REVEGETATION AND WATER QUALITY ASPECTS OF MINE AND TAILINGS DRAINAGE CONTROL

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INTRODUCTION

Mining is one of Canada's largest and most important industries. Production values in 1980 totaled more than C$14.8 billion enabling the country to be described as the world's largest exporter of metals products. Within such a large and diversified industry it is not, therefore, surprising that a wide variety of activities are to be found which impact upon the environment. The Canadian mining industry in the late 1960's, due to the nature of its extraction, processing and waste disposal practices was subject to most vigorous condemnation for causing highly visible environmental degradation (Marshall, 1982). As a result of public pressure, a considerable increase in government intervention occurred, through a wide range of controls aimed at reducing the impacts of major resource developments on the environment.

The impact of mining upon the environment in Canada has been reviewed by Ripley et al (1978) and Marshall (1982). The proliferation of minerals extracted, the number of contaminants associated with each, and the variety of political jurisdictions, has precluded, for the most part, comprehensive monitoring to provide quantitative information concerning the nature and extent of the environmental impact both in a regional and global context. As Marshall (1982) pointed out, each mine is unique; not only in the physical and chemical nature of ores and waste materials extraction and processing methods, but also location, topography and climate influence the type and dispersal of environmental contaminants. Variability of those factors hinders any attempt to estimate potential impact either for the industry as a whole or even to operations involved in the extraction and processing of identical minerals. The above mine uniqueness extends to methods for minimizing environmental impacts. Both for reclamation and water quality control, as for nearly all other techniques, each mine has, or will have to develop, its own particular and detailed methods for preventing environmental impact or restoring already degraded environments.

MINE AND TAILINGS DRAINAGE CONTROL

During underground operations, exposed material within the mine oxidizes and gives rise to acid production which contaminates the water. The nature of the oxidation in U.S. coalfields has been extensively investigated (e.g. Caruccio et al, 1977) but has received virtually no attention with regard to metal mining in Canada. Not all mines in Canada have acid-mine drainage problems. Where it occurs, it is associated with sulphide-bearing metallic ores such as pyrrhotite, chalcopyrite, sphalerite and arsenopyrite as well as pyrite and marcasite.

Acid contamination is increased by water entering the mine from external sources. In addition to seepage from natural watercourses, which constitutes the larger part of the external supply, water (usually one-third by weight) may be used to transport mill tailings underground for the purposes of backfilling excavations and for processing and servicing needs. The average composition of underground drainage waters has been calculated at 51 per cent from natural watercourses, 14 per cent from mine backfill (where employed), 34 per cent from service and process sources, and the remaining one per cent from other unspecified sources (Scott and Bragg, 1975).

As the total average water flow into an underground mine is estimated at 1,000 litres per minute, pumping must be maintained to ensure continuous operation. The estimated flow is an average for the industry and is subject to wide variations between mines and over time in any particular mine. Following pumping, the drainage water, which frequently contains significant quantities of highly toxic dissolved minerals, is impounded at the surface prior to discharge and recycling. The impoundment areas may range from small ponds accepting a few tonnes per day to large tailings dams enclosing several square kilometres and receiving slurry wastes at the rate of thousands of tonnes per day. A sequential approach to water clarification is normally employed and involves the use of a single pond, or a series, to allow the settling out of the contained solids. The effluent is then subject to additional treatment to neutralize acids and remove heavy metals.

