Manual of Methods Used in the Revegatation of Reactive Sulphide Tailings Basins

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PREPARATION OF A MANUAL OF METHODS USED IN REVEGETATION OF REACTIVE SULPHIDE TAILINGS BASINS

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SUMMARY

The Land Directorate of Environment Canada has estimated that by the year 2000 A.D. over 172,000 hectares of land would be disturbed by the mining industry. Of all the land used by the industry, the disposal areas for the waste from the benefication of sulphide ore have the greatest effect on neighbouring ecosystems. The sulphide tailings disposal areas, estimated at over 9,000 hectares by the 1984 report of Canmet, DSS 8032-8, impact the atmosphere, hydrosphere and lithosphere if left uncontrolled. To date, the only environmentally sound measure that has some remedial action on all three of the components of the ecosystem is reclamation by the use of vegetation. It should, however, be mentioned that the effect of vegetation on acid generation has not yet been realized.

Even though each sulphide tailings area has its own unique method of approach, seed mixture, fertilizer analysis, planting schedule, etc., there are a number of components, technical questions, problems and solutions that are common to all.

This manual provides as comprehensive a methodology as possible describing procedures for preparation, neutralization, fertilizing, seeding and follow-up maintenance, if required, for revegetation of reactive sulphide tailings disposal areas in Canada.

The manual introduces some fundamental basic building blocks which will assist the reader in discussions with agriculturalists and other consultants experienced in the art of reclamation. The building blocks are:

0 The concept of macro and micro-climate and their effects

0 Introduction to the nature and physical and chemical properties of soil

0 Types of materials (overburden, waste rock and tailings) encountered at a mine

0 General effects of lime, fertilizer and other amendments on soils and tailings

From these basic concepts a tailings revegetation program is developed. The site specific program covers a two to three year time frame covering a minimum of at least two growing seasons. It is divided into seven segments:

- Evaluation
- Program Planning
- Site Preparation
- Lime and Fertilizer
- Vegetation Selection
- Mulches, Chemical Stabilizers and Other Amendments
- Establishing Vegetation

The manual describes and illustrates some of the more common agricultural equipment and implements required to prepare, seed and maintain mine waste areas.

A brief discussion of the problems associated with establishing revegetation programs north of 60 degrees latitude is presented. As well, the new avenues of research presently being pursued in Canada and elsewhere are described.

Case histories are appended, reprinted from the May 1984 Canmet Tailings Management Study by the courtesy of Energy, Mines and Resources Canada. The case histories outlined include the following:

- Reclamation at Cominco's Bluebell and Pinchi Lake Mines
- Reclamation at Falconbridge Operations
- Reclamation Program on Inco Limited's Tailings Areas
- Reclamation at Noranda's Operations.

SOMMAIRE

Selon la Direction générale des terres d'Environnement Canada, avant I'an 2000 ap. J.-C., l'industrie minière aura exploit6 plus de 172,000 hectares de terre. Parmi toutes les terres qu'utilise l'industrie, ce sont les dépôts de résidus provenant de I'entrichissement du sulfure qui nuisent aux écosystèmes avoisinants. Les dépôts contenant des résidus, dont la superficie totale serait de 9,000 hectares selon le rapport du CANMET, DSS 8032-8, effectué en 1984, causent du tort a I'atmosphère, a I'hydrosphire et a la lithosphère lorsqu'aucune mesure de redressement n'est prise. Jusqu'à maintenant, la seule mesure qui soit favorable à l'environnement et aux trois composantes de l'écosystème est de rihabiliter des sites degrade's en semant des végétaux. 11 fault mentionner, cependant, qu'on n'a pas encoure prouvé que ces végétaux enrayent la production d'acides.

Bien que chaque dépôt contenant des risidus de sulfure soit aménagé d'une façon unique, c'est-a-dire en milangeant des grains, en analysant la composition chimique des fertilisants, en semant selon un horaire, etc., ils partagent tous plusieurs composants, questions techniques, problèmes et solutions.

Le présent manuel fournit une mithodologie aussi complète que possible décrivant des procédés de preparation, de neutralisation, de fertilisation, d'ensemencement et d'entretien futur qui pourraient être nécessaires à la restauration, au Canada, de la couche végétale des dépôts contenant des déchets de sulfure réactifs.

11 présent certains concepts de base qui aideront le lecteur à discuter avec des agronomes et d'autres experts en rihabilitation des sites dégradés. Ces concepts sont les suivants:

- Le concept des macroclimats et des microclimats, et les effets de ceux-ci.
- L'introduction à la nature et aux propriitds physiques et chimiques du sol.
- Les genres de matiriaux (morts-terraints, stérile et résidus) que l'on trouve dans une mine.

- Les effets généraux du chaux, des fertilisants et d'autres substances sur les sols et les résidus.

A partir de ces concepts de base, un programme de restauration de la couverture végétale à été créé. Ce programme s'échelonne sur une période de deux à trois ans, soit I'équivalent d'au moins deux saisons de croissance. I1 se divise en sept parties:

- L'évaluation
- La planification du programme
- La préparation du site
- Le chaux et le fertilisant
- Le choix de la vegetation
- Les paillis, stabilisateurs chimiques et autres substances ajoutées.

Le present manuel dicrit et donne des exemples de certains des appareils agronomes les plus communs nicessaires à la preparation, l'ensemencement et l'entretien des dépôts de résidus provenant des mines.

On présente un bref aperçu des problimes associés à la restauration de la couverture végétale au nord de 60 degrés de latitude. De plus, on décrit les nouvelles recherches que l'on effectue présentement au Canada et ailleurs.

On joint à ce manuel des cas tire's de la Recherche en administration des résidus effectuée par le CANMET en mai 1984, et réimprimés par Energie, Mines et Ressources Canada. Voici certains de ces cas:

- La réhabilitation des sites dégradés des mines Bluebell et Pinchi Lake de Cominco.

- La rdhabilitation des sites d&grade's de Falconbridge.

- Le programme de réhabilitation des sites dégradés utilisé au dépôt de résidus d'Inco Limited.

- La réhabilitation des sites dégradés de Noranda.

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INTRODUCTION

I.B. Marshall of Environment Canada estimates that by the year 2000 AD. over 172,000 hectares of land would be disturbed by the mining industry of Canada. The impact of mining has not only been felt on the land in use but also on the neighbouring environment. This is especially true of the 9,000 hectares of sulphide tailings (gangue of pyrite, marmatite, marcasite, arsenophrite, pyrrhotite, etc.) which are presently operational or abandoned in Canada. The impact of the disposa1 areas can be felt on all components of the ecosystem. Fugitive dust storms emanating from the dam surface cover vast hectares of the surrounding districts in acidic fines. They have been known to stop traffic on adjacent highways. Seepage and non-treated effluent discharge from sulphide tailings areas can chemically affect the ground water system as well as the surface water. Organic residues from the flotation chemicals as well as cyanide solutions used either as a depressant or in the cyanidation process of gold barring material could affect the hydrosphere if not controlled. Iron precipitation in its various forms such as yellow boy have a negative affect on adjacent fresh water streams as well as on the local aesthetics. Due to their fine nature tailings can also affect local receiving streams by siltation. Finally, there is the mere presence 'in the wilderness of reddish-brown barren disposal areas denuded of all vegetative life forms.

Even before fashion dictated, the mining industry of Canada was concerned with their effects on the Country's land resources. But in the early days, success stories were few; notably the abandoned roasting yards of Copper Cliff and the McIntyre and Hollinger Parks in Timmins. It should be noted that the Timmins efforts were not completed on sulphide wastes areas but on siliceous gold tailings. To its credit, Inco's agricultural department continued to search for a solution on how to vegetate sulphide (reactive) tailings areas. The other large Canadian companies, noticeably Noranda and Cominco, moved into the reclamation scene in the late 60s. Noranda utilized the method successfully developed by Inco to reclaim their sulphide disposal areas and attempted to vegetate the abandoned Waite Amulet tailings area. Although a few plants survived, as they do today, the attempt was a failure. After another attempt with the same disasterous results the following year, Noranda came to the conclusion that the Waite Amulet tailings area was not amenable to the Inco revegetation formula.

After years of experimentation on the tailings area and in the growth rooms of the University of Guelph, Noranda had developed its own method of revegetation tailings areas by direct seeding into the sulphide waste. The Waite Amulet tailings areas were successfully revegetated between 1978 and 1980. Cominco is able to tell a similar story of the search to unlock the secret code to predict which amendment and how much is needed to guarantee success. Like so many before and so many after, each came to the conclusion that each tailings disposal area is a unique, complex and distinctive body and what would work on one would not necessarily work on the other.

Both Inco Limited and Noranda Minerals Incorporated have captured their progress and approach to revegetate a sulphide tailings disposal area on film. The Inco film is titled “Rye on the Rocks”, while the Noranda film is titled “To Make a Wasteland Green”.

Even though each sulphide tailings area has its own unique method of approach, seed mixture; fertilizer analysis, planting schedule, etc., there are a number of components, technical questions, problems and solutions that are common to all.

The purpose of this manual is to provide as comprehensive methodology as possible describing procedures for preparation, neutralization, fertilizing, seeding and follow-up maintenance, if required, for revegetation of reactive sulphide tailings disposal areas in Canada.

Prior to proceeding, it should be realized that a revegetation program is a biological system subject to failures as well as successes. The causes, such as climatic conditions, cannot necessarily be predicted. It is the wish of the authors that the information contained in this manual will increase the successes.

CLIMATE

Climate has a pronounced effect on Canada. It molds its people and it identifies its distinct geographic zones of natural vegetation. Climatic knowledge can be a useful tool to provide some indication of the suitability of various plant species, planting schedules and, in some cases, the specific locations to commence the actual seeding program.

To know that Canada has a temperate climate with cold winters and warm summers is not enough. An understanding of the macro-climate (the general climatic environment of the region) and the micro-climate (the general climatic environment of the specific area in question) is required to formulate a successful reclamation program. Data on the macro-climate can be obtained from established Environment Canada meteorological stations, the Atlas of Canada, or from the generalized maps appended to this document. Data on the micro-climate can be obtained from local knowledge, and in some cases, if the mine is fairly new, from information obtained in the environmental impact statement submitted to obtain the original approval. The micro climate is mainly a product of the nature of the waste, method of deposition and variations in local relief and topography.

The climatic components of prime concern are:

Temperature

The importance of temperature is almost self-evident. Soils derives its heat almost entirely from the sun. The rate of seed germination, seedling growth, and root growth is dependent on soil temperature. Below a certain soil temperature, plant growth is negligible, and once the temperature rises above a certain point which varies from plant to plant, growth tapers off. Therefore, the three components of temperature to be aware of are:

- Frost-Free Period - defined as the period between the last occurrence of 0°C in spring and the first occurrence of 0°C in the fall.

- 0 Growing Season - defined as the period between the first occurrence of a mean daily temperature of 5.5°C in the spring and the last occurrence of a mean daily temperature of 5.5°C in the fall.

- 0 Mean Daily Temperature - defined as average daily temperature for that specific date.

These components will have an influence on the choice of species and the planting time. Planting time now becomes a window. The early window is when the frost is out of the ground and the soil temperature is capable of germination but not too hot to limit plant growth. The late window is also narrow and commences when the soil has cooled sufficiently so as it's not too hot or cold to inhibit growth.

Precipitation

Of equal importance as temperature is precipitation, which includes rain and snow. Heavy winter snowfalls and heavy spring rains can delay access to the tailings for planting. A light snow cover with a sudden warming period during winter may cause winter kill of sensitive plant, species and severe plant stress in others. Heavy rain events can lead to severe erosion or flooding conditions. The lack of summer rains can cause predictable drought stress as a result of the semi-arid conditions common to sulphide tailings areas. One can then conclude that precipitation, the amount, and time of the event may influence the choice of vegetation and time of planting.

Wind

The influence of wind is site specific, and it is not always a problem. Strong or consistent prevailing winds can, in certain circumstances, lead to sandblasting and lodging of plants and erosion and dehydration of the surface tailings material. Young seedlings are particularly susceptible to uprooting or to the stress of sandblasting by wind. The uniform texture of sulphide tailings are ideal candidates for erosion although this is more a problem associated with the silicious gold tailings. The moisture content and speed of the wind will influence drought conditions, evaporation and transpiration.

If wind is found to be problematic, one should stabilize the tailings surface until the vegetation program can form sufficient cover and root growth to resist its effects. Chemical surface stabilizers, mulches, snow fences, windbreaks, water sprays and strip cultivation are some of the aids that can provide temporary protection. Selecting plant species which grow rapidly and are drought tolerant should also be considered. The effects of wind and sandblasting on plants can also be minimized by commencing planting in a protected area or close to the source of the prevailing wind (i.e. if the prevailing wind is from the southwest, then start the planting at the southwest portion of the tailings area) and gradually extend the vegetative cover into more exposed and open areas.

PHYSICAL AND CHEMICAL PROPERTIES OF SOILS

Soil materials are formed by the breakdown and weathering of organic and mineral materials to form both new and rearranged products. This breakdown is a function of chemical, biological and mineralogical conditions. Tailings are finely ground rock material which have been rejected as part of the milling process. As tailings have a similar parent material to soils, namely rocks, and have been comminuted to similar size fractions, one would surmise that tailings would react in identical ways to soils. There is an increasing body of evidence and experience which both support and negate this supposition. It is then necessary to understand to some degree the nature of soils and tailings.

Agricultural soils are a heterogeneous mixture of particles containing inorganic mineral material; gravel, sand, silt and clay, organic material in the form of undecayed and decaying plant tissue and microorganisms. The proportions of each have a very marked bearing upon the physical and chemical properties of the soil.

Physical Properties

The proportion of each of the mineral particles determines the texture of the soil. The higher the clay content, the finer or heavier the texture the soil will be. Conversely with increasing amounts of sand (2.0 - 0.5 mm), the soil becomes progressively coarser or lighter in texture (i.e. sandy clay, sandy clay loams, sandy loams to sands). With increasing amounts of silt, the soil progresses from clay through to silt loams to silt.

These particles differ in their physical characteristics and in their mineral composition. Sand is composed of loose, single grained particles (Table 1). They are visible to the naked eye and are not sticky nor plastic. They consist mainly of quartz and some feldspars and contribute mainly to the "openness" or porosity of the soil. The silt particles are smooth and only slightly cohesive. They are visible only under a microscope and contain mainly quartz and feldspars. Their size contributes to the capabilities of a soil to retain moisture. Clay particles are very small (< 0.002 mm in diameter), contain mainly clay minerals, and are sticky and plastic when wet, and hard and cohesive when dry. Clay minerals contribute to moisture and to the chemical properties.

Structure of a soil is the arrangement or grouping of the individual particles in units. The arrangement or grouping has a tremendous influence upon the water relationships. The grouping may be specified in terms of their size, shape and stability. The structure may be destroyed by improper timing of tillage. particularly when the soil is wet and easily compacted.

Organic matter and microorganisms play a very important role in the development of the soil structure. As the plant roots, top and other organic compounds decay, a "sticky" substance is released which becomes the binding material for the mineral particles.

The microorganisms and other organisms such as earthworms, fungi, bacteria, and a very wide variety of very small organisms are present and which contribute to the breakdown and to the development of a soil structure by secretions of gummy substances.

Particle density of soils is the ratio of density of the solids to that of water. Bulk density is the weight per unit volume of the soil. Both are used to indicate and calculate the porosity of the soil and are indicators of the degree of compaction of soils. The closer the two values are, the more compact the soil is. Particle dknsity values in soils are about 2.65 g/cm^3, and bulk density about 1.5 g/cm^3. The range between the two values is generally less in tailings than in overburden (Table 1).

Porosity of a soil is a measurement of the pore space between the soil particles. It is calculated from the bulk density and the particle density values. It is a measure of the ability of a soil to hold and transfer moisture. The smaller the pore space, the greater the water holding capacity will be. Smaller pores hold water under greater tension than larger pores (due to the greater curvature of the water meniscus).

$$(\%)\ \text{Porosity} = \frac{\text{Particle Density} - \text{Bulk Density}}{\text{Particle Density}} \times 100$$

The balance between the amount of air and water in the pore space of soil is an important factor in plant growth. Air must be present to facilitate the exchange of carbon dioxide given off by the plant roots and the oxygen required by the plant. Water must be present to supply the requirements of the plant and for transfer of nutrients to the plant roots. A saturated soil, therefore, will contain too little oxygen, and a dry soil will contain too little water for growth for most plants.

These two extremes are termed field capacity (the maximum amount of water a soil can hold against the pull of gravity) and wilting point (water trapped on the surface of soil particles). The scale used to measure the water content is in units of pressure and ranges from 1.0 (field capacity) to 15.0 bar (wilting point). The pressure values for field capacity and wilting point will vary among soils and depend upon the texture. The finer the texture the greater will be the pressure needed to remove the moisture. Generally, soil field capacity is rated as 0.3 bar and wilting point at 15 bar. The field capacity of tailings 0.1 bar is a reasonable indicator of field capacity.

The water content of a soil or waste material can be determined by weighing a sample of the material before and after drying at a temperature of 105 F. It is expressed as % of the original sample weight.

Infiltration rate of water into a soil is an important consideration in that it measures the ability of the soil to “take in” the rain. The rate with which a soil will take in surface moisture is a function of the porosity and the level of saturation of the soil. It can be measured in the field and in the laboratory by measuring the rate of fall of water over time of a standard height of water.

Table 1. Physical Characteristics of Soil Particles. +

Name	Diameter (mm)	Physical Character	Mineral Composition
Sand	2.0 to 0.05	Loose, single grained not sticky	Mainly Quartz
Silt	0.05 to 0.002	Smooth, slightly cohesive	Mainly Quartz and Feldspar
Clay	Less than 0.002	Sticky and plastic when wet, hard and cohesive when dry	Clay minerals Some Quartz

+ Adapted from Bradshaw & Chadwick Restoration of Land
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Chemical Properties

The Cation Exchange Capacity, acidity, mineralogy, organic matter and microbiological activity will influence the success of vegetation.

Cation Exchange Capacity (CEC): The CEC is a measure of the ability of a soil to hold and to exchange the necessary mineral elements for growth. The clay mineral fraction along with the organic matter are the two components of soil that contribute to the exchange capacity which is measured in meg/100 g of soil. It is an indicator of the sites available for the retention of positively charged ions. A sandy soil would have a CEC of about 6 meg/ 100 g whereas the clay fraction could be as high as 300 meg/100 g of soil.

Acidity: There are three forms of soil acidity: Active, Reserve and Potential.

Active acidity is measured as the H^+ ion concentration in the soil solution. Here, the degree of acidity or alkalinity is indicated by a numerical pH value ranging from 1 to 14. Generally, soils will range from 5.0 to 8.0. Soils or wastes below or above this range contain too little calcium or an excess of sodium for plant growth. The measurement of pH is normally used to indicate the acidity-alkalinity of'soils. The value is highly correlated with base exchange, calcium, magnesium levels and toxicity levels of aluminum and manganese.

Reserve or exchange acidity refers to the hydrogen ions held on the negatively charged sites on the clay mineral. The hydrogen ions are exchanged for calcium and other mineral elements. The exchangeable H^+ ions, therefore, determine the buffering capacity of the soil. It can be used to calculate the lime requirements. It is determined by direct titration.

Potential acidity refers to the acidity which arises as a result of the oxidation of compounds. For example, where high proportions of pyrite occur in tailings and in the presence of oxygen and water, the oxidation of sulphides produces sulphuric acid. This type of acidity does not occur to any great extent in agricultural soils. It is, however, far the most difficult to determine and control, and one that presents the greatest problem in many tailings pits.

The acidity or alkalinity of a soil has a very profound effect upon the availability of both macro and minor mineral elements. Therefore, the pH measurements are ideal indicators of the increase and decrease in the solubility of nutrients and the activity of desirable and undesirable microorganisms.

Generally, when soils have a pH above 8, the major problem will be that the micronutrients iron,. manganese and boron become difficult for the plant to absorb. In acid soils (below pH 5.0) the concentration of aluminum, manganese, iron, copper and zinc may become toxic to plants. Molybdenum becomes limiting in acid conditions in many soils. Also, in soils below pH 4.0, microorganisms become involved in the oxidation of pyrite. Iron, phosphate and calcium play important roles in the availability of phosphorus. In acid conditions, aluminum and iron combine with phosphate to form an insoluble compound. In alkaline soils, the phosphate is combined with calcium to form an insoluble compound. Only in the range from 5.6 to 7.6 is phosphorus in a form that can be used by plants.

Some Minerals: Vegetation requires relatively large amounts of nitrogen,‘ phosphorus and potassium. These are called primary nutrient elements. Calcium, magnesium and sulphur are secondary nutrient elements. Manganese, boron, zinc, copper and molybdenum are considered trace elements. Each of these minerals play a distinct role in physiological functions of the plant. Thus a constant supply must be available from the soil.

Generally, grasses and legumes used in agriculture require larger amounts of each than those found growing under “natural” condition. This is due to the fact that the agricultural species have been “bred” for high production, and high production requires high levels of nutrient. The “natural” species have become through time adapted to the existing soil and environmental conditions and’grow and produce to a level consistent with the availability of nutrients.

Nitrogen is generally the most important element required for growth and is nearly always in short supply. It is usually taken up from the soil solution by the plant in the form of nitrate. Nitrogen in the soil arises from the decay of organic matter and is not derived as part of the weathering process. Microorganisms decompose the plant and animal 'tissue in the soil, and in so doing, excrete ammonia, some of which is oxidized to nitrate. The ammonium is held on the exchange, whereas the soluble nitrate unless absorbed by the plant is lost by leaching.

A second source of nitrogen for plant growth is the gaseous nitrogen in the air. This nitrogen is made available through the activities of nitrogen-fixing microorganisms called Rhizobium. The ability to fix atmospheric nitrogen is particular to legumes. The rhizobia live in symbiosis with the legume plant forming nodules on the root hairs, obtaining nutrition from the plant, taking nitrogen from the air and reducing it to ammonia. The amount of nitrogen fixed by rhizobia via legumes varies and ranges from 50 to 200 kg/ha/yr. The amount fixed is related to the factors which induce vigorous growth of the plant (i.e. temperature moisture, etc.).

For the most part, each legume species requires a specific species of rhizobia and because the legume chosen will be "new" to the overburden or tailings, the rhizobia must be introduced. This is accomplished by purchasing seed that has been "pre-inoculated" with the correct rhizobia or purchasing the correct inoculant and treating the seed.

Phosphorus is an important mineral element in plant nutrition. It is taken up by the plant in the form of $H_2PO_4^{-1}$ or HPO_4^{-2} phosphate ion. Phosphorus is chemically active and will combine with iron and aluminum in acid soils and calcium in alkaline soils forming insoluble compounds. Thus, much of the added phosphorus could be "locked up" and unavailable to plants unless the pH is adjusted to 'hear neutral. Even under these circumstances, however, some phosphorus becomes available slowly.

Phosphorus does not move in the soil. Thus losses due to leaching are nonexistent. Indeed the immobility of phosphorus may result in low supply to the plants. In order for the plant to take up phosphorus, the phosphate ion has to be within one or two mm. of the root. Therefore, in order to insure a supply of the phosphate ion in a form that can be used by the plant, the pH of the soil must be kept near 6.5 and in the root zone of the plant.

Potassium is essential for many of the biological processes in plants. It is held on the exchange of the clay and on the organic matter. In soils with a low clay content or low organic matter, applied potassium is readily lost through leaching.

Calcium is a dominant cation in the soil and is an essential element in the physiology of plants in that it takes part in the formation of cells and synthesis of proteins. In addition, it is the element which influences the acidity-alkalinity of soils. This, in turn, determines the availability of many nutrients. It can be held on the exchange of clay particles. It is soluble and readily available. As well, calcium is an important element in determining the structure arrangement of clay particles. Calcium is stored on the surface of the clay particles. Under wet condition, the structural arrangement of the clay may be destroyed which, in turn, releases the calcium into the soil solution. In this soluble state, much calcium can be lost through leaching. Estimates of up to 150 kg/ha/yr may be lost in temperature moist climates (Bradshaw and Chadwick). Agriculture limestone is the most commonly used source of calcium.

Magnesium is an essential element in the photosynthetic process being a' constituent of the chlorophyll. It is not needed in large amounts. It occurs in clay minerals and can be extracted easily by plants. The content of magnesium in grasses often is low and of concern in the production of livestock. Dolomitic limestone contains magnesium.

Sulphur is also an essential element in plant nutrition. It is essential for the synthesis of amino acids in plants. Its presence in soils is rarely a problem in industrial areas. Here, sulphur is supplied from the air as sulphur dioxide. Usually, adequate sulphur is obtained when superphosphate fertilizer is used. Deficiency could occur when high analysis phosphate fertilizers are used.

Trace Elements: Traces of elements such as iron, manganese, boron, zinc, copper and molybdenum are needed for plant nutrition, but in small amounts ranging from 0.5 to 0.005 ppm. All of these elements play roles as catalysts in enzyme systems. Molybdenum is required for nitrogen utilization and is essential for nodulation of legumes. The absence and, therefore, the need for molybdenum occurs under acid soil conditions. It can be supplied in the form of sodium molybdate.

In general, plant deficiency symptoms of these trace elements become evident following the increased use of the major elements. They become the limiting factor in production.

Other elements such as sodium, iodine, cobalt, and selenium are usually not essential for plant growth, but are necessary for animal production. However, some species of plants are tolerant to concentrations of sodium which occurs in alkaline soil conditions.

An excess of these trace elements on the other hand can result in a toxic condition. Copper, boron and zinc can be very toxic and become so in acid soil conditions. In addition, other metals not necessary for plant nutrition, nor needed by livestock are lead and nickel. The presence of these heavy metals is not of major importance in agricultural soils in Canada but they are present in tailings and in sewage sludge. In mining operations, however, the objective is to remove as much of these minerals as possible. Some will, however, be present in the tailings discharge areas, in rock and tailings particles. Some of the minerals may be “locked” in the particles, but amounts as much as 1% could cause toxicity to plant growth.

The occurrence of a toxic level of salts usually occurs under the dry environmental conditions associated with the western prairies. Only in rare cases are salt toxicities encountered under moist humid conditions. The salt concentrations of soil solutions are measured by electric conductivity and reported in **ms/cm.**

Toxic levels of salts can occur in pyrite tailings. Here, the sulphuric acid is neutralized with carbonates to form calcium and magnesium sulphates. Under arid conditions, these sulphates accumulate and cause salinity in the upper layers of the tailings. Under continued dry conditions, accumulations of these salts may reach 2%. Values of salts in excess of 4 **ms/cm** are considered toxic to plants.

MATERIALS ENCOUNTERED AT MINE SITES

There are three types of waste material which may be encountered at a mine site: overburden, waste rock and tailings. Whether all will be encountered will depend upon the type of mining. Surface mining will encounter all three, whereas in deep rock mining, perhaps only tailings will be encountered.

Overburden

Overburden is a term used to describe the surface material removed from the mining area to expose the bedrock beneath. Overburden is not generally considered a waste material; it is usually sulphide free and is utilized in reclamation. It consists of a top soil fraction and a subsoil layer. The top soil fraction is the soil which supported plant life and will vary in depth. The subsoil has not undergone weathering and contains lower amounts of organic material than the surface soil.

For the most part, the overburden, and in particular, the topsoil is the medium which possesses the most desirable physical and the chemical characteristics deemed necessary for sustained plant growth. However, the physical and chemical characteristics of overburden can vary widely. Indeed, there are differences among top soils within any location, and each is distinctly different from the underlaying subsoil.

Topsoil, which can extend from a few centimeters up to a metre in depth, is the desired medium for plant growth. It is more oxidized and weathered than the subsoil. It contains a greater amount of decaying plant material and organic matter, and in turn, supports greater biological activity.

Subsoil in contrast does not possess all the desirable physical and chemical characters for growth that topsoil does. It is comprised of material that has undergone less weathering. It usually does not have the structure or porosity of the topsoil. It contains less organic matter and often contains an accumulation of salts and dissolved mineral leached from the upper layers.

Waste Rock

Waste rock is the waste material beneath the "overburden" and which must be removed from the site before mining of the ore body begins. In open pit operations, this rock is blasted, loaded, hauled and dumped in piles with steep slopes and flat tops. Often the removed rock is separated into stockpiles of low mineralization, for possible future mineral processing, and barren material.

Rock material contains few soil size particles (.2 mm) and is the coarsest of the types of material (Table 2). On the average, this waste material has a proportion of 24% boulders, cobbles and gravel (< 2 mm in diameter), 70% sand size particles (2 to 0.05 mm), 24% silt (0.05-0.002 mm) and 10% clay (< 0.002 mm),.

Because of the large particle size of the material, vegetating the stockpiles is very difficult. The coarseness permits rapid movement of water through the media leaving little for plant growth. Both the organic matter (which holds plant nutrients and sustains microbiological activity) and the cation exchange capacity (the ability to "hold" nutrients on the surface of particles and release them to plants) are low. In turn, although some nutrients may be released from the rock as a result of weathering, it and any of the applied fertilizer can be leached out of the material and not available to the plant. Chemically, rock is usually alkaline and as such does not present a serious problem with vegetation. However, where sulphide is present, acid generation potential may be very high, and practices to increase the alkalinity must be undertaken.

The major problem associated with the vegetation of the rock material is physical and not chemical, There is a lack of a suitable medium for germination, rooting and growth of the plants. The application of overburden or tailings is a feasible method of providing this medium. Where the rock contains over 1 to 2% sulfide-sulphur and a high potential for oxidation, the application of overburden is the only way to overcome the acidity problem and permit germination and growth of seedlings. Acidity mentioned in the previous sentence refers to the "soil" conditions and not acid mine drainage. Where the amount of overburden is low and because of the problems associated with trucking and distribution, surface compaction of the rock with heavy equipment along with scarification of the compacted surface to provide a "seed bed" has been used with success to provide a medium for plant establishment.

Table 2. Physical Characteristics of Overburden, Rock and Tailings. +

Particle Size	Overburden	Rock	Tailings
Particle Size		24	
% <2 mm	38	70	20 - 100
% 2.0-0.05 mm	61		1 - 97
% .05-.002 mm	32	24	0 - 96
% CO.002 mm	11	10	o - 40
Available Water Storage Capacity %	12	9	o- 35
Bulk Density g/cm^3	1.42	2.04	0.2 - 3.1
Particle Density g/cm^3	2.27	2.73	0.01 - 4.29

Table 3. Chemical Characteristics of Overburden, Rock and Tailings. +

	Overburden	Rock	Tailings
pH	5.6	7.7	1.8 - 9.4
CEC meg/100g	16	11.4	0.19 - 46.5
Organic Matter %	4.4	2.5	0.02 - 25.0
Electrical Con. ms/cm	0.7	0.9	0.1 - 22.2
P ppm	7.3	4.4	0.1 - 400
K ppm	70	85	1 - 564

+ from Murray, Canmet Report 77-31
Pit Slope Manual, Supplement 10-l

Tailings

All milling processes have one thing in common. They must dispose of their waste product or tailings. Depending on'the degree of liberation required for the most economical return, the waste product can be coarse (over 10% larger than sand), medium (20 to 60% larger than sand) or slimy (less than 20% larger than sand). The average size of sand is 2.0 to 0.05 mm in diameter. Tailings are pumped to disposal basins to allow liquid-solid separation. This separation produces a sand fraction and an effluent. The most common methods of deposition on land are:

1. Spigotting which produces sand beach slopes of 1 to 10%. This is the most common method of dam building (upstream method of raising the perimeters of tailings disposal areas).

2. Open end spilling which produces delta like sand beach slopes of 1% or less. Although the most common method of deposition in the past, due to the vast amount of land required its use is now generally regulated to winter operations.

A few mining operations end spill their mill waste under water either into the ocean or a natural or man-made lake. Although in the past such operations have been frowned on by regulatory and environmental groups, it is a disposal method which warrants more studies. With proper operating procedures, environmental monitoring and regulations, the disposal of sulphide waste underwater should be environmentally secure.

Even though no two tailings basins will be identical, and every site is specific, there are some common features. The coarse material will settle out nearest the point of deposit in and with the greatest degree of slope. The slime fraction, produced by overgrinding or common to the ore body, will settle out nearest the clarification pond with little or no slope, and the medium material, as the name suggests, will settle somewhere in the middle with generally a.3 to 1% slope.

Because of the nature of the operation (the location of spill point will continually change during the life of the dam) and the mineralogical and size composition of the material (the rate of oxidation will vary depending upon the sulphide composition and the size distribution of the material) tailings basins will appear layered vertically as well as horizontally. One may find a weathered hard pan material beneath a recently settled medium tailings material. An exception to the above are tailings operations which use central discharge where the tailings are deposited to form a coned hill with the slimed material around the periphery

The effluent in the clarification pond is removed by overflow decantation, pumps, seepage or evaporation, The clarity of the effluent M-ill depend on the method of operation. the size of the settling pool, the pH and the residual chemicals in solution

Photo 1
Fugitive Dust Storm

Apart from the aesthetically unpleasing nature of sulphide tailings basins, they impact the environment physically as well as chemically. The coarse tailings drain rapidly, and as a result, are subject to wind erosion. Fugitive dust storms from tailings ponds have been known to be so severe that they have stopped highway traffic and deposited the dust many miles away in forests and lakes. Besides the ecological damage caused, the wind erosion can become an economical and operational problem when dam walls erode faster than they can be replaced. This is less of a problem on dams with a high sulphide content due to the binding effect of oxidation. Even here, severe storms may'occur under freezing conditions due to a phenomenon known as freeze drying.

There are, however, methods and technology which exist to control the dust from active and abandoned dams. An operational change to cyclical spigotting will help to maintain a moist surface. Commercial water sprays could be installed to achieve the same effect. Covering the exposed area with bark or smelter slag, harrowing or crimping straw into the top few inches, application of organic or inorganic mulches and the placement of windbreaks are just a few of the physical stabilization methods which will temporarily solve a dust problem.

Chemical stabilization involves reacting a chemical with the waste to form an air and water resistant crust or layer. Again this is only a temporary solution to one of the problem areas. Due to the uneven surface of the disposal area, there will be enough irregular overhanging material to allow the high winds to iip out sections of the chemical seal. After two years, between 25 to 30 percent of the seal will have blown away. Also because an active surface of a disposal area is being regularly replenished with fresh erodable tailings, any long term control from a chemical binder in this case is uncertain.

The preferred method of stabiiization of mineral waste and the most effective is a self-sustaining vegetative cover.

While the coarse tailings drain rapidly, the fine tailings hold considerably more water and drain at a much lower rate. As a result, the use of machinery on such areas may be difficult.

Tailings containing sulphide also pose considerable chemical problems. The most critical to the environment is tailings acidity.

