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Base Metal Mine Waste Management in North-eastern New Brunswick

Environmental Impact and Assessment
Report EPS 8-WP-73-1

Water Pollution Control Directorate
June, 1973

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BASE METAL MINE WASTE MANAGEMENT IN NORTHEASTERN NEW BRUNSWICK

A Synopsis Based on the Findings of the Northeastern New Brunswick Mine Water Quality Program

prepared by

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Environmental Protection Service

Report No. EPS8-WP-73-1
June, 1973

REVIEW NOTICE

This report has been reviewed by the Water Pollution Control Directorate, Environmental Protection Service, and approved for publication. Approval does not necessarily reflect the views and policies of the Environmental Protection Service. Mention of trade names or commercial products does not constitute endorsement for use.

ABSTRACT

In November, 1972, a two year Federal-Provincial program called the Northeastern New Brunswick Mine Water Quality Program was completed. It was aimed towards ensuring that the valuable fishery resources of Northeastern New Brunswick can be maintained and coexist with current and future base metal mining developments.

The Program analyzed in detail the fishery resources of the region, their water quality requirements, the mineral resources of the region and the many aspects of mining waste management at each phase of mine development. This bulletin summarizes the important aspects of base metal mining waste management in an environmentally critical area such as Northeastern New Brunswick as determined in the abovementioned Program.

Key Words: Effluent Requirements, Heavy Metals, Mine Waste Management, New Brunswick, Rehabilitation, Salmon, Stream Requirements, Tailings Pond, Toxicity.

RESUME

En novembre 1972 prenait fin le programme biennal fédéral-provincial intitulé "Programme sur la qualité de l'eau de mine dans le nord-est du Nouveau-Brunswick". Son but était de montrer que les importantes richesses en poissons de cette région pouvaient être conservées et qu'elles pouvaient coexister avec l'exploitation minière, actuelle et future, des métaux vils.

Ce programme a analysé en détail les richesses en poisson et en mineraux de la région, la qualité de l'eau dont elles ont besoin ainsi que les multiples aspects de la gestion des déchets miniers à chaque étape de l'exploitation d'une mine. Le présent texte résume les principaux aspects de la gestion des déchets de mines de métaux vils dans une région où l'environnement est menacé, comme le nord-est du Nouveau-Brunswick tel que l'avait établi le programme précité.

PRINCIPAUX TERMES: bassin de décantation, exigences quant aux cours d'eau, exigences quant aux effluents, gestion des déchets miniers, métaux lourds, Nouveau-Brunswick, rétablissement, saumon, toxicité.

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THE MINERAL AND FISHERY RESOURCES OF NORTHEASTERN NEW BRUNSWICK

Resource development in Northeastern New Brunswick is centred on the forestry, mineral and fishery resources of the region. The valuable fishery resources have, however, been threatened by water quality problems which have been, in part, created by base metal mining operations. In November, 1970, the Northeastern New Brunswick Mine Water Quality Program, involving both the provincial and federal governments, was commissioned to study the problem and to develop solutions. Its specific aim was to ensure that the fishery resources could be maintained in the face of existing and future base metal mining developments.

The program was completed in November, 1972, and its findings with respect to base metal mine waste management are summarized in this bulletin. The area considered by the program is shown in Figure 1.

1.1 Mineral Resources

Four of the six basic provincial metallogenic zones occur in Northeastern New Brunswick. Of these, the Tobique and Miramichi zones are of particular interest and contain many known copper, zinc, lead and pyrite deposits as indicated in Figure 1. The Tobique zone is characterized by calcareous host rocks whereas the Miramichi zone contains massive pyrite with sphalerite, galena and chalcopyrite, or pyrrhotite-chalcopyrite in association with massive pyrite. Presently known deposits in the region total in excess of 300 million tons of lead and zinc.

Development of these known areas of mineralization during the 1960's was primarily responsible for a dramatic increase in the Provincial mineral production values, which rose from $ 18.8 million in 1961 to $ 107.4 million in 1971. In 1971 metal production in the Northeastern part of the Province accounted for 85 per cent of the total Provincial mineral value which, in turn, accounted for 4.8 per cent of the gross Provincial product.

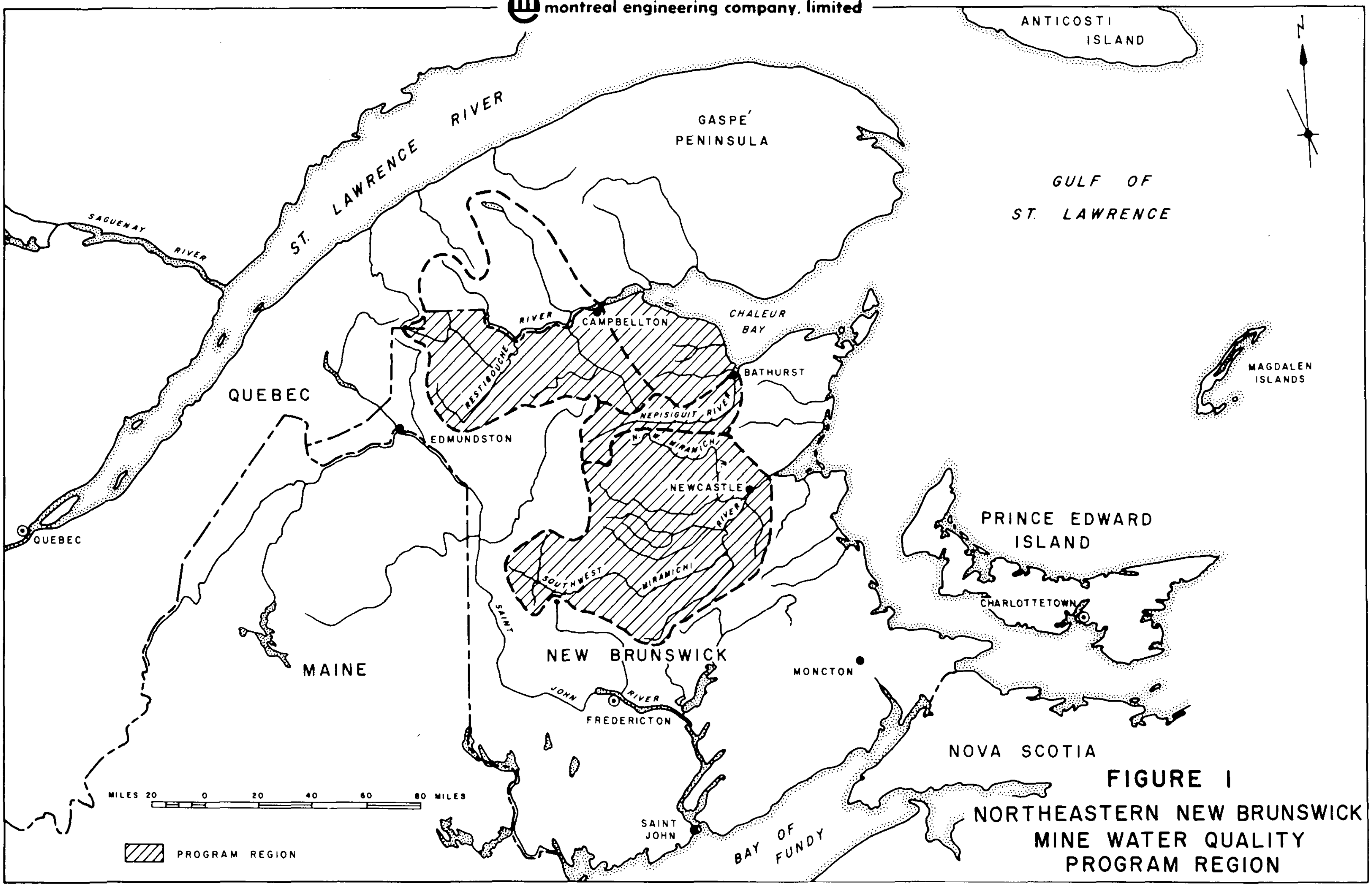
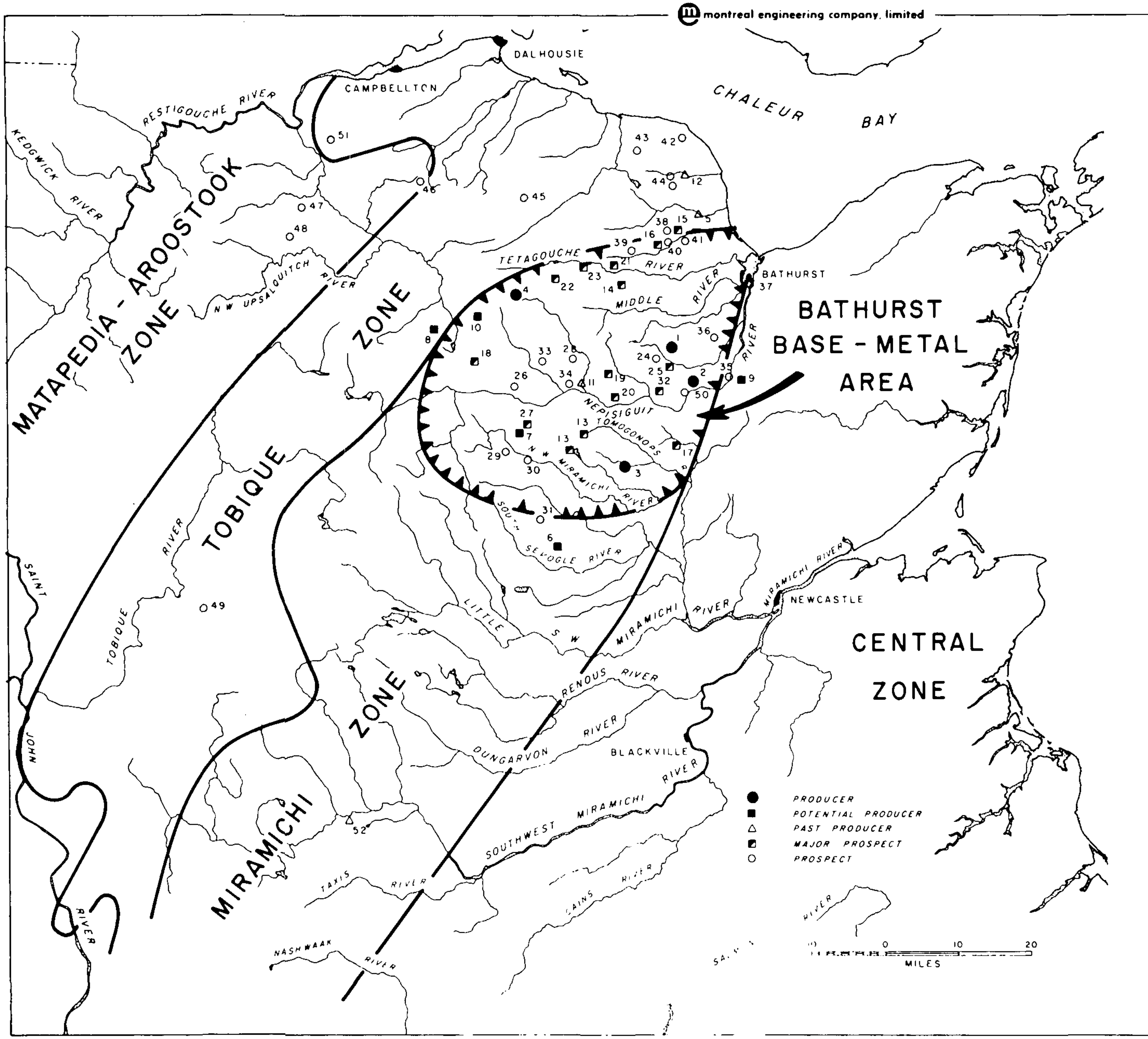