As in underground mines, surface operations (both open-pit and strip) are also prone to the effects of acid mine drainage. While the mean flow of water into an underground mine is approximately 1,000 litres per minute, for open-pit mining the mean value is 13,800 litres per minute, derived 78 per cent from natural watercourse, 9 per cent from service and process water and 13 per cent from other sources (Ripley et al, 1978). The substantial quantities of water involved in surface mining operations enhance the potential for effluents to enter the natural environment. The problem is compounded by the run-off, leaching, and percolation processes acting upon the residuals contained in the solid wastes which are considerably in excess of those produced in underground operations. The extensive use of water recycling in recent years has significantly reduced the potential for water pollution arising from the eneficiation processes. Nevertheless, most water is eventually discharged to impoundment areas, or settling ponds, where natural processes operate (seepage, evaporation, percolation, and runoff) and may allow the escape of toxic effluents to the surrounding environment. At this stage, measures are taken to neutralize the acidic elements in the water with alkaline materials, lime neutralization being the most widely employed process. Neutralization, however, must be sufficiently effective to ensure that the acid-forming capacity of the effluent materials is removed. After neutralization and settling out of the effluent materials, substantial quantities of precipitated sludge remain which may present difficulties for dewatering and safe disposal.

The major environmental problem associated with the beneficiation stage is that of the disposal of mill tailings. The common practice is to provide an impoundment area designed to accommodate the substantial quantities of waste materials generated. The design and construction of the impoundment area is critical to the maintenance of environmental quality. Embankment design and construction, transportation of waste materials, water retaining and decant systems, and seepage control are major design factors to be considered if the effects of earthflows, leaching, and wind and water erosion are to be minimized. Rarely though are revegetation aspects at abandonment considered part of the design and construction stages.

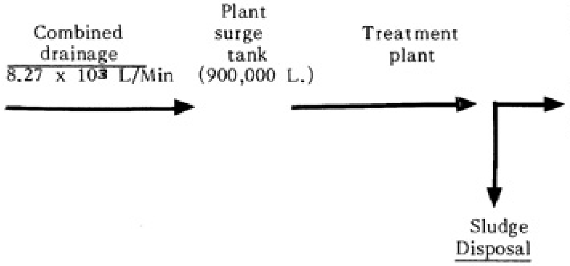
The state of the art of acid mine drainage control in Canada is reflected in the recent descriptions of mine and tailings effluent treatment at a large (6,500 tonnes per day) lead-zinc mine in British Columbia (Kuit, 1980) and at a smaller (45,000 tonnes per month) zinc, gold and silver open-pit mine in Quebec (Lecuyer, 1983). At Kimberly, British Columbia, complex facilities which provide for the collection, management and treatment of effluents emanating from the mine and concentrator tailings were made operational in 1979. Key features of the system are the use of upgraded tailings ponds for the storage of up to 800 million litres of metals-contaminated effluents, a treatment plant employing lime in a high-density sludge process and a sludge-impoundment facility designed for maximum long-term environmental safety. The completed works are capable of satisfying a difficult range of operating requirements imposed by highly variable weather conditions, drainage flows and soluble metal loadings. (Table 1). Final capital expenditures for the project approached $10 million and annual operating costs are about $0.8 million.

During early 1980, preproduction work commenced at the "Les Mines Gallen" project, north of Noranda, Quebec. Underground mining had taken place at the property between 1953 and 1962. As a result of the acid mine water associated with the property, a major preproduction phase included the installation of a water treatment plant to render the water environmentally suitable. Capital costs for the plant were approximately $1.0 million. Acceptable effluent quality was obtained in approximately one month after startup (Table 2). Plant operating costs during the first four months of operation were estimated at C$1.913/1000 Imperial gallons. As operating experience was gained it was estimated that costs would decrease (Lecuyer, 1983).

TABLE 1

Mine and Tailings Effluent Treatment at Cominco Ltd., Kimberly, British Columbia

Parameter	Mine Drainage mg/1	Iron Tailings Decant mg/1	Plant Effluent	(Federal Guideline)
Fe	200 - 1000	300 - 2500	1.0	-
Zn	30 - 200	10 - 50	0.2	0.5
Mn	20 - 75	5 - 30		
Al	35 - 150			
Pb	2 5	2 - 8	0.1	0.2
Suspended solids	200 - 900	25 - 100	15	25
pH	2.8 - 4.0	3.0 - 4.5	9.5 min	6.0



Source: Kuit, W.J., CIM Bulletin, Dec. 1980

TABLE 2

Acid Mine Water Treatment at "Les Mines Gallen" Project, Noranda, Quebec.

