NORTHWEST TERRITORIES WATER BOARD
ᓄᓇᕗᑦ ᐃᒪᖅ ᑲᒪᔨᑦ

Guidelines for Tailings Impoundment in the Northwest Territories

February, 1987

Cover Photo
Tailings impoundment,
Giant Yellowknife Mines
(*photo by George Hunter*)

Guidelines for Tailings Impoundment in the Northwest Territories

February, 1987

Foreword

Every mining operation in the world is faced with the problem of safely disposing of the waste products, or tailings, from its processing plants. In the Northwest Territories, because of the severe climate, permafrost and sensitive environment, there are numerous special factors that must be addressed by mining companies with respect to tailings impoundment. Because the safe disposal and containment of mine tailings is so important if the waters of the Northwest Territories are to remain unspoiled, the Water Board has prepared these Guidelines to assist the northern mining industry from site selection through to abandonment and restoration. Although other jurisdictions have guidelines for tailings disposal, they are not totally applicable to the Northwest Territories because of the unique conditions present in the North.

In 1981, the Water Board engaged L.P. Stephenson, an experienced concentrator operator with Cominco Ltd., to prepare a first draft of the Guidelines. This was done, and a review of the draft guidelines was carried out by the Board's Technical Advisory Committee. To complete the project, the Board established an independent committee. This committee consisted of W.A. Case, P.Eng., Chairman; Dr. J.B. Wilson; A.G. Redshaw, P.Eng.; J.K. Gowans, P.Eng.; B.C. Cross, and R.G. Killam, P.Eng. The approach taken by the committee was to have the firm of Hardy Associates (1978) Ltd., Consulting Engineers, prepare a final draft. The editing of the Guidelines was done by the committee and the final document was approved by the Water Board.

The purpose of the Guidelines is to bring to the attention of the mining industry the many factors which can have a bearing on designing, building and operating tailings disposal facilities in the north. It is hoped that the Guidelines will assist the companies in choosing good sites, sound designs, proper construction methods, effective operation plans, and finally, acceptable abandonment and restoration measures. It must be stressed, however, that these Guidelines are just that; they are not a "Design Handbook" nor were they intended to be. The intent was to prepare a "check list" which can be used by a mining company to ensure that all pertinent factors are considered during the several stages of implementing a tailings disposal facility.

The objective of the Board is to protect the waters of the Northwest Territories, and it anticipates that these Guidelines will help the mining industry to contribute to this objective. A side benefit to companies who give heed to these Guidelines could be cost savings achieved by avoiding inadequate or unacceptable approaches to tailings disposal in the northern regions of Canada. Finally, companies who make reasonable use of these Guidelines should find that the processing of applications for Water Licences is accomplished more rapidly and with fewer difficulties.

The Board wishes to thank all of those parties who contributed to the preparation of these Guidelines, particularly Dr. Ed McRoberts and the members of the independent committee.

Glenn B. Warner
Chairman
Northwest Territories Water Board
Yellowknife, Northwest Territories
Canada

TABLE OF CONTENTS

1.0 Introduction

The use of water for a mining operation and its subsequent storage in a tailings disposal facility or possible discharge to the surrounding environment is a regulated activity in the Northwest Territories. Under the authority of the "Northern Inland Waters Act", the Northwest Territories Water Board (the Board) has developed this set of guidelines for use by mining companies who propose to construct new tailings disposal facilities or expand existing facilities. The primary purpose of these guidelines is to provide information that the Board believes is relevant to the site investigation, design, construction, operation and abandonment of a technically safe and environmentally sound tailings disposal facility. The Board recognizes that each and every project is different, and each is finally judged on its own merits; however, the Board also recognizes that there are many common factors in mining projects. Therefore, it is possible to define in general terms what the Board expects from a proponent of a tailings disposal scheme. While the relevant regulatory acts are cited in Section 10.0 of these guidelines, it must be clearly understood that these guidelines have no regulatory authority and are solely provided as information to the proponent of a tailings disposal scheme.

The Northwest Territories contains an estimated 27% of Canada's fresh water resources. These waters are largely unspoiled by pollution or physical alteration by man. The Board has a fundamental mandate to protect this national resource in a manner consistent with, and balanced against, the legitimate and vital national interest in mining development. This mandate requires the Board to ensure the safe containment of tailings solids and to require an operator to discharge effluent into the environment at acceptable contaminant levels. Such levels are either set by law or are established as part of a Water Licence issued pursuant to the Northern Inland Waters Act and Regulations. However, effluent contaminant levels are beyond the scope of these Guidelines for Tailings Impoundment.

While the regulatory process is described elsewhere, it is useful to provide a brief synopsis of the Environmental Assessment and Review Process (EARP) as it applies to tailings disposal facilities. EARP was established by the Federal Cabinet on December 20, 1973 and revised by Order-In-Council on June 21, 1984. It obliges federal government departments to assess the environmental and socio-economic impacts of projects located on federal lands, involving federal funds or with potential environmental impacts on federal responsibilities, i.e., national parks. The Northern Affairs Program of Indian and Northern Affairs Canada is responsible for the implementation of EARP in the NWT. The implementation is through INAC's Regional Office of Environment and Conservation (OEC) with advice from the Regional Environmental Review Committee. To initiate the process the proponent files with OEC a "Project Concept Description" which identifies in general terms the nature and scope of the proposed project. This description is reviewed by EOC, and if no potentially significant impacts are identified, the project can proceed through the regulatory process. If potentially significant impacts are identified, the proponent is requested to prepare an Initial Environmental Evaluation (IEE), which documents potentially adverse impacts and proposed mitigation measures. This submission is screened by OEC with advice from the RERC. If no significant impacts are identified, the project can proceed through the regulatory process. If significant impacts are identified, the project must be referred by the Department to the Federal Minister of Environment for public review through the Federal Environmental Assessment and Review Office (FEARO). To date, no proposed mining projects have been referred to FEARO. While these processes may be viewed as being time sequential, it is in the interest of the proponent to initiate early discussion with the Water Board and its Technical Advisory Committee with respect to regulatory approval requirements under the Northern Inland Waters Act. It should be noted that regulatory approvals under the Territorial Lands Act are also required for use of the land on which the tailings disposal facility will be constructed. Information on the Territorial Lands Act can be obtained from INAC.

A proponent is advised that it may be necessary to consider the requirements for project design at the EARP stage. While this may not be necessary if a proponent has a flexible time schedule, the Board cautions proponents that all design requirements for tailings facilities must be in place before a licence to use water and dispose of wastes will be granted. Proponents are also advised that, where a mine is to be located on Commissioner's Land, land use approvals will be required under the Commissioner's Land Act instead of under the Territorial Lands Act. Where a mine is to be located within the boundary of a municipality, the proponent should address the requirements of any by-laws which deal with land use within the community.

2.0 The North: A Unique Environment

The northern regions of the world, and the Northwest Territories in particular, constitute a unique environment from many perspectives. It is certainly a special environment when viewed in geological and engineering terms as they apply to the design, operation and abandonment of tailings disposal facilities. While a proponent may feel that his experience elsewhere will allow him to safely undertake a tailing facility design, he will find that the northern environment invokes its own rules. A major theme of these guidelines is to offer comment on the unique aspects of northern conditions. While the northern environment establishes its own rules, a complementary fact is that unique solutions may also be available.

2.1 Climate

The major climatic features of the north are the long cold winter period and the extremes of winter and summer temperatures. There is a substantial imbalance between the long winter period and the short summer which results in the formation of frozen ground. Many portions of the NWT, and especially the high Arctic, are exceedingly arid with evaporation or sublimation of surface water or snow being considerably in excess of precipitation. In addition, high winds can be expected in many areas. Reviews of the climate and weather of the NWT, written from an engineering perspective, can be found in Brown (1970) and Johnston (1981).

2.2 Permafrost

The term "permafrost" was coined as a convenient short form of "permanently frozen ground". It is a term used to describe the thermal conditions of earth materials, such as soil or rock, when their temperature continuously remains below $0^{o}C$ for a number of years. Climate is a basic factor in the formation and distribution of permafrost, and observations indicate a broad relation between mean annual air temperature and ground temperature. Brown (1970) has conducted the major Canadian study on this relationship and Figure 1 provides a general delineation of the major permafrost zones of Canada.

In the continuous permafrost zone, permafrost occurs everywhere beneath the ground surface except in recently formed deposits where the climate has just begun to impose its influence. Similarly, permafrost may also form in tailings deposits. Permafrost may also be found beneath shallow lakes and small bodies of water, and may also extend offshore. In the discontinuous permafrost zone, frozen and unfrozen ground segments co-exist horizontally and even vertically. Factors governing this distribution include vegetation patterns, areas of winter snow accumulation, water flow (either surface or sub-surface), orientation of valley slopes and disturbance to the surface organic cover due to natural or man-induced changes. Altitude also affects permafrost distribution within the Cordillera Physiographic Region. (Figure 2). At higher altitudes one may encounter considerably greater frozen ground than at higher latitudes but lower elevations.