FIGURE I
NORTHEASTERN NEW BRUNSWICK
MINE WATER QUALITY
PROGRAM REGION



OCCURRENCES

1	BRUNSWICK No. 12	Pb, Zn, Cu
2	BRUNSWICK No. 6	Pb, Zn, Cu
3	HEATH STEELE	Pb, Zn, Cu
4	ANACONDA - CARIBOU	Pb, Zn, Cu
5	NIGADOO RIVER	Pb, Zn, Ag
6	CHESTER	Cu, Pb, Zn
7	TEXAS GULF - BAY COPPER	Pb, Zn, Cu
8	RESTIGOUCHE	Pb, Zn
9	KEY ANACON	Pb, Zn
10	KENNCO MURRAY	Fe, Pb, Zn, Cu
11	COMINCO - WEDGE	Cu
12	KEYMET	Pb, Zn
13	COMINCO - STRATMAT	Pb, Zn, Cu
14	ANACONDA - ARMSTRONG	Cu, Pb, Zn
15	BERESFORD	Cu
16	QUEBEC STURGEON	Pb, Zn
17	CAPTAIN	Cu, Pb, Zn
18	DEVIL'S ELBOW	Pb, Zn
19	CANOE LANDING	Pb, Zn, Cu
20	NEPISIGUIT	Pb, Zn
21	ROCKY TURN	Pb, Zn
22	McMASTER	Pb, Zn
23	ORVAN BROOK	Pb, Zn
24	QUEBEC MINING	Pb, Zn
25	HEADWAY	Pb, Zn
26	INDIAN FALLS	Pb, Zn
27	HALF MILE LAKE	Pb, Zn
28	CALIFORNIA LAKE	Pb, Zn
29	MALICEET MTN	Cu, Ni
30	RIO	Cu, Ni
31	BILL'S LAKE	Pb, Zn
32	NINE MILE - LOUVICOURT	Pb, Zn
33	O'HEARN	Pb, Zn
34	SELCO	Pb, Zn
35	MIDDLE LANDING	Cu
36	PABINEAU	Mo
37	BATHURST	Cu
38	MILLSTREAM	Fe
39	NORTH AMERICAN	Pb, Ag
40	Ag, Pb	
41	Cu	
42	TURGEON	Cu
43	PATAPAT	Pb, Zn
44	Pb, Ag	
45	McNAIR BROOK	Pb, Zn
46	POPELOGAN	Cu
47	LEGACY	Cu
48	BURNTLAND BROOK	Cu
49	BLUE MTN	Cu
50	AUSTIN BROOK	Fe, Pb, Zn
51	COX'S BROOK	U
52	BURNTHILL TUNGSTEN	W

FIGURE 2

MINERAL DEPOSITS OF NORTHEASTERN NEW BRUNSWICK

There are at present 3 operating mines in the region:

Heath Steele Mines Ltd.

Brunswick Mining and Smelting Corporation - No. 12 operation

Brunswick Mining and Smelting Corporation - No. 6 operation

The Heath Steele Mine includes a 3000 T/day mill, scheduled for expansion to 4000 T/day capacity in 1973. The Brunswick No. 12 operation includes a 10,000 T/day mill which concentrates ore from both the No. 12 and 6 operations. Two other mines in the region, Nigadoo River Mines Ltd. and Anaconda-Caribou Mines Ltd., suspended operations in the Fall of 1971, but may resume operations in the future.

The principal characteristics of the five active, or recently active mines are summarized in Table 1. The analysis of waste management characteristics is based on figures from a 3000 T/day mine/mill which the Sullivan Mining Group had proposed to open on what is known as the Chester Property. This proposal has since been deferred.

Development projections for the mineral deposits of Northeastern New Brunswick indicate that a doubling of the present production capacity in the region can be anticipated within the next decade.

1.2 Fishery Resources

The fishery resources of Northeastern New Brunswick are famous throughout North America, if not the world, for the size and quality of the region's Atlantic salmon population and for the large speckled trout also found in its freshwater streams. The Atlantic salmon (Salmo salar) is the more highly prized of the two species, both as a sport fish and as a gourmet food. It requires high standards of water quality in the freshwater streams in which it develops and later returns to spawn, and can therefore be regarded as an excellent indicator of water quality.

Along the eastern seaboard of continental North America man's activities over the years have steadily reduced the number of streams suitable for habitation by Atlantic salmon, which, coupled with commercial exploitation, has led to widespread alarm and recognition of the need to eliminate the various threats to the

TABLE 1

Principal Characteristics of Existing Mines

Name	General Description: Status & Type	Capacity	Known Reserves	Min. Op. Life	Concent. Produced	Ownership	Water Supply: Supply Stream	Supply Capacity	Water Balance - Process: Total Process	% Recycle Internal	% Recycle External	Fresh Water Make-up	Water Bal - Mine Water: Ave Mine Water	Treatment
		tons/day	tons x 10^6	Yrs.				gpm	gpm	%	%	gpm	gpm	
Anaconda Caribou	O/P Cu OPn Mill suspended U/G Pb/Zn deposit under exploration	1000	Cu-1.0 Pb/Zn-50.0	-	Cu	Anaconda American Brass Ltd. 75% Cominco 25%	Forty Mile Brook	550	400	-	67	120	100	During opn pumped to launders. Presently limed and TP
Brunswick No. 12	Primarily U/G. Small O/P+ mill.	6500 -mine 10,000 -mill	82	37	Pb,Zn,Cu	Noranda Mines Ltd. (64% interest)	Nepisiguit	2000	3600	-	70	1100	250	Neutralized at surface then to TP
Brunswick No. 6	O/P only, no mill	3500	10	8	Pb,Zn,Cu	Noranda Mines Ltd. (64% interest)	None	-	Not Applicable				165	Discharged to treatment system
Heath Steele	Primarily U/G + mill O/P unactive	3000	34	20	Cu,Pb, Zn,Ag	Amax Ltd. 75% INCO 25%	Little South Tomogonops & Little River	2300	2500	34	-	1650	580	Pumped to TP
Nigadoo River Mine	U/G + mill. Opn. suspended	1000	±2.5	7 (if re-opened)	Pb,Cu,Zn	Sullivan Mining Group Ltd.	Nigadoo River	1250	833	-	-	833	1250	No treatment

	Water Balance - Surface Drainage: Area	Average Flow	Storm Volume	Contaminated Not Treated	Unit Ratio	Waste Treatment: Average Treated Volume	Average Net Volume	Net Unit Effluent	Treatment Method	Receiving Stream
	Acres	gpm	acre-ft	acres	acres/tpd	gpm	gpm	gals/ton		
Anaconda-Caribou	85	103	35	Nil	.085	580	308	443	Tailings Pond	Forty Mile Brook
Brunswick No. 12	636	678	280	Nil	.064	4313	1819	262	Tailings Pond, biostabilization pond, pH control, Settling Pond	Little River
Brunswick No. 6	324	346	135	45 (est)	.105	511	559	230	Modified High Density Sludge	Knight Brook/Nepisiguit
Heath Steele Mines	935	1036	390	Nil	.31	3200	3200	1493	Tailings Pond	South Tomogonops
Nigadoo River Mine	49	46	20	16	.06	1183	2119	3052	Tailings Pond	Nigadoo River

All gallons Canadian

fishery resource. Ecologically, the principal rivers of Northeastern New Brunswick now constitute the core area of the freshwater range of the Atlantic salmon on the North American continent. In this region, sparsely populated areas with clear, fast flowing river reaches ideal for salmon are still in abundance.

Within the region two related and disturbing trends have been observed in recent years: salmon stocks have declined sharply to levels lower than any previously recorded, and; the egg deposition potential of those salmon reaching the spawning streams has been reduced by a change in the ratio of river escapement of grilse and salmon from 50% salmon prior to 1963 to only 13% salmon after 1963 (Ruggles and Turner[1]). However, with the recent ban on the commercial fishery and the reduction that can be anticipated in the commercial catch off Greenland, greater numbers of large salmon will reach the spawning areas of their natal streams in future years. The effects of increased egg deposition in terms of the restoration of adult salmon stocks can be expected to manifest itself in five to six years if suitable environmental conditions are maintained in the nursery areas and in the river systems that must be traversed by the salmon to reach them.

Gross annual expenditures attributable to salmon angling in the region appear to be in the order of $ 1,755,000 and gross annual expenditures on angling for other species, chiefly trout, are in the order of $ 1,936,000. The commercial Atlantic salmon fishery is in a state of flux. Landings of salmon attributable to the area declined from 536,000 lb in 1969 to about 230,000 lb in 1971. The corresponding values were $ 474,000 (88.5 cents/lb) and $ 213,000 (92.8 cents/lb). With the present 5-year ban on the commercial salmon fishery in eastern Canada the current value of the resource to the region is almost wholly attributable to the sport fishery.

Estimates of economic value are at best only a partial measure of the real value of the fishery to society. The resource has no substitute and Canadians are increasingly becoming aware of the social, as well as the economic stakes involved in its protection.

1.3 Interrelationship of the Resources

Without minimizing the potential effects of mining, it is nevertheless important to bear in mind that this is only one of several threats to the survival of the salmon resource. Others include overfishing, forestry practices (such as logging and insect control spraying), estuarine pollution and poaching. Management of the resource must effectively deal with all these threats. Overfishing, not mining is believed to be the primary cause of the present decline in Northeastern New Brunswick, but any threat to the freshwater habitat of the salmon, where reproduction takes place and the particularly sensitive initial stages of their life cycle are completed, must be viewed with special concern. If the spawning streams are rendered unsuitable or inaccessible, measures aimed at restoring the stocks will not succeed.

Base metal mining wastes may affect the aquatic environment in the following ways:

- Heavy metals (Cu, Zn and Pb) in the cation form are lethal at relatively low concentrations to fish and other aquatic organisms.
- Lower concentrations of these metals induce sublethal effects such as avoidance reactions and impaired fertility and developmental characteristics.
- pH changes in streams due to the discharge of unstable effluents and/or pyritic particulates can alter the aquatic environment and make it unsuitable for salmonid fish.
- Toxic effects caused by the discharge of reagents or residuals other than heavy metals can alter the stream environment, making it unsuitable for habitation by the native biota. This has not been identified as a problem in mining operations in Northeastern New Brunswick.
- Sedimentation on stream beds can alter the substrate, making it unsuitable for use as a breeding habitat by salmonid fish.

The reaction of salmonid fish to heavy metals has been well defined by biological research workers such as Lloyd and Herbert[2], Brown[3], and Sprague and Ramsey[4]. Variables known to affect metal toxicity include water hardness, concentrations of humic substances, lignosulphonates (Carson and Carson[5]) and other organics, dissolved oxygen, pH and temperature. Traditionally, only water hardness has been taken into account in quantitively evaluating metal toxicity, but as a result of research conducted within the Program, it is now possible to take the mitigating effect of humic compounds into account as well (Cook and Cote[6]). Increased levels of water hardness and of humic compounds decrease the toxic effect of metals present. The method of evaluating heavy metal toxicity in terms of toxic units as recommended in the Northeastern New Brunswick Mine Water Quality Program is included as Appendix I.

SECTION 2

MINE WASTE MANAGEMENT - OPERATIONAL PHASE

The approach adopted towards assessing the compatibility of the mining and fishery resources of the region in the Northeastern New Brunswick Mine Water Quality Program was to evaluate on the one hand the biological criteria necessary to protect the fishery resource, and on the other hand to determine and compare the levels that can be achieved by applying the best practical levels of waste management at new and existing mining developments. Section Four discusses the interrelationship of the recommended stream and effluent requirements.

The analysis of base metal mine waste management practices and the subsequent derivation of effluent requirements involved consideration of the two basic facets of waste management:

- categorization and minimization of wastes at source,
- treatment of the resulting minimized waste streams to best attainable levels using best practical treatment technology.

Guidelines were therefore developed to limit waste volumes and to specify maximum acceptable effluent concentrations.

An alternative approach might have been to derive and specify total acceptable effluent quantities but since effluent volumes, effluent concentrations and total quantities discharged are interdependent the specification of any two defines the third. It is therefore a question of emphasis rather than fundamental principle whether effluent requirements are related primarily to unit quantities of contaminants or to effluent volumes and concentrations. However, the latter approach enables emphasis to be placed on reducing both the effluent volume and the effluent concentrations and was thought to be better suited to the needs of reducing the impact of mining development to a minimum in an environmentally sensitive region such as Northeastern New Brunswick.

It is interesting to observe that of the two major mine/mill developments in Northeastern New Brunswick, one consistently achieves low metal effluent concentrations, but has a relatively high unit effluent volume, while the other has a low unit volume but somewhat higher concentrations. At new developments the emphasis must be on achieving minimum unit volumes and concentrations.

2.1 Aqueous Waste Components and Minimization

There are three main sources of aqueous waste at most base metal mine/mill developments: mine water, mill process effluent and contaminated surface drainage. A brief review of each component as it relates to conditions in Northeastern New Brunswick is presented, followed by a discussion on integrated mine waste balances. Chemical analyses of some mining waste components in Northeastern New Brunswick are shown in Table 2.