Acid Mine Drainage		Discharge to Environment	(Federal Guideline)
Fe 865 ppm	Treatment plant	0.75	3.0
Zn 530 ppm		0.45	0.5
Cu 0.26 ppm		0.04	0.15
pH 3.5		6.5 - 9.0	5.5 - 9.5
	Sludge Disposal		

Source: Lecuyer, N., CIM Bulletin, March, 1983

The above examples are representative of active mines operated by large and responsible companies, each of which have extensive environmental air and water quality programs at numerous mines in Canada. Throughout Canada, though, there exist numerous mine properties which operated and then were closed prior to the introduction of Federal and Provincial environmental controls. Acid mine drainage and acid tailings seepage is a perennial problem at those which mined and milled sulphide-ores (e.g. Hawley, 1972). Many are characterized by geographic isolation, unknown ownership or owned by relatively small companies. Abatement of acidic effluents at such mines is a difficult and expensive problem; certainly, the cost of abatement through the installation of water treatment plants is beyond the resources of smaller owners and represents a severe financial cost to the larger companies. The capital costs involved in acid water abatement may not necessarily be high; but operating and maintenance expenditures in perpetuity, even for small scale treatment units, can be, particularly where the inactive or abandoned property is isolated from habitation and services.

One such example is that of abandoned nickel-copper mine in Ontario, where extensive nickel contamination and acid water was arising from the tailings disposal area. Because of the mine's isolation, installation of even an automatic lime-feeder plant was not considered feasible, either by the owners or the Provincial government; also there was no single source or outlet of contamination from the tailings disposal area. The area had been formed by constructing two dams from the mainland to an island in a lake and then infilling over a number of years. Seepage did tend to follow one major course through the disposal areas, and exit through a constructed "reclaim" pond into the adjacent lake. The complexity of the seepage patterns was further enhanced by a) the fact that both dams were constructed as pervious dams (no longer permitted under new regulations) and that one of the dams had a failed section.

Approximately 13.6 million litres of water enter the 18 ha tailings area each year (from net annual precipitation). Given the dam location in relation to local topography and bedrock, that water exits the tailings through surface runoff to the failed portion of the dam and through seepage out of the area on the water table. The quality of the seepage water is depicted in Table 3. From discussions between concerned parties it was concluded that the only reasonable technology available was that of water diversion. Hence, the tailings management program developed in 1981 involved the deflection of all surface runoff waters from adjoining undisturbed land, the regrading of the tailings surface and the construction of drainage ditches within the tailings disposal area. The purpose of the latter was to ensure rapid removal of precipitation from the tailings surface and not permit precipitation or standing water to enter the tailings mass and metal dissolution to occur. Such work was undertaken in 1981 while the tailings surface was revegetated in a two-year program, 1981 and 1982. As yet it is too soon to evaluate the outcome of the environmental control program.

REVEGETATION OF ACID SULPHIDE TAILINGS

Despite extensive laboratory and field studies by many researchers, few common treatments and methods have emerged for revegetating tailings. Each tailings area requires individual investigation in order to devise the most efficient means of revegetation. The revegetation studies described below are representative of a number of studies undertaken in eastern Canada in recent years which illustrate the need for flexibility in establishing vegetation on tailings which differ widely in their physical and chemical properties.

