THE DECOMMISSIONING

OF LES MINES SELBAIE

VOLUME I - SUMMARY

IN FULFILLMENT OF PURCHASE ORDERS

1990:65733,

1991: 75171, 73922

FEBRUARY 13, 1992

It is to be understood that Boojum Research Limited has attended at Les Mines Selbaie for the sole purpose of conducting environmental work at the request of Les Mines Selbaie. During the time (Janaury 14, 1991 to December 31, 1991) that Boojum Research Limited or its agents conducted environmental work they at no time had the charge, management or control of the property and at no time did Boojum Research Limited have possession, occupation or direct control of any source of contaminant that may have been present on the subject property/site while undertaking to carry out the instructions of Les Mines Selbaie to conduct environmental work. Further, as a result of conducting environmental work, Boojum Research Limited is not to be considered a “person responsible” as defined under the *Environmental Protection Act*, R.S.O. 1980, c.141, as amended.

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I EXECUTIVE SUMMARY

Boojum Research Ltd. have carried out two years of investigation and experimentation on-site to develop an Ecological Engineering decommissioning program for Les Mine Selbaie.

Drainage basins which will generate contaminated run-off water are defined for the mill site, the waste rock, the open pit and the tailings. It is recommended that three distinct basins be created. The first will contain the waste rock pile, the general collection pond and the open pit, draining towards the north and east. The second drainage basin will contain the tailings and the polishing ponds, and drain from the existing decant structure. The third drainage basin encompassing the mill site and the ore stockpiles will join the second drainage basin's flow.

The ARD (Acid Rock Drainage) originating from the waste rock pile is high in oxidized iron. The iron will be precipitated in the B-ditch with phosphate. At the same time, acidity will be consumed. Estimates of the length of time for which treatment is required range from 285 to 1900 years. Non-reactive sand residue will remain following precipitation with phosphate. The sand residue produced from the iron precipitation and acid consumption will be integrated into the waste rock pile, and is expected to provide a less permeable cover material for the waste rock pile. On-site testing of the precipitation/acid consumption step will determine the logistics of the procedure during operations, prior to decommissioning.

Waste rock pile seepage will be retained in the general collection pond, where a microbially active sediment will be promoted which generates alkalinity, produces reducing conditions, and supports sulphate reducing bacteria. These bacteria generate hydrogen sulphide, which in turn precipitates metals as sulphides. ARUM (Acid Reduction Using Microbiology) experiments in the field and the laboratory indicate that microbial activity can be initiated in ARD generated by the waste rock pile. A retention time of one year is required for water quality improvements. This estimate is derived from laboratory tests of organic amendments, collected from the collection pond without pretreatment with phosphate. Laboratory tests examining pretreatment suggest that the acidity is significantly reduced, iron is precipitated, and a large fraction of the dissolved metals are removed. Improved post-phosphate water quality will augment the performance of ARUM.

The close-out scenario for the tailings consists of a series of ponds built as steps down the slope of the tailings surface. The beaches of the ponds are covered with a semi-aquatic vegetation. The sediments of the ponds will be developed so to maintain ARUM microbial activity. An oxygen-consuming vegetation cover will be established on the exposed slopes of the tailings. Experiments, examining whether it is feasible to establish an oxygen-consuming bacterial population in the root zone, were performed. Vegetation plots on the tailings established in 1990 survived the winter and continued to grow in l991. The successful combination of conditions was replicated in l991 on a 0.1 ha scale. The results of field and laboratory studies indicate that the concept of an oxygen-consuming vegetation layer is feasible.

During operations, a floating vegetation cover should be established on the clarification and polishing ponds. At time of decommissioning, organic matter from this vegetation mat will have integrated, to some degree, into sludge, accumulated in the polishing ponds due to liming.

The tailings decommissioning approach will produce a reduction in the acid generated, due to prevention of the oxidation and hydrolysis of ferrous iron. Oxygen-consuming ARUM sediments developed over the submerged tailings, combined with anoxic organic strata integrated into the unsaturated zone will remove heavy metals and increase the pH. Effluents passing through the polishing ponds with floating cattail covers will emerge with an environmentally acceptable quality.

It is recommended that the overall concept be implemented as soon as the upper part of the tailings area becomes permanently inactive, so that design criteria and maintenance requirements for the system can be determined.

At decommissioning, the drainage basin, presently containing the mill site and ore stock piles, will have been expanded such that the unaffected area to the west of the open pit will drain via the reclaim pond. The results of a soil survey of the concentrate loading area and the ore stock pile will identify highly contaminated overburden, to be segregated from less metal-laden material. The high metal material will be buried in a till-lined pit to prevent leaching. The low-metal material remaining will be used to create meanders and ponds for biological polishing in this drainage basin. Demolition material which are not reclaimed will be divided into inert materials, such as wood, and metal containing material. Inert materials will be deposited in the pit, whereas metal-containing demolition scrap will be buried in the till pile.

The chemistry of the tailings ponds was examined with respect to final effluent quality control. Monitoring data, collected since 1985, indicate that copper concentrations increase during the winter months. For zinc, two seasonal increases are noted, related to spring run-off and fall rains. The buffering capacity in the clarification pond appears to be three times lower in 1991, compared to 1990, although more lime was used in 1991. This is likely attributable to the arrival of acidic tailings pore water in the clarification pond. Over-usage of lime will produce increases in zinc concentrations when the pH exceeds 9.5, due to re-dissolution of zinc hydroxide.

The lime requirements to neutralize I-Ditch were calculated as 1,313 tonnes $Ca(OH)_2$/year, compared to 462 tonnes/year for the B-Ditch. These differences in lime consumption are due to the presence of ferrous iron in the I-Ditch, as compared to ferric iron in the B-Ditch.

II DECOMMISSIONING OF LES MINES SELBAIE

a) General Introduction

Boojum Research was retained in l990 to develop Ecological Engineering measures which will assist in decommissioning the site. Ecological Engineering, a low-maintenance decommissioning technology, has been developed over the past 10 years on sites where waste management efforts did not consider decommissioning costs. Based on this experience in identifying problems which could have been avoided by operators on hindsight, Boojum Research proposed to Les Mines Selbaie that economic benefits could be derived if decommissioning considerations were taken into account during operations.

The physical, chemical and biological aspects of the site were described in the first year of the investigation, and experiments were carried out assessing the applicability of Ecological Engineering processes to this site. Laboratory and on-site work has generated a large amount of information, which has been reported in several data summary reports. These data, along with experimentation on Ecological Engineering processes, form the technical foundation for the close-out scenario.

The close-out scenario, for the waste rock piles, the open pit, and the tailings basin, is presented in this section of the report.

Long-term considerations are presented as a reference point for decision-making during operations. In

Section III, estimates are derived for the expected magnitude and period of acid generation, and associated lime treatment projections. An overview of the test work carried out during 1990/91 is presented in Section IV, while the details of this work are presented in Volume 2.

Water chemistry, which dictates the quality of the final effluent is one of the most important aspects of waste management strategy, determining its ultimate success or failure. Extensive effort has been expended to understand the prevailing chemical conditions in the tailings ponds. This aspect is not only important for decommissioning, but assists in achieving Environmental Regulations. The tailings water chemistry and that of the important acid rock drainage (ARD) streams, collected in the B-Ditch, and AMD (Acid Mine Drainage) collected in the I-Ditch, are presented in Section IV a, along with potential alternatives to lime treatment.

Methods which would reduce or inhibit acid generation are being developed for freshly deposited tailings. It was proposed that reclaiming the tailings while they still contain alkalinity from the mill should be attempted, particularly if an oxygen-consuming bacterial population could be integrated into the tailings mass. Vegetation experiments were started in l990. Some of the plots, with "proper" growing conditions, produced a grass cover, which survived the winter and continued growing in l991. These vegetation plots were used to assess the microbiology in the root zone. Furthermore, the "successful" test conditions were replicated in l991, producing a vegetation cover over an area of 0.1 ha. Results from field and laboratory studies indicate that this vegetation layer is likely serving as an oxygen-consuming layer. This work is summarized in Section IV b, below.

