PIT SLOPE MANUAL

chapter 10

ENVIRONMENTAL PLANNING

This chapter has been prepared as part of the

PIT SLOPE PROJECT

of the
Mining Research Laboratories
Canada Centre for Mineral and Energy Technology
Energy, Mines and Resources Canada

First printing - March 1977
Second printing - November 1977
Third printing - March 1979

MINERALS RESEARCH PROGRAM
MINING RESEARCH LABORATORIES
CANMET REPORT 77-2

Available in Canada through

Authorized Bookstore Agents
and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Hull, Quebec, Canada K1A 0S9

Catalogue No. M 38-14/10-1977 Canada: $2.50
ISBN 0-660-00908-0 Other countries: $3.00

Price subject to change without notice.

Ottawa 1977

Reprinted 1979

En vente au Canada par l'entremise de nos

agents libraires agréés
et autres librairies

ou par la poste au:

Centre d'édition du gouvernement du Canada
Approvisionnements et Services Canada
Hull, Québec, Canada K1A 0S9

N^{O} de catalogue M 38-14/10-1977 Canada: $2.50
ISBN 0-660-00908-0 Hors Canada: $3.00

Prix sujet à changement sans avis préalable.

Ottawa 1977

Réimprimé 1979

THE PIT SLOPE MANUAL

The Pit Slope Manual consists of ten chapters, published separately. Most chapters have supplements, also published separately. The ten chapters are:

1. Summary
2. Structural Geology
3. Mechanical Properties
4. Groundwater
5. Design
6. Mechanical Support
7. Perimeter Blasting
8. Monitoring
9. Waste Embankments
10. Environmental Planning

The chapters and supplements can be obtained from the Publications Distribution Office, CANMET, Energy, Mines and Resources Canada, 555 Booth Street, Ottawa, Ontario, K1A OG1, Canada.

Reference to this chapter should be quoted as follows:

Whitby-Costescu, L., Shillabeer, J. and Coates, D.F. "Pit Slope Manual, Chapter 10 - Environmental Planning"; CANMET (Canada Centre for Mineral and Energy Technology, formerly Mines Branch, Energy, Mines and Resources Canada), CANMET REPORT 77-2; 93 p; Feb. 1977.

Reprinted November 1977
March 1979

FOREWORD

Open pit mining accounts for some 70% of Canada's ore production. With the expansion of coal and tar sands operations, open pit mining will continue to increase in importance to the mineral industry. Recognizing this, CANMET embarked on a major project to produce the Pit Slope Manual, which is expected to bring substantial benefits in mining efficiency through improved slope design.

Strong interest in the project has been shown throughout its progress both in Canada and in other countries. Indeed, many of the results of the project are already being used in mine design. However, it is recognized that publication of the manual alone is not enough. Help is needed to assist engineers and planners to adopt the procedures described in the manual. This need for technology transfer will be met by a series of workshops for mine staff. These workshops will be held in various mining centres during the period 1977-81 following publication of the manual.

A noteworthy feature of the project has been its cooperative nature. Most organizations and individuals concerned with open pit planning in the country have made a contribution to the manual. It has been financed jointly by industry and the federal government.

Credit must be given to the core of staff who pursued with considerable personal devotion throughout the five-year period the objectives of the work from beginning to end. Their reward lies in knowing that they have completed a difficult job and, perhaps, in being named here: M. Gyenge, G. Herget, G. Larocque, R. Sage and M. Service.

D.F. Coates
Director-General
Canada Centre for Mineral and
Energy Technology

SUMMARY

Mine designers must consider the effects of a mine on its surroundings. Engineering alternatives at both new and existing mines have to be judged according to their environmental influence. After a plan is adopted, the effects on the environment should be monitored. Chief among the many environmental factors of concern in mine planning are water pollution control and revegetation.

EXPLORATION

In the early stages of a mining venture, maintaining environmental quality is usually inexpensive and fosters good public relations. However, staking, line cutting, geophysical surveying and diamond drilling are frequently done by contractors who may not be concerned with protecting the developer's image. Consequently, contract supervision is particularly important. Some aspects to note are:

a. Fuel supplies should be stored above high water level.
b. If oil is spilled on land, it should not be removed or buried. Attempts to do so can create more problems; the area affected can be fenced to protect wildlife.
c. Stream crossings should be designed so that flow is not affected, causing deposition of sediment.
d. Oil, drilling fluids, garbage and other contaminants should not be dumped in lakes and streams.
e. Garbage may be burned with caution but should preferably be buried.
f. Sanitation facilities should be located away from fresh water.
g. Cutting of lines and stripping of vegetation should be minimized.
h. Test pits, trenches and other excavations should be filled in after use.

It may be advisable to take samples of fresh water sources to establish natural conditions before exploration starts. If there is a possibility of contaminating drinking water wells, it may be advisable to grout all exploration holes.

When close to residential areas, potential noise problems must be considered. Prior consultation with local government and other groups can often forestall complaints.

ECOLOGICAL INVESTIGATION

When a decision is made to bring an orebody into production, the local ecology along with social and economic conditions should be studied. This provides baseline data against which to measure the effects of mining. Aerial photographs provide information on the surface water regime and types of vegetation. A control area similar to the mine site but far enough away to be unaffected by operations should be selected as a reference.

Water courses are usually more vulnerable to change than land ecology. Considerations in pre-mining surveys and subsequent monitoring include:

a. physical aspects such as depth, temperature and sediment texture;
b. water characteristics such as colour, turbidity, dissolved solids and organic content;
c. toxicants such as heavy metals and detergents;
d. biota such as phytoplankton concentrations, plants, fish and bacteria.

Terrestrial studies usually include soil types, vegetation and animal life.

SOCIO-ECONOMIC STUDIES

Plant operation will affect the local economy and population distribution and will constitute a new land use. Local road and rail traffic and the community water supply may be significantly affected.

Harmonious relations with local residents are obviously desirable. Public presentations to discuss such aspects as parking facilities, location of the construction campsite, hours of work and reclamation plans can be very useful.

METEOROLOGICAL STUDIES

Knowledge of the local climate may be important. Air blast effects can be influenced by wind, as can plume dispersion from mills and smelters. It may be advisable to establish a local weather station to develop a data bank of pertinent information.

NORTHLAND CONSIDERATIONS

Although all of Canada is in the North, operating in the Arctic and sub-Arctic poses special problems. In permafrost regions, excavated slopes and stripped frozen soil may thaw, resulting in slumping. The disposal of garbage and sanitary waste is more difficult. Oil spills are more troublesome because of slower breakdown of hydrocarbons. Once initiated, stream erosion tends to continue with possible unsatisfactory consequences.

EFFECTS OF CONSTRUCTION

Vegetation extracts water from the ground, and its removal during construction can affect the groundwater regime. Drainage of operations will affect groundwater.

Removal of vegetation near water courses can lead to increased nitrogen levels in the water. Preproduction site drainage and drainage water from operations can also affect receiving waters. Fish and plant life can thus be affected.

WATER POLLUTION

The impact of operations on existing water courses is not easy to predict. Changes in one physical property can produce changes in others. For example, sediment may have no direct toxic effects on fish but may, however, destroy plant life and deprive the fish of food. Possible effects are best predicted by observing similar mining operations in similar environments.

The problem of acid contamination from mines and waste dumps is common throughout the country. It usually arises from the presence of pyrite, pyrrhotite and chalcocite. The production of acid can be prevented by excluding any one of oxygen, water or sulphide. The most economic approach must be determined for each property.

Groundwater levels as well as quality can be affected by operations. This may cause local water users considerable distress. Lowering of local wells is not uncommon but an extensive tailings pond can also raise groundwater levels.

The cost of an antipollution program may be minimized by determining water quality before operations start. This will prevent having to fulfill subsequent quality requirements that exceed the natural conditions. By rerouting streams and by ditching and dyking it is often possible to reduce the quantity of water that must be controlled.

Recycling of water may be possible, thereby reducing freshwater requirements. This could appreciably reduce the volume of water to be treated and consequently the extent of facilities. In some cases, reagent costs may be reduced.

The cost of controlling the impact of tailings ponds on water resources can be minimized by appropriate procedures. A seal on the upstream side of a dam, for instance, can be effective in reducing contamination. Vegetation of tailings will reduce mineral leaching by rainwater.

RECLAMATION

Reclamation requires establishing objectives for ultimate use of the site. In many cases there will be no ultimate use; consequently, ensuring safety of the casual visitor plus a minimum of revegetation will be adequate. In other areas, recreational, commercial or industrial developments may require land shaping and revegetation.

Revegetation requirements vary between and within mining properties. Tailings ponds and dykes, waste rock dumps and overburden soil dumps all require different treatment. Initial neutralization is often required together with the addition of fertilizer. A judicious selection of seeds or seedlings can produce a maintenance-free, self-sustaining vegetative cover. This may require an appropriate succession of plants and a maintenance period in which additional fertilizer and neutralization may be necessary. The period when maintenance is required can be as brief as three years. However, it may be much longer under severe conditions either of the environment or of the material on which growth is being promoted.

Many examples of successful revegetation programs now exist, and an inventory of selected properties across the country is included in the manual. This can provide guidance to new programs.

OTHER OPERATIONS

Haulage roads can create unsatisfactory environmental effects. Culverts must be planned to avoid the effects of flooding and silting. The effects of chemicals applied to road surfaces should be examined before use. Truck noise might be of concern to local residents, especially at night.

266. Pipelines - tailings, slurry, water and oil - must be designed to cope with blockage, power failure or breakage. Easy access is important and so is the provision of emergency dump points at suitable low points.

Mine dewatering plans must consider possible effects on groundwater and surface waters. Treatment may be required before disposal.

Blasting may require special consideration if the property is close to residential or urban areas. Blasts should be designed to avoid damaging vibration. Individuals are much more sensitive than buildings to ground shock. They may believe that blasting has caused minor structural damage that in fact existed previously. Consequently, photos and measurements before blasting begins can avoid later expense. An appropriate public relations educational program could be a good investment.

LEGISLATION

Environmental protection is an area of joint jurisdiction between the federal and provincial governments. In most cases provincial laws apply. However, federal laws set minimum standards.

Three federal acts are of particular importance. The Fisheries Act sets national standards for water quality, and provides powers to prevent industrial pollution. The Canada Water Act provides for water resource management and prescribes limits of waste discharge. The Clean Air Act sets standards for air quality.

The manual includes a list of the relevant legislation affecting environmental planning for mining. In addition, a review is available of the regulations issued under authority of the various laws.

COSTS

A preliminary ecological reconnaissance of the proposed mine site should require about five man-days, costing about $2 000 (1974).

A complete ecological investigation with baseline studies might require 30 to 250 man-days, and cost $10 000 to $60 000 (1974).

Most operating mines incur costs for water or air sampling. There may be a major requirement for waste water treatment; one mine in Eastern Canada spends $300 000 (1972) per year for operating and amortizing its treatment plant; an Ontario mine treats 3.2×10^9 gallons (14.5×10^6 m^3) of waste water per year at an annual cost of $31 000 (1970).

Revegetation of waste was estimated to cost $150 to $500/acre ($60 to $200/ha) in 1973, plus $200/acre ($80/ha) annually for maintenance. However, if soil cover is necessary, costs rise rapidly; revegetation of coal mines has been estimated at $300 to $3 000/acre (1972) ($120 to $12 000/ha). A Manitoba mine estimated initial and maintenance costs for sulphide tailings reclamation to be $750/acre ($300/ha) and $425/acre ($170/ha) respectively in 1972.

ACKNOWLEDGEMENTS

D.F. Coates was responsible for this chapter. Address enquiries to him at: 555 Booth Street, Ottawa, K1A 0G1, Canada.

The chapter was written largely by L. Whitby-Costescu and J. Shillabeer with assistance from C. Ferguson, P. Martin, T. Peters, J. Sparling and D. Bullock. D.F. Coates was responsible for consolidation and technical editing. INCO Ltd. kindly provided information for the writing of Appendix B. Many staff members of provincial and federal departments of environment and mines provided critiques of the initial draft.

Contractors: Dames & Moore, Toronto.

The Pit Slope Manual is the result of five years of research and development, cooperatively funded by the Canadian mining industry and the Federal Government of Canada.

The Pit Slope Group consisted of D.F. Coates*, M. Gyenge*, G. Herget, B. Hoare, G. Larocque, D.R. Murray, R. Sage* and M. Service.

*Pit Slope Group Leaders.

CONTENTS

FIGURES

TABLES

INTRODUCTION

1. The planning of a mine and designing pit walls can be affected by environmental factors. By making environmental assessments, quantitative estimates of the effects of the mine on its surroundings can be considered during design. Engineering alternatives have to be compared on criteria that include specific environmental requirements. It is important to have early identification of potential problems to devise practical solutions. After an environmental plan is adopted, monitoring of key criteria throughout the operating stage is required to identify and correct deviations from the plan.

2. This chapter provides a review of environmental factors of concern in mine planning. In light of previous experience, emphasis is placed on water pollution control and revegetation. Consideration is given to environmental aspects of the exploration, construction and operation phases of open pit mining.

PREPRODUCTION STAGE

EXPLORATION

3. In the early stages of a mining venture, maintaining environmental quality is usually inexpensive and often fosters good public relations. Developers are advised from the very beginning of a project to be aware of any environmental legislation or related issues which may concern the local population and other interested groups. There are requirements of federal and provincial government bodies regulating land use, water and air quality. It may eventually also be necessary to submit an environmental impact or assessment document. The existence of National and Provincial Parks, designated wilderness areas or Indian Reserves may also influence exploration policy and the choice of sites. In certain provinces, legally designated wilderness areas may be off-limits to most mining activities. However, such areas are usually small and their present status is uncertain because of possible legislative changes.

4. During the early stages of exploration, personnel involved in staking, line cutting, geophysical surveying and diamond drilling are frequently employed on a contract basis with little incentive to help the developer's public image. Supervision at this stage may be less than desirable and result in a neglect of the environment. Developers should therefore apply clear guidelines for environmental preservation during this phase. The basic rules need not be complicated nor time-consuming.

5. Some suggestions for maintaining environmental quality early in the life of the project are as follows:

a. Fuel supplies near water bodies should be stored above the high water mark. Land can absorb an oil spill more readily and with fewer harmful effects than can water courses.

b. If an oil spill occurs on land, especially in permafrost areas, no attempt should be made to remove or bury it. More damage is done in such efforts than if the spill is left and nature allowed to take its course. Significant oil spills should be fenced to prevent harmful effects on wildlife.

c. Oil spills in lakes and streams are serious. Their containment and final removal from the site involves specialized techniques like booming, dispersion and surface clearing by means of absorbent materials such as straw, peat moss, etc.

d. Inadequate or poorly placed stream crossing structures may affect stream flow. Silting and contamination of downstream areas are to be avoided. Ideally, bridge footings should be placed well back from the stream banks or be founded on rock outcrops. Bends should be avoided as they erode more rapidly.

e. Lakes and streams are sensitive to contamination by harmful materials such as oil, drilling fluids, garbage, excavated soil, etc. Likewise, digging construction materials from stream beds should be avoided and, in most cases, usually requires permission from the authorities.

f. Limited burning of combustible garbage is acceptable with adequate fire precautions. Burial of garbage is preferred in non-permafrost areas. In permafrost areas, garbage ideally should be removed from the site. Burial of more toxic materials is complex and should be carried out under government guidelines.

g. Improved sanitation facilities are usually required today, if only to maintain high quality working conditions. Simple burial away from water courses is adequate for disposal of waste from chemical toilets.

h. Cutting of lines and trails is often restricted to widths under 6 ft (2 m). Wholesale stripping of vegetation should be avoided until definite site plans have been formulated.

i. Most jurisdictions require that all test pits, trenches and other excavations should be filled in after they have served their purpose. Some can be utilized for waste and garbage disposal. To minimize land subsidence in permafrost areas, some attempt should be made at restoring the original vegetation or soil condition.

6. When an exploration project has proved sufficiently encouraging to warrant an increase in activity prior to actual construction, site management becomes more complex depending on the particular circumstances. Generally, however, site management will still focus on camp hygiene and on maintaining water courses and vegetation similar to their original condition.

7. When access to a public laboratory is convenient, it is advisable for the developer to take several water samples for independent analysis. Samples of 1-litre size should be taken in laboratory containers. For defining baseline water quality, they are best obtained from representative locations such as below strategic stream junctions and not from the margins of lakes and rivers. Where an extensive exploration program - say, more than 100 drillholes - is taking place near wells supplying potable water, it is advisable to grout holes that intersect an aquifer. The well water should be sampled. Groundwater migrating from the orebody could contaminate well water. In response to these problems, certain provinces have specific regulations governing water sampling and procedures for abandoning drillholes.

8. Local conditions may call for measures to control contaminated drill water such as recirculation, dilution, flocculation, use of settling ponds or cyclones. Apart from limits set by the authorities, judgement should be used in selecting controls for individual cases. For example, highly toxic contaminants such as heavy metals exist in low concentrations in surface waters; however, unusual minerals encountered while drilling complex orebodies may result in the accidental release of high levels of contaminants.

9. With increasing proximity to urban centres, problems of noise, equipment passing on public highways, blasting hazards, unauthorized access, etc, become more acute.

10. Environmental studies should begin early in the life of a project. An environmental reconnaissance (eg, a literature search, a brief site visit and an analysis of aerial photographs) should be included in the initial feasibility study. It is prudent at that time to establish working contacts with local governments and officials who are often invaluable sources of information and advice.

ECOLOGICAL INVESTIGATIONS

11. As part of a study to define conditions existing prior to development, investigations of the local ecology along with social and economic studies should be tailored to the scale of the development. Similar field surveys should be re-

peated during the operating stage to monitor the impact of mining.

12. Aerial photographs show soil distribution, types of vegetation and features of the watershed. A control area, similar to the mine site but far enough away from it to be unaffected by the operations, can be monitored as a reference base.

13. Generally, the ecology of aquatic systems is more vulnerable to change than that of land systems. The aquatic environment is characterized by four major subdivisions:

a. Physical (depth, temperature profile, velocity and sediment texture)
b. Water character (colour, turbidity, dissolved solids, suspended solids, biological oxygen demand, chemical oxygen demand, dissolved oxygen, organic content and nutrients)
c. Toxicants (heavy metals, biocides and detergents)
d. Biota (phytoplankton and zooplankton, plants, benthic (bottom) organisms, fish, and bacteria).

14. If required, data on most of the above factors can be obtained by examining water samples. Equipment for obtaining representative samples include Van Dorn water samplers, Wisconsin plankton nets and stream drift nets. Fish populations may be determined by gill netting, seining or capture-recapture techniques.

15. Bottom samples are obtained by a sediment sampler, such as a 9-in. Eckman dredge. Drive (core) samples can provide information on the physical and chemical properties of sediments. However, since the biota exist in only the top 1 to 2 in. (2.5 to 5 cm), a combination of the two methods may be advisable.

16. Terrestrial studies are concerned with soil types, vegetation, and animal life. Soil investigations can often be combined with those for foundation and drainage work. Undisturbed samples are used to determine soil distribution, texture, moisture content, porosity, humic content, and the presence of heavy metals, pesticides and herbicides.

17. Vegetation sampling methods are designed to produce statistically significant measures of plant cover, abundance, density, diversity and productivity. Many appropriate methods are available. For example, one method uses sample areas of one square metre usually selected at random from traverse lines or grids 100 m by 100 m. Within the square, the presence of each species is recorded and the proportion of the area covered by the species, or other suitable measure, is estimated. The species and girths of trees within the grid are recorded and their age estimated.

18. Animal populations are most readily estimated by capture-recapture techniques. Trap lines are set and animals tagged and released; from the proportion of tagged animals recaptured at the same location, an estimate of the total population can be made.

Socio-economic Studies

19. Mining may affect local and regional land use, economic conditions and population distribution. For a major project, the present and projected population distribution should be determined. It may be necessary to subdivide the population into age groups and ethnic communities to understand the full implications of the mine development.

20. Studies of local land use and economy will overlap with population studies. A diagrammatic presentation of land use patterns surrounding a mine site can be useful.

21. Calculating the loss of crop acreage and crop yield may be appropriate in rural areas. The magnitude of alterations to local road and rail networks for mining operations may have some effects. The use of community water supplies may have to be evaluated if, for example, a local river is to be restricted or altered.

22. In investigating the local and regional economy, the supportive capabilities of public institutions and facilities are of concern. Additional tax revenue will be generated locally from mine development, but schools, sewers and transportation links may become overburdened. Such infrastructure studies are often carried out by provincial or regional government agencies using data supplied from the mine's environmental studies. In remote locations, the developer should give detailed attention to the nature of

new housing, its location and desirable amenities.

23. The investigation should provide sufficient information to compare the mine's long range beneficial effects with: (a) increased demands on the local economy and infrastructure, (b) changes in life styles and local values and (c) the possible effects on local industry.

24. Achieving harmonious relations with local residents is a major concern as the construction period approaches. The importance of keeping local residents informed at the initial stages cannot be overestimated. In this connection, useful attempts have been made to involve local residents directly in the planning process (1). While such intimate public involvement is not necessarily the best method in all circumstances, public presentations are recommended for any major new development in Canada today. Forethought, well prepared material and concern on the part of the developer are all key factors in the success of such presentations.

25. Several means besides public meetings (eg, brochures, public opinion surveys, etc) can be used by a mining company to emphasize (a) its good intentions, (b) the economic benefits anticipated from its work, (c) the transient nature of construction and (d) the permanent nature of social benefits such as new or improved roads, tourism, service industries and wildlife management programs. While change is inevitably associated with a new mining venture, a developer can underscore his intention of preserving the high quality aspects of life in the neighbourhood.

26. Avoiding unnecessary or wasteful use of land at even remote properties will help minimize adverse impacts. Some questions that can be asked are as follows:

a. Can contractors' vehicles be parked within the mine area on ground that eventually has to be stripped?
b. What will be the final use of the construction campsite when only the permanent work force remains?
c. By careful scheduling, can the open pit be used even for limited waste disposal as mining continues?
d. Have slope angles been fully optimized to reduce the surface area affected?

27. The developer has an obligation to see that his employees understand and respect local community values. Staggered schedules of activities at various times of the day can avoid congestion of roads. Providing sufficient recreational outlets at the construction camp helps avoid strains and ill-will generated locally by the transient construction labour. Where development is planned near an established town, the flow of information to that community should be emphasized.

28. Tangible efforts directed toward land rehabilitation, even during construction, are a useful part of long term plans. They also contribute to good public and employee relations. Spoil heaps supporting vegetation give real evidence of corporate concern as well as eliminating dust hazards. A plant nursery, primarily directed at developing and testing hardy strains for re-vegetation but which also makes plants available to the local community, adds to good relations.

METEROLOGICAL STUDIES

29. A knowledge of local climate is important for planning the restoration of mined land. Short term forecasting may be required for smelter operations where sudden changes in diffusion characteristics can be important. A knowledge of the seasonal conditions is required for the design of open pits. Table 1 shows the climatological factors available from public records, including those that have a bearing on open pit design and operation.

30. The meteorological program should be designed to provide data relevant to the scope of operation. Often an adequate program will consist of a survey of existing data from nearby weather stations, together with an assessment of how the data relate to the mine site. Help can be obtained from the nearest office of the Atmospheric Environment Service, Environment Canada. AES officials can provide local information and some interpretation.

NORTHLAND CONSIDERATIONS

31. Special problems arise in the Arctic and

Table 1: Climatological factors available from public records

Meteorological parameters available from public record	Relevance to open-pit mining
Temperature (normals, extremes, etc)	Lube selection, permafrost, base for other calculations.
Wind and wind direction	Dispersion of fumes and dust, site and route selection.
Humidity	Ice accretion, cooling tower design.
Pressure	Base for other calculations, air compressors.
Precipitation	Drainage, slope stability, water recycling design.
Visibility	Truck haulage, safety.
Frost free periods	Vegetation.
Frequency of critical temperatures	Vegetation.
Times of freeze-up and break-up	Transportation, stock pile handling.
Lengths of cold spells	Vegetation, budgets.
Dates of first snow cover	Vegetation.
Number of days of snow cover	Road maintenance.
Average snow depth	Road maintenance, vegetation.
Probability of fog	Truck haulage, safety, ability to conduct month-end surveys.
Heating degree-days	Building design, budgets.
Growing degree-days	Vegetation.
Rainfall intensities	Vegetation, site drainage design.

sub-Arctic. Some of these are as follows:

a. Worked slopes and stripped frozen soil may thaw, resulting in slumping and increased erosion. Soils which are fine-grained and have a high ice content may liquefy when thawed. The result is the continuous flattening of excavated slopes.

b. The disposal of debris and sanitary waste is more difficult. Central disposal areas, where impact is lowest, are used for Northern developments.

c. Long-term scarring of the ground surface can result from the use of tracked vehicles in permafrost regions.

d. Fuel spills are particularly hazardous to the natural environment because of the slow rate at which hydrocarbons break down.

e. Foundations must be designed to prevent thawing beneath the structure, either by building above grade on piles frozen in place, or by building on a gravel pad placed on the undisturbed natural ground cover.

f. High ice loads and ice jams, together with a scarcity of stream flow data, make the design of river crossings difficult.

g. River banks in permafrost tend to deteriorate continuously once failure is initiated.

h. Revegetation is difficult as there is little experience or knowledge to draw on.

32. Some of these characteristics may be used to advantage in the North. Winter roads over frozen bodies of water can be used to reach areas that are normally inaccessible. These require little maintenance and reduce tire wear. Northern recreational possibilities have not yet been fully explored. The bibliography contains references on Northern developments.

EFFECTS OF CONSTRUCTION

33. Site preparation for mining involves removing vegetation, levelling, cut and fill operations, excavating and the like. Possible physical results of such activities are modification of the evapo-transpiration regime, excessive erosion, slope instability and dust problems.