TABLE 3

Seepage water and local water quality at a nickel-copper property

	Lake Sample Point (Distant)				"Reclaim Pond" Sample Point			
Sample Time	Ni*	Cu+Zn+Pb	Fe	pH	Ni*	Cu+Zn+Pb	Fe	pH
July 1980	.25	.03	.01	7.5	19	.30	.30	4.0
Sept 1980	.18	.03	.01	7.5	21	.09	.02	3.8
June 1981	.30	.10	.06	7.6	9.6	.10	5.0	5.4
July 1981	.12	.003	.07	7.5	7.5	.22	.75	5.8
Nov 1981	.25	.10	.28	7.2	14	.11	4.6	4.9
May 1982	.24	.08	.19	7.2	2.7	.05	.68	6.8
June 1982	.26	.05	.28	7.8	4.1	.06	.26	6.9
July 1982	.26	.06	.31	7.8	3.8	.08	1.1	7.1
Oct 1982	.27	.05	.17	7.3	6.4	.08	2.5	6.7

All data in ppm except pH

*Provincial guidelines on acceptable Ni vary between 0.5 and 1 ppm depending upon type and frequency of sampling.

Agricultural limestone is the most widely used material for acid neutralization in tailings. Other materials used occasionally have included rock phosphate, paper mill sludges, fly ash, sewage sludge, anhydrous ammonia and silicates. Such uses have remained experimental or limited to very local use. A major problem in the use of all neutralizing materials is the inability to accurately predict field requirements by chemical analysis.

Extensive work has been undertaken on coal mine spoils and acid sulphate soils to determine the relationships between pH, acidity, sulfur content and the requirement for agricultural limestone (e.g. Smith and Sobek, 1978; Berg, 1978; Dost and Breeman, 1982). By contrast, hard rock tailings containing sulphide materials have received less attention (Sorensen et al, 1980). For most practicing reclamationists therefore, agricultural limestone requirements must be determined by plant assay of amended materials (Table 4). Such assays have revealed the tremendous variation in agricultural limestone requirements of tailings samples, within and between sites, and the total lack of correlation between pH data and actual requirement levels.

Plant assay of tailings under controlled environment conditions is a simplistic, practical and effective approach for the mining industry faced with tailings reclamation (Watkin and Watkin, 1982).Such evaluation takes approximately 100 days compared to the 18 to 24 months required for field evaluation. Within this period, the evaluation determines precise agricultural limestone requirements, optimum levels of fertilizer application and reviews the adaptability of a large number of species to general site conditions. Further, this technique can quickly determine if seeding directly into tailings is a practical option or whether other options, such as the spreading of overburden have to be utilized.

TABLE 4. Sample pH within and between three tailings disposal sites and agricultural limestone (tonnes/hectare) required in order to obtain plant growth on sample material

SITE 8 Sericite schist contaminated with pyrite			SITE 9 Sulphide tailings (nickel -copper)			SITE 10 Sulphide tailings (lead-zinc)		
Sample	pH	t/ha	Sample	pH	t/ha	Sample	pH	t/ha
2	3.0	11	1	7.0	0	1	2.1	134
3	2.6	11	2	7.0	0	2	2.4	180
4	2.8	11	3	3.4	67	3	2.2	23
5	2.8	11	4	3.3	45	4	2.2	180
6	3.2	11	5	8.0	0	5	2.2	180
7	2.4	11	6	7.8	0	6	2.1	45
9	2.9	11	7	7.6	0	7	2.2	180

10	2.6	11	8	3.0	180+	8	2.3	180
12	3.0	11	9	7.7	0	9	5.1	180
13	2.8	11	10	2.7	23			
14	2.4	11	11	2.7	23			
15	2.4	11	12	3.0	45			

+ No plant growth, higher rates not investigated

At Site 9 (Table 4) for example, the evaluation of the nickel-copper tailings, using the above technique and the reclamation of approximately 18 ha were both completed within a 19-month period. A similar time frame is anticipated for the reclamation project presently underway at Site 8. In contrast, the high agricultural limestone requirements exhibited by Site 10 samples showed that direct seeding of tailings was not an acceptable technique. Reclamation now in progress involves extensive regrading of the tailings disposal area and placement of overburden which will then be seeded. Such activity, because of financial considerations, is taking place over an extended time period.