2.1.1 Mine Water

Mine water in the region is normally acid with a chemistry similar to 'acid mine drainage' (see Section 2.1.3) although the quality and volume varies widely from mine to mine depending upon the geochemical and hydrogeological characteristics of the mine. Mine water may contain significant quantities of ammonia resulting from the use of ammonium nitrate based blasting compounds.

The main sources of mine water are:

- groundwater seepage
- water pumped into the mine for machines and drinking
- water resulting from hydraulic backfill operations
- surface drainage into or through open pits

Groundwater seepage can be controlled to a limited degree by methods such as chemical or cement grouting and an economic balance between these measures and the cost of pumping and treating is normally sought.

Fresh water is normally pumped into the mine for machines and drinking. There is a reluctance within the industry to use recycled treated mine water for machines due to the cost of treatment, potential scaling problems and the habit of miners drinking the feed water.

Hydraulic backfill methods are not used at mines in Northeastern New Brunswick due primarily to the impermeability of most tailings which results from the fineness of the grind. Waste rock backfill methods are used in the region.

TABLE 2

Chemical Analyses of Mining Waste Components

	Heath Steele			Brunswick Mining & Smelting Corp.	
	Mill Effluent	Mine Drainage	Mine & Surface Drainage	Mill Effluent (No. 6 & 12)	Mine Drainage (No. 12)
pH	10.8	3.8	4.0	11.2	2.0
acidity	-	-	-	-	10,900
suspended solids	180,000	118	8.8	780	689
total diss. solids	582	1852	78.6	5800	23,991
Ca	-	-	-	209	-
Mg	-	-	-	6.8	-
hardness	500	295	293	550	2960
Cu	0.08	156	27	0.40	11.3
Zn	0.51	328	118	2.80	1086
Pb	0.43	0.44	0.36	0.10	57.6
Fe^{+2}	0.0	7.0	2.0	-	1515
Fe^{+3}	2.5	169	76.6	-	318
Fe (total)	2.5	176	78.6	1.3	1833
Mn	0.11	10.4	21		0
SO_4	137	1246	836	3169	16555
S_2O_3	0.0	157	36.4	1002	-
COD	-	-	-	505	245

All concentrations are mg/l

Average mine water volumes in the region are as follows:

Anaconda (Exploration workings)	100 gpm (Can)
Brunswick No. 12	250 gpm (Can)
Brunswick No. 6	165 gpm (Can)
Heath Steele	580 gpm (Can)
Nigadoo River (closed)	1250 gpm (Can)

2.1.2 Milling Process Effluent

The most common method of concentrating base metal ores and that used exclusively in Northeastern New Brunswick is differential flotation. The typical base metal concentrator therefore consists of the following basic processes: crushing and grinding, selective flotation, concentrate thickening and drying. The layout and degree of complexity in the cirucit varies widely from mill to mill.

The milling process effluent is therefore typically high in dissolved solids, has a high alkalinity, contains in the order of 80 per cent of the solid material processed, will often contain process reagent residuals, and may be chemically complex depending on the ore and the types of process reagents used.

In metallurgically simple mill circuits metal recovery efficiencies are often in the order of 90-98.5 per cent. However, the complexity of the metallurgy in Northeastern New Brunswick results in recoveries of a smaller magnitude. An ore balance at one mine, for example, indicates that approximately 38 per cent of the copper, 32 per cent of the lead and 12 per cent of the zinc in the ore are not extracted and therefore appear in the tailings. This represents 19 per cent of the total heavy metals in the ore.

Process water demands for recent and existing mines in Northeastern New Brunswick are presented in Table 3.

TABLE 3

Total Process Water Requirements - New Brunswick Mines

	Total Process Requirements		Percentage Provided by Recycled or Reclaimed Water
	gpm	gals/ton	%
Anaconda (closed)	400	576	67
Brunswick No. 12 (Fall '72)	3600	518	70
Heath Steele[a]	2500	1200	34
Nigadoo (closed)	833	1200	Nil
Chester (1970 proposal)	968	465	75

NOTE: All gallons Canadian

a Present 3000 ton/day capacity

The key waste management implications of the process are the treatability of the effluent and the degree to which the integrated net effluent from the development as a whole can be minimized by recycling water to the process.

2.1.2.1 Use of Recycled Water in the Flotation Circuits

Two forms of recycle may be utilized in milling operations: internal recycle within the mill circuits or the use of water reclaimed after treatment as part of the basic mill feed requirements. Often both can be used concurrently.

Until recently the use of high recycle ratios in complex mill circuits such as those in Northeastern New Brunswick was considered metallurgically unfeasible. However, technology and attitudes are changing rapidly and the use of recycle (or reclaim) ratios in the order of 80 to 90 per cent of the total process requirements should not only be feasible, but also of long term economic advantage to mine/mill developments within the region in the future.

A problem often encountered in the use of recycled water in the flotation circuit is a cumulative build-up of various constituents to levels where they may be problematical from the standpoint of either the process chemistry or the subsequent treatment of the process effluent. The build-up of hardness and soda ash will tend to occur in circuits employing these alkaline reagents. High concentrations of thiosalts resulting from the use of sulphur dioxide as a process reagent may constitute a restraint to reclaiming the effluent for the process unless the levels are reduced by oxidation. Ammonia can pose similar problems but is not used as a process reagent in Northeastern New Brunswick.

The build-up of trace reagents or metals in the recycle circuit may be of concern from the process standpoint as excessive concentrations in the feed water can interfere with the selectivity of the flotation process. However, treatment of the process effluent to levels consistent with the effluent requirements presented in Section Four will result in levels of these constituents which should not have an adverse effect on the flotation circuit. The application of recycle loops within the mill can result in reagent savings due to the deliberate reuse of residuals.

Boiler feed and gland water remain two applications where high quality feed water is required although the use of treated recycle water may be feasible for the latter application in some instances. Most fresh water supplies require special treatment for boiler feed applications and it may therefore be feasible to utilize recycled water for these purposes also.

In Northeastern New Brunswick the three main waste components (mine drainage, mill process effluent and contaminated surface drainage) are mixed for combined treatment and the resulting effluent is partially reclaimed as mill feed water in some instances. An alternative approach sometimes used in the other regions is to separately treat the process effluent to the quality required for recycle to the mill. Any bleed-off can then be treated in the separate system necessary for the mine and surface drainage components. The relative merits of these two approaches depends on the relative volumes and treatabilities of the three main waste components. This is further discussed in Section 2.2.4.

2.1.3 Contaminated Surface Drainage

This component of aqueous mining wastes is sometimes overlooked yet for mines in pyritic regions such as most of Northeastern New Brunswick, contaminated surface drainage can be the most difficult and expensive component to adequately control.

Sulphide bearing rock, when exposed to moisture and air, oxidizes to generate acid which then leaches heavy metals from the exposed rock or particle surfaces. The rate of the oxidation reaction is greatly increased by the presence of bacteria such as T. Ferroxidans and is normally associated with the oxidation of pyrite (FeS_2) or pyrrhotite ($Fe_{x-1}S_x$) as follows:

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

Other reactions are also involved in the further oxidation of the ferrous sulphate to ferric sulphate and thus to ferric hydroxide and further quantities of sulphuric acid. The ferric hydroxide thus formed precipitates as 'yellow boy'.

Because of its high acidity and high metal concentrations, contaminated surface drainage in sulphidic areas must be collected and treated. Since this adds to the water imbalance at a mine, minimization and segregation of the areas affected are fundamental to good mine waste management practice.

Potential sources of contaminated surface drainage include areas of the mine site around ore handling facilities, the mill and concentrator, haul roads, ore storage and waste rock piles, together with any areas where sulphidic rock surfaces have been exposed. The surface drainage characteristics of existing mines in the region are summarized in Table 1. The unit figures, which indicate the total area per unit capacity (tpd) contributing to the volume of water requiring treatment, are repeated as follows:

Anaconda	0.085	acres/tpd
Brunswick #12	0.064	
Brunswick #6 (open pit opn only)	0.105	
Heath Steele (3000 tpd mill)	0.31	
Heath Steele (est. for 4000 tpd mill)	0.23	
Nigadoo	0.06	
Chester (1970 proposal)	0.12	

It should be possible for most new underground mine/mill developments in Northeastern New Brunswick to achieve unit contributing drainage ratios in the order of 0.04 acres/tpd if the drainage from contaminated areas is reduced to a minimum and drainage from uncontaminated areas is segregated to the maximum degree possible.

The Northeastern New Brunswick Mine Water Quality Program recommended that a design storm of 5 inches in 24 hours with 100 per cent runoff be used for the design of mine drainage control works involving drainage areas of up to about one square mile. This storm has a recurrence of approximately 20 years in the region.

2.1.4 Integrated Mine Waste Control

Integrated mine effluent balances for mines in Northeastern New Brunswick are summarized in Table 1. The final integrated unit effluent volumes are repeated as Table 4.

Development of mine/mill operations with a zero average net effluent (on an annual basis) is impossible in the cool humid climate of Northeastern New Brunswick using available process and treatment technology. This situation is due to the excess of average precipitation over evapotranspiration (40 inches relative to 18 inches) which prevents a balance between mine water, rainfall/evaporation surplus, and process make-up requirements even if extremely high (say 95 per cent) recycle ratios are assumed.

TABLE 4

Integrated Final Effluent Volumes

Mine - Production	Average Integrated Effluent	Integrated Effluent per Unit Ore Processed	Integrated Effluent Less Mine Water
	gpm	gal/ton	gal/ton
Anaconda - 1000 T/day	308	443	301
Brunswick No. 12 - 10,000 T/day	1819	262	226
		342	283
Brunswick No. 6 - 3500 T/day	559	230	162
Heath Steele (1)	3200	1493	1257
- 4000 T/day (2)	3397	1189	936
Nigadoo River - 1000 T/day	2119	3052[d]	1251
Proposed Chester - 3000 T/day (1971)	951	457	265

All gallons Canadian

The Northeastern New Brunswick Mine Water Quality Program recommended that the following unit net effluent volumes (less mine water) should be strived for at mine/mill complexes:

Mill Capacity	Unit Net Effluent (Less Mine Water)
1,000 T/day	180 gals/ton
5,000 T/day	150 gals/ton
10,000 T/day	150 gals/ton

If mine water volumes in the order of 150, 225 and 300 gpm respectively, are assumed for the three capacities, the equivalent net integrated effluent figures become 400, 210 and 185 gals/ton respectively. (All Gallons Canadian)

2.2 Aqueous Waste Treatment

2.2.1 Conventional Treatment Practices

By far the most common means of treating base metal mining wastes in the industry as a whole is to discharge them into a tailings pond in which the pH is controlled. In this way the heavy metal ions in the waste are precipitated as hydroxides, these precipitates and other suspended solids are settled out, and the solids retained in perpetuity. In situations where there is no mill at a mining development, the mine water and surface drainage, if treated, have traditionally been discharged into ponds and neutralized with lime or similar reagents.

The situation in Northeastern New Brunswick has followed this general pattern although in recent years many improvements and refinements have been incorporated into the treatment systems. The treatment mehtods used at each of the mines in Northeastern New Brunswick are summarized in Table 5.

If consistently high effluent qualities are to be attained it is essential to be able to exercise a high degree of control over pH in the treatment system to achieve optimum precipitation of metals and it is equally essential to provide good sedimentation conditions for the removal of these precipitates from the decant. In addition, mine effluents with high thiosulphate concentrations resulting from the use of SO_2 as a process reagent require the provision of an oxidation phase capable of achieving high levels of stabilization under extreme climatic conditions. In some areas the removal of ammonia and cyanide are critical treatment functions although neither of these reagents are used in Northeastern New Brunswick.