34. At sites further removed from the construction zone, a change in stream flow rates and

patterns together with an increase in sediment loads could result. These changes need not necessarily affect the chemical quality or discharge characteristics of streams.

35. The removal of vegetation and construction noise may destroy the natural habitat of some wildlife. Some will die; others will change their forage area. The balance may also be disturbed in surrounding areas.

36. Increased turbidity of streams and lakes may interfere with breeding habits of fish. Deposition may change the stream bed characteristics, affecting aquatic vegetation, spawning and other characteristics of the fish habitat.

37. Construction may change the groundwater regime. Where drainage is required, the contribution of vegetation to water loss (evapo-transpiration) should be recognized. Trees contain 10% to 80% of the moisture available in nature to support life. The removal of trees and other plants may increase drainage requirements. Removal of vegetation may also alter colour of the ground surface, causing changes in ground temperature and evaporation. Removal of vegetation near water courses can lead to increased nitrogen levels in the water; this should be avoided if possible.

38. Drainage water may alter receiving waters unless these are large enough to provide adequate dilution. For example, water drained from a bog prior to stripping will usually be anaerobic, acidic and high in ferrous iron. The receiving water could be rendered turbid with ferric iron formation. Changes in pH and oxygen levels may adversely affect fish. Where problems of potential water quality changes may arise, contingency plans should be prepared. It is advisable to provide appropriate emergency sump locations for settling purposes. Routine samples should be taken at intervals to monitor drainage water quality. Hydrological studies should be conducted to investigate the possible influence of dewatering on domestic well water.

MISCELLANEOUS

39. In selecting a plant site, it is advisable to avoid areas where there are steep slopes or natural drainage features. Areas with relatively poor soil quality and correspondingly sparse vegetation are preferred because ecological disturbance is minimized. Site selection is treated in more detail in the section on water supply.

40. Vegetation and topographic screening, using natural or constructed features to shield the site from public view, serve to minimize adverse visual impacts. Such measures also help reduce sound levels to acceptable proportions. Trees decrease noise levels by 5 to 7 decibels per 100 ft (33 m) of woods. They also help precipitate airborne dust. Where machinery operates 40 ft (12 m) or more below ground level, noise is insignificant. At 25 ft (7.5 m) below ground level, the dust hazard from operations is normally small.

41. New access roads may be required or existing ones upgraded early in the construction phase. If it is recognized that such roads are a lasting contribution by the mine to the area as a whole, they can be designed with permanence and aesthetic values as well as efficiency and safety in mind. Vegetational screening may be appropriate.

WATER SUPPLY AND DISPOSAL

SUPPLY

42. A water supply that meets existing public health standards must be available at the site. As a general rule, 50 gallons (227 L) per person per day of potable water may be used for planning purposes; this allows a margin for some semi-industrial/commercial uses. Groundwater sources are generally preferred for relatively small quantities. The quality is usually close to required standards. Also, there is little chance of contamination by pathogenic organisms. Simple filtration and chlorination may be required. An ion exchange process to remove the iron common to some northern locations or to reduce hardness may also be needed. The economics of owning and operating a small water purification plant may appear attractive compared with buying water from a municipality. However, operating of small-scale plants is difficult because people trained in the discipline are usually not available at the site.

43. The availability of water decreases in Arctic and sub-Arctic regions. Groundwater is often inaccessible where there is permafrost. Even when available, it is high in iron and humic materials. Problems of water availability are aggravated by freezing during treatment and distribution. Several methods of meeting this problem are being used such as: (a) constant circulation of heated (4°C) water through insulated lines, (b) constant bleeding and wasting of water, and (c) using a heated utilidor. All are expensive. Very small sites in the far North may be most economically serviced by hauling water from a source not requiring treatment. Chlorination and storage in a heated tank house may be adequate. Scarcity of fresh water for domestic purposes on Arctic coasts has led to the use of small desalination plants.

44. As a rule, the quality of water required for mining processes is not high. Sea water, for example, has been used in the absence of other sources with appropriate precautions against corrosion. The quantity of water required will depend on the scale of the operation, the processes involved, and the extent of recycling. As a general rule of thumb, it can be said that to mill 1 ton (1 tonne) of ore requires approximately 1 ton (1 tonne) of new water, assuming maximum economy and recovery of process water. Mining itself may account for perhaps only one per cent of the total requirement. Generally, maximum economy is practised in arid areas of Canada, such as in the

porphyry copper mines of southern British Columbia where up to 80% may be recycled.

45. In southern Canada, the availability and quality of surface and groundwaters has been well documented. Information may be located in the appropriate section of the provincial ministries of the environment. Ontario, for example, has separate sections covering water quality and water quantity. Water availability problems in the North can be severe and less information is available. In Arctic regions where total precipitation is typically 9 to 12 in. (22.5 to 30 cm) annually, fluctuations in water supply from season to season are extreme. In some rivers, 80% of the annual runoff occurs during the short period of spring breakup. Besides impounding water for the long winter, care must be taken to control thawing rates under dams and lakes. Unlike operations further south, extensive site reconnaisance is usually important to secure water supplies throughout the year.

POLLUTION

46. The Environmental Protection Service, Environment Canada is issuing an environmental code of practice for mines, which deals with abatement of water pollution. That code is a useful supplement to this section. The most serious potential for water pollution in open pits is associated with the storage and processing of ore and waste, and in some cases with dewatering of the excavation itself. Other sources, such as treated sanitary effluent, run-off from roads and drainage from overburden excavation, are either minor in amount or are easily controlled.

47. Damage to rivers and lakes can take two forms: either short duration discharges of high levels of contaminants (plug flow), or long term discharges at low levels (normal flow). Either can be damaging. The ability of a water body to recover is a function of the intensity and duration of the stress and the presence of any residual toxicity. Time available for recovery and the distance from the source are important, as is the ability of the water body to supply healthy new organisms to replace those lost in the damaged area.

48. No single factor alone can account for changes in river flora and fauna. Changes in one physical parameter can manifest changes in other factors. For example, turbidity itself may have no direct toxic effects on fish or plants; however, it obscures light for photosynthesis and the production of fish food. Upon deposition, solids may bury and kill bottom life.

49. Effects of proposed changes to water bodies are best predicted by comparing with similar mining operations. The complexity of the physical, chemical and biological interactions is best studied empirically.

50. The scope of the pollution control measures required for an open pit mining project is determined by the scale of operations, the nature of the ore, the ability of local waters to assimilate discharge without significant degradation through dilution and dispersal, and the regulations in force. Mining of non-metallic minerals, except pyrite-bearing coal, presents few problems. The proportion of ore mineral extracted to waste is usually high, processing methods are often dry, and contaminants are few. Frequently, the only requirement is to allow discharge water to clarify by settling.

51. Metallic ores, especially in the Canadian Shield, are usually sulphides or have sulphides associated with them. Untreated base metal mining and milling effluents are usually highly acidic at a pH of 2-4. Gold is an exception, as most Canadian operations have sufficient carbonate present to compensate for acid-producing sulphides. Uranium ores are generally neutral, but processing by acid leaching removes the natural buffers and, even though current wastes are kept neutral by the use of lime or limestone, abandoned tailings may become highly acidic at a pH of 2 for exposed tailings and 4 for water discharged from the tailings dam.

52. Appendix A classifies the main types of water contaminants and notes important sources and biological effects of each.

53. The problem of acid mine drainage is widespread in Canada and poses serious long-term questions. Acid drainage comes mainly from pyrite, pyrrhotite and chalcocite. Sulphides of lead and

zinc are less important because their relative solubilities in comparison with iron at, for example, pH 5. The complexity of the reactions is best illustrated by considering the common mineral pyrite.

$$2FeS_2 + 2H_2O + 6O_2 \rightarrow 2FeSO_4 + 2H_2SO_4$$

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

a) $Fe_2(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 + 3H_2SO_4$

or

b) $Fe_2(SO_4)_3 + FeS_2 \rightarrow 3FeSO_4 + 2S°$

$$2S° + 3O_2 + 2H_2O \rightarrow 2H_2SO_4$$

54. These equations are only representations of some very complex chemistry still under investigation. Worth noting, however, are the following points:

a. sulphide, water and oxygen are necessary,
b. an excess of any one component can produce more acid,
c. the reaction is auto-catalyzed by the presence of acid,
d. biological catalysis via Thiobacillus and Ferrobacillus can occur,
e. ferric hydroxide is an insoluble yellow-brown substance that usually appears as a fine scum or scale when the pH is increased through dilution at the point of discharge,
f. the pyrite reactions control the presence of such toxic heavy metals as Pb, Zn, Cd, Cu in solution through pH,
g. acid production can be prevented by excluding either oxygen, water or sulphide.

55. How surface waters can be adversely affected by uncontrolled mine drainage is quite clear. Less familiar are cases of groundwater contamination. Three examples are given here to indicate the variety of problems that can arise.

56. Example 1. Sources of groundwater are being depleted in an open pit mining area where several large corporations are active. The region is arid. The groundwater is shared by a city, farms and the mines. Mining activities withdraw approximately 50 000 acre feet (62×10^6 m^3) per year, and between 50% and 75% of this is returned to the ground as seepage from tailings ponds. Water in the tailings contains between 1 000 and 3 000 ppm (mg/L) total dissolved solids due to solution of gypsum and anhydrite. Traces of copper and molybdenum are also found. It appears that precautions such as preventing or recovering tailings seepage and perhaps reusing treated sewage plant effluent will be required to protect both the quantity and the quality of groundwater available to all three major consumers.

57. Example 2. Dewatering of an open pit mine resulted in lowering of the water level in a major aquifer by 5 ft (1.5 m) or more, over an area of 1 400 square miles (3 600 km^2). About 50×10^6 gallons (227 000 m^3) are pumped from the aquifer per day. Studies showed that the only adverse effect was lowering the water level in about 900 water supply wells. The expense of deepening these wells was accepted as part of the mine development cost.

58. Example 3. Seepage from a new tailings pond caused the water table to rise and inundate a nearby older pond. Previously stable sulphides in the abandoned tailings pile were dissolved, contaminating the groundwater supplying local wells. A nearby stream was also contaminated. Placing an impervious blanket of segregated mill slimes over the active tailings dam is expected to alleviate this problem.

Planning

59. A topographical map of the mine catchment area showing the direction and quantity of surface flow entering or leaving the property is essential. Information on groundwater is also necessary, with particular emphasis on possible groundwater recharge from tailings areas.

60. A routine chemical analysis of each flow should be undertaken. For acid mine drainage, analytical results should include values for pH, sulphates, iron, copper, zinc, lead, cobalt, nickel and manganese. A complete scan analysis, which identifies all chemical elements, should be run at least once on all major flows.

61. Three general principles are worth empha-

sizing at this stage.

a. Define the physical area that must be controlled, making it as small as possible by appropriate re-routing of streams, ditches, and dikes.
b. Regard the ore as an acid producer until testing has shown otherwise. A routine testing procedure has been developed for predicting potential acid production. Details may be obtained from the Water Pollution Control Directorate of Environment Canada.
c. There is cause for concern if heavy metals occur in effluent at levels greater than the background concentrations. Combined effects at low concentrations may also be a concern.

62. The expense of an anti-pollution program will be less if the quantity and variety of water sources to be controlled are reduced. Estimates of the quantities of surface and groundwater that must be handled, their cyclic variations, climatic effects such as evaporation from tailings areas, together with requirements for mine, plant, and miscellaneous purposes, will permit the planning of the most economic re-use of water.

63. Local geology and economics will determine the size, shape, and location of an open pit mine. Mills, stock piles, waste dumps and tailings dams cannot be sited and designed in isolation. The concepts of area or systems planning should be applied. The following guidelines should be considered (2):

a. Locate facilities high in a watershed, thereby minimizing the amount of water that must be handled.
b. Wherever possible, route surface drainage around structures that are potential sources of contamination. Avoid building on natural drainage channels. This is particularly important in the case of acid-producing tailings dams. It also reduces or eliminates the need for flood protection.
c. Gravity collection of contaminated water prior to treatment, re-use, or disposal is preferable. General reliability and the possible need for continued treatment or control after operations close down may justify a gravity system in spite of greater construction costs.
d. Final disposal of water should be to mature water courses. Adequate supplies of clean water and healthy organisms from upstream are essential to minimize stresses imposed on the local system and to repair any damage to biota.
e. Investigate the permeability of foundation soils. If porous materials are present, use of impervious clays or such artificial material as imported clays or plastic sheet may be needed to prevent leached products from entering groundwater supplies.
f. The primary means of removing solids prior to re-use or disposal is to decant clarified water from a tailings pond and to use secondary and possibly tertiary recovery lagoons in series. A sheltered site is therefore preferable to assist settling and to avoid wave action. This, generally, will also reduce aesthetic problems. Airborne dusts from unvegetated sections may contaminate otherwise clean water.

64. Control of drainage water in both the plant and mine areas is required. Even where drainage is not acid, a minimum degree of treatment, such as settling, will be required before release to receiving waters.

65. Diking or ditching around plant areas to typical heights or depths of 3 to 4 ft (0.9 to 1.2 m) is good practice and may be required by regulation. This serves to minimize inflow of surface runoff to the plant area and at the same time is an inexpensive means of containing contaminated water. A natural depression or excavated sump of adequate size, which might have to be lined, can be used to collect contaminated runoff and spills. It can be used for later recovery of settled solids. Decanted water may be re-cycled directly into the mill or piped to the main recovery dam. A more complex sump might be required for separating of oily water collected from service areas.

Recycling

66. Recycling of mine and mill water has several advantages that generally outweigh any difficulties. Water quality standards for mining and milling processes, including flotation, are less

exacting than requirements governing discharge to the environment. Recycling of treated and untreated water, therefore, is generally economic. Some of the benefits of re-using water include the following:

a. Fresh water requirements are reduced and there may be fewer problems from seasonal variations in supply.
b. The volume of water and quantity of contaminants to be treated before discharge to a water course may be less.
c. Waste water treatment facilities may be smaller.
d. Savings in reagent costs may be realized along with savings in water supply facilities.

67. Regardless of whether mine drainage is acid or not, the above advantages strongly suggest that complete recycling of water should be considered in all mine-plant complexes where major expansions are contemplated or where serious pollution problems exist.

68. Most concentrators operate with a degree of internal water re-use. The complexity and scale of appropriate external water control will be determined in large part by: (a) the availability of water, (b) the compatibility of mill processes, especially flotation, with water re-use, (c) the cost of water supply related to the relative locations of concentrator, plant, mine and impoundment areas and (d) the need to treat effluent prior to discharge to the environment together with its complexity and cost.

69. About 90% of base metal ore is treated by flotation. This process is particularly sensitive to water quality. Considerable quantities of water are required and large volumes of chemically complex effluents are often produced. Recycling has advantages such as potential savings in reagent costs. However, it is necessary to avoid a build-up of reagents or slimes in the water to the point where they can interfere with flotation. Recent advances in reagent development together with internal recycling of water rapidly enough to avoid chemical breakdown of reagents hold much promise.

70. Mine drainage from dewatering wells is usually of adequate quality for use in milling. Treating of mine sump water may be necessary because of accumulated suspended or dissolved solids, high or low pH, or debris and oil. It would still require less treatment than if released to the environment.

71. Selective re-use of clarified mill process water in service applications has some attraction. However, unless corrosion-resistant features have been specified for such items as pump glands and cooling circuits, re-use may be limited to plant washdown and similar non-critical applications. Most service water, such as that used for cooling, will be of adequate quality to be added to process water directly. This is inexpensive and convenient.

72. Sewage should be handled entirely separately by conventional treatment plants. If it is not, health problems may result. Bacterial action in the sewage also may interfere with desired oxidation of effluent process water. Furthermore, the intestinal bacterium E. coli is viable in extremely acid conditions (pH 3) and has been suspected of accelerating acid production. Like plants for treating domestic water supply, small sewage treatment plants are difficult to operate and require skilled supervision. It is recommended that municipal facilities be used where possible. Developments in small sewage treatment packages which will require less stringent supervision are worth watching.

73. Where wet methods of beneficiation are used, most process water is discharged with the tailings. These are frequently discharged as slurries with 10% to 30% solids. Therefore, from 500 to 1 800 gal per ton (2 300 to 8 200 L/metric ton) of tailings may be involved. The tailings area provides the first stage of treatment. Coarse material settles to the bottom. One or more settling basins may be required for finer particles. Treatment facilities may be necessary.

74. The particular circumstances of the project will determine if, in addition to internal recycling of mill process water, staged recovery of progressively cleaner water from the treatment area will also be appropriate. Normally, the recycled water together with new make-up water is added at the primary grinding stage. Figures 1

and 2 show that flexibility, selectivity and control of sources of water pollution increase with sophistication of the recycling system (3, 4). Figure 3 is a diagrammatic representation of the waste water pilot treatment project at the Brunswick Mining and Smelting Corporation Limited mill near Bathurst, New Brunswick showing the capacity of the lime and flocculation processes (5).

TREATMENT

75. Water treatment will almost always involve settling of suspended solids as a first step. Other means include natural or induced oxidation, pH control, ion exchange methods, reverse osmosis and biological methods. Additional settling may also be used.

76. A few guidelines on the management of tailings ponds where acid drainage can occur are as follows:

a. Luxuriant and, if possible, self-sustaining vegetation may control acid production within a tailings pile.

b. In active areas where vegetation is not feasible, a water cover effectively excludes the oxygen necessary for acid production.

c. Tailings ponds should be shallow to minimize seepage.

d. Decanted water should be allowed to settle and oxidize in a separate impoundment.

e. Seepage flows should not be returned to the tailings impoundment. They may be highly acidic and promote further acid production by the reactions:

$$Fe_2(SO_4)_3 + FeS_2 \rightarrow 3FeSO_4 + 2S°$$

$$2S° + 3O_2 + 2H_2O \rightarrow 2H_2SO_4$$

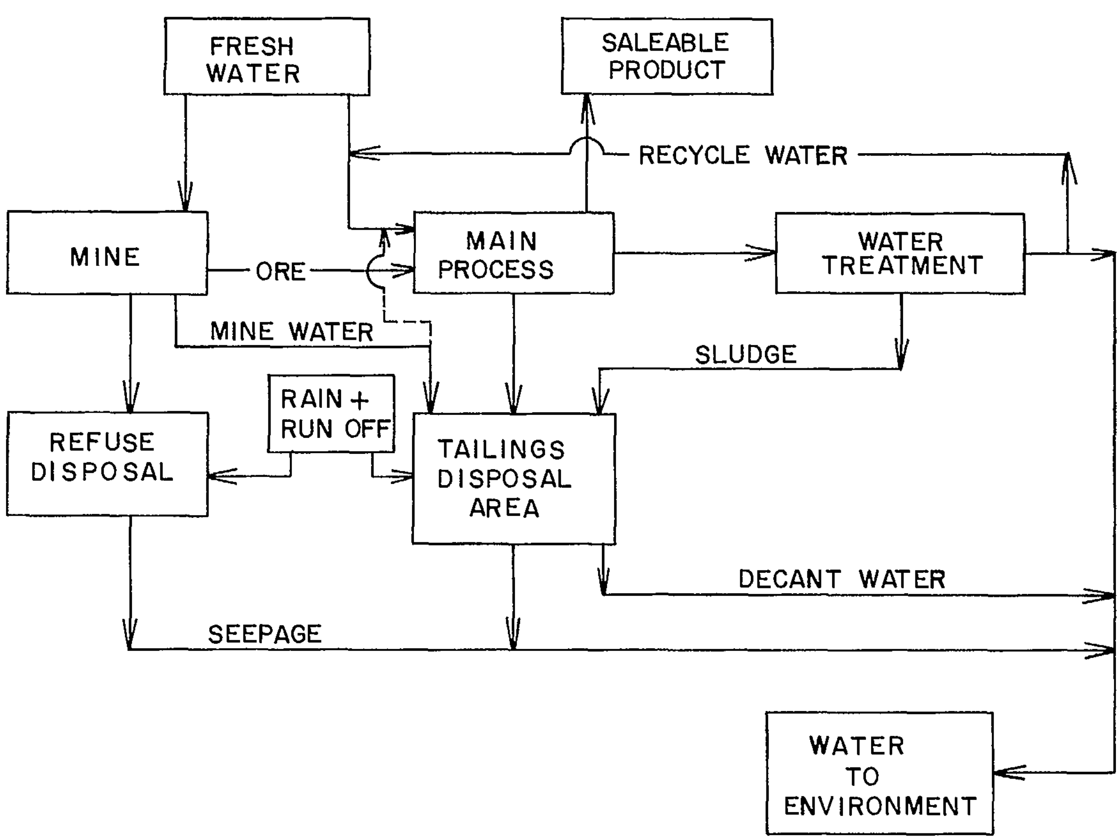


Fig 1 - Intermediate level recycling system (4).

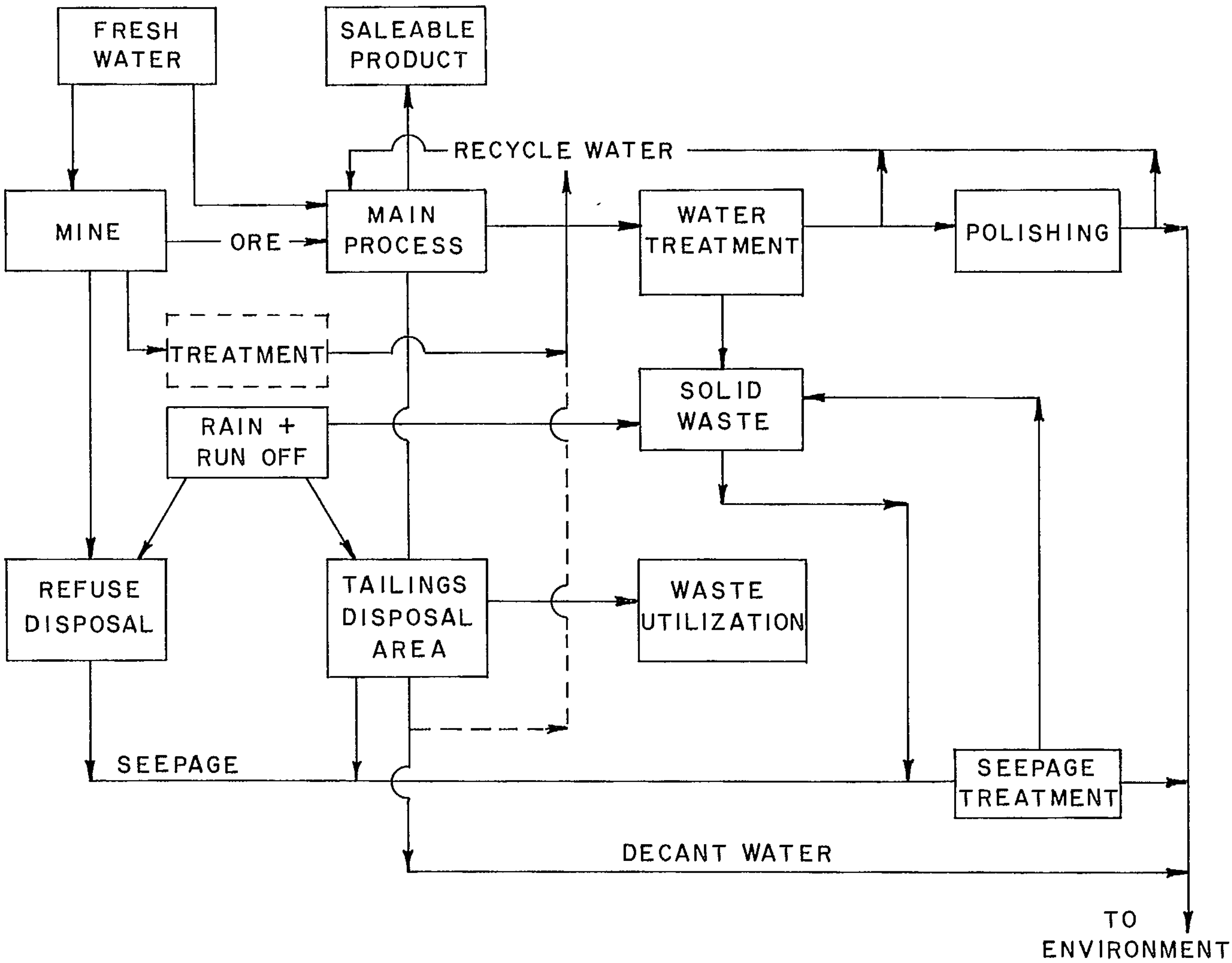


Fig 2 - Fully integrated recycling system (4).

77. Time should be permitted for oxidation of the clear seepage flows to occur with the formation of ferric iron in the hydroxide form and accompanying depression of pH. Dilution of seepage water after oxidation with water decanted from the tailings impoundment may be acceptable to achieve water quality suitable for discharge without further treatment. However, if the pH drops, neutralization may be required before discharge.

78. Natural oxidation of acid mine water can be achieved with time. Retention time in oxidation ponds should be in the order of months rather than days. Ponds should be shallow to facilitate oxygen transfer from the atmosphere. Freezing may preclude year-round natural oxidation. Space may not permit large areas to be devoted to this purpose. An alternative is to induce oxidation by mechanical agitators.

79. Control of pH through the use of neutralizing agents causes the following effects:

a. Acidity is reduced to levels acceptable for discharge.
b. Certain heavy metals that cannot be effectively coprecipitated with iron in acid conditions are removed. These include manganese, zinc, nickel, lead, and copper.
c. Colloidal suspensions of hydrated ferric iron complexes are coagulated.