The presence of permafrost is often indicated by a variety of surface features and comprehensive classification systems are available. Brown (1970), Johnston (1981), and Washburn (1973) provide reviews of these features and they are mentioned here because they constitute an important diagnostic tool for the skilled permafrost engineer and geologist when undertaking site assessments and descriptions.

A typical ground temperature profile in permafrost is illustrated schematically in Figure 3 (which also defines several common terms). During winter months, ground temperatures reach their minimum, but with the onset of the thaw season an active layer forms. This active layer is defined by the penetration of the thaw front into the ground. In warmer permafrost, characteristic of the discontinuous permafrost zone, this active layer can be up to 3 m in depth.

2.3 Ground Ice

The presence of ice as a major stratigraphic component of permafrost soil or rock gives rise to its unique properties. The normally rock-like qualities and relatively high strength of permafrost are primarily due to the cementing action of ice. Ice can be present in permafrost ranging from minor coatings or films to massive distributions where the volume of ice may be many times that of the soil volume. It is generally true that the finer-grained silty and clay soils contain more ice and that coarser-grained soils tend to be less ice-rich. However, even this generalization can have important exceptions and the presence or absence of ground ice, even in bedrock formations, may have to be confirmed by appropriate site investigation if it is an issue critical to design.

While ground ice in some form is generally present below O°C, certain exceptions exist. While these may not typically be of concern in a mining venture, it is noted that very fine grained clay soils or bedrock near, but below, O°C may be largely unfrozen (that is with no ice) due to physical-chemical factors. The same condition can be found in saline permafrost.

2.4 Permafrost Thawing

Permafrost thawing, or degradation, can be initiated by a wide range of processes such as forest fires, increased snow accumulation, stripping of vegetation or construction. In warmer permafrost, the construction of a tailings dam or an access road will more than likely initiate partial or complete degradation of permafrost.

High ice content permafrost can become highly unstable when it thaws. When ice-rich permafrost thaws, the water produced by thawing cannot immediately be squeezed out through the now-thawed soil above the permafrost table. In finer-grained soils, the permeability of the thawed soil can be relatively low compared to the rate at which water is produced by the thaw front. This means that the weight of the thawed soil is now carried by the water phase and the soil is highly weakened and in the extreme has no strength whatsoever. During rapid thawing, these strength losses can be substantial and can have major impacts on the stability of any structure founded on thawing permafrost.

The second consequence of thawing permafrost is the resulting settlement. The volume contraction of ice as it thaws and the loss of volume as water is squeezed to the surface results in settlement. Because ground ice is rarely uniform, this settlement is highly variable and can have disastrous consequences for a variety of structures.

2.5 Hydrology

The presence of permafrost imposes its influence on the hydrologic regime and therefore influences surface water hydrology and groundwater. Permafrost as a geologic agent alters the hydrologic system, but until recently, knowledge of the hydrology of northern North America was exceedingly rudimentary. While methods of analysis developed in more temperate regions may apply, the data base in northern regions remains limited. Predictions require a large degree of empiricism and a conservative viewpoint is mandatory, especially for the critical components of a project.

Permafrost constitutes a permanent low-permeability layer. As a result, permafrost has a significant, but regionally and locally variable, influence on hydrologic conditions as follows:

- Permafrost, depending on active layer thickness, increases run-off coefficients. This is especially true for the spring melt period. The chief contributions to runoff come from seasonal rainfall and snowmelt and the movement of these waters by direct surface flow or by flow through the active layer. Contributions from deep groundwater circulation are usually minimal in areas of substantially continuous permafrost.
- Permafrost affects recharge to deeper aquifers even during maximum thaw penetration of the active layer.
- Permafrost affects the rates of groundwater movement. The characteristic low temperature of water in unfrozen zones in permafrost regions reduces the rate of circulation by raising the viscosity of water by a factor of approximately 1.5 relative to temperate regions.
- Permafrost influences the spatial distribution of groundwater movements such that groundwater discharge areas may be cut off or new springs initiated by the growth or degradation of permafrost.

2.6 Geology

Much of the surface of the NWT has been shaped in one fashion or another by the direct action of glacial ice. In some areas, for example the Precambrian Shield (Figure 2), the terrain consists of rock knobs interspersed with innumerable lakes and poorly drained depressions. Soil cover is generally thin or absent, and the intensive glaciation has resulted in a scarcity of suitable earth materials in many areas for constructing roads, dams, pads or other similar structures. In the Arctic archipelago, all earth materials are frozen and have to be thawed before they can be used for construction. Some areas of the archipelago have extensive frozen glaciofluvial deposits consisting of sands and gravels which are good sources of building materials. The mountainous Western Cordillera consists of ranges, plateaus and deep valleys where soils are exceedingly variable. The relief of the Interior Plains, including the Mackenzie River Valley, is rolling with isolated highlands, and soils are primarily fine-grained (such as silts and clays).

While much of the NWT is not prone to earthquake activity (particularly the Precambrian Shield), some areas of the NWT are seismically active. It has only been in recent years that adequate seismic ground motion monitoring has covered the NWT. An updated version of the possible seismic risk areas of Canada is provided by Basham et al. (1982). While this work is not yet adopted in the Canadian Seismic Code, any mine sites in close proximity to the major areas of seismic activity indicated in Figure 4 will require a seismic risk assessment appropriate to the type of tailings facility selected.

2.7 Vegetation

There is a wide range in naturally occurring vegetation or surface cover in the NWT. This can be an important source of engineering design information. Varying vegetation can reflect varying permafrost conditions as well as the likely range of effective reclamation measures. Natural variation can be extreme within a given mine site as a result of micro-climate variations such as snow cover, ground moisture, altitude, exposure to prevailing winds and thawing.

The major vegetation regions of the NWT are presented by Fremlin (1974) and shown by broad geographic zonation (Figure 5). Each of these major zones (polar desert, tundra, woodland and forest) is characterized by a general uniformity in vegetation structure and compostion which has developed in response to regional climatic, physiographic and soil conditions. Within each of these major regions, one can recognize further sub-divisions.

The polar desert, as the name implies, is a cold arid region with little precipitation. Plant cover is generally sparse with low mat-like plants such as mosses, lichens, low grass and dwarf shrubs covering less than 15% of the ground except for closed meadow vegetation in near-coastal lowland areas. Tundra vegetation ranges from low Arctic and coastal types to alpine types at higher altitudes above the tree lines of major mountain ranges. Tundra vegetation covers between 25% and 80% of the ground surface and consists of sedges, cottongrass tussocks and a variety of willows and shrubs.

The tundra region gives way to woodland at the tree line. The tree line is generally characterized by the most northerly extent of the open black spruce forest. The woodland region has a short growing season, moderate precipitation and a variety of open tree cover which is comprised primarily of spruce, alder, birch, tamarack and a shrub cover of willow found in varying soil and moisture conditions.

The southern part of the NWT is largely forested with merchantable stands of white spruce along the major river valleys of the Mackenzie, Slave and Liard. Mixed forests of aspen, white spruce and pine occupy large areas of sandy soil away from the river valleys, while in wet muskeg areas, black spruce forests dominate.

3.0 General Requirements

While these guidelines focus primarily on the technical aspects of tailings impoundments, the proponents must recognize that there are a number of environmental regulations which apply to mining operations in the Northwest Territories.

The taking of water, and its subsequent storage and discharge, is governed by the Northern Inland Waters Act, and all tailings impoundment facilities will be subject to the terms and conditions of a Water Licence. However, the Water Board recognizes that each mining operation will have its own singular characteristics and that it is therefore not possible to establish in advance fixed rules for the location, design, construction and operation of tailings impoundment systems. The Board, and other regulatory agencies, will require that the proponent submit environmental background data and engineering designs so that the potential impact of the project on the environment can be properly assessed. The type of background data, and the detail required, will vary from project to project. It is therefore important that the proponent contact the Board as early as possible so that a suitable data collection program can be established. Failure to do so could result in a delay in granting a Water Licence.