TABLE 5

Treatment Methods in Northeastern New Brunswick

Mine	Process Wastes	Surface Drainage	Mine Water	Comments
Anaconda-Caribou [a]	Alkaline circuit - no regular lime addition	Partially directed into TP. Balance into storm treatment pond.	U/G water to mill limed and to TP. Open pit water to storm	Mine water pumped to mill, neutralized, and to TP.
Brunswick #12	Lime pptn in TP. Bio-stabilization of thio-salts & subsequent lime neutralization and sedimentation.	Contaminated drainage collected & discharged to tailings pond.	Pumped to surface, neutralized & discharged to TP	Recycle from last treatment pond installed in Oct '72.
Brunswick # 6	Not applicable	AMD collected by dam on Knight Brook & diverted through HDS treatment system.	Pumped to surface drainage treatment facility.	HDS process installed in 1971
Heath Steele	Lime addition prior to discharge into TP. No recycle from pond.	Complex collection system feeding into TP with lime addition.	Pumped to TP.	$2.5 million surface drainage control system recently constructed.
Nigadoo [a]	Pumped to TP - calcite based ore - no lime addition.	No treatment - direct runoff into Nigadoo River	Partially used for tailings slurry dilution. Balance untreated to Nigadoo River.	Low metal levels in all effluent streams due to natural alkalinity of ore.

[a] Operations suspended fall 1971

NOTES:

TP - Tailings Pond

DWF - Dry Weather Flow

AMD - Acid Mine Drainage

SWF - Storm Weather Flow

HDS - High Density Sludge

U/G - Underground

The tailings pond performs many processes, the most critical of which from the treatment standpoint, are metal precipitate formation, sedimentation and oxidation. Other key functions include perpetual solids retention and storm flow balancing.

The two factors that can seriously detract from the reliability and performance of a tailings pond treatment system are the loss of pH control due to wide flow variations in the effluent and the loss of good sedimentation conditions due to short circuiting, thermal skimming or peak through-puts.

The following measures will aid in eliminating these problems and will enable the tailings pond to be used as the basis of an effective treatment system at many mines, although if a high degree of oxidation is required (e.g. for the stabilization of thiosalts) a separate oxidation phase will have to be provided:

- minimization of incoming flow variation by reducing the contributing drainage area to an absolute minimum
- proportioning of lime feed rates to incoming flow volumes as well as the system pH level
- optimum inlet/outlet positioning and design
- maintenance of a distinct settling zone in proximity to the outlet
- use of a two cell pond system to increase control and reliability.

Specification of a recommended retention time for traditional tailings pond design is problematical because the influence of pond geometry, inlet-outlet details, and other factors that ensure even distribution and an absence of short circuiting are of greater importance than the theoretical retention provided. A design retention time of 30 days based on the average flow to be treated is often specified and is appropriate if the above provisions to ensure that short circuiting does not occur are incorporated.

2.2.2 Attainable Levels - Heavy Metals

The residual levels of heavy metals attainable in the effluent are dictated by the solubility of the metal hydroxide and any associated metal complexes in the waste being treated, and by the efficiency with which these precipitates can be settled from the decant.

Sodium carbonate, sodium hydroxide, ammonia, limestone and lime are commonly considered for pH adjustment and of these limestone is normally the cheapest. However, it has several disadvantages and lime is the reagent most used in Northeastern New Brunswick at an on-site cost in the order of $24 per ton.

Purely theoretical consideration of metal hydroxide solubility relationships suggests that the following metal levels are theoretically attainable:

Cu^{++}	1 - 8 ug/l	pH 9.5
Zn^{++}	10 - 60 ug/l	pH 10
Pb^{++}	1 ug/l	pH 8
Fe (Total)	1 ug/l	pH 8 if totally ferric

Many factors such as the effects of widely differing solubility products, mixed metal hydroxide complexing and metal chelation render these levels of only limited value when assessing attainable concentrations in a treatment system.

Due to the inherent limitations of considering only the theoretical relationships, an in-depth analysis of the performance of existing mine/mill waste treatment systems in the region was performed in the Northeastern New Brunswick Mine Water Quality Program with a view to deriving attainable levels. Treatment data were available for three mine/mill systems in the region: Heath Steele, Brunswick Mining and Smelting Number 12, and the Anaconda-Caribou mines. Conclusions drawn in the case of each mine were as follows:

<u>Heath Steele</u> Levels of 20 ug/l copper and 50 ug/l zinc are consistently attained if the pH is controlled in the 10-11 range and sedimentation conditions are maintained. In practice the effluent

copper concentrations exceed 30 ug/l at about a 7 per cent frequency and zinc concentrations exceed 150 ug/l at approximately 8 per cent frequency but these extremes tend to coincide with values of pH less than about 8.5 or extreme flow conditions which almost certainly affect sedimentation conditions adversely. These figures are based on daily analyses over a period of 2 years.

Anaconda-Caribou Although data are available for only a few weeks of operation levels as low as 10 ug/l copper and 25 ug/l zinc were achieved while the pH was maintained in the order of 11. Dramatic increases in effluent metal concentrations were recorded once the pH dropped below about 8.5.

Brunswick Number 12 Copper concentrations recorded in the effluent are in excess of 30 ug/l in 59 per cent of samples and zinc in excess of 150 ug/l in 83 per cent of samples. However, extreme fluctuations in pH were recorded throughout the 12 month data period and sedimentation conditions were generally considered unsatisfactory. As a result of these facts and the findings of laboratory tests conducted by the mine and by a government laboratory it was concluded that levels of 30 ug/l copper and 150 ug/l zinc would be practicably attainable if good pH control and sedimentation conditions are consistently applied.

On the basis of these analyses and considerable confirmatory laboratory work it was concluded that mines in Northeastern New Brunswick should be able to achieve effluent concentrations of at least 30 ug/l copper and 150 ug/l zinc.

These levels require further confirmation under controlled continuous test conditions and a pilot scale treatment project has been established in the region for this purpose (a brief description of the project is included as Appendix II.

Operating data similar to those used to evaluate attainable levels of copper and zinc are not available for lead, iron, cadmium and arsenic, meaning that more reliance had to be placed on isolated samples and the theoretical levels. The following are thought to represent best attainable levels in conventional treatment facilities for other metals encountered in Northeastern New Brunswick:

Lead	100 ug/l
Iron	1 mg/l
Cadmium	40 ug/l
Arsenic	50 ug/l

These levels also require further verification under continuous operating conditions and will be investigated as part of the pilot scale treatment project described in Appendix II.

2.2.3 Attainable Levels - Other Effluent Characteristics

The Northeastern New Brunswick Mine Water Quality Program examined effluent stability, hardness, pH and suspended solids in the course of deriving attainable levels and recommending effluent requirements.

Effluent Stability In order to produce a stable effluent that will not be subject to further chemical or biological oxidation in the receiving stream and thereby result in decreased values of pH or dissolved oxygen, it is necessary to oxidize as fully as possible any unstable components in the effluent such as reagent residuals, thiosalts, or ferrous iron, etc.

Laboratory scale tests indicate that biological oxidation is the most economical treatment alternative for stabilizing thiosalts in the effluent stream and that aerated lagoon systems should be capable of oxidizing thiosalt concentrations in the order of 1000 mg/l with a retention of six days.

At present, thiosalts appear in significant concentrations in Northeastern New Brunswick only at the Brunswick No. 12 mine where a biostabilization lagoon has been installed to treat the thiosalts. Removals in the range of 70-90 per cent are achieved under summer conditions but the system is not effective in winter. It appears that temperature is a limiting factor to the kinetics of the oxidation reaction and an investigation of this and other inputs of thiosalt treatment is included in the previously mentioned pilot scale treatment project.

Oxidation facilities provided for thiosalts will simultaneously oxidize other effluent constituents requiring stabilization. In cases where oxidation is not a major consideration, the degree of surface oxidation achieved in a tailings pond will often be sufficent to stabilize minor quantities of oxidizable components in the waste.

Flotation reagent residuals were identified in all mine effluents in Northeastern New Brunswick but concentrations were generally in the order of 1 mg/l or less and they do not appear to pose an environmental problem.

Effluent Hardness The hardness of the effluent is dictated by the amount of lime added in the treatment process, the alkalinity of the process effluent and the quantity of hardness components that exist prior to treatment. Very little can be done to control the hardness levels in the effluent without recourse to advanced treatment practices such as reverse osmosis. The control of pH without excessive use of lime is obviously of advantage to the over-all final effluent quality but no 'best attainable level' could be stated for effluent hardness due to the above considerations.

Effluent pH The effluent pH subsequent to treatment may be as high as 11 which is in excess of acceptable receiving stream values. The adjustment of pH to virtually any required level is relatively simple technically and in some cases this may be necessary. However, in general, it was felt that the natural buffering capacity of most receiving streams will reduce the pH to acceptable levels from very high effluent values, where they exist, so quickly that a specific treatment operation to adjust pH downwards would not generally be required. Furthermore, it was felt that since it is impractical to absolutely stabilize the majority of mine effluents, they should be discharged with an alkaline pH. For this reason, a minimum pH of 8 was recommended as an effluent requirement with an upper limit being set only in cases where the stream requirements presented in Section Four would otherwise not be achieved.

Effluent Suspended Solids The impact of suspended solids in a treated mine effluent depends primarily on its metal composition. If significant quantities of metal are manifested in colloidal or finely divided forms in the decant it will be correspondingly difficult to achieve the required metal concentrations. A maximum effluent concentration for suspended solids of 30 mg/l was therefore recommended. In many cases far lower levels will need to be achieved in order to meet the metal requirements.

2.2.4 Other Treatment Considerations

In cases where a specific oxidation treatment phase is necessary or where adequate pH control and sedimentation efficiencies cannot be assured using a tailings pond as the basic method of treatment, it may be necessary to separate and individually optimize the necessary treatment processes. This would involve the provision of separate oxidation, reagent mixing and sedimentation operations with the tailings impoundment used primarily for the permanent retention of tailings and treatment sludges.

There are advantages in using the tailings impoundment for the primary separation of solids and also for balancing storm flows, particularly where large contaminated areas are involved as discussed in Section 2.1.3. Use of the tailings impoundment for these functions results in a treatment sequence as indicated in Figure 3A. Using this approach the surface area of the treatment system can be minimized and each operation designed and operated so as to best fulfill its primary objective.

As mentioned in Section 3.1.2.1, there may be advantages in maintaining a separate circuit for the process effluent involving only those treatment operations necessary to produce water of adequate quality for reclaim to the process. It may prove possible for example, to segregate the main thiosalt bearing waste streams and treat these independently to reduce the thiosalt concentrations before recycling them to the process. In such instances it would be necessary to provide separate treatment facilities for the mine and surface drainage components together with any process water bled off the reclaim circuit to prevent