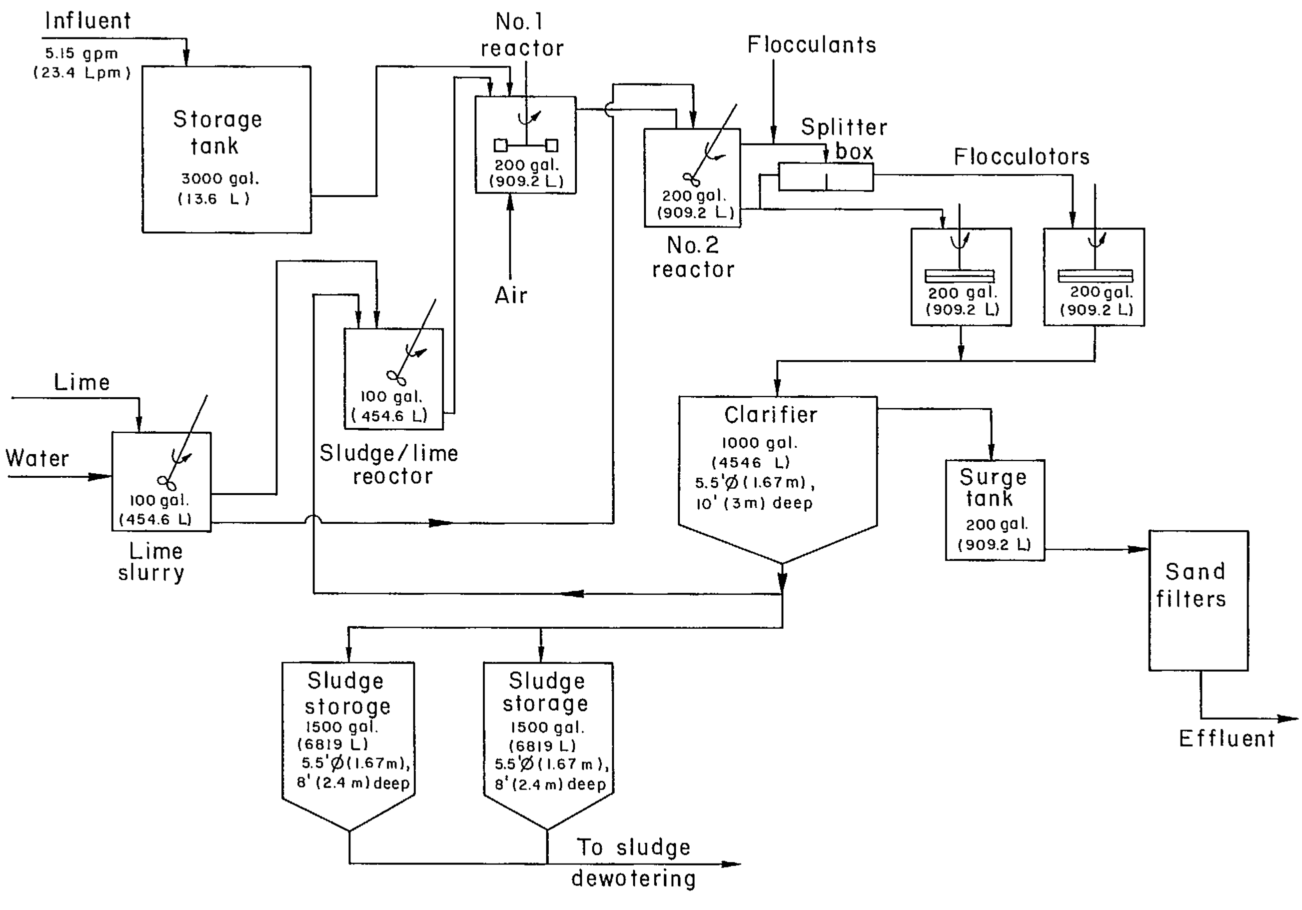


Fig 3 - Mine waste water lime and flocculation treatment project.

d. Faster oxidation of ferrous iron is promoted.

e. Sulphate levels are lowered.

80. Numerous alkali agents can be used for pH control. These include lime, limestone, fly ash, soda ash, and ammonia. Only the first two are usually economical enough for practical use. Ammonia is toxic. Limestone cannot be used for ferrous iron concentrations higher than 50-100 ppm; some oxidation is required first.

81. Low magnesium limestone is usually preferred over lime because it costs less and is easier to handle since it can be stored in the open. On the other hand, the reactivity of lime is several times greater - generally, reactions are completed in about one hour compared with 24 to 28 hours for limestone. Lime has 1.35 times the reactivity of limestone. The choice of either lime or limestone should be based on laboratory testing of effects on samples of the drainage to be treated. Samples of different limestones from alternate sources may reveal significant differences in performance, depending on the proportion of magnesium and other impurities present. Laboratory tests will generally reveal that from 1.4 to 3 times the stoichiometric ratio of the limestone will be required. The reactivity of the limestone can be improved by resorting to a fine grind. Without agitation, build-up of ferric iron scale on large limestone lumps may inhibit the reaction. In certain instances where acidity

problems are acute, combination lime/limestone additions may be appropriate.

82. Solids precipitated from mine drainage during treatment are normally not chemically stable over long periods. They are often also very fine. Special precautions for the long-term disposal of such treatment products are therefore recommended, provided that no industrial use exists.

83. Two methods are available for disposing of treatment sludges, each involving burial and isolation from groundwater. Burial in a natural rocky depression where seepage into the groundwater has been eliminated is feasible. Alternatively, precipitated solids could be buried within a well-managed tailings impoundment. In both cases, vegetation over the burial site should be actively encouraged. Note, however, that treatment solids are usually very finely divided and are difficult to handle. Adequate dewatering of these slimes before handling can pose severe problems.

84. Ion exchange processes have been found effective with slimes. Used to remove cations such as iron, calcium, copper, and zinc, and certain anions like sulphate and nitrate, the method is applicable when effluent water quality standards are especially stringent. Operating costs are up to six times greater than lime or limestone for pH control.

85. Reverse osmosis may be used to remove dissolved salts. An expensive process, it is subject to fouling of the membranes by suspended matter and is not generally considered effective. Future developments may encourage wider application.

86. Biological treatment of mine drainage is, as yet, rare. AMAX Lead Company of Missouri, operating in a National Forest, constructed meanders in the treated effluent discharge stream (6). Phosphorus present in the discharge had promoted excessive algal growth in the receiving stream waters. Construction of the meanders kept unusual algal growth on company property, effectively removed the phosphate nutrient residues from flotation reagents and utilized the algae as

Fig 4 - Meander system for effluent control (Courtesy Amax Lead Co.).

a final mechanical filter. Indications are that this procedure is relatively maintenance-free and reliable. The system is illustrated in Fig 4.

87. Recycling of neutral and alkaline drainage has economic advantages. In treating neutral waters, fewer processes are required. Settling is normally sufficient. Alkaline waters require neutralizing just as acid mine drainage. A maximum pH of approximately 8 is usually acceptable for receiving waters. Aluminum sulphate is a convenient acidifying agent. Alternatives include sulphur, gypsum and ferrous sulphate.

RECLAMATION OF MINERAL WASTES

88. Reclamation involves returning mine waste and pit areas to stable and aesthetic landforms with the establishment of a permanent, self-sustaining and eventually maintenance-free vegetation cover. Plant cover tends to reduce erosion, decreases airborne and waterborne dust movement, and is believed to reduce weathering of the lower mineral layers. Potential uses for rehabilitated mine sites are both varied and challenging. However, the first objective is usually to establish vegetation cover on critical areas. Since mine wastes are not true soils, sustained watering and fertilizing may be necessary.

LAND USE

89. Vegetation studies should be planned for the ultimate use of the site. In certain cases these studies can even lead to a more productive use than before mining commenced. Examples of ultimate land use are:

a. grasslands to stabilize and prevent erosion and to serve as pasture-land in temperate regions and range-land in drier zones,
b. wildlife sanctuary encouraged by grass cover and invasion by forest species,
c. farms and forests for the production of cereal crops, wood-harvesting and sod farming,
d. fishing or fish hatchery in residual ponds,
e. recreational, commercial and industrial developments that can include parks, ponds, playgrounds, campgrounds, golfcourses, residences, commercial buildings and air strips.

NATURE OF WASTES

90. The amount of waste material is normally large compared with the quantity of ore removed in most open pits. Wastes can include tailings, waste rock, and overburden. Usually each class of material requires separate disposal areas.

91. There are also other areas to be considered, such as those required for slag piles, stock piles, impoundment dams, and free areas surrounding the mill and plant. There are also sludges and residues from milling processes and waste water treatment which require space.

92. There are a number of physical and chemical factors to be considered before initiating studies to grow vegetation on waste. The size of granular material affects permeability, porosity, and rate of wind and water erosion. Pit waste and overburden usually contain large, irregular-sized particles through which rain can

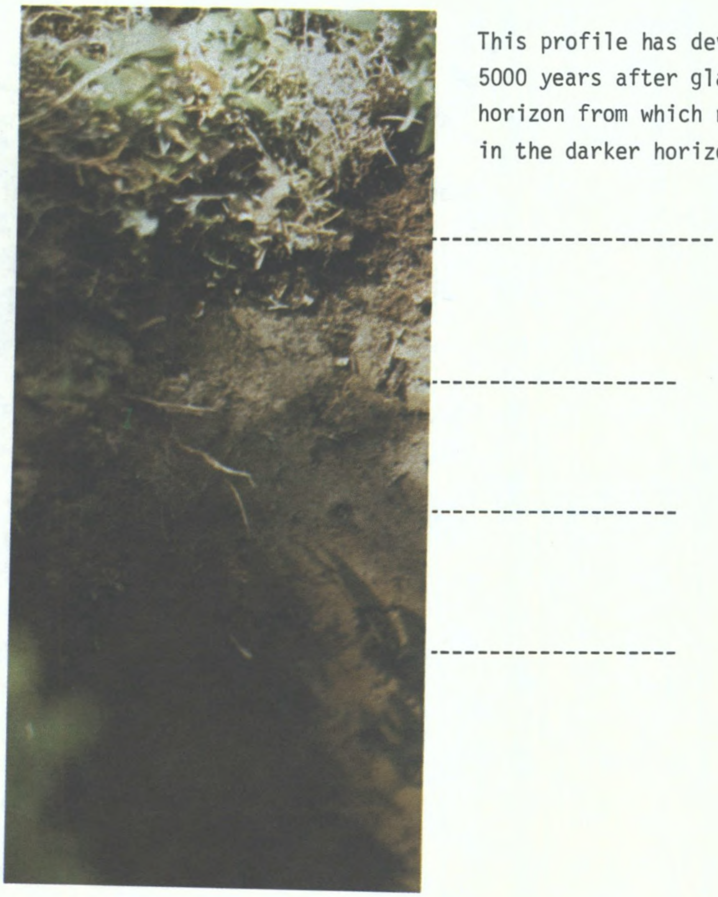
readily percolate, reducing surface runoff. Such materials generally have low water-holding capacities and are prone to drought. Growth of vegetation may be reduced by drought or by scouring damage from loose airborne particles.

93. Fine-textured wastes often become waterlogged and are subject to water erosion; when dry, they are subject to wind erosion. The presence of fine particle sizes reduces pore size and water infiltration, increasing surface runoff. Oxygen levels required for plant growth may become depleted and cause poor growth. Agricultural soil development will be slower without vegetative cover. An accumulation of decayed organic matter, nutrients and inorganic particles are required to produce a stable profile. Figure 5 shows an example of soil profile development under healthy vegetative cover.

94. The colour of mine waste is also important. Light coloured materials reflect solar radiation back into the air, creating high temperatures just above the surface and reducing moisture available for plant growth. Dark coloured surfaces absorb more energy; consequently the air around the plant is not as hot.

95. The chemical characteristics of mine waste strongly influence establishing vegetation. Inorganic chemical conditions are determined by the concentration of metals, salts, reagents, plant nutrients and hydrogen ions (pH).

96. Subsurface pH values are important because few plants can tolerate either very acidic or very alkaline conditions. A pH range of from 5.5 to 8.0 is optimum for plant growth. Where pyrite,



This profile has developed under coniferous vegetation 5000 years after glacial retreat. Note the light grey horizon from which nutrients are leached and deposited in the darker horizon below.

Fig 5 - Typical soil profile.

pyrrhotite or massive sulphides are common, sulphuric acid produced by oxidation or weathering creates an acid environment. Acidity leads to leaching because the acid solution dissolves salts. Acidity may also build up in the surface as salts are leached to the lower layers. Thus, it is possible for plants, particularly trees, to grow well initially, but then fail when surface layers become acidic or when the roots contact toxic compounds in the subsurface layers.

97. Weathering and acid production occur only at the surface where air and water are available. Each time the weathered material is removed, another fraction undergoes weathering. Thus, disturbing the soil surface may increase acidity problems. As acidity increases, the solubility of metal ions increases, which may be toxic to plants and to animals.

98. The availability of plant macronutrients (nitrogen, phosphorus, magnesium, calcium, potassium and sulphur) may be low on most solid waste heaps. Macronutrients are less available for plant growth in acidic or basic conditions, ie less than pH 5.5 or greater than pH 8.0.

99. Micronutrients necessary for plant growth are iron, copper, manganese, zinc, boron, and molybdenum. These are often present in toxic quantities under acidic or basic conditions. There are some dumps in which trace levels of these nutrients are more readily available than from the original soils, and lush plant growth is possible.

100. Vegetation may be maintained at first but then fail if the nutrients are not continually replaced. The organic conditions at the surface are important because humus increases bacterial and fungal growth, and also improves soil structure. Humus is a major source of soil nitrogen and sulphur. It increases moisture retention and reduces the toxicity level of ions. Vegetation of land without humic content is possible, but success is much greater with it.

RECLAMATION BY VEGETATION

101. Mine sites may be subject to landslides, erosion and altered drainage. These may result in air and water pollution and may reduce aesthetic values.

102. Reclamation can alleviate these conditions through an appropriate vegetation program. Usually vegetation establishment should be aimed at decreasing the erosion rate, improving soil conditions and increasing the vegetation cover.

103. Analysis of waste samples can determine its suitability as a growth medium and indicate proper conditioning procedures. Factors to be considered include acidity or alkalinity, levels of plant nutrients, soil particle size, moisture capacity, cation exchange capacity, organic content and salinity. More details on this aspect can be found in Supplement 10-1 which gives guidelines for reclamation by vegetation.

104. Two of the most important soil parameters are acidity and pH. Other soil parameters such as nutrient availability, humus and water content are related to them. Wastes can be divided into three broad categories: acid (pH below 5.5), neutral (pH 5.5 to 8.0), and basic or alkaline (pH above 8.0).

105. Canadian mining activities generally associated with each pH range are listed below.

a. Acidic conditions occur with massive sulphide deposits such as pyrite, pyrrhotite and pentlandite ores, copper, nickel, zinc, lead and silver sulphides, and most base metal ores in Eastern Canada.
b. Neutral conditions occur with gold, iron ore and construction aggregates.
c. Basic conditions occur with asbestos, gypsum and anhydrite.

These are not strict classifications.

106. The ability of waste to support plant growth is not easily determined. Approaches are many and varied. The classification of waste by pH is one important means. Classifications on the basis of soil texture, salinity, nutrient status and colour are also useful. More details can be found in Supplement 10-1.

107. Methods presently used for rehabilitation are: natural vegetation, seeding with chemical fertilizer, and seeding with chemical and organic additions. Selection depends on effectiveness and costs.

108. Natural invasion of plants is only practi-

cal where mine wastes have sufficient plant macro-nutrients, are of neutral pH, have a suitable size range and contain few toxic materials. For example, the reclamation of 28 000 acres (11 300 ha) of strip mines in Illinois included 14 000 acres (5 700 ha) being reforested by natural encroachment.

109. Chemicals can be added to improve conditions for plant growth. In areas where the pH is quite low, large quantities of lime are added to neutralize acidity. When weathering and oxidation of pyrite and other sulphides continue to produce sulphuric acid after vegetation establishment, periodic lime additions will be required to maintain growth.

110. Sufficient lime should be added to raise the pH to between 5.5 and 7.5. In this range, nutrients are most available, heavy metal toxicity is reduced and activities of nitrogen-fixing bacteria are optimal. Lime is usually added as feed-grade or agricultural-grade limestone. Small initial applications of hydrated lime or finely ground limestone may raise the pH values of the soils quickly, but the effect is often short-lived and subsequent additions are required. Agricultural-grade limestone is preferable as it releases its neutralizing capacity to the soil more slowly. The soil should be tested for pH, and applications adjusted to maintain values between 5.5 and 7.5. Limestone is usually disked into the soil to a depth of approximately 6 in. (15 cm). If the acidity is extremely high, a detailed study should be made to determine the cause and best method of correction. This may involve several cycles of limestone addition and mixing.

111. If the waste is too basic, with pH above 8.0, establishing vegetation is difficult. In this case, the pH of the soil can be adjusted by adding various sulphate materials such as aluminum sulphate, sulphur, gypsum or acidic tailings. Nutrients may be added. Mill residues and waste water treatment sludges may be added to the waste to break up and improve soil texture.

112. Nitrogen-phosphate-potassium (NPK) fertilizers are available in various grades expressed as elemental nitrogen, phosphate as P_2O_5 and potassium as K_2O. The grade ratios may be 7-7-7, 4-12-10, 8-16-16, 5-20-20, etc. The ratio represents the amounts of nitrogen, phosphates and potassium expressed as percentages. For example, 4-12-10 contains 4% nitrogen (N), 12% phosphate (P_2O_5) and 10% potassium (K_2O). Examples of the use of fertilizer and other conditioning agents are given below.

113. High fertilizer levels in soil may burn seedlings. They may also retard legume and nitrogen-fixing bacterial growth. To avoid burning it is better in the early growth stages to use low grade fertilizers frequently rather than high grade fertilizers only once. Least cost combinations of grade and number of applications can often be predicted on the basis of test plantings.

114. Chemical fertilizer is disked about 6 in. (15 cm) into the surface. This is done after any limestone application. It is advisable to monitor pH values after the fertilizer is applied since decomposition of some fertilizers reduces pH by producing weak acids. Surface applications of fertilizer or lime may be required periodically through the first few years while a plant cover is being established.

115. Trace micro-nutrients do not normally limit growth in mine wastes. They can be added as additional trace fertilizers; however, there are usually sufficient quantities in chemical fertilizers.

116. The third method of preparation differs in that not only chemicals but also organic matter of several types may be added. These include organic mulches such as straw, wood chips, wood fibre, pulp, sewage sludge, domestic refuse, or fly ash. Preserved top soil can also be spread on the waste. Peat from peat bogs may be used in a similar manner. These additions improve soil structure, soil aggregation, oxygen penetration, nutrient supply and moisture capacity. They also darken soil and speed soil development. The organic additions support the microbial population necessary for all aspects of soil development.

117. Organic soil binders, such as bitumen compounds, may be used to stabilize the surface. They are expensive and, except in very difficult

areas, their performance has yet to justify the costs.

PLANT SELECTION

118. In most cases, grasses and legumes have been seeded together with companion crops such as oats, wheat, rye or barley. Companion crops are only used for the first year when a fast growing, rough quality cover is needed to provide protection against soil erosion. Companion species also produce stubble that can catch snow and reduce winter kill.

119. Legumes which fix atmospheric nitrogen function better and faster if they are inoculated with the nitrogen-fixing bacteria before planting.

120. Table 2 lists species suited for various climates which are currently used for vegetation in Canada. Most would suffer winter kill if used in Arctic conditions. It appears that natural encroachment onto sculptured spoils may be the most effective solution. In moist Arctic conditions, the cotton grasses may prove suitable. Seed supply would be a problem.

121. The species chosen depends on the nature of waste, climatic conditions and ultimate land use. Grasses are more tolerant of adverse soil pH and moisture than legumes, and are therefore easier to establish. They do, however, require more fertilizer. Species with a high nutrient requirement include bent grass and bromegrass; those with medium nutrient requirement are reed canarygrass, timothy, wheatgrass, red clover and alfalfa. Red top, ryegrass, fescues, birdsfoot trefoil, crownvetch, and sweetclover have low nutrient requirements. Many species cannot tolerate very wet conditions; however, grass species such as reed canarygrass, timothy, bromegrass, red top, bentgrass, bluegrass and fescues will tolerate some flooding. Legumes cannot tolerate more than about 14 days of flooded conditions. Pasture grasses and legumes can be used for stabilization once a good seed mixture is found for the soil conditions of the waste. They may be established on tailings, overburden and rock dumps. Trees and shrubs are used where a windbreak is desired or when a visual shield is wanted. They are also useful on steep or rocky

Table 2: Plant species used for vegetation in Canada

Companion species	Legume species
Bromegrass	Alfalfa
Oats	Red clover
Barley	Sweetclover
Winter rye	Alsike clover
	Crownvetch
	Birdsfoot trefoil
	White clover

Pasture species	Tree species
Canada bluegrass	Carolina poplar
Kentucky bluegrass	Silver maple
Reed canarygrass	Jack pine
Red top	Balm-of-Gilead
Creeping red fescue	Willow
Timothy	Black alder
Crested wheatgrass	Paper birch
Highland bentgrass	Ash
Ryegrass	Black locust
	Black spruce
	Colorado blue spruce
	Red pine
	Scotch pine
	Douglas fir

terrain and coarse waste. Sweetclover is often used in combination with trees or shrubs.

122. The successful vegetation establishment of waste is also dependent on such factors as micro- and macro-climate, disease and insect resistance, competition, growth habit, life span and success of reproduction.

123. The availability of moisture in the tailings, especially during warm dry summers, is important. If the water level is not high enough to provide moisture, irrigation may be necessary. As the vegetation becomes mature and self-sustaining, the need for irrigation diminishes since grasses are adapted to dry summer conditions. Availability of moisture is especially important with light coloured soils.

124. The variety of plant used should be resistant to common diseases of that species. Another variety, or even another species, should be substituted if the disease is prevalent. Similarly, plants may need protection against insects by a pesticide spraying program. Weed species can provide a surface cover in the first few years but many will compete with the desired species and reduce the potential of the land. If the objective of the reclamation program is to return the area to native vegetation, then weeds should be encouraged.

125. Much research remains to be done on the development of hardy strains suited to mine rehabilitation by vegetation. Seeds harvested from established waste vegetation projects may be more resistant to the severe conditions encountered.

126. The ability of the species to reproduce is essential if the plant cover is to remain. Grasses are important in vegetation programs because of their high reproduction rates. Roots and rhizomes spread out and tend to hold the soil in place. Sod formers, or species with a thick rooting system, include red top, bentgrass, and bluegrass. Most of the other grass species propagate by cloning (spreading out from the parent plant). Many of the legumes, such as birdsfoot trefoil, crownvetch and alfalfa, spread by underground rhizomes. Figure 6 shows the root structure of birdsfoot trefoil, with nitrogen-fixing root nodules. Several tree species reproduce by cloning or suckering from the parent plant, eg, birch and poplar. Figure 7 shows the typical root growth pattern of balsam poplar. Species that reproduce sexually are not usually important in the early stages of vegetation, since the plants then must produce viable seed during the growing season and these seeds must survive in severe conditions.

127. Because of physical, chemical, and climatological conditions, not all plantings of recommended species will be successful. Several test plots of species may be required to determine the best combination of species for each type of waste under the actual conditions to which the plants will be subjected. Companion species are often planted first. These are followed by pasture grasses, which should be seeded at the same time as the legumes. Tree species are planted several years after the pasture species when a soil profile is developing, acidity is controlled and the soil is stable.

128. Some seed mixtures include several grasses and legumes. This method should be approached

Fig 6 - Typical root structure of birdsfoot trefoil. Note the small white nodules which contain nitrogen-fixing bacteria. (Courtesy Inco Ltd.)

Fig 7 - Typical growth pattern of the tap root of a balsam poplar. The branching root system has been outlined by the deposition of ferric ions around the tap root, which reduces the acid-producing potential of this zone.

with caution since competition between species could hamper the establishment of the desired stand. Mixtures of one or two grasses and only one legume may produce best results.

129. Monitoring of soil pH throughout the soil preparation period and over the first few years is important. pH can be used to estimate nutrient availability, to determine when fertilizers or lime must be applied, and to appraise when the soil has developed enough for the vegetation to be self-maintaining.

130. Soil formation in temperate regions of Canada is normally a slow process. For example, since glaciation 8 000-12 000 years ago, soil depths of only 12 - 20 in. (30 - 50 cm) have been formed on the Canadian Shield. It is thus good practice to separate topsoil from overburden and stockpile it for use in reclamation. Additional organic material can be obtained from peat bogs which have high humic content and large amounts of nutrients.

131. In the initial stages of mine development, overburden can be dumped in the best locations for overall rehabilitation of the land form. In some areas, tailings can be added to coarse glacial till to improve moisture retention capacity and overburden texture. Adding a layer of previously segregated topsoil promotes vegetation and natural succession.

132. Temporary stockpiles may be sources of groundwater contaminants. Periodic examination of leachates and stockpile stability should be made.

133. The reclamation of waste rock is usually difficult. It usually has no organic matter and a small proportion of soil-size material. Long steep slopes with rock size increasing towards the toe also make it difficult to establish vegetation. Compacted surface materials with good subsurface drainage can lead to very dry conditions. A topping of soil is usually essential for seeding. Slopes, however, will require more elaborate treatment unless the waste

rock is completely covered with other material.

134. The vegetation of very fine tailings, which may have low permeability, may be difficult. The addition of coarser fractions of waste rock or overburden is usually expensive. Reducing surface compaction may improve the soil conditions. Regrading of tailings dams once the impoundment is inactive is usually necessary to achieve adequate stability for revegetation. Usually, the slope should be reduced to less than 30° (preferably 25°) with few depressions that could concentrate drainage. Ideally, grading of slopes into a gently undulating land form is best for vegetation. Once structural stabilization is assured, the surface can be prepared for vegetation establishment. This entails characterization of the land surface by chemical and physical analyses. Work can then proceed with either of the three methods described above. In areas close to roads or public access, aesthetic enhancement by tree screens or shelter belts should be considered.

Examples of Reclamation

135. There are numerous examples of mine waste vegetation programs in Canada which have had varying degrees of success. Waste embankments tend to be unique with respect to vegetation. The examples described here should be considered only as illustrations and not as solutions.