The chemistry of acid generation in sulphide tailings has been well documented (Boorman and Watson, 1976). The sulphide mineral reacts with air and water to form sulfuric acid and ferrous sulphate.

$$2\ FeS_2 + 7O_2 + 2\ H_2O \text{ ----> } 2\ H_2SO_4 + 2FeSO_4$$

This reaction occurs ordinarily at temperatures up to 11^{o} C. At temperatures higher than this, the ferrous sulphate **oxidizes** to the water soluble ferric state.

$$4\ FeS04 + 02 + 2H_2SO_4 \text{ ----> } 2\ Fe_2(SO_4)\ 3 + 2H_20$$

The ferric sulphate will in turn **hydrolyze** to form acid plus an hydroxide.- The **white** material forming on a sulphide dam during the hot summer days is ferric sulphate.

$$Fe_2(SO_4)\ 3 + 6\ H20 \text{ ----> } 3\ H_2SO_4 + 2\ Fe\ (OH)3$$

Further to this, the ferric ion enters an oxidation • reduction reaction with pyrite whereby the ferric ion "backtriggers" the oxidation • reduction reaction which accelerates the acid forming process.

$$7\ Fe_2(SO_4)_3 + FeS2 + 8\ \underline{H20}\ 15\ FeS04 + 8\ H_2SO_4$$

Although the above reactions are an oversimplification of a very complex acid. formation process, it does demonstrate the need for air (02) and water (H20) to proceed. The reactions are also very dependent upon different catalytic agents acting either independently or in combination. The catalytic agents can be physical (temperature), bacterial (Ferrobacillus sp. and Thiobacillus sp.) and chemical.

All the above reactions have dealt with pyrite (FeS2) as very little work has been done on the more volatile iron sulphide, pyrrhotite ($Fe_{1-X}S$ (where X = 0 to 0.2). The more rapid oxidation rate of pyrrhotite, however, can be expected to have an important consequence in the development of tailings acidity.

The acid generation reaction in sulphide tailings is very difficult to overcome as the chemistry of the reaction and the catalytic agents have not been completely determined. However, applications of lime will raise the **pH** to a level which will permit the establishment of vegetation. The oxidation will be reduced in the surface layer of the tailings in which vegetation is to be planted, but where there are high amounts of pyrite, oxidation will continue and the sulphur acid produced will again increase the acidity. Thus, continual monitoring of the **pH** of the tailings and frequent applications of lime may be required.

The technique for the measurement of the pH of sulphide tailing is not particularly reliable. The quantity of lime that must be applied to "neutralize" the acidity cannot accurately be determined using the calculations based on the chemical relation between pH and neutralization of lime. Watkin and Winch, (1973) developed a growth room/greenhouse technique to determine limestone requirements (Land for Waste Management). This technique estimates the requirement for lime using a number of representative samples from a pit, applying lime and/or other neutralizing agents such as rock phosphate at incremental rates and establishing vegetation. The degree of growth of birdsfoot trefoil was used as a measure of the level needed.

Agriculture limestone, either the calcitic or dolomitic type, is used generally to neutralize tailings. Watkins and Winch (1973) used a combination of rock phosphate and lime, however, there did not appear to be a consistent response to the rock phosphate in all tailings sampled.

it is usual for a large number of trace and major elements to be present in the tailings but in amounts too small to be of importance in plant nutrition.. The accumulation of salts at the surface is more prevalent in the fine than coarse tailings. This is due to the high pore space and capillary movement of soil water containing salts to the surface and the eventual evaporation of the water.

TAILINGS REVEGETATION PROGRAM

A period of 2-3 years covering a minimum of at least 2 growing seasons for the development of a tailings revegetation program should be allowed for a new site, This period could be longer if difficulties are encountered in developing the proper seed bed amelioration program required for plant growth.

A tailings revegetation program can easily be divided into 7 basic segments which follow one after the other in a natural sequence. The success of the overall program is dependent on the thoroughness and care with which the individual steps in each segment are completed. Each step is a building block on which the next step is built.

The seven segments are:

- Evaluation
- Program Planning
- Site Preparation
- Lime and Fertilizer
- Vegetation Selection
- Mulches, Chemical Stabilizers and Other Amendments
- Establishing Vegetation

EVALUATION OF VEGETATION POTENTIAL

Sampling

The vast majority of mines producing sulphide tailings have only forest and/or wildlife habitat as a land-use potential. The isolation from densely populated centres or class 1,2 or 3 farm lands generally precludes development for recreational, agricultural, residential and commercial end use. Reclamation by revegetation should, in this circumstance, lean towards the establishment of a permanent self-sustaining and maintenance free plant cover. Developed as an important component of an overall tailings area management program, reclamation by revegetation can often eliminate or reduce certain problems associated with surface erosion, fugitive dust, aesthetics, and sedimentation of associated streams.

To determine the vegetation potential of a tailings area, each disposal area has to be studied and evaluated separately. Disposal history, aerial photographs - past and present, and walking over the entire area can offer a large amount of useful information. This information will provide insight into the variations encountered and an indication of suitable sampling locations.

The main sampling systems utilized over large heterogeneous areas are grid or random. The latter is the most common and probably the most useful. The information acquired previously 'should be reviewed in order to minimize the sampling density and, in turn, the cost of the evaluation. Sample selection is mainly a subjective procedure governed by visible variation on the sulphide tailings surface such as colour, particle size and difference in moisture levels, etc.

A sufficient number of samples of the top **10-15 cms.(4-6")** of the tailings surface should be collected for analysis to provide a reasonably accurate knowledge of the makeup of the tailings. The number required for an accurate assessment will vary with the site but should be a minimum of 10 per hectare (4 per acre). The sample locations should be plotted on a plan.

Soil Testing Techniques

Agricultural soils containing clays and organic matter fractions use standard soil testing techniques to determine agricultural limestone and nutrient requirements. Many people have used the soil testing techniques to **analyze** sulphide tailings requirements. The reliability and usefulness of the results obtained from the analytical procedures have been seriously questioned by experts in the field (Watkin and Watkin 1982).

Research and field observation have indicated a lack of correlation between observed plant growth on tailings and soil test data. The greatest discrepancy occurs with the parameter of **pH** of the sulphide tailings. It has been observed at **Inco,** Noranda, Waite Amulet, Normetal, and Elliot Lake tailings disposal areas(+), and at many other sulphide tailings dams, that although the **pH** level of most tailings are outside the published levels for plant growth, an acceptable vegetative ground cover can be grown. There are also areas in the same disposal. sites that are within the same **pH** range but completely devoid of plants. **At** present, standard soil testing techniques should be considered as only a broad indicator of the presence or absence of potential problems in the establishment of a vegetative cover. More research into the development of suitable soil testing techniques applicable to tailings disposal areas would appear a necessity.

This is not to say that chemical analysis should be abandoned in the evaluation process. It is advisable to assess the program's potential on as broad a base as possible.

Representative samples of the material collected should be analyzed for a selection of elements based on those known to be present in the ore, suspected elements which may be present in minute quantities, and any that are added in the milling process. The information obtained from these tests will give some indication of the presence of the various elements; also, if the elements are present at level which may be toxic to plants or tie-up essential plant nutrients.

(+) Personal communication with Dr. E.M. Watkin, Dr. J.E. Winch, Dr. T.H. Peters and B.W. Brooks.

The pH of all samples should be taken in order that realistic estimates of limestone or other ameliorants levels required to be tested in the growth room or greenhouse could be made. The glass electrode meter is the standard instrument used for pH measurements. A water solution is usually used for the estimation of the pH in agricultural soils. However, using the water solution where soluble salts are present, as often occurs in tailings, the pH values may be reduced by 0.5 to 1.0 units. May & Bengtson (1978) suggest the use of 0.002 M $CaCl_2$ rather than water. This standard method will give a fairly accurate indication of the active acidity of the tailings samples. However, it will not give any indication of the reserve or acid-forming potential of the material. May & Bengtson suggest that the total sulphides and pH must be determined to obtain information that will lead to the correct amount of lime required. Benhisel et al (May & Bengtson) determine the sulphide through the use of hydrogen peroxide (oxidizes sulphides to sulphuric acid) and titrating with sodium hydroxide to pH 7.0. The amount required to neutralize is used to calculate the amount of lime needed to neutralize the potential acidity of the samples.

Watkin & Winch (1973) suggested the use of a biological method -where incremental rates of limestone, fertilizer and mixtures of lime and rock phosphate were used to assess the requirements for neutralization and fertility needs of the tailings. The needs are measured by the growth and vigor of the seedling in a period of about six weeks. This is used in conjunction with a pH measurement of the material.

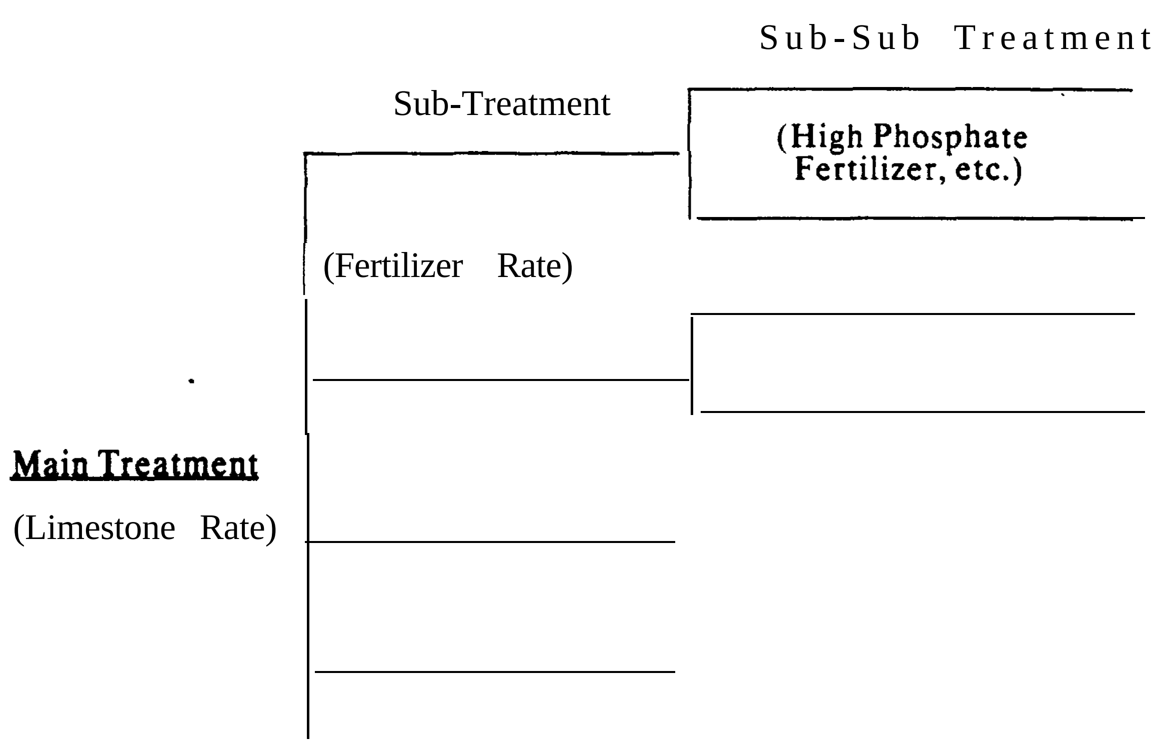
Field Trial Investigation

While the use of standard soil testing approach has proven frustrating, practical experiments in growth rooms and greenhouses have proven useful in determining the vegetation potential of the various areas sampled in a sulphide tailings disposal area. Evaluation studies should be set up to compare amelioration rates of agricultural limestone and/or other pH modifiers of the acidic tailings, fertilizer requirements, and the most suitable species. The experiments are usually designed as a split-split test with three replications, Figure 1. The material from each sample location along with the soil and nutrient amendments to be tested are placed in a series of 15 cm diameter pots.

As a control, three pots in each main treatment receive no amendments at all. Several seeds, in most cases Birdsfoot trefoil, are sown in each pot at a known depth. The purpose of the replication is to eliminate random error. The results should be plotted on the plan showing the sample locations. Limestone and fertilizer applications rates for specific portions of the total area may be indicated. Having this information plotted on a plan will facilitate the marking of the areas requiring different treatments. Although growth room and greenhouse experiments can be carried out year round, most people schedule them for late summer and autumn.

Figure 1

Split-Split Test



The success rate of a test is usually established by comparing the above ground dry matter production to either the adjacent native herbaceous plant communities or, more commonly, to similar agriculturally grown crops. Root development is also observed. Both standards have their limitation, and an understanding of why one of the treatments is successful or why others are not is often absent. If the establishment of an herbaceous cover is an acceptable end point, then the whys and hows of the biological aspect can be disregarded and left to the research scientist. More often than not, the solution will be pertinent to only one specific tailings disposal site.

Without the use of a growth room or greenhouse for the growth characteristic evaluation, experience in eastern Canada would indicate that a minimum of 18 to 24 months would be required for the traditional direct field evaluation. Should a reclamation program being evaluated in the field be judged a failure after 24 months of assessment, then 24 months have been lost in which time alternative establishment methods could be developed; The growth room or greenhouse reduces the evaluation time to approximately 100 days. One becomes rapidly aware of the degree of ease or difficulty to be faced in conducting a tailings area reclamation process. Unsuccessful trials can be discarded. Unhampered by the uncertainty as to the growth potential of an amendment, field trials can be conducted which concentrate on the practical field aspects of vegetation establishment. The time sequence of field trials is now reduced to a single growth season rather than the traditional 2 to 3 year field testing program.

The initial vegetation potential evaluations are conducted under indoor con trolied conditions. Field trials are designed to determine the effect of the natural environmental conditions, verification of the growth room test results, variation of the different plant-growth potentials common across the surface of a sulphide dam, suitability of the agricultural method and equipment to be used, as well as accessibility of the equipment. The program also allows one to obtain cost projections for budgeting purposes.

The minimum size recommended for a field trial is l/lOth of a hectare. Any smaller than this will increase the chance of an erroneous conclusion. It will also make it difficult for the agricultural equipment to operate in actual field-like conditions. It is important that the agricultural equipment envisaged to be used in the actual tailings disposal area reclamation program be used in the field trial.

Most field trials are set up so that they are at least one width of the seeding area of the equipment being used. The length of the field trial is designed so that the test area will encompass as many of the surface variations evaluated in the preliminary indoor tests as possible. Every effort is made to simulate the actual agricultural procedures envisaged necessary to complete the large scale reclamation by revegetation program.

If one is not comfortable in evaluating the results of the preliminary growth room or greenhouse investigation and/or the field trial study, it is recommended that the advice of an agronomic consultant be sought, preferably a consultant with hands-on experience in the revegetation of sulphide tailings.

In general, two years are required prior to the actual site reclamation by revegetation to ensure that the necessary procedures are developed and evaluated, prior to implementation, and to determine the most cost efficient and practical method is selected. A reclamation program requires the same technical input and commitment as any other segment of a mining operation and, if not treated as such, will be subject to failure.

Photo 2

Growth Room tests, as shown above, permit a large number of amendments to be evaluated in a short time frame.

PROGRAM PLANNING

Site Inspection

In order to determine the accessibility of the site and to determine the type of equipment which can be used for the revegetation program, a site inspection must be made.

The physical state of the tailings surface should be examined at this time. If the surface has oxidized to a point where there are large areas which will require breaking up by heavy equipment or whether it is soft and relatively fine grained and easily workable will influence equipment selection, as well as time and cost budgets.

The need for any shaping or contouring of the surface to permit the use of agricultural machinery in the seeding operation can be ascertained and, if required, can be included in the schedule to be followed in implementing the program.

At this time, observation and records of the climax vegetation cover in existence on the natural undisturbed land adjacent to the tailings site should be made. These observations will form the basis of species selection and their subsequent manipulation to achieve the desired final plant community for the revegetated area.

Consult Regulatory Personnel for the Area

As part of the planning process, it is necessary to be aware and certain of any government, regulations which may apply to the area in which the project being considered is located.

Many of the rules followed are based on the requirements which are currently in practice and not specifically spelled out in any regulation. The local regulatory personnel will be aware of these requirements or practices and advise on the standards which have to be met.

Plan of Development of Vegetation Program

As the information from the preceding steps becomes available, a planned program for the vegetation of the proposed area should be progressively developed. This plan should contain a degree of flexibility to allow changes which may be required as various input factors become known.

In addition to the information indicated above, other factors, such as the proposed end use of the area, future maintenance costs, possible pending government legislation, etc., can and will impact on the ultimate plan adopted for the site.

The first seeding should always start at the portion of the tailings closest to the prevailing wind during the growing season. This will minimize the covering or injuring of the young plants by drifting tailings.

SITE PREPARATION

In order for the program to proceed with minimum costs of labour and money, any site preparation or repairs, which are required, should be undertaken and completed prior to the initial seed bed cultivation.

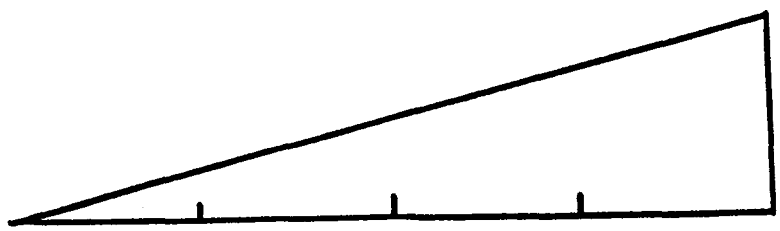
These preparations include the development of reasonable access for the type of equipment to be used in the project. A degree of permanence should be built into this access to permit future maintenance.

The state of repair of the drainage system must be checked to ascertain if any repairs or alterations to the system are required. Any repairs or changes which are indicated by this inspection should be carried out prior to the seeding operation. Failure to do this can result in a blockage of the system with at least the drowning out of some of the new vegetation, or, at the worst, the overtopping of the dam bank and a subsequent washout. The necessary repairs, carried out before the seeding, will eliminate the future need to repair any areas which may be damaged in the future.

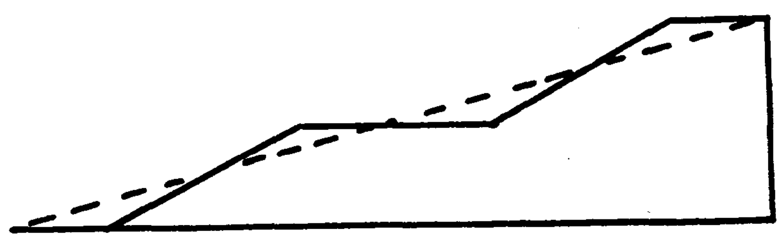
Any contouring of the surface required to permit the safe and efficient operation of the equipment to be used in the overall vegetation program should be done at this time. The rounding off of the weathered peaks or those more recently cast by various operations, to present a level to gently undulating surface on the inside of the tailings dam, should be the objective of this phase of the operation. The outside slopes, if normal agricultural implements are to be used, should be graded to a 1:4 slope by eliminating the crests and the flat areas developed by the progressive series of raises used to increase the dam height.

If it is impossible to grade the slope to an angle suitable for the safe use of agricultural tractors and implements, access roads for hydroseeding equipment should be built on the slope. If roads are built on the outside slopes, adequate provision for the collection and dispersal of the natural precipitation water should be included in the design of the road network to protect the integrity of the dam. Any gullies on the slope should be repaired at this time.

FIGURE 2



A 1 : 4 slope suitable for the safe use of "wheeled" agricultural equipment.



The contouring of a stepped slope to one suitable for establishing vegetation.

It may be necessary at some sites to use a soil or clay cover on the slopes with a south to southwest exposure. These exposures in the northern hemisphere receive prolonged exposure to the afternoon sun during the summer months with the resultant increase in the loss of substrate water by plant transpiration. Since the dam raises, due to the natural physical deposition of tailings, are constructed with the coarser sized particles of the tailings, the porosity of this material results in a lower capability for the upward movement of water by capillary action. In addition, the greater distance from the phreatic level of the water or the water table at the crest of the slope, reduces the amount of "soil moisture" available to the plants. During periods of stress caused by high rates of evapo-transpiration due to long periods of high temperatures and sun, the amount of "soil moisture" can be reduced to a level below minimum requirements. This water stress, if present for prolonged periods, can cause the dehydration and desiccation of individual plants in the vegetative cover with their resultant death. The water retention capability of a soil or clay cover is significantly greater than the coarse tailings on the slope and at the crest. Therefore, under normal weather conditions, there is a greater reserve of moisture available from these covers for the plant roots.

The use of a soil or clay cover on a slope surface changes the porosity of the surface, thereby reducing the rate of infiltration during precipitation events. The resultant increased shedding of water from the newly covered portion of the slope can lead to erosion and gullying of the lower tailings slope by runoff water. It is evident from experience-that the whole slope must be treated the same to preserve the integrity of the dam. This uniform treatment will also assist in keeping future structural maintenance costs at a minimum. The use of a suitable mulch, and if necessary, a "tackifier" or "binder" during the seeding operation on slopes will help reduce potential erosion during the germination period and early growth stages of the vegetation.

LIME, FERTILIZER AND OTHER AMENDMENTS

Pyritic mining spoils are sterile in terms of the physical and chemical characteristics which are conducive to growth. These conditions must be overcome before vegetation will be a success.

The physical characteristics in themselves offer poor conditions for growth.

Chemically, the extreme ranges of acidity or alkalinity found in the tailings ponds present a problem. These extremes in pH values in themselves do not inhibit plant germination or growth. It is the effect of the level of pH on the release and/or the availability of undesirable or desirable elements. For example, under high acidity conditions there is an increase in the aluminium and manganese concentration and a decrease in the availability of phosphorus. Under saline conditions, sodium and calcium salts are present in toxic amounts. Also severe deficiencies of the desirable nutrients and in particular nitrogen, phosphorus and potassium often are more limiting than the growth limiting soil acidity. (Mays and Bengtson cp 17-ASA). The solution to these problems lies in the correction'of the pH and the addition of adequate fertilizer for germination and growth of the vegetation.

Lime

Lime which is used to neutralize the acidity of the disposal area is of prime concern. There is the amount of lime to be used, but also the quality and the time of application.

The determination of the amount of lime required to neutralize the disposal area presents the first and the main problem. In most cases, there is a variation in the physical and chemical characteristics across the area. Secondly, the techniques used to determine pH do not accurately depict the level of lime needed.

The importance of the type, quality and time of application of lime should also be given adequate consideration.

There are two types of limestones available: calcium carbonate and dolomitic limestone. The latter contains magnesium carbonate ($MgCO_3$) whereas the former is primarily calcium carbonate ($CaCO_3$). The chemical effectiveness of limestone is measured by its $CaCO_3$ equivalence. High quality limestone should have an equivalency rate of 90% or greater (May and Bengtson, 1978). In general, dolmitic limestone has a higher equivalence than the calcium carbonate.

The effectiveness of limestone in correcting acidity is dependent upon rapid dissolution. The rapidity of dissolution is dependent upon the fineness of grind. Lime should pass a 60 mesh or finer screen to be effective. Larger particles are of little use in correcting acidity. In agriculture soils, limestone is applied well in advance of planting in order to insure that the calcium and magnesium has been incorporated into the chemistry of the soil. Often lime is applied in the fall and worked into the soil, and the area sown the following spring. This practice should be considered in the vegetation process of tailings areas.

The fall application of lime reduces the number of operations required in the spring and "speeds up" the early sowing of legume grass mixtures.

Lime is usually distributed over the surface of the tailings using spinner-type spreaders, mounted on trucks or pulled by tractors. These machines often lead to uneven distribution of the lime over the surface of the tailings. The spreaders can be calibrated to deliver one-half the application rate and two traverses over the tailings impoundment area at right angles to ensure uniform distribution of the limestone.

The lime is then **disced** into the tailings.

Table 4: Recommended Ground Limestone Rates for Kentucky Spoils

Buffer pH	Limestone Required to Adjust ** 5.5	6.4
	(mt/ha)	
6.7 - 6.3	2-4	5-9
6.3 - 5.9	5-9	9-13
5.9 - 5.3	9-13	13-18
5.3 - 5.0	13-18	18-25
5.0 - 4.5	18-25	25-34
4.5 - 4.0	25-34	34-56
Below 4.0	34-56	>56

* From: Barnhisel, R.I., 1975
Lime and Fertilizer Recommendations for Reclamation of Surface-mined Spoils. Agric. 40. Dept. Agron. Univ. Kentucky, Lexington.

** To Adjust Spoil to pH

There is an upper economic limit to the application rate that lime should be applied. This may be determined by costing the lime application in relation to the cost of purchasing, transporting and covering the area with overburden. However, a source of overburden in mining areas may be limited. Bulk limestone should be used whenever the site factors permit. The elimination of packaging costs as well as the associated costs of emptying the bags will prove significant.

In addition to lime; other materials have been investigated and used to reduce the acidity of tailings areas. Fly ash, cement flue dust, blast furnace Slag, as well as waste by-products from pulp and paper mills have been used. These materials are effective, but the availability may be low and/or the cost of transportation prohibitive. Watkin and Winch (1973) investigated the use of lime and rock phosphate alone and in combinations. The response in terms of growth of seedlings indicated that 25, 45 and 65 tonnes/ha. (10, 20 and 30 tons/ac) of lime resulted in similar weights of plants as 11 tonnes/ha. (5 tons/ac) of lime mixed with rock phosphate at rates from 0 to 35 tonnes/ha. (0 to 16 tons/ac).

However, only at the high rate of lime 11 tonnes/ha. (5 tons/ac) in combination with high rates of rock phosphate 18 to 36 tonnes/ha. (8 TO 16 tons/ac) did the pH level of the tailings remain similar after the 88 days of the experiment to those pH values attained by the initial application of lime and phosphate. in addition, it was found in future experiments that the response to rock phosphate varied considerably among tailings samples from within the area and from different tailings discharge areas.

Fertilizers

The major elements needed for germination and growth of grasses and legumes are nitrogen, phosphorus and potassium. These are lacking in tailings discharge areas.

In agricultural soil, nitrogen is held on the organic matter, but some may be available in the soil solution as NO3 and NH4 or absorbed on the clay fractions. However, in tailings there is little organic matter and there is little or no clay. Thus nitrogen deficiency is severe and must be applied. Applied nitrogen can be lost. It is soluble and can be lost through leaching.

There are a number of N fertilizers available. Ammonium nitrate (33.5% N) and urea (45% N) are the most common. Both are soluble in water and are used in the granular form. They can be used at establishment or in maintenance applications.

The application of both phosphorus and potassium is recommended.

The most economical way of purchasing phosphorus is in the’ triple superphosphate form (0-46-O). It is very water soluble and high in P. The high concentration results in’ ease of handling and application. Ordinary superphosphate (0-20-O) is not widely used because of its low P content and the increased work involved in spreading the low concentrated material. Rock phosphate finely ground (0-32-O) can be used to satisfy the P requirements. In this form, the phosphorus becomes soluble under acid conditions. This is an advantage in long term maintenance but is not advantageous to young established plants. Watkin and Winch (1980) found that the response to rock phosphate alone, and in mixtures with lime, were variable and the combinations were not used under field conditions (Brooks, 1981).

Considerable research has been conducted on the development and advantage of "slow release" fertilizers (Sheard 1976; Mays and Bengtson 1978). The advantages in the use of a slow release form of fertilizer is a reduction in the loss of nutrients to leaching in a porous medium, a reduction in the number of maintenance applications required, a reduction in fertilizer "burn" and the cost per unit.

Slow release forms of potassium are not on the market at this time; however, sulphur coated urea (S.C.U.) is available and trials at the University of Guelph indicated that the production of reed canarygrass (Phalaris arundinacea L) was maintained with S.C.U. into the year after nitrogen applications were discontinued.

From a fertility point of view, there are two considerations: the amount and type for establishment, and the amount and'type for long term maintenance of the established stand.

Establishment Fertilizet

In agricultural soils, the amount and the type of fertilizer to be used will depend mainly upon soil tests. The available phosphorus and potassium in the soils when calibrated against crop requirements for growth will indicate the amount and type to be used. However, in tailings, soil testing will not result in any great assistance except to indicate that all the necessary elements are lacking.

In some circumstances, approximately the same rates of fertilizer are used in establishing grasses and legumes on tailings ponds as in low fertility fields in agriculture. Reported rates of nitrogen range from 50 to 100 kg/ha and 40 to 80 kg/ha of phosphorus (May et al). These rates were reported to be inadequate in all situations. Watkin and Winch (1973) suggested the use of a biological method for estimating fertilizer and lime needs.

In addition, where legumes are included in the mixture often the use of nitrogen is omitted from the establishment fertilizer. The reason given is based on the assumption that the legume will, if properly inoculated, fix atmospheric nitrogen and supply all that is required. This symbiotic relationship between the rhyizobia and plant does not take place, however, for a period of time that could extend up to 8 or 10 weeks and will depend on the growth and vigor of the plant. During this period, the legume seedling is in competition with the other seedlings for nitrogen to develop. Thus, it is recommended that nitrogen be included in the establishing fertilizer along with the phosphorus and potassium.

Since the tailings are essentially void of all the necessary elements for plant growth, and since the levels and the necessary components (nitrogen, phosphorus, potassium) cannot be determined with a degree of accuracy, and since the cost of fertilizer constitutes only a very small portion of the total cost of the vegetation project, relatively high levels (0.6 to 2.5 tonnes/ha.) should be used.

Maintenance Fertilizer

Although one objective of vegetation is to avoid the cost of yearly applications of fertilizer, there is a need to monitor the area each year. The monitoring should take the form of analysis of representative tailing samples for pH and plant samples for the required growth nutrients. The analysis will not specify the amount of each that is required, but the values will indicate the need. The major nutrients required for maintenance of a stand of vegetation are nitrogen, phosphorus, potassium, and perhaps other elements such as magnesium or boron. Additional limestone may be required to insure that the pH remains in the range from 5.5 to 6.5.

Although there are analytical methods for the determination of nitrogen levels in soils, they have been shown to have limited success (Berg W.A. p. 653 in Recl. of dist.Lnd). As well, their use in tailings disposal areas may not be justified because there is little organic matter in the material and usually there will not be unless there has been considerable organic matter added in the process of ameriolation or until there is an accumulation as a result of decaying plant roots and tops. Analysis of the plant material will result in the determination of the level in the plants and offer an indication of the need.

The most feasible manner in which to overcome the need for maintenance nitrogen applications is to sow an adapted legume in a mixture with a grass or grasses. Brooks (1981) found that by the use of birdsfoot trefoil and creeping red fescue on tailings areas in Noranda, no nitrogen maintenance fertilization was required.

However, where non-legume mixtures of grasses are used, nitrogen in the form of urea or ammonium nitrate should be used. These should be used when the plant analysis indicates that the nitrogen level is from 1.5 - 2.0% and the plant tissue appears deficient (tips of leaves brown). Normally, growing grasses in the vegetative growth stage (prior to heading) have a content of about 3.0%.

The rate of nitrogen application should be sufficient only to maintain the stand and not sufficiently high to produce excessive growth nor to induce nitrogen leaching from the soil. Rates of from 25 to 30 kg/ha of elemental nitrogen applied in the spring (late May - early June) or August or September, when active growth is occurring and soil moisture is available, should be adequate to maintain the stand. The alternative to the yearly applications of nitrogen would be the introduction of a legume into the grass stands.

For the most part, if adequate phosphorus has been applied at sowing time, additional phosphorus may not be needed. The level of phosphorus in the tissues of grasses and legumes that are productive ranges from 0.14 to 0.50%. An application of phosphorus at the rate of 100 kg/ha of 0-46-O in late August-early September when the plant level goes below 0.1 should be considered.

Similarly with other elements, the range reported for potassium is 1.0 to **4.0%,** for calcium 0.28 to **2.50%,** and magnesium 0.06 to 0.73%. These nutrient elements are usually not required, but if the values are low and deficiency symptoms appear, applications should be made in August or early September.

In time, oxidation of sulphur compounds may result in the pH of the tailings becoming increasingly acid. The rate of decrease would be dependent upon the degree the sulphur bearing minerals were sealed from oxidation. Yearly determination of the pH over the discharge area would supply information as to the need for lime (Table 4). The lime should be spread evenly over the surface of the tailings in August or September.

Monitoring could aid in preventing potential serious stress conditions to the vegetation. The application of pH monitoring at Inco has indicated that additional liming could be delayed until the eighth year from germination.

Other Amendments

Improvement in the physical conditions are related to the addition of organic materials. Materials ranging from farmyard manure, peat (Chadwick), straw, hay, sawdust, wood shavings or sewage sludge (Watkin & Winch 1973) have been used. Bradshaw and Chadwick (1980) reported that if the organic matter of sandy soil is increased by adding 25% peat, its available water holding capacity should be doubled. In addition, planting of rapidly growing annual species such as buckwheat without the removal of the top growth has been used with success in Elliot Lake. The use of any of these materials will add to the physical conditions with particular reference to the moisture holding capabilities of the material, the chemical capability (increase in the cation exchange capacity) and the addition of desirable nutrients needed by the plant. In the case of the use of sewage sludge, heavy metals such as zinc and lead may be present and be toxic to plants or cause water quality problems. However, it has been demonstrated that these minerals rarely reach a toxic level to plants or to be of a major problem in drainage water (Chadwick).

VEGETATION SELECTION

Successful vegetation of tailings is dependent upon three important factors . if one aspect is ignored, success will not be achieved. However, each is within the control of the Project Manager. They are:

a) the choice of species adapted to the site

b) the choice of the correct method of establishing the species/mixture, and

c) the correct maintenance during the establishment year and in ensuing years.

Selection of the Type and Species of Vegetation

The objective in species selection for the revegetation of any stressed or waste area, including sulphide tailings, is to provide for the establishment of the initial plant communities using available species which are tolerant of drought, low soil pH, low nutrient availability, the lack of organic matter, and the other components usually found in tailings. At the same time, these species must be. capable, through the management of plant competition, to permit the evolvement of a climax plant community similar to those found in the adjoining area (Peters, 1988).

This need for the vegetation on the reclaimed area to be similar to that in the surrounding natural stands is dictated primarily to ensure plant survival under climatic conditions found in the specific site area. Climate in general cannot be manipulated, with the exception of the modification of the microclimatic conditions around each plant. This modification **is** achieved by the use of companion crops or other shields to provide shade, reduce wind velocity, reduce water evaporation from the substrate, etc.

The next question to be faced in the selection of species is the use of “native” or the use of introduced species commonly referred to as “exotics” or agronomical.

Some regulatory agencies in Canada are making the use of “native” species mandatory in the reclamation of industrially stressed **land in non-urban areas.**

These regulations also state that in the case of trees and shrubs, the plants to be used in the reclamation project must not only be indigenous species but come from parent stock originating under the same conditions of altitude, latitude, and other macro-environmental conditions native to the site to be reclaimed. It is, therefore, obvious and essential that in the early stage of developing a site specific reclamation program, the planner should investigate and review any and all regulatory requirements in force in the jurisdictional area in which the site to be rehabilitated is located.

The benefits of using "native" species which are indigenous to the area surrounding the site to be revegetated have been proven in principle and in practice with trees and shrubs for the climax vegetation. However, in the case of grasses and legumes, the results, although also acceptable in theory and in principle, have not proven themselves to everybody's satisfaction in practice. There are very few "native" species that are adapted to the physical and chemical conditions of the tailings pond. -It is of interest to note that very new native species originate on soils similar to most mine wastes.

The principle drawback in using "native" species is securing a source of sufficient seed. The high labour intensive practice involved in gathering seed from sparse or scattered plant populations makes it extremely difficult to obtain enough seed for large scale reclamation. Field collection can be difficult due to irregularities of seed production of the desired species. Increasing the problem is, the fact that for many species, there is a definite lack of agronomic knowledge about the germination requirements and the seedling establishment of many of the "natives". This information is required to ensure proper seeding rates for the establishment of an acceptable stand. In many cases, the "native" species may not be ecologically suitable or adaptable to the conditions found in the mine wastes produced in the particular area.

The observation and establishment of an inventory of the indigenous species growing under the natural conditions of soil and climate in the area around the site to be reclaimed is, however, the first step to be taken in determining which species can be used. This inventory will serve as a guide for selecting the species for revegetating the site.