At another site (No. 7), lead-zinc tailings, assaying 32-35 per cent sulphur, studies have shown that particular combinations of agricultural limestone and triple superphosphate are critical to plant establishment and persistence. Agricultural limestone incorporated at 90 t/ha resulted in only marginally acceptable growth of a grass-legume mixture at a commonly selected fertilizer level. An increase in agricultural limestone to 135 and 180 t/ha. produced only slightly extra plant growth. When the triple superphosphate portion of the basic fertilizer application was increased four-fold (from 1121 to 4484 kg/ha) acceptable levels of legume growth were obtained at 135 and 180 t/ha agricultural limestone (Table 5). Field trials are now required to confirm the experimental results before consideration is given to a site reclamation program.

As already briefly described, technology for the treatment of acid mine drainage and acid tailings seepage has received much attention. In meeting the prescribed effluent standards large volumes of iron hydroxide sludge are produced. Disposal of the water treatment waste is a serious problem, not the least, the continuing need for large disposal areas (e.g. see Ackerman, 1982).

TABLE 5. Plant growth (g/dry on high sulphide (32-15% S) lead'-zinc tailings

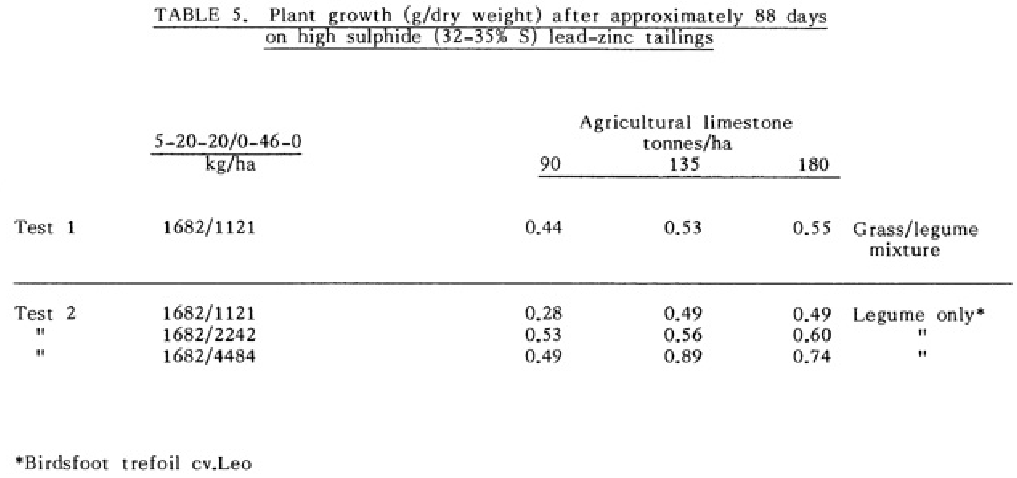


TABLE 5. Plant growth (g/dry weight) after approximately 88 days on high sulphide (32-35% S) lead-zinc tailings

	5-20-20/0-46-0 kg/ha	Agricultural limestone tonnes/ha			
		90	135	180	
Test 1	1682/1121	0.44	0.53	0.55	Grass/legume mixture
Test 2	1682/1121	0.28	0.49	0.49	Legume only*
"	1682/2242	0.53	0.56	0.60	"
"	1682/4484	0.49	0.89	0.74	"

*Birdsfoot trefoil cv.Leo

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TABLE 6. Partial composition of two acid water treatment sludges

	SITE 1 Acid Water Treatment Sludge	SITE 2 Acid Water Treatment Sludge	SITE 3 Water Treatment Sludge
pH	7.7	8.1	7.1
E.C. (micromhos/cm)	1,450	2,000	1,250
Phosphorous ppm	1	5	14
Potassium ppm	12	8	76
Magnesium ppm	200	200	112
Calcium ppm	2,000	13,600	2,000
Manganese ppm	3,430	-	350
Copper ppm	1,115	-	75
Zinc ppm	23,250	-	31
Lead ppm	4	-	–
Boron ppm	650	-	167
Iron ppm	-	-	1,929

N.B. All reported values should be considered as indicative only, not absolute; various per cent values have been converted to ppm on basis 1% = 10,000 ppm.