136. The stabilization of mine tailings at Copper Cliff is particularly interesting (7). These have a high concentration of pyrrhotite and are acidic with a pH of 3.0 to 3.5. It took approximately 10 years to develop an effective means of vegetating these tailings. By the end of 1975 over 1 000 acres (405 ha) were under grass. Trees were establishing themselves naturally (Fig 10).

137. The Copper Cliff area has a relatively late spring, and summer drought problems are frequent. Seeding is done in late July. The waste is graded and feed-grade limestone at the rate of 3 tons/acre (6.7 metric tons/ha) is disked into the top 6 in. (15 cm) during early June. In early July, an additional 2 tons/acre (4.4 metric tons/ha) of agricultural limestone and 400 lb/acre of fertilizer are harrowed into the surface. In late July, fall rye is planted at a rate of 1.5 bushels/acre (approximately 85 lb/acre or 95 kg/ha).

138. The following grass mixture is seeded at the same time at the rate of 50 lb/acre (56 kg/ha): 1 part Kentucky bluegrass, 1 part Canada bluegrass, 1 part timothy, 1 part creeping red fescue, and 2 parts red top. Immediately after, bromegrass is broadcast over the area at the rate of 8 lb/acre (9 kg/ha) and pressed into the surface with a culti-packer. Conventional seeding equipment is employed, except on steep slopes where a hydroseeder is used. An additional 400 lb/acre (448 kg/ha) of fertilizer is applied at this time.

139. When applied in late July, the plants have an opportunity to germinate and "harden off" before winter. The rye serves as a companion crop to reduce soil erosion and to improve the microclimate. The rye is cut the following year leaving a 10- to 12-in. (25- to 30-cm) stubble that collects snow, providing insulation for the pasture species during the winter.

140. At one time, the grass was cut and the hay sold for forage, but at present it is left to decay to provide organic matter. Tailings that were vegetated 12 years ago have a good soil profile as shown in Fig 8 and 9.

141. After freeze-up in the fall, 100 lb/acre (112 kg/ha) of urea is applied. Fertilizer is applied at the rate of 200 lb/acre (2.24 kg/ha) in the spring.

142. In some of the steep tailing areas facing prevailing winds, a mulch of wood fibres is applied with a bitumen soil binder. This is mixed with the seed and fertilizer and applied with a hydroseeder at the rate of 1 000 lb wood fibre/acre (1 120 kg/ha), 25 gallons bitumen/acre (233 L/ha) and 200 lb/acre (244 kg/ha) of fertilizer.

143. The uranium tailings of Elliot Lake provide a different challenge. Extraction of uranium from the ore by acid leaching increases acidity. The tailings contain from 2 to 8% pyrite and have pH values from 2 to 4. Furthermore, the fine and coarse tailings have different chemical and physi-

Fig 8 - Soil profile development on tailings after 12 years of vegetation cover. A distinct humus horizon 2 in. deep has been produced, which is faster than under natural conditions. (Courtesy Inco Ltd.)

Fig 9 - Soil profile development on tailings after 6 years of vegetation cover. The profile actually has not yet developed. The tailings are darker than those in Fig 8 because the extraction process was changed to recover iron, which made these tailings easier to revegetate because of their reduced acid potential. (Courtesy Inco Ltd.)

Fig 10 - Copper Cliff tailings area after 12 years of vegetative cover. The yellow flowers are birdsfoot trefoil, a legume which fixes nitrogen. The grasses growing close to the birdsfoot trefoil are greener due to the extra soil nitrogen. (Courtesy Inco Ltd.)

cal properties. The fine material has excess moisture, reduced aeration and greater reactivity. The coarse fraction is susceptible to drought, erosion and low reactivity. Both fractions, with appropriate soil amendments, have produced good growth. The fines have produced superior growth in most instances, but moving equipment on the unstable surface is difficult. Successful treatment incorporates feed-grade limestone at a rate greater than 10 tons/acre (22 metric tons/ha) for coarse tailings and 30 tons/acre (66 metric tons/ha) for fine tailings, using a disk, harrow, or rototiller. The grass and legume mixture is drill-seeded without a companion crop, and periodic fertilization is carried out during the growing season using 100 to 200 lb per acre (112 to 224 kg/ha) of fertilizer at four- to eight-week intervals. Timing is most critical during the period when growth is being established but may be relaxed in subsequent years. Species selection has not been critical; red top, creeping red fescue, Kentucky bluegrass and reed canarygrass have shown good growth. Alfalfa, sweetclover, and birdsfoot trefoil have been the better legumes. Studies are continuing to identify the species most likely to be self-sustaining (Fig 11 and 12).

144. Tailings at Asbestos, Quebec, require different techniques for vegetation. Asbestos tailings tend to be highly alkaline and retain a large quantity of moisture which, however, is not all readily available for plants. The surface is hard, fibrous and matted and must first be loosened by such means as a rototiller. One approach then is to apply a neutralizing agent, in this case acidic sulphide tailings at the rate of 30 to 40 tons/acre (67 to 90 metric tons/ha). Chemical fertilizer (grade 10-10-10) at the rate of 1 to 2 tons/acre (2.2 to 4.4 metric tons/ha) and poultry manure (grade 4-3-2) at the rate of 1 to 2 tons/acre (2.2 to 4.4 metric tons/ha) are disked into the seed-bed together with the acidic tailings. The poultry manure encourages bacterial growth in the mixture. The tailings are then seeded with a mixture of timothy, forage mixture and inoculated birdsfoot trefoil. With this approach, grasses and legumes grow well in the first year. Studies of vegetation as a long term solution on asbestos tailings are continuing.

145. Neutral tailings are much easier to handle. At the Hollinger mine in Timmins, a very

handle. At the Hollinger mine in Timmins, a very diversified scheme for tailings revegetation has been implemented that will benefit the community at large. Preparation of the tailings after grading included the addition of 2 tons/acre (4.4 metric tons/ha) of triple superphosphate, one ton/acre (2.2 metric tons/ha) 15-15-15, and 2 tons/acre (4.4 metric tons/ha) agricultural limestone. The reclamation program is to provide a tree nursery, a sod farm and a cattle farm.

Fig 11 - Nordic tailings pond, Elliot Lake, before revegetation (July 1971).

Fig 12 - Nordic tailings pond, Elliot Lake, after revegetation (July 1974).

OTHER OPERATIONS

146. This section covers certain activities common to most forms of open pit mining that can have both natural and social significance. These activities are truck hauling, pipelines and dewatering. They are treated briefly as their impact is frequently small in relation to solid waste disposal and water resource contamination. Blasting control in relation to ground shock and acoustic disturbance is discussed in somewhat greater detail in an attempt to bring together some of the published knowledge which - especially in relation to climatic effects - is not readily available for easy reference to the practicing mining engineer.

TRUCK HAULAGE

147. The haul road is an integral part of most Canadian open pits. Environmental considerations are largely those of current operations rather than of long-term effects.

148. The greatest advantage of truck haulage is flexibility, and this very point can lead to environmental effects if not well managed. New roads can be constructed rapidly across country to cut corners or to give easier access to the remote side of an existing dump. Road construction of this nature may be initiated and carried out without adequate prior investigation. For example, culverts may be omitted or be undersized, with consequent damage through silting and flooding.

149. Chemicals are often applied to haul roads to assist traction or to control dust. Materials such as salt, sand, crushed slag, calcium chloride and engine oil may be used. The chlorides, and especially the tars present in certain oils, are potentially toxic. Environmental damage will be insignificant near the road but could be important if heavy accumulations of the toxic materials are transported into natural water bodies during the spring thaw. During the planning stage, total loadings of toxic materials from haul roads should be estimated and compared with levels permitted in rivers and streams. Treatment may be required. Whether this is done at a common sump location together with contaminated water from other sources, or independently, should be decided on the merits of the particular situation. Periodic monitoring of water quality from this source should be instituted. Alternatively, only inert material may be used for road surface maintenance. Ground and surface water contamination may occur from accumulations of spillage at loading and

dumping points. This is of greatest importance where concentrates are involved and is commonly seen at railway loading facilities.

150. Noise may be a source of concern to local residents, especially at night. Special engine muffling may be a partial solution for off-highway equipment, but topographic or tree screening may also help. In planning new operations, noise in general should be limited to no more than 40 decibels for a 24-hour operation at the edge of a residential area; 50-55 decibels may be acceptable for an operation working only during the daytime. Careful scheduling to curtail haulage at night while compensating with increased activity during daylight hours may alleviate conditions and avoid a possible confrontation. Scheduling must also take into account the use of public highways by mine trucks and their impact on local traffic patterns.

PIPELINES

151. Slurry pipelines serving Canadian open pits are generally limited in length to less than 10 miles (16 km) and in diameter to 10 in. (25 cm). Water supply lines may in some cases be larger. Such pipelines frequently traverse broken terrain. They may be of woodstave, plastic or steel construction and are frequently protected for cold weather operation by burial or electrical heating. They may be placed on timber supports which can be realigned as necessary.

152. The greatest potential for environmental damage with slurry and dewatering pipelines will occur in the event of a malfunction involving discharge onto the ground at points along the route. It is normally good engineering practice to incorporate emergency dump valves at low points in slurry lines. These operate in case of power failures or blockages. Route selection for slurry lines should consider the distances apart of such emergency dump points, their location and the ability of local terrain to contain slurry in emergency sumps without widespread environmental degradation in adjacent watercourses. Where possible, pipelines should follow roads for access and maintenance, and sumps should be designed for easy approach and clean-up using mobile equipment. Pipelines may not be economically feasible in seismically active areas or in permafrost regions.

DEWATERING

153. The presence of an open pit mine will have a significant effect on groundwater surrounding the mine. The degree and extent of the effect will depend on the type of groundwater regime in the area. It will be most pronounced in flat-lying areas where the groundwater is near surface and permeable strata are present.

154. Major dewatering schemes require estimation of surface and groundwater flows, climatic variations, water quality and recharge. The ability of water bodies to receive increased flows of discharge water from a dewatering scheme should be examined. Additional water from wells, stream diversions and lake and bog drainage may result in overloading through erosion, silting and high turbidity. Groundwater used by others may be contaminated by leachates drawn into aquifers.

155. Wells or adits are sometimes used to lower the water table prior to mining. In operating pits, either gravity drainage to a sump in the bottom of the pit or peripheral well drainage is used. In rare instances, for example with saturated overburden of low permeability and limited vertical extent, multiple well points connected to a central suction pump may be employed. These are limited to about 20 ft (6 m) drawdown.

156. Sump dewatering at the pit bottom will be required. The water may contain suspended solids such as silt, salt, chemicals, leachates and miscellaneous debris. Treatment can be integrated with the mine-mill water clean-up system. Gravity drainage to sumps or underground produces water containing abrasive material. Sumps can freeze and the system can be interrupted by operations. However, economics and local geology may dictate use of this system.

157. Dewatering through wells is the preferred method, provided it can be justified economically. Wells of up to 6 ft (1.9 m) diameter have been drilled (eg, at lignite mines in Germany). Churn, rotary, reverse rotary and other types of drills are used for water wells. For dewatering projects

where it is necessary to maximize inflow to the well, either screens are installed or the casing is perforated from the water table down unless caving ground is encountered. Well screens with openings comparable in size to the particle size of the formation are useful in maximizing flow from specific horizons. In well-development, surging causes violent water action near the screen or casing perforations and loose sand is drawn out of the ground. Removal of fine sand with a bailer gradually leaves a layer of coarse particles around the hole to act as an effective filter.

158. After adequate development, dewatering wells should yield reasonably clean or even potable water, provided the dissolved mineral content is not high. They should be monitored for suspended solids and ion concentrations. Treatment such as settling, oxygenation by agitation, or pH adjustment may be needed if the water cannot be used in milling.

BLASTING

159. On detonation, some of the energy from a blast is dissipated as shock waves travelling either through the atmosphere or through the ground. Air blast damage can be produced through line of sight transmission or by atmospheric reflection of sound waves. The latter phenomenon occurs at typical ranges in the order of 10 to 20 miles (16 to 32 km) and is caused by temperature inversion. Occasionally, inversions may cause unusual disturbances at ranges of about 150 and 300 miles (240 to 480 km) respectively. These are only significant with blasts involving the equivalent of several hundred tons of TNT.

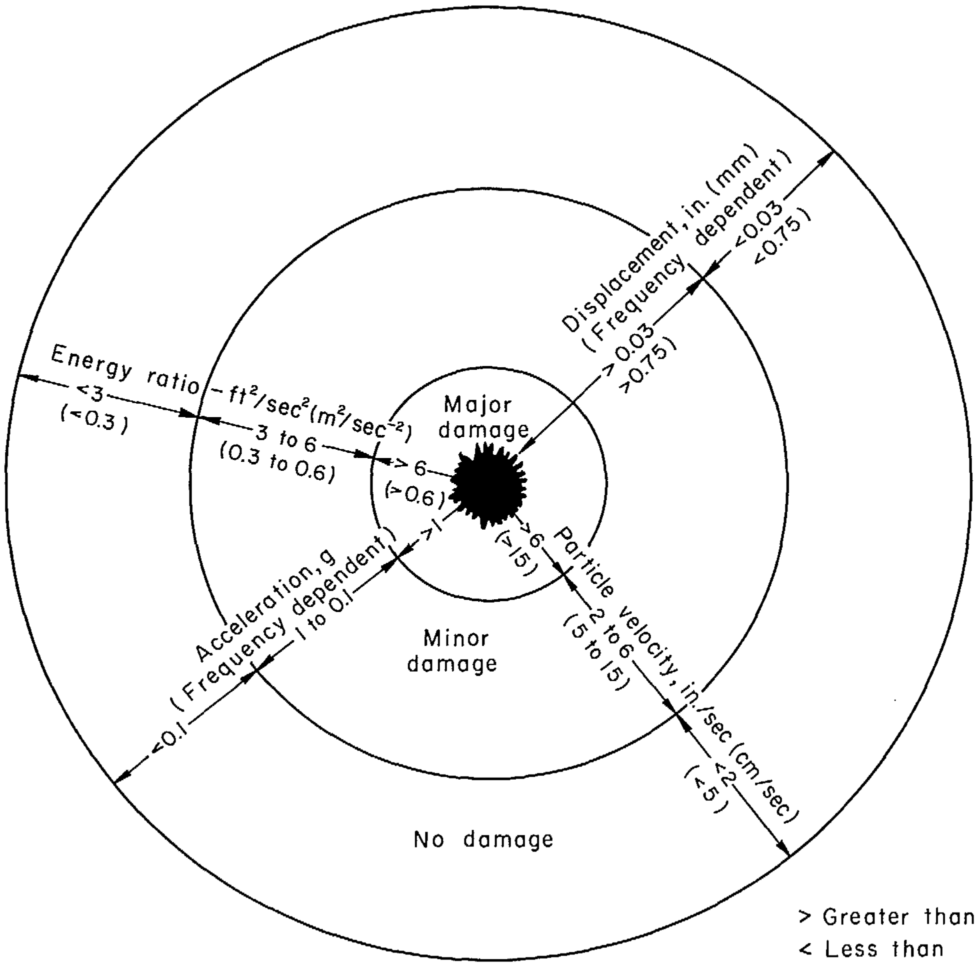
160. People and animals are highly sensitive to ground motion and air shock noise. As a result, complaints may be based on anticipation or expectation of damage, rather than on actual damage. People are disturbed and react unfavourably to ground motion with a peak particle velocity as low as 0.1 in./s (0.25 cm/s). By contrast, a peak particle velocity of 2.0 in./s (5 cm/s) is considered a safe design limit to avoid damage to houses. Instances of ground shock and air blast noise as high as safe design limits are rare around Canadian open pits. In formulating blasting legislation, the Ontario Department of the Environment (under authority of section 14 of the Environmental Protection Act) is proposing limits of 130 db and 0.4 to 0.5 in./s (1 to 1.25 cm/s).

161. Investigation of blasting damage has shown that an empirical relationship exists between ground motion velocity and damage to buildings in the frequency range typically associated with blasting (8). Table 3 gives examples of the correlation between peak particle velocity and building damage (8, 9, 10). Figure 13 shows in pictorial form a variety of criteria for evaluating the probability of damage.

Table 3: Damage to structures as a function of peak particle velocity

Type of damage	Peak particle velocity (in./s)	Peak particle velocity (cm/s)
Readily perceptible by people	0.05	0.12
Widely recommended for design near residences (ie, objectionable to people)	2.0	5.0
Slight damage (eg, fine cracks in plaster) may begin	2.8	7.0
Minor falls of plaster, more significant cracking in plaster	4.3	10.7
Concrete block foundations may split	8	20
Pumps, compressors, and shafts misaligned	40.0	100.
[Jumping on a house floor	0.05-5.	0.12-12.]

162. When blasting is contemplated close to property not owned by the mining company, it is advisable to survey neighbouring structures prior to blasting. This will limit claims to



Damage levels

1. Minor damage: fine plaster cracks —opening old cracks
2. Major damage: fall of plaster serious cracking
3. Air-blast damage threshold: 1 psi (7 kPa) overpressure
4. Energy ratio criteria

$$ER = \left[\frac{\text{Acceleration}}{\text{Frequency}}\right]^2 = \left[\frac{\text{ft/sec}^2}{\text{Hz}}\right] = \text{ft}^2/\text{sec}^2$$

$$\text{or: } \left[\frac{\text{m/sec}^2}{\text{Hz}}\right]^2 = \text{m}^2\text{sec}^{-2}$$

General propagation low

$V = K(D/\sqrt{Q})^{-Y}$

V = particle velocity

D = distance from blast to measurement point

Q = maximum charge weight per delay, lb

K = site constant

Y = exponent (slope of regression curve)

Particle velocity is the most widely accepted criteria used for blast damage evaluation.

Fig 13 - Blast damage criteria.

blast-related damage only and also demonstrate a firm, fair attitude on behalf of the operator.

163. Some fly rock usually cannot be avoided in open pit blasting. Its control is an important aspect of operations, especially when blasting near a local community or mine structure. To minimize potential hazards, blasting must be carried out according to prescribed regulations.

164. Ground motion measurements can be used to determine the relationship between charge size, distance and such damage criteria as peak particle velocity. This relationship can be used in blast design and monitoring procedures.

165. Ground motions resulting from blasting are transient and similar to ground motions from earthquakes. Velocity recordings, as opposed to deformation or acceleration, should be used since they are directly related to damage, regardless of frequency.

166. Shock waves emanating from blasts or other disturbances will travel through rock at speeds varying up to 20 000 ft/s (6 100 m/s). The propagation velocity of the ground is essentially equal to its seismic velocity. The velocity attained by a particle as it vibrates momentarily while the ground wave passes, varies with distance from the blast. Particle velocity can be recorded by a seismograph. Most engineering seismographs can measure all three components of motion: vertical, radial and transverse. Generally it has been found that the transverse component is small compared with the other two and can be ignored. Sometimes the radial component will exceed the vertical component. After initial confirmation of the relative magnitudes, it may be appropriate to use widely distributed single component gauges for routine monitoring. Similarly, it may be practical to record vibrations only in a specific frequency range. Figure 14 illustrates a typical vibration record for all three components of motion.

167. Table 4 lists typical engineering seismographs commonly used for blast monitoring. Approximate prices are included together with their main characteristics. This information should not be taken as a product recommendation.

168. While damage criteria have been discussed in terms of the peak particle velocity of a single component, this concept is still open to question. As shown in Fig 14, the vector resultant peak particle velocity can readily be obtained by selecting an appropriate instant when the disturbance is at a maximum and obtaining the individual particle velocities for each component. The vector sum of these components is:

$$V = \sqrt{(V_t^2 + V_v^2 + V_r^2)} \qquad \text{eq 1}$$

where V_t = transverse peak particle velocity, V_v = vertical peak particle velocity, and V_r = radial peak particle velocity.

As a check, the algebraic sum of the three component maxima can be calculated. This is larger than the true vector resultant peak particle velocity but can be used as a field check that an acceptable maximum level has not been exceeded.

169. Experience has shown that for a particular site, ground shock vibration is a function of explosive charge weight and distance. Local variations in geology and types of explosives have a minor effect. The relationship is as follows:

$$V = K[D/Q^x]^{-y} \qquad \text{eq 2}$$

where V = peak particle velocity, D = distance gauge to shot, Q = charge weight per delay, K = site constant, and x and y are exponents.

170. When the delay interval between charges exceeds about 8 - 9 ms, shock pulses from individual delays usually do not overlap. The allowable charge size can be calculated on the basis of maximum charge per delay.

171. Extensive studies by the U.S. Bureau of Mines have indicated that a value of 0.5 for x best fits available data (10). A value of 0.33 has sometimes been used. $[D/Q^x]$ is referred to as scaled distance. K and y must be determined for the site and blasting system by plotting measured velocities against scaled distance on log-log paper. A linear chart of Q versus D for blast control can thereby be developed for any limiting value of scaled distance.

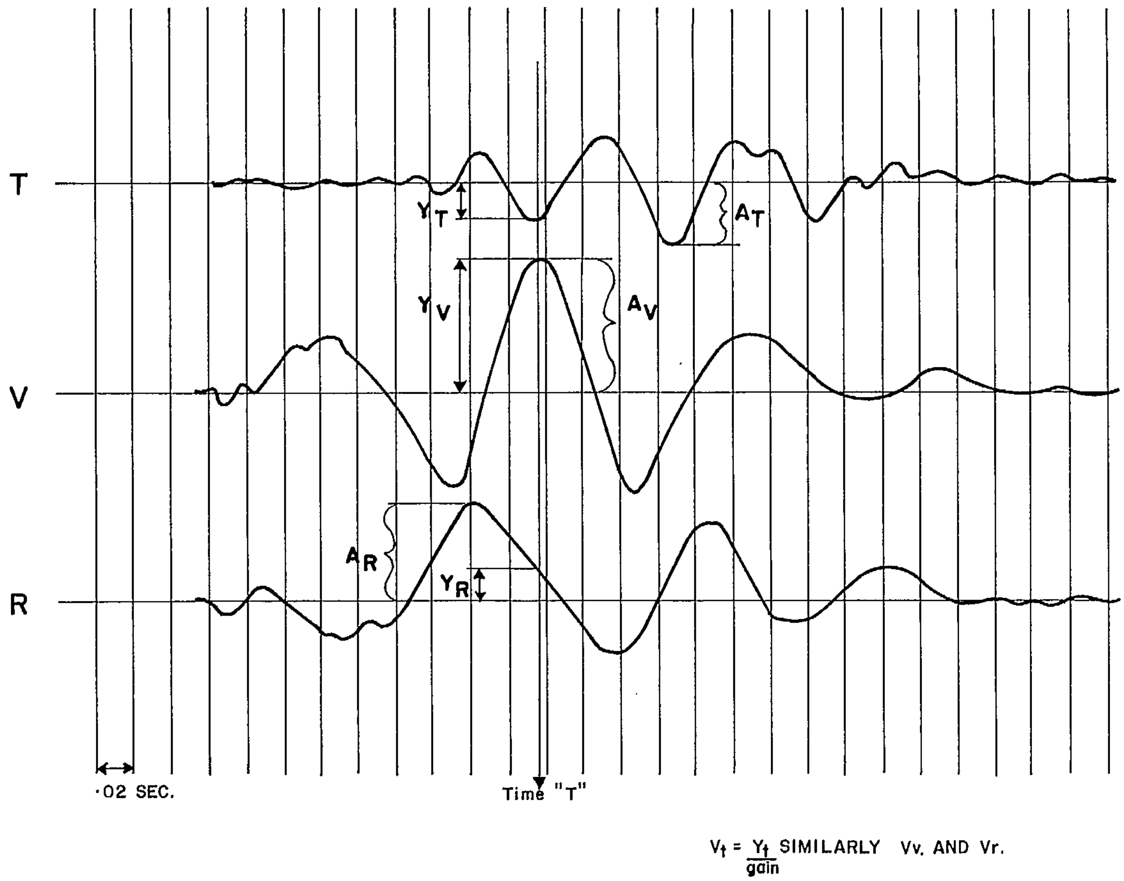


Fig 14 - Measuring component velocities to produce a vector sum. R = radial motion. V = vertical motion. T = transverse motion.

172. As a first approximation for blast control, the scaled distance value should be $[D/\sqrt{Q}] \geq 50$ ft/lb$^{\frac{1}{2}}$ (33.5 m/kg$^{\frac{1}{2}}$) (10). However, scaled distance is not related directly to ground shock damage. If trouble is foreseen, quantitative monitoring of vibration should be initiated.

173. Tables 5 and 6 shows that unacceptable sound levels at private residences through line-of-sight propagation are unlikely for most blasting operations. However, through variations in temperature, the atmosphere may either bend, diffuse or disperse sound rays. It can sometimes act as a converging lens to concentrate sound rays. The path of a sound ray, relative to a stationary observer, depends also on the wind.

174. Over short distances of a few miles, the temperature varies vertically more than horizontally. Therefore, the vertical temperature gradient is the major controlling factor in air blast phenomena. Normally, temperature decreases with height. Under such conditions, sound rays bend upwards and are lost. Trouble occurs when the speed of sound at some higher elevation is greater than the speed of sound at ground level. Sound rays will be reflected back to earth; increasing wind speed with height aids this process. As a general rule, the higher the temperature inversion, the further the ray will travel before returning. Low level inversions are of primary concern in open pit blasting as a ray may arrive

Table 4: Examples of blast monitoring instruments
(not to be considered as an endorsement)

Manufacturer	Model no.	Output	Measured characteristic*	Band width	Sensitivity to velocity	Weight lb	Weight kg	Approx. price ** $	Remarks
Sprengnether St. Louis, USA	VS1200	Photographic	Displacement velocity or acceleration	1.8-25Hz	1-200 in./in./s (1-200 m/m/s)	53	24	5 600	Internal batteries, fourth channel for sound (or other) measurements.
	VS1100	Photographic	Velocity	1.8-25Hz	0.2-20 in./in./s (0.2-20 m/m/s)	53	24	4 700	External amplifier available.
	VS4000	Photographic	Displacement	2Hz up	-	38	17	3 200	Internal batteries.
Vibration Measurement Engineers Ill. USA	Seismolog	Photographic	Displacement	-	-	45	20	1 700	Internal batteries.
Teledyne Geotech	PRA-103	Magnetic tape erasure	Acceleration	-	-	1.5	0.7	440	No power required.
	RFT.250	Photographic	Strong motion only	-	-	35	16	3 000	Internal batteries.