With the agronomic species, ample quantities of either "commercial or pedigree" seed are usually available in the area. Ail seed will have been inspected and graded as to its percent germination and weed seed content. The grade thus does not indicate whether the seed is commercial or pedigree. Pedigree seed will have a blue tag. It is a guarantee of trueness to type. In contrast, commercial seed does not have a guarantee of trueness to type.

In many cases, commercial seed is used for the vegetation of tailings ponds. The seed is lower in cost. However, if a specific variety is required, the seed will be by law, pedigree seed. The use and therefore the choice of a variety is important in most cases. For example, either Empire or Leo birdsfoot trefoil should be used. They have a wider adaptability to wet soil conditions and pH tolerance than the upright rapid regrowth varieties such as Viking.

The seeds for the legumes currently used in mine waste reclamation are generally all introduced agronomic species available from commercial sources. In the case of grasses, shrubs and trees, when seed or seedlings are not available for the desired "native" species in sufficient quantities, seeds and seedlings may be‘ available commercially for other species of the same genus.

In the botanical classification of plants, each one is identified by genus and species. An example of this is Common Twitch or Scutch Grass (Agropyron repens). It is illegal to buy, sell or trade the seed of this species for use in Canada. If Twitch Grass is found in our review of local species growing in the area around the proposed reclamation site, an alternative but closely related species, obtainable commercially, should be considered. One possible candidate for inclusion in the seeding program, providing it is adaptable to the other conditions found at the site, is Crested Wheat Grass (Agropyron cristatum).

Generally, in Canada, due to the size and scope of the individual reclamation projects, the use of species which are commercially available in seed or seedling form is recommended.

Factors Affecting the Selection

The major factors which have a bearing on the selection of the type of **vegetation,** the species and variety chosen are: the final or ultimate use of the site and their adaptability to the physical and chemical condition of the site.

Ultimate Use of the Site

Under most conditions, the purpose of vegetating mine tailings is to return the site to as close as possible to "its undisturbed condition" • a condition that would conform to the surroundings (i.e. forest and wild life). Here the choice of species would be directed first towards those that would stabilize the tailings material to prevent wind and water erosion. The aesthetic appearance of the vegetation may not be a concern, however, the species chosen should be "self sustaining" and require little maintenance.

However, where tailings disposal areas are located near a town site, the eventual use of the tailings area may be for a park or a recreational area, and in other locations such as a wildlife preserve. Here, in addition to the ability to stabilize the site, there will be a need for the species to provide an aesthetically pleasant appearance and/or to withstand heavy use and/or to provide feed for wildlife. Under these conditions, low maintenance may not be a major concern in the selection of species for mixtures, but the height, foliage and flower colour will be important in addition to the ability of the species to colonize the area. The concept of what is attractive will vary among individuals. Some may prefer a cover of lawn type grasses. Others may not wish a uniform cover in a "manicured" condition, but one where height and colour would be of importance (i.e. crown vetch). Still others may wish the site to conform to the natural surroundings. Often trees and shrubs are important components of such reclamation projects.

The best source of information on adapted species would be the recommendation lists from the local, regional agricultural offices of the area. These recommended lists will contain the names of the highest performing varieties of species adapted to the area. Where agricultural species are not in the plan, vegetation similar to that of the surrounding natural stands should be chosen.

Adaptability of Species to Site

The physical and chemical conditions of the mine waste are different from site to site. Species differ in their ability to withstand the conditions, both the physical and chemical conditions, imposed on them, thus the choice of species should be "Specific for the Site". This involves for the most part, the selection of species based on their tolerances to the pH level and the water content of the tailings.

Although most agricultural species will grow over a range of pH values (5.0 to 8.0), optimum growth occurs for most species at a pH near neutral (pH 6.8-7.0). As the pH values approach the extremes, the growth of species is progressively reduced. The amount of reduction in growth, however, varies among species and is related to their tolerances to high and/or low concentration of minor elements and/or ability to survive and grow under low levels of necessary nutrients. For example, as the pH drops below 6.0, phosphorous becomes fixed in compounds with aluminum and calcium reducing the availability of calcium and phosphorous to plants. Also, toxic levels of manganese, aluminum and iron may occur at these low pH levels. Under high levels of pH, sodium and/or calcium may be present in excess amounts which inhibit growth of plants.

Although all species will have a specific tolerance level to one or all of the chemical conditions imposed by the pH value, grasses in general are adapted to a wider range of conditions than legumes. This is due to the fact that legumes require bacteria in order to fix atmospheric nitrogen and each bacteria requires pH neutral. There are, however, differences in pH levels required by the bacteria of legumes (i.e. alfalfa pH 6.8 to 7.0, birdsfoot trefoil pH 5.8 to 6.0).

Water relationships in the material is a second consideration in the selection of species. Although species require water for growth, there is a wide variance in the efficient use of water, in their tolerance to flooding, to high or low water levels and their tolerance of dry soils. Species vary widely in the adaptation to these conditions.

Growth water for plants is obtained from the rooting medium. The available water is that which is held between the wilting point and field capacity. The amount that a particular soil can hold in this range is dependent upon the texture (sands-low, clays-high) and the amount of organic matter.

Plants utilizing this moisture cause the soil to “dehydrate” to a depth of their rooting system, and replenishment must come from rainfall or from the lower levels by capillary action. The latter method usually provides only sufficient moisture for maintenance of vegetation, not growth. Thus deep rooted plants are favored for dry areas.

Species differ in the efficiency in the water use which points out the differences in the rate of growth of species (250 to 800 kg water/kg dry matter production). The annual land biennials have high growth rates and use less water than the perennials which are the more desirable slower growing perennial species. Thus, under dry conditions, the use of annual grain crops such as the cereal rye, wheat and spring grains may unduly affect the establishment of the more desirable species.

Plants also differ in their ability to withstand flooding and high or low water tables. For the most part, the species which have tolerance to flooding are those that begin growth in the spring late and become dormant early in the fall. This coincides with the periods of high water levels brought about by the snow melt in the spring and the high rainfall periods of the fall.

Species that withstand high water tables are those that possess shallow rooting habits such as most grass species and some legumes such as birdsfoot trefoil and alsike clover.

Types of Vegetation

There are two broad types of vegetation that can be used to vegetate a tailings area: Herbaceous (grasses and legumes) and Trees/Shrubs species. In general, the rehabilitation should begin with the use of.herbaceous species. They "cover the ground", prevent immediate erosion and begin the process of stabilization of the waste by preventing the exposure of new acid-generating material, reduce water levels and seepage through the dam through transpiration (Ripley et al). In contrast, trees or shrubs do not provide an adequate method of controlling water erosion from the surface of non-vegetated areas. However, they are valuable species in reducing wind erosion and offer protection and habitation for bird life. Generally, tree/shrub plants have followed the successful establishment of the herbaceous species.(+)

Herbaceous Species/Varieties

There are large numbers of grass and legume species that can be used. These include those that are used in agriculture often called "exotic" and those that are' considered to be "natural" or common to the site. In the case of the natural species, there are "strains or ecotypes", and in the agricultural species, there are varieties. In most cases, the species used in land reclamation are agronomic. There are as many differences in adaptability to soil conditions and habit of growth between ecotypes and varieties within species as there are between the species.

There are a number of very basic differences between grasses and legumes. In general, all legumes are considered to be "minimum" maintenance vegetation. They have the ability to fix atmospheric nitrogen, and as a result, require little or no fertilizer for maintenance. In order to "fix" the atmospheric nitrogen, the legume seed must be inoculated with the correct bacteria. However, they begin growth in the spring later than grasses and are not as tolerant to adverse soil conditions as grasses.

(+) Personal conversation - Dr. T.H. Peters, Dr. **E.M.** Watkin and B.W. Brooks

In contrast, grasses require nitrogen for long term maintenance. They are generally more winter hardy than legumes. They begin growth earlier in the spring and remain vegetatively active later in the fall than most legumes. They have in addition a higher tolerance to: higher acidity and alkalinity conditions, higher soil moisture levels, and higher concentrations of "heavy" metals than legumes. As well, there are fewer difficulties in the establishment of grasses than legumes.

TABLE 5 Some Tolerant Grass and Legume Species

	Tolerance Level	
Good	Moderate	Poor
Western Wheat Grass	Sweet Clover	-White Clover
Canada Wild Rye	Perennial Rye grass	Mead. Foxtail
Nutall alkali grass	Birdsfood trefoil	Alsike Clover
Beard's Wild rye	Alfalfa	Red Clover
Saltgrasses	Tall fescue	
	Reed Canary grass	
	Smooth Bromegrass	
	Cicer Milk vetch	

* Adapted from Semple A.T. Grassland Improvement. CRC Press Clevelend, Ohio ppl58

TABLE 6 Species Tolerance to Soil Acidity •

	Tolerance Level		
Very	Moderate	Slightly	Sensitive
Blueberry	Reed Canary	Red Clover	Alfalfa
	Red top	Alsike	Sweet clover
	Birdsfoot tref.	White clover	Barley
	Oats	K. Bluegrass	
	Rye	Brome grass	
		Wheat	

* Adapted from Jones, E. Liming Ohio Soils Est Bul 177, 1936

In view of the above, the ultimate choice of the vegetation for a particular site will be a mixture of varieties of grasses and legumes. In order to develop a satisfactory mixture, however, the correct species and varieties must be chosen for inclusion in the mixture.

There are a number of species and varieties of grasses and legumes that could be used, and the selection process would appear to be difficult. However, there are only a few species of legumes and grasses that have been shown to be successful and are used extensively in the reclamation of sulphide tailings.

Legumes

Three legumes have been used and have the greatest range of adaptability to reclamation conditions. They are:

Birdsfoot Trefoil	(Lotus corniculatus L.)
Crown Vetch	(Cornilla varis L.)
White Clover	(Trifolium repens L.)

Other legumes that can be used are: red clover (Trifolium pratense L) and alsike clover (Trifolium hybridum L).

Bradshaw and Chadwick (1980), Thornbaurg and Fuchs (1978) and Bennett et al (1978) outline the characteristics of cool season species and those adapted to dry conditions.

All legume seeds must be inoculated with the correct rhizobia in order to ensure that they will fix atmospheric nitrogen. Each legume requires a specific species of rhizobia and because the legume chosen will be “new” to the overburden or tailings, the rhizobia must be introduced. This is accomplished with the correct rhizobia or purchasing seed that has been “pre-inoculated” with the correct rhizobia or purchasing the correct inoculant and treat the seed.

Care should be exercised to ensure the viability of the rhizobia regardless of whether pre-inoculated seed or peat inoculants were purchased. High temperatures and age affect the viability. With age, the viability of the rhizobia decreases. All inoculants are dated. High temperature will result in death but low or freezing temperatures will not affect the rhizobia. Thus, care must be exercised in storing the purchased inoculant and the pre-inoculated seed. Inoculated seed should be stored under cool conditions until seeding time. If the seed is "carried over" until the following spring, it should be inoculated with newly purchased peat inoculant.

The procedure for inoculation of seed with peat inoculant involves moistening the seed with milk or a mixture of water and syrup, applying the inoculant over the seed and mixing thoroughly. The objective is to have adequate rhizobia on every seed. Where a legume is to be planted for the first time in a soil, the amount of inoculant recommended on the package should be at least tripled. This is also a rule of thumb to follow when seeding a legume with a hydroseeder.

The rhizobia species required for nodulation of alfalfa, clovers, birdsfoot trefoil, crown vetch and other legumes in use in Canada generally are most active under slightly acid to alkaline soils conditions. However, there are differences among the rhizobia species to levels of acidity. For example, the optimum pH for the rhizobia of birdsfoot trefoil is from 5.8 to 6.0, whereas those for alfalfa require a pH of 6.8. These differences tend to explain the reason for the adaptability of the legume.

Research, however, shows that alfalfa rhizobia can be developed to function under higher acid conditions than the normally required pH of 6.8. As a result, alfalfa has been grown at lower pH levels than previously. Alfalfa inoculant sold in Canada does contain the "higher" acid tolerant strains.

Birdsfoot Trefoil (Lotus corniculatus L)

Birdsfoot trefoil is a perennial legume that has been used in mixtures with success on tailing ponds in Ontario, Quebec, Manitoba, the Maritimes and British Columbia. Varieties of this species have a wide range in adaptability from poorly drained to draughty, acid to alkaline soils, and will survive and grow under infertile conditions.

Birdsfoot trefoil has a shallow tap root relative to alfalfa with numerous lateral branches near the surface of the soil. The plant is aesthetically pleasing. It produces deep yellow flowers in mid-June which remain colorful well into August and after the seed has ripened. The vegetation remains a deep green well into the fall until snow falls.

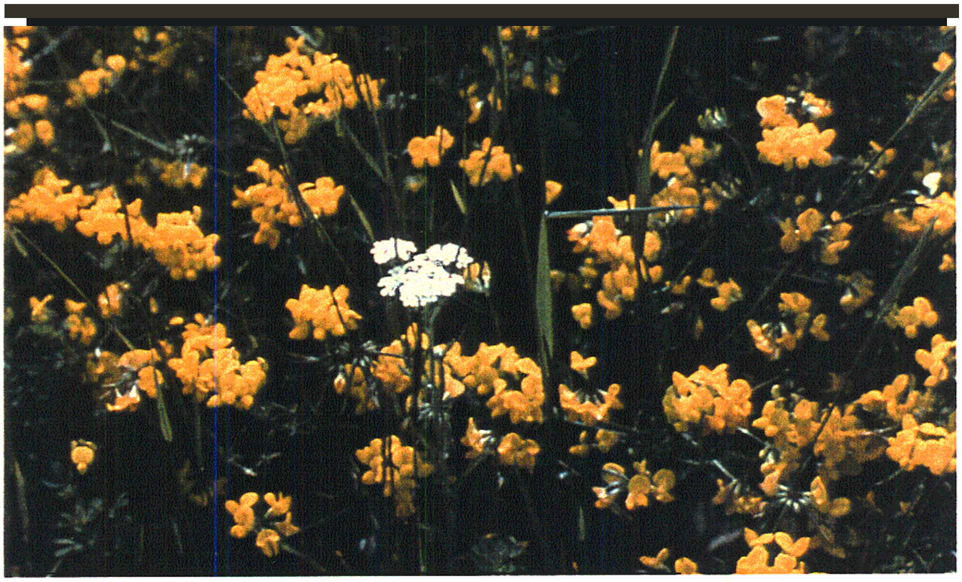


Photo 3
Birdsfoot Trefoil and Creeping Red Fescue

There are two types of birdsfoot trefoil which differ significantly in adaptation to drainage and soil pH: early and late.

Early type: The early type trefoil is characterized by earlier spring growth, a more rapid recovery following cutting and will grow later in the fall that the late types.

The varieties of this type are not as tolerant to imperfectly and poorly drained or flooding conditions as those of the late type.

Seed of Viking, the most prominent variety of this type, is available.

Late type: The varieties of the late type trefoil begin growth somewhat later in the spring than the early types and bloom 15 to 20 days later (late June early July). They are adapted to poorly drained situations and will withstand pH values that range from 4.5 to 8.0.

Empire and Leo varieties are available.

There are about 990,000 seeds per kilogram in birdsfoot trefoil. Seedling rates of 11 to 17 kg/ha. (10-15 lb/ac) of birdsfoot trefoil are used when seeding alone or in mixtures with grass. This legume is used in mixtures with creeping red fescue 20 kg/ha.(18 lb/ac) or tall fescue 11 kg/ha. (10 lb/ac) in most reclamation projects. Neither of these grass species "out compete" the trefoil seedlings. Other aggressive grasses, such as bromegrass or orchardgrass, do offer too much competition to the trefoil. Birdsfoot trefoil must be sown in the spring (April-June) when moisture is available or during the very early spring or late winter (March) when the depth of snow is shallow and the soil is freezing and thawing which covers the seed.

Crown Vetch (Cornilla varia L.)

Crown vetch is a perennial legume which has become very popular for use on mine spoil tips and on embankments along roadways and dam faces.

It is adapted over a wide geographic area in Canada and the United States, extending from Newfoundland in the east to British Columbia in the west and south to the states of Nebraska and Alabama.

It is deep rooted, winter hardy and drought tolerant. It does not withstand poorly drained soils and requires a pH value of above 5.5 to persist and grow. Ideally, the pH should be between 6.0 to 7.0. Crown vetch has underground rhizomes which spread through the surface of the soil. These bind the soil and prevent erosion.

It is a "low maintenance crop" and is aesthetically pleasing. The semi-reclining habit of growth does not require cutting. The mature plant has coarse stems from .9 to 1.5 metres (3 to 5 feet) in length, but the vertical height may not be more than .3 to .6 metres (1 to 2 feet). The plant blooms from mid-June to August, and the whitish-pink to purplish-pink flowers are attractive to the sight and to bees.

Varieties of Crown Vetch are Penngift, Emerald and Chemung. However, obtaining a satisfactory establishment of crown vetch is difficult. This is due to the fact the seed germinates late and is under severe competition from the established weeds and other crops. In addition, a high proportion of the seed is "hard". The hard coat inhibits the intake of water, thus germination of the hard seed does not occur. In most cases, the hard seed coat is ruptured by the freezing and thawing during the ensuing winter. Germination is thus delayed until the following spring.

There are about 245,000 seeds/kilogram (110,000 seeds/pound) of crown vetch. The crop can be established by planting seedlings or by sowing seed. The former method is used when small difficult areas are to be established. The seed is planted in small pots filled with a soil-peat mixture in a greenhouse about six to eight weeks prior to the time of field planting. The seedlings, 15 to 20 centimetres (6-8 inches) tall, are planted in .6 to .9 metre (2 to 3 foot) intervals on the square. Seeding of crown vetch should be made in late May or early June after the soil has become warm. It is seeded at a rate of about 22 kg/ha. (20 lbs/ac). Usually the crop is seeded alone. A special innoculant is required for Crown Vetch.

<u>White Clover</u> (Trifolium repens L)

White clover grows in moderately acid to slightly alkaline soils (pH 5.5 to 7.0). It is not tolerant of salinity. It is widely adapted throughout most of Canada and the United States. White cover is a perennial.

This legume has a fibrous shallow rooting system. The stems are referred to as stolons. These stolons grow along the surface of the soil, and as such, white cover has a creeping habit of growth. Stands of white clover will continue to be established by new stolons. The leaves as well as the flowers arise from the nodes of the stolons. Flowers are white.

There are three types of white clover: Ladino, white dutch, and wild white. Ladino is tall (.5 metre), less winter hardy and requires more moisture for production than the other types. White dutch is intermediate in height, between ladin and wild white, and is slightly more winter hardy than Ladino. It will also withstand drought conditions more than Ladino. The fatter two types are used in reclamation projects.

There are no varieties of either of the latter two types. There are about 1,760,000 seeds/kg. (800,000 seeds/lb.) of white clover. It is included in mixture with grasses and other legumes and is considered the "bottom" vegetation. The seed germinates rapidly and may offer competition to the slower germinating species. Thus, only two to three kilograms per hectare of seed are included in the mixture.

Red clover (Trifolium nratense L)and alsike clover (Trifolium hvbridum L)

The seed of both clovers germinate rapidly but they are relatively short lived species (1 to 2 yrs.). They are adapted to poorly drained soils and possess tolerance to low pH values. They are used in mixtures as the "early growing species". Seeding rates of these clovers are 2 to 5 kg/ha. (2 to 4 lb/ac) for red clover and 7 to 10 kg/ha. (6 to 8 lb/ac) for alsike. The innoculant for these two species is combined in a mixture available at seed houses. Red and alsike clover should be planted in early spring (April - early June) or in a dormant seeding during the winter.

Grasses

There are considerably more grasses than legumes that are available and could be used in the reclamation of mine tailings. However, there are a few that have proven to be ideal for most situations encountered. They are creeping red fescue (Festuca rubra L), tall fescue (Festuca arundinacea L), bromegrass (Bronus inermis L), red top (Agrostis alba L), Canada bluegrass (Poa compressa L), Kentucky bluegrass (Poa pratensis L), and reed canary (Phalaris arundinacea).

Red Fescue

There are two types: Creeping red fescue which possesses a creeping root system, and Chewings fescue which has a tufts or bunch root system. The former is used most extensively in reclamation projects because of its "soil binding qualities". Both types are long lived perennials and are winter hardy.

Creeping red fescue has a wide range of adaptation to soil pH values (4.5 to 8.0), to soil moisture conditions (poor to droughty) and grows well under shade conditions. The species has a very fine leaf and will grow under shade conditions. It is not as tolerant to alkaline soil conditions as tall fescue.

This species is used extensively in lawn mixtures, particularly those used in shady areas in all provinces of Canada. Varieties have been developed within regions of Canada and the United States and are recommended on a local or regional basis.

There are about 1,430,000 seeds/kg. (650,000 seeds/lb.) of red fescue. The seed is long and narrow, and therefore, relatively difficult to sow. It has been used extensively in mixtures with birdsfoot trefoil at a rate of 20 kg/ha. (18 lb/ac). When red fescue is sown alone, it could be sown in the fall of the year, however, when sown with birdsfoot trefoil, it must be sown early in the spring.

Tall Fescue

In contrast to creeping red fescue, tall fescue grows to heights ranging from 60 to 80 cms. Tall fescue has coarse wide leaves with serrated edges and a deep fibrous root system. It is a perennial which has a wide range of adaptability to acid and alkaline soil conditions (3.0 to 8.5), to soil moisture conditions (poorly drained to dry soils), and is more tolerant to droughty and saline soil conditions than red fescue. It begins growth early in the spring and grows late into the fall. This species, however, is somewhat less winter hardy than red fescue. Thus, its use in northern areas where there is little snow cover during the winter should be avoided.

There are about 500,000 seeds/kg. (230,000 seeds/lb.) of tall fescue. The seeds are large, but they “feed” easily through a grain drill. There are a number of varieties available from commercial sources, all of which would be adaptable for use on mine tailings. This species is used in mixture at a rate of 7 to 9 kg/ha. (6 to 8 lb/ac). When seeded alone, rates of 11 to 13 kg/ha. (10 to 12 lb/ac) are used. It could be sown in the fall (August-September) when in “all grass mixtures or alone",.but when mixed with legumes, it should be sown in the spring (April-early June) or as a dormant seeding during the winter months.

Bromegrass

Smooth bromegrass is a long lived perennial with a creeping root habit. It forms a dense heavy sod which resists erosion. The species is wide leaved with a deep green color which begins growth early in the spring but does not recover readily if cut or harvested in the early summer. It does not grow late into the fall. It is adapted to soil pH levels ranging from 4.5 to 8.0, and is very drought resistant and moderately tolerant to poorly drained soils.

It is adapted for use across Canada and is widely used in agriculture and has found considerable use in the control of erosion and stabilization of ditch banks, road sides and on strip mine soils. Without clipping management and nitrogen fertilizer, bromegrass should not be used on sites where aesthetics are important.

There are about 330,000 seeds/kg. (150,000 seeds/lb.) of bromegrass. The bulky seed is difficult to sow through a seed drill. It is usually mixed with a legume (alfalfa) at a rate of 9 to 11 kg/ha. (8-10 lb/ac). When seeded alone (ditchbanks, etc.) bromegrass is sown at 11 to 17 kg/ha. (10 to 15 lb./ac). When sown alone or in mixtures with other grasses (no legumes) it can be seeded in the fall (Aug.-Sept.). However, when sown with a legume, it should be sown either in the spring (April-early June) or as a dormant seeding in March.

Red Top

Red top is a medium fine leaved, low growing species, .3 - .5 metre (1 - 1.5 ft.), that is adapted to poor drainage, to very acid soils (pH 3.5) and to low fertility conditions. It has a creeping root system which makes the species ideally suited for acidic, high water table sites. It does not have much tolerance to alkaline or saline soil conditions. However, once established, the species will withstand summer drought.

The species is well adapted to the climate of eastern Canada and northeastern United States. Although there are no varieties of this species available, commercial seed is produced and available often in limited quantities.

The seed is small, 11,000,000 seeds/kg. (4,990,000 seeds/lb.) and does not germinate rapidly. Thus establishment problems may occur. However, when sown at a shallow depth (< 6 cm.), at rates of 22 kg/ha. (20 lbs/ac.) and in the fall (August-September) when moist conditions are present, excellent stands will occur. It can be sown alone in very poorly drained areas, 22 kg/ha. (20 lbs./ac.), or in mixtures with other grasses or legumes.

Canada **Bluegrass**

Canada Bluegrass is one of the most prevalent species found on the dry terminal moraine and shallow (5-15 cm. above bedrock) soil in Ontario. It is a low growing, very drought tolerant species that will exist under low fertility and slightly acid conditions. Under natural conditions, this species will colonize areas that are too well drained or draughty for red top.

This species has a slightly coarser leaf than Kentucky bluegrass, but has a very. pleasant blue color. It begins growth early in the spring (late April to early May) and grows late into the fall. Summer growth often is slow due to its drought escaping mechanism.

There are no varieties of Canada Bluegrass available on the market. However, adequate amounts of commercial Bluegrass seed are usually available.

The seed is small, 5,510,000 seeds/kg. (2,500,000 seeds/lb.), and the germination is slow (two to three weeks). Establishment may, therefore, present a problem. It can be seeded alone at a rate of from 11 to 17 kg/ha. (10 to 15 lbs./ác.) or included in mixtures on dry sites at 3 to 6 kg/ha. (3 to 5 lbs./ac). Sowings made in the fall or early spring are successful.

Kentucky Bluegrass

Kentucky Bluegrass is a very important lawn grass in Canada and the United States. It is a long lived perennial with a shallow, creeping root system. The leaves are dark green in color with a shiny undersurface. **It grows** to a height of **.3** to **.5** metres if left uncut. It will withstand cutting, It is adapted to well drained, slightly acid to alkaline soils. It lacks the drought resistance of Canada bluegrass, and therefore, should not be used in areas where drought is prevalent or irrigation is lacking.

The major use of this species would be for areas that are designated for parks. It has some tolerance to tramping, but not as tolerant as tall fescue or Canada Bluegrass.

The seed is small, 2,710,000 seeds/kg. (1,230,000 seeds/lb.). Often stands of this species are difficult to obtain. Thus large seeding rates are used, 45 - 135 kg/ha. (40-120 lbs./ac.). There are numerous varieties of Kentucky Bluegrass available on the market, each having certain characteristics which may influence the choice (i.e. leaf color, disease resistance, etc.). It is usually included in mixture with red fescue, Canada Bluegrass, and annual rye grass.

Reed Canary

This species is adapted to very poorly drained or flooded soils and has been known to withstand such conditions for as long as 50 days (ASA pp292). It has a wide range of adaptability to soil pH levels (4.9 to 8.2). It is more drought resistant than some other cool season grasses (timothy, orchard grass). It spreads by short underground rhizomes which results in a dense sod.

It is tall (1.2 to 1.5 m at maturity) with coarse broad leaves. The leaves are deep green in color and will remain so during the summer months. It is pleasing aesthetically only when managed (mowed).

Its main use has been on poorly drained areas where management (cutting) is difficult or impossible and where a dense sod cover is required to reduce erosion. It is adapted and used mainly in reclamation projects in eastern Canada and United States. It has been used extensively for areas where liquid sewage and industrial waste is spray irrigated, on ditch banks where the water table is high and ditch banks are prone to erosion.

Mixture of Species

Under most situations, mixtures of grasses or mixtures containing grasses and legumes are used to rehabilitate mine tailing. The correct choice of the individual species for the mixture, however, is the major key to success. But the combination of compatible species and correct proportion of each species into a mixture is also a factor in success. A factor to be considered in judging the success of the choice of a mixture is the eventual return of the natural vegetation to the site. In most cases, the choice of species and the mixtures are designed to permit the colonization of the natural vegetation (i.e. indigenous or natural grasses and trees adapted to the area).

There are two general types of mixtures used in reclamation projects: simple (one or two species) and complex (more than two or three species). Both of these types are important and are used extensively.

Simple mixtures which may consist of one grass, one legume or two grasses or a legume and a grass are designed and used under specific conditions - for example: reed canary used alone on stream banks or in ponds, or where the conditions at the site have been precisely defined and species are available and adapted to them (i.e. saline tolerant species (tall fescue) sown on pockets where high salts are present in an otherwise slightly acid or neutral dam on which red fescue is required). As well, these simple mixtures may be used to provide rapid cover to prevent erosion. For the most part, such mixtures have been well tested under field conditions and have been found to perform very well. Indeed, the natural vegetation has been shown to appear in three years following a successful establishment of the single species and mixtures. Examples of some of the simple mixtures used are:

i. Monocultures - Single Species
- Red Fescue
- Tall Fescue
- Bromegrass
- Reed Canary
- Crown Vetch

ii. Two species grass mixtures
- Red Fescue + Tall Fescue

iii. Two species legume grass mixtures
- Birdsfoot Trefoil + Red Fescue
- Birdsfoot Trefoil + Tall Fescue

The latter two species mixtures were developed by Noranda Minerals Inc. It has been used with-success at Normetal, Waite Amulet, Agnew Lake and Noranda.

A) for wet, very fine grained areas -

60% Tall Fescue (Festuca arundinancea Schreb)
40% Birdsfoot Trefoil (Lotus corniculatus L.)

B) for dryer, coarser grained areas -

60% Creeping Red Fescue (Festuca rubia L.)
40% Birdsfoot Trefoil (Lotus corniculatus L.)

The percentage indicates the proportion by weight of each species in the seed mixture.

Under situations where the conditions of the site are not well defined or there is a great deal of diversity in the physical and chemical conditions across the site, complex mixtures (more than three species) are used. They contain a number of species, each of which has been chosen because of its need and adaptability to the site. The advantage of this type of mixture is that one or more of the species may become dominant over all of the site or may colonize specific areas within the site to which they are particularly adapted. Seeding rates of these mixtures are often high. There are a number of mixtures that have been used on tailing areas. Inco has developed a complex mixture that has proven to have potential.

Inco Limited Tailings Grass Seed Mixture

25% Canada Blue Grass (Poa compressa L.)
25% Red Top (Agrostis gigantea Roth.)
15% Timothy (Phleum pratense LK.)
15% Kentucky Blue Grass (Poa pratensis L.)
10% Tall Fescue (Festuca arundinacea Schreb.)
10% Creeping Red Fescue (Festuca rubra L.)

The percentage indicates the proportion by weight of each species in the seed mixture.

Legumes, usually Birdsfoot trefoil (Lotus corniculatus L.), are sown into the herbacious cover during the first or second spring after the original seeding, using a power till seeder.

Thirgood (1978) listed a number of mixtures that include species that are adapted to tundra sites, boreal sites and to wet and dry sites south of 52 degrees north latitude.

The factors to be considered in species selection are:

1. The selection of the species to be used in a particular project should be based on the observation of the same or similar species growing in the surrounding area under natural conditions.

2. The species used should be adaptable to the climatic conditions of the site.

3. Consideration should be given, when selecting the species to be used, to their adaptability to the conditi.ons found in the seed bed at the site; e.g. moisture level, water table level, soil porosity, **pH,** nutrient availability, metal toxicity, etc.

4. The species' capability of fitting a management plan to achieve a self-sustaining vegetative cover.

5. The species to be used on a particular site must meet any and all regulatory guidelines or regulations which may be or are in effect for the particular area.

MULCHES AND CHEMICAL STABILIZERS

The physical characteristics of the tailings as well as the topographical features of the location most often present a serious problem in vegetation of tailings discharge areas. The site may have a high water table. The coarse texture of the mine tailings enhances loss of growth water causing drought. Parts or all of the site may be steep or unaccessible to equipment, thus the use of farm machinery to prepare a seed bed is frequently restricted. Without the use of cultivation and packing equipment to level, to prepare a fine, firm seed bed and/or seeding equipment to place the small seeds of the grasses and legumes at the proper depth (0.6 cm), success in establishment is markedly reduced.

The use and value of mulches at the time of sowing has been recognized for a long period of time. They protect the soil by shielding it from the impact of raindrops, they retard water-flow and soil erosion, they increase water retention. They enhance plant establishment. They act as a substitute for shallow planting. They are a method of “seed coverage”. They retain the surface “growth” water which the seedling requires to germinate and develop. They prevent the surface soil from crusting. They modify the surface soil temperatures and protect the seedlings from the extremes of the existing temperature and moisture conditions.

In the vegetation of tailings discharge areas, the use of mulch has become a very valued tool in the vegetation process, particularly on sites which are considered dry or on locations where farm machinery cannot be easily or safely used. In some cases, organic mulches (straw, hay) are used as a replacement for the cereal grain companion crop on sites which have been prepared by farm machinery. In most of the inaccessible areas of a site, organic mulches, chemical stabilizers and fertilizers have been mixed in solution with seed and applied with success by hydroseeding.

Mulches are defined as organic or inorganic material that is applied to the soil surface. Stabilizers are organic or inorganic compounds which are applied in water solutions. Stabilizers form a protective film on the surface of the soil or infiltrate in to the soil and “bind” the soil particles together. Stabilizers should:

prevent wind and water erosion as soon as applied, decompose following establishment of the seedlings, retain moisture from evaportation, resist freezing temperatures, be easily handled, and be suitable for most soils. They should not be toxic to seedlings or the surroundings, retard germination, corrode equipment or be hazardous to living organisms, and they should not prevent moisture from entering into the soil nor prevent the exchange of gases (carbon dioxide & oxygen) between the soil and the air.. They should not prevent the emergence of the seedling from the soil.

Mulches

All mulches are organic in nature and are generally classified as either long fibre or short fibre. The most common long fibre mulches are straw and hay. The short fibre mulches are those derived from the forest industry, such as wood fibre, bark, wood chips or sawdust, and those obtained from industrial manufacturing processes (i.e. fibre glass).

Long Fibre

Straw and hay are the most common mulches used and are considered to be among the best of all the mulches. In particular, straw alone or with asphalt or fastened with netting has rated better in trials than many manufactured mulches. They conserve moisture, dissipate the energy from the raindrops and solar radiation and reduce erosion. They can be applied by hand or they can be distributed by a "mulch blower" which cuts, shreds and scatters the material evenly over the area. The straw blowers or spreaders have a capacity of about 13.6 metric tonnes/hour and spread the material up to distances of 25 metres.

Barley (Hordeum vulgare L), oats (Avena sativa L) or wheat (Triticium aestivum L) are the most common crops from which straws can be obtained. Grasses. or mixtures of grass and legumes harvested as hay may be available in the area. In recent years, the availability of these materials has become increasingly difficult due to drought conditions and cost. Both the straw and the hay must be free of noxious weeds and seeds. The weed or the seed of the crop (barley, etc.) will germinate, grow and offer competition to the establishing seedlings. In addition, the introduction of weeds to the area would be undesirable.

The amount applied will depend a great deal upon the erodibility of the site and the kind of mulch material available. In general, about 2.0 mt/ha. are used. However, where crimping is to be practiced or netting applied, higher rates (4.5 mt/ha)can be used. (Meyer et al 1970 in Kay pp 469).

Both mulches usually need to be held in place against the wind until plant growth starts. The most common method of holding the straw in place is by “crimping”, “rolling” or by covering with a netting or spraying with a “tackifier”.

Crimping is accomplished using commercial machines which have blunt, notched disks which force the straw into the notched portions of the soil by the heavy weight of the machine. Rolling or disking is done with a specifically designed roller. It has straight studs and is of sufficient weight as to incorporate the straw into the soil and have a uniform surface.