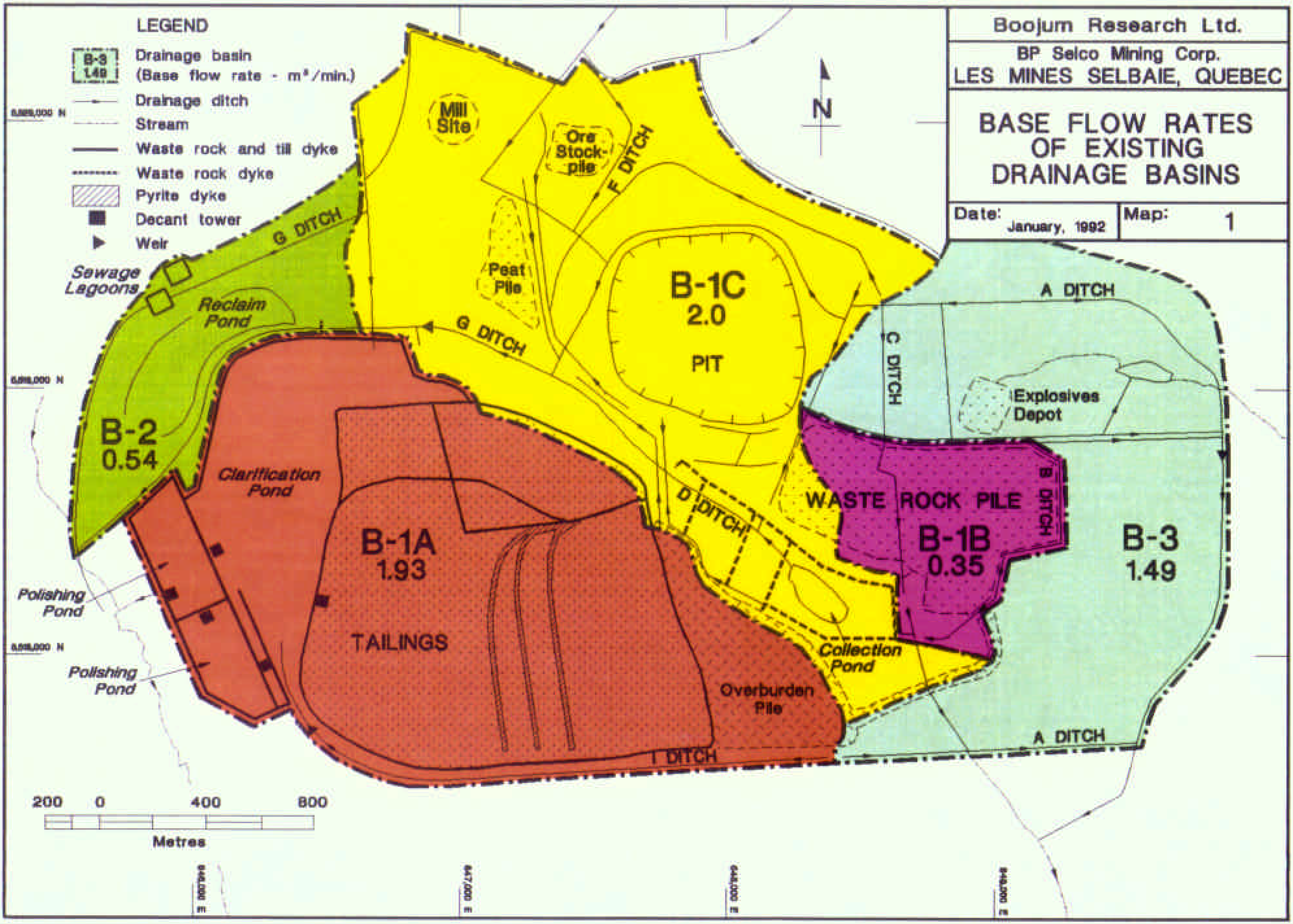
Extensive experimentation was carried out with respect to those conditions which would assist the initiation of the ARUM process, given the ARD and AMD characteristics at Selbaie. These experiments are summarized in Section IV c, of this report.

b) General Assumptions For The Close-out Scenario

The decommissioning approach presented here is based on the existing configuration of the mine site, in that the pit expansion and further tailings area requirements have not been taken into account. The expected inventory of waste material at the time of closure (50 million tonnes) is taken from the Golder Report #891-7022-A, January 1990. The total waste management area covers about 801 ha. This area is divided into sub-drainage basins, as shown in Table 1, while the lay-out is shown in Map 1.

Table 1 - Subdrainage Basins of the Waste Management Area

AREA NAME	SIZE	AREA FLOW DATA - m3/min		
	ha	Precipitation	Evaporation	Base Flow
B1-C Open pit/Mill	254	3.99	1.99	2.00
B1-A Tailings area	245	3.85	1.92	1.93
B1-B Waste rock pile	45	0.71	0.36	0.35
B-3 Outside B-Ditch	189	2.97	1.48	1.49
B-2 Sewage/Reclaim Pond	68	1.08	0.54	0.54



LEGEND
B-3 1.49
Drainage basin (Base flow rate - m³/min.)
Drainage ditch
Stream
Waste rock and till dyke
Waste rock dyke
Pyrite dyke
Decant tower
Weir
N
Boojum Research Ltd.
BP Selco Mining Corp.
LES MINES SELBAIE, QUEBEC
BASE FLOW RATES OF EXISTING DRAINAGE BASINS
Date: January, 1992
Map: 1
Mill Site
Ore Stock-pile
F DITCH
G DITCH
Peat Pile
B-1C
2.0
PIT
A DITCH
C DITCH
Explosives Depot
B DITCH
WASTE ROCK PILE
B-1B
0.35
B-3
1.49
D DITCH
Collection Pond
Overburden Pile
I DITCH
B-1A
1.93
TAILINGS
Clarification Pond
Sewage Lagoons
Reclaim Pond
B-2
0.54
Polishing Pond
Polishing Pond
200 0 400 800
Metres

Prior to closure, the water quantities which need to be treated must be determined to provide a calibration of the water balance model. Meterological data were used to derive the base flows for the sub-drainage basins. Due to the large distance between the mine site and the closest weather station at Matagami, climatic data were compared between the discontinued station Lac Bouillon and Matagami. A correction factor between the two sites was derived, based on the meteorological differences between these two data records. This correction factor was 0.75, indicating that Matagami had significantly higher precipitation than could be expected for Les Mine Selbaie (Table 2). Evapotranspiration was estimated at 50%, based on records collected at Amos.