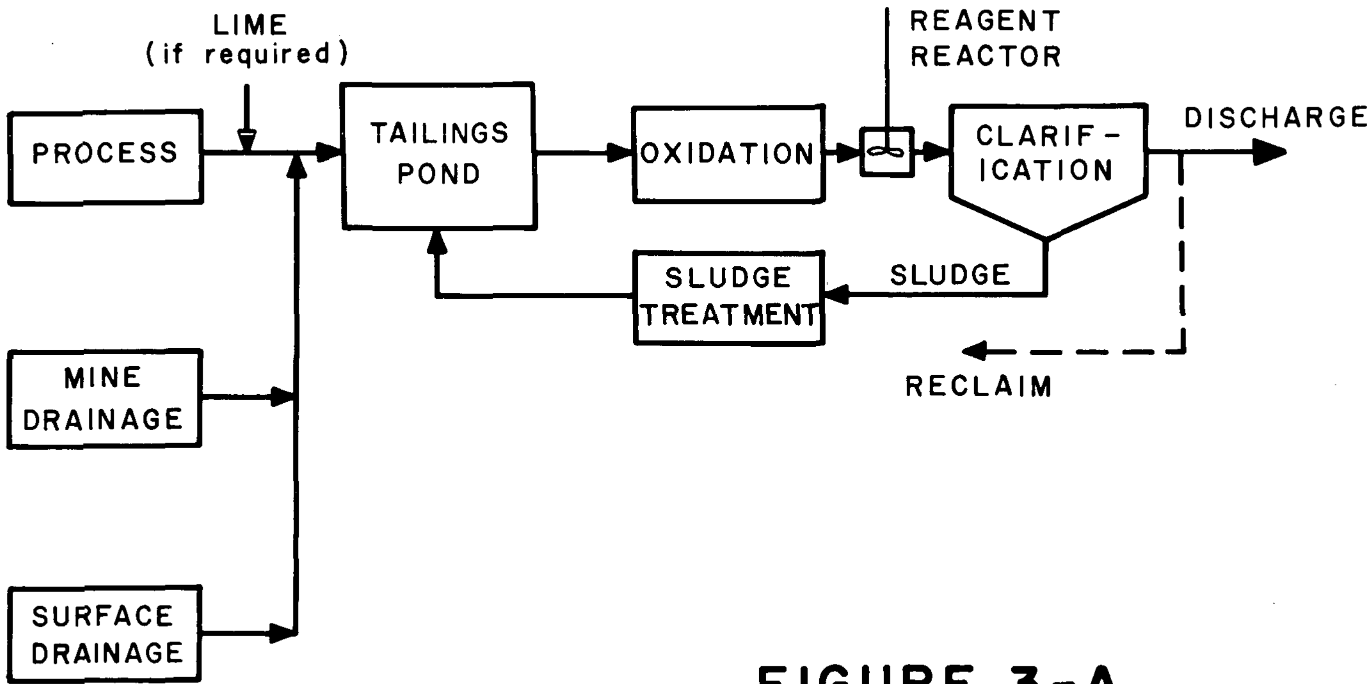


FIGURE 3-A

TREATMENT CONFIGURATION
INTEGRATED WASTE STREAM

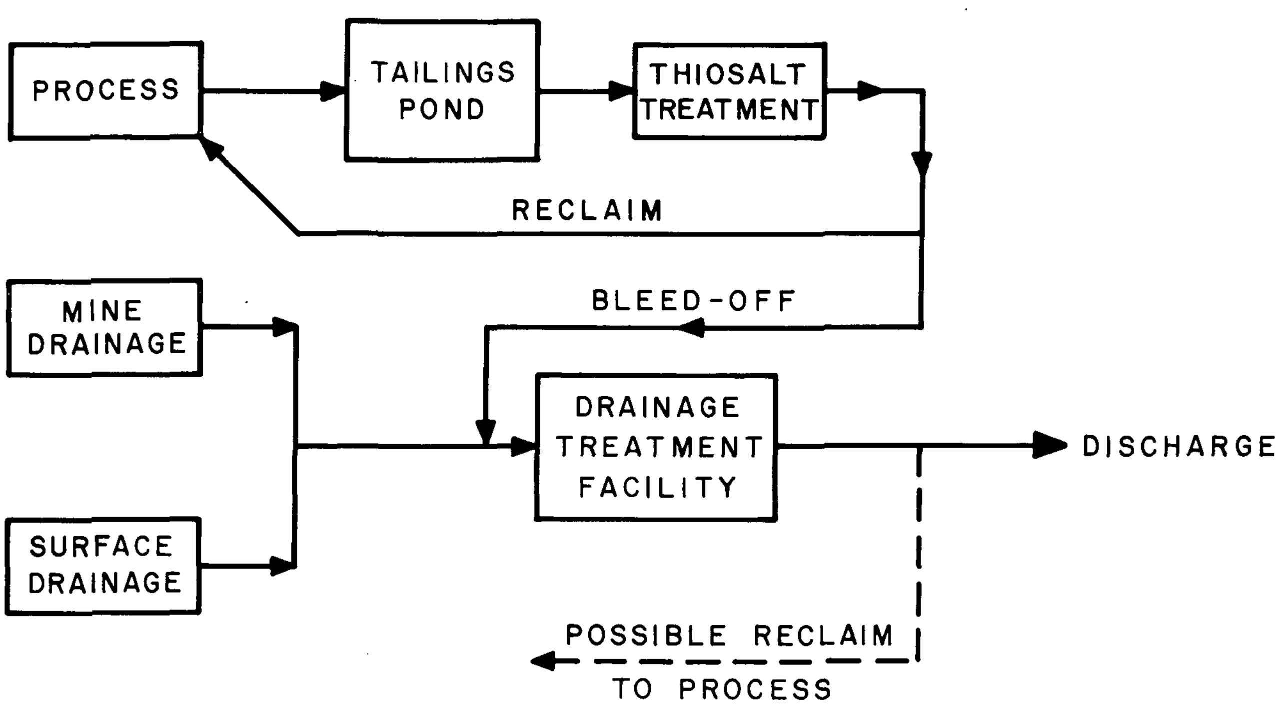


FIGURE 3-B

TREATMENT CONFIGURATION
SEGREGATED PROCESS EFFLUENT

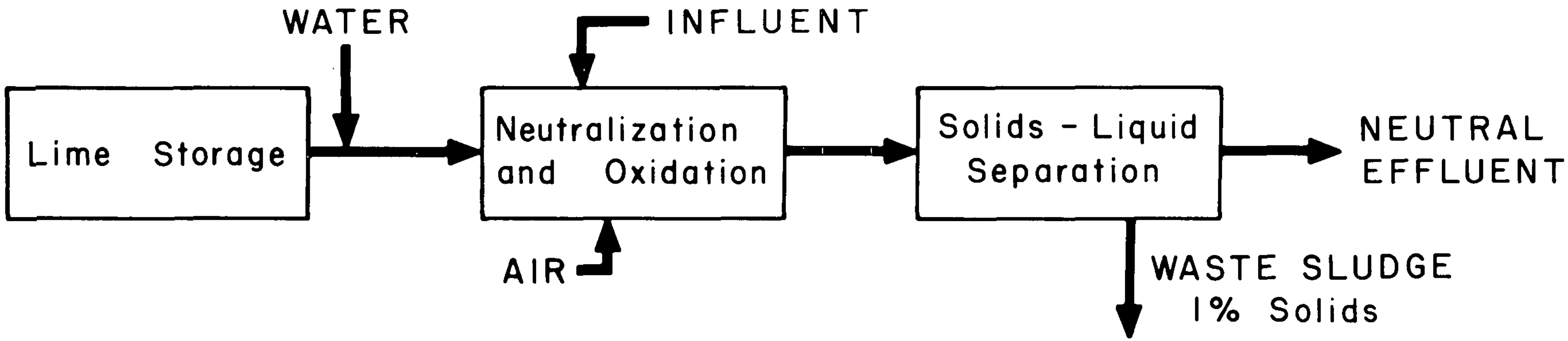
excessive accumulations of problem constituents. Such a system is indicated in Figure 3B. Separate treatment systems are not used at mines in Northeastern New Brunswick and have an inherent disadvantage in areas where the treatment of contaminated surface drainage is a major consideration because separate storm balancing facilities would be required.

In cases where only mine water and surface drainage are being treated problems may be encountered with sludge thickening and disposal because sludges with high iron contents are notoriously problematical in this respect. In such cases, improved sludge characteristics can be achieved by using a modified form of the lime neutralization-sedimentation system known as the 'High Density Sludge' system. The characteristics of this treatment system relative to conventional neutralization and sedimentation are shown in Figure 4.

Where the three waste components are mixed before treatment it appears that the mass of solids in the mill process effluent (tails) acts as an aid to sedimentation of fine precipitated material and may also be instrumental in reducing effluent metal concentrations by providing adsorption sites for metals remaining in solution. Attempts will be made to evaluate these effects as part of the pilot treatment project described in Appendix II. The Heath Steele mine presently incurrs considerable expense to discharge mill tailings and the drainage components into the tailings pond at the same point in the belief that significant treatment benefits are obtained.

It appears that in the majority of situations it will not be necessary to apply the so-called advanced methods of waste treatment to mining effluents with a view to further reducing the effluent metal levels or to decreasing the level of other effluent constituents (such as total dissolved solids or hardness) below the levels attainable with conventional methods. The majority of advanced waste treatment methods such as ion exchange or reverse osmosis have yet to be fully developed or applied to mining waste treatment applications. Most are prohibitively expensive at their present state of development.

CONVENTIONAL PROCESS



HIGH-DENSITY SLUDGE PROCESS

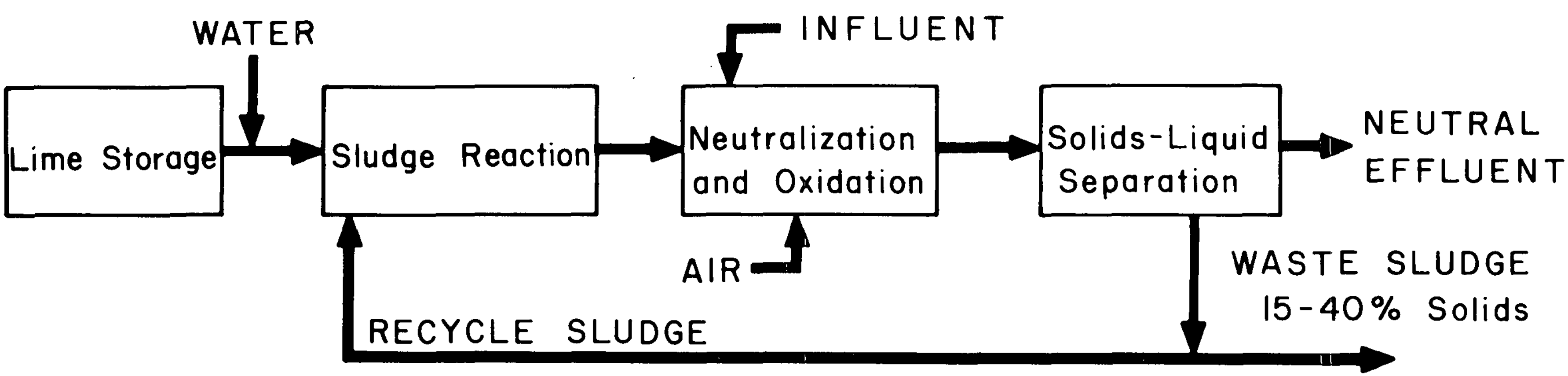


FIGURE 4

CONVENTIONAL AND HIGH DENSITY SLUDGE TREATMENT SYSTEMS

Source: Kostenbader & Haines (7)

2.3 Solid Wastes

The mining industry is perhaps unique in the volume of solid wastes it generates in the course of producing a finished product. To produce one ton of finished metal commonly required handling 100 times or more that amount of rock and ore, most of which manifests itself as solid waste in the form of mine waste rock, mill tailings or smelter slag.

At many mines, and particularly at underground operations, the mill tailings constitute the largest portion of the solid wastes generated. In the course of mining, approximately 80 per cent or more of the ore mined appears as finely ground slurried waste. The disposal or storage of these continuously accumulating mill tailings often exerts a major influence on the design and operation of a mine/mill complex.

Methods of dealing with tailings include the following:

- impoundment in perpetuity
- offshore marine disposal
- disposal in deep lakes
- use as backfill in the mine
- processing for secondary values.

Perpetual impoundment is the most common method of tailings disposal employed by the industry as a whole and that exclusively used in Northeastern New Brunswick although the other methods listed may provide alternatives in particular circumstances. The Northeastern New Brunswick Mine Water Quality Program recommended that every encouragement be given to the development of secondary uses for pyritic tailings as it is apparent that in the long term, perpetual containment of pyritic tailings with adequate environmental safeguards will prove to be a costly alternative.

Potential environmental implications of impounded tailings deposits may include:

- physical and esthetic modification of the area
- contamination of streams by seepage of low pH and high metals content
- contamination of streams due to surface runoff from the deposit

- air and water contamination resulting from wind eroded particulate material
- difficulty in establishing vegetation or otherwise permanently stabilizing the deposit at the rehabilitation phase due to the unfavorable soil characteristics which pyritic tailings provide
- possible risk of a large scale release of slimes in the event of a structural failure of the containment structure

The technical means to counter most of the above problems are generally available but may often impose severe cost implications, as for example, would the perpetual collection and treatment of seepage from a tailings deposit.

The design and construction of tailings dams is influenced primarily by the availability of suitable materials near the site and also by foundation conditions, seepage requirements, hydrologic conditions and the risk of seismic disturbances. In Northeastern New Brunswick the tailings are usually too fine to provide sufficient sand sizes for use as the principal dam building material. Low inherent strength and the danger of liquefaction in the event of an earth tremor render unclassified tailings unsuitable as a dam-building material.

Tailings slimes must be excluded from the structure meaning that the upstream method of tailings dam construction should not be employed in Northeastern New Brunswick. As a general rule, borrowed materials will have to be used, but advantage should be taken of suitable waste rock and, if available in sufficient quantities, sands obtained from the tailings.

The safety of tailings dams can be assured by applying sound design and construction techniques. The stability of the structure and its foundation must be confirmed and adequate freeboard and spillway capacity provided to safely handle storm flows.

2.4 The Economic Impact of Waste Management

As an integral part of the Northeastern New Brunswick Mine Water Quality Program an assessment was made of the incremental costs of attaining the effluent requirements recommended, over and above the costs that would be incurred in any event by a new mine developing under today's conditions.