3.1 Basic Requirements

In general terms, the Water Board expects that:

- the quantity of water taken, stored and discharged will be kept to a minimum. Water recycle is encouraged and deliberate dilution of tailings effluent is not allowed;
- the proponent will present evidence that he has considered the technical and economic viability of several possible tailings disposal schemes (Section 4);
- the proponent will present background site data to demonstrate that a sufficiently detailed site selection and investigation program has been undertaken (Section 5);
- the proponent will demonstrate that, during the design process for his impoundment facilities, he has addressed the unique conditions expected in permafrost areas (Section 6);
- the construction phase will be carefully executed. Past experience has demonstrated that costly delays and unsatisfactory performance can result from well-designed but poorly-constructed facilities (Section 7);
- the proponent will submit an Operating Control Plan for the tailings facility, details on a proposed Monitoring Plan and a Contingency Plan prior to the granting of a Water Licence (Section 8); and
- the proponent will demonstrate that an Abandonment Plan to permanently contain tailings solids in an environmentally safe manner is possible at the proposed site (Section 9).

The level of detail to which these requirements must be satisfied will clearly depend upon the size and nature of the proposed facility.

3.2 Professional Qualifications

Depending on the nature of the proposed facility, the Board may (as do jurisdictions in other parts of Canada) require information on the qualifications of the Professional Engineer(s) undertaking the design studies, and may impose an independent review process. As part of its submissions, the proponent may be asked to identify the technical qualifications and applicable Arctic engineering experience of the responsible Professional Engineer(s) undertaking the design work. The Board, as part of the terms of The Water Licence, may require that the Design Engineer(s) be represented on site during construction and be responsible for ensuring that design requirements are followed by the construction forces.

Further, the Board may require, in the case of a complex facility, that the proponent have all designs reviewed by a Technical Review Board operating independently of the proponent design team, but funded by the proponent, prior to the final granting of a Licence.

The Board may also require, in special cases, that independent safety inspections, on an annual or other basis, be carried out to ensure that safe operating conditions are being maintained.

The proponent is ultimately responsible for the design, construction and operation of the tailings impoundment facility. While the Board will not act unreasonably in imposing any requirements, the quality of the work done on the project is of utmost importance to the Board.

4.0 Methods of Tailings Disposal

Tailings disposal options at a given site will be governed by site foundation conditions, availability of construction materials, allowable effluents, the availablity of coarse sizes in the tailings stream and climatic factors to name a few. The key requirements for tailings disposal are that the facility must safely contain tailings solids, must be safely operated and must be abandoned in an acceptable manner. The Board expects that the proponent's decision to elect a certain method for disposal will be reached by logical consideration of options and that the elements in this decision process will be clearly documented as part of any submissions to the Board. Before accepting any proposal for tailings disposal, the Board expects to review studies confirming that the proposal is environmentally sound and that better options do not exist.

Acceptable methods of tailings disposal have changed in recent years due to environmental concerns. Previous methods of tailings disposal were selected primarily to achieve the lowest unit cost for waste disposal, and if dams were used, such dams often had high seepage rates. Present requirements for environmental protection seek to minimize seepage, regulate effluent quality and establish acceptable levels of safety to prevent failure of the dam and spillway. Some of the possible methods are outline in the following sections.

4.1 Sand/Slime Impoundments

Conventional tailings impoundments use the coarser sand fraction of the tailings stream to construct dykes in order to retain the fine fraction or slimes. A good summary of this approach is provided in Canmet (1977). The designer has the choice of three methods: upstream, downstream or fixed centerline. The upstream method usually offers lowest unit cost but is highly vulnerable to seismic action and poor foundation conditions. The other methods may give more stable configurations, but placement costs are higher. All methods suffer from high potential seepage rates which are environmentally unacceptable. In addition, in a severe climate, drainage control becomes difficult because of deep frost penetration into the sand shell. If foundation permafrost degradation leads to thaw settlement, drainage systems can be broken and disrupted.

In permafrost environments, the conventional approach may also introduce extra heat into the dam area, thus increasing the potential for thermal degradation and setting off a chain of events leading to poor performance.

In colder areas, however, it may be possible to stage construction such that a frozen core can be incorporated into a dam built with a centerline approach. This approach is discussed in more detail in Section 6.2.

4.2 Embankment Dykes

Because of environmental and technical considerations, it may be necessary to adopt a design approach for a tailings dam essentially similar to that used for water storage dams. While there are few precedents for high water storage dams in the Canadian North, the Soviets have constructed several large dams in Siberia (Johnson et al., 1984).

The basic concept for a water storage type of tailings dam involves construction using non-tailings materials. Such a dam may have an impervious soil core and shells of waste rock. For low height dams, it may be possible to use an artificial liner for seepage control. Suitable core material is often not available, and if it is, it is usually frozen and must be pre-stripped, thawed, stockpiled, and then placed during a short summer season. A possible variant of this approach is to build a "cold" dam (see Section 6.2) with waste rock shells and a frozen impermeable core.

4.3 Use of Lakes and Sloughs

While the Board may consider the use of lakes or sloughs as tailings disposal sites, the proponent should be aware of the substantial public interest in such bodies of water. It is unacceptable to dispose of tailings solids into any river, or into any lake forming part of a water course. The Board may, however, consider the use of small shallow lakes which can be dammed and isolated from the surface water regime. Disposal in deep meromictic lakes, which have water that is permanently stratified and which do not circulate on an annual basis, can also be considered.

4.4 Thickened Tailings

In this form of tailings disposal, the tailings stream is at a sufficiently high solids-to-water ratio that the stream is non-segregating upon deposition. Such a stream has to be reduced in water content, or thickened, at the end of the milling process. Such techniques are of interest as they minimize net water demand, minimize the volume of high water content slimes that must be stored, minimize the volume of effluent and maximize water recycle. Thickened tailings flow like a viscous slurry when deposited and form moderately flat slopes. Only small dams are required to contain relatively large volumes of material, although large areas are necessary.

Drawbacks to a thickened tailings approach include process-related problems, slope instability caused by freeze/thaw weakening of the viscous slurry, control of wind erosion and solids loss during operations and on abandonment. However, if a suitable top cap or revegetation medium is available to restore the surface of the thickened tailings in order to control wind and surface erosion, a thickened tailings operation may have considerable merit.

4.5 Tailings Disposal Below Ground

Two methods of tailings disposal below ground may be considered. Disposal of all of the tailings to worked-out areas of underground mines is unlikely to be practical. However, in mines where cut and fill stoping methods are applicable, the coarse fraction of the tailings (usually 40% to 60% of the total tailings volume) may be disposed of in the underground workings. The second method is a cell system which is operated in a manner similar to a sanitary landfill. Operation of such a facility involves excavation of pits or cells in the ground, the storage of tailings in the cells and the subsequent capping of the settled and drained tailings. Difficulties with such an operation in permafrost soils include the effort required to excavate suitable pits and the stablility of such pits during the summer thaw period. Information on geothermal and geotechnical factors of sumps in permafrost as used by the oil industry is provided by French and Smith (1980). This concept is attractive if the long term objective is the freezing and essential immobilization of the tailings wastes. Disposal of tailings in excavated pits and quarries is also possible, but seepage and groundwater contamination must be considered.

4.6 Multiple Pond Systems

The proponent may wish to consider the flexibility afforded by a multiple pond disposal facility. In some operations, different water quality is produced by different ore fractions or by changes in milling processes. If all tailings are stored in one pond, a larger-than-necessary volume of water is contaminated by some substances that may not always be present. Multiple ponds also allow effluent to be polished prior to discharge. The multiple pond approach especially deserves consideration for gold mines using the cyanide extraction process.

5.0 Site Selection and Investigation Considerations

The selection of a site for tailings disposal is coupled to the type of disposal method, and for some mines, site considerations may even dictate the selection of the tailings disposal method. For example, in some parts of the NWT, suitable construction materials are in very short supply or are completely uneconomical. Haul distances to suitable borrow sources may be excessive or the construction season during which material can be stripped, thawed and placed may be impossibly short. In such cases, it may be possible to use a lake or slough for disposal. In other situations, ground ice conditions may be very poor so that it is impossible to construct and operate a safe tailings dam. In the extreme, it may be necessary to locate the mill and disposal facility at some distance from the mine area in order to arrive at an acceptable solution. The Board expects the proponent to consider all viable alternatives for disposal sites.

5.1 Site Investigation Requirements

The planning and execution of the site investigation phase of a project is often a crucial element to the overall project schedule and approval process. Given the extreme remoteness of many mining sites and the short time periods in which certain data collection activities can occur, adequate planning and scheduling of site investigation activities is important.

The requirements for a comprehensive site investigation will vary depending, for example, on permafrost conditions, soil and bedrock types and likely methods of tailings disposal. A range of possible requirments for site investigation is provided in Table 1.

In addition to the technical requirements contained in Table 1, there is a range of environmental baseline data that may be required by the Board for the area of the proposed tailings disposal facility. For example, baseline surveys of water quality, aquatic life, mammals, birds and vegetation may be requested. Such baseline data may be of great value to the Board and the proponent during the operations phase of a project in establishing actual project impacts in relation to background levels.