* All instruments listed here record transverse, radial and vertical components of motion.

** Taxes etc., extra; some accessories included. Rental arrangements are also available for some instruments.

Table 5: Examples of noise levels generated by blasting

Total charge	25 000 lb (11 400 kg)	28 000 lb (12 700 kg)	14 700 lb (6 700 kg)
Charge/delay	2 000 lb (900 kg)	1 900 lb (860 kg)	1 020 lb (480 kg)
Noise level	137 db	135 db	140 db
At distance	700 ft (230 m)	2 000 ft (600 m)	1 000 ft (300 m)

Table 6: Threshold values for air blast

Type of damage	Level db
Shaking of loose sashes	153
May damage plate glass windows	160
Threshold value for failure of normal window, well mounted	165
Minor damage to plaster, all glass windows fail	173

back at ground level at any distance from zero to 20 miles (32 km) away.

175. Temperature inversions occur in stable atmospheric conditions. Deep inversions occur during continental Arctic winters. Others occur at night in clear weather when the earth is not radiating heat to the atmosphere and when there is little or no convective mixing in the air. Afternoon cumulus clouds indicate unstable conditions when inversions will be absent, and as a general rule, large blasts should be confined to afternoons. Figure 15 shows typical sound reflection and inversion phenomena (17, 18, 19).

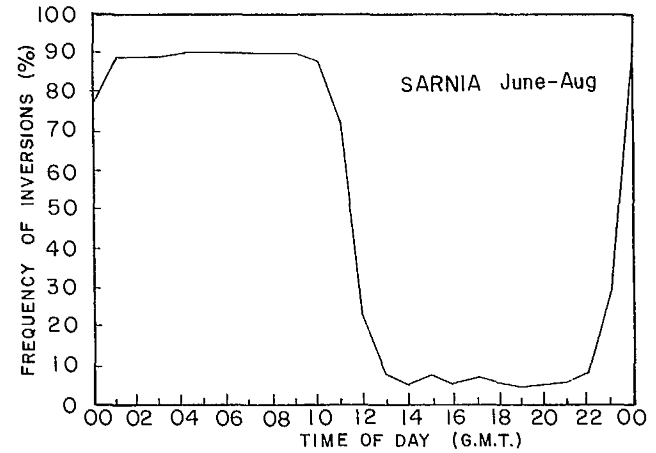
176. Two methods are available for determining the likelihood of significant sound reflection. First, the vertical profile of temperature and wind is required. These are used to calculate the paths of individual rays in the vertical plane. The distance from the origin to the point of return for all returning rays is calculated and is used to predict the concentration of returning rays.

177. In the second method, pilot shots are detonated ahead of the main blast and the sound rays are monitored. The intensity of air shock disturbance depends on total energy, rate of release, degree of confinement, distance from the blast, and atmospheric and thermal conditions. Provided there is little time delay between pilot shot and main blast, the atmospheric condition and distance factor can be assumed to be constant. Knowing the characteristics of the planned detonation, it is possible from the pilot shot records to predict the sound level of the main blast.

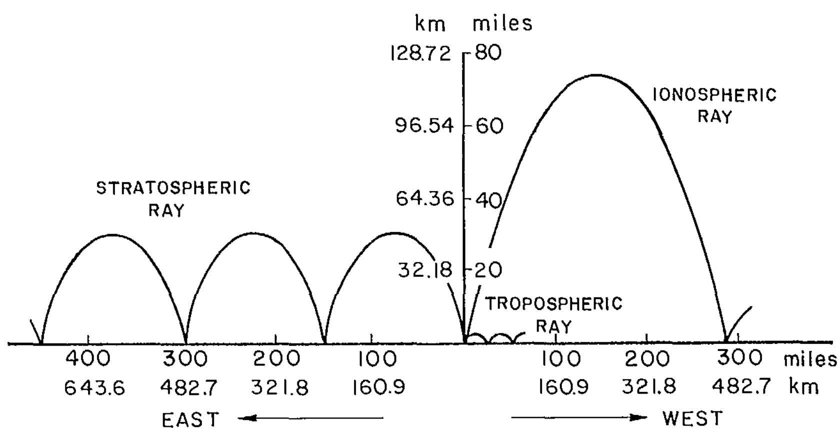
178. The following procedures minimize air shock: (a) stemming all blast holes; (b) using electric caps rather than detonating cord, but if cord is used, covering it with at least 6 in. (15 cm) of fines and using low energy primacord; (c) shooting near mid-day and never at night; (d) avoiding sound-focusing temperature inversions; and (e) not blasting when winds over 12 to 15 mph (20 to 24 km/h) are blowing toward residences. With these precautions, detailed analysis will usually be unnecessary.

179. Ground shock can be minimized by the following procedures:

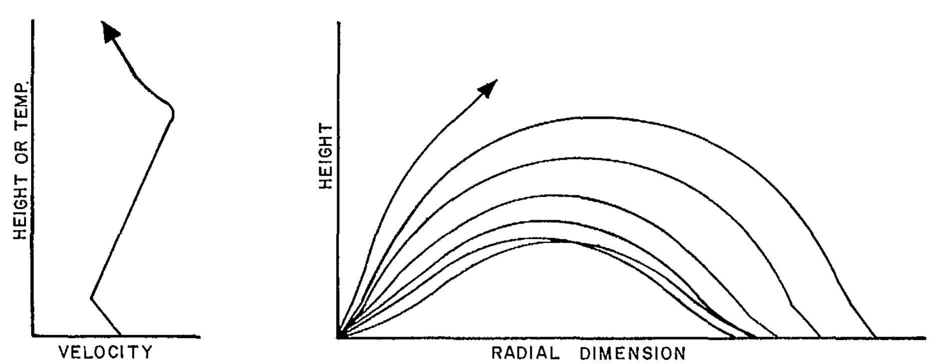
a. Design the blast so that the minimum amount of energy is wasted through ground shock. Essentially, this means finding the best burden:spacing ratio and avoiding excessive column loading.
b. Use blasts with a maximum charge per delay only when ground shock problems are unlikely.
c. Monitor ground shock when maximum charge per delay is used and develop the site parameters for eq 2 (para 169).
d. In the absence of legal regulations, do not permit peak particle velocities in excess of 2 in./s (5 cm/s) near structures.
e. When measured peak particle velocities approach or exceed 0.2 - 0.5 in./s (0.5 to 1.25 cm/s), advise the local population about blast damage and survey as many structures as possible before blasting.



EXAMPLE OF FREQUENCY OF GROUND BASED INVERSIONS BY HOUR OF THE DAY, AT SARNIA IN JUNE JULY AUGUST 1965 - 1968.



PATHS OF SOUND RAYS (THE VERTICAL SCALE IS EXAGGERATED)



TEMPERATURE INVERSION ——— AND ——— ASSOCIATED SOUND PATTERNS

Fig 15 - Sound transmission and inversion phenomena (17, 18 and 19).

180. An additional precaution that may be appropriate is to check with local airports before blasting to ensure that the area is clear of low-flying aircraft.

MINE CLOSURE

181. Before a mine closes down, it is usually required to erect a fence around the pit, remove service buildings, post warning signs and generally ensure that the public is protected from injury while on the property.

182. Maintaining vegetation is desirable as it reduces dust, stabilizes slopes and increases aesthetic appeal of the area. Vegetation reduces oxidation of tailings and reduces the quantity of water leaching through tailings.

183. Water pollution should be avoided after mining operations have ceased. Initial site planning and layout should recognize this factor and minimize the need for long-term pumping or water treatment; the cost of water pollution abatement could otherwise be significant.

184. Haulroads can be covered and landscaped. Access roads may have to be fenced off or rendered impassable.

185. Because the open pit may fill with water, fencing the edges may be especially necessary.

186. If water supply lines and slurry pipelines are visible, it may be necessary to disconnect and dispose of the pipes.

TIME AND BUDGET GUIDELINES

BASELINE STUDIES

187. The objective of the environmental program is to ensure that an ecologically balanced environment satisfying the final land use objectives is established on completion of mining.

188. During the feasibility stage of property development, a brief environmental reconnaissance is advisable to outline problem areas in advance. This may require a one-day site visit and three days of office work and is likely to cost about $800 plus expenses. (Costs quoted throughout this section are in 1974 dollars except those mentioned in connection with specific properties which are from published material as early as 1971.)

189. After it has been firmly established that the mine is to be put into production, an environmental baseline study should be undertaken. This includes an inventory of all plant and animal species, land and water resources, examination of present land and water use and socio-economic costs and benefits. These aspects should be examined in sufficient detail to understand the interrelationships in the ecosystem and to examine what part each plays.

190. During the mine design stage, an investigation should be made of the potential impact that the open pit will have on the local ecosystems. From the site plans, it is usually possible to define potential environmental problems and to determine how they will affect the area. It may be necessary at this time to modify the processing flow chart to minimize impact. It is generally more economical to avoid damage in advance than to correct and rehabilitate later.

191. It is best to combine the baseline study with the impact assessment to avoid unnecessary duplication between investigators. The resources required for baseline and impact assessment will vary for each mine area. The number of distinct ecosystems within the study area will determine whether one sample set is sufficient or whether each must be sampled separately. The legislative framework within which the mine will operate will determine the degree of detail needed. The impact that similar operations have had on the environment may also influence these studies.

192. A small dry operation like a limestone quarry may require only a site visit of several days, plus approximately two weeks for background literature reviews and report writing. A budget figure of $3 000 (15 man-days) plus expenses would be appropriate.

193. A small baseline survey of mine receiving waters could require a water sampling survey of ten sample stations over five days, as well as background reviews and reports. This may require 15 man-days at $200 per day or $3 000, plus $2 000 for water analysis. Living and travel expenses would be additional. In many instances, it is necessary to sample water quality over a full year to assess seasonal fluctuations.

194. The development of a large mine with a mill and service complex situated in a recreational area would require a much more extensive survey. For example, this may need 240 man-days of effort for 4 scientists at $200 per day plus expenses.

195. It is at this time that the ultimate land use must be determined. The development of a long-term program that will return land to other productive uses may be appropriate. It is possible that the overall cost of the mining operation could be reduced by modifying mining techniques and methods of waste disposal to conform with the ultimate land use program.

WATER SAMPLING AND ANALYSIS

196. Because water is usually the first system to show the effects of inadequate management, it is necessary to begin monitoring of both ground and surface waters before construction starts. This involves collecting data on the following aspects:

a. physical properties (meteorological conditions, solar radiation, depth and velocity of receiving waters, temperature, sediment texture and chemistry);
b. water quality (colour, odour, total dissolved solids, suspended solids, total organic carbon, nutrients, total hardness, pH, conductivity, turbidity and transparency, BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand) and dissolved oxygen);
c. toxicants (heavy metals, anions, cyanides, phenols, biocides, synthetic detergents and oils; and
d. biological properties (phytoplankton, zooplankton, benthic organisms, periphyton, submerged aquatic macrophytes, bacteria and fish).

Initial information on these parameters should form part of the baseline study.

197. Monitoring several of these parameters in the effluent and receiving waters will indicate whether the degree of treatment is sufficient or if additional precautions are necessary. Each mine will have criteria for its own operation. The data likely to be required include: total dissolved solids, total suspended solids, total organic carbon, hardness, pH, conductivity, turbidity, heavy metals, anions and biocides.

198. If the operation is not large enough to support in-house facilities to carry out these investigations, there are several companies that can be utilized to take samples and perform the analysis, or to analyze supplied samples. For the parameters listed in the previous paragraph, this may require one man-day per water sample at an approximate cost of $360 per sample. Utilizing in-house expertise and new equipment is likely to result in the same order of costs.

WASTE WATER TREATMENT

199. Monitoring of water quality will continue throughout the life of the mine. Changes in water quality may indicate the need to modify operations.

200. Facilities to maintain and improve water quality vary in size depending on such factors as the ore being mined, the quantity of water treated, the extent of recycling, the use of treatment chemicals, the type of treatment and the degree to which the water must be treated.

201. The following are published examples of capital and maintenance costs involved in waste water treatment plants.

202. Brunswick Mining and Smelting Corporation has an acid mine drainage problem that has required extensive changes in plant construction and waste water treatment. Approximately 260 x 10^6 gallons (980 000 m^3) of acid mine drainage are treated each year, requiring 5 000 tons (4 500 metric tons) of lime. Amortized capital and treatment operating costs are about $300 000 a year.

203. The Falconbridge Hardy mine treatment plant cost $144 000 in 1971 (12). Approximately

4.5×10^9 gallons (17×10^6 m^3) of acid mine drainage are treated annually. Treatment cost $36 000 in 1972, of which 70% was the cost of lime. In 1973, the water quality improved and the treatment costs were reduced to $24 000.

204. The Falconbridge Onaping mine treatment plant cost $100 000 in 1967 (13). Its operating costs are $27 000 a year to treat 3.2×10^9 gallons (12×10^6 m^3), and $4 000 a year is required for maintenance.

205. The water treatment plant for the Heath-Steele mine in New Brunswick had a capital cost of $2 500 000. It treats approximately 50×10^6 gallons (190 000 m^3) of acid mine drainage a year at a cost of $220 000, or about 26¢ per ton (tonne) of ore.

206. Operating costs for lime treatment range from $0.05 to $0.50 per ton (tonne) of ore. Ion exchange treatment ranges from $0.30 to $1.00 per ton (tonne). Reverse osmosis treatment ranges from $0.05 to $1.50 per ton (tonne) of ore (4).

REVEGETATION

207. As construction is finished, landscaping and revegetation of areas disturbed during construction are commenced. These areas should become self-sustaining.

208. The largest area to vegetate would probably be the tailings disposal site. If this is filled by successive stages, revegetation should be carried out as each section is completed. Development of an efficient program is possible. Time and costs can be reduced towards the end of the mine life.

209. If the final shape of the land is not attained by the methods of infilling or construction, the land must be contoured for seeding. This can average $1.35 to $10.80 per cubic yard ($14/m^3) of material.

210. There are four basic methods for seeding. Costs involved include the capital cost of the machinery and the labour cost to operate it. It is possible, in many instances, to rent the equipment or have work carried out by a contractor.

211. The Hudson Bay Mining and Smelting Co. Ltd. in Flin Flon, Manitoba, estimate their initial costs for sulphide tailings reclamation at $750 per acre ($1 850/ha) ($200 material, $50 machinery and $500 labour) and their yearly maintenance at $425 per acre ($1 050/ha) ($125 material, $50 machinery and $250 labour).

212. Brenda Mines in Peachland, British Columbia, estimate their landscaping of areas disturbed by construction at $85 per acre ($200/ha) using normal agricultural methods and $250 per acre ($600/ha) by hydroseeding (15).

213. The cost of revegetating wastes is estimated to be $150-$500 per acre ($350-$1 250/ha) with an additional maintenance cost of $200 per acre ($500/ha) per year (4). Adding soil cover stripped from another area may raise the cost to the range of $300 to $3 000 per acre ($750-$7 500/ha) per year, but maintenance becomes negligible after two to three years. Seepage of water from vegetated areas may be about 200 000 gallons per acre (2.2×10^6 L/ha) per year (4). Treatment of this seepage water may cost $10 to $100 per acre ($25-$250/ha) per year.

214. In some provinces it is necessary to maintain the vegetative cover for at least two years after mine closure. A careful examination of the pertinent legislation in this respect should be made for each province.

LEGISLATION

215. Mineral resource development is the responsibility of the provinces. The responsibility for environmental protection is not clear, but the provinces have a large role to play. Federal laws governing protection of water, land, and air represent the minimum standards. Provincial environmental legislation may be more stringent than federal legislation, but it cannot be less stringent. The three most important pieces of federal legislation are the Fisheries Act, the Canada Water Act and the Clean Air Act.

216. The Fisheries Act was implemented to protect both commercial and sport fishing. It authorized the establishment of national standards of water quality and invested power in the Department of Fisheries and Forestry to prevent industrial pollution of Canadian waters. It requires submission of plans and specifications of any construction or operation likely to result in deposition of deleterious substances in water or in a place where they are likely to end up in water. Regulations and guidelines, specific to base metal mining effluents, are made under authority of the Fisheries Act. They may be augmented with regulations specific to other sectors of the mining industry.

217. The Canada Water Act provides for management of the water resources of Canada. It prohibits the discharge of waste into water and may require fees to discharge within the prescribed limits. Presently, a federal-provincial committee is to set water quality criteria for permissible limits of pollutants discharged to water courses.

218. The Clean Air Act guarantees the quality of the atmosphere. Air quality objectives were established by a joint federal-provincial committee, but the objectives will be implemented and enforced by the provincial authorities.

219. The majority of acts and regulations for environmental protection rest with the provincial governments. There is wide variation from province to province in aspects covered by each piece of legislation.

220. Most of the legislation is not specific to mining and very little concerns open pit mining. Most aspects of possible contamination of the environment from mining are covered under general regulations such as "no person, directly or indirectly, may deposit any contaminant or waste into any water course, soil or air". Although this is not specific to mining, mining can fall under the generality of the legislation.

221. For example, the Prince Edward Island Environmental Control Commission feels that the Environmental Control Commission Act, 1971, and Fish and Game Protection Act, 1959, have sufficient provisions in this legislation to deal with any mining activity. In provinces where mining is carried on at a significant scale, the legislation tends to be more direct. For instance, the Province of Alberta requires a full environmental impact assessment before any phase of mining is started. Alberta, British Columbia, and Ontario have specific legislation dealing with the requirements for restoring surface land in areas disturbed by mining and for protecting water courses. Other provinces, such as Saskatchewan and Manitoba, are presently (1976) writing legislation to deal with these problems.

222. Appendix B lists federal and provincial legislation most relevant to environmental aspects of mining. Most of the legislation is non-specific but can be applied to the mining industry by virtue of this generality. Limitations of space have confined attention to the most important acts together with brief comments on their relevance to mining. To a mine engineer faced with an unfamiliar problem, Appendix B will be of assistance in determining in broad terms the jurisdiction of important pieces of legislation. A comprehensive review of the regulations issued under legislative authority is available from CANMET, EMR, 555 Booth St, Ottawa, K1A 0G1 (16). However such compilations quickly become out of date, and the reader is strongly advised to contact the appropriate agency for information about recent changes.

REFERENCES

1. Ackerman, D.H. "Environmental impact study - a tool for sound mineral development"; Min. Congr. J.; v. 59, no. 12, pp 16-22; Dec. 1973.

2. Environment Canada. Environmental Protection Service. "Draft environmental code of practice for mines"; Ottawa; Nov. 1975.

3. Bragg, K. "Pollution potentials and interactions in mine waste embankments in Canada - their costs and prevention"; CANMET (Canada Centre for Mineral and Energy Technology, formerly Mines Branch, Department of Energy, Mines and Resources), Divisional rep. EMA 73-12; 32 p; June 1973.

4. Bragg, K. "A systems view of tailings and waste management (water and solids waste from mine-mill operations)"; CANMET, Divisional rep. EMI 73-5; 9 p; Mar. 1973.

5. Bell, A.V. "Base metal mine waste management in Canada"; Proc. Int. Symp. on Minerals and the Environment, London, June 4-7, 1974; Ed. M.J. Jones; Inst. Min. Metall., London; pp 45-59; 1975.

6. Hardie, M.G., Jennet, J.C., Bolter, E. et al. "Water resources problems and solutions associated with the new lead belt of S.D. Missouri"; Proc. Nat. Symp. on Water Resources Related to Mining, Golden, Colo., 1974; Am. Water Resour. Assoc., 1974.

7. Young, C.A. "Use of vegetation to stabilize mine tailings areas at Copper Cliff"; Can. Min. J.; v. 90, no. 6, pp 43-46; June 1969.

8. Langefors, U. and Kihlstrom, B. "The modern technique of rock blasting"; Almqvist & Wiksell, Stockholm; 405 p; 1963.

9. Bauer, A. and Calder, P.N. "Trends in explosives, drilling and blasting"; CIM Bull.; v. 67, no. 742, pp 51-57; Feb. 1974.

10. Nicholls, H.R., Johnson, C.F. and Duvall, W.I. "Blasting vibrations and their effects on structures"; U.S. Bur. Mines Bull. 656; 105 p; 1961.

11. Thirgood, J.V. "Land reclamation must follow land disturbance"; Can. Min. J.; v. 93, no. 12, pp 33-34, 39-40; Dec. 1972.

12. Oko, U.M. "Monitoring waste water quality at Falconbridge's Sudbury operations"; Proc. 3rd Ann. Meet. Can. Mineral Processors, Ottawa, Jan. 19-21, 1971; Comp. C.S. Stevens; Mines Branch, Ottawa; pp 181-193; 1971.

13. Rivett, L.S. and Oko, U.M. "Tailings disposal, generation of acidity from pyrrhotite and limestone neutralization of waste water at Falconbridge's Onaping mines"; CIM Bull.; v. 64, no. 712, pp 108-113; Aug. 1971.

14. Busse, E. "Acid drainage control and water treatment at Heath Steele Mines Ltd."; CIM Bull.; v. 67, no 751, pp 54-61; Nov. 1974.

15. Tetu, H. and Pells, F. "Design, construction and initial operation of the tailings system at Brenda Mines Ltd."; CIM Bull.; v. 64, no. 712, pp 101-107; Aug 1971.

16. "A digest of environmental regulations pertinent to open pit mining in Canada"; CANMET Report 76-16; 59 p; 1976.

17. Munn, R.E. et al. "A preliminary climatology of ground-based inversions in Canada"; Atmosphere; v. 8, no. 2, pp 52-68; 1970.

18. Stephens, E.R. "Temperature inversions and the trapping of air pollutants"; Weatherwise; v. 18, no. 4, pp 172-175; Aug. 1965.

19. Cox, E.F., Plagge, H.J. and Reed, J.W. "Meteorology directs where blast will strike"; Bull. Am. Meteorol. Soc; v. 35, no. 3, pp 95-103; 1954.

BIBLIOGRAPHY

Aston, W.M. "Fools gold pollutes"; Can. Min. J.; v. 95, no. 3, pp 59-61; Mar. 1974.

Baxter, C.W. "Controlled blasting on a production scale at Thunderbird mine"; Min. Eng. (N.Y.); v. 24 no. 11, pp 51-55; Nov. 1972.

Bell, A.V. "The tailings pond as a waste treatment system"; CIM Bull.; v. 67, no. 744, pp 73-78; Apr. 1974.

Berube, Y. et al. "Studies of mine waste containment at two mines near Yellowknife, N.W.T."; INFOCAN; ALUR 72-73-32.

Billings, W.D. "Arctic and alpine vegetation: similarities, differences and susceptibility to disturbance"; BioScience; v. 23, pp 697-704; 1973.

Bliss, L.C. and Wein, R.W. "Plant community responses to disturbance in the western Canadian Arctic"; Can. J. Bot.; v. 50, pp 1097-1109; 1972.

Bullock, W.D., Brittain, R.L. and Place, G.A. "Environmental aspects of the North American mining industry"; Proc. Int. Symp. on minerals and the environment, London, June 4-7, 1964; Ed. M.J. Jones; Inst. Min. Metall., London; pp 27-43; 1975.

Davies, E. "International symposium on wastewater treatment in cold climates"; Environment Canada; Economic and technical review report EPS-3-WP-74-3; 1974.

Davison, A. and Jeffries, R. "Some experiments on the nutrition of plants growing on coal mine waste heaps"; Nature (London); v. 210, no. 5036, pp 649-650; May 1966.

Dean, K.C. and Havens, R. "Methods and costs for stabilizing tailings ponds"; Min. Congr. J.; v. 59, no. 12, pp 41-46; Dec. 1973.

Down, C.G. "Problems in vegetating metal-toxic mining wastes"; Proc. Int. Symp. on Minerals and the Environment, London, June 4-7, 1974; Ed. M.J. Jones; Inst. Min. Metall., London; pp 395-408; 1975.

Duncan, D.W. "Environmental problems associated with the disposal of mining and milling wastes"; West. Miner; v. 45, no. 9, pp 14-24; Sep. 1972.

Falk, M.R. et al. "Biological effects of mining wastes in the Northwest Territories"; Can. Dept. Environ. Tech. Rep. Ser. CEN/T-73-10; 1973.

Hawley, J.R. "The use, characteristics and toxicity of mine mill reagents in the Province of Ontario"; Ont. Ind. Wastes Branch, Toronto; 244 p; 1972.

Hawley, J.R. "The problem of acid mine drainage in Ontario"; Ont. Ind. Wastes Branch, Toronto; 338 p; 1972.

Hawley, J.R. "The problem of acid mine drainage in Ontario"; Ont. Ind. Wastes Branch, Toronto; 338 p; 1972.

Hawley, J.R. and Shikaze, K.H. "The problem of acid mine drainage in Ontario". Ten basic rules for dealing with acid mine drainage; Can. Min. J.; v. 92, no. 6, pp 82-93; June 1971.

Hill, R.D. and Wilmoth, R.C. "Limestone treatment of acid mine drainage"; Trans. Soc. Min. Eng. AIME; v/ 250, no. 2, pp 162-166; June 1971.

Horn, W.R. "Metal mining and the environment - where does the industry stand?"; CIM Bull.; v. 65, no. 718, pp 56-60; Feb. 1972.

James, A.L. "Stabilizing mine dumps with vegetation"; Endeavour; v. 25, no. 96, pp 154-157 Sep. 1966.