For the purposes of analysis waste management was assumed to consist of the following features:

General	- collection and treatment of all waste streams including all contaminated surface drainage
	- segregation of non-contaminated surface drainage
Waste Minimization	- the provision of a maximum degree of recycle to the process
	- minimization of surface area contributing to contaminated surface drainage
	- use of mine water in the process or elsewhere when feasible
Improved Treatment	- controlled reagent additions resulting in close pH control
	- optimum sedimentation conditions utilizing clarifiers or cellular lagoon systems
	- oxidation/stabilization facilities as necessary
	- provision of failsafe features for maximum reliability

As a basis of comparison two types of mines exhibiting different characteristics were considered, the first being one with only nominal oxidation requirements and relatively simple effluent chemistry (similar to Heath Steele), and the second, one with high effluent stabilization requirements due to high concentrations of thiosalts and generally complex effluent chemistry (similar to Brunswick No. 12). In each case an evaluation was made for hypothetical mill capacities of 1000 tons, 5000 tons and 10,000 tons per day. Results of this analysis indicate that the costs of waste minimization including maximum recycling and reclaiming of waste waters will impose only minor incremental costs for new developments although for existing developments, the costs may be considerable. Provision of the more sophisticated treatment system involving separate operations may result in incremental costs in the order of 5¢ to 15¢ per ton processed as shown in Table 6.

TABLE 6

Incremental Costs of Waste Management

Item	Simple Effluent			Complex Effluent		
	1,000	5,000	10,000	1,000	5,000	10,000
	¢/ton	¢/ton	¢/ton	¢/ton	¢/ton	¢/ton
Oxidation	2.05	0.88	0.73	6.27	3.66	3.32
Clarification including Reagent Additions, etc.	5.6	4.0	3.0	5.6	4.0	3.0
Sub-total	7.65	4.88	3.73	11.87	7.66	6.32
Allow 25% for misc. piping, pumps, etc.	1.91	1.22	0.93	2.97	1.91	1.58
TOTAL Cost ¢/ton Processed	9.56	6.10	4.66	14.84	9.57	7.90
¢/1,000 gal treated	12.5	10.4	8.32	19.4	16.4	14.1

On the basis of this analysis it was concluded that the costs of achieving the proposed levels of waste minimization and treatment would not be a major factor in the cost of production and would not inhibit the viability and growth of the industry in the region.

SECTION 3

MINE REHABILITATION

The rehabilitation phase of base metal mining in a sulphidic, environmentally sensitive area such as Northeastern New Brunswick may pose the most difficult phase of mining from the standpoint of controlling potentially deleterious effects on the environment. Rehabilitation problems may include the following:

- Control of contamination from mine pits and underground workings
- Rehabilitation of tailings areas
- Continued control of contaminated runoff
- Mining subsidence
- General esthetics and redevelopment of area.

Each of these problems are briefly discussed in turn.

3.1 Open Pit and Mine Workings

In general there should be few problems associated with the rehabilitation of underground mine workings unless there are direct seepage paths and a positive gradient from the workings to the surface. Rehabilitation of open pits where contaminated seepage or overflow would result is far more difficult and must be aimed at either eliminating essential reaction components; water, oxygen, sulphides, or bacteria, or alternatively isolating the whole reaction area. The following approaches have been considered:

- sealing the face of the entire mine area to prevent leaching
- neutralizing water in the pit to prevent leaching
- backfilling the pit with waste rock, tailings or sanitary landfill
- use of bactericides to reduce the rate of leaching
- seeding pit with sulphate reducing bacteria to balance acid production

- application of solution mining principles to displace the leaching equilibrium
- hydrologic isolation of pit.

None of these methods provides a totally satisfactory solution to the rehabilitation of open pits because of doubts as to technical feasibility and/or totally unrealistic costs. In general it must be concluded that once an open pit operation is commenced in a sulphidic area, that treatment of the water from the pit in perpetuity may be necessary if contamination of ground or surface waters is to be positively avoided.

3.2 Rehabilitation of Tailings Areas

Rehabilitation of tailings areas has been successfully achieved in many areas of Canada, the United States and elsewhere by establishing vegetation on the area and thereby stabilizing the surface, improving its esthetic properties and reducing seepage. A reduction in the rate of seepage will, in most cases, reduce the rate of acid generation in pyritic tailings. However, the majority of rehabilitation case histories do not apply to highly pyritic tailings deposits on which it is extremely difficult to establish and maintain vegetation, and from which very contaminated seepage can be anticipated for indefinitely long periods of time. The thixotropic nature of many tailings in Northeastern New Brunswick, due to the fineness of grind commonly used, is a further problem to vegetating or sealing the surface.

It appears that perpetual collection and treatment of the seepage from pyritic tailings deposits may be a necessity at mines in Northeastern New Brunswick.

3.3 Control of Contaminated Runoff

Contaminated runoff that is collected and treated during the operational phase must be stopped once the mine closes if continuing treatment is to be avoided. The principal sources of contaminated surface water include:

- General ore and concentrate handling areas
- Exposed rock faces containing pyrites (highway cuts, etc)
- Waste rock and lean ore dumps

In general, the first source can be satisfactorily cleaned up on closing the mine while the second source, if minimized during the operation, will probably be ammenable to sealing techniques where necessary. The rehabilitation of rock and waste piles, however, will often require more difficult and expensive measures. Since rock dumps are normally associated with open pit operations backfilling is a possibility but will result in extremely large expenditures in the case of large mining operations. Covering and sealing may often provide a cheaper and satisfactory solution, but the long term effectiveness of this approach needs to be tested.

3.4 Cost of Rehabilitation

It was recommended in the Northeastern New Brunswick Mine Water Quality Program that the cost of rehabilitation be borne by the developer and therefore be internalized as an integral part of the cost of production.

The best way to establish this principle and to ensure that due consideration is given to minimizing rehabilitation requirements is to require that the developer outline proposed rehabilitation measures as an integral part of the application for a permit and that he be required to deposit a bond to cover the estimated costs of rehabilitation as discussed in the following Section.

SECTION 4

REQUIREMENTS AND PROCEDURES RECOMMENDED FOR NEW BRUNSWICK

In general terms it was concluded in the Northeastern New Brunswick Mine Water Quality Program that if the best practical means of waste management are implemented and maintained at mining developments in the region, metal toxicity in the receiving streams should not endanger the freshwater habitat of the fishery resource. This conclusion was primarily based on the following key findings:

- that base metal mine/mill complexes in Northeastern New Brunswick should be able to achieve effluent metal concentrations in the range of 20-30 ug/l for copper, 50-150 ug/l for zinc, and an average net effluent volume in the order of 200-400 gals/ton, depending on the size of the mine and the volume of mine water. Hardness may vary considerably, but will commonly be in the 450-600 mg/l range.
- that from the biological standpoint, increased hardness (up to an assumed 100 mg/l in the stream), can be taken into account when evaluating the metal toxicity of receiving streams.

Thus where the background metal concentrations (and therefore toxicity) in the receiving stream are relatively high, the effect of discharging disproportionately more hardness than metals into the stream is to reduce the toxicity of the stream.

This is not to imply that treated mine effluents are generally beneficial to salmon streams but merely that since metal toxicity is related to hardness, the mitigating effect of the increased hardness in a treated mine effluent will normally be greater than the detrimental effect of the metals in a mine effluent treated to the quality indicated above. For this reason the emphasis in deriving mine effluent requirements was placed on waste minimization and best attainable levels rather than on their direct evaluation from stream requirements.

An integrated set of stream quality requirements, effluent requirements, waste management guidelines and procedures were recommended which will adequately protect the receiving waters. Effluent requirements were recommended as the primary means of regulation.

4.1 Stream Requirements

Two levels of stream protection were proposed as the means to evaluate and manage the impact of mining waste discharges on receiving stream quality.

The objective for Protection Level One streams is to protect all functions of salmonid fish and in practice the great majority of streams in the region would belong to this category. Protection Level Two streams would constitute the immediate mine effluent receiving streams and would, in effect, act as a buffer zone between the point of discharge and the Level One stream. As such, the requirements for Level Two streams are somewhat less stringent but the objective is to maintain as healthy an aquatic environment as possible, recognizing that changes in the aquatic ecosystems of these streams is inevitable due to the changes in certain key water quality parameters.

Recommended stream quality requirements for the two levels of protection are shown in Table 7. Considerable emphasis was placed on relating the requirements to instantaneous background levels meaning that levels are evaluated on an instantaneous comparative basis with points that properly represent background conditions rather than on the basis of median or other composite values.

4.2 Effluent Requirements

It was recommended that regulatory control for mines in New Brunswick should be exercised through a comprehensive set of effluent requirements which are derived for each mine on the basis of best available waste management practices and the stream requirements pertaining to the area in which the mine is located.

Consequently, effluent requirements will tend to vary from mine to mine, and in order to limit this variability and establish a common base, a set of maximum acceptable concentrations was recommended for the

Table 7

Recommended Stream Requirements

Parameter	Protection Level One	Protection Level Two
Stream Objective	Protection of all functions of salmonid fish.	Maintenance of as healthy an aquatic environment as possible consistent with the role of the stream as a buffer zone.
Heavy Metal Toxicity[a]	If the background[b] toxicity is greater than 0.1 T.U., the stream toxicity shall not exceed[c] the background value. If the background toxicity is less than 0.1 T.U., the stream toxicity shall not exceed[c] 0.1 T.U.	
Hardness	Level of hardness not to exceed 100 mg/l under 7 day in 10 yr low flow conditions.	No specific requirement (will be limited by effluent requirement).
pH	Not changed from background by more than 0.5 units.	To be in the pH range of 5.0 to 9.3.
Dissolved Oxygen	No change from background level.	Equal or greater than 65 per cent background saturation level.
Temperature Change	No perceptible change over background.	Changes to stream temperature limited to those consistent with the maintenance of the DO requirement.
Turbidity	No perceptible change over background.	Maximum increase of 5 JTU over natural turbidity.
Sulphur Compounds	Sulphur compounds limited to concentrations that will not result in pH requirements being exceeded.	
Bioassays	----------------------------	Caged salmonids or other sensitive indigenous species held in the stream immediately above the confluence with the Protection Level 1 stream shall not exhibit mortality rates significantly in excess of similar fish held in background stream quality conditions.

NOTES: [a]Evaluation of Toxicity. Metal toxicity shall be evaluated for the combined effects of Cu, Zn and Pb at the actual (rather than background) level of hardness using the procedure described in Appendix I. The toxicity of a stream should not be expressed without further qualification if the hardness is in excess of 100 mg/l. (Cont'd on p. 40).

Table 7 (Cont'd):

Notes: [b]Definition of Background Levels. The point (or points) which represent background conditions shall be defined for each development. References to background levels shall then be made on an instantaneous comparative basis at these points in preference to median or other composite values.

[c]Within the statistical limitations imposed by analytical accuracy in the determination of the toxic unit index.

Table 8

Interim Waste Management Guidelines and Recommended Effluent Requirements For New Mines in Northeastern New Brunswick

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General Requirements

- All contaminated waste streams including contaminated surface drainage are to be collected and treated. Surface drainage from non-contaminated areas should be segregated from the waste collection and treatment system to the maximum degree possible.

Waste Minimization

- The average net effluent volume should be specifically defined for each development consistent with best available minimization techniques and in accordance with achieving stream requirements.
- Net effluent volumes will necessarily vary from mine to mine but the following unit effluent ratios (EXCLUDING MINE WATER) should be strived for at underground mine/mill complexes:

Mill Capacity	Unit Ratio
1000 T/Day	180 gals/ton
5000 T/Day	150 gals/ton
10000 T/Day	150 gals/ton

- Recycled water should be employed for all mill requirements unless shown to be metallurgically or technically unfeasible.
- Total surface area contributing to the waste volume should be minimized to the order of 0.04 acres per ton of ore processed per day for underground mine/mill complexes. (The ratio for open pit/mill complexes cannot be defined but will inevitably be greater.)
- Mine water volumes can be influenced to a lesser degree than other components bur should be minimized to the greatest extent feasible and should be utilized elsewhere (e.g. as process make-up) wherever possible.

Metal Concentrations

- Effluent requirements should be set for each development based on the best attainable levels for that specific development. The best attainable levels should be derived by taking into account factors such as: the nature of the receiving system; the type of process; the results of pilot and laboratory scale testing and experience with other similar types of development.