5.2 Methods of Site Investigation

Depending on the nature of the ground ice and soil conditions, drilling equipment suitable for ore body evaluation may be completely inappropriate for site investigation for the tailings facility. This could become a major cost issue at a remote site. Prior to undertaking any detailed geotechnical site investigation, it is advisable to first undertake a detailed aerial photographic interpretation (using stereo-photographs), followed by an on-site inspection. It is desirable that a representative of the design team be involved at this early stage.

For small facilities and low head dams, excavation of test pits can form the basis of an adequate field investigation program. For major structures in sensitive terrain, it may be necessary to use specialized drilling equipment to obtain frozen core samples and to maintain such cores in a frozen condition until they can be shipped to a permafrost testing laboratory. There are special core barrels which can cut frozen soil core. Alternatively, rotary rigs with chilled circulation fluid may be considered.

Mapping of permafrost distribution in discontinuous permafrost terrain can be economically and effectively enhanced by geophysical techniques, especially resistivity surveys. Near-surface mineralization may influence resistivity surveys. Resistivity surveys have been used with great success in the NWT in mapping frozen versus unfrozen zones and giving insight into permafrost depth. When used in conjunction with borehole data, resistivity surveys can build up a rapid and comprehensive picture of site conditions.

5.3 Site Selection Factors

There are many factors that need to be balanced in the selection of a site for a tailings storage facility. Often, however, there are few choices and the facility must be designed to accommodate the available site.

Clearly, the site must have sufficient volume capability to handle the tailings generated during the expected mine life. The proponent should note that any increases in size of the facility over that approved in the Water Licence may require an amendment to the Licence. Depending on the size of any required additions, and especially if these are the result of changes in process technology, additional studies may be required before an amendment to the Water Licence can be issued.

Foundation stability is a major technical issue for a tailings dam. If the proponent proposes a warm dam (see Section 6.2), then a search for unfrozen terrain is indicated. Conversely, if the cold approach is to be considered, site selection would clearly favour a location with primarily frozen foundations.

Site selection should also consider the nature of the underlying bedrock, if it is near surface. In the western portions of the Cordillera, weak bedrocks of Cretaceous age, such as clay shales, may introduce weak elements into the foundation. In addition, such bedrocks may weaken upon thawing. Karstic limestones exist in the NWT and special caution is required for tailings facilities located in such areas.

If a tailings facility is unavoidably located near an active water course, it may be necessary to undertake a hydraulic investigation of the stream or river channel to ensure that river migration and flooding will not undermine or erode the facility. Complex drainage areas should be avoided. Where appropriate, diversion ditches should be provided for run-off in order to minimize water storage requirements.

Environmental factors will also have to be considered when choosing the location for a tailings storage facility. The sensitivity of both the land and water environments must be addressed.

6.0 Design of Impoundment Facilities

Design analyses by a qualified Professional Engineer on the stability of the proposed site and structure will almost certainly be required by the Board. This section reviews the range of details that may be required and which should be considered by the proponent. These guidelines have concentrated on design issues viewed as being unique to cold regions. This is not to say that conventional issues are less important, but as they are more generally understood, they are presented here in less detail.

6.1 Permafrost Engineering

In recent years, there have been substantial advances made by the engineering profession in the understanding of permafrost, and major text books have been published (see Andersland and Anderson (1978) and Johnston (1981)). Major aspects of this technology which may be of value to a proponent are contained in the following sections.

6.1.1 Geothermal Analysis

Geothermal analysis permits the prediction of ground temperature regimes beneath and within a tailings dam, and the interaction of the pond contents with the dam, foundations and flanks of the reservoir. Geothermal analyses offer substantial insight into the likely performance of site facilities, especially when site-specific data such as temperature, snow cover and ground temperatures are available.

A variety of simple analytical techniques are available for first order predictions. For more complicated two and three dimensional studies, computer models are available which can simulate complex conditions and non-linear material properties. The models can be used to predict likely ground temperatures, rates of thaw and rates of freezing due to frost penetration of fills. Models primarily handle conductive heat flow, but some also handle convective heat flow due to flowing ground water. Convective heat flow can be a major problem for dams in permafrost.

6.1.2 Thaw Settlement and Consolidation

When permafrost soils thaw, the strength of the thawed earth material is severely weakened and settlement can be expected. High ice content permafrost definitely will settle upon thaw. If settlement occurs underneath a major impoundment structure, it can lead to differential movements within the structure, cracking of the dam and subsequent internal erosion followed by breaching of the dam. Even low ice content soils may settle somewhat upon thawing as the full weight of the imposed structure causes the thawed soil to further consolidate. Even a sample of unfrozen soil will undergo irreversible deformations when it is first frozen, and then thawed, under a fixed applied load.

Thawed soil is weaker than frozen soil and certain permafrost soils are even weaker when they are actively thawing than when they are completely thawed. In ice-rich, finer-grained permafrost, the rate at which water is produced at the thaw front as it advances into the soil is greater than the rate at which it can be squeezed out of the soil. This phenomenon can be modeled analytically and quantitative predictions of the degree of soil weakening made. A summary of this phenomenon is provided by Johnson et al. (1984).

6.1.3 Slope Stability

There is a unique range of slope failure mechanisms in permafrost soils which may have particular relevance to the stability of any tailings dam, its abutments and the flanks of the reservoir or tailings pond. A classification of slope failure types has been developed by McRoberts and Morgenstern (1974). These failure mechanisms are primarily associated with the weakening of soil which occurs during the actual thawing process. Technically, what occurs is that porewater fluid in the soil void (piezometric pressure) is increased by the thawing process. This pressure can exceed normal hydrostatic pressures and, in a sense, can be considered artesian in that the pressure head at the thaw interface rises above the ground surface. This high pore pressure will reduce soil shear strength in terms of effective stress concepts. The technical basis for this mechanism is presented by Johnson et al. (1984) and McRoberts (1978). There is considerable field evidence for this thaw weakening process, both in the permafrost areas of the NWT and elsewhere, as well as in the fossil records of periglacial phenomena in Northern Europe.

6.1.4 Frozen Strength

The strength of frozen soil or ice is highly time-dependent. In the extreme, the strength of frozen soil approaches that of the same soil in an unfrozen state. Frozen soil has high strength if rapidly loaded to failure, but under sustained loads, frozen soil can creep, resulting in considerable deformation. Field research in the NWT has shown that in some cases, natural slope failures of steep, high banks have taken place in ice-rich permafrost soils (McRoberts, 1978). In foundation designs for piles in permafrost, the frozen bond strengths which govern the pile designs are low compared with the rapid or instantaneous strength of frozen soil. While this issue may not be of great significance in most projects, it should not be ignored if the shear stress imposed by a structure is high and the foundation soils are ice-rich and relatively warm.

6.1.5 Frost Penetration Effects

A variety of undesirable effects may result when frost penetrates into earth materials. Some of these effects are directly due to the frost penetration, while others result from the subsequent thawing process. The cyclic nature of freeze-thaw over geologic time is a highly destructive process which has, to a large degree, shaped the land surface in the NWT, and which, over the typical design life of a mining project, can have substantial effects.

When frost penetrates into the ground, whether it is fill material or underlying natural deposits, water contained in the soil pores will move. Typically, in finer-grained silty or clay soils, water is attracted to the vicinity of the freezing front by capillary forces, and ice lenses form. Such soils are generally described as being frost-susceptible and the ice lenses formed are referred to as segregational ice. In coarse-grained, relatively clean sands or gravels, pore water undergoes a volumetric expansion when it freezes, and if the soil pores are saturated, water is expelled away from the freezing front in an open system. If water cannot escape, the fluid pressures build up. This mechanism is the cause of pingo formation in the Mackenzie River delta, and the ice bodies formed are called injection ice. In a tailings dam where the shell material is built out of the relatively coarse fraction of the tailing stream, a similar effect can occur. Alternatively, and depending on fines content in the sands, the sands may be frost-susceptible and sustain segregational ice lensing.

When segregational ice lensing occurs, substantial frost heaving results. This frost heaving imposes a loading on buried structures such as decant lines, low level outlets or similar pipelines. Pile structures supporting pipelines may be jacked out of the ground. Spillway structures and control weirs are particularly susceptible to damage by frost heaving.

When frost penetrates into the ground, the segregational ice lensing process creates a soil fabric. When the soil is thawed, the permeability or hydraulic conductivity of the thawed soil can be increased by 10 to 100 times. This effect is especially critical in dam core construction, particularly in silty soils or in the construction of clay liners. Good cores or liner material placed to tight specifications will exhibit low hydraulic conductivity, but if such soil is allowed to freeze-thaw, the entire effort may be wasted.