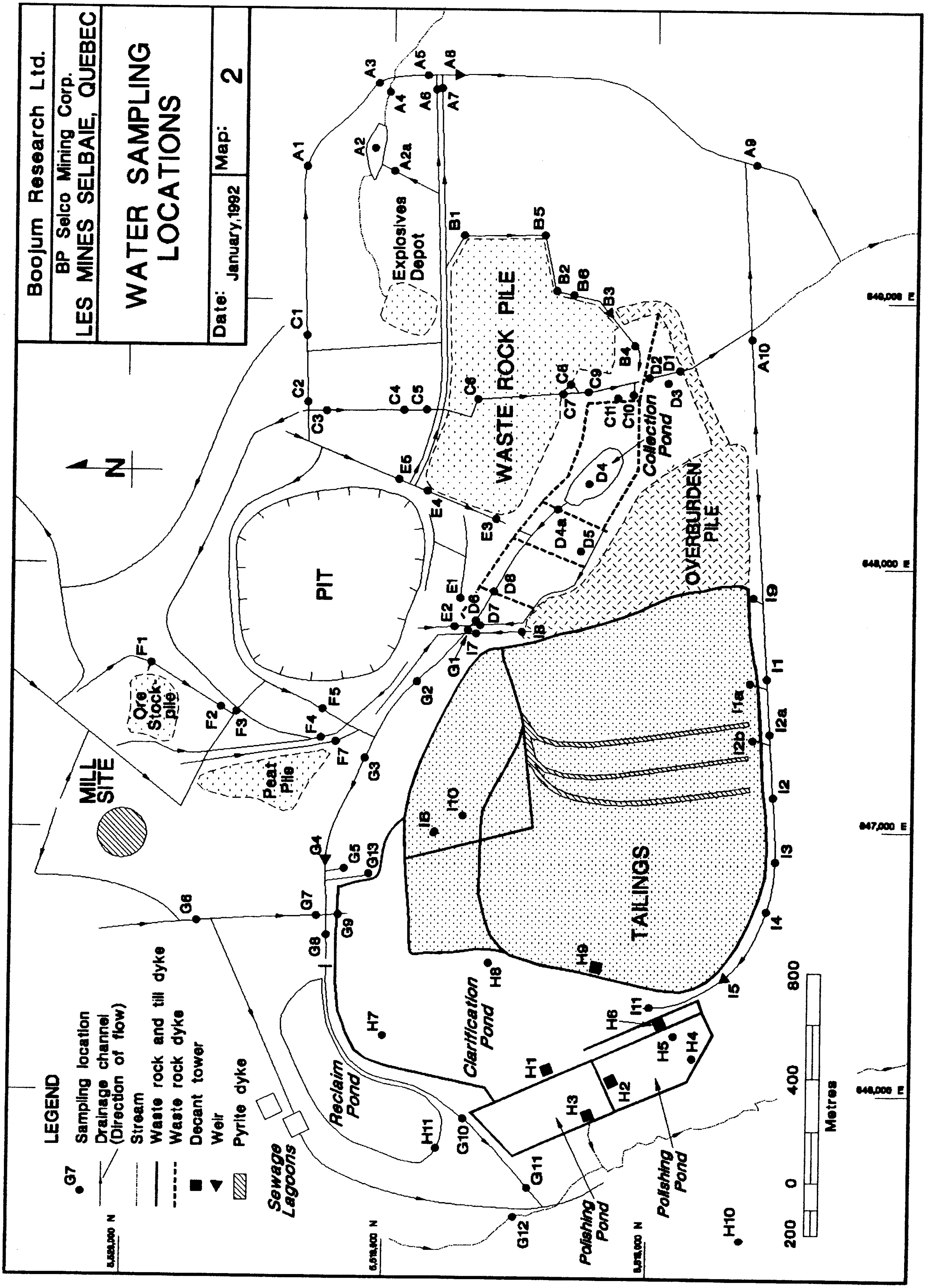
Table 2

Climatic Data

(per Presentation Report, Nov.12, 1990, page A-23)

SELBAIE CLIMATE DATA	Brouillan (1981-86)	Matagami (1981-86)	Matagami (1951-80)	Amos (1985-88)
Rainfall (mm)	453.6	609.9	565.9	-
Snowfall (cm)	172.0	275.9	317.5	-
Total Water (mm)	625.2	875.4	850.4	-
Evapotranspiration	-	-	-	417.4

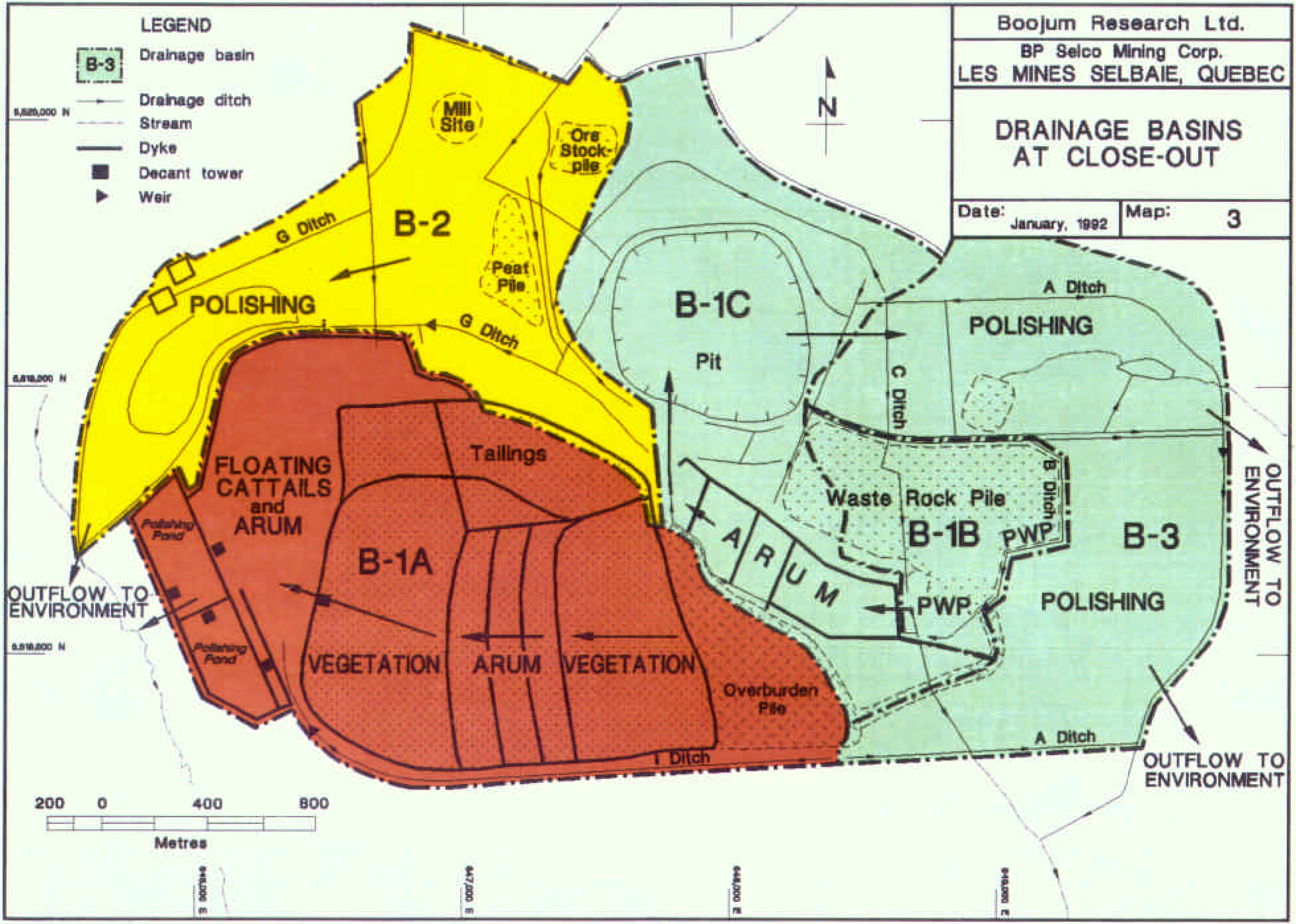
Weirs have been installed in all drainage basins (Map 2) and flows are being monitored. When sufficient data have been collected, information should be used to verify the base flows predicted.


Boojum Research Ltd.
BP Selco Mining Corp.
LES MINES SELBAIE, QUEBEC
WATER SAMPLING LOCATIONS
Date: January, 1992
Map: 2
LEGEND
Sampling location
Drainage channel (Direction of flow)
Stream
Waste rock and till dyke
Waste rock dyke
Decant tower
Weir
Pyrite dyke
N
PIT
WASTE ROCK PILE
OVERBURDEN PILE
TAILINGS
MILL SITE
Ore Stock-pile
Peat Pile
Explosives Depot
Collection Pond
Clarification Pond
Reclaim Pond
Polishing Pond
Polishing Pond
Sewage Lagoons
A1
A2
A2a
A3
A4
A5
A6
A7
A8
A9
A10
B1
B2
B3
B4
B5
B6
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
D1
D2
D3
D4
D4a
D5
D6
D7
D8
E1
E2
E3
E4
E5
F1
F2
F3
F4
F5
F7
G1
G2
G3
G4
G5
G6
G7
G8
G9
G10
G11
G12
G13
H1
H2
H3
H4
H5
H6
H7
H8
H9
H10
H11
I1
I1a
I2
I2a
I2b
I3
I4
I5
I6
I7
I8
I9
I10
I11
200
0
400
800
Metres
5,528,000 N
5,518,500 N
5,518,000 N
649,000 E
648,000 E
647,000 E
646,000 E

c) Drainage Basins at Close-out

The definition of the drainage basins at close-out will take advantage, as much as possible, of the natural topography. These basins are defined; one for the mill, a second for the waste rock pile and the pit, and a third for the tailings. To control effluent streams utilizing ecological systems, it is essential to distribute the contaminant loadings across, and achieve long retention times within, these new ecosystems.