At two mines in eastern Canada, preliminary investigations have been carried out to determine, what use the AWT sludges may have in land reclamation. Partial composition of the two materials is presented in Table 5, Sites 1 and 2. Plant assay trials have shown that both sludges may be successfully vegetated. (Table 7, Site 2 and Table 8, Site 1). Laboratory and field experimentation have confirmed that AWTS-Site 2 may be used to amend acid leached rock (pH 2.9) created by uranium mining. More extensive sampling and evaluation is required of Site 1-AWTS before field trials on its use as an amendment for pyritic waste rock is attempted. Despite the high vegetation potential of the two sludges, several practical difficulties will have to be overcome, particularly that of transference from present disposal areas to on-site locations requiring revegetation. It is possible that full utilization of the sludges as reclamation materials will be dependent upon the redesign of current disposal practices.

Water treatment sludge (Table 6, Site 3), resulting from an antimony mine operation, has also been investigated, both as an overburden and an incorporated amendment on what appear to be arsenic-contaminated tailings. Initial plant growth trials have shown that the sludge is an acceptable overburden material but that incorporation into antimony tailings actually decreases plant growth below that recorded on non-amended tailings.

One of the major reasons for revegetation of tailings and other wastes is that a vegetative cover, through evapotranspiration will reduce the amount of precipitation incident upon an area or site from eventually becoming subsurface drainage. Evapotranspiration must occur, and theoretical values can be calculated of the amount returned to the atmosphere. The author though,

TABLE 7. Plant growth on acid leached waste rock amended with agricultural limestone and acid water treatment sludge[1,2]

	Grams dry weight after 101 days
Acid leached waste rock (pH 2.6)	
+ 0 t/ha agricultural limestone	0.28
+ 11 t/ha agricultural limestone	0.26
+ 22 t/ha agricultural limestone	0.42
Acid leached waste rock (pH 2.6) + acid water treatment sludge (pH 8.1)	0.52
Acid water treatment sludge	0.54

1. All treatments received 840 kg/ha 5-20-20 + 1120 kg/ha 0-46-0
2. Seeds mixture: birdsfoot trefoil var. Leo and creeping red fescue cv. Reptans

TABLE 8. Growth of four species (grams dry weight/ replicate after 49 days) on acid water treatment sludge amended with fertilizer only

Species	Plant weight
Birdsfoot trefoil var. Leo	0.89
Crownvetch var. Chemung	0.54
Creeping red fescue var. Reptans	0.79
Tall fescue cv. K31	1.38

is not aware of any sound scientific field data which would enable an accurate estimate of by how much seepage quantity (and quality) is affected following the establishment of a vegetation cover. There are several reasons for the lack of reliable data.

1. A number of experiments reported in the literature can be faulted for poor experimental design, creation of too artificial drainage conditions and the establishment of poor vegetative cover on the test areas.
2. Where complex management schemes have been imposed upon a tailings disposal area (e.g. Brooks, 1981) or coal mine affected area (e.g. Herrmann, 1980), it is virtually impossible to determine what proportion of the change in drainage is due to evapotranspiration or to area water management schemes such as diversions of fresh water entering the area.
3. The complex management schemes have possibly not been in operation for a sufficient period to obtain adequate data on area hydrology and water quality patterns.

Over the last 10 years reclamation of sulphide tailings in eastern Canada has made considerable progress. It is true to say that an understanding of the factors affecting plant growth on these types of tailings is very far from being understood in chemical and biological terms. From a management viewpoint, though, it has developed to the stage where costly and unsuccessful reclamation programs can be avoided.

Where large scale reclamation programs are or have been undertaken, they have been initiated with confidence that success will result considering that biological, not engineered, systems are being created. The need to form a reclamation team comprised of personnel with expertise in agronomy, engineering, hydrology, water quality and milling is a now recognized imperative.

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