Frost penetration on the saturated downstream slope of a tailings dam, which results in segregational ice lensing, leads to thaw weakening as discussed in Sections 6.1.2 and 6.1.3. Shallow slope failures can result. Frost penetration which intercepts large seepage rates can lead to dramatic pressure build-ups and the blow-off of slabs of frozen soil or the build-up of surface icings.

Freeze-thaw cycles can also cause dramatic disaggregation of porous rocks due to the volumetric expansion of water-saturated voids.

6.2 Fundmental Design Choice: Warm vs Cold Dams

In the warmer discontinuous permafrost zone, the dam designer is faced with constructing a tailings dam during summer months and taking design precautions against severe winter frost penetration into the core, the downstream section and associated facilities. If the dam is located over a permafrost foundation, the designer will have to account for the implications of foundation settlement and thaw weakening on the stability and integrity of the structure. Such a dam might be called a warm dam as compared to a cold dam in which the designer relies on just the opposite effects. A cold dam may be viable in the colder areas of the NWT where the permafrost zone is continuous. Whichever alternative is selected, the choice must be explicit and the full implications of the design decision investigated and substantiated.

6.2.1 Cold or Frozen Dams

The concept behind a cold or frozen dam has been used with success for water supply and hydroelectric dams in the Soviet Union (Johnson et al., 1984). There are a variety of technical reasons why such a method of construction would be economical and viable in Canada. A listing of some dams constructed for water storage purposes in permafrost regions is provided in Table 2 (A). A similar list of tailings dams in the NWT is provided in Table 2(B). The major experience with construction of cold frozen dams is in the Soviet Union. Dams from 8 m to 20 m high have been operated in a frozen condition. In some cases, artificial chilling has been used to establish permafrost within the dam.

There are potential advantages to a cold dam. Virtually any construction material is conceivable; one might even consider an ice core (Tsytovich, 1973). There are clear advantages in the length of construction season as cold dams are best constructed during winter months, although summer construction is also possible as long as summer fill is allowed to freeze the following winter. Establishing permafrost in the core, downstream section and foundation will give substantial foundation and seepage integrity as ice saturated voids will be essentially impermeable. In seismic areas, liquefaction susceptibility will be eliminated.

In addition to the unproven aspects of cold tailings dam construction in Canada, there are several other disadvantages. The possibility of freezing point depression of process-contaminated water could make the freezing of a seepage stream, should it occur, more difficult to accomplish. Heat from the tailings in the pond could make it more difficult to establish or maintain frozen conditions. Finally, the interactions between a frozen dam and any spillway or decant structure which necessarily passes "warm" water may require relatively costly solutions.

6.2.2 Warm or Unfrozen Dams

A warm or unfrozen dam is technically no different than a conventional dam in a more temperate region of Canada, although the designer will have to allow for more severe winter frost penetration and for potential settlement of the foundations due to permafrost thawing. Frost penetration may be such that permafrost actually forms in the structure. Generally speaking, this will have positive effects, but unless it is actually anticipated (and then a cold dam is being constructed), the dam must be designed to safely function through a number of freeze-thaw cycles. It is cautioned that extreme frost penetration into a dam designed on a warm basis may have adverse effects.

In warm dam design, there are two basic choices: should the dam be essentially impervious; or is substantial seepage allowed and controlled by design measures?

An impervious tailings dam is desirable in order to minimize effluent discharge through the structure. Such a design approach requires either finer-grained impermeable soil in the dam section, a well compacted core or some form of artificial liner. If the dam can be placed on stable low ice-content soil or rock foundations, such a design solution should give good performance. If, however, substantial thawing of ice-rich permafrost is generated by the operation of the dam, settlements and thaw weakening will result. The settlements that result will not likely be uniform, and the differential movements will impose stress changes in the tailings dam, making it vulnerable to cracking and subsequent internal erosion (more commonly known as piping). This process is a major cause of failure in water supply dams and design solutions are available. Solutions generally require graded filters behind or downflow of the impervious element in order to seal cracks and contain leakage.

A pervious dam may be acceptable depending on effluent quality. Conventional tailings dams constructed out of the coarse tailings fraction and retaining the fine portion of the tailings stream (or slimes) are usually pervious. For such a dam, seepage is expected and controlled by design measures and usually has to be collected and returned to the pond. Positive design measures may be required to ensure that frost penetration or permafrost aggradation does not interfere with seepage control.

6.3 Design Issues and Analyses

Design analyses by a qualified Professional Engineer on the suitability of the proposed site and the stability of any tailings dams will be required by the Board. The analyses should consider a range of issues as listed in Table 3, and any other aspects of the design which are unique to the facility.

7.0 Construction

All too often, well thought-out and comprehensive designs are poorly executed during the construction phase. The Board can, and will, take steps to ensure that a satisfactory level of supervisory control is in place during construction, and that the facilities are constructed to specifications. Major design changes, both during the construction phase and subsequent to it, will require Board approval.

It is recognized that design changes may be required because of changing field conditions, and that the ability to react to changing field conditions with appropriate design measures is an important step in ensuring a safe structure. Such field design changes, however, must be approved by a Professional Engineer. Moreover, the design team, whether it is in-house or a design consultant, should be represented on site throughout construction to ensure that design requirements are followed by the contractor. If deemed necessary, the Board may require copies of progress reports and an as-built report as a condition of the Water Licence. After the initial construction phase, and if the operator is continually raising the dam, the Board may require progress reports or amendments to the Licence.

In planning the construction phase of a tailings disposal facility, there are many factors that require consideration. Some of these issues are closely coupled with the design phase. Three factors which the Board suggests may require consideration are detailed in the following Sections.

7.1 Timing Constraints

If a warm dam is being constructed, the short summer season will limit the time available for construction. Prestripping, thawing and drainage of construction materials will have to be planned in advance of the construction season. Construction materials may be in short supply or may only be transportable to the site during winter months on snow or ice roads. Clearly, advance planning and preparation is more critical than in the case of southern operations. Construction timing may also be affected by such environmental constraints as fish migration or spawning activities, caribou migration and bird nesting.

Sites may often be exceedingly remote with the result that heavy equipment cannot be moved by air freight. In such circumstances, some combination of barging and winter roads may be required. Specialized items of heavy equipment which may only be needed for 4 to 8 weeks of actual construction may be tied up for an extended period. It is therefore important that transportation activities by properly planned.

7.2 Terrain Sensitivity and Site Access

While the short summer season is often the only time of year that certain work can be undertaken, summer thaw may render the ground impassable. The active layer at a site is often ice-rich and cross country travel by vehicle is impossible. In addition, the resulting surface disturbance is environmentally unacceptable. Thermal disturbance, once initiated, is often difficult to stop, and extreme care must be taken in avoiding such disturbance. Attention should also be given to taking full advantage of natural drainage patterns. The use of conventional ditches can aggravate thermal degradation by exposing permafrost in ditch walls.

Construction and operation of roads and work pads, especially in warmer permafrost, requires close attention to preservation of the underlying permafrost. Temperate region construction practice calls for pre-stripping of all organics and vegetation prior to fill placement. In permafrost situations, it is usually desirable for geothermal reasons to leave this insulation layer in place. The manner in which snow clearing proceeds can influence road stability. Clearing snow off road surfaces helps preserve permafrost, but allowing thick snow layers to accumulate on road shoulders promotes permafrost thawing in the shoulders. Roads which have performed satisfactorily with frequent snow clearing may begin to break up if they are abandoned for one or more winter seasons and significant snow accumulates on the road surface. In the more northerly areas of the discontinuous permafrost zone, a thick road fill of 3 to 5 m may hold the permafrost. In the very warm discontinuous zone, construction of a road will invariably cause permafrost degradation, no matter what fill thickness and snow clearing methods are adopted.

7.3 Cold Weather Dam Construction

While site access is made easy during winter months, the construction of earthworks which require adherence to density or compaction control specifications is essentially impossible. Depending, however, upon borrow types and the type of dam (i.e. warm vs. cold), the dam design can be modified to suit cold weather construction. Dry fill material with low ice content, or waste rock from the mining operation, can be placed during winter months as long as the design accommodates the resulting potential settlements.

8.0 Operating Control

As part of the Water Licence, the Board will stipulate the level of operating control it deems necessary. The proponent should therefore submit to the Board a proposed Operating Control Plan. The Licence is issued stipulating a yearly quantity and rate of water use and the allowable discharge of the water used. This gives the mining company the right to alter, divert and use this water subject to the terms and conditions specified in the Licence. Once granted, the terms of the Licence cannot be changed without reopening the regulatory process except as permitted by the conditions applying to modifications contained in the Licence.

All personnel involved in operating the tailings disposal facility must be aware of the design limitations imposed on the facility and must be familiar with the terms and conditions of the Licence. Some mine and process operating parameters which are often coupled directly to the operation of the tailings disposal facility are provided in Table 4.