By the time of decommissioning, the drainage basin B-1C will have been changed from the current configuration, outlined in Map 1 (yellow), to that indicated in Map 3 (green). The flow from the eastern third of existing B-1C basin, in the area of the mill site and ore stock pile, will be included with that of the B-2 drainage basin, and will leave the site via the F and G-Ditch system, ultimately draining via the G11 station. The existing polishing pond within the expanded B-2 drainage basin (Map 3: yellow) will be utilized, if required, for biological polishing before discharge at G11 (Map 2).



Boojum Research Ltd.
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LES MINES SELBAIE, QUEBEC
DRAINAGE BASINS AT CLOSE-OUT
Date: January, 1992
Map: 3
LEGEND
B-3 Drainage basin
Drainage ditch
Stream
Dyke
Decant tower
Weir
N
B-2
Mill Site
Ore Stock-pile
Peat Pile
G Ditch
G Ditch
POLISHING
B-1C
Pit
C Ditch
A Ditch
POLISHING
B-1B
Waste Rock Pile
B Ditch
PWP
PWP
B-3
POLISHING
A Ditch
A R U M
B-1A
Tailings
FLOATING CATTAILS and ARUM
VEGETATION
ARUM
VEGETATION
Overburden Pile
I Ditch
Polishing Pond
Polishing Pond
OUTFLOW TO ENVIRONMENT
OUTFLOW TO ENVIRONMENT
OUTFLOW TO ENVIRONMENT
200
0
400
800
Metres
646,000 E
647,000 E
648,000 E
649,000 E

Relatively uncontaminated drainage from the most northerly portion of the reduced B-1C drainage basin will flow into the pit.

Flow originating from existing B-1B drainage basin (Map 1: purple), collected by the B and C-Ditches, will be retained and treated in the collection pond. At decommissioning, relatively clean water can drain from the collection pond into the pit. The pit will subsequently overflow to the east into the A-Ditch. If necessary, biological polishing ponds can be constructed in the area between and A and C-Ditches (Map 3, northeastern corner: green) to further treat pit overflow discharge. In summary, drainage from the waste rock pile area (B-1B) will join run-off from the collection pond and flow into the pit (B-1C) basin, whereupon the cumulative flow will move through the B-3 drainage basin to discharge at A5 and/or A11 (Map 2). The treatment strategy over this drainage path is given in e) below.

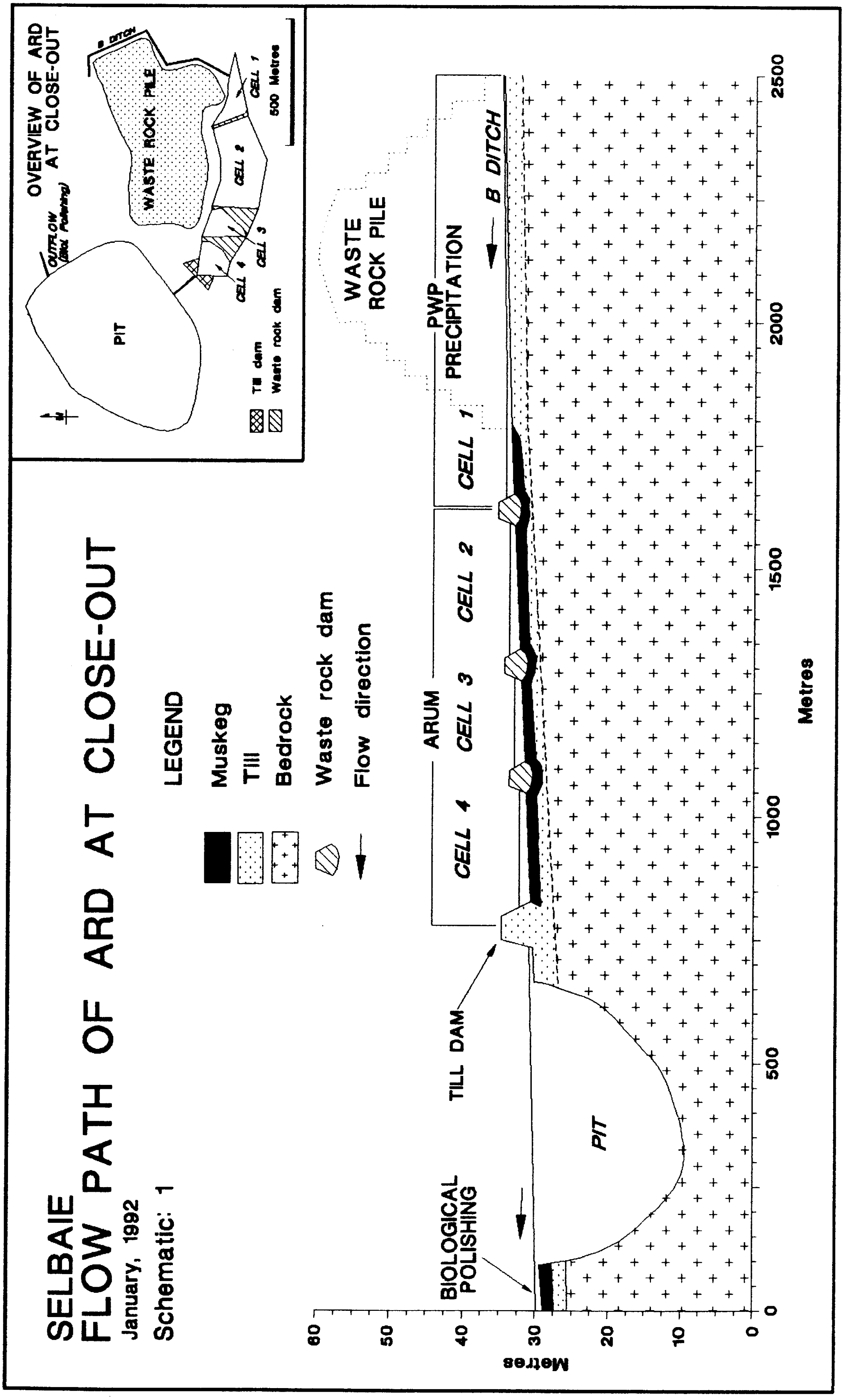
Flow into the pit will not only consist of ARUM-treated water from the collection pond, but also run-off and ground water moving into the pit. It is expected that the water quality leaving the collection pond with clean ground water dilution will produce acceptable water quality in the pit. Clean ground water will depend, in part, upon the potential for AMD generation from the pit walls and from underground. However, should this not be the case, then further treatment can be implemented in the pit and in the polishing ponds, as described above.

The single drainage basin (B-1A) will likely encompass the tailings area, as is the case in the present configuration. For the close-out scenario, it is assumed that the I-Ditch dike will be sealed and the flow of AMD into the clarification pond will be significantly reduced.

d) Mill Site And Ore Stock Pile Area

The mill site will probably be the area which produces the highest metal loadings, due to the spread of dust from the ore and concentrate piles. Acid generation in this drainage basin will likely be minimal. The depth of contamination of the yard material around the mine, mill and stockpile area has to be determined. The most highly contaminated material would be contained in a till lined pit, while less contaminated material can be used to construct a series of meanders, thereby increasing the polishing capacity prior to entering the polishing pond. Biological polishing (algae) will be utilized in the western portion of the B-2 drainage basin in the existing ponds (sewage lagoon and mine water retention ponds). It is not expected that this drainage basin will generate significant amounts of acid, and the pH of drainage will likely remain circumneutral.

Non-saleable demolition material from the buildings will be segregated. Inert materials (wood, concrete, insulation, etc.), can be disposed of in the pit. Reactive materials such as galvanized siding will be disposed of on the till pile and covered, in order to prevent zinc leaching.