Jeffrey, D.W., Maybury, M. and Levinge, D. "Ecological approach to mining waste revegetation"; Proc. Int. Symp. on Minerals and the Environment, London, June 4-7, 1974; Ed. M.J. Jones; Inst. Min. Metall., London,; pp 371-385; 1975.

LeRoy, J.C. and Keller, H. "How to reclaim mined areas, tailings ponds and dumps into valuable land"; World Min.; v. 25, no. 1, pp 34-41; Jan. 1972.

LeRoy, J.C. "How to establish and maintain growth on tailings in Canada - cold winters and short growing seasons"; Tailings disposal today; Proc. 1st Int. Tailing Symp., Tucson, Ariz., Oct. 31-Nov. 3, 1972; Ed. C.L. Aplin and G.O. Argall, Jr.; Freeman, San Francisco; pp 411-449; 1973.

Ludeke, K.L. "Soil properties of materials in copper mine tailing dikes"; Min. Congr. J.; v. 59, no. 8, pp 30-37; Aug. 1973.

Ludeke, K.L. "Vegetative stabilization of copper mine tailing disposal berms of Pima Mining Company"; Tailing disposal today; Proc. 1st Int. Tailing Symp., Tucson, Ariz., Oct. 31-Nov. 3, 1972; Ed. C.L. Aplin and G.O. Argall, Jr.; Freeman, San Francisco; pp 377-410; 1973.

McGee, G. "Mining environmental law"; Can. Miner. Resour. Branch, Miner. Bull. MR 138; 187 p; 1973.

Mamen, C. "Island Copper - ecology wise"; Can. Min. J.; v. 94, no. 7, pp 31-33; July 1973.

Matthew, F.L. "Pros and cons of combined treatment of mining and domestic wastes"; Tailing disposal today; Proc. 1st Int. Tailing Symp., Tucson, Ariz., Oct. 31-Nov. 3, 1972; Ed. C.L. Aplin and G.O. Argall, Jr.; Freeman, San Francisco; pp 700-713; 1973.

Murray, D.R. "Vegetation of mine waste embankments in Canada"; Can. Mines Branch Inf. Circ. IC 301; 54 p; 1973.

Oko, U.M. and Taylor, W.L.W. "Treatment of acid mine waste water at Falconbridge's Hardy crown pillar project"; CIM Bull.; v. 67, no. 744, pp 43-49; Apr. 1974.

Ontario. Water Resources Commission. "Waste control problems in the mining industry"; technical papers and articles, 1970-1971. Comp. J.R. Hawley; Toronto; 71 p; 1972.

Pelusco, R.G. "A federal view of the coal waste problem"; Min. Congr. J.; v. 60, no. 1, pp 14-17; Jan. 1974.

Plass, W.T. "Revegetating surface-mined land"; Min. Congr. J.; v. 60, no. 4, pp 53-59; Apr. 1974.

Proc. Int. Symp. on Wastewater Treatment in Cold Climates, Univ. Saskatchewan, Saskatoon, Aug. 22-24, 1973; Ed. E. Davies; Can. Dept. Environ. Rep. EPS-3-WP-74-3; Ottawa; Mar. 1974.

Rabbitts, F.T., Banks, G.N., Sirois, L.L. and Stevens, C.S. "Environmental control in the mining and metallurgical industries in Canada"; National Advisory Committee on Mining and Metallurgical Research, Ottawa; 50 p; 1971.

Richmond, T.C. and Adler, J.E. "Mineral development and land conservation in Montana's Stillwater District"; Min. Eng. (N.Y.); v. 26, no. 3, pp 37-40; Mar. 1974.

Riley, C.U. "Design criteria of mined land reclamation"; Min. Eng. (N.Y.); v. 25, no. 3, pp 41-45; Mar. 1973.

Roy, M. et al. "Stability of dykes embankments at the mining sites in the Yellowknife area"; INFO-CAN; ALUR 73-73-31.

Swaisgood, J.R. and Toland, G.C. "The control of water in tailings structures"; Tailing disposal today; Proc. 1st Int. Tailing Symp., Tucson, Ariz., Oct. 31-Nov. 3, 1972; Ed. C.L. Aplin and G.O. Argall, Jr.; Feeman, San Francisco; pp 138-163; 1973.

Watson, W.Y. and Richardson, D.H. "Appreciating the potential of devastated land"; Forestry chronicle; Dec. 1972.

APPENDIX A

TYPES OF WATER POLLUTION WITH SPECIAL RELEVANCE TO CANADIAN OPEN PIT MINES

This appendix lists the major types of contaminants, how they are measured, their sources and some known harmful effects.

Suspended solids (turbidity): measured by weight of material left after evaporation in mg/l. Important sources are inadequate settling in tailings ponds, wave action on tailings ponds, high runoff over unvegetated loose material, overloading of natural drainage courses. Known harmful effects are difficult to ascertain since there are no areas polluted only by suspended solids that are not influenced by other pollutants. Solids may kill bottom organisms by covering them, reduce growth by cutting light to green plants, may prevent spawning of salmon and trout, coat or scour fish gills, and may deoxygenate water by chemical reaction.

Acidity and alkalinity: measured by pH units. Important sources are sulphide minerals in ore or wall rocks, acids and bases used in process leaching, and acid water found in nature. Known harmful effects include fluctuations of 1 or 2 pH units, which are devastating to life as organisms are adapted to specific ranges; life does not normally exist outside a pH range of 3-9. Low pH makes nutrients insoluble; changes in pH can cause metal ions to deposit or become soluble; deposition can cause turbidity problems and solubility may release toxic ions.

Poisons and toxins, eg, heavy metals: measured by atomic absorption spectrophotometry, mass spectroscopy, colorimetry, and fluorimetry in mg/l (ppm). Important sources are tailings material, wastes, and process chemicals. Known harmful effects include: death of fish and plant life at low concentrations (eg copper kills phytoplankton at 0.25 ppm). Note background levels dependent on geological strata over which water passes. Normally these levels are low. Hard water may cause ions such as Pb and Zn to precipitate. Toxins are temperature dependent and have greater effect in summer (toxicity doubles for every 10°C rise in temperature).

Inorganics: measured by spectroscopy and gas chromotography in mg/l (ppm). Important sources are salts used in processing, winter road salt, and evaporation of process or drainage water in arid areas. Known harmful effects include reducing agents that remove oxygen otherwise available to support aquatic life.

Oils: measured by spectroscopy in mg/l (ppm). Important sources are mobile equipment, workshops and storage areas. Known harmful effects are as an efficient herbicide. Note 1 gallon (3.8 l) of oil can cover 4 acres (1.6 ha) of water.

Organic residues: measured by total organic carbon (wet oxidation) in mg/l (ppm). Important sources are mill process reagents (flotation) and sewage. Known harmful effects include being toxic (0.01 ppm of sodium isopropyl xanthate and sodium ethyl xanthate is believed by some to have long-term toxic effects on fish), they may increase demand for oxygen, may be a nutrient and may upset balance of organisms.

Pathogenic microorganisms: measured by colony techniques of total and fecal coliforms, viruses and protozoa in cells per 100 ml. Common source is domestic sewage. Note - E. coli, while itself pathogenic, is an easily measured and reliable indicator of the presence of pathogenic microorganism. It is often found in acid mine drainage.

Radioactivity: measured by liquid scintillation detectors in curies/l. Sources are uranium ores. Known harmful effects are that aquatic flora and fauna can accumulate radioactive elements through the food chain; radio nuclides are known to substitute for metals.

APPENDIX B

PRECIS OF ENVIRONMENTAL LEGISLATION

WITH REGARD TO MINING

LEGISLATION	AREA CONCERNED	RELEVANCE TO MINING AND ENVIRONMENT
FEDERAL		
CANADA WATER ACT 1970	Canadian water	Management of water resources in Canada. Prohibits discharge or waste deposition in water and may require fees to discharge within prescribed limits.
CLEAN AIR ACT 1971	Canadian air	Establishment of air quality. Objectives have been established and must not be exceeded. Information relating to any operation which may affect air quality must be submitted.
CRIMINAL CODE 1970	Canadian air, land and water	Any person who pollutes water, land and air with anything that endangers lives, safety, health or comfort of public is guilty of an indictable offence and liable to imprisonment or fine.
ENVIRONMENTAL PROTECTION	Territories air, land and water	Prohibits discharge into environment of a contaminant that causes impairment of environmental quality or affects health, safety or comfort of any person.
FISHERIES ACT 1970	Canadian waters	Requires plans and specifications for any construction or work likely to result in deposition of deleterious substances in water or in a place where it is likely to end up in water.
MIGRATORY BIRDS CONVENTION ACT 1970	Water frequented by migratory birds	No person shall deposit, or permit the deposit of substances harmful to migratory birds in any waters or any area frequented by migratory birds. However, this does not apply to deposition when authorized by regulations under another act.
NORTHERN INLAND WATERS ACT 1970	Territories inland waters	Management of waters not covered by Canada Water Act. Covers control of diversion and obstruction of watercourses and deposition of wastes in water. No regulations pertaining to open pit mining.
NORTHWEST TERRITORIES PUBLIC HEALTH ORDINANCE 1957	Territories water and air	Prohibits any business or trade likely to endanger public health, affect sanitary conditions of water or pollute water or air.

LEGISLATION	AREA CONCERNED	RELEVANCE TO MINING AND ENVIRONMENT
FEDERAL (continued)		
TERRITORIAL LANDS ACT 1970	Territories land	Land use management areas for ecological balance. Excavation, water crossing, highway crossing, clearing and other use of land may require land-use permit.
YUKON PUBLIC HEALTH ORDINANCE 1958	Territories water and air	Prohibits any business or trade likely to endanger public health, affect sanitary condition of water or pollute water or air.
INTERNATIONAL RIVER IMPROVEMENT ACT 1970	Water	Regulates, through a licensing system, construction projects that would "improve" international rivers.
ARCTIC WATERS POLLUTION PREVENTION ACT 1970	Arctic water	Regulates the disposal of waste material that might affect the ecological balance of Arctic waters and their associated plant and animal life.
AGRICULTURAL AND RURAL DEVELOPMENT ACT 1966-1967	Land and water	Of marginal relevance to mining, the act is concerned with land use in rural areas. It provides for federal funding of soil and water conservation projects in any province or territory. The act may apply to rehabilitation in the absence of more specific legislation.
NEWFOUNDLAND		
DEPARTMENT OF HEALTH ACT 1970	Water	Empowers the Minister of Health to control all services, measures and institutions relating to public health. Discharging industrial wastes into water bodies must receive the written approval of an inspector of the department.
DEPARTMENT OF PROVINCIAL AFFAIRS AND ENVIRONMENT ACT 1973	Air, water and land	Regulates use of all surface, ground and shore water; allocation for use of water; pollution of air, water and land; and alteration of natural features of a water body. No regulations pertain specifically to open pit mining.
ORE TREATMENT TAILINGS (LABRADOR) DISPOSAL ACT	Land and water	Restricts rights of occupiers of land adjacent to land or water affected by iron ore mine tailings.
WASTE MATERIAL (DISPOSAL) ACT 1973	Land and water	License for waste disposal sites must be granted from Minister of Provincial Affairs and Environment, whether on private property or crown land.

LEGISLATION	AREA CONCERNED	RELEVANCE TO MINING AND ENVIRONMENT
NEWFOUNDLAND (continued)		
WATERS PROTECTION ACT 1964	Water	Protects water against contamination for drinking purposes. Each week is a separate offence and a fine may be levied.
WILDLIFE ACT 1952	Land and water	Obstruction and pollution of non-tidal waters frequented by fish is not permitted.
NOVA SCOTIA		
ENVIRONMENTAL PROTECTION ACT 1973	Air, water, land and noise	Prohibits discharge, deposition or emission of any waste which may affect the environment. Controls waste management and waste disposal. Regulates use of minerals and construction of facilities that may affect the environment. Promotes restoration and reclamation of degraded or despoiled areas.
PUBLIC HEALTH ACT 1967	Air, water and land	Prevents contamination of air, water or soil by any substance that may endanger public health or may become a nuisance. No regulations pertaining to open pit mining.
WATER ACT 1967	Water	Prohibits discharge of any pollutant into a water course. Any facility relating to water flow diversion or alteration must be submitted for approval.
MINERAL RESOURCES ACT 1975	Land	A bill that will regulate mineral resource development and reclamation of mined land.
NEW BRUNSWICK		
CLEAN ENVIRONMENT ACT 1971	Water, air and land	Prohibits deposition into water, air or soil of any contaminant or waste by any person either directly or indirectly. Any facility that may contaminate the environment is regulated by the Minister of the Environment.
MINING ACT 1961	Land and water	The Minister may make regulations concerning disposal of tailings, slimes, waste products or any noxious or deleterious substance upon any lands or into any waters.
WATER ACT 1961	Water	Prohibits discharge or disposal of any material into any water course that may impair quality of water for beneficial use. Water quality criteria are currently being determined (1976).

LEGISLATION	AREA CONCERNED	RELEVANCE TO MINING AND ENVIRONMENT
PRINCE EDWARD ISLAND		
ENVIRONMENTAL CONTROL COMMISSION ACT 1971	Air, water and land	Prevents discharge or deposition onto land, air or any water course of any item that may cause pollution or impair quality of land, air and water. Regulations are not specific to open pit mining but may be modified by the Minister.
FISH AND GAME PROTECTION ACT 1959	Water	Provides for the protection of water courses frequented by salmon from any contaminant, including lime.
OIL, NATURAL GAS AND MINERALS ACT 1971	Land	Directed towards oil and natural gas exploitation, there is provision to regulate land and water course reclamation.
RECREATION DEVELOPMENT ACT 1969	Land	Permits designation of any area as public park, protected area or beach (includes land under tidal water).
QUEBEC		
ENVIRONMENTAL QUALITY ACT 1972	Air, water, land and noise	Governs water quality, waste management, water management and atmospheric pollution. Prohibits emission, deposition and discharge to atmosphere, soil or water of any contaminant at concentrations greater than guidelines.
INDUSTRIAL ESTABLISHMENTS ACT 1964	Water, land and air	Guidelines for disposal of trade wastes.
MINING ACT 1965	Air, land, water and noise	Regulates mine land use with placement of overburden, waste rock, liquid or solid residues and waste matter from mining operations. Provides for protection of men against noise, dangerous substances and control of dust.
PUBLIC HEALTH PROTECTION ACT 1972	Water, air and land	Prohibits threat to human health by pollutant or public nuisances. Prohibits discharge of heavy metals into the environment.
ONTARIO		
CONSERVATION AUTHORITY ACT 1971	Water	Establishment of conservation authorities to manage natural resources in watersheds. Prohibits placement or discharge of any fill that may cause flooding or pollution.

LEGISLATION	AREA CONCERNED	RELEVANCE TO MINING AND ENVIRONMENT
ONTARIO (continued)		
ENVIRONMENTAL PROTECTION ACT 1971	Air, water, land and noise	Prohibits dumping or discharge into the environment of any pollutant above provincial regulations. Air pollution regulations cover stationary sources; waste management regulations cover rock fill or mill tailings. Effluent guidelines and receiving water quality objectives for the mining industry are included.
MINING ACT 1970	Air	Prevents discharge into air of contaminants from smelting, roasting or refining operations.
ONTARIO WATER RESOURCES ACT 1970	Water	Covers any material that will pollute and affect persons, animals, birds that may consume plant, fish or other living organisms from water. Guidelines and Criteria for Water Quality Management in Ontario.
PITS AND QUARRIES ACT 1971	Air, land and noise	Applies to pit development in numerous Ontario townships and requires security for rehabilitation of pits and quarries.
PUBLIC HEALTH ACT 1970	Air, land, water and noise	Covers any conditions that may be injurious to health and restricts establishment of offensive trades.
ENVIRONMENTAL ASSESSMENT ACT 1975	Air, land, water and noise	Requires environmental assessment of public projects and will be extended to private industry at a future date.
MANITOBA		
CLEAN ENVIRONMENT ACT 1972	Air, water and land	No person, directly or indirectly, shall cause, suffer or permit contamination of air, water or soil in excess of prescribed limits.
GROUNDWATER AND WATER WELL ACT 1969	Water	Requires precautions during drilling of water wells to avoid pollution of ground water and prevents placement of substances so that they pollute, contaminate, or diminish ground water purity.

LEGISLATION	AREA CONCERNED	RELEVANCE TO MINING AND ENVIRONMENT
MANITOBA (continued)		
MINES ACT 1973	Land	Provides for the safe and efficient operation of mines and for the rehabilitation of affected land. Allows the Minister to prohibit commencement or continuation of mining operations when in his opinion it is against the public interest, taking into account resource management and protection of the environment.
MINING AND METALLURGY COMPENSATION ACT 1967	Air, land, water and noise	Sets aside several districts in which no legal proceedings may be taken against mine operators.
PUBLIC HEALTH REGULATIONS 1970	Air, water and land	Concerned with public health matters, applies to water supply and sewage disposal from open pit mining operations.
WATER RIGHTS ACT 1972	Water	Governs use and management of water in the province. Permit required for any water use in the province.
INDUSTRIAL MINERALS DRILLING ACT 1962	Water	Governs the boring of wells in the exploration and development of certain minerals and provides for the issuance of permits.
SASKATCHEWAN		
AIR POLLUTION CONTROL ACT 1965	Air	Prohibits emission into the atmosphere of any contaminant that may affect the quality of the atmosphere. Mine operators are required to undertake waste control programs to minimize or prevent the pollution of air, water or soil. Includes maximum quantities of certain solids and gases in the outdoor atmosphere permissible under the regulations.
DEPARTMENT OF THE ENVIRONMENT ACT 1972	Air, water, land and noise	Establishes the Department of the Environment and gives the Minister control over all acts concerning the environment. There are no regulations presently in effect under this act regarding open pit mining, but these can be determined at the discretion of the Minister.
GROUNDWATER CONSERVATION ACT 1965	Water	Act for management of groundwater resources. Any person utilizing ground water for an industrial source or changing ground water pattern must submit detailed specifications to obtain a license.

LEGISLATION	AREA CONCERNED	RELEVANCE TO MINING AND ENVIRONMENT
SASKATCHEWAN (continued)		
MINERALS RESOURCES ACT 1965	Water, land and air	Pollution Prevention Regulations for the Mineral Industry apply to prevention and control of gaseous, liquid and solid industrial waste pollution resulting from any process of the mining industry or from development of any mineral resource.
MINING REGULATIONS ACT 1971	Water, air and land	Requires owner of mine to institute program of protection and reclamation of land and water courses affected by mining. Requires overall land-use plan for the mine property and surrounding area.
WATER RESOURCES MANAGEMENT ACT 1972	Water	No person shall discharge, deposit, drain or release any substance capable of changing the quality of water or causing water pollution. Requires persons polluting water to consequently remove the contaminant. Published Water Quality Criteria.
ALBERTA		
CLEAN AIR ACT 1971	Air	Prevents atmospheric emissions exceeding maximum levels. No mining construction may proceed without approval of plans and specifications. Maximum permissible levels for various pollutants are regulated.
CLEAN WATER ACT 1973	Water	Prohibits dumping of any deleterious substance that may impair water quality. Any contaminant of water may have regulations imposed on the company using it by the Minister. Requires a permit to construct and a license to operate any structure that may influence water bodies. Contains regulations for industrial operations.
COAL MINE REGULATION ACT 1970	Land	The land on which a strip mine is located shall be filled and levelled as the operations progress, and shall be restored as nearly as possible to its original condition.
COAL CONSERVATION ACT 1972	Land and water	The evaluation of coal deposits and their economic development is the prime concern of this act.

LEGISLATION	AREA CONCERNED	RELEVANCE TO MINING AND ENVIRONMENT
ALBERTA (continued)		
DEPARTMENT OF THE ENVIRONMENT ACT 1971	Air, land, water and noise	Covers conservation, management, utilization and prevention of pollution of natural resources, prevention of noise from industry, and preservation of natural resources for aesthetic value. The Minister may make regulations concerning the environmental aspects of any individual industry.
LAND SURFACE CONSERVATION AND RECLAMATION ACT 1970	Land	Requires a detailed environmental impact assessment of any proposed activity or operation. Requires reclamation of land disturbed by any acvity, as well as protection of vegetation and wildlife during the operation of any plant.
PUBLIC LANDS ACT 1970	Land	Provides for the removal of facilities after abandonment of mining on public land. The restoration of the land surface must occur as the exploration, stripping, excavation and other operations progress.
WATER RESOURCES ACT 1972	Water	No person shall divert or use any water, construct near or over any water course, or remove any material from a stream bed that may interfere with the present or future development or management of the water course, except by license.
BRITISH COLUMBIA		
COAL MINES REGULATIONS ACT 1969	Land and water	Each mine owner must fulfil program for protection and reclamation of surface land, surface water and ground water. Requires overall land-use plan for area during and after operations.
ENVIRONMENT AND LAND USE ACT 1971	Land	Ensures that all aspects of preservation and maintenance of the natural environment are fully considered in administration of land use and resource development commensurate with the most beneficial land use and minimum of adverse after-effects.
HEALTH ACT 1960	Land, water and air	Prohibits endangering life or safety of public by deposition or emission of any contaminant into the environment.

LEGISLATION	AREA CONCERNED	RELEVANCE TO MINING AND ENVIRONMENT
BRITISH COLUMBIA (continued)		
MINES REGULATIONS ACT 1967	Land and water	Regulations cover reclamation programs to return distributed resources and environment to best and fullest use. Also, contains Guidelines for the Design, Construction and Operation of Tailings Impoundments. Requires monitoring of ground and seepage water.
POLLUTION CONTROL ACT 1967	Air, land and water	Prohibits discharge, either directly or indirectly, into air, water or land of any contaminant that may impair quality. Permits are required to operate. Published comprehensive report "Pollution Control Objectives for the Mining, Mine-Milling and Smelting Industries of British Columbia."

APPENDIX C

SHEBANDOWAN CASE HISTORY

SUMMARY

The Shebandowan mine and concentrator, with a capacity of 10,000 tons per week, was opened in 1972 after several years of environmental study and planning. The mine is located in a popular vacation cottage area about 60 miles (96 km) west of Thunder Bay, Ontario. Undertaken before environmental assessment procedures had become an established requirement, Shebandowan is one of the first Canadian examples of effectively integrating environmental work into overall mine planning. Although it is an underground mine, many of the environmental considerations are common to open pit operations and hence it provides a case history for the use of all mine planners.

Early attention was focused on establishing baseline conditions in a two-year water quality monitoring program. Since production began, water quality monitoring has shown that mining has not caused any significant changes. However, mine drainage disposal arrangements had to be modified in the light of operating experience.

There is no townsite associated with the mine and workers commute from established municipalities. Harmonious relations have been achieved with local cottage residents after their initial fears were dispelled.

Plans are ready to begin revegetating the tailings when a sufficient area of dry elevated tailings has been accumulated. Rehabilitation of the land disturbed during development was begun before start-up and was completed during initial operations.

INTRODUCTION

The Region

1. Shebandowan is one of the first examples in Canada of integrating environmental planning into mine design. Although it is an underground mine (2 500 tons/day), many of the environmental considerations are common to open pit operation. For these reasons, it provides a case history that is useful for all mine planners.

2. Shebandowan is an Indian word meaning "a summer place" (referring probably to the value of the lake to its earliest inhabitants). It is situated in heavily glaciated terrain where depressed areas hold wetlands, muskegs and lakes.

3. The forests are composed of black and white spruce, with aspens and birch on the deeper till soils. Jack pine is present in the more sandy soil areas. Forest fires together with logging and some marginal farming have disturbed the natural ecology of the region. Figure C-1 shows vegetation typical of the region.

4. The composition of the forest changes with soil conditions. The soil is poor in nutrients (weakly to strongly podsolized). The surface water draining off these soils is consequently low in nutrients. This means that the lakes have little capacity to resist change in pH and hence are vulnerable to pollution.

5. The site is in Northern Ontario as shown in Fig C-2. This case history illustrates how investigations were tailored to the requirements of the project, to the site and to the regulations then in force. The precautions taken and the effects on design would be similar for an open pit mine. Publication of the history is made possible through the cooperation of INCO Ltd.

Mine Development

6. Historically, the first white man to see Shebandowan Lake was the explorer Jacques de Noyon in 1717. Over 10 000 settlers passed by this area commenced from the 1 000 level. The decision to igate the northwestern Ontario waters entered Shebandowan Lake in 1871.

7. In 1913, the Cross brothers discovered traces of nickel near the western tip of Lower Shebandowan Lake. The claims held by Jules Cross were purchased by INCO in 1936. Surface exploration programs were intensified in the 1960's, and an orebody of commercial significance was confirmed. During 1966-67, the No. 1 development shaft was completed and underground exploration commenced from the 1,000 level. The decision to

Fig C-1 - Vegetation in the Shebandowan region

bring the mine into production was announced in 1968.

8. The orebody lies directly below the lake in Southwest Bay and strikes in an easterly direction from Discovery Point to the opposite shore (Fig C-3). It extends almost vertically to a depth of 2 000 ft (610 m) and averages 25 ft (7.6 m) in width. It is approximately a mile (1 600 m) long. The orebody is contained within a sequence of volcanic rocks and occurs as stringers or veins of sulphides. The principal ore minerals are pyrrhotite, pentlandite and chalcopyrite in peridotite host rock. The ore contains about three parts nickel to two parts copper. Other metals include small amounts of cobalt, silver, gold and the platinum group.

9. The ore movement in the Shebandowan mine is shown in Fig C-4. Ore is passed from the mined area down to the 1 000 level and trammed about one half mile (800 m) to the main ore pass at No. 2 shaft. It drops to the 2 080 level and is crushed in a 36 x 48-in. (0.91 x 1.22-m) jaw crusher. The crushed ore then drops to the 2 160 level to be hoisted to a 4 000-ton (3 630-tonnes) underground storage bin above the 400 level. From the storage bin, it moves by conveyor along an inclined ramp to the mill, located a half mile (800 m) inland from the No. 2 shaft. Ore is mined at 2 500 tons (2 270 tonnes) per day, four days a week for a weekly output of 10 000 tons (9 070 tonnes). The main conveyor is capable of handling 650 tons (590 tonnes) per hour. The No. 1 shaft, which served as the exploration shaft, now acts only as a return airway. An additional return air raise is located on a small island in the centre of Southwest Bay. The main fresh air raise is located near the No. 2 shaft.