A number of netting products have been developed and are used especially on steep slopes. They are available in twisted paper, plastic fabric, poultry netting, concrete reinforcing wire, and jute forms. They must be sufficiently anchored to prevent the wind from whipping the netting. Cost of the netting and its installation are factors that must be considered.

The use of tackifiers is the most common method of holding straw or hay in reclamation projects. It is particularly valuable on relative steep slopes which are inaccessible to crimping or rolling equipment. Asphalt emulsion, the most common tackifier, is applied at 19 to 47 kg/ha, either over the straw or applied simultaneously with the straw blowing operation. Kay (1976) reported that products such as Terratack I and II, which are made from guar and seaweed extracts respectively, are equally as effective as asphalt and environmentally more acceptable. As well, a number of emulsion products from the paint and adhesive industries are available. Wood fibre alone was shown to be effective for short periods of time.

Short Fibre Mulches

Wood fibre is a fine-textured, short-fibre wood product which is produced from wood chips. It is designed specifically for use in hydroseeders. It can serve as a short term tackifier for straw and hay applications.

It is best used on steep slopes where conventional seeding and mulching with hay or straw cannot be practiced or on relatively flat areas where soil erosion will not be a significant problem.

Wood fibre when applied in hydroseeders can be mixed with the seed and fertilizer. It is usually applied at a rate of 1,120 kg/ha. to 1,680 kg/ha. (1,000 to 1,500 lb./ac).

Paper mulch is derived from processing old newsprint through a hammermill. It is commonly referred to as wood cellulose. The fibres in this wood cellulose are short, and the longevity of the mulch is less than the long fibre types. It is applied with' hydroseeders in a slurry at a rate of about 1,680 kg/ha. (1,500 lbs./ac). in tests, paper slurry mulch resulted in satisfactory establishment of vegetation, but the residue did not remain as long as straw applied with an asphalt tackifier of wood fibre.

Bark is waste product from sawmills and is available in most mining areas. The bark may be used as it comes from the debarker at the mill, or it may be hogged to reduce it to a more uniform size.

Up to 28 kg/ha. (25 lb/ac.) of elemental nitrogen should be applied. The recommended rate of application of bark is 47 to 57 m^3/ha. (25 to 30 yds/acre).

Wood chips are another waste product derived from chipping branches, shrubs and trees during the clearing operation of forestry. The chips may be spread with a straw mulcher after the seed and fertilizer have been applied. If applied to the surface of the soil, no nitrogen fertilizer need be applied. If incorporated, at least 28 kg/ha. (25 lbs/ac.) of elemental nitrogen should be applied at seeding time. The rate of application of wood chips is 57 m^3/ha. (30 yd^3/ac).

Sawdust is a by-product of the lumber-industry and can be used as a mulch or as a soil amendment material. On the surface, when dry, it is subject to wind erosion and will disappear due to water flow on steep slopes. Additional nitrogen should be applied at seeding time at a rate of 28 to 56 kg/ha. (25 to 50 lb/ac) per 1 tonne of sawdust.

Nitrogen should also be applied in the second year at about one-half that of the first year. Sawdust is applied to a depth of from 5 to 15 cm and at a rate of 520 to 1,530 m^3/ha. (275 to 810 yd^3/ac).

Fiberglass is another short fibered mulch. However, it is not organic in nature, and as such, will not rot, corrode or burn. As a mat or blanket, it provides long-term resistance to erosive forces when stapled tightly to the ground.

Stabilizers

Soil stabilizers have become an important part of hydroseeding on difficult and inaccessible areas.

Stabilizers are applied to the soil surface in water solutions. Most infiltrate the upper levels of the soil to a depth of about 2.5 cm. Others form a thin layer on the surface which gives temporary protection to the soil.

There are a number of products on the market that are classified by their basic formulae: polyvinyl acetate, crytlic copolymers, elastometric emulsion, and natural vegetable gums (Plass pp332). The differences among the commercially available products is related to the additives which affect curing time, crust durability, and moisture infiltration rates. Some of the products are Aerospray 70, Crust 500, Curasol AE, Enviro, MGS, Stickum, Terra Kertete, Soil Bond and Verdyol.

Selection of the product to be used should be based on the intended use, cost, availability, and field test results. (Plass). An ideal soil stabilizer should not restrict infiltration. The mechanism which affects infiltration of water is related to the binding together of the small soil particules and preventing them from "filling in" the pore spaces through which the water would move. Soil crusting can inhibit the emergence of seedlings. This is particularly true with grass and legume seedlings.

The rate of application of stabilizers is dependent primarily on the soil type, but consideration should be given to the time required for protection until a suitable vegetative cover is obtained. They should be applied on a weight basis (kg. of dry solids/ha) and at a dilution rate that will produce the type of crust that will reduce erosion and not prevent seed germination.

ESTABLISHING VEGETATION

The selection of the proper species and mixture is the first step in successful vegetation of sulphide tailings areas. A second and equally important aspect of success is the establishment of a satisfactory stand of the plants. Involved in this procedure is the availability of machinery for tilling, spreading fertilizer and lime, sowing the seed, preparing the area for seeding, and of the time and depth of planting.

The machinery available for use in establishing the vegetation will be discussed in a following chapter. In many situations, farm equipment is available in the vicinity and can be used. In particular, heavy disks, packers, fertilizer spreaders, seeders and tractors are necessary. Where farm equipment is not available, heavier custom type machinery is used (i.e. hydroseeders, fertilizer distributors mounted on trucks, etc.).

In either case, the machinery should be able to apply the lime and fertilizer, incorporating it into the spoils as well as properly sow the seed.

Seed Bed Preparation

Providing that the ground contours and the drainage system have been correctly established, the next step is the preparation of the seed bed.

The best way to ensure a successful planting is to place the seed directly in the substrate or tailings. This will entail the cultivation of the surface of the tailings to a depth of 10 - 15 cms (4 - 6 ins.).

The physical condition of the surface (i.e. wet, dry, loose, open, large oxidized areas, tree remnants, etc.) **will** determine which pieces of equipment or implements will be required to do the job.

If the surface is firm and moist, but not wet, a standard farm disc will normally suffice for the initial cultivations. If the surface is dry and loose, a set of harrows is all that is required.

If the surface is oxidized with large flat plates or if there are large lumps of oxidized material present, repeated passing with an offset disc is usually sufficient. In extreme cases, it may be necessary to make the first few passes with a bulldozer or road grader fitted with ripping teeth. The oxidized layer must be broken to the depth required to permit the upward and downward movement of water to help ensure adequate "soil moisture" in a highly porous substrate.

This cultivation can be done well ahead of the actual seeding. In some cases, a lead time of 6 - 8 weeks is part of the program in order that a portion of the limestone,used to improve the pH of the substrate, can be applied 6 weeks ahead of the seeding to initiate the pH adjustment.

The presence of small egg size or smaller pieces of oxidized material is often beneficial as it provides an artificial form of soil structure to keep the substrate open for the passage of air which is necessary for root growth. In the whole cultivation process, the purpose is to establish a firm, not too loose nor too hard, seed bed. The final seed bed should be sufficiently firm that it will just cover the sole of a shoe while walking.

pH Adjustment

The most commonly used material to improve the soil pH is limestone, ground sufficiently fine to meet the specifications of agricultural grade. Bulk limestone should be used whenever possible - see the section on Lime (page 34).

From time to time, lime is available as an unwanted waste by-product of some industries (eg. cement plants, pulp and paper mills) and can be obtained at very low cost. However, the cost of handling and spreading will vary with the shape, particle size, presence of other elements, moisture content, etc. At first glance, the use of these waste by-products may look attractive cost wise, but the costs associated with using them should be carefully examined.

The rate at which the limestone should be spread will be based on the results obtained in the pot and field growth tests. The amount used should be the minimum one which gives the desired plant establishment and growth in the presviously mentioned tests.

The size and capacity of the equipment used to spread the limestone is based on the load bearing ability of the tailings surface. Bulk limestone loaded by front end loaders into large trailer type broadcast spreaders is the most viable eonomic method for large areas.

With agricultural grade limestone, there is an application problem due to the small size of the particles and the necessary dryness of the material for successful spreading. The discharge point of the spreader becomes a moving dust source point. This requires the operator of the spreader to consider such factors as wind speed and direction in organizing his spreading route to ensure an even coverage with the lime and to minimize the dust exposure to the other workers present and himself.

As previously mentioned, if the required amount of limestone per hectare is large, two applications should be made. Approximately half should be spread and worked into the surface from 6 to 8 weeks prior to seeding, and the remainder applied just prior to seeding.

Immediately after spreading, the limestone should be worked as evenly as possible, through the top 10 - 15 cms. (4 - 6") of the tailings. If the tailings are reasonably dry to powdery, one or two passes with the harrows should be all that is needed. If the tailings are on the damp side, it may be necessary to make one or two passes with the discs before using the harrows.

When the fertilizer and the limestone are being broadcast just prior to seeding, it is advisable to apply the fertilizer first. This will enable the evaluation of the coverage and provide an opportunity to make any necessary corrections to the spreading procedure. The spread of the fertilizer is normally more easily observed against the colour of the tailings than the grayish white colour of the limestone.

Due to its weight and variation in particle size, it is difficult to keep agricultural limestone evenly suspended in a water slurry, and therefore, it does not lend itself to spreading by a hydroseeder.

Fertilizing

As with limestone, the amount and analysis of the fertilizer required is based on the results in the pot growth tests and the subsequent field test plots.

The impact of this program usually necessitates the fertilizer ratio to be weighted toward a higher phosphate level. This can be accomplished by including some extra superphosphate in the fertilizer broadcast prior to seeding. This application, spread just prior to the final limestone treatment, is followed by mixing the two into the top 10 - 15 cms. (4 - 6 ins.) with the appropriate tillage implement. Only about 1/2 of the total fertilizer requirements should be applied at this time if a conventional farm seed drill is to be used for the seeding.

On slopes which are too steep to use seed drills, the total amount of fertilizer to be used is broadcast and then tilled into the surface prior to seeding. If the seeding is being done with a hydroseeder, the total amount of fertilizer along with the seed and mulch is applied in one pass of the area.

Although slightly more expensive, the use of slow release fertilizers is most helpful in prolonging the availability of nutrients for the plants and their use is recommended.

Once the seedlings develop their first true leaves, one or two light top dressings of nitrogen in the nitrate or slow release urea form are very beneficial.

If organic waste (e.g. sawdust, leaves, straw, etc.) is worked into the tailings prior to seeding or applied afterward as a mulch pressed into the surface, an additional application of nitrogen should be made.

If the pot growth tests or field tests indicate the need of adding a minor or trace element(s), it can be done by obtaining the fertilizer with the material included from a firm which custom blends fertilizer as part of their service.

In order to reduce the cost of transportation and handling, it is possible to request that the fertilizer supplier provide the fertilizer minus the filler. The filler represents a significant portion of commercial fertilizers.

Time of **Seeding**

Legume and grass seedlings must be well established before the onset of winter. Seedlings and, in particular, legume seedlings are very susceptible to winter kill. This will occur particularly where little snow accumulates to form a “protective blanket” against low temperatures. Thus, the time of seeding should provide sufficient time for the seedlings to develop to a “winter hardy stage”.

In general, all seedings should be made during or just immediately before the onset of the “best growing” period (i.e. when the probability of rain will occur and temperatures are sufficiently high to induce germination and growth). In some locations, this period occurs in early spring (April-May), in others in early summer (late May-June), and in others in August-September. The early spring dates, however, may not coincide with the suitability of the tailings to support equipment due to water table levels.

Seedings, however, can be made during periods when conditions are not conducive to germination and growth. These seedings are known as “dormant seedings” and are undertaken when conditions are such that seedings cannot be made during the most desirable periods. The time of seeding could begin in November following the freezing of the tailings and end at a time when the tailings has thawed and would not hold equipment.

Legumes for the most part (i.e. birdsfoot trefoil and crown vetch) are considered to have very low seedling vigor; that is, the seedlings do not develop rapidly. The other aspect with legumes is their need for higher temperatures for germination and growth than most cool season grasses such as brome, reed canary, red top, etc. Thus, for the most part, all mixtures containing legumes should be sown as early in the spring as possible. Experience has shown that fall seeding of these two legumes usually fails. Germination is delayed and seedling growth is slow. They enter into the winter with little root development and meager top growth. Even with what is considered an adequate snowcover, the seedlings seldom live over the winter. Thus, for the most part, the seeding dates for these legumes is early to late spring or dormant seedings.

In contrast, grasses require lower temperature for germination and growth. Late spring or summer seedings are usually not successful unless adequate moisture is available to offset the high temperatures. The choice of seeding times, therefore, is spring to early summer, and fall for dormant seeding.

Seeding Methods

There are basically 4 seeding procedures which can be used in seeding tailings:

1. The seed drill which places the seed in the soil or substrate.
2. Double corrugated roller grass (cultipacker) seeder.
3. Broadcasting which places the seed on top of the soil and requires a second operation to cover the seed.
4. Hydroseeding.

Each method has a definite place in the repertoire of methods, and its employment will depend on site particular circumstances at the time of seeding. At times, facets of each procedure may be combined partially with another of the procedures.

In all cases, the seeding should take place immediately after the final application of limestone is tilled into the surface of the tailings.

The seed drill or a combination of a standard farm seed drill and a double corrugated roller grass (cultipacker) seeder provides the optimum environment by placing the seed in the substrate for seed germination and seedling establishment. These implements are limited to and most suitable for the larger flat or gently undulating areas of the tailings inside the perimeter dams. They can also be used on some outside slopes if the grade is sufficiently gentle.

If the farm seed drill alone is used, the balance of the fertilizer, the companion crop, and permanent mixture of grass and legume seeds are sown in one operation. This will utilize the three hoppers or boxes, fertilizer, grain and grass seed, normally found on this implement.

Controls are set to obtain the desired rate of seeding or fertilizing. The grass and legume rate will be in the 54 - 66 kg./ha. (50-60 lbs./ac.) range for most mixtures. The companion or nurse crop should be seeded at a rate about two-thirds (2/3) of the usual rate for cropping purposes.

During the seeding operation, care must be taken by the operator to ensure that the seed is not planted too deeply. This frequently happens when the equipment moves from firmer ground onto lighter softer ground where the seeder will sink into the tailings and thus place the seed deeper. When planted too deep, the shoot of the germinating seed uses up extra energy in reaching the surface, and thus, the chance of successful establishment is reduced. By adjusting the depth the drill is penetrating under different surface conditions, the operator can eliminate this problem.

The seed of the companion crop should be placed about 1 inch below the surface with the "starter" fertilizer placed in bands 6 to 8 centimeters below the seed row. This band seeding method has shown to have tremendous benefit in the establishment of forage crops on land that is low in fertility. When the seed germinates and roots have developed, the needed fertilizer is readily available. The grass and legume seed should be placed on the surface where the chains attached to the drill will place them just under the surface as they are dragged over them.

If available, a cultipacker or roller should be passed over the surface after the seeding. Sometimes, just after seeding the weather will cooperate, and a rain will come along and firm the ground as well as provide the moisture required for seed germination.

The combined use of a standard farm seed drill and a double corrugated roller grass (cultipacker) seeder is the optimum seeding procedure. The first pass by the conventional farm seed drill sows all the companion crop, one half (1/2) of the total amount of grass and legume mixture and the remainder of the fertilizer. This is followed by the double corrugated roller grass (cultipacker) seeder with the balance of the grass seed. This seeder pushes the grass seed into the surface of the tailings and firmly packs the ground. The ridged pattern left after it passes over the surface is beneficial to the plant microenvironment as it provides for moisture entrapment and some surface wind velocity reduction.

If Brome grass is to be seeded as part of the total mixture, it should be seeded separately due to its size and light weight. The opportune time to seed Brome grass is by broadcasting it between the seeding by the standard seed drill and ahead of the double corrugated roller grass (cultipacker) seeder which will press the seed into the tailings.

A second method that has found considerable favor is the use of a double corrugated roller grass (cultipacker) seeder alone. This machine combines the action of packing the soil and covering the seed while sowing the seed. The seed drops to the soil surface between two rollers. The front roll firms the soil and creates a small furrow into which the seed falls. The rolls of the rear roller are offset to those of the front and cover the seed while firming the surface. This system provides for uniform sowing of seed at a uniform depth and helps to provide a firm seed bed. However, the equipment does not permit the application of fertilizer or the sowing of a companion crop.

Due to its low center of gravity and its complete contact with the ground along its width, the double corrugated roller grass (cultipacker) seeder can be used where the conventional farm seed drill cannot.

The third method of seeding is broadcasting the seed on the surface. This method is useful in small irregularly shaped flat areas or where there are obstructions such as stumps and dead standing trees as well as on slopes. The seed must be covered by a second operation if the method is used. When seeding a companion crop, it is sown first and then covered by using the harrows to bury the seed to a depth of 1 inch. The smaller seeds of the grass and legume mixture can then be broadcast over the surface. These are covered by dragging a light chain or plank over them. In some instances, a spread of small deciduous tree tops (birch, trembling aspen) attached to a spreader plank make an efficient and adequate drag for covering this seed.

In the above seeding operations, it is essential to prevent misses and the resultant gaps in the seeded areas by regularly checking the seed and fertilizer hoppers on the equipment. In addition to insuring that there is an adequate supply of the seed or fertilizer in the hopper, a visual comparison of the amounts in the other hoppers will indicate whether or not they are all feeding evenly. If they are not feeding evenly, then one of the hoppers is blocked.

The fourth seeding method is by hydroseeding where the fertilizer, seed and mulch are usually applied at the same time. This is by far the best method for steep slopes, small areas with limited accessibility, and it is often the method used to seed small isolated tailings areas. When used, it is essential that the operator apply an adequate coverage of the mulch and seed. In most cases, the water, seed, fertilizer, mulch and binder (if used) should be fed into the tank in that order with the agitators in action to keep all the materials in suspension.

Whenever possible on slopes, equipment should work across the slope instead of up and down in order to minimize the potential development of water erosion channels in old tracks or grooves left by the passage of the equipment.

The final phase of the seeding operation is the application of the mulch in the areas requiring it. Mulches are perhaps the greatest tool available for modifying the microclimatic conditions in the immediate vicinity of the young seedling or plant. By shading the ground, they reduce the loss of soil water by evaporation and reduce the reflected heat. In addition, they reduce the velocity of surface winds. In the end, as they are usually an organic material, they decompose to provide improved soil structure and a slow release of nutrients.

They should be used on slopes with a south to south-westerly exposure, on dam crests, and on high flat areas exposed to winds and excessive drought conditions. They can be applied by hydroseeders as most wood fibre or combination wood fibre and straw types are. Straw or poor quality hay can be spread on the surface and punched into the tailings by a crimper to anchor it or sprayed with a binder to hold it in place.

The possibility of including seeds of trees and shrubs in the seed mixture is receiving considerable attention at this time. A test plot was established by Herman Keller on some tailings in the Elliot Lake area of Ontario in the 1970s and the fact that it is still standing (+) indicates the potential of this practice.

If the area is to be returned to forest cover, as its end use, similar to the adjacent land cover then an early start should be made on planting seedling trees. There will be a natural invasion by some species, particularly the transition deciduous forest species, into the area once nutrients and ground cover are established.

VEGETATION MAINTENANCE

Although the objective in any tailings reclamation and vegetation program is to end up with a maintenance free site which can be walked away from, it is not always possible to do this with a one shot treatment. It must be remembered that in addition to improving the aesthetic appearance of the usually barren site with eye pleasing vegetation, the real objective is the establishment of a self-sustaining plant ecosystem. This entails the development of root systems, the accumulation of plant debris from successive seasons of annual growth, and the decomposition of this organic material to recycle the accumulated nutrients.

+ Personal comment - H. Keller, 1988.

The natural sequence of this development takes many years, and it is the reclamationist's objective to minimize this period considerably. It is recommended that provisions be made for annual, or more frequent, inspections for the first few years after the seeding. Light applications of a complete fertilizer should be applied as required based on the results of plant analysis. Of course, any area where the vegetation has not grown or has been damaged by repairs, winter kill, etc. should be reseeded.

If a soil or clay cover has been used in the program, the presence of soil micro-organisms will speed up the decomposition of organic matter and the recycling of the nutrients and thus reduce maintenance requirements.

Figure 3

SUMMARY

TAILINGS VEGET[redacted]GRAM SCHEDULE

YEAR 1

1. Site examination
2. Sampling program
3. Pot growth test
4. Consultation with regulatory personnel for the area
5. Initiate the development of an overall plan

YEAR 2

1. Continue pot growth tests if required
2. Set out field test plots on the tailings
3. Complete plan based on knowledge gained from field test plots
4. Possibly start site preparation progam

YEAR 3

1. Complete site preparation
2. Start seed bed preparation
3. Carry out required substrate amelioration
4. Seed at appropriate time

YEAR +3

1. Monitoring by analysis of plant tissue
2. Fertilize as required.

EQUIPMENT

The types and amount of equipment required to prepare, seed and maintain a mine waste area will vary from site to site and on the conditions encountered at a particular site.

Some of the equipment required in the early stages of preparation may be present at the mine site or available from local contractors who rent earth moving and scarifying equipment. Earth moving equipment such as bulldozers and graders are used to develop terrain contours suitable for using agricultural implements employed in the actual revegetation portion of the project, safely and to their maxium advantage. Both bulldozers and graders are used to develop access roads to the areas and in the case of oxidized tailings, when equipped with rippers or scarifiers, used to break up the surface crust.

In most cases, the expertise to direct this equipment will be present at the mine site, usually in the person of the "Yard Foreman" or his staff. Equipment may also be hired with an operator familiar with the limits and capabilities of the piece of equipment. In both cases, direction on what the job entails and the results desired must be given.

The primary job of the person in charge of the reclamation program at this stage is to determine in his/her mind what is required in the contouring of or access to the site and to relay this information clearly and concisely to the equipment operators or forepersons.

The implements used in the revegetation portion of the program falls into several categories. They are as follows:-

1. Tractors
2. Tillage implements
3. Fertilizer and lime spreading implements
4. Mulch applicators
5. Seeders
6. Maintenance

Before discussing these categories individually, it is essential to point out that in order to achieve successful results in any program, the operators of this equipment must be knowledgeable as well as skillful. Their ability to react to changes of ground conditions and adjust their equipment's mode of operation to compensate for the change will often be the difference between success and failure in the establishment of a vegetative cover. If a contractor has been hired to do the job, the mine management will not be responsible for the skill of his operators. However, these programs to reclaim small areas stressed by the local operation are often placed in the hands of some person at the mine site as part of his duties. The need to locate someone with the operating skill and experience is even more essential in this instance.

If the equipment for the tillage and seeding operations is to be rented from a local farmer, it might be advisable to hire him/her to operate it. His/her capabilities can be easily assessed by a casual inspection of the crops currently growing on the home farm. The other potential source of operators for these implements is in the mine employees. Many have had farm experience and will be familiar with the art as well as the practice of establishing a successful seeding.

As outlined above, the first category of equipment used in the actual revegetation is the tractor. The tractor provides the transportation and, in some cases, provides the direct operating power to a piece of equipment.

1. Tractors

The size and horsepower of the tractor to be used on tailings for revegetation work will be determined by the size and power required to operate the various implements which will be used in a particular program. The weight bearing ability of the tailing area will also limit the type of equipment being used. Tractors may have to be modified to reduce the load per unit area by increasing the size of the wheels or tracks contacting the surface.

Photo 4
Tractor Mired in Wet Tailings

The use of four wheel drive tractors makes for much easier handling, particularly turning on slopes. As well, four wheel drive tractors reduce the possibility of becoming mired (photo)in the sandy conditions frequently found in tailings areas.

All tractors used on tailings areas should have authorized roll bars and seat belts installed or be equipped with approved safety cabs. Most provinces (Ontario for one) require that all tractors, while working on land used for mining or related activities, have this safety equipment in place.

To provide year round protection from the weather for the driver, as well as meet government regulations, more and more operators are switching to using safety cabs on their tractors. Many of these cabs are equipped with air conditioning to enable the drive to work in a dust free and temperature controlled atmosphere.

In order to use the full range of implements available, it is essential that any tractor being considered for use in tailings revegetation have live power take-off (P.T.O.), a three point hitch, and a hydraulic system which can be equipped with additional pump control systems.

2. Tillage Equipment

The implements used to prepare a seed bed on tailings areas are generally the same as those used to do the same job for cultivated crops on agricultural land. The main difference is that on tailings there are seldom requirements to incorporate the organic residue from the previous year's crop into the tailings seed bed. In this respect, the cultivation of tailings uses the principles established over the years by the inhabitants of near desert areas - "stir tillage". Stir tillage, as opposed to the "turn under" tillage, is practiced in the more temperate climatic zones of the world. The mold board plough is not used in "stir tillage" and, therefore, is not an implement used in the preparation of seed beds on tailings areas.

The breaking up of the surface of older sulphide tailings which have had a sufficient period of time to have become heavily oxidized requires very strong aggressively styled implements. This need for strength and the use of abrasive resistant material in its construction to reduce the wear from the sharp sand particles of the tailings.

If the tailings area surface is heavily crusted from prolonged oxidation, it might be necessary to use a road grader or bulldozer equipped with teeth (rippers) to break the surface up to a lump or chunk size so that an offset or a regular tandem disc can, with a sufficient number of passes, reduce the material to a particle size suitable for a seed bed.

It is recommended that the first row of discs in both types be made up of notched discs and that the second row be made up of the regular entire circle discs.

2.(a) The Offset Disc

The offset discs are the heaviest, most rugged and aggressive type of discs available for tailings seed bed preparation. If these discs cannot break the surface of the tailings, the use of bulldozers or road graders equipped with ripper teeth is indicated. These discs were developed for larger scale operations in heavy agricultural land. The frame is of heavy construction, and the discs, usually 56 - 61 cms. (22" - 24") in diameter, provide the weight to keep this implement cutting into the ground. They are mounted on hydraulically operated wheels for ease of transport to and from the work area. They are towed behind the tractor and not mounted on the tractor. Their use is not limited to breaking up oxidized tailings surfaces as they can be used on the softer more workable fresher tailings. In the latter case, care should be taken to ensure they are not set to a greater depth than is required to carry out the program for the particular site. Their heavy weight can cause them to sink into the surface if not regulated, and as a result, disturb the material to a greater depth than desired or required.

Photo 5
Offset Disc

2.(b) Tandem Discs

Tandem discs are normally used for cultivating agricultural land. The sizes most commonly used on the farms with the smaller fields, as associated with the farming found near most of the mining sites in Canada, range from 2.4 m to 3 m (8-10 ft.) in width. The older models are usually pulled behind the tractor. The tandem discs are equipped with pans or racks above the discs, for adding additional weight. The added weight increases the disk penetration into the surface layer.

Most discs of this type are mounted on the tractor by a 3 point hitch system. They are an integral part of the tractor when mounted. Mounted disks are easier to transport and are ideal for working in confined areas. The two sets of discs are independently flexible which allows them to float with the ground contour. The tractor driver has control of depth penetration.

2.(c) Harrows

Harrows are the final implement used on tailings. The harrows are used to prepare a level seed bed and to incorporate and evenly distribute the fertilizer and agricultural limestone throughout the upper growth horizon or root zone area.

There are at least three types of harrows:-

1. Fixed spike toothed
2. Adjustable spike toothed, and
3. Flexible or chain type harrows.

The fixed and adjustable spike toothed harrows come in individual sections approximately 1 m. (3 ft.) wide. The toothed sections are attached to a spreader bar, usually 3 or 4 at a time to give a unit width of 3 or 4 m (9 or 12 ft.). The use of too many toothed sections on a harrow results in a loss of maneuverability efficiency by requiring a greater turning circle for the tractor.

The flexible or chain type harrows come as a single unit, either 3 or 4 m. wide (10 or 12 ft.) attached to a spreader bar. Because of their flexibility, they fit the ground contours encountered more readily than the two other types. However, due to the backward slope of the tynes, they do not stir and mix the seed bed area as well as spike toothed types.

The harrows are attached to the drawbar of the tractor by a chain connected to two points on the spreader bar. Care should be taken when turning. Ensure that the turn is wide enough so that the chain does not ride up on the inside rear tractor wheel and hit the driver from behind.

Under certain conditions, particularly in dry soft tailings, spike toothed harrows can be used in place of discs for seed bed preparation.

2.(d) Klod-Buster

A more site specific tillage implement is a “Klod-Buster”. This piece of equipment has been designed for work on steep slopes. It allows the driver and tractor to operate safely by driving along the crest of the slope and not up and down the slope or on parallel cross slope runs.

It consists of several lengths of fairly heavy chain joined together with swivels. Pieces of iron reinforcing bar are welded to individual links of the chain at regularly spaced intervals. The unit length of the chain is approximately 15 m. (50 ft.). A number of unit lengths can be shackled together to meet whatever length an individual job requires. The longer the unit will dictate the additional amount of power required to operate it. A large weighted flanged wheel is attached to the bottom end of the chain and rotates along the base of the slope. This prevents the chain from creeping up the slope. The top end of the chain is attached to the drawbar of the tractor, and the tractor is driven along the crest of the slope and parallel to it.

Photo 6
Klod-Buster

As mentioned above, this implement is site specific and is only meant for use in special situations.

3. Fertilizing and Limestone Spreading Implements

Since the providing of an adequate supply of available plant nutrients is a prerequisite to establishing vegetation on sulphide tailings areas, the selection and use of this equipment is an important facet of the overall program. The need to ensure an even distribution of the required amount of limestone to adjust the substrate pH is an important and often misunderstood basic fact of tailings revegetation.

3.(a) Spreaders which place material in rows

In the past, the basic spreader available applied the material being spread in rows or bands about 20 cms. (8 in.) apart. Their capacity was about 1,000 kg. (2,200 lbs.) and the hopper was hand loaded due to the narrow width. Although they were adequate for the spreading of limestone where eveness of coverage is not an overly critical factor, their use in the application of fertilizers where per area unit levels are much more critical left much to be desired. The rate with which the material is spread is determined by the speed over the ground as there is a direct drive from the wheel axle to the agitator. The amount ejected from the hopper is determined by the size at which the opening in the base of the hopper is set.

This, type of spreader is still useful for applications of limestone in smaller areas or in areas where there are many obstacles to navigate equipment around.

Caution. The above remarks do not indicate that the placing of fertilizer in bands below the seed, particularly the cereal grain companion crop, at seeding time is not a valid practice. It is standard practice when done with a conventional seed drill where the amount of fertilizer is being precisely monitored.

3.(b) Cyclone type spreaders

The development in the size and capacity of the cyclone type spreader to meet the needs of large scale agricultural operations has been a boon to the tailings reclamation segment of the mining industry.

In most revegetation projects on sulphide tailings, large quantities of limestone are required to neutralize high pH soils to a level which permits plant uptake of nutrients. The use of the large hopper tandem wheeled spreader, operated by the tractor's power take-off, has permitted cost reductions associated with the factor of scale. This type of equipment uses bulk limestone and is loaded by a front end loader, giving lower labour and material costs

Photo 7
Cyclone Type Spreader

The fine particle size of the limestone and the consequent dust potential makes the spreading of limestone by rear mounted cyclone spreaders on tractors impractical. The dust generated under these conditions makes the working conditions for the tractor driver completely unsatisfactory. The development of pelleted limestone is providing an answer, but presently, the price is unrealistic for large scale operations.

However, this type of cyclone spreader is most effective for the broadcast spreading of fertilizer. They can be adjusted to spread over arcs behind or at either side of the tractor on which they are mounted.

4. Mulch Applicators

Although a mulch, if required, is usually applied at the time of seeding or immediately afterward, they will be discussed at this point as their use can influence the selection of the type of seeding equipment to be used.

There are two type of mulch applicators: one which produces a dry mulch form, and the second produces a water suspension spray.

4.(a) Dry mulch applicator

The use of this type of equipment is limited to the application of straw mulches. Although it has lost some of its popularity with the introduction and increased use of hydroseeders in recent years, it still has a place in tailing revegetation.

It consists of a feed tray on which the straw bales are placed and from which the bales are fed automatically into a shredder. The loose straw then is blown out through a pipe by a jet of air generated by a powerful high speed fan. The operator is seated at the back end of the pipe above the machine. The coverage of the blown straw is controlled hydraulically by changing the pipe direction and elevation. The machine is mounted on two wheels and is towed behind a truck or wagon carrying the straw.

Photo 8
Straw Mulcher

Sometimes there is need to use a binder to hold the straw in place on the ground from time to time. A circular ring applicator containing several spray nozzles is mounted at the end of the pipe. The nozzels are oriented to spray a coat of binder on the straw as it exits the pipe. The binder is often towed behind the spreader and is pumped over to the spray nozzles.

Instead of using a binder, the mulch can be anchored in place by crimping. The crimper is similar in appearance to the disc, but the crimper discs are flat and not cupped or saucer shaped. Once the straw is spread, the crimper is towed over the area by a tractor, and the weight of the crimper pushes a part of each piece of straw into the ground anchoring it in place.

The mulching of small areas or the patching of large areas is most economically accomplished by manually spreading the straw with forks.

A straw mulch is applied only after seeding.

3.(b) Hydroseeders

Hydroseeders permit for simultaneous fertilizing, seeding and mulching of tailings. Because of this, they are frequently used on level tailings areas for seeding and mulching after the seed bed preparation has been completed. In many cases, the use of a hydroseeder for the seeding of slopes is the only practical and economically viable method.

The basic hydroseeder consists of a tank of the desired capacity with a system of either paddles or liquid recirculation by pumps to agitate the contents and keep the solids (seed, mulch, fertilizer) in suspension. The material, as a water suspension, is pumped from the tank and sprayed, on the area to be covered, from a manually operated spray gun mounted on top of the tank. The hydroseeder is mounted on a truck or a large all terrain vehicle. If necessary, hoses can be attached to the pump to reach areas which are inaccessible to the transporting vehicle.

Photo 9
Hvdroseeder

The make-up of the material used in mulches for hydroseeder varies and can include various forms of wood fibre, low quality dry pulverized vegetative matter, short straw, cotton ends, and even wastes from the food processing industry. It is beneficial, in most cases, to include a binding material, such as straw, to provide a more open texture and a tieing together of the applied mulch layer.

An advantage of the hydroseeder is that it can also be used to apply various chemicals to provide temporary dust control on temporarily inactive tailing areas.

5. <u>Seeding Equipment</u>

The success of any revegetation project ultimately rests on the proper placing of the seed in a firm seed bed containing the necessary plant nutrients to ensure healthy growth. With the time, effort and money expended to reach the seeding point on any project, it is essential that the seeding be done with utmost care.

The placing of the seed directly in the growth substate is still the best method and should be used whenever and wherever possible. There are two basic types of seeders used for this purpose:-

1. The Seed Drill (includes the Power Till Seeders)
2. The Double Corrugatred Roller Grass (Cultipacker) Seeder

In addition, there are surface seeders:-

Broadcast, and
Hydroseeders.

The use of the seed drill and the corrugated roller grass (cultipacker) seeder is limited to flat or gradually sloped land suitable for agricultural equipment.

5.(a) The Seed Drills

The common farm seed drill is usually the most available of all the types of seeding implements throughout Canada. In most instances, it will be suitable for seeding on tailings which are level and have a low slope.