SELBAIE
FLOW PATH OF ARD AT CLOSE-OUT
January, 1992
Schematic: 1
LEGEND
Muskeg
Till
Bedrock
Waste rock dam
Flow direction
OVERVIEW OF ARD AT CLOSE-OUT
PIT
OUTFLOW (Biol. Polishing)
B DITCH
WASTE ROCK PILE
CELL 1
CELL 2
CELL 3
CELL 4
Till dam
Waste rock dam
500 Metres
WASTE ROCK PILE
PWP
PRECIPITATION
B DITCH
ARUM
CELL 1
CELL 2
CELL 3
CELL 4
TILL DAM
BIOLOGICAL POLISHING
PIT
Metres
0
10
20
30
40
50
60
Metres
0
500
1000
1500
2000
2500

e) Waste Rock Pile - Collection Pond And Pit

In Schematic 1, a conceptual cross section of waste rock pile and pit is presented, accompanied by the overall treatment phases. After PWP (Precipitation With Phosphate) treatment in the B-Ditch and the first cell of the collection pond, water passing through the remaining cells (cells 2, 3 and 4) will be treated with ARUM. The volumes of cells 2, 3 and 4, are half the existing volume of the collection pond which has a total volume of about 500,000 m^3. A retention time of more than one year for ARUM treatment can therefore be expected. It is important that the permeability of the existing cross dikes is maintained, so that short-circuiting of the water is minimized. Based on present experience with ARUM, this retention time is sufficient for effective water quality improvements.

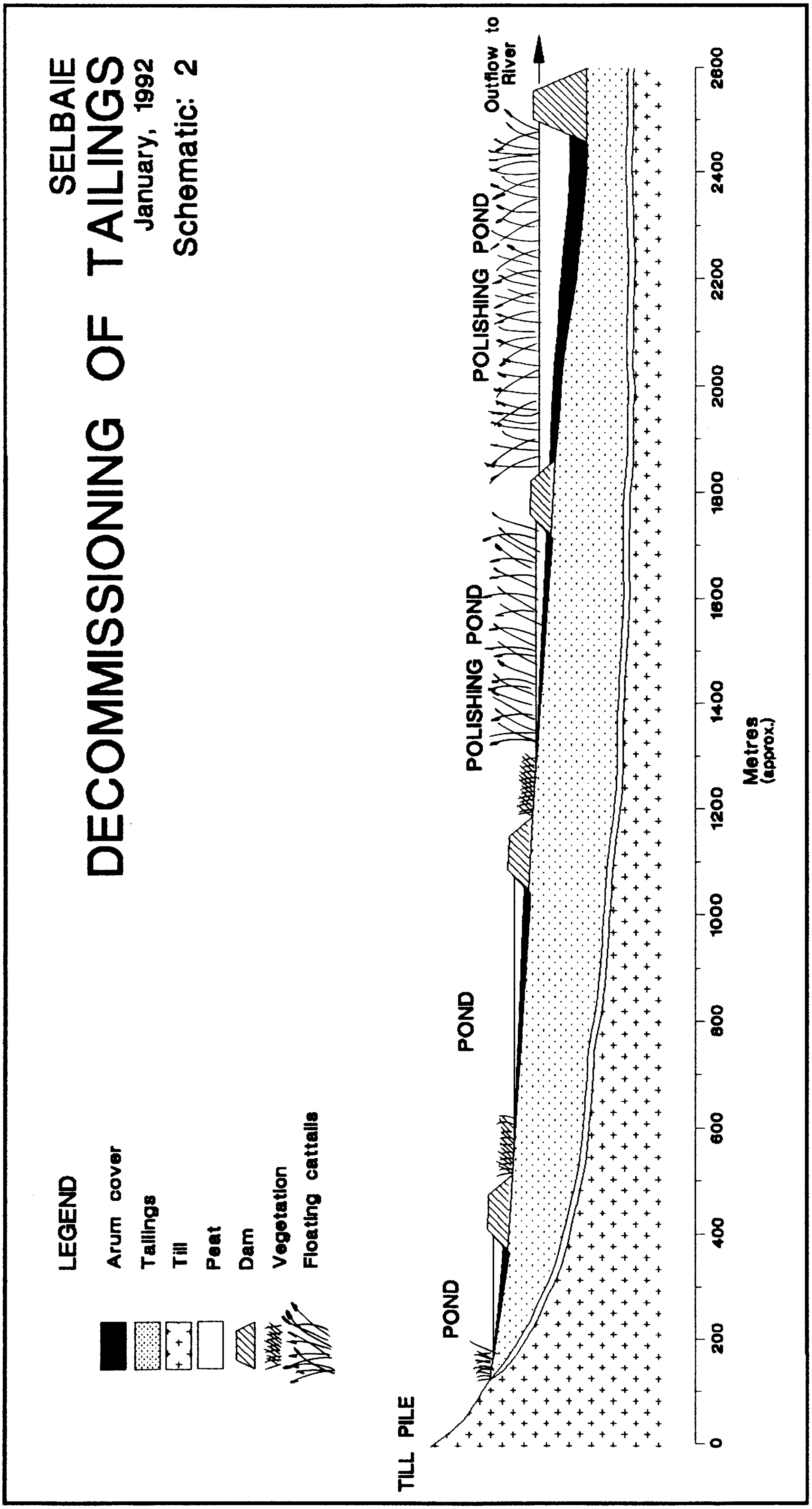
PWP treatment will take place in the B-Ditch and the first cells of the collection pond. The resulting PWP sand will be deposited in and on the waste rock pile, and finally will provide cover material. The disposal of this inert material is expected to reduce permeability, encourage run-off from the pile, and reduce acid generation rates. The stability of the PWP sand and precipitates deposited in and over the waste rock pile are residues formed in acidic conditions and will therefore remain inert.

If the quality of water leaving the ARUM system in the collection pond is unsatisfactory, additional ARUM capacity could be established in the pit at the time of decommissioning. This would be needed if ground water entering the pit contained ARD. Alternately, should ground water entering the pit during pit filling be relatively clean, it would provide some dilution. Both scenarios must be kept in mind, as predictions cannot be made with respect to ground water quality without ground water quality monitoring data.

It is estimated that the reduced-area B-1C drainage basin will result in an overall base flow around 1 m^3/min. As described under c) above, some of the flow from the northern section of the pit is assumed to be reasonably clean, as little disturbance is expected to have taken place in this area.

Provisions also have to be made for potential acid generation from that part of the waste rock pile which is located outside the B-1B drainage basin. At present, there is insufficient information concerning conditions in this area to integrate this area into the close-out scenario. However, it is assumed that PWP and ARUM will be used in some configuration which would integrate this drainage basin into the overall plan.

Field tests will be carried out to determine the specific requirements and performance of the system. Meanwhile, it may be prudent to monitor the outside perimeter of the B-1B drainage basin for leakage of ARD to the south-east.


SELBAIE
DECOMMISSIONING OF TAILINGS
January, 1992
Schematic: 2
LEGEND
Arum cover
Tailings
Till
Peat
Dam
Vegetation
Floating cattails
TILL PILE
POND
POND
POLISHING POND
POLISHING POND
Outflow to River
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
Metres
(approx.)

f) Decommissioning Concept For Tailings And Polishing Ponds.

The final configuration of the tailings pond is outlined in cross section in Schematic 2, and in plan view in Map 3. The till pile is the highest elevation in this drainage basin. The tailings surface is expected to slope towards the clarification and polishing ponds.

At decommissioning, low, non-reactive waste rock dams will overlie the high pyrite waste rock dikes presently traversing the tailings area. These low permeability dams should be impervious enough that they retain water from the spring melt and fall rains, thereby providing saturated tailings and ponded areas. Integrated weirs are required to achieve effective water retention and greater control over water levels. The ponds should have a total storage capacity of 2 million m^3 of water, given the base flow of the drainage basin. The final height of the dikes will depend on the slope of the tailings surface.

There has not been an opportunity, during the two years of the study, to determine if the high pyrite waste rock dumps, currently deposited in the tailings, have started to generate acid within the first year after disposal. These pyrite dumps could potentially act as conduits for a) air infiltration into the tailings and b) drainage paths for tailings water. This close-out scenario assumed that this will not be the case but, instead, it has been assumed that tailings will fill all the airspaces in the dumped pyrite wastes.