(Cont'd on p. 41)

Table 8 (Cont'd)

- The best attainable levels should not exceed the maximum acceptable concentration for a given parameter within the region as a whole.

Metal	Maximum Acceptable Concentrations µg/l	Best Attainable Levels as Presently Defined µg/l
Copper	30	20
Zinc	150	50
Lead	100	50
Iron	1000	300
Cadmium	40	10
Arsenic	50	--

Variation'

- Regulation of the degree of variation in effluent metal concentrations should be a discretionary matter but the following approach is suggested as a guideline: The variation should be limited so that the total quantity of any metal discharged in any consecutive 7-day period does not exceed the total given by the product of the effluent requirement for that metal and the specified average net effluent volume. The concentration of any metal as measured in any six hour composite effluent sample should not exceed two times the effluent requirement.

Effluent Stability

- Specific limitations on effluent stability cannot be made until the standard stability test (quoted in the Northeastern New New Brunswick Mine Water Quality Program Report, Volume 4, Section 2310) has been practically evaluated.
- Effluent COD should be limited as follows:

Maximum acceptable concentration	50 mg/l
Best attainable level probably in order of	10 mg/l

NOTE: The concentrations of thiosalts, ferrous and ferric iron should be stated when quoting mine effluent COD values due to their important influence on COD.

Hardness

- To be evaluated for each development in accordance with the type of treatment, degree of recycle and attainment of the stream requirements for Protection Level One streams.

pH

- Effluent pH should not be less than 8. An upper limit should be specified only in cases where the stream requirements would not otherwise be achieved.

Suspended Solids

- Maximum acceptable concentration	30 mg/l
Best attainable level	10 mg/l

(Cont'd on p. 42)

Table 8 (Cont'd)

Accidental Spills	- A "failsafe" philosophy should be adopted in the layout and operation of the development with respect to possible pipe failures, treatment systems breakdowns, spillages, etc.
Existing Mines	- These recommended requirements and guidelines are specifically directed at new mining developments and may not be realistic in all aspects for existing mines. A schedule of improvements which are feasible should be individually negotiated with existing mines.

industry as a whole throughout the region. The specification of minimum effluent volumes and best attainable effluent concentrations rather than the total quantity of pollutant discharges was adopted for the reasons previously discussed.

The recommended effluent requirements and guidelines that are presented in Table 8 are specifically directed towards new mining developments. Each development must be examined in detail and effluent requirements established at the planning stage. In the case of existing mines, it may not be feasible to achieve some of the requirements; and to meet others may entail detailed planning and possibly major expenditures. A schedule of improvements which are feasible should be negotiated with each existing mine individually. The guidelines and requirements are termed 'interim' as the concentrations expressed require further evaluation under continuous operating conditions. This is a principal objective of the pilot scale treatment project described in Appendix II.

4.3 Monitoring

The Program recommended that effluent monitoring be the responsibility of the mining companies who should make available the effluent quality data to the regulatory agencies on at least a monthly basis. Stream monitoring would be the primary responsibility of the regulatory agencies who would also make random checks on effluent quality.

Effluent monitoring should be performed at the point of discharge from the treatment system and continuous monitoring of effluent flow and pH were recommended. Other parameters should be monitored on a composite basis possibly involving the automatic collection of four, 6-hour, flow regulated composite samples every 24 hours. If the variation in pH over the 24-hour period is minimal these four samples could then be combined to constitute a single 24-hour composite sample for the purpose of analysis.

For stream quality monitoring, it was recommended that a program similar to that presently operated in the region by the Environmental Protection Service (including biological monitoring) be maintained at key upstream and downstream locations at all existing and potential developments.

4.4 Procedures

Procedures recommended in the Northeastern New Brunswick Mine Water Quality Program for the regulation of each phase of mining developments in the region essentially entail a formalization of present procedures excercised under existing legislation at both the federal and provincial levels of jurisdiction. However, several important changes were proposed:

- that prior to granting authorization for a new development to proceed (or an existing development to undertake major changes) that the regulatory agencies, acting jointly, require issuance of a formal permit to the company concerned. The permit should define the quality and quantity of the effluent and describe the agreed waste management practices and guidelines for the development. The permit would be issued after the agencies had reviewed a formal submission from the company and had judged that best practical mine waste management practices would be reliably applied and that the environmental impact of the development would be within acceptable limits.

- that posting of a rehabilitation bond be required and that the value of the bond be set so that it effectively guarantees that sufficient funds are available to cover the capital costs of rehabilitation and to establish a fund for long term operating costs where necessary.

This requirement would ensure that the cost of rehabilitation would be borne by the developer and therefore be internalized as an integral part of the cost of production, and also that full consideration would be given to the many factors involved in rehabilitation at the planning and development stages as well as during operation of the mine, thereby minimizing the cost and environmental impact of the development at the rehabilitation stage.

- that, in addition to the present requirements of the New Brunswick Mining Act concerning exploration and prospecting activities, companies involved in exploration be required to notify the regulatory agencies of the commencement of any drilling, stripping or trenching that may be performed at an exploration site. The environmental implications of these activities in the area concerned can then be evaluated and if necessary the company engaged in exploration can be required (under the terms of existing legislation) to make good any aspects of the work that may pose an environmental hazard.
- that a standing committee be appointed to coordinate action on mining regulation and procedures between the various federal and provincial agencies, and to ensure the systematic exchange of both information and viewpoints. The committee would comprise appropriate representatives from the key mining developments and environmental regulatory agencies.

Mining activities normally fall into four distinct phases: exploration, development, production and closure. However, the pattern of development varies from mine to mine, and flexibility must be incorporated into procedures to allow for this. The procedures recommended in the Northeastern New Brunswick Mine Water Quality Program for the regulation of mining activities at each phase in that region are summarized in diagramatic form in Figure 5.

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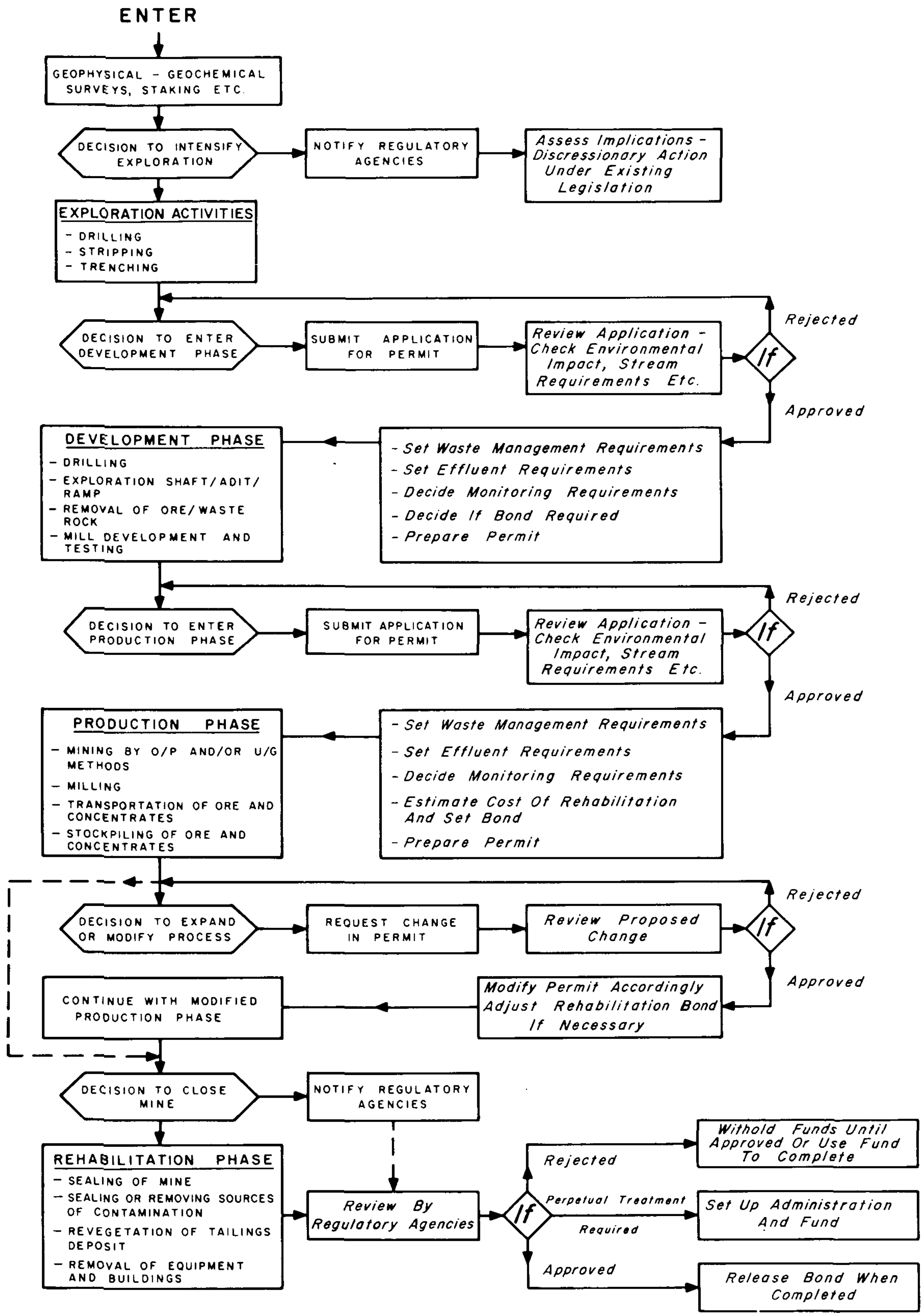

Lower Case print indicates actions by regulatory agencies

Capitalized print indicates actions by mining companies

FIGURE 5

DECISION DIAGRAM FOR MINE REGULATION PROCEDURES

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APPENDIX I

PROCEDURE FOR EVALUATING HEAVY METAL TOXICITY

APPENDIX I
PROCEDURE FOR EVALUATING HEAVY METAL TOXICITY

The toxicity of copper, zinc and lead, taking into account the mitigating effect of water hardness and the presence of humic compounds, can be evaluated using the following procedure:

1. For the prevailing (rather than background) level of hardness determine the Incipient Lethal level for copper, zinc and lead using Table 1-1 or the following equations from which the Table is derived:

$$LZ = 19.5\ H + 291 \qquad (0 < H < 46)$$
$$LZ = 10.2\ H + 710 \qquad (H > 46)$$

$$LC = 2.02\ H + 7.87 \qquad (0 < H < 53)$$
$$LC = 1.56\ H + 32.2 \qquad (H > 53)$$

$$LL = 17.9\ H + 585 \qquad (0 < H < 27)$$
$$LL = 10.2\ H + 790 \qquad (H > 27)$$

where -------- LZ is the incipient lethal level of zinc to trout in ug/l
LC is the incipient lethal level of copper to trout in ug/l
LL is the incipient lethal level of lead to trout in ug/l
H is water hardness expressed as mg/l of $CaCO_3$

Total, rather than dissolved, metal concentrations are used in Northeastern New Brunswick to provide a factor of safety but this procedure might not always be appropriate elsewhere.