The seed drill is an essential tool when a companion or nurse crop of a cereal grain is to be planted with the grass and/or legumes mixture. The basic drill consists of a two compartment hopper with one compartment fitted for dispensing the grain at a regulated rate and the other for the fertilizer which is placed in bands below the seed row, The grain is fed through a tube and placed in a furrow cut by a disk mounted below the hopper. Either a following wheel or drag chain covers up the seed. One or two seed hoppers can be attached to the drill for the seeding mixtures of grass and legume seeds.

The drill is towed behind a tractor from which, in the case of the newer drills, the depth of the seeding can be controlled hydraulically.

The two main problems which can be encountered with the seed drill are:

1. The seed tube can be easily plugged by some foreign objects in the seed. This can be eliminated by using clean seed. It is difficult to spot a plugged tube during the seeding unless there is a person riding the rear board on the drill.

2. The fertilizer and seed hopper compartments can empty without being noticed. The same person who is checking for tube blockage can also, by frequent inspections, make sure there is an adequate supply of seed and fertilizer in the respective hopper compartments.

The power till drill has the same seeding arrangement, but it is designed for seeding in established turf swards. Driven by power from the tractor, the disc which cuts the furrow to place the seed in has small hardened steel points on its circumference. These cut down through the grass surface to the mineral soil underneath and thus permit the placing of the seed in direct contact with the substrate.

The need for this type of seeder is limited to overseeding a grass area with a legume. It is necessary in some areas where climatic conditions do not favor spring seedlings and late summer seedings. Legumes require a full growing season to establish a sufficiently strong root system to resist the heaving and tearing of the roots caused by the alternate freezing and thawing of the following early spring weather. There are also a number of heavy duty renovator drills (shoe type and disc) for seeding legumes into existing grass stands.

5.(b) The Double Corrugated Roller Grass (Cultipacker) Seeder

Seeds should be buried to a depth equal to their circumference for the maximum chance of development into healthy vigorous growing seedlings. The small size of the seeds of most of the common grass species indicates that they should be planted just below the surface and in a firmly compacted seed bed. The double corrugated roller grass (cultipacker) seeder was developed for this purpose.

The double corrugated roller grass seeder consists of two sets of corrugated cast iron rollers mounted one behind the other with a larger diameter roller in front. The ridges on the rollers are offset to the extent that the ridges on the second and smaller roller are opposite the valleys of the front roller. The seed is placed in a hopper mounted above and between the rollers. The seed is ejected through regulated openings evenly spaced across the bottom on the hopper by a rotating brush or open roller feeder. The feeder is driven by a chain drive from the roller and thus the speed varies with the rate of travel over the ground.

They can be mounted on a three point tractor hitch or towed by a tractor. Due to the heavy weight of the seeder, the towed version with hydraulically controlled transport rubber tired wheels is the most economically efficient type.

Photo 10
Cultipacker Seeder

This type of seeder is recommended for seeding grass and legume seeds. It not only has a superior ability to place the seed at the right depth, but it also acts as a cultipacker and leaves a firm properly compacted seed bed.

5.(c) Broadcast Seeders

The smaller tractor mounted broadcast seeders are the same machine as is used for the broadcast application of fertilizers. The broadcast method can be used for seeding, but is not generally recommended. If used as a seeder, care must be taken to establish an even distribution of seed with no overlapping or void spaces. This can be difficult when there is sufficient wind velocity to disrupt the normal spread pattern from the seeder. In addition, the seed is placed on top of the ground, and additional operation is required to cover it. The seed can be covered by various light weight drags.

There is a small manually operated cyclone seeder. This small broadcast seeder is useful in patching small areas, or for seeding a limited area with a particular species which is more adaptable to the conditions found therein.

6. Maintenance Equipment

Other than a periodic replenishment of the plant nutrients during the early years after establishment, little or no maintenance is required. The availability of a tractor mounted fertilizer spreader is probably the only piece of maintenance equipment likely to be needed.

NOTE:
To prolong the life and reduce wear on equipment used for tailings vegetation, it is recommended that lubrication and the cleaning and/or replacement of filters be undertaken at shorter intervals than normal.

REVEGETATION NORTH OF 60 DEGREES LATITUDE

The additional problems imposed by the harsh climate on establishing vegetation on tailings in the area north of 60 degrees latitude are obvious. In some respects these conditions are similar to those experienced in establishing vegetation at the higher altitudes in mountainous country. Problems include the reduced number of appropriate species available, slow growth rates due to cooler temperatures, a shorter frost-free growing period, arid conditions and other related factors. The main difference between the high altitude soils and those in the north is that northern soils tend to be poorly drained with high water tables and are often underlain with permafrost.

The basic fundamentals for ameliorating the growth substrate with nutrients supplied by fertilizer and adjusting the pH, if required, will be the same as in the areas with more favourable climatic conditions. However, care must be taken that the nutrients are in a readily available form and yet not applied at a rate which will produce a high level of salts, resulting in toxicity problems. The use of soluble fertilizers can be considered as one means of ensuring readily available nutrients.

The variety of commercially available species of grasses and legumes will be limited. Agronomic grasses do survive in a state of reduced vigour, but they will not renew growth without regular fertilizer (Blundon and Winterhalder, 1983). The use of northern native species of grasses offers a possible economic alternative to commercial species in the north as they do not require as high a level of nutrients (Kuja and Hutchison, 1979). It may be necessary to collect and use seeds and cuttings from local indigenous plants.

The lower atmospheric and, ground, temperatures will-reduce the rate of decomposition with the consequent slower recycling of nutrients.

From the foregoing, it is apparent that establishing vegetation under the conditions found north of 60 degrees latitude poses a challenge to the resourcefulness of the individuals undertaking the project. Although it will take longer and with higher costs to achieve a satisfactory cover for tailings, it can be done.

It may be necessary to consider other methods of tailings stabilization due to the cost factors. In any case, the methods outlined in this handbook could be adapted for an undertaking of this nature. Regular observations of the progress, coupled with a flexibility in the approach which permits program modification, if required, are essential under northern conditions.

NEW AVENUES OF RESEARCH

It has been estimated that 90% of the acid generation in tailings can be traced to bacteria action. The rate at which bacteria function is controlled by the amount of oxygen available to them.

To a degree, the amount of oxygen available can be controlled by the placing of a barrier between the tailings and the atmosphere. This barrier must prevent the oxygen of the atmosphere from entering the pore spaces between the sulphide tailings particles.

The development of a vegetative cover was believed to be a possible way of doing this, as the amount of organic matter on the surface will increase slowly each year with the accumulation of plant debris or refuse from the annual growth. With time, the tailings take on the character of a soil. The upper layer produced becomes an “A” horizon and thus becomes the oxygen barrier. At the same time, the pore space between the tailings particles will become filled with the roots as they spread. Unfortunately, in the early years, the slow development of decay causing organisms in the almost sterile tailings atmosphere limits the rate of decomposition and the accompanying oxygen consumption.

Oxygen barriers develop slowly under live vegetation covers. The amount of oxygen required by roots in carrying out their normal growth function acts to increase the effectiveness of this barrier in the early years particularly. It should, however, be mentioned that the effect of vegetation on acid generation has not yet been realized.

In recent years, other methods of developing oxygen barriers have been devised and are currently moving from the laboratory stage to the field.

About the simplest method is to keep the tailings under water. In this method, adequate arrangements to handle accumulations of natural precipitation water must be established and kept in repair. This method is being seriously looked at in some provinces. The associated problem of ensuring the provision of adequate funding to maintain treatment facilities for the effluent water from the site after cessation of mining activities is under consideration. (+)

Falconbridge Mines Limited is examining the installation of both wet and dry layers of organic matter of various thicknesses as immediate in place oxygen barriers. On the former Fecunis tailings area, which has been covered with approximately 2 meters of waste rock, they are using waste material from local sources to develop possible dry covers. Digested sewage sludge from the Regional Municipality of Sudbury is being used to fill the voids of the waste rock cover in one test. This material will not only slow down diffusion of atmospheric oxygen to the tailings, but will also act as a partial source of nutrients for the ultimate vegetative cover. Another waste material composed mainly of calcium carbonate plus hydroxide from a pulp and paper mill is being used as an amendment to block the voids. An expected side benefit from both materials is the inhibition of Thiobacillus ferroxidans bacteria due to the raising of the pH. The sewage may have a further inhibiting effect due to the presence of undigested sugars.

Falconbridge is also investigating the use of domestic garbage as an oxygen barrier. A 2 meter layer of domestic garbage along with a 30 - 60 cm cover over the garbage has been installed at the Fecunis site. This treatment is expected to block the oxygen by the production of methane during the decomposition of the domestic garbage.

All of the dry covers will eventually be vegetated using existing technology.

The development of man made wet covers is under investigation on a portion of the tailings at their Falconbridge site. In essence, they are attempting to create an artificial marsh on top of their tailings (Griffiths, 1988). First of all, wood chips, sewage sludge or other organic matter is placed to a height of 30 - 60 cm on top of the tailings. It is to act as a sponge to retain the water pumped into the area and as a growth medium for aquatic plants.

Both these projects are in their early stages and although giving some indications of promise, more research is needed.

(+) Personal communication with W. Bardswick and Dr. T.H. Peters.

Both Cominco and Falconbridge have been active over the years in the investigating of intercept barriers to eliminate the upward migration of acid by capillary action. Falconbridge (Michelutti, 1978; Spires, 1975) have utilized overburden material successfully as well as waste mine rock to control this potential problem. Cominco has experimented with float rock as an intercept barrier in combination with glacial till as a base on which to establish a vegetative cover.

The information on intercept barriers will be of increasing interest as environmental trends in the mining industry continue to have sulphide wastes rejected early especially in the milling process.

The experience gained in the reconstruction of a complete ecosystem as it is progressing on Inco Limited's tailings at Copper Cliff will provide direction for many others. Their program is not static, and new methods of achieving the desired results are continually being reviewed and when merited, they are tested.

Inco's present research program, in association with Boojum Limited, in developing vegetative covers for those portions of the tailings areas with a fluctuating or a too high water table for the growing of herbaceous type of plants is of interest. Nearly all tailings areas contain acreages with similar conditions. The use of a wetland vegetative cover under these conditions in the mid north will be, no doubt, extended to sites farther north where there are shorter frost-free growing periods. The use of cattails and bulrushes on these wet to damp areas will not only provide a cover for wildlife, but will also reduce oxidation, tie up heavy metals, and have a beneficial effect on the effluent water. (Kalim, 1987).

Research into the beneficial effects of wetlands on the treatment of acid mine drainage has been pioneered by the U.S. Bureau of Mines. This biological engineering, the use of various species of lower aquatic plants to polish acidic and metal bearing tailings pond effluent prior to discharge, has been the subject of numerous research programs and papers, both in Canada and the United States.

Other companies have examined the possible uses of bacterial growth inhibitors to reduce or eliminate the activity of Thiobacillus ferroxidans to reduce acid production (Bohac and Rastogi, 1987).

It is also of interest to note that in other countries, experiments are underway to assess the potential for certain crop species for commercial production on mine wastes. Since most of the sulphide mine wastes in Canada are in the Precambrian Shield or a similar rock dominant terrain, it is unlikely that end uses other than Christmas trees, timber and/or pasture land would be suitable for commercial consideration. Whether or not the added expense of developing commercial ventures as the end use of reclaimed areas will be economically viable will require future research. This research will be on an almost site specific basis to determine methods, species and the economics for this type of venture.

A considerable amount of research is continuing in the agricultural sector to develop varieties of different grain and grass species which have a tolerance for growing in soils with high salt levels. The findings of this research will probably increase the amount of material available for use in mine waste reclamation, and as developments occur, their potential for use in solving reclamation problems should be investigated. (+)

As can be seen from the foregoing, new methods to improve the aesthetic appearance of tailings along with removing their potential adverse impact on the environment are under continuous investigation. The need for programs which can lead to the successful termination of the mining and milling activities is the goal of all mining companies. Equally important is the development of an equitable research program to carry out this work.

(+) Personal communication with S. Bengson and Dr. D.H. Peters.

APPENDIX A

REGULATIONS

REGULATIONS

The need to enact requirements to address environmental concerns related to the mining industry was recognized in the 1960s. The initial need was met principally by amending a number of Provincial and Federal statutes. Most of the amended statues were the various Mining Acts, and these were generally amended to require the mines to close out their operations at the various sites in a safe and environmentally sound manner. (Blakeman, 1989).

In the 1970s, specific statutes requiring the mining industry to carry out waste rock and tailings reclamation programs concurrent with their mining and milling operations were passed.

Many of these statutes do not deal with tailings reclamation directly. They are more specifically directed to mine and mill effluents, however, there is usually a catch-all section, in all of these statutes, which can be interpreted to require the reclamation of tailings.

In general, all of the statutes, Federal and Provincial, dealing with environmental protection in the mining industry prohibit the emission of a contaminant into the natural environment which:

1. impairs the quality of the natural environment;
2. causes injury to property, plant or animal life;
3. causes harm or discomfort to any person; or
4. impairs the health or safety of any person.

(from the Ontario Environmental Protection Act).

The following material provides a list of Federal and Provincial acts, regulations and guidelines which directly or indirectly by implication require the stabilization or reclamation of tailings areas.

NOTE: **In order for the reader to be knowledgeable of the requirements which affect the geographical area and the type of tailings to be reclaimed, it is strongly advised that the reader consult the specific federal and provincial documents containing the regulations applicable to the site.**

FEDERAL REGULATIONS

Fisheries Act, (RSO 1970, as amended)

The purpose of this Act is to prevent the contamination of inland waters and territorial seas by the addition of deleterious substances. It can indirectly require revegetation of tailings areas as a means of reducing seepage, preventing or reducing runoff, erosion, dust, etc.

Metal Mining Liquid Effluent Regulations (M.M.L.E.R.) **(SOR/77-178)**

These regulations prescribe the authorized concentrations of metals, suspended solids, radioactivity levels, pH levels, etc. permitted in the effluent or discharges from mine operations. They are administered by Environment Canada in the Yukon, Northwest Territories, the Atlantic provinces, Newfoundland, and the areas in British Columbia drained by rivers which are spawning grounds for Pacific salmon. Under agreement, Provincial agencies in the other provinces administer the M.M.L.E.R.s.

Metal Mining Liquid Effluent Guidelines (M.M.L.E.G.)

These Federal guidelines do not have the force of law, but do specify as objectives the various levels of metal concentration, pH, etc. allowed in the effluent.

The Environmental Code of Practice for Metal Mines

This code, issued in 1977 by Environment Canada, is applicable to the mining industry as a whole. It is issued in company with the M.M.L.E.R.s and the M.M.L.E.G. in publication EPS-l-WP-77-1.

The purpose of the Code is to guide mine operators in meeting the necessary level of pollution control from the exploration phase through construction, start-up, operation, phases to the close-out of the site. The section on the general rehabilitation of the site is very thorough and explicit on what is expected.

The Atomic Energy Control Act

The Atomic Energy Control Act (RSC 1970, C A-19) regulated all phases of uranium and thorium mining, milling, refining and waste management in Canada.

It is pointed out that all Provincial requirements must be as strict as or stricter than the Federal requirements.

PROVINCIAL REQUIREMENTS

Newfoundland

Newfoundland Minerals Act (1976 C-44 as amended)

Although this Act does not specifically make any mention of tailings revegetation, it does contain clauses requiring the operator to meet Federal and Provincial environmental requirements. Under these clauses, an operator could be required to carry out the required reclamation to ensure that there would be no degradation of the environment.

The Department of the Environment Act (S. Nfld. 1981, cl. 8)

This Act can require a person, a corporation or a municipality to take steps to prevent pollution.

The Waste Material Disposal Act (S. Nfld. 1973, No. 82)

Tailings disposal can be regulated under this Act.

The Environmental Assessment Act (S. Nfld. 1980, c-3)

This Act contains specific references to the reclamation of mines and ancillary sites.

Nova Scotia

The Environmental Protection Act (SNS 1973, c.6 amended 1975)

This Act outlines the conditions which must be met before a license for a disposal site will be granted.

Environmental Guidelines for Surface Mining Operations (1981)

These guidelines were developed in conjunction with the Canada Department of Mines and Energy and apply to all surface mining in the Province.

Mineral Resources Act (SNS 1975)
Metalliferous Mines and Quarries Act (SNS 1973)

These Acts authorize the Minister of Mines to issue regulations concerning the reclamation and restoration of surface lands.

New Brunswick

The Mining **Act (RSNB 1971, amended 1977)**

New Brunswick amended its Mining Act in 1977 to include specific requirements for stabilization and reclamation.

The Clean Environment Act (RSNB 1973, C. A 9)

This Act empowers the Minister to approve reclamation plans submitted under the Mining Act.

Quebec

The Mining Act (SQ-1977 as amended)

Although this Act does not directly require the mine operator to stabilize tailings, it clearly places the onus on the operator to take measures for complete containment on the mine property and reclamation to prevent the wastes from damaging the property of others.

The Environmental Quality Act (RSQ-Q-2, 1972 as amended)

This Act contains provisions which address the reclamation of mine' sites specifically.

Ontario

The Ministry of the Environment is the principal agency concerned with the reclamation of mill tailings.

The Environmental Protection Act (RSO 1980, as amended)

This Act does not directly require the reclamation of mine wastes, but clauses within it can be interpreted to indirectly require it.

Section 161, The Mining Act

The authority of this section has been delegated to the Ministry of the Environment, and it does require the reclamation of disturbed lands.

Guidelines for Environmental Control in the Ontario Mining Industry (1981)

In these guidelines, it is specifically stated that “tailings areas, dams, waste rock dumps and mill sites should be revegetated in an approved manner”. (Blakeman, Peters et al).

Manitoba

The Mines Act (Chapter M 160)

Under Sections 52 and 53 of this chapter, operators are required to protect adjoining lands and carry out the rehabilitation of surface lands during the course of mining operations and after the operations have ceased.

The Environmental Act

This Act requires that the plan submitted to obtain a license to operate a new mine must include a plan for the site rehabilitation as part of the Environmental Impact Statement.

Saskatchewan

There are no regulations or guidelines specifically directed toward tailings reclamation. However, there are requirements under pollution control legislation. (+)

(+) Personal conversation C. Potter with T.H. Peters.

The Mineral Industry Polluton Prevention Regulations

These regulations under the control of the Saskatchewan Environment and Public Safety Ministry include reclamation as a part of the overall program of pollution prevention.

The Environmental Assessment Act

This Act requires a conceptual decommissioning plan for all mining proposals. The plan must include such information as the potential acid generating capability of both the tailings and the waste rock, leachability, etc., based on the early information obtained from the drill core.

Alberta

The Land Conservation and Reclamation Act

This Act has been amended and enlarged, over the years, to cover a wide range of specific operations ranging from pipe lines to gravel pits.

It is very specific in its requirements of reclamation plans as part of the Development and Reclamation Proposal and Plan required for approval of any project which will impact on the existing environment of a site in any shape or form.

British Columbia

The Mines Act 1980

Section **6** of **this Act states** that no tailings impoundment shall be constructed or operated without the **written approval of the Chief Inspector** of Mines. **Approval** must also be obtained from the Ministry of the Environment.

A reclamation plan is required as part of the submission for approval to operate a tailings impoundment.

The Guidelines for the Design, Construction, Operation and Abandonment of Tailings Impoundments

These guidelines were issued by the Chief Inspector of Mines on December 20, 1983, and outline the requirements for tailings impoundments.

All tailings ponds and impoundment structures shall be reclaimed to the approved land use.

Yukon Territory

The Yukon Government does not have guidelines or regulations dealing with the stabilization of mine tailings. This facet of the mining industry is supervised and controlled under federal regulations.(+)

You are referred to the section on Federal Regulations earlier in this chapter.

Northwest Territories

Mining is generally controlled in the Northwest Territories by the issuing of a land lease or land use permit and a water license.

Mines situated on lands regulated by the Government of the Northwest Territories (GNWT) or Commissioner's Land fall under the regulations of the Commissioner's Land Act.

Mines situated on Territorial Lands are regulated by the Federal Government under the Territorial Lands Act and Regulations.

(+) Personal communication M.Y. Chasin with T.H. Peters

Tailings and general water/effluent are mainly regulated through a water license. Issuance of a water license is under the control of the Northwest Territories Water Board which derives its mandate from the Northern Inland Waters Act and Regulations. The Water Board and its Technical Advisory Committee review the application. They set the conditions and standards for the safe environmental operation as well as those for abandonment and restoration.

It is now becoming accepted that, in the initial review stage, the proponent provide an abandonment and restoration plan.

This enables the project to be iniated with the view to an acceptable and planned closure of the site.(+)

The "Guidelines for Abandonment and Restoration Planning for Mines in the Northwest Territories" is in draft form. It is very specific on all aspects of site abandonment including tailings. It specifically mentions possible alternatives for handling sites which are potential sources of acidic effluent.

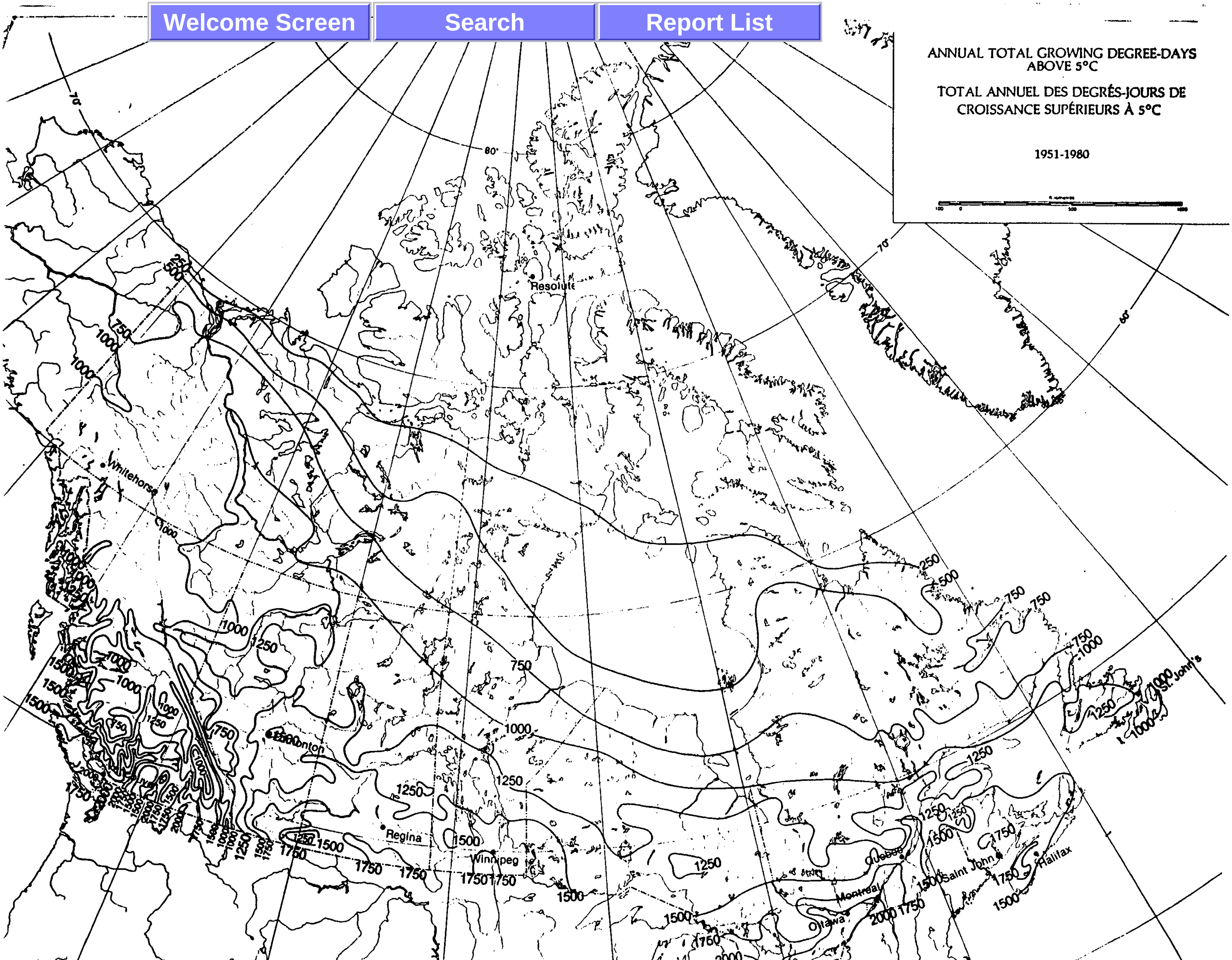
(+) Personal communication Thompson with T.H. Peters

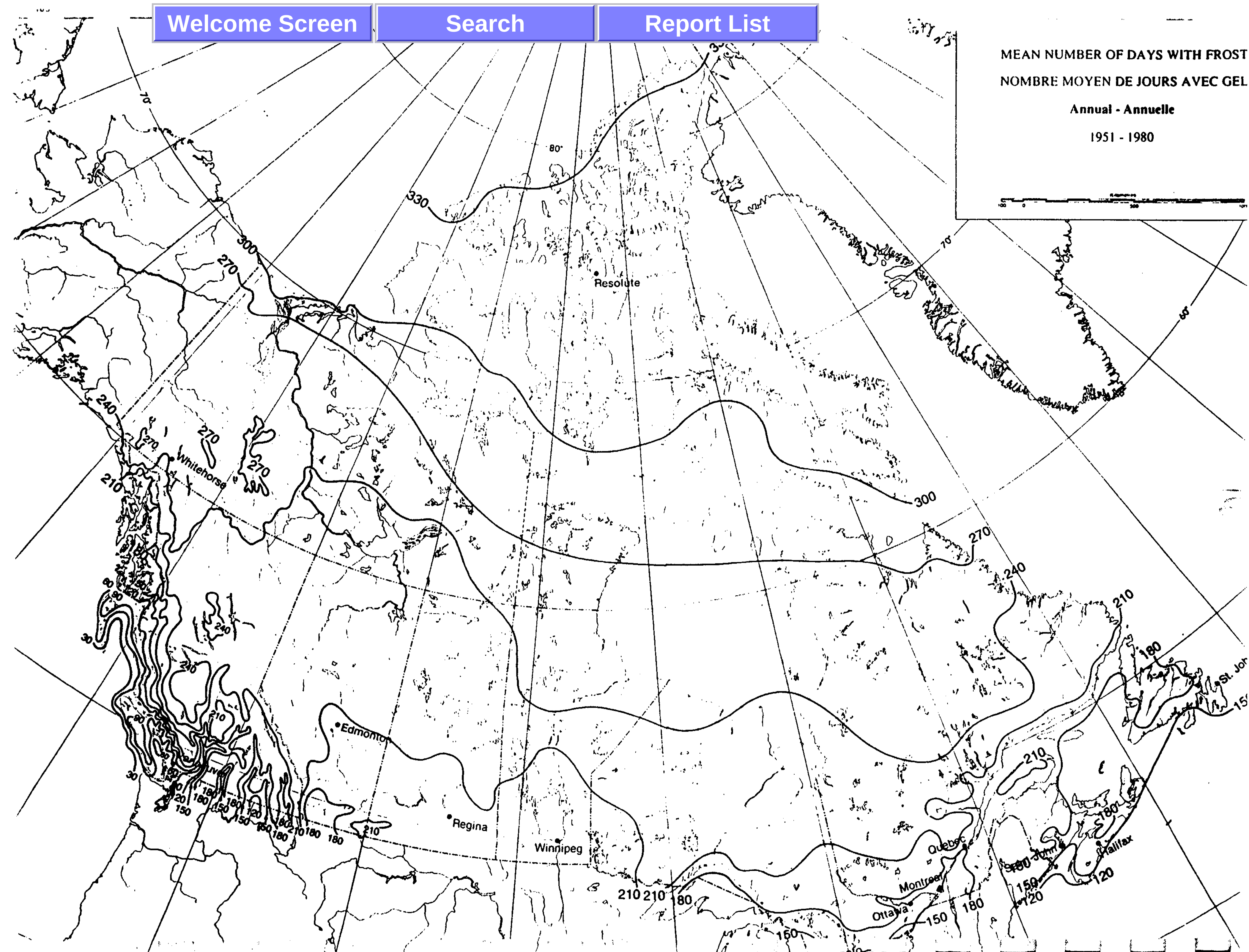
APPENDIX B

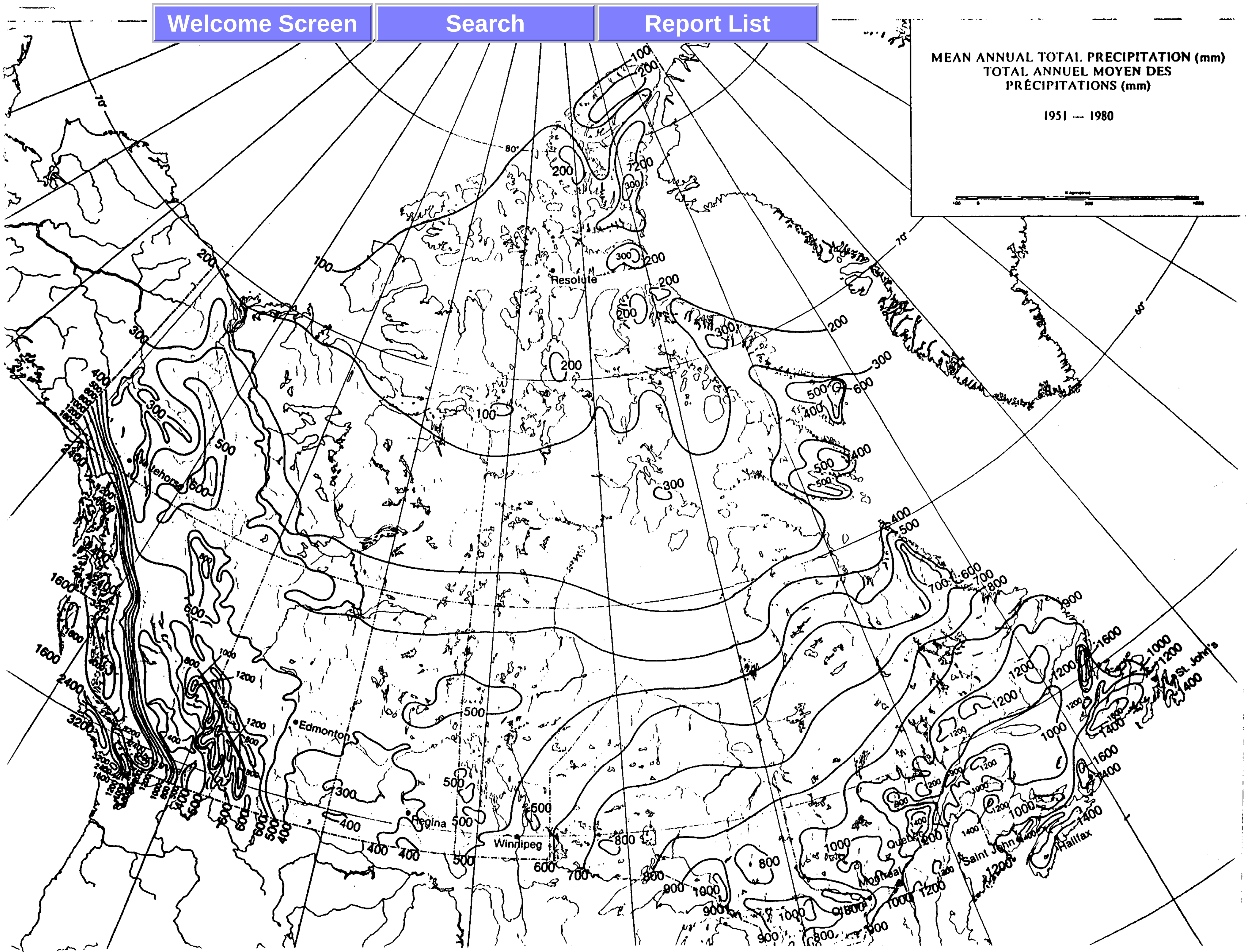
CLIMATIC MAPS

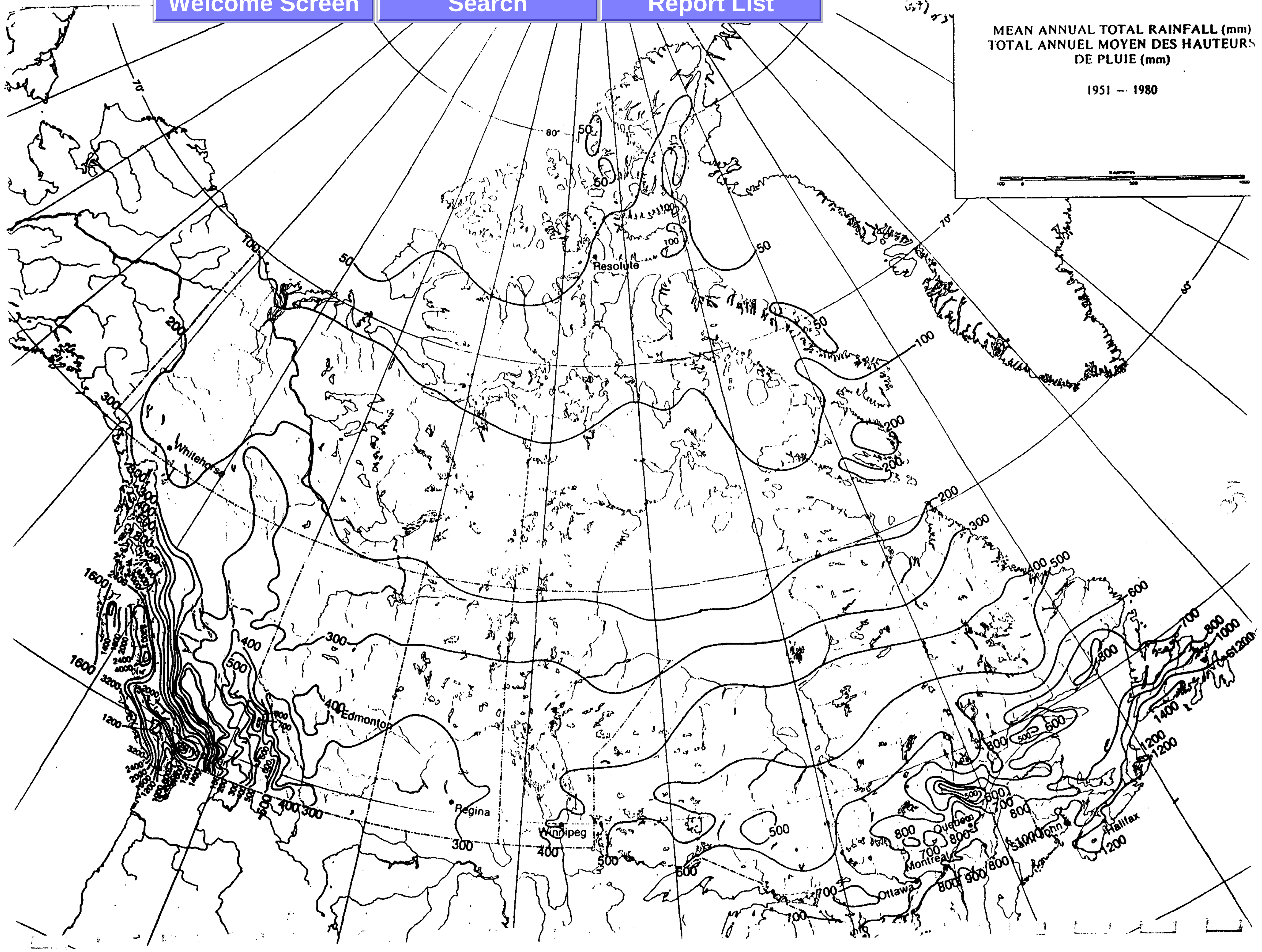
This appendix contains climatic maps which include growing degree-days, days with frost, rainfall and snowfall information. They provide a general introduction to the macro-climate of Canada. More information can be obtained from the Climatic Atlas, Atmospheric Environmental Services, Environment Canada (ISBN 0-660-52683-2), and the National Atlas of Canada published by MacMillan Company of Canada Limited. Both books should be available in the reference department of your local library.