If the entire tailings area (245 ha) and the base flow (1.93 m^3/min) are used to calculate the water level of ponds over the tailings, a water depth of about 1 m can be expected. However, given the slope of the tailings, the entire tailings area cannot be expected to be ponded, and maximum depths of the ponds can be expected to be much higher.

Sediments will be developed in the ponds maintained behind the dikes. These sediments will be essentially microbially active ARUM sediments, reducing sulphate and precipitating ferrous iron (i.e. un-oxidized iron) emerging from the tailings slope. It is expected that the reducing conditions in the sediment will prevent the oxidation and hydrolysis of ferrous iron and promote its precipitation. Therefore, water with significantly reduced acidity will leave the tailings drainage basin.

During the summer, water levels in the ponds will decrease by up to 50%, due to evaporation and, subsequently, areas of tailings will be exposed during this period. Vegetation and associated organic matter deposited in these areas should be integrated into the unsaturated zone, or those strata spanning the range of water level fluctuations. The species comprising the final vegetation cover must be semi-aquatics, such as sedges and cattails, known to survive in widely fluctuating moisture regimes. This configuration is expected to produce oxygen-consuming and, possibly, reducing conditions in the unsaturated layer of the tailings where otherwise AMD would most likely be generated.

During operations, a floating vegetation cover should be established on the clarification and polishing ponds. Organic matter from this vegetation mat will be integrated (to some degree already during operations) into the sludge, which will have accumulated in the polishing ponds due to lime neutralization. Precipitate-containing sediment may require additional organic matter to provide sufficient ARUM capacity. Due to the reduced acidity expected with the installation of ARUM sediments, the slow release of acid generation products from the tailings and the oxygen consuming layers installed in/over the tailings, it is expected that the final effluent of the tailings drainage will have acceptable quality.

Since the upper part of the tailings area has nearly reached its final height, construction of a test cell is recommended as soon as possible, to verify the overall decommissioning approach for the tailings basin. The next steps will involve development of detailed design criteria and maintenance requirements for the overall system.

III LONG-TERM CONSIDERATIONS

The acid generation potential of Les Mines Selbaie mine site area must be evaluated in order to derive, a conceptual time frame over which acid generation can be expected. For planning purposes, estimates of the volumes of neutralizing agents are required, based on the total volumes of waste material produced. Estimates of sludge volumes, produced as a result of this treatment, are needed to allocate sludge storage space.

a) Lime Treatment Projections

Water treatment requirements are dependent on the time frame over which the contaminants are generated from tailings and waste rock. Contaminant generation is a function of the oxidation rates of exposed pyritic surfaces in both the tailings and the waste rock. These rates are not known, and hence assumptions have to be made. The first approach is to assume that the existing tailings seepage lime requirements will remain at levels determined in l991. The second approach is to assume that all the pyrite will ultimately oxidize. A comparison of the characteristics of Selbaie effluents to other mining operations is made, based on published literature and their lime consumption/tonne of waste material. At best, these considerations are a reference point, representing worst case scenarios.

1991 conditions: Tailings deposited in the first cell of the tailings pond are nine years old and have, on average, 16 kg $CaCO_3$ equivalents of acidity per tonne. One year old tailings (1990 vegetation experiment area) have lower acidities, namely 5 kg/tonne. These results indicate increasing amounts of lime are consumed with time. It is therefore recommended that tailings not be allowed to remain exposed or inactive for more than one year.

About 560,000 tonnes of pyritic waste rock have been placed in the waste rock pile. Within 5 years after placement, in 1991, this pile has contaminated the entire yearly flow from the B-1B drainage basin, amounting to a volume of 184,000 m^3 discharging at a rate of 0.35 m^3/min. As a rough estimate, it may be said that one tonne of waste rock in this pile presently produces 0.3 m^3 of ARD per year.

One m^3 of B-Ditch ARD contains 7.0 kg $CaCO_3$ equivalents of acidity. Therefore, over the next five years the B-Ditch will discharge about 1,300 t $CaCO_3$ equivalents of acidity each year. Since the B-Ditch water requires 5 kg/m^3 of CaO for neutralization (titration data), 920 tonnes of lime (CaO) are required per year to neutralize B-Ditch ARD alone. On this basis, comparison of the tailings and the waste rock lime requirements indicates that the tailings will require twice as much lime as the drainage from the waste rock pile in the long term.

Observations of waste rock presently in place for 5 years indicates that oxidation of newly placed waste rock will contribute to the ARD source within 5 years. Integration of compacting material in waste rock should, therefore, be completed as the rock is being placed. Boojum has been notified that this is currently being done, by adding layers of till into the pile as it is built.

Sulphur content of wastes: The Acid Generating Potential (AGP), based on the sulphur content, is estimated at 0.20 tonne H_2SO_4/tonne wastes. The estimate is derived from the A1 zone mill heads up to the end of 1989. This AGP would require 5.7 million tonnes of CaO to neutralize all the potential AMD which could be produced from the wastes (1:1 H_2SO_4:CaO molar basis). The resulting acidity, derived from the estimated AGP, is 10 times higher than actual acidities determined in the 9 year old tailings.

Comparisons to other operations: The total expected tonnage of pyritic waste at close-out is approximately 50 million tonnes. Based on La Mine Doyon lime usage (0.4 kg lime/tonne waste/a), it would require 20,000 tonnes of lime per year to treat all wastes. The 5.7 million tonnes of CaO, derived from the AGP, would therefore be consumed during treatment of all effluents over a period of 285 years.

Similarly, based on Equity Silver lime usage (0.06 kg lime/tonne waste/a), 3,000 tonnes of lime would be required per year. Using this rate, 1900 years would be required to treat the effluent.

Based on the present lime requirements of the B-Ditch (5 kg lime/m^3 ARD) and using the base flow of the fraction of the waste management area with tailings and waste rock (B-1B + B-1A; 0.35 + 1.93 = 2.28 m^3/min), 5,992 tonnes of lime are required per year. Assuming a constant rate of AMD/ARD generation, it would take about 951 years to consume the 5.7 million tonnes of CaO.

b) Potential Treatment Time Requirements

Assuming that the actual period required for liming falls within the range of 285 to 1900 years estimated above, perpetual treatment of AMD/ARD must be projected for all practical purposes.

Although the minimum time of this estimated range is not unexpected, it underlines the urgency of implementing measures which curtail or inhibit acid generation as soon as possible.

c) Why Lime is Not An Option

Assuming the base flow into the open pit will include both the entire B-1B basin and about half of the flow from the B-1C basin, approximately 1 m^3/min will represent the flow from the waste rock pile-pit drainage basin. Lime requirements will be about 3,548 tonnes per year for this drainage basin alone (based on 1991 B-Ditch acidity measurements). This is equivalent to about 10 truckloads per month.

As lime-treated B-Ditch ARD produces at least 15% sludge by volume, a minimum of 106,000 m^3 of sludge will be generated per year. The estimated open pit volume will be 32×10^6 m^3 at close-out. If, for example, the pit is considered as a disposal area for sludges from the B-1B and B-1C drainage basins alone, it will reach maximum capacity within 302 years. The minimum estimated period for acid generation treatment is almost equal to this estimated maximum period before pit capacity is reached.

IV TESTWORK OVERVIEW

a) Selbaie Chemistry

Final effluent control: An analysis of trend in both zinc and copper concentrations in the final effluent at H3 was carried out. Monitoring data collected since l985 were utilized. Comparisons for results obtained for the same sampling date, from the Selbaie and Noranda laboratory was carried out. Details of this analysis are given in Section 3, of volume II.

The evaluation indicated that, when copper concentrations rise above the compliance level, Noranda data are invariably higher than Selbaie data. Furthermore, it appears, that during the winter months, consistently higher concentrations are found in the effluent.

For zinc, seasonal increase are noted likely related to spring and fall run-off. Differences in concentrations reported by the two analytical laboratories are more frequent and they are larger than for copper.

