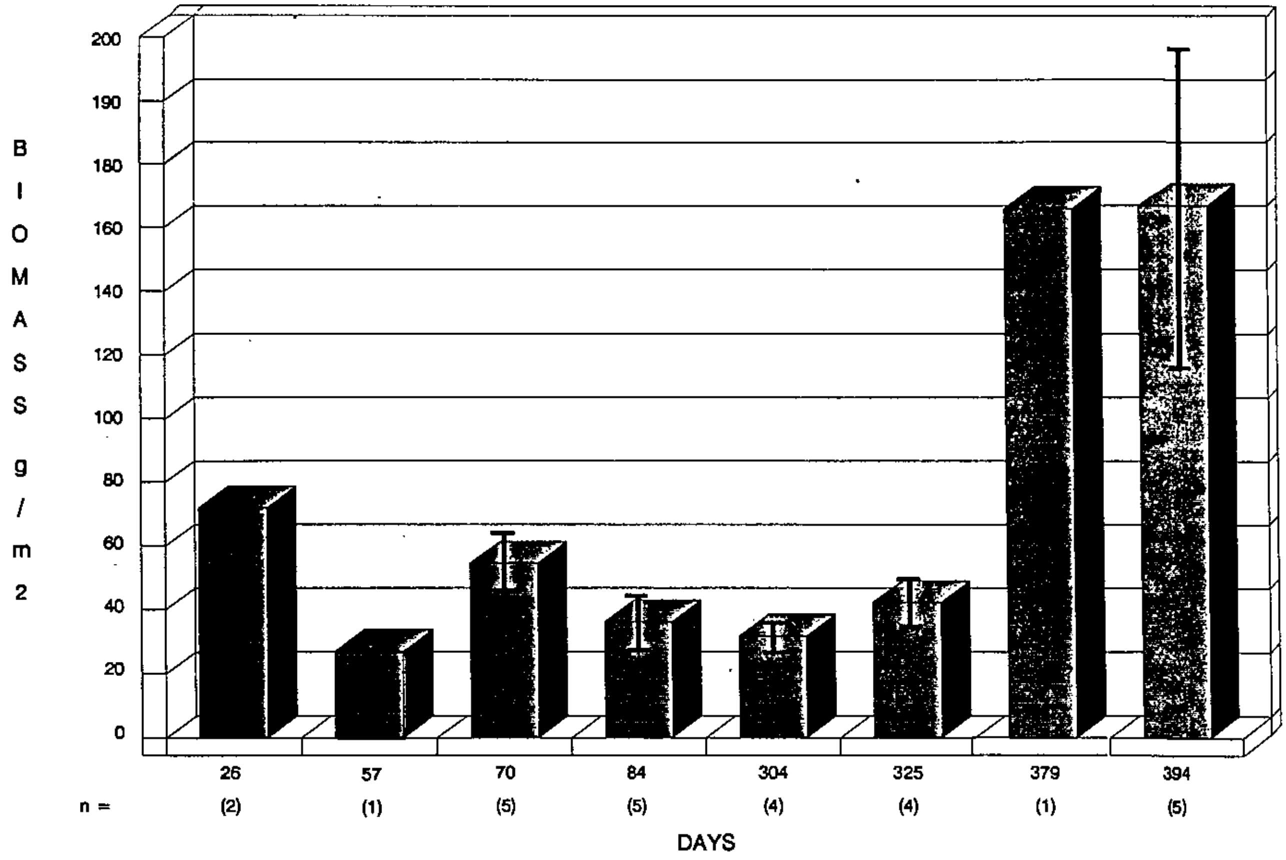


Figure 4: Moss biomass produced during the growing season

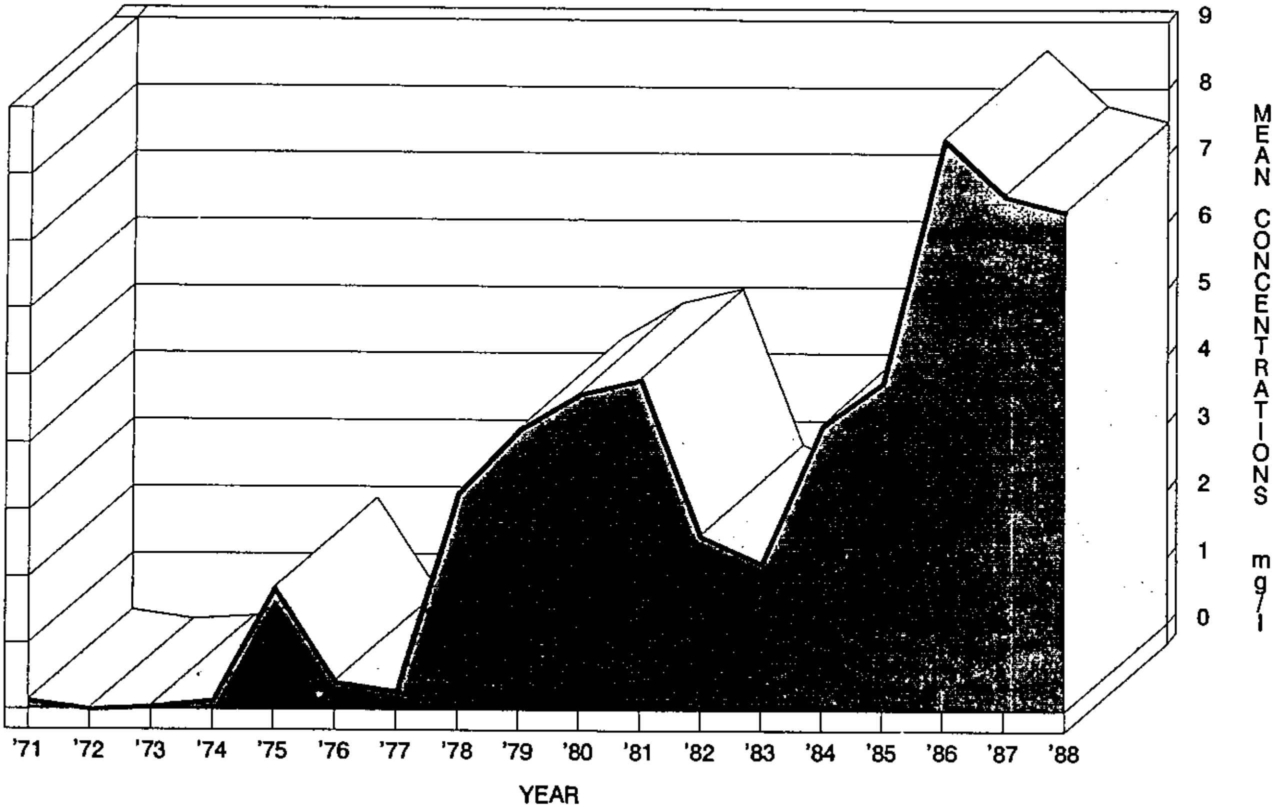


Figure 5: Zinc concentrations in Boomerang Lake from 1971 to 1988

interceptor ditch, colonization by other biota will increase.

The ultimate proof of the effectiveness of the measures implemented can only be obtained directly by a determination of the concentrations of zinc in Boomerang Lake. In Figure 5, the zinc concentrations in the lake since 1971 are given. A steady increase can be noted up to 1981, whereupon a decrease by an average of 2 mg/l was observed in 1982, attributable to liming. The remnants of this liming activity are still noticeable in the lake. Within the same year, the concentration of Zn in the lake continued to increase. The 1986 year marked the beginning of the implementation of the Ecological Engineering measures and a slight decline in the Zn concentrations is evident by 1988.

Given that the time lag with which the ground water from the tailings reaches the lake can range from about 0.45 years to about 3 years, the downward trend noted in zinc concentrations is promising. However, only a continued downward trend in zinc concentrations will confirm the effectiveness of the measures taken.

Conclusion

This is the first implementation of Ecological Engineering measures to achieve a walk-away scenario from an acid-generating tailings area, and many questions remain to be answered. However, without such an on-site demonstration, it would not be possible to determine the actual effectiveness of these measures.

From the results of the first two years of the project, it can be concluded that the measures which were put in place appear to hold promise for a long-term performance.

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