8.1 Operating Manual

An Operating Control Plan is required, and for large and complicated impoundments, a detailed Operations Manual may be necessary.

8.2 Monitoring Plan

Depending on the size of the tailings disposal area and the tailings dams, the sensitivity of the surrounding environment and the consequences of failure, a range of instrumentation may be required. The monitoring plan must be tailored to provide performance data on critical factors relating to the safety and stability of the structure. Such critical factors should be identified by the designer of the facility, and it is important that performance data be reviewed by a qualified Professional Engineer.

Performance monitoring should begin with visual inspections of the facility on a regular basis. In view of the significant staff turnover often encountered in remote locations, the mining company would be well advised to maintain a photographic record of the major features of the facility, updated on at least an annual basis. Such records, which should be kept at the mine site, are often invaluable in establishing long-term trends. Instrumentation monitoring may be required. Such monitoring should be reviewed and assessed on a regular basis, and performance projections should be made of any significant trends and their possible impact upon the stability and integrity of the facility.

Inspection of man-made structures should be undertaken in detail on a regular basis. Daily inspections of the tailings lines and general dam area are recommended. Mine personnel making the inspections must be aware of the design criteria used for the tailings dam in order to determine whether the facility is being operated properly. For example, the location of the pool relative to the dam, the depth of the pool, the expected rate of rise, the minimum allowable freeboard, the discharge rates during the decant season and the ultimate capacity of the structure should all be considered. In addition, the operator making the inspection must be aware of the terms and conditions of the Licence.

Overtopping of tailings dams is the most serious and potentially catastrophic cause of failure. Inspection frequency must be increased during periods of high pool level or during above-normal periods of precipitation or spring run-off. Immediate inspection is required following any seismic activity.

A summary of possible check points for tailings dams inspection is provided in Table 5.

8.3 General Contingency Plan

The Licence will require that the mining company have a General Contingency Plan for the mining operation approved by the Board. This Plan must include the tailings impoundment function. The level of detail required in the Plan will vary according to the environmental implications of failure, the size of the impoundment and various other factors. The Licence will also require a regular review of the Plan (usually annually) and modifications to the Plan, as necessary, to reflect changes in performance, operations, technology, etc. The proponent will also be required to provide Oil Spill and Hazardous Materials Contingency Plans.

8.4 Performance Report

A performance report on the stability of the dams and related works may be required by the Board. Such reports will usually be on an annual basis. Items that may be required in the report include, but are not limited to:

- assessment and interpretation of all quantitative data and performance projection of trends;
- any indication of adverse performance based on visual inspections (e.g. seepage, cracking, surface slumping) and corrective action taken;
- assessment of the present stability of all structures and future stability as indicated by trends;
- construction details if the dam has been raised during the reporting period;
- measured freeboard and projected freeboard allowing for extreme storm events and anticipated construction; and
- Water/mass balance for the reporting period.

In addition, performance reporting of the quantity and quality of effluent will be required as stipulated in the Licence.

As a condition of the Licence, the Board may also require the Licensee to commission a safety inspection by a qualified independent expert.

9.0 Abandonment and Restoration Plans

As part of the Licence, the licensee will be required to submit a plan for abandonment and restoration. In sensitive environmental areas, and for large impoundments of toxic tailings waste, the Board may require a detailed Abandonment and Restoration Plan prior to the granting of a Water Licence. The Board may also require a Maintenance Plan for the facility during periods of temporary closure. The objective of the Abandonment and Restoration Plan is to ensure that the tailings facility can be safely abandoned with minimum environmental impact. It is obvious that some types of tailings impoundments offer good operational solutions in terms of economy and ease of operation, but such facilities can be very difficult or expensive to abandon. The regulatory requirements for abandonment must therefore be considered at an early stage in the design process.

The major issue for abandonment or closure is the physical integrity of the site. All mechanisms which can lead to failure or unsatisfactory performance must be assessed.

Abandonment and restoration is an on-going process and cannot be left to the end of the project. For example, restoration work may begin early in the project when organic topsoil is stripped and stored for revegetation programs. The Board may require that the Abandonment and Restoration Plan be reviewed annually and modified as necessary to reflect any ongoing research studies or changes in operations and technology.

9.1 Technical Issues for Abandonment and Restoration

Surface erosion by wind, snow melt and precipitation can, in the long term, lead to removal of solids from the tailings dam or impoundment area. In addition, severe erosion can lead to gullying, focusing of runoff and in the extreme, the breaching of a tailings dyke and the release of the stored tailings.

Revegetation of the downstream slope of a tailings dam offers a good reclamation option and is viable, with the appropriate plant species selection, in much of the NWT. Items to be considered include the following:

— the climate of the area, and potential for revegetation must be considered. Revegetation is impractical in the tundra and polar desert zones of the Arctic archipelago, but is often possible in regions to the south;

— the reclamation goals must be identified so that the appropriate measures can be chosen (e.g. planting grasses for soil stabilization, planting shrubs and grasses to regenerate wildlife habitat);

— if the tailings are chemically unsuitable for sustaining plant growth, other capping methods should be considered;

— if the tailings are suitable for the growth of vegetation, proper preparation of the surface will be required, (e.g. application of soil, peat, lime, fertilizer);

— to minimize erosion and maximize the benefits from precipitation, it may be necessary to recontour the tailings surface; and

— if the tailings surface is compacted, it may be necessary to carry out ripping prior to undertaking any revegetation measures.

Successful revegetation requires the selection of suitable plant species. Combinations of grasses and legumes are available which are capable of providing short term cover for erosion control and long-lived plant cover for stability. Where reclamation goals include enhancement of wildlife habitat, shrubs and specialized grasses should be included in the specifications. Specialized fertilizers may also be required when revegetating tailings sand to establish and maintain a plant cover. A qualified reclamation biologist can formulate specific seed mixtures and planting programs adapted to the soil and climatic conditions of the site.

The long term geotechnical stability of the structures must be considered. If permafrost degradation or aggradation is not anticipated to reach a stable configuration over the life of any tailings impoundment, longer-term implications must be assessed.

If a tailings dam is located in an earthquake zone, and will remain unfrozen after abandonment, the period over which ground motion design parameters are established should be commensurate with the time required for natural stabilization and consolidation of tailings pond solids.

9.2 Pond Abandonment

In some instances, it may be possible to drain the pond, place a surface cap or cover over the tailings solids, and promote permafrost aggradation into the tailings solids. For such a plan, surface erosion factors and revegetation options will also require consideration.

For large catchment areas, and where a pond cannot be drained, substantial runoff in excess of evaporation may collect behind the pond. Such impoundments may require a permanent spillway designed to appropriate standards.

9.3 Final Abandonment Report

Prior to final abandonment, the Board will require a Final Abandonment Report outlining the proposed post-operational maintenance of all dams, impoundments and spillway works. The proposed monitoring programs must be described. This report must assure the Board that the impoundment will remain secure.

10.0 Relevant Acts

Tailings impoundment facilities in the Northwest Territories are subject to a number of statutes. At the time of publishing these Guidelines, the primary Acts and Regulations were those listed below. However, it is incumbent upon the proponent to ensure compliance with all pertinent legislation

Relevant Acts and Regulations

FEDERAL

Northern Inland Waters Act and Regulations
Fisheries Act and Regulations
Territorial Lands Act and Regulations

TERRITORIAL

Mining Safety Act and Regulations
Environmental Protection Act and Regulations
Commissioner's Land Act and Regulations

Assistance may be obtained from the Water Resources Branch, Department of Indian Affairs and Northern Development, Yellowknife; the Chief Mining Engineer, Department of Government Services, Government of the Northwest Territories, Yellowknife; and the NWT Water Board, Yellowknife.

11.0 References

Andersland O.B. and Anderson D.M. (ed.) 1978, ''Geotechnical Engineering for Cold Regions'', McGraw Hill, New York.

Basham P.W., Weichert D.H., Anglin F.M., and Barry M.J., 1982, ''New Probabilistic Strong Seismic Ground Motion maps of Canada'' Earth Physics Branch, Energy Mines and Resources (Open File Number 82-33) Ottawa.

Brown, R.J.E., 1970 ''Permafrost in Canada'' University of Toronto Press.

Canmet, 1977, Chapter 9, Waste Embankments of Pit Slope Manual. Canmet Report 77-01, Catalogue No. M38-14/g, Energy Mines and Resources, Ottawa, Ontario.

French H. and Smith M. 1980, Sump Series 2 — Geothermal Disturbance in Permafrost Terrain Adjacent to Arctic Oil and Gas Wellsites. Catalogue No. 71-19/14-1980 E, Environmental Series No. 14, DIAND, Ottawa, Ontario.

Fremlin, G. (ed.) 1974. The National Atlas of Canada. Department Energy Mines and Resources, Ottawa, Ontario.