2. Evaluate the hardness based toxic units for each metal as:

$$TU = \frac{\text{Actual Concentration}}{\text{ILL}}$$

Table A1-1

Recommended Toxic Unit Evaluation Chart Based on a Mathematical Expression of the ILL for Zn, Cu and Pb

Total Hardness	Incipient Lethal Level Zn	Cu	Pb	Total Hardness	Incipient Lethal Level Zn	Cu	Pb
mg/l as $CaCO_3$	ug/l	ug/l	ug/l	mg/l as $CaCO_3$	ug/l	ug/l	ug/l
5.0	382	18	575	48	1220	104	1280
7.5	439	23	719	49	1230	106	1290
10.0	488	28	764	50	1240	108	1300
11.0	508	30	782	51	1250	110	1310
12.0	528	32	800	52	1260	112	1320
13.0	548	34	818	53	1270	114	1331
14.0	568	36	836	54	1281	116	1341
15.0	587	38	854	55	1291	118	1351
16.0	607	40	871	60	1342	126	1402
17.0	627	42	889	65	1393	134	1453
18.0	646	44	907	70	1444	141	1504
19.0	666	46	925	75	1495	149	1555
20.0	686	48	943	80	1546	157	1606
21.0	706	50	961	85	1597	165	1657
22.0	725	52	979	90	1648	172	1708
23.0	745	54	997	95	1699	180	1759
24.0	765	56	1015	100	1750	188	1810
25.0	764	58	1033	105	1801	196	1861
26.0	804	60	1050	110	1852	204	1912
27.0	824	62	1068	115	1904	212	1963
28.0	844	64	1076	120	1955	220	2014
29.0	863	66	1086	125	2006	228	2065
30.0	883	68	1096	130	2056	236	2116
31.0	903	70	1106	135	2107	244	2167
32.0	923	72	1116	140	2158	251	2218
33.0	942	74	1127	145	2209	258	2269
34.0	962	76	1137	150	2260	265	2320
35.0	982	78	1147	160	2311	281	2422
36.0	1001	80	1157	170	2464	297	2524
37.0	1021	82	1167	180	2566	313	2626
38.0	1041	84	1178	190	2668	329	2728
39.0	1061	86	1188	200	2770	345	2830
40.0	1081	88	1198	225	3025	383	3085
41.0	1101	90	1208	250	3280	422	3340
42.0	1120	92	1218	275	3535	461	3595
43.0	1140	94	1229	300	3790	500	3850
44.0	1160	96	1239				
45.0	1180	98	1249				
46.0	1199	100	1259				
47.0	1209	102	1269				

3. Evaluate the mitigating effects of humic acids (which apply only to copper) by applying a Humic Acid Correction Factor (Figure 1-1) to the hardness based toxic unit for copper as follows:

$$\text{Corrected Toxic Unit} = \frac{\text{Hardness Based Toxic Unit}}{\text{Humic Acid Correction Factor}}$$

   This relationship has not been verified for values of hardness in excess of 60 mg/l, consequently if the hardness is in excess of 60 mg/l the mitigating effect of humic compounds on copper cannot be taken into account until such time as further research better defines the interrelationship of humic compounds and metal toxicity at higher hardness values.

4. Add the corrected copper toxic units to the hardness based zinc and lead toxic units to give the total corrected toxic units of the stream.
   In this way the mitigating effects of increased hardness and the presence of humic compounds are taken into account in the expression of heavy metal toxicity as toxic units.

NOTE: Iron concentrations in excess of 1 mg/l interfere with the presently employed humic acid analytical procedure resulting in erroneously high values of humic acid.

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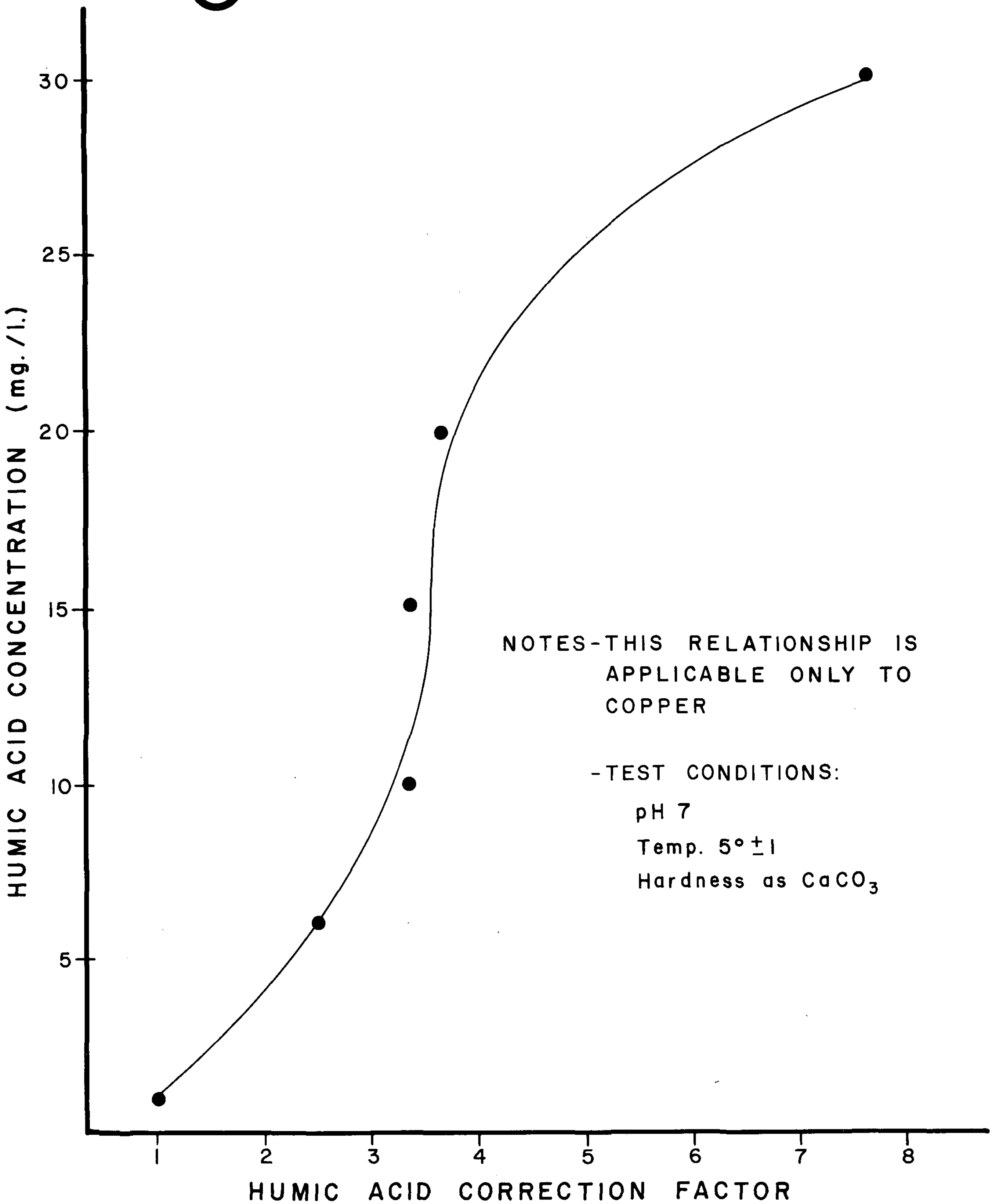

FIGURE I-I

TOXIC UNIT - HUMIC ACID RELATIONSHIP

SOURCE: COOK AND COTE (6)

APPENDIX II

MINE WASTE WATER PILOT TREATMENT PROJECT

APPENDIX II

MINE WASTE WATER PILOT TREATMENT PROJECT

The need to evaluate and demonstrate attainable levels of effluent quality from base metal mining developments under continuous operating conditions was identified in the Northeastern New Brunswick Mine Water Quality Program. Accordingly a project to fulfill these objectives was established during the fall of 1972 involving the operation of a 5-10 gpm pilot scale treatment plant at the Brunswick Mining & Smelting Corporation No. 12 mill. The project is jointly financed by the Federal Government, the New Brunswick provincial government and by Brunswick Mining & Smelting Corporation. The plant was set up and ready for the commencement of test procedures by March 1973. Scheduled completion date is August 1974.

In addition to the important demonstration philosophy incorporated into the project the following specific aspects will be investigated:

- best attainable levels for copper, zinc, lead, iron, cadmium and arsenic under optimum continuous operating conditions using conventional precipitation and sedimentation treatment techniques. These levels will be determined for as many different mines within the region as possible and will include an evaluation of alternative precipitation methods.

- determination and definition of the optimum performance characteristics of the major components in the treatment sequence and particularly for oxidation, metal precipitation and sedimentation.

- continuous pilot scale evaluation of effluent stabilization performance using biochemical oxidation techniques and including an evaluation of the correlation between effluent stability, COD, thiosalt residuals, etc.

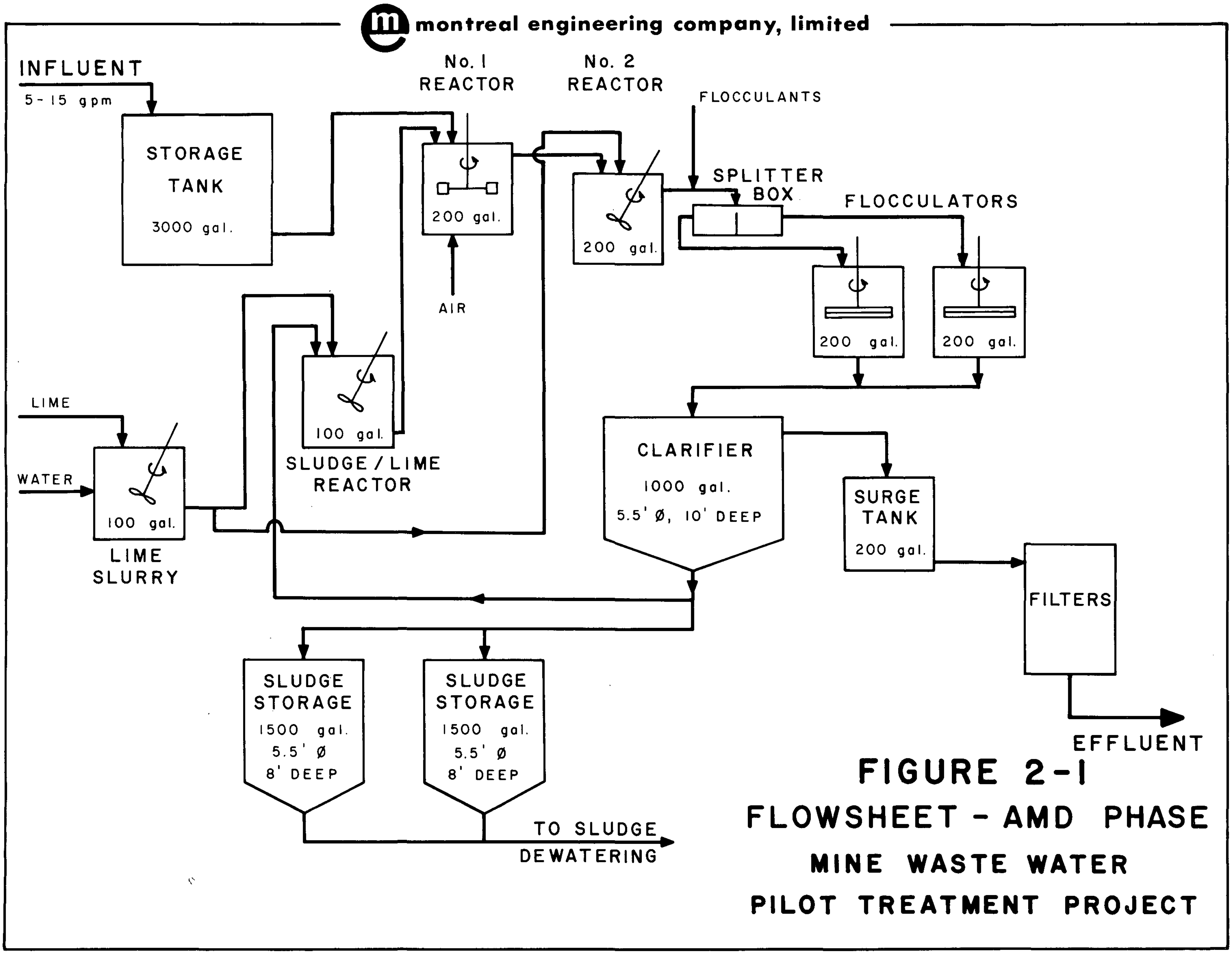

FIGURE 2-1

FLOWSHEET - AMD PHASE

MINE WASTE WATER PILOT TREATMENT PROJECT

- sludge characteristics and the means of handling treatment of sludges. The high density sludge technique should be incorporated into the tests to further define its modifying effects on sludge characteristics and treatment performance generally.

- investigation into the need for various polishing techniques subsequent to the conventional treatment sequence and an evaluation of such techniques as feasible.

The flowsheet being used for the initial stages of the project is indicated in Figure 2-1. Mine drainage from the Brunswick No. 12 mine is being used as the initial test stream but water from other mines in the region will be trucked to the plant for evaluation. The test program will include the evaluation of thiosalt oxidation measures using the mill process effluent from the Brunswick No. 12 mill and will be followed by testing of integrated effluent treatment as presently used in Northeastern New Brunswick. Two stage precipitation as a means of offsetting treatment costs by separating a zinc rich sludge from the treated wastes will also be examined.