10. At the mill, after grinding, the ore is fed to a bank of 72 flotation cells - 24 roughers, 24 primary scavengers and 24 secondary scavengers.

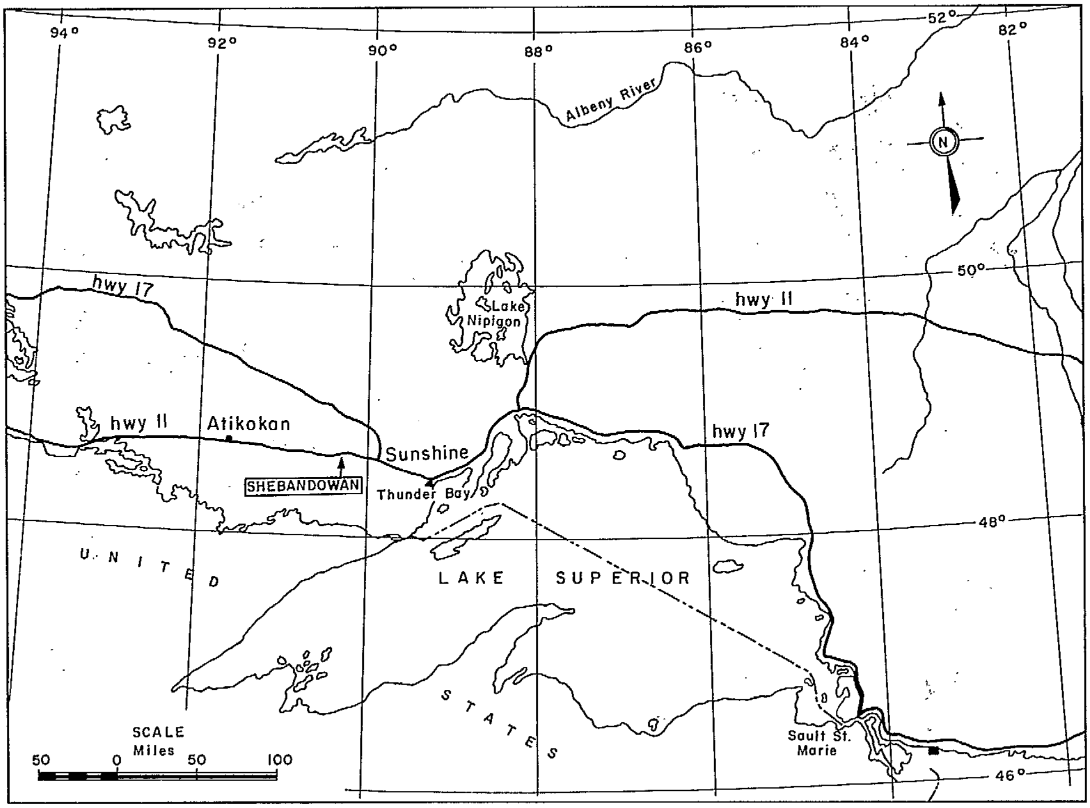


Fig C-2 - Shebandowan mine location

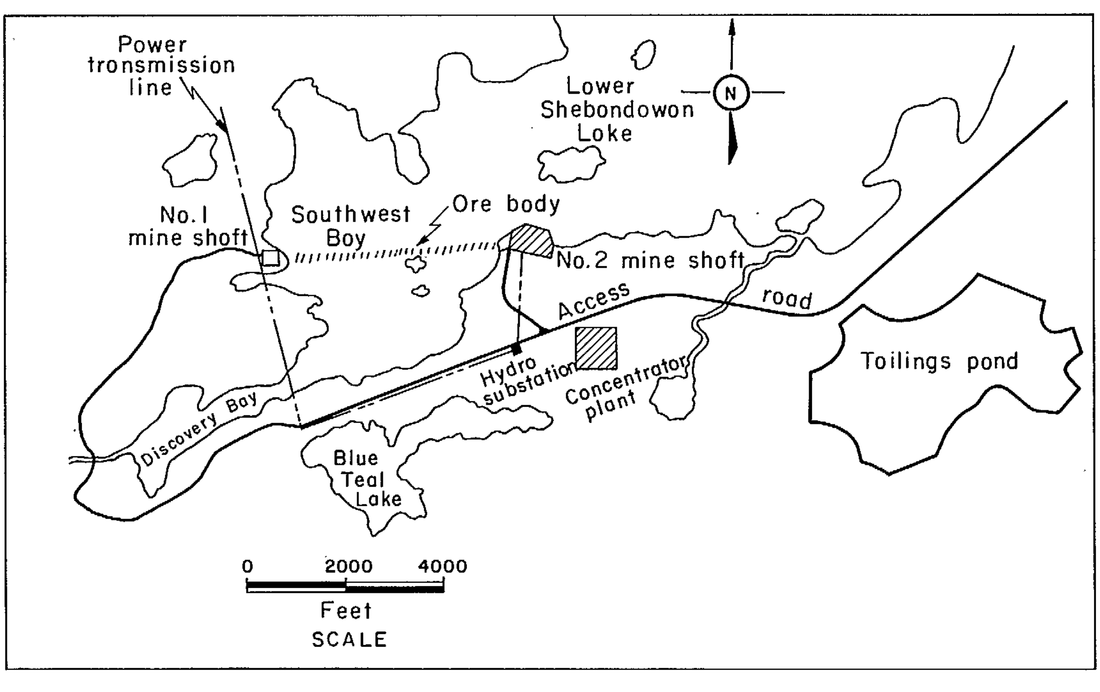


Fig C-3 - Location of mine shafts and concentrator

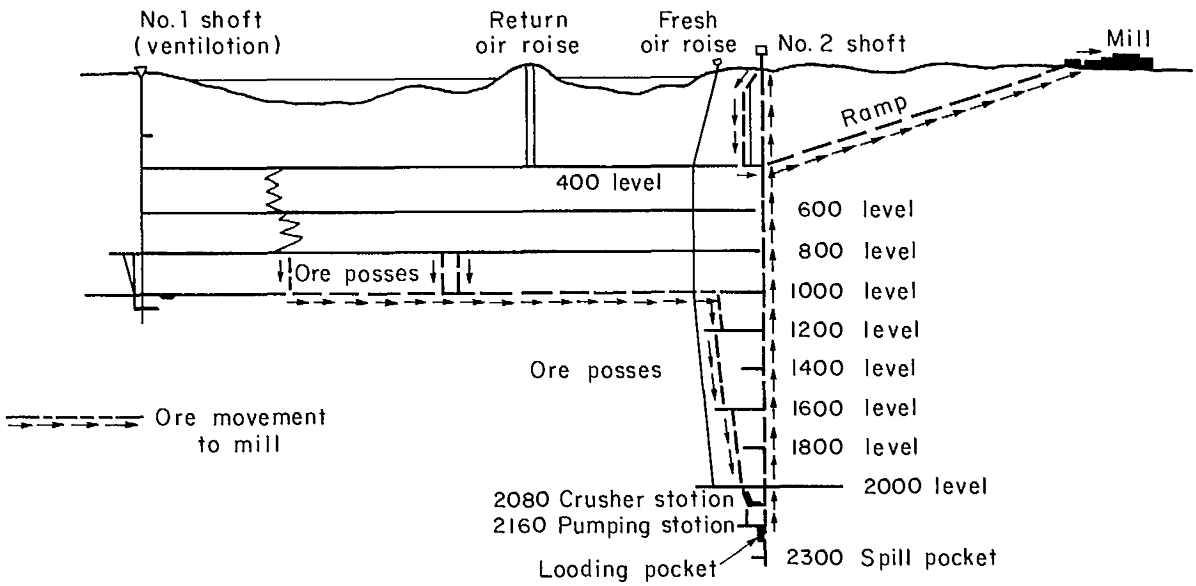


Fig C-4 - Ore movement at Shebandowan mine

Chemicals used in the flotation process include pine oil, potassium amylxanthate and depramix as a talc depressant. After thickening, the concentrate is dewatered to 18% moisture on a disc filter and is further reduced to 8% moisture in an oil-fired dryer. It is trucked to a railsiding at Sunshine and from there is shipped by rail to Copper Cliff for smelting and refining.

THE PREPRODUCTION PHASE

BACKGROUND

11. In the years before development of the orebody, Shebandowan Lake had gained a wide reputation as a popular vacation centre. Over 750 cottages are located along its shores. Swimming, boating and fishing are popular. Local residents expressed concern over the development of a mine in the midst of their vacationland.

12. Based on concern for environmental protection and to reassure local citizens, the company initiated an intensive environmental study to define the ecology of the region before the commencement of mine operations. This study helped anticipate any adverse effects.

13. No legislation requiring the assessment of environmental impact existed in Ontario or in Canada at the time but had just been passed in the United States (National Environmental Protection Act, 1969). Shebandowan was one of the first mine developments to formally consider environmental aspects in the design of the mine, undertaken not in response to existing legislation, but against a background of developing statutory control. Aquatic and social aspects of the development were recognized as being of the greatest significance. Terrestrial ecology was not overlooked.

TERRESTRIAL STUDIES

14. Surveys were carried out in the early stages of the preproduction phase. Aerial and ground topographic detail was required as basic input for both mine engineering and environmental studies.

15. Timber rights were independently owned, and it was therefore necessary to evaluate the timber resources on the property to help negotiate appropriate levels of compensation. Forest reserves were sampled by estimating tree densities and basal area at intervals along line transects.

16. In addition to environmental staff involvement, the agricultural department was actively concerned in the project. It ensured that soil was removed and stockpiled during construction and that as many pockets of natural vegetation as possible were left in their original state.

RESIDENTIAL REQUIREMENTS

17. A potential conflict existed between the traditional need for a townsite to support the mine and the value of the area as cottage vacationland. A townsite could have detracted from the recreational values. Since 1966, it has been

the Ontario government's policy to reinforce existing towns and avoid residential development spreading into remote rural areas. Hence, the feasibility of a townsite to support the Shebandowan mine was questioned. In 1969, Reid Crowther and Associates prepared a townsite selection study and elementary layout - "The Province of Ontario Report on Site Investigation and Cost Analysis Program Affecting Portions of Sites H and G at Shebandowan, Ontario". The then Ontario Department of Municipal Affairs assessed the extent of support required to provide for a town. With no townsite, the alternative was to provide for a moderate expansion in adjacent centres such as Thunder Bay.

18. Several applications for subdivision of nearby land holdings were received soon after the decision to bring Shebandowan into production was announced. These were refused. Financial support for a local townsite was withheld by the province in favour of permitting expansion within existing organized and serviced communities. Some of the ramifications of this strategy are discussed in a later section on the Social Aspects of Design.

Aquatic Baseline Studies

19. The objectives of the aquatic monitoring program were to characterize the aquatic environment in the vicinity of the mining operations and to determine the baseline conditions before the mine came into production.

20. The principal watershed drains to the Shebandowan Lake system. Water leaving Lower Shebandowan Lake flows into the Shebandowan River and eventually enters Lake Superior. Gold Creek originates to the south of Lower Shebandowan Lake, near the present tailings area, and joins the Matawin River before its confluence with the Shebandowan River (Fig C-5).

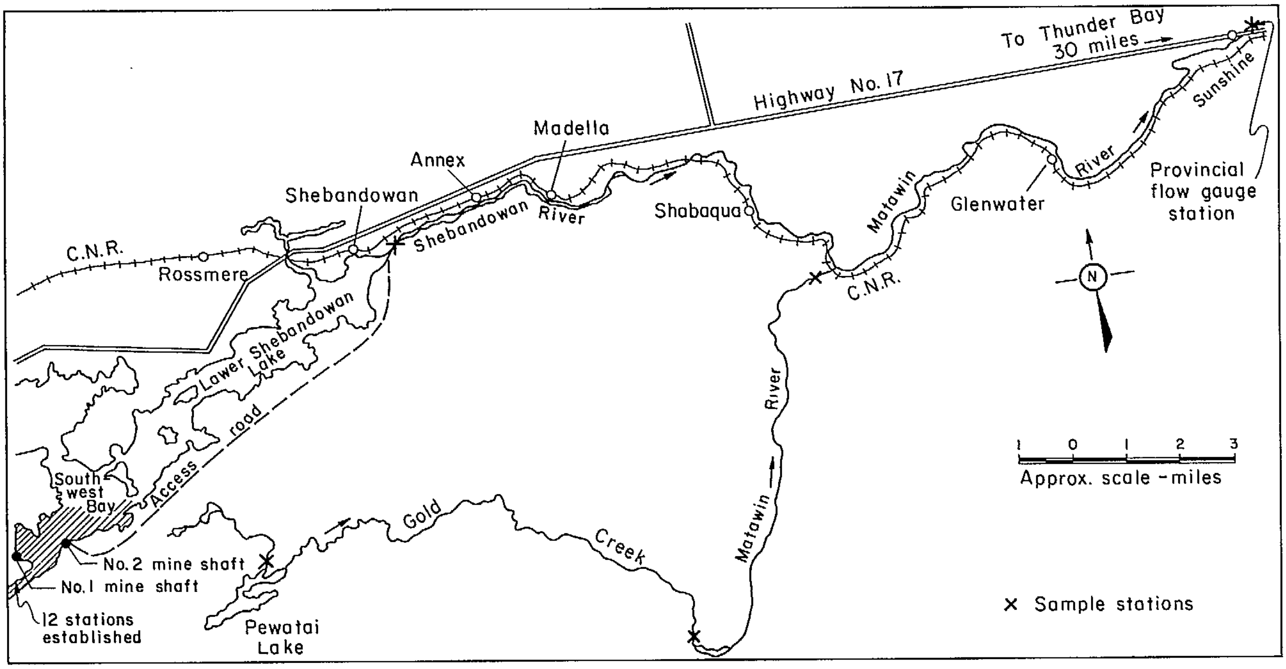


Fig C-5 - Water courses around Shebandowan mine

21. The mine could influence both water courses: the Gold Creek - Matawin River and the Lower Shebandowan Lake - Shebandowan River system. A view of Gold Creek is shown in Fig C-1. The two drainage systems are separated by a height of land but join approximately 20 miles downstream just south of the Trans Canada Highway (Fig C-5).

22. The Ontario Ministry of the Environment (at the time the Ontario Water Resources Commission) in the Thunder Bay region examined the types of problems that might arise and the precautions to be taken. James F. MacLaren Ltd. was retained for baseline studies to examine the aquatic ecosystems in existence before operation of the mine began and to monitor the same parameters after mining had started. Detailed site planning was delayed until after some of the results of the aquatic program were available.

23. Sampling stations were selected to include critical areas such as river junctions and sites representative of the systems to be studied. Appropriate sampling procedures were used at each. An initial reconnaissance was performed in the Shebandowan area before the actual sites were chosen. At that time, the depth of Southwest Bay was determined. Depth profiles for temperature, dissolved oxygen and conductivity were taken with slight variations in these parameters being found. Six sampling stations were then established to monitor water quality. The sampling stations were located in Southwest Bay as this was expected to show the first signs, if any, of the impacts of mining activity. Bottom samples revealed very low numbers of organisms. A further six sampling stations were established in shallower water closer to the mine shafts for benthic studies and to be able to detect changes faster. A seventh sampling station was located at the outlet of Shebandowan Lake. These are the permanent sampling stations for Southwest Bay and Shebandowan Lake.

24. The sampling stations on the more remote Gold Creek - Matawin River system were determined by their accessibility. Four sampling sites were chosen to provide representative samples and were located where major changes in the quantity of water occurred in the system.

25. Lake samples for physical and chemical analysis were obtained from depths of 3 ft (0.9 m) below the surface and 5 ft (1.5 m) above the bottom sediment. Earlier reconnaissance had shown that the lake has an average depth of 37 ft (11.2 m). It is thermally stratified in the summer months with warm water on top of cooler water. Since the phytoplankton and zooplankton mainly inhabit the upper (photic) zone of a lake, plankton samples were obtained from depths of 3 and 15 ft (0.9 and 4.6 m) below surface. Fish population was estimated by gill-netting or seining. Bottom living organisms (benthos) were collected using an Ekman type dredge to obtain a measured quantity of sediment. The substratum was sieved, and organisms were preserved on site for future identification of species.

26. River samples were taken from selected areas. Benthic fauna were collected with a drift sampler.

27. In the original sampling program it was intended to take samples each month during the ice-free period from May to November. However, because of the lack of accessibility of some of the sites, the sampling program was conducted when access was possible. Physical and chemical parameters were determined each month and the biological characteristics every second month.

28. An adequate baseline monitoring system has to span a period of more than one year. The quantities to be measured change with time and the results of one year may not be similar to those of the second year. Environmental factors, such as climate, may lead to an early or late spring and, therefore, baseline conditions should preferably be established over at least two years or over two ice-free periods.

29. The measured physical characteristics of the water were temperature, turbidity, depth and rate of flow. These properties most clearly influence water quality. Temperature governs the growth rate of biological organisms. Turbidity indicates how much suspended material is in the water from both particulate materials and biological organisms. Depth and flow rates indicate the volume of water available to disperse contaminants as well as natural materials.

30. The chemical characteristics investigated

were conductivity, hardness, alkalinity, pH, colour, dissolved oxygen, nitrogen, phosphorous and heavy metals. These are the characteristics that often determine the growth and productivity of aquatic organisms. They were also most likely to change after mine operations began. The metals chosen for close study were those present in the ore which could also be present in the mining effluent. Many heavy metals can be detrimental to the biota, even at very low concentrations. Other important plant nutrients were added to the list so that changes could be detected early.

31. Impact on aquatic ecosystems cannot always be determined strictly in terms of physicochemical factors. However, the biota that inhabit the water may quickly reflect changes in the water chemistry. Aquatic organisms are in intimate contact with the water - they have no thick cuticles or skin to protect them. They are adapted to specific water qualities. Small changes in water quality may severely retard the health of a population or completely eliminate it. Because of this intimate contact, aquatic organisms often reflect changes in quality before they are detectable by physical or chemical methods. For this reason, bio-assay or toxicological studies of effluents may be required for predicting the effects of pollution.

32. In biological monitoring, a number of communities were examined. The phytoplankton are microscopic algae that are free floating in the photic zone and derive their nutrients directly from the water. Periphyton are usually algae attached to rocks or other living organisms. They also derive the majority of their nutrients from the water. The species in these communities may be arranged according to either their susceptibility to environmental change or to the status of the environment in which they exist. More diverse or varied communities usually survive environmental changes better than less diverse communities. Environmental stress, by affecting species differently, may decrease diversity. Sensitivity is thus shown by both individual species and the population as a whole. This classification by diversity of species and concentration of population can be useful in studying water communities and understanding the effects of pollution. Zooplankton, the free swimming organisms that feed on phytoplankton and periphyton, and the fish communities were studied less extensively because food chain effects usually take longer to manifest themselves in these higher organisms. However, low levels of materials such as pesticides and heavy metals may accumulate in the higher organisms and have impacts disproportionate to their original concentrations.

33. Benthic organisms were studied since effects of pollutants accummulated in the sediment are often identified first in such communities.

34. The physical and chemical data ranges for the year 1969-1971 are given in Table C-1 for Lower Shebandowan Lake and Table C-2 for the Gold Creek - Matawin River system. The data shown are the ranges of each of the variables throughout the sampling season and at all sample points. Although some parameters show a considerable range of values throughout the season and from year to year, no mining effluents were added during this time. Hence, these parameters reflect the natural state of the waters. They also illustrate the point that monitoring programs should be conducted for more than one year and at a number of different sites within the system.

35. The water has physical and chemical characteristics typical of most Northern Ontario lake systems. The waters are soft with very little buffering capacity and low concentrations of plant nutrients. This is also reflected in the biological communities. The phytoplankton population is extremely low (21 to 66 cells per millilitre of water) and consists mainly of diatoms and Dinobryon spp. However, the presence of Asterionella, Melosira, and Tabellaria as common organisms may indicate some enrichment. With low food supply, zooplankton do not form large populations and average only 1 to 6 organisms per 10 millilitres of lake water. Benthic organism counts are also extremely low. The species found in this lake would be sensitive to the addition of contaminants and are thus good indicators of pollution.

36. In 1969, the conclusions reached after the first year of the survey were as follows:

Table C-1: Water quality data Lower Shebandowan Lake, 1969-71 ranges

	1969	1970	1971
pH	-	-	6.4 - 7.5
Temperature (°C)	6.0 - 21.5	3.0 - 20.0	7.5 - 19.5
Turbidity (J.T.U.)	5 - 10	5 - 5	0.4 - 2.5
Colour (°H)	10 - 20	15 - 15	15 - 50
Conductivity (µmhos)	53 - 59	55 - 57	51 - 68
Dissolved oxygen	8.1 - 12.3	9.5 - 10.5	7.4 - 9.8
Total solids	22 - 64	32 - 58	42 - 52
Suspended solids	0 - 1	0 - 1	0 - 10
Dissolved solids	22 - 64	32 - 58	32 - 48
Alkalinity	27.0 - 34.0	19.0 - 20.5	17.3 - 26.0
Total hardness	24 - 29	24 - 27	-
Chloride	1.00 - 1.75	0.75 - 1.50	0.4 - 3.4
Sulphate	-	5.5 - 7.6	5.0 - 9.0
Total nitrogen	0.24 - 0.37	.21 - .45	0.01 - 1.00
Total phosphorus	0.008 - 0.019	0.003 - 0.048	0.005 - 0.090
Total copper	0.007 - 0.050	0.035 - 0.057	0.006 - 0.014
Total nickel	< 0.008	< 0.010	< 0.020
Total zinc	0.014 - 0.060	0.025 - 0.081	0.004 - 0.028
Total iron	0.03 - 0.07	0.02 - 0.06	<0.02 - 0.19

All values mg/l unless otherwise indicated.

a. The aquatic environment within the study area was found essentially free of inorganic pollutants. The water was soft, with a low concentration of dissolved solids. The components found were considered to be of natural origin.

b. Chemical analysis indicated that the nutrients nitrogen and phosphorus were present in concentrations that favour algal blooms. However, biological examination showed that the area was not rich in organisms and had low productivity. Thus, some other environmental condition was creating the limitations.

c. The biological flora and fauna exhibited sufficient variety to indicate that the aquatic environment was normal.

d. No evidence was found that discharges from temporary waste water treatment facilities during construction were affecting the quality of the Southwest Bay area of the lake.

e. It was anticipated that the discharge into Gold Creek from the proposed tailings lagoon would have a high sulphate content. The existing soft water would be changed to moderately hard water, affecting the biological flora and fauna in the creek. To a lesser extent, this might also occur in the Matawin River, particularly at times of low flow. However, the effect on the water quality below the confluence of the Matawin River with the Shebandowan River was expected to be minimal.

37. Conclusions from the 1970 monitoring program were as follows:

a. The study area aquatic environment was representative of nature, most of the chemical elements being of natural origin.

b. It could not be determined how much of the nitrogen and phosphorus already present in some quantity in the lake had been contributed by

Table C-2: Water quality data Gold Creek - Matawin River system 1969-71 ranges

	1969	1970	1971
Ph	-	-	6.5 - 7.5
Temperature (°C)	5 - 24	-	10.1 - 21.0
Turbidity (J.T.U.)	15 - 45	25 - 40	1.1 - 7.0
Colour (°H)	80 - 140	50 - 140	20 - 120
Conductivity (μmhos)	60 - 132	69 - 145	37 - 165
Dissolved oxygen	7.0 - 14.0	8.8 - 10.8	6.9 - 9.2
Total solids	53 - 100	106 - 136	34 - 120
Suspended solids	0 - 9	1 - 10	1 - 10
Dissolved solids	46 - 100	104 - 135	28 - 110
Alkalinity	39.0 - 84.5	27.5 - 68.5	18.5 - 71.5
Total hardness	29.5 - 73.0	42.5 - 70.0	-
Chloride	0.75 - 1.50	0.5 - 1.50	0.3 - 1.75
Sulphate	-	6.1 - 11.9	4.0 - 7.0
Total nitrogen	0.56 - 0.97	0.46 - 0.84	0.52 - 1.59
Total phosphorus	0.035 - 0.061	0.038 - 0.108	0.015 - 0.108
Total copper	0.007 - 0.061	0.014 - 0.025	< 0.006 - 0.017
Total nickel	< 0.009	< 0.010	< 0.020
Total zinc	0.007 - 0.024	0.010 - 0.044	0.008 - 0.360
Total iron	0.48 - 1.17	0.24 - 0.94	0.15 - 0.61

All values mg/l unless otherwise indicated.

local human activities. There had been cottage developments on Lake Shebandowan for some years, which may have contributed these important elements.

c. There were no significant increases in the levels of nitrogen and phosphorus in Southwest Bay as a result of construction activities in the area. Rather, the lowest values found for these two elements occurred in the general vicinity of the two shaft sites.

d. The productivity of Lake Shebandowan, contrary to most lake studies in Northwestern Ontario, did not appear to be controlled by nitrogen, phosphorus, silicon or sulphur. Analysis showed that carbon sources were adequate for a healthy environment in the sediment on the floor of the lake. The limiting factor was not determined.

e. No increase in the low phytoplankton productivity had been observed in Southwest Bay. From this observation, it was predicted that Lake Shebandowan would not sustain a large fish population.

f. Other activities, such as logging, on the Gold Creek - Matawin River system might affect the local ecology.