Johnson T.C., McRoberts E.C., and Nixon J.F., 1984, ''Design Implications of Subsoil Thawing'' in ''Frost Action and Its Control'' ASCE Tech Council on Cold Regions Engineering Monograph Berg R.C. and Wright E.A. (ed.) ASCE New York.

Johnston, G.H. (ed.) 1981 ''Permafrost, Engineering Design and Construction, J. Wiley and Sons.

McRoberts, E.C. 1978 ''Slope Stability in Cold Regions'' in ''Geotechnical Engineering for Cold Regions'' Andersland O.B. and Anderson D.M. (ed.) McGraw Hill, New York.

McRoberts, E.C. and Morgenstern N.R. 1974 ''The Stability of Thawing Slopes'' Canadian Geotechnical Journal Vol. II, No. 4, p. 447-469.

McRoberts, E.C. 1985, Draft Guidelines for Tailings Impoundment; Project EG-05990, Hardy Associates (1978) Ltd., Edmonton, Alberta.

12.0 TABLES

TABLE 1
Site Investigation Requirements for Tailings Dam

Topography

— Topographic map covering tailings area

— In detail sufficient to locate boreholes and test pits and undertake volumetric calculations for tailings storage

Geology

— Bedrock geology, structural features, jointing, presence of weak members in sedimentary rocks, bentonitic layers, gouge zones

— Surficial geology, soil types, terrain classification mapping if appropriate

— Identification of features such as previous landslide activity, thermokarst, karst activity in limestone areas

Earthquake Risk

— If area is potentially seismic, and depending on size of dam and method of construction, it may be necessary to undertake a seismic analysis

Geotechnical Aspects of Tailings Area

— Boreholes, descriptions of frozen cores if permafrost encountered

— Permafrost conditions and distribution, range of ground ice types expected in foundations, abutments and reservoir

— Results of specialized testing on cores or in situ testing such as strength, thaw strain, creep, permeability

Climate

— At early stage of site investigation process, proponent is encouraged to install ground temperature measurement devices in boreholes. Data can be very useful in later design stage geothermal analyses

— Consider installation of meteorological station, especially for remote locations where climatic data can only be estimated by extrapolation over large distances

Construction Materials

— If borrow material required for tailings dam construction, require comprehensive delineation of soil types and ice contents of borrow

— Delineation of borrow critical for impervious soil for dam core or seals

— Influence of freeze-thaw cycle on durability of exposed rip-rap, etc.

— If mine waste rock to be used for dam construction, delineate rock types, expected properties.

Hydrology

— Delineation of catchment areas, distribution of precipitation, runoff, stream flows, evaporation

— Investigation of groundwater regime

— Assessment of groundwater conditions and unfrozen zones in permafrost areas

Ore Alienation

— Wise to confirm that no ore alienated by proposed tailings facility

TABLE 2(A)
Water Storage Dams in Permafrost Regions

Canadian Dams

In Canada, experience is primarily with smaller thawed dams in discontinuous zones.

Name	Height	Description
KELSEY DYKES	6 m	Clay fills or sand section
KETTLE	9 m	Sand fill on sand drains
LONG SPRUCE	11 m	Sand fill on sand drains
SNARE RAPIDS	20 m	Earth dam with impervious clay core
SNARE FALLS	20 m	Earth dam with impervious clay core
SNARE FORKS	16 m	Earth dam with impervious clay core
TWIN GORGES	17 m	Earth dam with impervious clay core
NONACHO LAKE	8 m	Rock fill dam
		Other Dams
BARROW, AK	4 m	Frozen sandy gravel
CRESCENT LAKE THULE GREENLAND	6 m	Till fill frozen
HESS CREEK, AK	24 m	Hydraulic fill, artificial freezing
		Soviet Dams
PETROVSK DAM	9.5 m	Built 1792 winter construction. In 1929 accidentally thawed out
DOLGAIA DAM	10.0 m	Built 1943 with artificial cooling and timber shading on downstream slope
ANADYR DAM	8.5 m	Existing frozen; planned extension to 16 m. Summer core placement. Planning on artificial chilling using vapour/liquid thermopiles
IRELYAKH DAM	20 m	Core chilled with cold air
VILYUI DAM	74 m	Sloping core, rockfill shells built as warm dam. Grouting gallery to grout foundation in successive increments as foundation thawed. Convection in rockfill caused dramatic and unexpected chilling of downstream shell
KOLYMA DAM	126 m	Vertical core. Conventional warm dam section. Gravel mantle on rockfill to prevent convection

TABLE 2(B)
Examples of Tailings Dams Located in the N.W.T.

Mine	Height	Description
SALMITA MINE	2.5 m	Sand and gravel with fine mill tailings liner. Foundation glacial till and rock debris. Continuous permafrost.
CULLATON LAKE MINE	5 m	Compacted sand and mine rock on frozen soil and rock foundation. Hypalon liner on felt fabric. Continuous permafrost region.
PINE POINT MINE	12 m	Silt, sand and gravel on sand and gravel foundation. Discontinuous permafrost conditions.
LUPIN MINE	11.5 m	Silty-sand on glacial till and rock foundation. PVC liner. Continuous permafrost region.
GIANT MINE (NO. 11 DAM)	18 m	Rockfill, clay core, sand and gravel filter zone. Foundation mainly bedrock. Discontinuous permafrost.
CANADA TUNGSTEN MINE	13.5 m	Silt, sand and gravel starter dyke. Coarse tailings beached upstream side. Foundation alluvial gravels. Discontinuous permafrost.
NANISIVIK (WEST TWIN LAKE)	2 m	Earth and rockfill, impervious liner. Glacial till and rock debris foundation. Discontinuous permafrost.
CON MINE (DAM NO. 2)	3 m	Reinforced concrete with buttresses at 3 m O.C. Bedrock foundation.
CON MINE (DAM NO. 4)	7 m	Waste rock cover over filter cloth over tailings/clay core. Tailings foundation. Sheet piling driven to bedrock along central part of dam.

TABLE 3
Typical Design Information and Issues for Tailings Dam

Mass/Water Balance Information

— Drainage area into and beyond pond

— Storage volume/elevation rating curve

— Bulking factors of tailings and slimes

— Details of stage construciton requirements

— Details of pond sizing analyses

— Water balance including operational water, recycle water, sewage water, runoff, mine water, evaporation, sewage, tailings solids and water entrained in the solids, snow drifting

— Impact of summer-only effluent discharge

— Impact of winter ice or permanent ice entrapment in pond on storage volumes

— Consideration of under ice tailings injection to prevent buildup of frozen non-settled tailings solids

Typical Cross Sections

— Type of construction method (i.e. upstream, downstream, centreline)

— Size of starter dykes

— Time-elevation sequencing if staged construction adopted

— Embankment slopes and dimensions

— Position, dimensions and materials of any core or cut off wall

— Provision for internal drainage seepage control, internal erosion control, filter zones

— Nature and dimension of slope protection

— Specifications for the engineering properties of all material, filter zones, etc.

— Details of abutment treatment

— Freeboard protections for windset, wave uprush

— Details of foundation conditions

Hydropology and Groundwater Analyses

— Details of surface and subsurface water conditions

— Diversion of water courses, storm run-off and snow melt

— River engineering factors if major water courses present below toe of dam

— Details of sub or intra permafrost ground water flow

— Possible reservoir leakage rates if thaw affects foundation hydraulic conductivity

— Effect of ice build up in pond, ice rafting, ice push on decant structures, etc.

Stability Analyses

— Factor of safety of critical sections supported by design analyses. Thaw weakening factors in permafrost

— Allowance for seismic factors, liquefaction potential assessment

— Stability of abutments

— Stability of pond flanks, wave erosion, thermo-karsting

— Back up data as appropriate for soil strength, prediction of phreatic surface, geothermal analyses, etc.