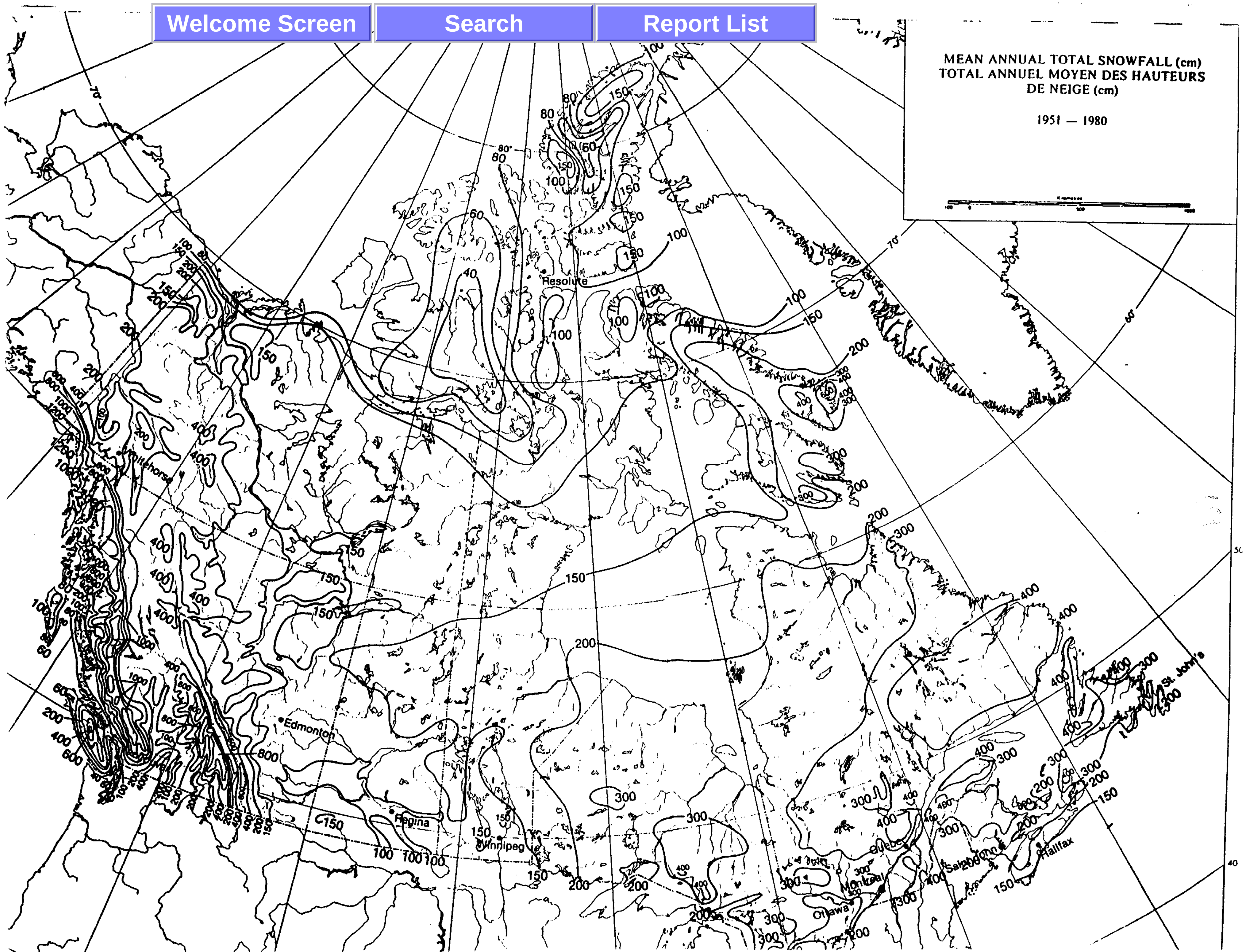
Note: Drawings in this Appendix are taken from the Climatological Atlas of Canada.


ANNUAL TOTAL GROWING DEGREE-DAYS ABOVE 5°C
TOTAL ANNUEL DES DEGRÉS-JOURS DE CROISSANCE SUPÉRIEURS À 5°C
1951-1980
Resolute
Whitehorse
Edmonton
Regina
Winnipeg
Quebec
Montreal
Ottawa
Saint John
Halifax
St. John's
250
500
750
1000
1250
1500
1750
2000


MEAN NUMBER OF DAYS WITH FROST
NOMBRE MOYEN DE JOURS AVEC GEL
Annual - Annuelle
1951 - 1980
Resolute
Whitehorse
Edmonton
Regina
Winnipeg
Quebec
Montreal
Ottawa
Halifax
330
300
270
240
210
180
150
120


MEAN ANNUAL TOTAL PRECIPITATION (mm)
TOTAL ANNUEL MOYEN DES PRÉCIPITATIONS (mm)
1951 — 1980
Resolute
Whitehorse
Edmonton
Regina
Winnipeg
Quebec
Montreal
Saint John
Halifax
St. John's


MEAN ANNUAL TOTAL RAINFALL (mm)
TOTAL ANNUEL MOYEN DES HAUTEURS DE PLUIE (mm)
1951 — 1980
Resolute
Whitehorse
Edmonton
Regina
Winnipeg
Ottawa
Montreal
Quebec
Saint John
Halifax


MEAN ANNUAL TOTAL SNOWFALL (cm)
TOTAL ANNUEL MOYEN DES HAUTEURS DE NEIGE (cm)
1951 — 1980
Resolute
Whitehorse
Edmonton
Regina
Winnipeg
Ottawa
Montreal
Quebec
Saint John
Halifax
St. John's

A P P E N D I X   C

CASE HISTORIES

The case histories appearing in this appendix are reprinted from the May 1984 Canmet Tailings Management Study by the courtesy of Energy, Mines and Resources Canada. The case Histories outline:

- Reclamation at Cominco's Bluebell and Pinchi Lake Mines
- Reclamation at Falconbridge Operations
- Reclamation Program on Inco Limited's Tailings Areas
- Reclamation at Noranda's Operations.

March, 1979

Operational Reclamation Experience at Cominco's Bluebell and Pinchi Lake Mines

1. Introduction

Operational reclamation experience at Cominco's lead-zinc and Pinchi Lake mercury properties will be described. The history of mining, biological setting, land use capability, and the nature and extent of land disturbance will be briefly summarized. The objectives, approach, and method of implementing the reclamation plan including short-term results will be illustrated and discussed in more detail.

2. Bluebell Mine

2.1 Location and History

Bluebell is located within the village of Riondel on the east shore of Kootenay Lake, about 50 km east of Nelson. The property has had a colourful mining history. Over a century ago Indians were reported to have smelted crude musket bullets using ore from the Bluebell outcrop (1). At the turn of the century about 8300 tons of ore were mined and treated in the nearby Pilot Bay mill and smelter. During 1905-1927 about 560,000. tons or ore were mined and shipped to the Trail smelter by barge and railway before Cominco acquired the property (2). from 1952-71 Cominco produced about 4.8 million tons of ore from the Bluebell grading about 5% lead and 6% zinc (3). Ore containing galena and sphalerite was mined by underground methods from sulphide replacements in limestone located under Kootenay Lake.

2.2 Ecological Settinq and Land Use Capability

Bluebell is situated on Galena Bay at 560 m elevation. The moderating climatic influence of Kootenay Lake provides more than 150 frost-free days per year and about 2 cm of precipitation per month during the growing season. Total annual precipitation is 90 cm (4). The Riondel area is classified within the Interior Western Hemlock Zone (5). The effect of southern exposure, lakeshore microclimate, and shallow soils developed on glacial till and colluvium from the bedrock outcrop have resulted in forests dominated by Douglas fir with lesser amounts of white pine, larch, cedar, birch, and cottonwood.

Riondel land has best physical capability for outdoor recreation and agriculture according to the Canada Land Inventory (6). Deer winter on south-facing slopes in the area.

2.3 Nature and Extent of Land Disturbance

Total land disturbance at Bluebell was 13 acres and consisted of the industrial site, a waste rock dump, a small tailings spill, and an open pit and mill site remaining from early mining days (Table 1). Tailings were deposited in Galena Bay. Waste rock and tailings consisted primarily of limestone, quartrite, and schist with smaller amounts of pyrrhotite, pyrite, and chalcopyrite.

During 1972-76 equipment and buildings were removed from the property and levelled to concrete foundations. Mine portals were sealed and the open pit and industrial site were fenced.

2.4 Reclamation Plan

Operational reclamation was initiated in November 1977 based on a reclamation plan submitted to the Ministry of Mines and Petroleum Resources.

2.41 Objectives

The objectives of revegetation were to stabilize disturbed land surfaces against erosion, discourage refuse disposal, enhance lakeshore recreation potential, and improve the appearance of the site.

2.42 Approach

Plant species and fertilizer programs were selected for the reclamation plan based on the results of a modest field study program carried out during 1976-77. Characterization of the chemical and physical properties of waste rock and disturbed soils usina conventional soil tests indicated that the main plant growth limiting factors were deficiency of organic matter, lack of essential plant nutrients nitrogen and phosphorus, compaction, and moisture deficiency. Species selection trials showed that grasses such as timothy, Canada bluegrass, orchard-grass, and red top established satisfactorily with fall seeding. Spring seeding was necessary for establishment of legumes such as alfalfa, birdsfoot trefoil, and alsike clover. Short term fertilizer experiments showed that incorporation of the equivalent of 56 kg/ha N, 112 kq/ha P_2O_5, and 56 kq/ha K20 before seeding resulted in satisfactory establishment of a grass-legume mixture.

2.43 Implementation and Results

Site preparation was carried out by Dorjack Contracting Ltd. of Kaslo B.C. during November 1-9, 1977 using a DB caterpillar with rippers and a 3 yd3 Caterpillar 950 Pay loader. Waste dump slopes were reduced to 10^o slope and graded to blend with the foreshore of Galena Bay. Cemented tailinas and, where possible, concrete foundations were buried with at least 45 cm depth of overburden. Metal objects, timber, and garbage were either removed from the site, burned or buried with overburden or waste rock. Cables, barrels, etc. exposed during ripping and re-sloping were removed by cutting torch.

After resloping ammonium phosphate fertilizer was broadcast on waste surfaces at 407 kg/ha using an "Erocon" air applicator. Fertilizer was incorporated to 15-30 cm depth by back-blading with the cat's brush blade or by dragging back the teeth of the payloader bucket. Compact surfaces were scarified in N-S and E-W directions before applying the seed mixture. Creeping red fescue (40%), Canada bluegrass (27%), timothy (26%). and red top (7%) were surface broadcast at 34 kg/ha using Erocon applicator and cyclone spreaders. Seed was incorporated by payloader bucket leaving contour furrows for trapping moisture on the dump surface. The Payloader pushed down or removed larae rocks exoosed in rioping and left a tidy surface appearance.

Site preparation was carried out in 7 days (21 md). Seed and fertilizer were aoplied in one day (27 mh).

In April 1978 Rambler alfalfa (50%) and birdsfoot trefoil (50%) were surface broadcast on al 1 areas at 22 kg/ha using cyclone spreaders. Later in June and September 1978 split maintenance fertilizer applications were broadcast at 224 kg/ha in the form of a complete fertilizer (13-16-10).

About 1800 trees and shrubs were planted in April 1977-78 to screen the open pit and concrete foundations. Bare root 2-0 Douglas fir, ponderosa and lodgepole pine. and paoer birch seedlinqs were supplied by the B.C. Forest Service in Nelson. Arnot bristly locust, a spiny acid-tolerant nitrogen fixing shrub, and black cottonwood were planted to restrict access to the open pit. A local resident donated 28 four year old Eastern maple trees. Trees were planted usinq pick ~~and crowbar~~.

During the initial qrowinu season the grass-legume mixture established and grew satisfactorily on areas having sufficient fines and was dominated by creeping red fescue and timothv.

2.44 Costs

About $35,000 has been spent on reclamation related activities at the Bluebell mine, During 1977-78, $27,000 was spent on planning and implementing operational reclamation (Table 2). Since 1972 $8,000 has been spent administering the Bluebell permit including preparation and submission of permit applications and renewals, annual progress reports, and a very modest field study program. Costs associated with mine abandonment such as fencing, barricading openings, security, etc. have not been included. Similarly receipts from sale of buildings and equipment were not included.

An additional $10,000 may be spent at Bluebell before reclamation is completedbringingthetotal reclamation cost to $45,000. Based on production between 1952-71, reclamation cost about 0.96 ton of ore or 9¢ ton of combined lead-zinc produced. Based on area of disturbance, reclamation will cost about $3,500/acre.

In spring 1979 maintenance fertilizer will be broadcast on all areas. Additional trees will be planted around the open pit and along the lakeshore. Althouah future plans for the property are currently undecided; revegetation has made the area compatible with neighbourinq residential areas and discouraged refuse disposal on the site.

3. Pinchi Lake Operations

3.1 Location and History

Pinchi Lake Operations is located on the north shore of Pinchi Lake, about 50 km northwest of Fort St. James and 160 km north-east of Prince George. The mine was first operated by Cominco during 1940-44 and produced 53,000 flasks of mercury from 700,000 tons of ore (1 flask = 76 lbs). The mine was re-built in 1968 and produced close to 2½ million tons of ore and 176,000 mercury flasks before shutdown in 1975 (7). Cinnabar ore-was mined by open pit and underground methods from the Pinchi limestone outcrop and treated in a concentrator and roaster (7).

3.2 Ecological Setting and Land Use Capability

The mine is situated within the Sub-Boreal Spruce Zone at an elevation of 716-814 m (5). The climate is characterized by cold winters and a short growing season. Annual precipitation averages 46 cm with 2.5-5 cm per month during the growing season (4). Forests on the Pinchi outcrop are dominated by lodgepole pine. trembling aspen, and white spruce with scattered black spruce, Douglas fir, cottonwood, birch, and alder trees. Soil parent materials vary from fine-textured glaciolacustrine silts near the lakeshore to shallow coarse-textured glacial till and colluvium at higher elevations (8).

The Pinchi Lake area was reoorted to have moderatelv hiah outdoor recreation capability near the lakeshore and was an important winter range for moose (9). Forest capability on the Pinchi outcrop was low.

3.3 Nature and Extent of Land Disturbance

The total land disturbance at Pinchi Operations is 200 acres consisting of about 34 acres of open pits and waste rock dumps, a 60 acre tailings disposal area, and 106 acres of other disturbances such as roads, the industrial site, lagoons, portals, etc. (Table 3). Twenty five percent of the disturbance consists of tailings, 25% of waste rock, and about 50% of disturbed soils.

During mine shutdown. hazardous chemicals were removed from the property, mine portalswere blocked, the West Zone Pit was fenced, the tailings dyke was raised, and a spillwav was constructed to control drainage overflow from the tailings oond. A watchman-caretaker currently resides at the site.

3.4 Reclamation Plan

3.41 Objectives

The objectives of revegetation were to imorove plant-growth conditions on disturbed mined-land to encourage succession of self-sustaining native and naturalized plant communities. An initial vegetative cover of suitable adapted arasses and legumes, established using commercial fertilizer, would rapidly stabilize waste surfaces against erosion and improve the the aoDearance of the site.

3.42 Approach

The revegetation approach was based on laboratory, growth room, and field research studies conducted since 1970 in accordance with the surface work permit. Pertinent results will be briefly summarized.

Disturbed soils and parent materials revegetated naturally within 2-5 years following disturbance. However, waste rock and tailings required application of essential plant nutrients nitrogen and phosphorus for establishment and growth of both native and commercial species. Native species invasion and survival and growth of planted conifers and seeded grasses and legumes was poor on unfertilized waste rock and tailings.

Rambler alfalfa, alsike clover, Canada bluegrass, creeping red fescue, timothy, hard fescue, and crested wheatgrass established and grew satisfactorily on waste rock and tailings and produced seed during 7 growing seasons of evaluation. Grasses and legumes were established by broadcast application of seed and fertilizer with no site preparation. Legumes and legume-grass mixtures have provided satisfactory vegetative cover, biomass, and seed production for 4 growing seasons since discontinuation of maintenance fertilizer applications.

During the first few growing seasons invasion of dense legume-grass cover by native plants was limited by competition. Eventually as cover decreased, invasion of native plants accelerated.

The mercury content of grasses and legumes grown on waste rock and tailings was slightly elevated compared to values reported for the same species grown on normal soils; but was lower than values for vegetation growing in the vicinity of mercury mineralization in B.C. (10, 11).

3.43 Implementation and Results

Reclamation at Pinchi has been on-going for a number of years. In 1971 roadcuts, a borrow pit, and portal entrances totalling 15 acres were hydroseeded. Mulch, ammonium nitrate-phosphate fertilizer (24-24-O), and a seed mixture were broadcast at 1120, 233 and 84 kg/ha respectively. In 1973 the 4 acre West Zone Pit waste dump was revegetated using hand-operated cyclone spreaders. Before seeding ammonium phosphate, ammonium nitrate, and muriate of potash fertilizer were surface broadcast to supply 56 kg/ha N, 112 kg/ha P_2O_5, and 56 kg/ha K_2O. The seed mixture was surface broadcast at 112 kg/ha. Maintenance fertiliter applications of 466 and 233 kg/ha applied as 24-0-0 were surface broadcast in 1974 and 1975 respectively.

In May 1978, 76 acres consisting of the tailings disposal area, open pits, waste rock dumps, and areas not likely to be disturbed during removal of surface structures were revegetated.

using Jet Ranger helicopter. Saturated tailings conditions in spring limited access of conventional seeding equipment.

Materials were broadcast on waste surfaces without site preparation. A complete fertilizer (13-16-10) was broadcast on waste rock and tailings at 431 and 862 kg/ha respectively. A Rambler alfalfa (30%), alsike clover (20%), creeping red fescue (25%), red top (10%), and Canada bluegrass (15%) mixture was broadcast at 56 kg/-ha.

Twenty-five tons of fertilizer and 2.2 tons of seed were applied by helicopter in 7 hours; 1.6 hours were required to fly the helicopter to and from Prince George. Fertilizer and seed were applied as follows:

a) at the.staging area a 4 man crew loaded 700 lbs of fertilizer or 300 lbs of seed in 30 seconds into two 45 gallon barrels attached to each side of the helicopter,

b) a fifth person lined up the fliaht path of the helicopter to control material application,

c) application rates were controlled by the helicopter enqineer by sliding a metal plate to vary the size of opening on the bottom of each barrel and by varying altitude and speed. At 200 feet altitude and 25 mph, materials covered a 25 foot wide strip,

d) the total time required to load, fly to the site, apply materials, and return to the staging area varied from 4½ to 5 minutes,

e) the staqinq area was generally about ½ mile from the point of materials application.

Seed and fertilizer application were uneven in some areas. To improve coverage on these areas, cyclone spreaders were used. This will be remedied in future by using 2 people to align the helicopter and by using proper cyclone applicators mounted on the helicopters.

By late October 1978 waste rock and tailings were covered with relatively uniform seedling populations. Seedlings did not establish satisfactorily on waste rock left at the natural angle of repose or where seed and fertilizer application were uneven. Fertilizer accelerated regeneration of native conifer and deciduous seedlings on waste rock. On tailings invasion of native Nuttall's alkaligrass was promoted by fertilizer. Establishment of seeded creeping red fescue and red top was satisfactory on portions of the tailings pond; but legume establishment was poor and confined to cracks. Relatively poor establishment of seeded species on tailings was attributed to a drier than normal summer.

3.44 costs

About $108,000 has been spend on reclamation related activities at Pinchi Operations since 1970. The major cost of $69,000 was spent on the research orooram and administering the surface work permit. The balance of $39,000 was spent on operational reclamation. Of this, $31,000 was spend on planning and implementing reclamation operations in 1978. (Table 2).

Reclamation cost $408/acre in 1978 and was similar to costs for revegetating the two smaller areas in 1971 and 1973. Based on production between 1968-75, reclamation cost about 4.3¢/ton of ore and 616 per flask of mercury. Including research and administration, reclamation costs to date for areas requiring no site preparation totalled $540/acre.

About 65% of the land disturbance at Pinchi has been revegetated to date. In 1979 maintenance fertilizer will be applied by helicopter to areas seeded in 1978 and dismantling and removal of surface structures will begin. Current plans are for site clean-up to be completed during 1980. The remaining 38 acres of disturbed land will be prepared for seeding in sprina 1981. If necessary an additional maintenance fertilizer aoplication will be made to 1978 areas. Assuminq satisfactory establishment on areas planned for seeding in 1981 and the need for only one maintenance fertilizer application, planned reclamation activities could be completed as early as 1982.

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Table 1: Nature and Extent of Land Disturbance and Reclamation Bluebell Operations

Nature of Disturbance	Area of Disturbance (acres)
Galena Bay waste rock dump	5.0
Open pit waste rock dump	1.0
Mill tailings pile	0.2
Cemented tailings	0.2
Old mill site	0.6
Service and storage area	6.0
	13.0

Compliments of Falconbridge Nickel Mines Limited

How to Establish Vegetation on High Iron-Sulphur Mine Tailings

by

R. E. Micheiutti

Reprint from Canadian Mining Journal.

A

How to establish vegetation on

By R. MICHELUTTI
Falconbridge Nickel Mines

The ore in the Sudbury Basin consists of a number of sulphide minerals composed predominantly of nickel, copper and iron with various other minor but valuable elements. To separate the valuable minerals from the gangue. the ore is crushed and ground to at least a fineness of 100% - 48 mesh. The copper-nickel sulphide minerals are separated from the gangue minerals by a combination of flotation and wet magnetic separation processes.

Three products result - a copper. nickel concentrate that is sent on for further processing, a pyrrhotite (iron-sulphide) concentrate that is either stockpiled or disposed of, and the tailings. Although consisting predominantly of silicate minerals, the tailings do contain minor amounts of sulphide minerals and a typical analysis will show about 0.85% sulphur. The pyrrhotite concentrate contains about 36.5% sulphur and 56.0% non.

The relatively coarse tailings fraction, above 25 microns, amounting to about 70% of the total is separated by cycloning and returned to the mine for backfill. The fine tailings or tailings slimes. generally minus 25 microns in size, is discarded, either separately or mixed with the pyrrhotite, to tailings disposal sites.

A ton of average grade Sudbury ore produces 200 lbs of concentrate. 800 lbs of tailings backfill. 500 lbs of pyrrhotite and 500 lbs of tailings slimes. Thus. half of the ore mined consists of waste products that may be disposed of on surface. If possible. land-locked basins or lakes are selected as tailings disposal sites. but if such natural depressions are unavailable the tailings slimes must be contained behind artificial dams.

Falconbridge Nickel mines over 4 million tons of ore annually and therefore each year has to dispose of some 2 million tons of tailings slimes and pyrrhotite. which occupy a volume of over 35 million cubic feet.

Seepage

When a tailings disposal area reaches its designed capacity and is abandoned there are liable to be three major problem areas, acidic seepage or run off, dust and aesthetic appeal. A properly designed and maintained tailings disposal area will minimize the problem of acidic seepage and run off, however, it is unlikely that it can be completely climinatcd.

The material constituting tailings is by its very nature a dust, and large areas denuded of vegetation may be picturesque in some locations on our planet but they cannot be considered as attractive features on the wooded landscapes of north-central Canada.

During the life of the tailings pond, water is continually seeping through it and becoming contaminated with iron and various metal sulphates. Because of the fine particulate nature of the tailings, the constituent minerals present 3 tremendous surface area, making thrm extremely susceptible lo leaching and other chemical reactions.

Where sulphide minerals are present. sulphuric acid is generated, and depending on the amount of sulphides and the composition of the gangue minerals, the pH of the seepage effluent may be in the order of 3.0 or lower and if the volume is sufficient the downstream ecological environment may be seriously endangered.

Dust storms

Once a tailings pond has dried up, the fine particles easily become windborne. This, coupled with the flat topography of tailings areas, results in severe dust storms, even at moderate wind velocities. Since the dust contains metallic salts and is easily dispersed throughout the adjoining area, widespread contamination of a watershed may result.

If residential areas or manufacturing industries are located nearby, the dust will present both a serious nuisance and incrcared problems and costs in the maintenance of machinery and equipment.

Although mining operations arc usually located in remote areas, this is not

1971

1972

high iron-sulphur mine tailings

always the case. and even so. with our increasing awareness of the necessity to preserve wilderness areas for recreational purposes. the past practice of merely abandoning tailings areas without any attempt lo restore them to their natural state is no longer acceptable.

Stabilization of tailings

Abandoned tailings areas must be stabilized to reduce or eliminate the problems previously mentioned. Various methods have been employed to reduce these problems, but most fail to eliminate all of the problems. Dust problems. for example, may be solved by placing an overburden of crushed slag, rocks or gravel on the tailings, This will not, however, reduce seepage or improve the appearance of the area.

Water cover

Another method is to completely cover the tailings area with water. Provided that dams are properly constructed to slop seepage this method will solve all three problems. The only disadvantage is that the area must always be maintained to ensure that dams won't fail and that the water cover remains. Once a mining complex becomes inoperative maintenance will normally cease and it is only under particular circumstances that this method could be acceptable.

Other methods, such as chemical stabilization with asphalt or polymers to produce a layer impervious to both air and water, also have the disadvantage of requiring maintenance. Furthermore, with this type of cover, the aesthetic quality of the area is hardly likely to be improved.

The obvious solution to the problem, if it can be achieved, is to restore the terrain to some reasonable semblance of its natural state by providing a cover of vegetation over the tailings. This method restores the aesthetic value and may even improve on the intrinsic value of the property.

Revegctation prevents the material from becoming windborne and will restrict, even though it may not entirely eliminate seepage. Also, with time, the endemic species will encroach to make the area self-sustaining.

The estabhshmcnt of vegetation on tailings, unfortunately, is not a simple task, for the following reasons:

- Tailings are unsuitable as a soil for supporting plant life for a number of reasons. The material has a poor structure lacking in aggregates. Tailings are almost entirely deficient in nutrients and in an ion exchange capacity. Proper bacterial communities are absent, and toxic concentrations of heavy metals may be present.
- Because of the extremely fine particulate nature of the tailings, dewatering takes a long time and the area remains an inaccessible bog long after the surface has dried. Specialized machinery may therefore be needed to attempt the revegetation operation
- Since the areas are large flat expanses composed of very fine particles, dust storms are common and for this reason it is essential that the entire tailings area be stabilized at one time. Otherwise established vegetation can easily he destroyed by sandblasting or burial by the unstabilized material. If it is not practical to vegetate an entire tailings area at one time it will be necessary lo provide some form of temporary stabilization to the unvegetated portion.

Nickel Rim mine tailings

Nickel Rim Mines operated a mine and concentrator between 1952 and 1958 on a property located at the east end of the Sudbury Basin approximately 7 miles north of the town of Falconbridge. During these years, some 35 acres of land were covered with tailings.

In the Nickel Rim concentrator operation, no attempt was made to recover pyrrhotite which was discarded with the tailings. Neither was any tailings used for mine back fill at this operation so the material discarded consisted of approximately two-thirds silicate gangue minerals and one-third pynhotite.

Although the silicate gangue is inert the pyrrhotite is highly reactive (8) times more so than pyrite), and under certain conditions spontaneous combustion will occur at room temperature.

$$3\,FeS + 5\,O_2 \rightarrow$$
$$Fe_3O_4 + 3\,SO_2 + 1.9 \times 10^3\ \text{K. caf. lb}^{-1}$$

Fven when mixed with tailings the heat produced by the oxidation of the pyrrhotite. where any segregation has occurred, will be sufficient to prevent the growth of any vegetation.

The present surface of the Nickel Rim tailings. from 1 in. to 5 ft in thickness, is a reddish brown colored mass of hydrated iron oxides. Greater than average concentrations of iron and sulphur are present in this oxidized surface layer because of capillary action which brings dilute salt solutions from the interior of the tailings mass to the surface. Subsequent loss of moisture at the surface due to evaporation results in a build up of metallic salts. (Table I)

The iron and sulphur accumulating at the surface produces a complex matrix known as 3 "ferruginous cap". This ferruginous cap may become as hard as concrete and virtually impossible to vegetate.

Another barrier to overcome in establishing vegetation on tailings which contain pyrrhotite is the production of sulphuric acid. Polythionates reacting with ferric sulphide result in the production of sulphuric acid which towers the pH in the oxidized layer (Table 1) to values that are intolerable to any form of vegetation.

$$Fe_2(SO_4)_3 + FeS_2 + H_2O \rightarrow$$
$$3\,FeSO_4 + 2\,S\ (7)$$

$$S + 3\,O + H_2O \rightarrow H_2SO_4$$

In 1964 Falconbridge purchased the Nickel Rim property to acquire the considerable amount of low grade ore that had not been mined. At the time pollution was not a serious concern but with changing conditions, Falconbridge subsequently became aware tftat it had not only purchased some low grade ore but also a pollution problem of considerable proportions.

Unique problem

Although the techniques for estabfishing vegetation on tailings piles of silicate minerals were well known, nothing had ever been done with the high sulphur content (pyrrhotite) tailings such as those at Nickel Rim. Falconbridge, therefore, found it necessary to embark on a research program with the objective of determining whether the establishment of a permanent cover of vegetation could be accomplished economically on this type of tailings.

This report is a summary of the research work performed by Falconbridge to date in its attempts to vegetate this troublesome area.

Research summary

Research on the vegetation of acid mine tailings commenced September 1970 by the Industrial Wastes Control Department at Falconbridge. Initial tests were conducted in a growth chamber to determine first of aff whether plant life could be made to grow at all on oxidized high iron-sulphur and acidic mine tailings. The most economical neutralizing agent and fertilizer requirements had to be determined as well as the plant species that are best adapted to this environment.

Because of Limited space in the growth chamber only one or two parameters could be investigated during each test.

TABLE 1 — ANALYSIS OF NICKEL RIM TAILINGS

	Upper Oxidired Layer	Lower Unoxidized Layer
Magnesium	4.25 %	6.4 %
Sodium	.16 %	1.64 %
Potassium	.41 %	.74 %
Calcium	4.44 %	5.53 %
Aluminum	[illegible] %	3.2 %
Sulphur	6.23 %	2.31. %
Nickel	.05 %	.220 %
Copper	.031%	.063 %
Zinc	.003%	.0128%
Cobalt	.041%	.03 %
Iron	27.9 %	12.7 %
pH	3.0	4.5

Since any solution to the problem had to be cconomicafly viahlc. it was fundamental that in conducting the experiments the materials utifited would be locally available at a reasonable cost.

Neutralization

The initial series of experiments was set up by Fedko and Michelutti (I) to determine whether the acidity of the tailings could be neutralized by the application of agricultural limestone ($CaCO_3$) and/or lime ($CaOH$) and also whether a commercial grade fertifizer (IO-IO-IO) would provide the nutrients required to sustain plant growth.

Slightly acidic alluvial sand from the Falconbridge area served as a control. Plant species for these tests were chosen from varieties suited to focal climatic conditions and on proven ability to withstand acidity and drought, as well as their availability.

Prom these preliminary tests it was quite apparent that lime and/or limestone were essential for plant growth on acid tailings. The more agricultural limestone or lime applied to the tailings, the greater the plants' longevity, (Fig. 1).

In the initial experiment all plants died within 30 days but the length of survival was directly related to the amount of neutrafiting agent provided. Since both lime and limestone produced similar rcsutts on plant vigor and longevity, the fimc was discontinued because of its corrosive nature and its potential to produce a toxic alkaline soil by over liming.

No conclusions as to the suitability of the fertilizer utilized in the experiment could he drawn since all the plants died hecause of insufficient ncutralizing agent. Ifowcvcr. the control sand pots did indicate the best application rate for 10-10-10 fertifizer to be 1/2 ton per acre.

Optimizing limestone

Having determined that limestone was essential, a second set of experiments was designed and undertaken to determine just how much would be required to ensure plant survival. For these tests the fertilizer content was maintained constant at 1/2 ton per acre.

In January 1971, Hulley set out to determine the appropriate limestone requirements for Nickel Rim mine tailings. Besides limestone content. the advisability of using 3 straw-asphalt mulch cover was also tested. Although the duration of the test was restricted to a two month period, positive results were achieved as all plants survived during this period.

It was determined that for the Nickel Rim tailings an initial dosage of IO tons of limestone per acre would be rcquircd. The test also showed that a straw mulch cover resulted in greater yields than no cover on both the sand control pots and the tailings pots, with all other conditions being equal. (Fig. 2)

Now that the appropriate limestone content had been determined and it had been shown that a mulch cover of straw-asphalt was beneficial, it was decided that the next step should he to perform cxpcrimcnts in the fictd to test the validity of the laboratory results.

In May 1971, Langford set up field tests using a randomized block design. Test plots were established on alluvial sand, inactive low iron-sulphide Falconbridge tailings (12% Fe, 1% S), and Nickel Rim mine tailings. The alluvial sand and Falconbridge tailings were to act as controls. Unfortunately the test plots on the Falconbridge tailings were mostly covered and destroyed by blowing dust in a matter of only two weeks time.

So that there would be a basis of comparison with the lab tests the fertilizer (10-10-10) was still maintained at 1/2 ton/acre on all the plots. The agricultural limestone (not more than 40% + 100 mesh), was applied at 10 tons per acre on both tailings areas and at 4 tons per acre on the alluvial sand. These tests were, therefore, an attempt to duplicate in the field what was felt to be the proper fertilizer and limestone application, based on the laboratory tests.

Because of the success obtained in the growth chamber with a mulch cover, it was also decided to test various mulches in the field. The mulches tested were: straw-asphalt, curasol (a polymer dispersion material), and a 2 *in.* soil cover. At the same time. 16 different grass and legume species were tested, in a block design. under each mulch cover. Data accumulated between May and October was analysed by Langford (3) in March 1972, with the following conclusions.