38. Of special note was the inclusion later in 1973, soon after production began, of a complete analysis of all chemical elements (SCAN) of the Shebandowan Project effluent waters. The SCAN results are given in Table C-3 for both mine water and tailings effluent. It was shown that the potential biological toxicants - the heavy metals - were present in very low concentrations. Other studies have indicated that if one of the metals is present at concentrations greater than 1 mg/l, environmental damage can occur. Also, if the sum of the metals, especially lead, zinc, cadmium and nickel, is greater than 1 mg/l, the combined influence of the metals may be detrimental. The analysis showed that these problems were unlikely to occur in the Shebandowan effluents.

Table C-3: Water quality data scan analysis of effluent waters 1973

	Mine drainage effluent March 1973	Tailings effluent April 1973	Tailings effluent August 1973
pH	6.9	7.2	7.2
Sulphate	321	185	161
Suspended solids	23	1	1
Total solids	775	499	406
Copper	0.01	0.01	0.02
Nickel	0.37	0.04	0.04
Iron	2.75	0.32	0.14
Cobalt	0.02	< 0.02	< 0.01
Arsenic	< 0.02	< 0.02	< 0.02
Lead	< 0.05	< 0.01	0.01
Zinc	0.02	0.01	< 0.01
Chromium	0.10	< 0.01	< 0.01
Cadmium	< 0.005	< 0.003	< 0.003
Mercury	< 0.005	< 0.005	< 0.005
Manganese	0.09	0.54	0.25
Magnesium	10.6	12.1	13.0
Aluminium	1.39	< 0.2	< 0.2
Lithium	< 0.01	< 0.01	< 0.01
Molybdenum	0.08	< 0.05	< 0.05
Tin	< 0.05	< 0.05	< 0.05
Titanium	0.078	< 0.05	< 0.05
Chloride	60	31	26
Barium	< 0.2	< 0.2	< 0.2
Sodium	24	91	88
Potassium	3.0	10	1.5
Calcium	157	53	63
Total alkalinity	73	168	122
Total Kjeldahl nitrogen	5.0	4.2	1.7
Ammonia as nitrogen	4.0	2.4	0.4

All values mg/l except pH.

MINE DESIGN AND OPERATING EXPERIENCE

39. Armed with results of the two-year water quality monitoring program, final process design and locating of the tailings pond were completed.

WATER SUPPLY

40. Fresh water is drawn from Shebandowan Lake via a low elevation pump house at the shoreline near No. 2 shaft. The approximate water balance between the mine, tailings pond and concentrator is shown in Fig C-6. Chlorination is carried out before use. Some potable water during summer months has a detectable taste. This may be caused by iron or algal blooms in the lake.

41. With the mine and concentrator working as an integrated unit, fresh water demand is relatively low. Sufficient pumping capacity was installed to maintain an adequate water supply in the event of a malfunction when it might be necessary to run the concentrator on open circuit.

Tailings Disposal

42. The tailings disposal area plays an intricate part in the overall operation of the complex, with recycled water for the mining and milling operations being taken from the tailings pond. Almost 2 x 10^6 gallons (9 x 10^6 litres) of this water are recycled between the tailings pond and the mill each day.

43. The results of the water quality monitoring program and projections of types and levels of contaminants that could be expected showed that disposing of excess water into Shebandowan Lake would have a small impact on the local ecology. The tailings pond could have been located in a convenient valley near the concentrator adjacent to the lake. The concentrator would then draw its process water from the tailings pond with a comparatively small net discharge of clean effluent to the lake. Although acceptable on technical grounds, such a location would have received strong opposition from residents and the Ontario Water Resources Commission. Accordingly, a site near and discharging into Gold Creek was selected that met all engineering, social and environmental requirements. A recent aerial view of this site is shown in Fig C-7.

44. The 300-acre (140-ha) tailings pond was designed to be sufficient for the 20-year life of the mine. After cyclone separation of the coarse tailings for underground backfill, the fine fraction is pumped one mile (1 600 m) east to the tailings pond. After settling in the tailings

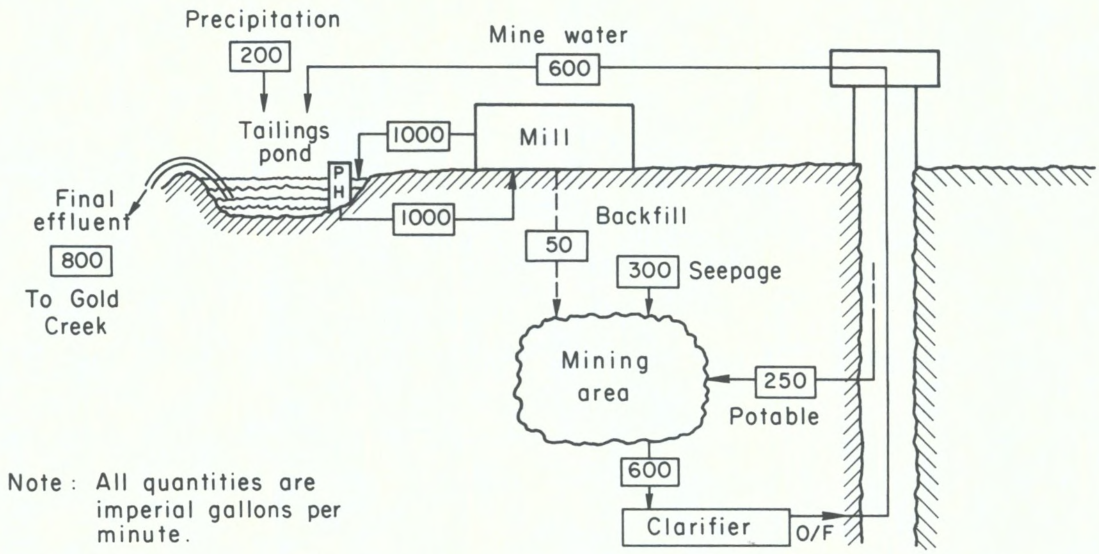


Fig C-6 - Schematic water flow at Shebandowan mine

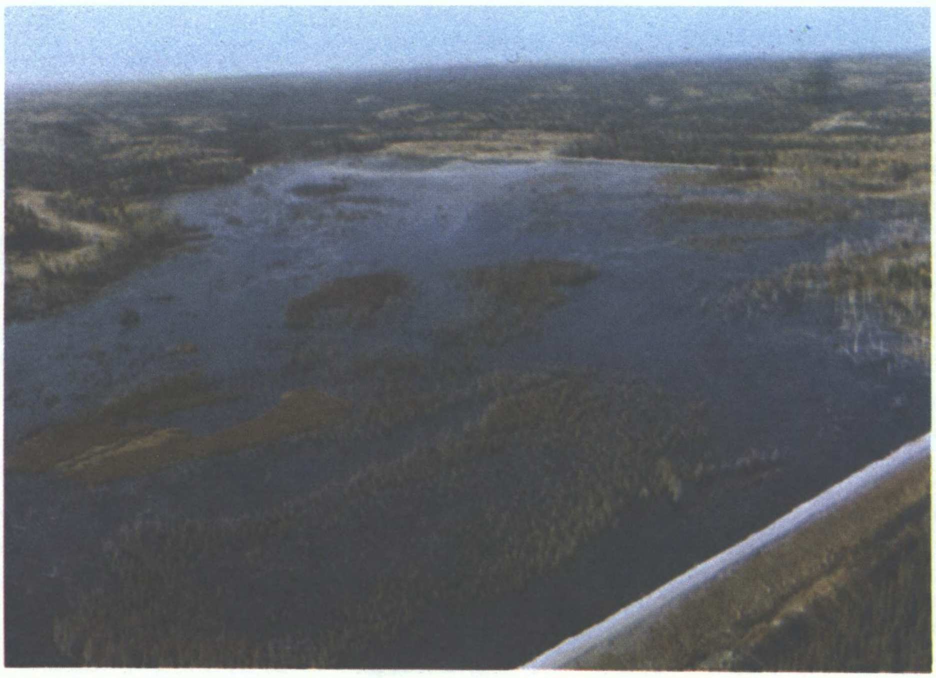


Fig C-7 - Aerial view of tailings pond in late 1974 pond, water is recycled directly back to the concentrator.

45. One major drawback to the settling of tailings in open impoundments is resuspension of particles by wave action, which occurs even in light winds. The tailings pond was originally a peat-filled tree-covered depression. Rather than remove the trees, their value in reducing wave action and thus promoting more efficient settling was recognized. Originally hydrogen sulphide was produced due to anerobic decomposition of the organic material. This was related to turbulence induced at the return water pump house intake. This localized problem was corrected by relocating the discharge from the return pump overflow which reduced local turbulence. Four 4-in. (10-cm) fixed siphons are used to regulate the outflow from the pond so that it remains proportional to the rate of flow of water in Gold Creek.

Control of Contaminated Water

46. Two tailings lines were installed, leading from the concentrator, one being a spare. Suitable natural depressions were prepared at low points along the route to be available as emergency sumps. Sumps have a graded rock base and are equipped with dump valves. A portable pump is available for rehandling material from the sumps should the need arise.

47. The other source of contaminated water is drainage from the mine itself. The mine water is collected underground and treated using a complete system of chemical feeders, a clarifier and vacuum filters. Originally, this treated water was to be pumped directly into the Gold Creek - Matawin River system. However, the underground mine water would not respond to clarification and was not a good enough effluent for direct discharge (Table C-4). On the other hand, the tailings water was

Table C-4: Water quality data mine drainage analyses 1971-73

	Mine drainage effluent 1971	Mine drainage effluent 1972	Mine drainage (as flow to tailings pond) August 1973
pH	6.9 - 7.6	6.6 - 7.9	6.9
Turbidity (J.T.U.)	14 - 60	320	-
Colour (°H)	-	3.0	-
Suspended solids	8 - 102	144 - 766	23
Alkalinity	22 - 73	350	-
Total hardness	-	571	-
Sulphate	21 - 440	54 - 650	321
Total copper	0.052 - 0.242	1.3 - 1.5	0.01
Total nickel	0.100 - 0.240	0.6 - 1.4	0.37
Total zinc	0.018 - 0.033	< 0.1	0.02
Total iron	2.68 - 7.38	12.7 - 21.8	2.75
Conductivity (μmho)	141 - 1 260	-	-
Total solids	106 - 1 104	-	775
Dissolved solids	98 - 1 002	-	-
Chlorides	9 - 102	-	-

All values mg/L unless otherwise indicated.

of sufficiently good quality for direct discharge (Table C-3). After the start of mining operations, the treated mine water was directed to the tailings pond. Excess water from the tailings pond was discharged to the receiving streams. Actual operating experience did not confirm the original predictions about the quality of mine drainage. Sufficient factual information was available from the monitoring program to assess the situation and make the appropriate changes. Figure C-6 shows schematically the present overall water balance.

48. As a precaution to help control surface run-off that could be significantly contaminated with oil and grease, areas adjacent to the service buildings have been asphalted. Additional precautions have included diking, rerouting streams and installing appropriately sized culverts at road crossings.

49. Septic tanks were provided by the contractors for their own work crews living in trailer accommodation near No. 1 shaft during the development phase. The baseline water quality monitoring program did not reveal contamination of the lake water from this nearby potential source of pollution.

50. All plant sewage is disposed of via a separate 4-in. (10-cm) diameter polyethylene pipe to the tailings pond. INCO's previous experience elsewhere had shown this to be an adequate arrangement. A chlorination facility is provided on a standby basis. Coliform levels are monitored regularly.

Aesthetics, Noise and Dust

51. The position of the mine shafts and headframes were dictated by the location of the orebody; consequently, they are close to the shorelines. No. 1 shaft headframe has since been dismantled and area rehabilitated (Fig C-8 and C-9). This cleared area remains partly visible across Southwest Bay. The No. 2 shaft headframe is the only significant indication that a mine is operating in the vicinity. A return air raise is located on a small island in the centre of Southwest Bay; this ventilation raise is so well camouflaged that few people are aware of it.

52. Primary crushing, storage above the 400 level and conveying ore underground to the fully enclosed concentrator about a half a mile (800 m) inland all serve to reduce noise levels across the lake. Atmospheric dust is likewise minimized.

53. Built for efficient transportation of concentrates, a quality paved road links the mine to Highway 17 and the rail siding at Sunshine. To minimize dust losses and environmental problems from dried concentrates, truck boxes are covered with tarps. This main access and haulage road is now maintained by the Ontario Ministry of Transportation and Communications, which is also responsible for snow clearance.

Social Aspects

54. There is no townsite associated with the Shebandowan mine. The predicted life of the mine is 20 years. There were fears that the greatest environmental impact would arise from development of a townsite to house the 350 workers. The Provincial Government decided that creating a potential ghost town had to be avoided. Furthermore, provincial participation to provide the necessary infrastructure for a new town could not be justified on financial grounds. It is normal to make cost-benefit calculations for a 50-year period.

55. A commuting trip of one hour is considered by planning officials to be about the maximum that employees at a new operation can reasonably be expected to undertake. The majority of the workers live in Thunder Bay and can travel to work by local bus. Because of the relatively long time spent in travel to and from work, the mine and mill operate four 10-hour shifts per week.

56. There have been moves to winterize summer cottages which would make them suitable for year-round occupancy by mine employees and hence change the character of the area. Such moves were discouraged, in part, to avoid later demands for public services like paved roads, school buses and snow clearance. Most local cottage roads are privately owned and maintained. Outside the immediate vicinity of the mine, few developments have occurred that can be attributed, even indirectly, to the presence of the mine.

Fig C-8 - Shaft No. 1 with development work in progress

Fig C-9 - Shaft No. 1 after contouring and seeding (October, 1974)

57. Local cottage owners originally expressed strong opposition when the mine development was first announced. The initial alarm, distrust and opposition at having a mining operation seemingly thrust upon them, in the midst of their vacation land, was dispelled by the open door policy adopted by the company. In addition to a formal public hearing when the decision was made to develop the deposit, meetings with the public and local associations were held to provide an opportunity for the residents to express their concerns and for the company to explain the way they intended to develop the mine. Fostered in part through an annual newsletter to all residents from the company, a close relationship has since developed between the company and residents.

RECLAMATION

LANDSCAPING

58. It is the visual or aesthetic aspect of a mine that so often causes people to perceive a pollution problem. It is important to rehabilitate all areas disturbed by construction as well as areas affected by later mine operations.

59. The company's agricultural staff was involved during construction and ensured that, in addition to leaving as many pockets of natural vegetation as possible, soil, rocks and other forest debris were saved to help in reclamation.

60. By 1972, when the complex was nearing completion, a program to rehabilitate the area was instituted. This was begun at the No. 2 shaft and concentrator locations. Figure C-10 shows activity near the concentrator in preparation for

Fig C-10 - Regrading prior to revegetation at the concentrator

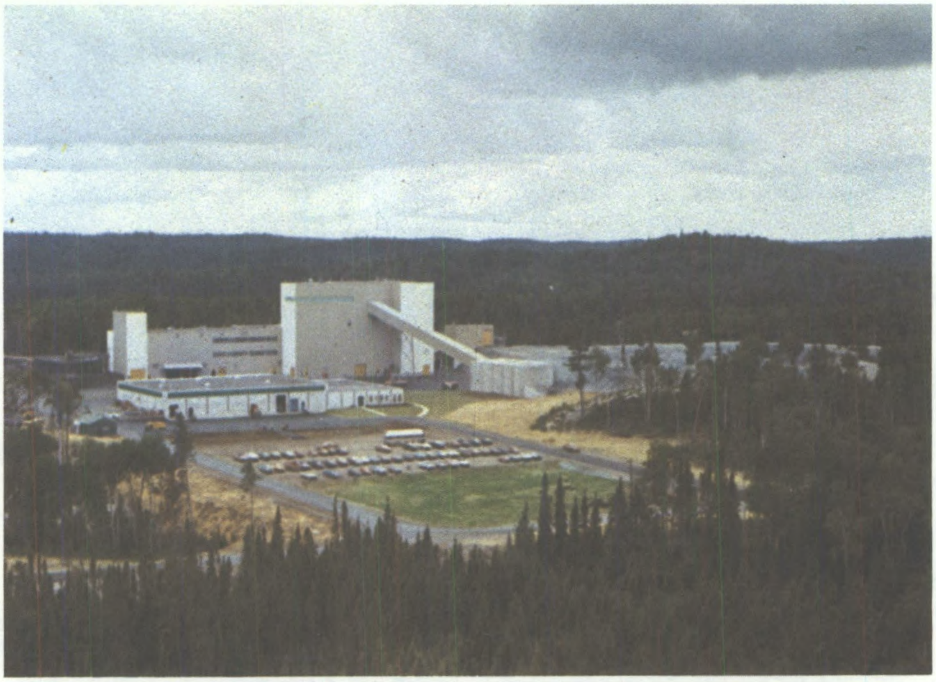


Fig C-11 - Aerial view of the concentrator after rehabilitation

revegetation. Figure C-11, taken in 1974, shows the extent of the rehabilitation work that had been completed.

61. The aim was to return affected areas as nearly as possible to typical Northern Ontario forest conditions. Rehabilitation of sites included collecting scrap material and either selling or burying it. The waste rock dumps were contoured to complement the natural physiography. There was no desire to create a flat grassland interspersed with exotic tree species, but rather to retain the natural topography and vegetation. To this end, the occasional large rounded boulder, indigenous to the region, was left exposed. Soil was spread to a depth of about 4 in. (10 cm) over the waste rock surface. Forest debris, such as large tree roots, which had been left in the preserved soil, served to trap moisture and minimize erosion on the slopes. Figure C-12 shows soil being placed on a contoured rock slope, illustrating the use of natural debris. Fertilizer was added to the soil. Grass species were introduced along with companion crops of rye or oats. Only native tree species have been used in the plantings in 1974 and 1975. The agricultural staff has also experimented with different fertilizer rates to encourage native species to encroach upon the grassed areas. At No. 2 shaft, the number of tree plantings was increased near the lakeshore as no belt of trees was left as camouflage when the area was originally cleared.

62. Figures C-8 and C-9 show the scope of rehabilitation required at No. 1 shaft after the contractors had left. The headframe has since been removed. The shaft is used only for ventilation. As activity is now centred across the lake at No. 2 shaft, a beach and picnic area was created near the No. 1 site for the benefit of local residents.

63. Pipelines to the tailings pond have been buried, covered with soil and revegetated using a hydroseeder to place mulch, seed and fertilizer

Fig C-12 - Rock dump reclaimed using soil and forest debris

(Fig C-12). The broad cleared areas along the access roads were grassed in 1973 using similar techniques.

TAILINGS REVEGETATION

64. Drawing on their extensive experience of revegetating the Copper Cliff tailings, the agricultural staff is devising a method suitable for the Shebandowan tailings area. The area will be revegetated progressively as each portion of the pond is filled and after allowing a suitable period for the tailings to dry out. Initially, it is proposed to revegetate with the same plants as those at Copper Cliff, with the subsequent introduction and encroachment of native trees being encouraged.

Fig C-13 - Tailings pipe lines revegetated after being buried

CONCLUSION

65. If the property had been developed according to short-term economic criteria alone, it is quite likely that part of Lower Shebandowan Lake would have been drained to permit mining by open-pit methods. This was not acceptable because of the value of the area for recreational purposes.

66. Shebandowan is among the first Canadian examples of extensive, formal environmental studies being carried out before and during the development of a mine.

67. The physical, chemical and biological monitoring system was started during the mine start-up and is continuing. No change in the aquatic environment has been detected since the baseline monitoring program was completed.

68. As a result of the company's open door policy, especially in the early stages of development, initial local resistance to mine development has been dispelled. It is now common for citizens to bring their own technical problems, such as septic tank layouts, to the company staff. The grounds of the complex are always open to the public. Regional planning officials have successfully avoided residential developments that could have reduced the natural attractions of the area.

69. The Shebandowan experience has shown that environmental considerations can be effectively incorporated into mine design with relatively minor additions to capital requirements. Monitoring of key environmental parameters at the initial stages and during production can identify problems before they cause major damage. In this way, environmental degradation and costly remedies can be avoided. Operating costs attributable to environmental considerations are considered to be minor at Shebandowan. No staff is assigned to environmental protection exclusively, although expert assistance is available from the Sudbury operations. Three years after production began, activities associated with maintaining a quality environment were effectively integrated into the normal routine of local management and supervision.

GLOSSARY

ACID MINE DRAINAGE
A term referring to all sources of acid water in a mining operation.

AVAILABLE
A term used in plant nutrition to refer to material present in a form that can be used by plants.

BENTHIC
An adjective describing plants and animals living attached to the sediments of water bodies.

BIOMASS
The amount of plant and animal matter in a given area. May be distinguished as plant and animal biomass or below and above ground biomass. Usually expressed in g/m or lb/acre.

BOD
Biological (Biochemical) Oxygen Demand. The decrease in oxygen content of a sample of water brought about by the bacterial decomposition of organic material.

BUFFER, BUFFERING CAPACITY
Waters which tend to resist changes in pH are said to be buffered. In nature, water bodies that have a high buffering capacity usually rely on chemical equilibria involving calcium (or sodium) carbonate, bicarbonate, carbonic acid and water. The relatively soluble calcium (or sodium) salts are derived from natural sources like limestone through the action of water enriched with carbon dioxide from organic sources while draining through the upper soil horizons.

BURN
Visible damage to plants produced by application of large quantities of fertilizers or chemicals. Symptoms may resemble those produced after heat stress.

CHELATED
Bound. In plant nutrition, the term refers to the binding of one ion to another, usually an organic compound. Chelation can increase or decrease the solubility of ions.

COD
Chemical Oxygen Demand. The decrease in oxygen

content of a sample of water brought about by oxidation of contained chemical compounds. (See BOD).

COMPANION CROP

A crop usually sown with another to improve soil and microclimate conditions to encourage the growth of the desired crop.

EVAPOTRANSPIRATION

The process of by which plants remove groundwater by transporting it internally from roots to leaves, where it evaporates.

GRADE OF FERTILIZER

The amount of each element present in a fertilizer - the higher the grade the greater the quantity of the elements available.

GROWING DEGREE DAYS

A concept used as a rough estimate for the amount of warmth or heat available for plant growth. If the mean temperature for a day is t°F., then the number of growing degree days, above a base temperature of 42°F. is:

$$G.D.D. = \sum n(t - 42°F)$$

n = number of days

HARDEN OFF

A term used to describe the processes a plant undergoes in preparation for winter or cooler conditions - complex physiological changes, the storage of nutrients and the reduction of water content in the plant.

HEATING DEGREE DAYS

A concept used to estimate the number of days and extent to which heating of buildings will be required. If the mean temperature for a day is t°F., then the number of heating degree days, above a base temperature of 65°F. is:

$$H.D.D. = \sum n(65°F - t)$$

n = number of days.

IBS AREAS

Are areas designated under the auspices of the International Biological Program as being of high scientific merit and are included in the world-wide inventory of so designated areas. They usually contain examples of rare, possibly unique species of plants or animals or of nationally important ecosystems.

LEGUME

A name given to members of the pea or bean family. Legume roots have nodules containing nitrogen-fixing bacteria.

MACROPHYTE

An aquatic plant normally found growing attached to the bottom.

MACRONUTRIENT

Elements or compounds required in large amounts by living organisms; they include H, O, N, P, Ca, K. "Macro" refers to quantity.

MICROCLIMATE

Describes small local variations (spacially or temporally) in climate related to buildings, vegetation or ground surface.

MICRO NUTRIENT

Elements required in very small amounts for the growth of living organisms. "Micro" refers to the amount rather than to the element being essential. Examples include Cu, Zn, Mo, Fe, B, and Cl.

NPK

Nitrogen, phosporus, potassium - usually as contained in various fertilizers.

OLIGOTROPHIC

Oligotrophic waters are usually distinguished from eutrophic waters on the basis of their phytoplankton population. They are characterized by low levels of nutrients, low productivity and high levels of dissolved oxygen.

OVERBURDEN

The soil that overlies a deposit of ore.

PERIPHYTON
Microscopic and macroscopic plants attached to rocks, weeds and bottom sediments.

PHYTOPLANKTON
Minute plants living in the water of ponds, lakes and rivers. Includes free living algae.

PODSOL, PODSOLIZED
Podsolic soils are imperfectly drained soils that have developed under coniferous and mixed-forest vegetation, mostly in cold to temperate climates and on acid parent materials. Below the organic debris layer, these soils are acid (usually pH 5.5), and the organic matter in combination with iron and aluminum forms coatings on soil particles.

POLLUTION, POLLUTE
"To make unclean, impure, or corrupt; desecrate; defile; contaminate; dirty" - Webster. It usually implies an unnatural circumstance (either physically, chemically or biologically impure) that adversely or unreasonably impairs the existing quality of the environment. In this chapter a health hazard is not necessarily implied.

RECLAMATION
The process of returning a disturbed area to its natural state, or to a state suitable for equivalent or superior use or benefit. Most frequently used in conjunction with areas whose properties have been drastically changed.

REHABILITATION
Restoration to the original or equally satisfactory condition. Normally used to describe restoration of land disturbed by construction.

RHIZOME
An underground stem.

RHIZOSPHERE
The portion of a soil in the immediate vicinity of plant roots.

SCAN
A scan of a sample is one in which every chemical element is analyzed. It is usually performed by mass spectroscopy.

SOIL
The upper portion of the earth's layer that has been weathered by environmental factors. Agricultural soil is stratified and has an organic humus fraction containing living forms.

SOIL PROFILE
The stratified organization of agricultural soil into litter, humus and weathered parent mineral layers.

SPOIL
Used in this chapter as a general term relating to solid mineral waste materials resulting from the mining, concentration or refining of mineral resources.

SWARD
A stand of uniform vegetation, usually given to grass cover.

SYNERGISTIC
The combined action of different agents producing an effect greater than the sum of the effects of the agents acting independently.

TOXIC, TOXICITY
Poisonous. Applied to both inorganic and organic chemicals which, even in extremely low concentrations, may kill organisms or reduce their growth vigour.

ZOOPLANKTON
Small animals, mainly crustaceans, living free in the water of ponds, lakes, rivers.