The evaluation of the tailings chemistry, together with the analysis of the monitoring data, indicate that retention time, suspended hydroxides and pH have to be controlled. The optimal pH is 9.5 and higher pH values will increase the concentrations of zinc.

The Chemistry of the Tailings Pond Effluents: The characteristics of the final effluent are affected by acid generation in the tailings, lime usage in the pond, proportions of fresh and reclaim water, the thickener / treatment plant operations and the I-Ditch chemistry. The findings, with respect to each of these factors, are briefly summarized below and details are discussed in Section 3 of Volume II.

Acid generation in the tailings: Alkalinities of the polishing pond and the clarification pond waters in l991, compared to l990, were lower. It required less sulphuric acid to bring the pH down to a value of 3 in 1991. In l991, more lime was used to control the final effluent, but 3 times less buffering capacity was present in the effluent samples tested. The changes in acidity, or conversely the loss of buffering capacity in the ponds, are likely due to acid generated in the tailings pore water, which is now emerging to the clarification and polishing ponds.

Lime usage in the pond: The buffering capacities of H1 and H3 water are equivalent to excess lime and calcium carbonate, which consume acid without changing pH value. Therefore, the flat part of any titration curve presented would represent the buffering capacity. The titrations indicate that 14 g lime/m^3 was overused in treatment, amounting to about 140 kg/day for a water usage of 10,000 m^3/day.

If lime is overdosed and the pH is higher than 9.5, precipitated zinc hydroxide will redissolve. Aluminum hydroxide also redissolves in high pH water. Aluminum will behave in the same way as zinc. Both zinc and aluminum can dissolve in either acidic or strongly basic solutions. When zinc concentrations and pH are correlated, based on the final effluent data, it is apparent that the lowest zinc concentrations are obtained around pH = 9.5. Hence, it is recommended that, in order to control effluent zinc concentrations, this pH should not be exceeded. Although liming is the only control option at the present time, its effects on effluent quality is important.

Reclaim / Mill / Thickener: Effluent control to the compliance level can not be easily achieved by liming alone. Additional control may be exerted through selecting specific amount of reclaim water used in the milling process. This option has been explored briefly.

The water collected from tailings pond was stored in closed bottles in the refrigerator for about one month. The pH of water from the thickener underflow dropped from 11.5 to 5.6 over one week, and the pH of the reclaim water dropped from 10.3 to 7.4. This demonstrates the chemical reactivity of the effluent waters. Such changes in the water chemistry are significant, in terms of water quality for milling, the effluent water quality and meeting compliance in the receiving water body.

Chemical reactivities result not only in changes in pH, but are associated with the formation of precipitates. In l990, tailings pond chemistry was addressed through geochemical simulations to predict the types of precipitates. Alkaline samples from the tailings pond showed saturation with respect to one or more carbonate minerals, and hence precipitation was inevitable.

In 1991, the entire water circuit was sampled for analysis. From these results, it could be estimated, upon comparison of the Sag Mill and Reclaim water, that 41 % of the sulphur in the water will be lost as magnesium and calcium precipitates of sulphate in the grinding circuit. These precipitates may interfere with flotation. It is suggested that the ratio by which reclaim and fresh water is used should be considered as a potential avenue for water quality control.

The Chemistry of B-Ditch (ARD) and I-Ditch (AMD) Water

In order to monitor metal loadings, weirs were installed in the B and I Ditches in 1990. The assay ranges of all major elements are similar for both B and I Ditches, with the exception of zinc. The tailings area receives about 441 tonnes of iron per year and about 730 t of zinc through the I-Ditch. The iron from the I ditch is precipitated as a mixture of ferrous and ferric hydroxides. These sludges will continue to oxidize in the clarification pond, and therefore further add acid to the system, unless the sludges are kept alkaline and in reducing conditions. As the B-ditch iron precipitates are all in the oxidized (ferric) form, no further oxidation can take place.

More lime is required for I-Ditch than for B-Ditch water to raise the pH to 9.5. Given the flows in both ditches, the estimated amounts of lime required to raise the pH to 9.5, are 1.8 g CaO/L for the B-Ditch, and 2.2 g CaO/L for the I-Ditch. Lime consumption, based on CaO and $Ca(OH)_2$ respectively, is 346 t/year and 462 t/year for the B-Ditch, and 963 t/year and 1313 t/year for the I-Ditch.

The acidity of the B-Ditch is primarily due to the hydrolysis of ferric ions. I-Ditch acidity is, on the other hand, mostly caused by ferrous iron. The pH of I-Ditch water is higher than B-Ditch water, but their acidities are almost the same. This demonstrates that pH is not indicative of acidity or alkalinity. Generally, pH values greater than 7 are considered alkaline and below 7 acidic.

At the start of titrations performed in the laboratory, the samples have the same pH, reflecting the ongoing acidification which can also be noted in the I-Ditch itself. When the seepage emerges, it has a circumneutral pH. The pH changes as the water is exposed to oxygen. Oxidation of Fe^{+3} is the major acid generation process in I-Ditch. Ferrous iron is easily oxidized to ferric iron by contacting air. However the rate at which the oxidation occurs is different under acidic or alkaline conditions.

If reduced iron is oxidized in basic water, the iron will precipitate without generating further acidity. Maintaining a basic environment and reducing conditions, will reduce the rate of the oxidation of ferrous iron and less acidity will be generated. Reducing conditions in the ARUM system could prevent ferrous iron oxidation entirely.

Natural precipitation of ferric iron: At low pH, (B-Ditch), ferric iron precipitates naturally. An estimate of the natural iron removal was derived from the accumulations on hay bales. Samples of precipitate were collected from the surface area of a hay bale. The amount of precipitate which had accumulated since placement was washed off the organic surfaces, and the volume and weight were determined to be 2.6 m^3/t. The total amount of ferric hydroxide that precipitated on the hay bales (1440 bales in the B and C Ditches), and the ditch surfaces, was estimated to be 23 t for B-Ditch, and 9 t for the C-Ditch. The important point about this precipitation process is that, each year, at least 32 tonnes of ferric hydroxide precipitate will accumulate in the B and C-Ditches.

b) Vegetation Experiments

Experiments were conducted to establish vegetation on fresh tailings. Vegetation may serve to generate an organic layer which will stimulate the growth of oxygen-consuming heterotrophic organisms, thereby inhibiting oxidizing bacteria in the tailings. This vegetation may also serve as a water-retentive layer, thereby reducing the unsaturated zone, as well as reducing wind erosion. Experiments in the laboratory and field have sought to identify conditions which would facilitate the establishment of a vegetation layer fulfilling all these functions.

In 1990, various treatments were set up on an experimental basis. Vegetation overwintered and continued to grow on five of the six plots planted with grass. Biomass including shoot, roots and litter, were greatest on fertilized plots which were previously sparsely vegetated, and exceeded 10 t/ha. Roots in these plots penetrated to depths of 20 cm.

The presence of iron-oxidising bacteria (*Thiobacillus*) was examined, specifically to determine whether roots stimulate or inhibit iron oxidising bacteria. *Thiobacillus* was detected in samples showing visible zones of oxidation (orange coloration) and absent from samples with no such zones. There was no clear association of *Thiobacillus* with the root zone.

The 1990 vegetation experiment, demonstrated that grass species can grow on the tailings to form a continuous organic layer on the tailings surface and stimulates microbial activity (heterotrophs) without favouring oxidising bacteria (*Thiobacillus*). Laboratory experiments were carried out in the winter of 1991, in order to identify less expensive ammendments. Those used in the field in l990 were too costly.

The first experiment, carried out in plastic pots, established that roots likely experience difficulty penetrating de-watered tailings. The second experiment was, therefore, set up with freshly slurried tailings in 50 x 50 cm wooden boxes. A variety of surface treatments were applied to assist germination and subsequent grass establishment.

This experiment determined that roots can successfully penetrate into tailings, provided that the tailings are fresh, unconsolidated, and moist. Surface roughening promotes grass seed germination, while wood chips are a good substitute for expensive Verdyol matting (as used in the 1990 field experiment), but provides comparable conditions for germination. Meanwhile, addition of molasses, intended to stimulate heterotrophic bacterial activity, however it inhibited germination of seeds. Furthermore the run-off water acidified due to organic acid production. Therefore, molasses is not a viable option as a tailings addition.