- The plant species best suited to the acidic tailings were: fall rye, bromegrass, red top, colonial bentgrass, creeping red fescue, sheep fescue, sweet clover, alfalfa and white clover.
- The mulch covers all proved to be superior to no cover.
- The greatest differences in mulch covers appeared in the test plots on the Nickel Rim tailings where a 2 in. soil cover resulted in a healthy vegetation growth compared to the other plots on these tailings where the growth was stunted and had a high mortality rate. The exact reason why this plot was successful it still not known since the soil became very acidic with a pH of 3.5 in the space of a months time. Perhaps the soil contains a greater ion exchange capacity,

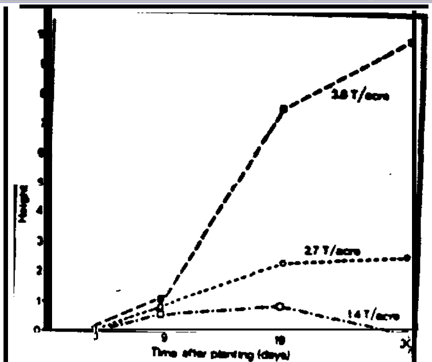


Fig. 1 Effect of limestone on Timothy in tailings

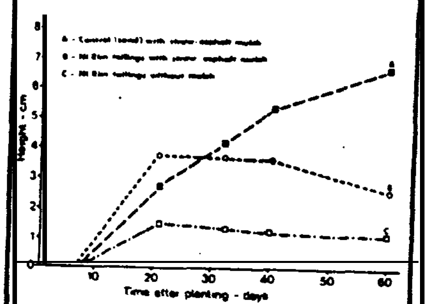
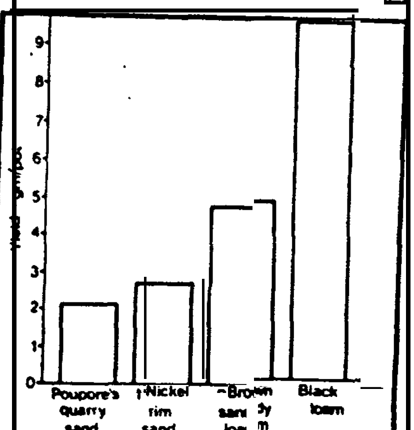


Fig. 2 Effect of straw asphalt mulch on legumes



ig 3 Comparison of topsoils

beneficial microorganisms, *or* the micronutrients required by the plants which the fertilizer does not provide. Root studies the following year showed that the roots tended to fan out a great deal in the soil cover before eventually penetrating the tailings. Perhaps this soil cover helps to establish the young plants when they are most susceptible to adverse conditions and upon maturing their root systems are then able to invade the inhospitable high iron sulphur tailings.

- The physical grade of the limestone is very important in affecting a pH change since it must be solubilized to be effective. In one test plot that was treated with 50 tons/acre of a coarse limestone (80% + 10 mesh) compared to the finer grade (60% - 100 mesh) normally used, the seeds all failed to germinate. Even after a six month observation period, there was no growth on this particular test plot.

The results of this initial field test work with the Nickel Rim tailings gave some hope that vegetation could not only be established but also maintained on this type of highly oxidized acidic tailings.

The next series of tests by Gaylor (4) set out to determine the best locally available soils for use as a cover and the optimum thickness of application. The soils were spread in 1 in., 2 in., 4 in. and 6 in. layers and not mixed at all with the underlying tailings. This was done in an attempt to reduce metallic salt concentration at the surface by applying soils having a lesser capillarity rate than the tailings.

Four locally available soils ranging from sand to loam were selected for testing in the growth chamber. 10 T/acre of limestone with 1/2 T/acre of fertilizer was applied on top of the soils. After two months, yields were determined and black loam at a 6 in. depth proved to be superior to the other soils. Even a 1 in. to 2 in. layer of black loam showed a definite improvement in plant growth over any of the other soils. (Fig. 3).

Tests conducted by Cyr (5) on soil properties had demonstrated that a loamy soil has a lower capillarity rate than sandy soils. This, coupled with the fact that black loam has a greater cation exchange capacity (8), could account for the increased yield.

A significant result was that the legumes did far better in these tests than any previous growth chamber tests, and appeared healthier than the grasses for the first time. A good legume catch is very significant in establishing vegetation over long periods of time because of their ability to fix atmospheric nitrogen in the soil.

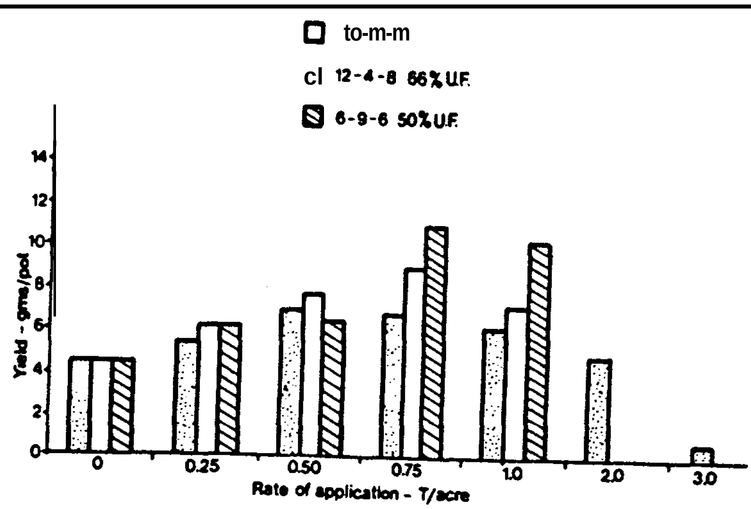


Fig. 4 Fertilizer application rates of three best fertilizers tested.

Fertilizer types

Up until this time, the fertilizer used

had been exclusively 10-10-10 N-P-K because it was readily available. Cyr (5), therefore, set out to determine whether there might be a better fertilizer to use for establishing vegetation.

Fig. 5

Five fertilizers were studied: CIL 10-10-10, CIL 6-9-6 50% U.F., CIL 12-4-8 665 U.F., CIL 15-S-10 40% U.F. and CIL 2-1-2 sheep manure.

The slow release fertilizer, 6-9-6 50% urea formaldehyde, performed the best at 3/4 T/acre (Fig. 4). The original 10-10-10 at 1/2 T/acre produced much lower yields during the 10-week duration of the experiment and over a longer period of time might have shown even greater differences. A significant observation, as shown in Fig. 4. is that an excess of fertilizer stunts plant growth and is more harmful than no fertilizer at all.

This situation has been termed physiological drought and exists when water is plentiful but a greater osmotic pressure results in the soil because of the high salt content compared to the plants roots. Water will then leave the plants to reduce the pressure gradient created and in this way the plants dehydrate. As previously mentioned, legumes are important as soil enrichment agents, and once properly established the fertilizer requirements may then be substantially reduced.

The field plots set up by Langford during May 1971, were examined by Johnston (6), Oct. 1972. for legume root nodules (Fig. 5). Preliminary observations showed that alfalfa has more nitrogen nodules than sweet clover and that legumes growing in the 2 in. soil cover have much better nodulation than legumes growing directly in the tailings.

The plants on the soil cover had most of their rout structure fanning out in the soil with portions penetrating down into the tailings. Most of the nodulation in these plants occurred in the upper root zone growing in the soil cover. This is probably attributable to a proper bacterial ecology in the soil cover, especially the nitrogen producing bacteria, nitrosomonas and nitrobacter which oxidize ammonia to nitrate.

Even though good nodulation was observed in some plants. none had the characteristic healthy pink coloration. The pink coloration is hemoglobin produced symbiotically by the bacteria and legume. More tests are therefore necessary to determine if these nodules are adequate for soil enrichment or if healthier nodulation can be induced by innoculation with the appropriate bacteria. Tests are now under way to determine the effects of innoculation on legumes.

From all the data accumulated over the past two years, some basic conclusions can be made at this time on the vegetative stabilization of the acidic high iron-sulphur tailings at Nickel Rim.

Conclusions

- The tailings area should be first covered with a 4-6 in. layer of the best locally available soil. If this soil is low in organic content, it should be supplemented with sewage sludge, manure or loam. This should reduce the rate of salt build-up at the surface as well as increase the cation exchange capacity.
- High grade fine pulverized agricultural limestone (60%-100 mesh) at 10 T/acre should then be applied to the soil cover.
- 6-9-6 50% U.F. fertilizer should then be applied at a rate of 3/4 T/acre. The slow release factor of the fertilizer will help sustain the plants for the maximum possible period of time without maintenance. Instant release fertilizers can dissolve and wash away during periods of heavy rain fall and may therefore be largely wasted.
- The seed mixture to be used on these tailings is: fall rye, bromegrass, red top, colonial, bentgrass, creeping red fescue, sheep fescue, sweet clover, purple alfalfa, and white clover. For all the test plots rye was maintained at 60 lbs/acre and the other seeds were applied at a combined total of 90 lbs/acre.
- Finally, a mulch cover of straw is extremely beneficial in protecting thr young seedlings. This will however, greatly increase the cost, and further work is necessary to determine whether the extra expense is justified.

The research performed to date has resulted in a far better understanding of the problem of establishing vegetation on highly acidic iron-sulphur tailings. The effectiveness of this method in establishing a permanent cover of vegetation that will require little or no continuing maintenance has still to be determined. Also to be determined is whether a cover of vegetation will reduce the seepage from the tailings areas sufficiently to prevent or reduce to arccptable proportions the contaminants that get into the adjacent surface drainage systems. Only by continuing lab and field test programs may it become possible to find answers to the particular questions and problems which arise when attempting to vegetate troublesome areas.

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Nitrosomonas: $NH_4 + 1.5\ O_2 \rightarrow NO_2 + 2\ H^+ + H_2O$ + 75,000 cal.

Nitrobacter: $NO_2 + 0.5\ O_2 \rightarrow NO_3$ + 20,000 cal.

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CANADIAN LAND RECLAMATION ASSOCIATION

PROCEDDEINGS
OF
THE THIRD ANNUAL MEETING

Laurentian University, Sudbury, Ontario
29 May - 1 June, 1978

THE ESTABLISHMENT OF VEGETATION ON HIGH IRON-SULPHUR MINE TAILINGS BY USE OF AN OVERBURDEN

R. E. Michelutti 1/

ABSTRACT

Since 1971 numerous tests have been conducted at Falconbridge Nickel Mines Limited to establish vegetation on tailings containing high percentages of pyrrhotite.

The object was to produce a self-sustaining vegetative cover which would reduce or eliminate seepage long after the operations cease. This solution was not a simple task, however, due to the low pH (3.0), the heavy metal toxicity and the hard pan produced by the pyrrhotite.

Vegetation research, mainly on Nickel Rim Mine tailings, led to the use of overburdens as the most promising method of achieving the primary objective of a maintenance-free vegetative cover. The ideal overburden was found to be three inches of coarse material (1/4 inch) overlain with three inches of loam. The coarse material prevents the upward leaching of solubilized metallic salts, while the loam provides a suitable growth media for the plants.

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Introduction

The sulphide ores of the Sudbury Basin contain economic quantities of nickel, copper and iron, which occur mainly in the minerals pentlandite, chalcopyrite and pyrrhotite respectively. These valuable minerals are associated with a variety of igneous silicate host rocks.

In order to separate the metallic minerals from the waste host rock, th ore must be crushed and ground to at least minus 65 mesh. Separation t is effected by the process of flotation and wet magnetic separation. Or ton of average grade Sudbury ore, once processed, results in the follow products:

1. 250 lbs. of copper-nickel concentrate
2. 500 lbs. of pyrrhotite (iron-sulphide concentrate)
3. 900 lbs. of coarse tailings (+25 microns)
4. 350 lbs. of tailings slimes (-25 microns)

The tailings are classified by hydrocyclones to produce a coarse fractic (70%) called sands and a fine fraction (30%) called slimes. The coarse fraction is returned to the mine as backfill and the slimes are discard; with the pyrrhotite. Falconbridge Nickel Mines Limited mines four milli tons of ore annually which results in 1,800,000 tons of tailings slimes pyrrhotite, occupying a volume of 30 million cubic' feet. This waste material is pumped as a slurry containing 15% solids, to landlocked bas: or low lying areas called tailings- ponds.

Here the solids are retained behind dams and the water is decanted off a treated prior to re-use or discard. Once these tailings ponds are full, however, they must be reclaimed, to eliminate or reduce pollution arisir from them, as well as to improve the aesthetics of the area.

RECLAMATION PROBLEMS

The most acceptable method to date in reclaiming these tailinys areas is by means of a vegetative cover. This, however, is no simple task for the following reasons:

1. The tailings acidify with time to pH 2.5 - 3.0
2. Heavy metal concentrations are high, especially upon acidification
3. The top 2 inches to 2 feet becomes rock hard due to a complex iron-sulphur matrix called a ferruginous cap
4. The tailings are devoid of nutrients and appropriate bacteria

EXPERIIIENTAL WORK

(a) Fertilizers

Experiments were conducted in the laboratory and field with the objecti of establishing a maintenance free vegetative cover that would revert back to nature. Of the fertilizers tested, 6-9-6 with 50% urea formald allows the nitrogen to be released slowly and should therefore reduce or eliminate maintenance.

(b) Neutralizing Agents

From the laboratory tests, the minimum amount of limestone required to sustain plant growth over the 3-month test period was 10 tons per acre. The limestone used was "Beachville feed-grade" which has a 70% coarse fraction (sand particle size) and 30% fine fraction (dust size). This was chosen over other nectralizing materials for its ease of handling as well as for the coarse fraction which would act like a buffer and maintain a constant pti. In the field tests, however, the test plots acidified in 2-3 months' time to pH values ranging from 3.5 to 4.5. This was believed to be caused by the upward movement of sulphuric acid by -capillary action during hot dry periods. The acid would also dissolve metallic salts and concentrate them upon evaporation *on* the surface. This was evidenced by white and yellow crystals (mainly Ca and Mg sulphates) on the surface of our tailings. It soon became apparent that continued maintenance would be necessary to maintain a vegetative cover on our tailings area.

(c) Overburdens

Due to the initial difficulties encountered with direct seeding in the tailings, tests with overburdens were begun in the laboratory and field. The overburdens used, ranging from gravel to-black loam, had a pronounced effect in increasing yields, as well as allowing legumes to become established for tile first time. Of the soils tested, black loam resulted in the greatest yields in tile 3-4 month test period. However, there was some concern as to' the long term effects. Due to the fine particle nature of the black loam it was felt tnat the upward movement of solubilized metallic salts would not be halted by the black loam and that after several years the concentrations would become toxic.

Dr. G. Courtin of Laurentian University was consulted and a decision was made to conduct research toward a master's thesis on this problem with Falconbridge Nickel Mines Limited personnel assisting with materials, assays and labour. Tony Spires, who was performing this work, came up with some basic conclusions. First of all, the black loam did result in the best initial growth cf plants, but also had the highest heavy metal accumulation at the end of the experiment. Tile coarse sand and gravel overburden on the other hand acquired very little if any metallic salts, but growth was mediocre due to lack of moisture. The ideal overburden in these tests was a 3-inch layer of 1/4 inch crushed slag'overlain with 3 inches of black loam. The slag broke up the capillary action and the black loam provided a growth medium with a good cation exchange capacity (128.5 me/100g) and mois ture retention capability (137g/100g).

As with some of our earlier experiments, Mr. Spires demonstrated that a solid barrier between the tailings and 6-inch overburden resulted in zero to poor growth due to a lack of moisture.

REVEGETATION PROJECTS

(a) Nickel Rim Mine

Nickel Rim Mine is an abandoned mine which was purchased by Falconbridge Nickel Mines Limited in 1964. With the put-chase of this property, Falconbridge then became responsible for the pollution originating from the tailings area, covering approximately 30 acres. These tailings are composed predominantly of siliceous gangue (662) and pyrrhotite (34%) and had been exposed since 1958.

After several tests with various overburdens, the results were sufficiently successful tiiat we proceeded to reclaim 20 acres by use of an overburden. The overburden material used was a sandy loam located within one mile of the site. The cost of this project is outlined below.

Materials	Cost/Acre
Limestone	$100.00
Fertilizer	163.00
Seeds	90.00
6-inch Overburden (includes Labour)	660.00
Labour (liming, fertilizing and seeding)	100.00'
Total	$1,190.00

A test plot with similar overburden material has been monitored since 1973 for pH to determine if re-acidification is taking place. The initial pH in September 1973 was 7.4 and as of March 1975 was 6.G. No maintenance on the 20-acre area has been conducted since it was established in 1975.

(b) Hardy Pyrrhotite Stockpile

In the Onaping area, 30 miles northwest of Sudbury, pyrrhotite had been stockpiled for future reclamation and recovery of values. This resulted in *severe* reclamation problems since the pyrrhotite containing 56% iron and 36.5% sulphur had not been diluted with tailings (siliceous gangue) as in other areas.

Adjacent to the pyrrhotite stockpile, a sandy gravel overburden was being removed from an open pit operation. This material appeared suitable as overburden and a 6 foot deep cover was placed over the pyrrhotite stockpile at no cost to the reclamation project, due to the close proximity of the pit operation.

This 17-acre area was seeded with the use of conventional farm equipment at a cost of $326.00 per acre in August 1973. There was some concern, however, that the sand-gravel overburden was so coarse that the nutrients would wash out faster than in a loamy sand overburden. To maintain a healthy veyetative stand an additional 300 pounds per acre of 12-18-12 40% sulphur coated urea fertilizer was applied during August of 1976 at a cost of $150.00 per acre.

The vegetation is doing very well and numerous unidentified weeds as well as several tree species, including trembling aspen and birch, have already encroached.

(c) East Mine Tailings

The East Mine tailings should have been relatively easy to vegetate since pyrrhotite was not discharged in to this area, These tailings were seeded in 1969 without the use of any overburden and the resulting grass cover was poor. Large bare areas were scattered throughout, without any vegetation whatsoever. It soon became apparent that the tailings were not homogeneous and that these bare areas had a very high iron content and a pH of 2.5. Unknown to the reclamation group at that time was that high iron waste products had been dumped into this area. These bare patches were covered with gravel at a cost of $404.00 per acre and re-seeded.

The vegetation cover initially was not very healthy and required annual maintenance for the first five years. This was possibly due to the proximity of the nearby smelter.

More recently, however, birdsfoot trefoil and alfalfa have begun to spread. Fertilizer requirements should be reduced since these legumes can produce their own nitrogen.

OBSERVATIONS

1. Tailings should be pumped over pyrrhotite stockpiles during the final stages of a tailings pond to eliminate the need for an overburden,

2. The use of domestic garbage, mine wastes, etc. as overburden materials should be investigated. This would result in one revegetation scheme for both the tailings and garbage.

3. Planning in conjunction with operating departments will save considerable dollars, e.g.- removal of overburden materials from open pits or dam construction, etc.

4. Finally, it should be kept in mind that continued monitoring of the vegetation is essential in order to determine the effectiveness of the overburden material in achieving a maintenance free vegetation cover.

CONCLUSIONS

Based on past and continuing research on tailing pond reclamation at Falconbridge Nickel Mines Limited since 1971, the following conclusions are reached:

1. Tailings areas containing high quantities of iron-sulphur and/or heavy metals can be vegetated successfully by use of an overburden material.

Conclusions (cont'd)

2. The ideal overburden should be coarse enough to reduce or eliminate upward leachate migration from the tailings while at the same time providing sufficient moisture retention and a cation exchange base for the vegetation.

3. Initial establishment costs by using overburdens are quite high but maintenance work is substantially reduced.

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CANMET'S TAILINGS' MANAGEMENT STUDY

A JOINT PROJECT OF MONENCO LIMITED,

NORANDA MINES LIMITED, COMINCO LIMITED AND

INCO LIMITED.

THE REVEGETATION PROGRAM

ON

INCO LIMITED'S TAILINGS AREAS

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THE REVEGETATION PROGRAM ON INCO LIMITED TAILING'S AREAS

There are three areas in Canada where Inco Limited carries on integrated mining and concentrating operations. They are located at Sudbury and Shebandowan in Ontario and at Thompson, Manitoba. The ore milled at all sites is a sulphide ore and consequently the tailings areas have varying degrees of acid generating potential which must be considered in developing successful revegetation programs.

Preliminary test work has been carried out at both Thompson and Shebandowan to develop revegetation programs. However, since major areas at these sites are still operational, no large scale reclamation program has taken place.

The main revegetation program has taken place at the Copper Cliff Tailings Area where approximately 600 hectares have been revegetated in the last 30 years.

The steps in developing a successful vegetative cover on tailings' areas follow a logical order,. Although the main steps are constant, the ability to adapt minor variations into each step is required due to the infinite number of variables which can occur at each site. The principle steps followed at Inco Limited are as follows:-

1. Pre-Seeding Investigation

If possible, this should be done during the growing season prior to the year the area is to be seeded. This permits sufficient time for changes in contours of the area to be made, if required. -Samples of the tailings in the area are taken for greenhouse growth tests to ascertain the rates of limestone and fertilizer applications required to ensure successful establishment of the vegetation. In all cases, it is assumed in developing these tests that there is no available plant nutrients present.

This information provides a realistic basis for ordering supplies and establishing costs for budgeting purposes.

2 . Site Preparation

Site preparations falls into two categories, the inside beach area and the outside slopes.

The angles of the outside slope will determine the type of equipment to be used in the seeding operation. If the slope is sufficiently gentle that conventional agriculture machinery can be used, the procedure is similar to the one employed in seeding the beach areas. The "step in SPACE" associated with the procedure used to construct the dames in 10' lifts at Inco Limited permits grading of the slopes from their original angle of repose to an angle which will permit the safe use of required agricultural equipment. Slopes facing the south and southwest are usually covered with clay in order that there will be a sufficient quantity of moisture available to permit plant growth during the hot dry periods of the year. Due to the difference in water absorption of tailings and clay, it has been found that the whole slope should be covered with clay to preserve the integrity of the dam. If the top portion is covered and the bottom portion left as tailings, severe erosion will occur in the lower levels as the clay on the upper level sheds the precipitation in heavy periods of rain or snow melt.

Wherever possible, equipment should travel across the slope and not up and down as this practice will reduce the rill and washouts from precipitation until the vegetation is sufficiently established to elimine this development. In addition when slopes are seeded at Inco, a water permeable chemical sealant is now applied to reduce the development of water runs on slopes.

After slopes have been seeded by conventional agricultural equipment, a mulch is applied with a hydroseeder. In the case of steep slopes, the mulch is applied with the grass seed and fertilizer by the hydroseeder. This mulch provides shade and reduces moisture loss, thus increasing the survival rate of the young seedljngs.

Gradual slopes and the beach areas receivesimilar site preparation. Approximately half the amount of limestone required to adjust the pH to a satisfactory level is broadcast over the area at least six weeks prior to seeding time. Depending on the friability of the tailings surface, the lime is disced or harrowed into the tailings.

3. Seeding

In the Sudbury area, experience gained over the past 30 years, indicates a late summer seeding provides the optimum chance for seedling survival and successful establishments of grass stands. Seeding now commences after the first substantial rainfall after July 20 each year.

. The necessity of having a firm seed bed, to ensure success, will determine whether the tailings are disced or harrowed to incorporate the second half of the required limestone application.

After the limestone is incorporated into the tailings surface 450 kg/ha of 5-20-20 fertilizer (5% nitrogen, 20% phosphate, 20% potash) are broadcast over the area and harrowed into the top 5-8 cm of the surface. A conventional farm seed drill follows seeding 94 kg/ha of fall rye, 22 kg/ha of grass seed mixture and an additional 390 kg/ha of 5-20-20 fertilizer. Prior to 1983 9-11 kg/ha of Brome grass seed was then broadcast after the seed drill planted the fall rye and one half the grass seed, but this step is now omitted. A Brillon seeder is used to plant an additional 22 kg/ha of the grass seed mixture. This mixture compacts the soil and places the grass seed at the proper depth to ensure the maximum change of germination.

The grass seed mixture currently used is:-

25% Canada Blue grass (Poa compressa L)
25% Red Top (Agrostis qiqantea Roth)

15% Timothy (_Phleum pratense_ L)

15% Park Kentucky Blue Grass (_Poa pratensis_ L)

10% Tall Fescue (_Festuca Brundenaceae_ Schreb)

10% Creeping Red Fescue (_Festuca rubra_ L)

On slopes, which are too steep to permit the use of conventional farm equipment to seed, a hydroseeder is used.

The seed mixture, the fertilizer and a mulch (Verdyol • trade name) are mixed in the tank with water at the appropriate rates for the capacity of the machine and sprayed as a slurry on the area to be seeded.

In cases where slopes can be seeded with conventional farm machinery, a mulch is subsequently sprayed over the area and in some case a suitable chemical sealant is applied. This treatment reduces water loss from evaporation and erosion runs during runoff from rainfall before sufficient root structure is established by the young plants.

4. Post Emergent Handling

Two to three weeks after the seed has germinated, a light application of nitrogen is applied to encourage growth. Due to the lack of organic matter in tailings, very little reserve nitrogen is available or retained by tailings from the original application.

Harvesting of the rye in the following year is done in such a manner as to leave the maximum height of stubble. This stubble provides shade and reduces surface winds during the growing season. In the following winter it will trap snow, which will ensure adequate moisture for the start of growth the following growing season.

5. Introduction of Legumes

The practice of late summer seedings has made it difficult to establish legumes. The seeds germinate and grow in the fall but do not develop a sufficiently strong and extensive root system to withstand the alternate freezing and thawing and resultant heaving of the surface ground the following spring. Various methods to establish legumes the following year have been tried. At present the use of a power-till seeder is the most promising but dormant fall seedings and seedings just after the snow melt in the spring have shown limited success.

6. Trees

Establishment of grass has been found to be the first step in the rebuilding of an ecosystem. Once ground shade and soil fertility were provided, the natural invasion of trees, principally birch, commenced. Some of these trees are now 3 - 5 m high.

Experimental plantings of more desirable species, with the prospect of future commercial use, are showing success. Jack Pine, Red Pine and hybrid poplar are currently under test.

7. Wildlife Management Area

The possible end use of Inco Limited's tailings as a wildlife management area is being investigated.

BASIC STEPS IN INCO LIMITED'S REVEGETATION PROGRAM

1. The seeding should be established on that portion of the area which is closest to the source of the prevailing wind to minimize covering or damaging of young plants by drifting tailings.

2. Half the agricultural limestone required, should be applied at least 6 weeks prior to seeding. This permits sufficient time for the reaction to raise the tailings pH to approximately 4.5 • 5.5. The remaining half is applied just prior to seeding.

3. In the Sudbury area, late summer is the best time to seed grasses. . After July 20, rates of success of seed germination and seedling establishment are enhanced due to more suitable temperatures and the increased availability of moisture.

4. Spring seeding the following year of grass seeded areas or dormant fall. seeding of legumes is necessary. Legumes are unable to develop sufficiently strong root systems, if planted with grasses in late summer to withstand heaving of the surface the following spring caused by alternate freezing and thawing.

5. The use of a companion crop to provide shade, and reduce winds is beneficial, if not essential.

6. Several applications of nitrogenous fertilizer should be applied, as required during the establishment period,, to ensure maximum uptake and subsequent growth.

7. Slopes, particularly with south and southwesterly exposures should be mulched to provide shade for seedlings and to reduce evaporation of moisture from the soil during the critical period of seedling establishment.

TAILINGS REVEGETATION RESEARCH

1. Establishment of criteria to evaluate the potential of success of permanent vegetation stands.

2. Establishment of criteria to establish the actual benefit of permanent revegetation related to seepage control, etc.

3. Establishment of meaningful chemical analysis of nutrient requirements, e.g., proper management of phosphate supply relative to aluminum and' iron ion availability and concentration.

4. Development of procedures to speed up nutrient recycling and decomposition of the thatch by incorporation and multplication of soil flora and fauna into revegetated tailings areas.

5. Optimum final contour of tailings areas for successful revegetation.

6. Intercept procedures for upward movement of acids and salts in sulphide tailings.

7. Selection of suitable vegetation species.

8. Develop chemical analytical procedures to ascertain acid generation potential of pyrites in sulphide ores and in coal to permit proper amelioration procedures.

9. The effect of residual trace elements (heavy metals on root growth).

10. The adaptability of various hybrid tree species to tailings areas with the ultimate objective of producing a quick maturing harvestable crop of pulpwood, firewood or other forest by-products.

11. Fertilizer or nutrient supply studies to provide a long term nutrient supply for forest species growing on tailings.

12. The influence of an iron pan and the physical structure and texture of tailings on the selection of suitable revegetation species of grasses, legumes, shrubs and trees.

13. The possible effect on wildlife by the uptake of heavy metals from the tailings strata into plants and the subsequent food chain.

REHABILITATION ACTIVITIES AT NORANDA GROUP MINES

B. Brooks, Horne Division

Introduction

Of all the operations associated with modern mining the impoundment of liquid and solid wastes or tailings disposal has the most profound affect on the environment. The probable major impacts involved with-tailings deposition are: aesthetics, fugitive dust, surface water hydrology - its quality and use, ground water hydrology - its quality and use, aquatic ecology, terrestrial ecology, land use, topography and public safety. Just as tailings areas are heterogeneous in their composition so are they diverse in their effects on nature. Some tailing dams only affect the aesthetics of the local area while others affect areas beyond their boundries.

Across Canada Noranda Mines Limited(*) has a total of 10,790 acres of active and inactive disposal areas of which 84 per cent contain some percentage of sulphide, mostly pyrite. The areas containing sulphides can be devided equally into those which should provide little problem to direct vegetation procedures and those with a sufficiently high sulphur concent which will require either the addition of a pH modifier or a top cover or both before reclamation can be fruitful.

Approximately 92 per cent of successful revegetation of sulphide disposal areas by Noranda has been completed by the Group's Horne Division. Situated in North Western Quebec, the division is renowned for its expertise in the mining and smelting of copper sulphide ore. During its 60 years of operation over 700 acres of land have been used in order to deposite its sulphide waste. Over .

the years, the oxidation of the iron sulphide minerals contained in the mine wastes has resulted in the generation of an acidic effluent.

It should be noted at this time that water quality of the effluent being discharged from the active areas is controlled by lime addition and that remedial action is either in the planning stage or being acted upon for the rest of the areas.

Sulphide Tailing Chemistry

The chemistry of acid generation has been well documented[1]. The sulphide mineral reacts with air and water to form a sulfuric acid and ferrous sulphate.

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

This reaction occurs ordinarily at temperatures up to 11° c. At temperatures higher than this the ferrous sulphate oxidizes to the ferric state.

$$4\ FeSO_4 + O_2 + 2H_2SO_4 \longrightarrow 2\ Fe_2(SO_4)_3 + H_2O$$

The ferric sulphate will in turn hydrolyze to form acid plus an hydroxide. The white material forming on a sulphide dam during the hot summer days is ferric sulphate.

$$4\ Fe_2(SO_4)_3 + 6\ H_2O \longrightarrow 3\ H_2SO_4 + 2\ Fe(OH)_3$$

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The ferric sulphate also reacts with the pyrite to produce additional acid.

$$7\,Fe_2(SO_4)_3 + FeS_2 + 8\,H_2O \longrightarrow 15\,FeSO_4 + 8\,H_2SO_4$$

Although the above reactions are an oversimplification of a very complex acid formation process, it does demonstrate the need for air (O_2) and water (H_2O) to proceed. The reactions are also very dependent upon different catalytic agents acting either independently or in combination. The catalytic agents can be physical (temperature), bacterial (Ferrobacillus sp. and Thiobacillus sp.) and chemical.

All the above reactions have dealt with pyrite (FeS_2) as very little work has been done on the more volatile iron sulphide, pyrrhotite(Fe_NS_{N+1}). The more rapid oxidation rate of pyrrhotite however can be expected to have an important consequence in the development of tailings acidity,

Work *undertaken by the Mineral Research Laboratory, Ontario Ministry of Natural Resources[(2)] indicated that the Horne Division's No. 3 tailings could be broadly described as pyrrhotitic in nature while those from the Waite-Amulet were more pyritic in type. The Waite-Amulet Mining Company operated the second largest mining operation in the region. This copper and zinc producer was controlled by Noranda during its years of production and was purchased just prior to its closure in 1962. Since the 1970's the property has been under the care of the Horne Division.

As this section of the task force deals with the revegetation of spoils and tailings the remainder of the paper shall only briefly touch on the Horne's efforts concerning fresh water diversions, acidic effluent impoundment, etc. It should be noted at this time that it is the Horne

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Division's belief that revegetation is only a part, although an important part, of an overall water quality program.

At the Horne Division efforts to delineate and find solutions to the problems posed by acid-generating tailings disposal areas commenced in the late 1960's by the establishment of sampling stations for the major effluent flows and natural watercourses in the area. As analytical data were collected it became apparent that the Division knew very little about the activity of its tailings dams and their effect on the various watercourses.

Acidic effluent from the various dams were seeping into numerous small streams and seemed to be flowing to all points of the compass, These were all diverted away from fresh water streams when possible. The seepage initially clear and colourless, assumes a faint yellow tint which as it is affected by time and atmosphere -changes to a deep amber-red. This latter colour is due to the suspended particles of ferric oxide, $Fe_2O_3 \cdot nH_2O$.

Apart from the environmental impact caused by acidic seepage, the fine granular nature of some tailings material will cause it to be picked up by the wind on occasion - to form dust storms. The two dams are located adjacent to the City of Noranda. Surface oxidation gave a yellow-brown appearance to the dams while the surroundings showed decaying trees due to the acidic effluents around them.

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Mine Waste Stabilization

There are several known methods (physical, chemical and vegetative and combinations thereof) to stabilize the mineral waste to reduce water contamination and prevent air pollution.

Many materials have been tried for physical stabilization. Covering the dam with bark or smelter slag, harrowing of straw into the top few inches of tailings and the placement of wind-breaks are just a few. Physical methods will temporarily solve the dust problem'but will not improve the aesthetics or the water quality.

Chemical stabilization involves reacting a chemical with the waste to form an air and water resistant crust or layer. Again this is only a temporary solution to one of the problem areas. Due to the uneven surface of the disposal area there will be enough irregular overhanging material to allow the high winds to rip out sections of the chemical'seal. After two years between 25 to 30 per cent of the seal will have blown away.

The preferred method of stabilization of mineral waste is a vegetative cover.

Noranda's Reclamation Concept

During the past decade from research, trial and'error, and common sense the Borne Division has developed a concept quite unique in the field of the reclamation of sulphide tailings areas. The concept involves the use of bioassays to assess the vegetation potential of the wastes to substain a directly seeded, maintenance free plant cover. That is a vegetative cover directly seeded into the sulfide waste without an overburden cover and that requires no maintenance or care after the initial germination. The bioassay technique took preference over standard soil chemical analysis which following a two year university investigation proved unsuitable as a method for developing a reliable field reclamation program. An assessment of a tailings area using the bioassay technique will reveal any wide spread differences within and between sites in agricultural limestone requirements necessary for sustained plant growth to occur. It will also indicate areas where some sort of overburden should be considered because of cost considerations.

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It was Noranda's'opinion and those of the specialists of the dam that vegetation would best control the three problems: acidic seepage, fugitive dust and unpleasing appearance of the area. In 1969, Noranda decided to revegetate the Waite-Amulet tailings disposal areas. A contract was entered into with a reclamation company which had a successful record in the tailings field. So sure was the contractor of the state of the art at that time that he gave the Horne Division a written guarantee. It should be noted at this time, that both companies' reclamation experience on acidic sulphide tailings where the surface pH levels varied from 2.8 to 3.5 was very limited. The results bore this out.

Using the technology that had proven successful for him on the tailings areas of Timmins and the Sudbury basin, the contractor disced, fertilized and seeded the entire Waite-Amulet primary tailings dam, a total of 100 acres. On the swampy secondary dam the amendments were just broadcasted. The amendment material rates used were:

- 5 tons of hydrated lime
- 650 pounds of 10-10-10 fertiliter
- 256 pounds per acre of a seed mixture of equal proportions of perennial rye and New Zealand fescue.

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Within a month, the large dam was green but during the second month it returned to its original reddish and yellowish brown colors. The initial seeding was virtually a complete failure.

The contractor returned in August of the following year to fulfil1 the guarantee clause in his contract. Three one acre test plots were set up. St was his belief that the lime rates were the reason for the extremely poor results. The lime rates tested were 5, 7, and 10 tons per acre of hydrated lime. The fertilizer, seed mixture and application rates were the same as the previous year, All the test plots germinated and he concluded that the tailings area required 7 tons per acre of hydrated lime. During October of that year, the contractor spread and disced to a depth of 8 inches, 7 tons of lime per acre. In May 1971, the contractor once again seeded and fertilised the large Waite-Amulet dam. The results were just as disastrous as before.

Initial 'Noranda Test Program

Noranda made two decisions at this time: first, to release the contractor from his guarantee clause and second, to initiate its own program of reclamation of tailings dam. During the winter, a study was 'conducted, using a rolling bottle test similar to a laboratory cyanidation test, to determine the amount of limestone required to maintain the pH to a point estimated adequate to sustain growth. The test showed that 25 tons of lime would be required. Using this information, advice from various universities, government. agencies, other mining companies, the contractor, and a little common sense, Noranda designed its 1972 test program.

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Attempts to establish a vegetative cover over the Whole area had been a failure and would not be attempted again until better techniques had been established. The 1972 test program covered only 2.5 acres which was sub-divided into 10 one-quarter acre plots.

TABLE 1

1972 TEST PROGRAM

PLOT NO	LIME TONS/ACRE	FERTILIZER (LBS/ACRE) 5-20-20	FERTILIZER (LBS/ACRE) 0-46-0	SEED (LBS/ACRE) MIXTURE	SEED (LBS/ACRE) NURSE CROP
1 IRRIGATED	50	1200		80	
2 CONTROL	50	1200		80	
3	50	1200		60	100(CHARLOTTETC BARLEY)
4	50	1200	2000	60	100(CHARLOTTETC BARLEY)
5	50	1200		60	100(OATS)
6	50	1200	2000	60	100(OATS)
7	50	1000		80 --	
8	50	1000		80	
9	50	3000		80	
10	75	3000		80	

THE SEED MIXTURE WAS EQUAL PROPORTIONS OF:

BIRDSFOOT TREFOIL, CANADA BLUE GRASS, TIMOTHY, RED TOP, CREEPING RED FESCUE, Besides varying the combinations of limestones, seed mixtures, fertilizer types and rates, one plot was irrigated. The seed mixture used was basically a variation of the mixture Inco had used successfully in Sudbury. One of the blue grasses was dropped and on the contractor's advice, birdsfoot trefoil was substituted. The results were encouraging.

Satisfactory growth was observed on all the plots, although the use of a nurse crop at the Waite-Amulet proved unsuccessful. There was no sign of the birdsfoot trefoil. Three years later, however, the 1972 test plots, which continue to thrive today, maintenance free, were covered with the yellow flower of the trefoil plant. The irrigated plot was superior for the first growing season. In subsequent seasons the difference disappeared. We continued to monitor the plots during 1973 to formulate our ideas.

Notanda had demonstrated that vegetation could be grown on high sulphide tailings by direct seeding but at a high cost. The cost of applying an overburden cover, clay or siliceous gold tailings, was even more prohibitive, three to five times higher than direct seeding. The monitoring of the field trials indicated that variations in the tailings, granular size, chemical composition, moisture retaining capacity, degree of oxidation and subsequent hard-pan formation, caused varied responses to the revegetation techniques employed. The Horne Division lacked sufficient information to answer all its questions and also the agricultural expertise to ensure success of another large scale revegetation program.

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Noranda - University of Guelph Program

In April 1974, a 5 year research program was initiated in co-operation with the university of Guelph, one of the foremost agricultural research centres in North America. Under the contract agreement, a more detailed investigation was undertaken of two principal aspects. These were:

a) To determine the degree of variation within and between high sulphide tailings as it could significantly affect plant growth.

b) To improve the techniques being used or develop new procedures with the intention of formulating a basically common program for the amelioration of high sulphide tailings. Although the program was to look at the mine and industrial wastes within the Noranda group of companies the first priority of the program would be the tailings areas in the Noranda region.

Between 1972 and 1977 significant effort was spent on tailings analysis in an attempt to relate known vegetation potential to their chemical and physical properties as determined through growth room and field trial experiments. Numerous analyses were performed in the laboratories of Noranda Mines Ltd., the Ontario's Ministry of Natural Resources(2), and those of the universities of Guelph, and South Carolina(3). Unfortunately none of the analyses revealed any consistent relationship between the various parameters. Analyses for total and water soluble components, relationships between sulphur and sulphate in non-oxidized and oxidized tailings and for iron, heavy metals and sulphur concentrations and various ratios all proved inconclusive. The large amount of analytical data recorded up to 1977 had not proved beneficial, and as a result traditional forms of metallurgical and soil analyses were discontinued.

While the academic approach proved frustrating, practical experiments in the growth rooms proved useful in determining the vegetation potential of the various areas in a tailings dam. Using the artificial conditions provided by a growth room or chamber, different combinations of neutralizing agents (pH modifiers), fertilizers and individual plants and seed mixtures were studied.'

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TABLE II

GROWTH OF BIRDSFOOT TREFOIL AND CREEPING RED FESCUE, ON SAMPLE AREAS FROM WAITE AMULET TAILINGS TREATED WITH VARYING RATES OF AGRICULTURAL LIMESTONE.

GRAMS DRY WEIGHT/POT AFTER 90 DAYS

LIMESTONE TONS/AC	SAMPLE AREA & "BIRDSFOOT TREFOIL"				SAMPLE AREA & RED FESCUE			
	B3	B5	B6	B10	B3	B5	B6	B11
0	0.000 / 0,041	0.207	0,000	0,000	0,000	0.804	0,000	0,031
5			0,000	0,139	0,030		0,016	0.268
10	0.049	1.098 / 1.072	0,049	0,748	0,000	1,471	0.329	0,415
20			0,295	0,759	0,053	1,535	0,581	0.690
30	0,661	1.360	0,689	0.691	0,075	-	0,676	0,807
40	0,706 / 0,853	-	0,482	0,740	0,745	-	0,523	0.940
50			0,405	0,453	1,184	-	0,375	0,958

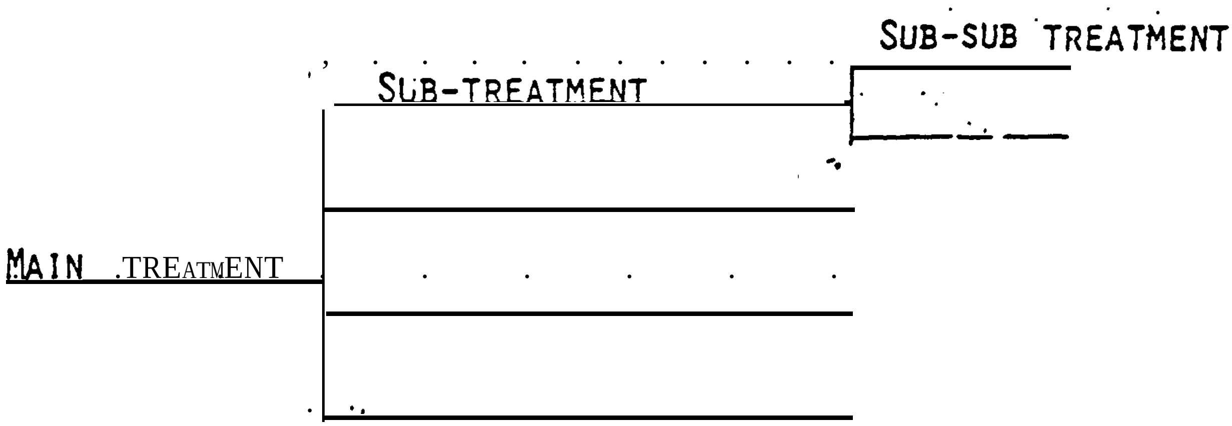
______ = APPLICATION RATE AT WHICH GROWTH WAS CONSIDERED SATISFACTORY.

Results that might require three to four years to obtain in the field were available in four to six months. Although the growth room was operated all year most of the work was scheduled during automn and winter.

Field trials at the Waite-Amulet recommenced in 1975 based upon the growth room studies. In June, test plots were set up to compare agricultural limestone and rock phosphate as amelioration treatments for acidic sulphide tailings. The experiments were designed as a split-split plot with three replications as shown in Figure I.

FIGURE I

1975 SPLIT-SPLIT TEST PLOTS



MAIN TREATMENT: COMPANION CROP

A, FALL RYE 50 LBS/ACRE

B. CONTROL

SUB TREATMENT: AMELIORATION MATERIALS

A, AGRICULTURAL LIMESTONE 25 TONS/ACRE

B. AGRICULTURAL LIMESTONE 50 TONS/ACRE

C, AGRICULTURAL LIMESTONE 10 TONS/ACRE PLUS ROCK PHOSPHATE 5 TONS/ACRE

D. AGRICULTURAL LIMESTONE 10 TONS/ACRE PLUS ROCK PHOSPHATE 10 TONS/ACRE

SUB-SUB TREATMENT: SEED MIXTURE

A,	BIRDSFOOT TREFOIL(EMPIRE)	10 POUNDS/ACRE
	CREEPING RED FESCUE(PENNLAWN)	20 POUNDS/ACRE
B.	CROWNVETCH(CHEMUNG)	20 POUNDS/ACRE
	REED CANARY-GRASS(FRONTIER)	10 POUNDS/ACRE

All treatments received an application of 1200 pounds/acre of S-20-20 fertilizer.

After one complete growing season, the following conclusions were drawn:

1. Seed mixture "A" was superior to mixture "B".

2. The use of a companion crop retards the growth of the legume. This verified the conclusion drawn from the 1972 test plots.

3. Although success was considered adequate with both pH modifiers, on an economic basis agricultural limestone was chosen.

In August of the same year field trials were continued to find a substitute for agricultural limestone, the major cost item of sulphide tailings revegetation. The growth room studies had shown that other materials besides rock phosphate showed promise. The two amendment materials tested were anhydrous ammonia at rates of 500, 1000, 1500 and 2000 pounds per acre and two grain sizes of fly ash, raw and aeroseparated,

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at rates of 250 and 500 tons per acre. The materials were allowed to winter before fertilizing and seeding the following June. The pH of the tailings was monitored.

The study showed that although the injection of anhydrous ammonia would instantaneously raise the pH of the acidic tailings from 3.4 to 7.2 and remain at this level for a long time, seeds would not germinate. Fly ash proved to be an excellent amelioration material but the transportation costs for tonnage of this magnitude were prohibitive.

As a consequence of the results obtained from the field trials of 1972, 1975 and 1976, a comprehensive evaluation of the entire Waite-Amulet tailings was undertaken in the growth room using the "bio" assay technique developed by the Noranda-Guelph program. Such a technique had taken preference over chemical analysis which, following a two-year investigation, had proven unsuitable as a method for developing a reliable field reclamation program. Over twenty samples were 'obtained from the Waite-Amulet for the study. These samples represented a wide range of variations in color, granulometry, location and surface moisture content. The intensive testing confirmed that although a single fertilizer application was suitable for the entire dam, agricultural limestone requirements varied from 10 to 75 tons per acre. Surface plans were developed to indicate the limestone rates to be applied to the various areas of the dam.

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Revegetation of the Waite-Amulet Tailings Dam

In addition to developing growth room procedures, the Noranda program had also developed an expertise not normally associated with mining, a curious blending of many disciplines, engineering, mining, agriculture and environment control. All the streams of fresh water were diverted around the tailings areas or in some cases through the discharge area in plastic pipes. Impervious dams were constructed to isolate the effluents affected by the tailings from other water courses in the surrounding region. Detail studies were prepared to determine the drainage patterns in the region and to estimate peak run-off rates. As Noranda's knowledge of the Waite-Amulet area increased so did its awareness of the fact that reclamation of a tailings area was just one important facet of a complete ecological program.

Sufficient confidence in Noranda's ability to apply laboratory results to field situations had been developed by the fall of 1977. The large scale reclamation project envisaged some eight years earlier and abandoned due to failure was reborn. The vagaries of weather during the relatively few frost-free days required a well co-ordinated schedule for the application and incorporation of agricultural limestone, fertilizer and seed. The schedule had to be timed to start when the tailings surface was dry enough to allow large agricultural equipment to operate but before all the surface moisture had evaporated due to the extremes of the summer heat and the tailings texture and colour. Contrary to popular belief, photosynthesis of plants is not continuous while the sun is shining: under the high temperature conditions of summer photosynthesis

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may almost completely. stop. Furthermore, most accumulations of mill tailings are light in colour and may reflect excessive radiation to the plant surfaces, thus intensifying physiological stress. Inco has measured the under leaf temperature on their tailings areas approaching 140°F. To reduce the risk of failure through abnormal and unpredictable weather conditions the large scale direct vegetation of the Waite-Amulet dam proceeded in two phases: one half of the dam, the windward Side, was revegetated in 1978 followed by the remainder in 1979.

The technique used to revegetate the Waite-Amulet dam involved the following procedure:

1. In certain areas where a hardened crust or hard-pan had formed as a result of the oxidation of the tailings, the surface would be ripped or disced depending upon the thickness of the hard-pan.

2. Agricultural limestone was applied using a rotary spreader on a 10-ton capacity wagon.

3. The limestone was incorporated using an 18-foot rotovator which resulted in a well mixed and level seed bed.

4. Next the fertilizer was spread as in the lime application. The Waite-Amulet required a blend of'1500 pounds of S-20-20 and 500 pounds of 0-46-O per acre. The filler had been removed to reduce shipping costs.

5. The fertilizer was incorporated using the adjustable teeth of a culti-packer. The machine also compacts the tailings to form a firm seed bed. A harrow was attached to the culti-packer to prepare the seed bed for mechanical seeding; it is not required for hydroseeding.

6. The area was then seeded using:

   a) A mechanical brillion seeder on areas which were relatively flat and able to retain some surface moisture or

   b) A hydroseeder on areas which did not retain sufficient moisture and were prone to wind disturbance, or were crested or sloped. A Canadian-made straw'and cotton waste mulch, 1400 pounds per acre', was applied on all areas which were hydro-seeded.

7. Two seed mixtures were used:

   a) For wet, very finely grained areas
   30 pounds per acre of tall fescue (K-31)
   20 pounds per acre of birdsfoot trefoil, (Empire)

   b) For relatively dry, coarser grained areas
   30 pounds per acre of creeping red fescue (Pennlawn)
   20 pounds per acre of birdsfoot trefoil, (Empire)

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Six days after seeding the first plants appeared and within three weeks, the areas had a green haze on them. Excellent results have been obtained at the Waite-Amulet dam with an estimated 90 per cent coverage after the initial growing seasons. More than five years have passed since the 1978 seeding and the area continues to support a lush growth up to three feet high which could require no additional care or maintenance.

The smaller secondary tailings dam at the Waite-Amulet property is situated in a low-lying swampy area, completely unsuitable for the heavy farm equipment used on the main dam. It was therefore decided to reclaim this area by the placement of a clay overburden cover over the tailings and surroundings swamps prior to seeding. This work, only feasible during the winter months started in 1978. Up until the end of 1980, only 15 acres had been covered and seeded. In 1981 a major effort was made to cover the remaining area. Contractors were hired and an additional 37 acres were covered and seeded. The acreage would have been greater but for an abnormally wet and warm February which curtailed the project for a month. The cost of this technique is four to five times higher than direct seeding.

All the major fresh water streams running through the swampy tailings area were diverted prior to the placement of the clay. The largest creek was ditched to a new receiving stream almost a mile to the north while a smaller tributary was piped through the area in an 18 inch polyethylene pipe.

Horne Division's No. 3 Dam

The Horne Division's No. 3 dam runs for approximately 5,000 feet down the back of the city of Noranda and covers 130 acres in surface area. Its western and eastern boundaries are two of the three highways supplying access to the city, routes 101, and 117. A total of 11,000,000 tons of mill wastes were discharged in this area from 1931 to 1949. The tailings consist mainly of pyrite and pyrrhotite.

At the same time that large field scale tests based on the Guelph laboratory testwork were being carried out at the Waite-Amulet site similar studies were being conducted at the No. 3 dam. The success of the field trials were identical and developed the same enthusiasm to reclaim the whole dam as they did at the Waite-Amulet.

During 1978 a total of 45 acres were attempted using the same fertilizer and seed rates as were used at the Waite-Amulet. The previous year, the entire dam had been thoroughly sampled. Growth room tests at the university.05 Guelph delineated the lime requirements for each area. The agricultural limestone was spread at a rate of 25-40 tons per acre depending upon the location.

Unfortunately the success of the Waite-Amulet was not repeated at the Noranda site. The resulting vegetative cover was estimated to be only 50 per cent of what was expected. This figure is somewhat misleading as there are areas where the coverage was as dense as that at the Waite-Amulet and there are other locations where germination did not occur at all.

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The inability to take the growth room results and apply them to the total surface area of No. 3 dam when this action had been so successful at the Waite-Amulet raised a lot of questions. A careful examination of the events and conditions encountered during 1978 seeding indicated:

a) The high water table in the dam made it extremely difficult to operate equipment.- This was especially true of the lime spreader.

b) The Heterogenous nature of the tailings dam was more pronounced than had previously been recognized. Thus in certain locations, the lack of plant growth could be attributed to insufficient limestone.

c) Climatic conditions -the dam's profile is dish shape. The night after the seeding operation had been completed, a heavier than normal rainfall occurred which washed the mulch and seed towards the center of the dam.

d) The dish shaped profile of the dam plus the high water table allowed water to pond for several weeks after a heavy precipitation.

e) The success of the earlier successful field trials could have been due to the fact that the locations chosen had lower water tables than the rest of the dam. In order to give the greatest visual impact to the citizens of Noranda, the field trials were always placed close to the roadways or on the highest ground available.

.The result of the study was that the revegetation program scheduled for 1979 was postponed until solutions could be found.

In order to lower the high water table, a small-network of sub-surface drainage tiles were installed in July 1980. The trial consisted of 300 feet of a 6 inch collector drainage pipe which intercepted 4,200 feet of smaller 4 inch interceptor drainage pipes. All tubing was covered with a filter Sock to prevent the fine tailings material from blocking the perforations in the pipe. The study indicated that although the drainage system worked and it is still operating, the volume of discharge was not sufficient enough to have a significant effect on the water table.

The Chadbourne Mine project's start-up in mid-1979 offered the Horne Division with an alternative method to lower the water table on tailings area No. 3 and to eliminate its dish shape profile. Growth test conducted at the university of Guelph indicated that the Chadbourne tailings requir only the Waite-Amulet seed mixture and fertilizer requirements as the material was rich in carbonates. The pH of this overburden material is 7.8 - 8.2. It was the Horne's intention to hydraulically place this material over as large an area of oxidized sulphide tailings as possible to an average depth of 2 - 3 feet.

The deposition program in this area was completed at the end of 1983. Areas which could not be covered by this alkaline siliceous waste due to land elevation or the possibility of destroying large areas of vegetation already thriving is being covered with 18 inches of borrowed clay. The clay will then be reclaimed using standard sod growing methods.

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As much fresh water entering the tailings basin as was physically and economically possible was diverted away from the sulphides. The acidic effluent from No. 3 dam which flowed west to the Pelletier drainage system is now pumped to the North Osisko watershed. This will improve the control of the Horne Division's final discharge from their active dams into Lake Pelletier.

Horne Division's No. 1 and No. 2 Dams

For years Noranda's No. 2 dam was seen by tourist and citizens as a blood red pond full of decaying tree stumps. It seems that one's most recent impressions are the ones that last. Although the reasons for the red colour, the oxidized sulphide tailings, have been there since the thirties, the Lake was but ten years old. After children had burnt a trestle between dams No. 1 and 2, the CNR decided to fill in the low area with slag to eliminate the need for a new trestle. The weight of the slag caused the culvert which was to drain the area to collapse. The railway replaced this culvert with a new one but at a much higher elevation and thus formed the red pond.

About this period, the city and the Quebec government decided to build an underpass on the main street of Noranda. The waste from this site was dumped on No. 2 dam and vegetated. For the remaining five years, the image remained a blood red pond, decaying stumps and a 3.3 acre spit land jutting out into the middle of the area, lush with vegetation. The Tree stumps were removed. The availability of the silicious Chadbourne tailings gave the Division an opportunity to change this image. The non-sulphide tailings were pumped into No. 2 da:: until the red pond disappeared. During 1981 and 1982 28 of the 32 acre dar was seeded. The results have been quite successful except for a small 1.5 acre low laying area near the highway and a 1 acre area used in the past by union carbide to deposit the waste from their acetylene plant. These two areas will required a 1 foot overburden cover followed by vegetation.

During 1982 the Division's concentrator completed the covering of the No. 1 dam with 2 feet of the alkaline tailings from the siliceous Chadbourne gold mine. The scheduled reclamation of this area has been delayed for a number of reasons.

a) Unfortunately a flaw developed in a nearby tailings line used for sulphide waste. Before the line could be replaced almost half of the overburden was covered with sulphides. The area will either have to be recovered with an overburden material or directly seeded after the required amount of agricultural limestone has been applied.

b) A separate company, Agrinor, has indicated that it wishes to use the area to construct three large greenhouses for plant production. Until the situation has cleared all reclamation plans for this area have been put on hold.

c) At the time the Division was investigating the area as a site for-possible expansion of the slag cooling area.

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Horne Division's No. 4 and 5 Dams

The use of the Chadbourne tailings as an overburden is just one part of the Division's water quality program. On our two large dams, 5 miles to the west of the concentrator, a different overburden strategy is being employed. The tailings from the Borne's slag circuit is an inert material consisting mainly of magnetite (Fe_3O_4) and iron silicates. The flotation circuit takes the slag from the Noranda continuous smelter and recovers the copper and precious metals[4, 5]. Growth room tests conducted by the university of Guelph indicated that the material was an extremely poor growth media. The fine size of the material, 80 per cent passing 325 mesh, along with a crusting effect did not allow plant roots, once germinated, to penetrate the material more than a few millimeters. Even though its cementing effect inhibited growth, it also had an advantageous effect in that it also suppressed the infiltration of oxygen, a major component in the formation of an acidic effluent.

The first project to use the inert slag tailings as a barrier to minimize sulphide oxydation was on the 100 acre No. 4 dam. The surface area was covered with 2 feet of the non-sulphide tailings. There are still a few areas, due to higher elevations, which are not covered. These will be completed by a tractor next year. In addition to eliminating further oxydation, the total area will be flooded to create a large lake. During the winter of 1978-80, the retainer dam was raised 10 feet to permit this higher water level. It is well known that water inhibits the infiltration of oxygen. This program will provide a double overburden over the old sulphide tailings, one solid and one liquid. The program has not been fully evaluated as only recently the discharge has stopped flowing from No. 5 dam to No. 4 dam. As previously mentioned this. discharge is now pumped eastward to the North Osisko watershed.

On our large 170 acre active dam No.5, the use of this inert overburden material is also being used. The Division's tailings disposal program anticipates that this dam in future will be used solely for slag tailings disposal. Thus the acid-producing sulphide material will be covered eventually by many feet of inert slag tailings.

Ouemont No. 2 Dam.

During 1981, the Horne reactivated an old abandoned sulphide tailings area upon agreement with the Quebec Ministry of Energy and Natural Resources. The dam had been previously used by Quemont Mines Ltd., a division of Kerr Addison Mines Ltd., but it had reverted back to the crown after the mine ceased operating in 1972. The disposal permit covers an area of 250 acres of which approximately 105 acres is exposed sulphide material and 80 acres is a pond averaging 9 feet deep. It is the Division's plan to dispose of all sulphide material in this discharge area. It is an ideal location as there are no other sources of effluent entering the permit site. As in the case with the greatest majority of all sulphide flotation circuits the tailings were discharged into the area at a high pH, 9.0 - 10.5. A monitored alkaline discharge flows to the Kinojevis River which has no difficulty meeting the governmental guidelines. When the sulphide circuit is not operating, as presently due to the world metal market prices, the discharge is maintained by pumping a limed flow into the retention pond.

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Although the' Horne Division has designated this dam an active discharge area preliminary work has been completed concerning the vegetation potential of the high sulphide waste. Starting in 1971, during the final operating years of the Quemont Mining Company, a series of ¼ acre test plots studied the effects of different lime addition rates as well as different seed mixtures. Over the years none of the growth has persisted with the exception of a single plot which was covered with a 10 inch layer of waste rock and then topped with 10 inches of sand before seeding. Each year the vegetation coverage of the overburden plot becomes less and less as dunes of fugitive dust creep over the small area. In 1972 the Quemont Mining Company concluded that an overburden cover would be the most economical method to establish a vegetative cover. During 1979 growth room studies showed that agricultural limestone requirements for the disposal area varied from 25 to 125-plus tons per acre and that there was no truly discernible pattern in the distribution of the limestone requirements. The studies also indicated that fertilizer application levels, especially high levels of phosphate applications, appeared critical for successful plant growth. This is the one factor that has been common in all the Horne's growth room studies and field programs on sulphide tailings. There is a striking response to the level of phosphorous fertilizer application. The same may be true of nitrogen applications but since the cornerstone of the Horne's revegetation program involved the establishment of a legume species, particularly the legume Birdsfoot Trefdil (Lotus Corniculatus), only minimal rates were ever used.

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The consensus of opinion is that an overburden cover on the Quemont No. 2 dam would be the most practical and economical method of establishing a vegetative cover. The closest location of sufficient suitable overburden material is approximately three miles away. Detailed reclamation plans have not been contemplated for this sulphide dam in the near future as it has been designated an active working dam and proposes no environmental threat from fugitive dust or in the quality of its effluent discharge.

Quemont No. 1 Dam

The Quemont No. 1 dam runs into Lake North Osisko between the Horne Division's plant yard and the Noranda Golf Course. It started as an emergency tailings discharge area as well as a location to receive the Quemont concentrator thickener overflows and the mine water discharge. Later on the tailings were extended further into the lake in an effort to stabilize the ground over an underground working area. The dam extension also allowed the construction of the No. 3 ventilation shaft as it formed-a peninsula out into the lake. During the later life of the mine, closed in November, 1971, more sulphide tailings were deposited in the area to "level off the tailings surface". Although all of the above reasons for discharging sulphide tailings into and along the shoreline of a lake seemed valid during the time they were carried-out, in retrospect they were not.

At the same time as vegetation experiment& were being carried out on the large No. 2 dam Quemont Mines Ltd. was conducting similar tests on their emergency area, No. 1 dam. Two of the eight test plots were covered with an overburden of clay, rock and sand. One received 7 tons per acre of agricultural limestone while the other received 75 tons per acre. The non-overburden plots received from 50 to 200 tons. The fertilizer applications were either 6400 pounds per acre of 0-20-0 plus 1920 pounds per acre of 5-20-20 or 1920 pounds per acre of 5-15-15. A variety of 10 different legume and grass species were seeded at 88 pounds per acre with and without a 2 bushel per acre rye grain nurse crop. The results were spotly to nil where less than 100 tons per acre of limestone were applied. Unfortunately before any serious evaluation could be made the water level in the lake rose as a result of a beaver dam constructed across the lake's discharge channel. Quemont Mines Ltd. did however conclude that the tendency of the sulphide tailings to form a crust on the surface as well as a hard pan was a serious handicap for plant growth. Their report also concludes that a soil cover or similar overburden cover would be the most economical and possibly the only way to establish a vegetation cover on their No. 1 dam. This is similar to the conclusions drawn for their No. 2 dam. The overburden plots flurished for a number of years until even they were covered by acidic water as a result of a high lake level.

In December 1983, after the Horne Division had completed the covering of its own No. 3 dam with an overburden layer of Chadbourne tailings, the silicious gold tailings pipeline was installed to start the covering of the old Quemont No. 1 dam. It is Noranda's intention to cover the area with several feet of the non-sulphide waste material. The area will then be vegetated using a program similar to the one

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designed for the Horne's No. 3 dam. The covering of the sulphide area will take over a year as almost half of the acres to be covered are either under water or on the lakes-flood plain.

Quemont No. 3 Dam

This small 20 plus acre discharge area runs adjacent to the Borne's No. 1 dam. It was maintained as a stockpile for a pyrite concentrate which was sold to a number of customers while the Qcemont mill operated. When the mine closed there was several hundred thousand tons of concentrate stockpiled with an average sulphur content of 46 per cent. It is believed that this area will have to be isolated from the surrounding environment to minimize the effect it has on the local ecology.

Normetal Mine Ltd.

Located 72 miles north of Noranda, Quebec this copper, zinc, pyrite mine operated from 1935 to 1975. During this period over 11,100,000 tons of sulphide ore were. mined which resulted in three large sulphide tailings dams. The tailings dams boarder along the northern edge of the town and the western bank of the Calamity River. During certain weather conditions the sulphide tailings would cover the town with a reddish-brown dust. From 1968 until the closure of the mine

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attempts to establish a vegetation procedure for the 40 per cent pyritic tailings were tried yearly with little success. The size of the test plots ranged from small hand raked areas to a large 7 acre plot seeded by a contractor. In the early years the formula tried was low rates of lime and fertilizer additions with high rates of seed.

A brief history of these early attempts follows:

a) In 1968 two small test plots of unknown dimensions were worked by hand. The results were discouraging and what growth was established died off at an early stage.

b) In 1969 a contractor was engaged to develop a reclamation program. It was the same contractor who seeded the Waite-Amulet dam. He selected seven acres of slope plus one half an acre of flat surface. Three tons per acre of lime were added followed with 650 pounds per acre of 10-10-10 fertilizer. The seed mixture, perennial ryegrass and New Zealand fescue, was applied at a rate of 265 pounds per acre. It should be noted that one half of the slopes was hydroseeded while the rest of the area was seeded with a seed drill. Very little success was noted on the flat surface while the slopes were written off as a complete failure.

c) The following year the contractor treated 4.5 acres of flat tailings surface with the same seed and fertilizer applications as the previous year. The lime was increased to 10 tons per acre. On part of the area a mulch of wood chips was spread, Although the results were an improvement over the past years they were far from satisfactory. The area which had the best growth had the wood chip mulch appeared to have the best growth.

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d) In 1971 the contractor returned to re-seed the area again with the addition of 30 tons per acre of limestone but keeping the seed and fertilizer rates the same as the previous year. The resultant vegetation was a significant improvement over previous efforts. Again there was evidence that a wood chip mulch improved the vegetation's'success rate. During the same period the contractor was investigating the use of basic asbestos waste. Two trial areas were spread with 40 and 60 tons per acre of asbestos tailings; these were disced into the acidic sulphide waste to a depth of 6-8 inches. The trial plots were treated with the same seed and fertilizer applications as mentioned previously. The results were as negative as similar test plots he installed on the Noranda tailings areas.

e) In 1972 after consultation with the contractor, and Noranda and Quemont personnel Normetal redesigned its program. Lime addition rates of 15, 25 and 30 tons per acre were investigated. The seed mixture was changed to Timothy, K-31, Trefoil, Alsike clover, and crownvetch and the application rate was reduced to 50 pounds per acre plus a barley cover crop. The fertilizer rate was increased to ½ a ton per acre. Although the growth was patchy it was an improvement over the earlier testing. The mine personnel concluded that limestone application rates higher than 30 tons per acre were required.

f) In 1973 8 acres of sulphide tailings were covered with approximately 1600 cu. yards of a sand and clay overburden. The following year the area was successfully seeded. This was the last seeding attempted while the mine was in operation.

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In 1980 a five year rehabilitation plan was developed with the assistance of the Group's Environmental Control Co-ordinator and the Horne Division of Noranda Mines. Basically the project entailled the installation of drainage ditches around the parameter of the sulphide disposal area to intercept all fresh water which previously flowed over the waste material creating acid. The extremely high dam walls were regraded to a slope of less than 20 degrees. All of the exposed sulphide tailings were covered with 12 inches of sand from an adjacent borrow area. This sand material was sent to the growth room for "bio assay" tests and for standard soil test analyses. The analyses revealed no highly acidic or high total salt situations. Both pH and total salts were in the normal range of normal agricultural soils. Like the tailings itself the sand was very deficient in phosphorous and potassium. Of the micro-nutrients calcium was considered adequate while magnesium tended to be on the low side.. The "bio assays" indicated no apparent problems with the overburden as the tests produced acceptable growth. The seeding procedure is similar but not identical to what is used on the gold tailing overburden used at the Horne Division. The seed mixture calls for 30 Ibs per acre of Creeping Red Fescue and 20 Ibs per acre of Birdsfoot Trefoil while the ratio for Chadbourne tailings is slightly higher at 40 Ibs of Creeping Red Fescue and 30 Ibs per acre of Birdsfoot Trefoil. The fertiliser, S-20-20, is applied at 1000 pounds per acre while the Borne used 1500 pounds of S-20-20 plus 500 pounds of 0-46-0 per acre. Both the Normetal and the Horne apply 2000 pounds per acre of mulch although the type is different. Normetal uses a hallow form wood fibre mulch from Texas. The Horne uses a straw paper cotton mulch from Canada. This is the same type as used by Inco and Ontario Department of Highways. Both the Horne and Normetal use a Brillion grass seeder with a split seed box followed by a hydromulcher,

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To-date Normetal No. 3. and No. 2 tailings discharge areas have been revegetated. One third of the large No. 3 tailings area has been completed and the remainder of the dam has been covered with the sand overburden. This May it will be seeded. All that will remain to be done is touching up the few areas which were not successfully vegetated, placing a central drainage system in the area between the three dams, and seeding the old plant area.

This will fulfill the commitments of Normetal Mines Ltd. as outlined in their letter of intent which was submitted to and accepted by the Ministre de l'Environnement de la Province de Québec.

Conclusions

Noranda's efforts to establish vegetation on highly acidic mine tailings and swamps have been successful. Even though the research contract with the Crop Science Department of the University of Guelph terminated in 1979., the use of growth rooms will continue for other revegetation projects. A great deal of interest from other mining companies across Canada has been shown in Noranda's revegetation program and research projects have been undertaken on the behalf of several companies outside the Noranda Group,

The ability to establish a maintenance-free vegetative cover on acidic mine tailings by direct seeding has been demonstrated. Where a successful vegetative cover has been achieved natural seeding by indigenous species follows as evidenced by the appearance of many trees on both Waite-Amulet & No. 3 dams. Many of the self-seeding trees stand over 15 feet in height. The fauna as well as the flora have returned to what was once a barren and sterile environment. The birds have returned to nest and the insect population, especially the bees, are flourishing.

It is the Horne Division's opinion that a dense vegetative cover will either solve or will largely reduce the three problem areas previously mentioned.

1. Vegetation appears to have reduced the volume of acid seepage from the dam. The ability of a vegetative cover to reduce acid seepage from mine wastes has been documented in the United States.[5.6] It is a well known biological fact that vegetation utilizes enormous quantities of water in its life processes. Precipitation

is intercepted and absorbed by the plant roots and is transpired back into the atmosphere thus reducing the amount of water which would percolate through the tailing mass and emanate the seepage. The plant leaves themselves intercept large amounts of precipitation which evaporates into the atmosphere before reaching · the acidic tailing surface,

Presently there is insufficient evidence to indicate whether the vegetative cover has had any effect on the water quality. It is probably too soon to tell as the vegetation has not matured in some areas to form any depth of organic layer.

2. Dense vegetation eliminates the problem of fugitive dust clouds emanating from the tailings surface.

3. One would hardly raise an argument by stating that the aesthetics of the area are improved.

The establishment of a vegetative cover alsc had a further effect. The organic matter resulting from a mature vegetative cover has developed into soil layer. It is the formation of this organic layer that has allowed the indigenous species to propagate.

Noranda's experience at the Waite-Amulet and its other properties has shown that vegetating a sulphide tailings area is just one part, although a crucial one, in an overall ecological program.

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