A tailings vegetation experiment was set up in July 1991 on fresh tailings over the pyrite waste-rock pile, based on the results of the lab and 1990 field experiments. The experiment compared three seed mixes, each expected to grow well on tailings, and two rates of fertilizer addition. In addition, wood chips, and the introduction of phosphorus scavenging, root infecting fungi (mycorrhizae), were also tested. Surface roughening was applied to all plots by driving a Muskeg (all-terrain truck), over the site.

Visual assessment of the growth status of the vegetation was made. The data show no clear difference between the three seed mixes and no effect due to wood chips. However, the benefits of fertilizing at the highest rate were evident at the end of the growing season.

Fertilizer is the largest material cost in vegetation establishment. It is, therefore, important to establish the minimum amount of fertilizer required for a good vegetation cover. Each additional 100 kg/ha will increase costs by approximately $ 250/ha.

A series of titrations were performed on solutions decanted from resettled tailings-distilled water slurries. The decant water from the slurries was titrated to simulate run-off water from tailings surfaces. A considerable acid loading can be noted (2958 mg/Kg equiv. $CaCO_3$ for Old Pond tailings and 4233 mg/Kg equiv. $CaCO_3$ for I5 tailings).

Tailings samples from the surface of the 1990 vegetation plots (one year old tailings) had much higher acidities and alkalinities than the 1991 plots, suggesting that over one years at the surface residual alkalinity has been consumed.

Acidities in the root zone in both the 1990 and 1991 plots were not dissimilar from those of samples without plants. Substantial alkalinity was present in all samples. However, less was found in the root zone. These plots provided the test ground to evaluate, if heterotrophic bacteria are present in the root zone and confirmed that the overall concept of such a vegetation layer is viable.

Counts of heterotrophs and presence of *Thiobacillus* were carried out for tailings samples from the mill circuit and from tailings around the site including the vegetation plots. *Thiobacillus* was not detected in the new tailings (H1 beach) but present on the vegetation plots and older tailings. Heterotrophic bacteria numbers were generally low except in the presence of vegetation.

Floating Vegetation Mats

The establishment of floating plant populations, such as *Typha* (cattails), in polishing and clarification ponds could provide improvements to the polishing ponds' performance, due to the elimination of wind-driven water movement, and provision of surface areas for sedimentation of suspended solids. A floating vegetation cover would provide organic carbon to the microbial community in the underlying water column and sediments, where dissolved metals can be precipitated as sulphides (ARUM Process).

The objective of the work was to establish the conditions required to grow such a cover. Experiments performed in spring 1991 at the Boojum laboratory indicated that large numbers of cattail seedlings could be grown from seed. This technique could be applied at any mining site, thereby generating a seedling supply on site. The work at Selbaie indicated that the correct conditions of moisture maintenance during establishment of the seedlings is essential.

The results of the Selbaie work, which indicated the pitfalls, together with the more successful experiments at other mine sites, have brought the development phase of a technique for germination of cattail seeds and establishment of cattail populations to an end.

c) ARUM Experiments

In June l990, when the initial assessment was made of the collection pond area (Hockey Lake), the muskeg was still alive and the water had low acidity. It was recommended, based on successful experiments in a bog receiving coal acid mine drainage, that the muskeg and the ditches be amended with hay bales and straw. This would initiate ARUM capacity in this area. However, as the B-Ditch construction was completed, the characteristics of the water changed drastically and appeared to present those conditions which could potentially preclude microbial alkalinity generation.

Experiments were under way at that time to determine rates of alkalinity generation with amendment placed into the ditches. Within a two to three week period, alkalinity generation had taken place. Meanwhile in the field conditions, the hay bales, although showing extensive decomposition by September l990, were becoming increasingly coated with iron. Means were then sought to remove the iron as a precipitate prior to ARUM treatment.

Applications of ARUM in acid mine drainage with high iron concentrations require a precipitation step, as otherwise, the organic material becomes unaccessible to the microbial community. The work on ARUM, therefore, focused on quantification of natural iron precipitation, placement techniques of organic material and mechanism by which the microbial activity could be initiated in the organic amendment.

Small-scale tests in 40 mL vials have been employed during experiments screening a wide variety of organic and inorganic amendments, in terms of their capacity to stimulate or inhibit the development of an ARUM microbial community. For example, the experiments revealed that by increasing pH to 4.5 through addition of lime, beneficial effects were not observed, in terms of expediting ARUM onset; in fact, lime inhibited the process.

Alfalfa pellets with iron were found to be the most successful amendments. The second series of experiments, therefore, addressed the proportions required for a proposed scale-up field tests.

Concentrations as low as 500 mg elemental iron/l were found sufficient for the initiation of ARUM. Tests cells for field trials, with flow control were designed but not constructed.

Concurrent to the determination of the appropriate ratios of amendment required, an experiment addressed the microbial activity inside the amendment was conducted. Twenty litre containers were set up with an inner cores, and sampling ports were distributed throughout the inner and outer amendment layers. In field experiments at other sites, the onset of ARUM occurred in pockets, i.e., the pH increased in a particular nuclei within the organic amendment. This experiment was designed to address the microbial spread of these pH pockets. In the field, this could then lead to a particular configuration of placement of the amendment, which would be favourable for the process's establishment and maintenance.

The chemical changes in the reactors were monitored. Rapid increases in pH and decreases in Eh at the outset of the experiment appear to be primarily related to the corrosion of steel wool added to the reactors. However, the addition of iron did not affect the acidity, although the pH increased.

Sulphate-reducing bacteria have been detected in Reactor 1's core, where the bulk pH is presently 5.77. This indicates that sulphate-reducing bacteria can tolerate the high iron, sulphate and the high metal concentrations in B-3 water.

A concurrent experiment, determining of the ratios of required amendment, indicated that excess alfalfa in the compressed pellet form produces concentrations of volatile fatty acids which inhibit ARUM activity. These findings were confirmed by the reactors since, to date, only that reactor which received a large dose of sulphate reducing bacteria inoculum has significant sulphate reducing activity. The experimental set-up was used, therefore, to study decomposition steps which are required to produce the ethanol needed to feed sulphate reducers. The experiment is still running.

The hay bales placed into the B-Ditches and cell 1 of the collection pond were investigated for microbial activity, and amendment samples brought into the laboratory from the field were used for the jar experiments.

The results of open-faced jar experiment indicate that B-3 water is amenable to ARUM treatment after reduction in iron concentrations. Alkalinity was generated after about 150 days. This incubation time for the amendment with the AMD is in the same time range as those of field experiments carried out in 53 m^3 enclosures, where ARUM started after about 210 days.

The results of the field survey performed in July 1991 indicate that microbially-mediated increases in pH, and reductions of Eh, are not present within, or in the immediate vicinity of, the organic amendments added.

The results of Rapichek tests performed in the field and lab indicated that low numbers of sulphate reducing bacteria populate the hay bales and sawdust, while the endemic *Sphagnum* sample from C11 harboured a healthy population of SRB's. Although the number of SRB's in the hay and sawdust amendments were low, this group of bacteria were, none the less, present in 4 out of five samples in the first cell of the collection pond.

High numbers of microorganisms were suggested from ATP levels, ranging from 9.1 to 55.5 mg/L. Very interesting results emerged from analysis for iron reducing bacteria and ammonifiers. Despite pH's less than 2.8, these bacteria were found in B and C Ditch amendments in comparable numbers to those in the C11 sample, collected from the pool with a pH of 6.0.

The pH of amendment samples, collected in the field and sealed during storage at refrigerator temperatures for three months following collection, increased, while the Eh decreased. The activities of sulphate and iron reducing bacteria, as well as ammonifying bacteria likely induced these changes.

In summary, it is clear, from both the laboratory results, in conjunction with the field observations, that ARUM activity can be established in the collection pond. Testwork proposed for the B-Ditch and the first cell of the collection pond should give further confirmation of the viability and effectiveness of PWP followed by ARUM.