Centreline Profile of Dam

— Final crest elevation

— Time-elevation sequence of crest elevations and starter dykes

— Natural ground surface, stratigraphy

— Probable depth of foundation preparation, cut-off depth for clay core

— Location and dimension of any conduit outlets through the dam

Seepage and Effluent Control Details

— Through dam decants permissible but not with poor foundation conditions

— Seepage interception, collection and return systems

— Design detail for spillway, effluent quantity monitoring weir or decant pipes

— Impact of ice buildup on control structures

- Spillways: Consider permanent and emergency requirements, interaction with permafrost, geothermal aspects

Sufficient Instrumentation Details Must be Proposed

- Monitoring of settlement if critical
- Monitoring of pore pressure, phreatic line
- Monitoring of ground temperatures
- Monitoring of foundation stability using slope indicators
- Monitoring of the chemical quality and volume of effluent at controlled discharge point, and possibly sub-surface water, will be required but the details will be contained in the Water Licence

TABLE 4
Mine and Process Factors Which Influence Tailings Disposal

- Lead times for regulatory approval for increased storage capacity may be considerable
- Increases in process tonnage cannot be made without consideration of present and ultimate capacity of tailings system
- The tailings disposal area must only handle wastes authorized by the Licence
- Changes in mill water balance that result in increase in storage water may exceed pond liquid storage. Storage of mine drainage water must be carefully monitored
- Tailings solids storage increases if mine backfill delayed or modified
- Prolonged shutdowns may interfere with tailings dam construction using mine or process wastes, but spring runoff, precipitation, and mine dewatering still require storage. Need safety factor, and from operations viewpoint, freeboard greater than design minimum is desirable
- Changing ore grades not accounted for in initial tailings pond sizing influence pond filling schedule
- Gross increases in liquid storage use can result if excess water used to counter freezing problems in water supply and waste water systems not accounted for. Especially critical during shut-downs as water consumed unrelated to milled tonnage
- Increased mill grind fineness may decrease coarse sand fraction available for dam construction, increase storage requirements, and increase bulking factor requiring higher unit storage per ton of ore
- Operation of an add-on backfill system using fresh water can have a serious effect on pond volumes if mine water must be stored in tailings disposal facility
- If additional solids used for mine backfill, material available for dam construction decrease

TABLE 5
Checkpoints for Tailings Dam Inspections

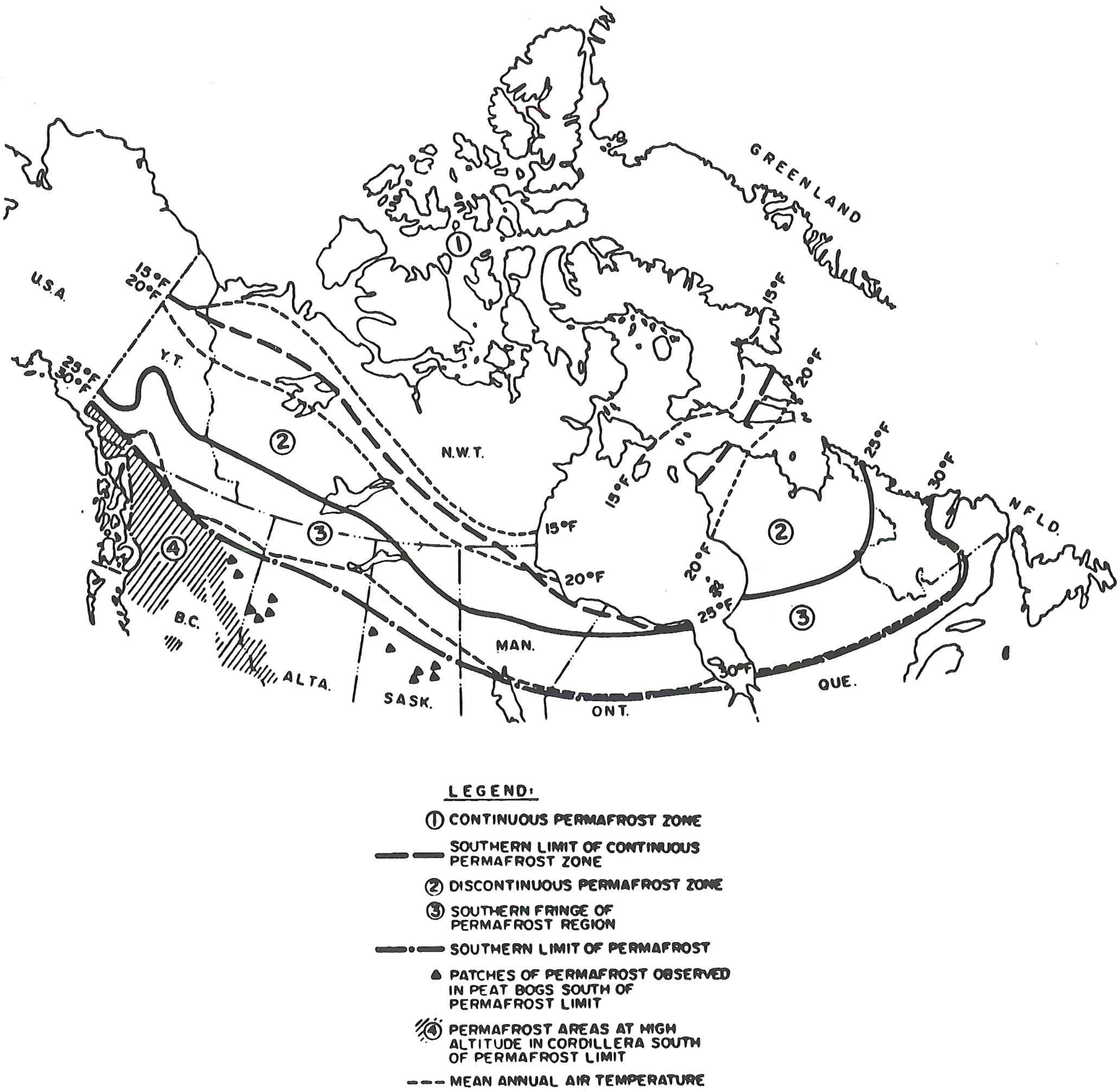
- Check pool height and location relative to design stipulations
- Ensure tailings discharged to pond in accordance with design and good practice to avoid freezing of slurry as it enters pond and to provide adequate pool depth for sedimentation
- Inspect condition of tailings lines, return water lines for support, sagging, leaks
- Inspect diversion ditches for clogging and erosion
- Examine tailing impoundment area for potential landslides that could enter impoundment and result in overtopping of dam
- Check decant system and spillways for proper operation, or readiness for operation
- Check decant and spillway for appropriate discharge away from toe of dam
- Check emergency and/or operational spillway for frost heaving, settlement and/or differential movement and integrity of structure
- Check for longitudinal or transverse cracking of dam
- Check for sinkholes in dam
- Check for sloughing on the upstream or downstream faces
- Check for changes in the piezometer readings if dam is so equipped
- Check for heaving at toe of dam
- Check for horizontal and vertical movement of the dam crest. For larger dams, surface reference markers and slope indicators may be required by the designer
- Horizontal and vertical movement is not detectable except in extreme cases without reference points
- Check integrity of membrane or clay liner where exposed above the pool height
- Check for operational readiness of seepage return system, if so equipped
- If stage construction in progress, check for improper construction or operating techniques, for example: placing of fill or tailings to be compacted at temperatures below freezing, end dumping of graded filter rock, etc.
- Animals burrowing in slopes of the dam and beaver activity in spillways must be prevented
- If the dam has a decant culvert, carefully inspect for seepage along the outer walls. Check for collapse of decant structure indicated by increase of volume of discharged water compared with water that enters decant line, or by sinkholes along decant
- On large dams, an annual visual inspection of the decant line is recommended
- If the dam is equipped with underdrains, they must be checked for flow volume and turbidity. Any seepage should be clear. Any flow that becomes turbid will indicate a serious condition that may result in piping that, if allowed to continue, could result in failure of the structure.
- Clear water or springs that develop on dam downstream face must be corrected. If springs develop turbidity, emergency action must be taken.
- Trees should not be allowed to grow on dam slopes as piping failures are possible along the root system. Brush and grasses should be encouraged to reduce wind and water erosion and thawing
- Stream flow or run-off must not be allowed to erode abutments

13.0 FIGURES

MAJOR PERMAFROST ZONES
OF CANADA

After Brown (1973)

FIGURE 1



CANADIAN PHYSIOGRAPHIC REGIONS

After Brown (1973)

FIGURE 2

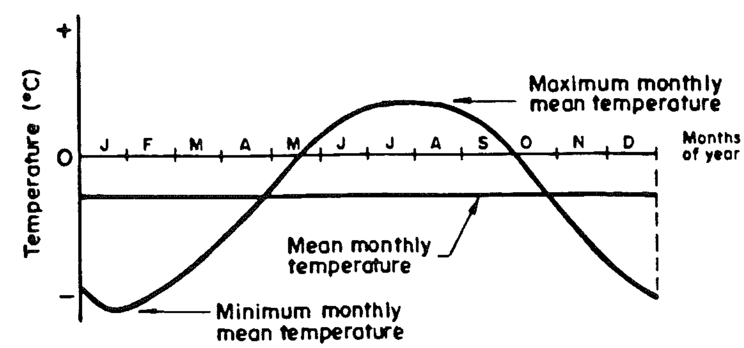
LEGEND:

① PRECAMBRIAN SHIELD
② HUDSON BAY LOWLAND
③ INTERIOR PLAINS
④ CORDILLERA
⑤ ARCTIC ARCHIPELAGO

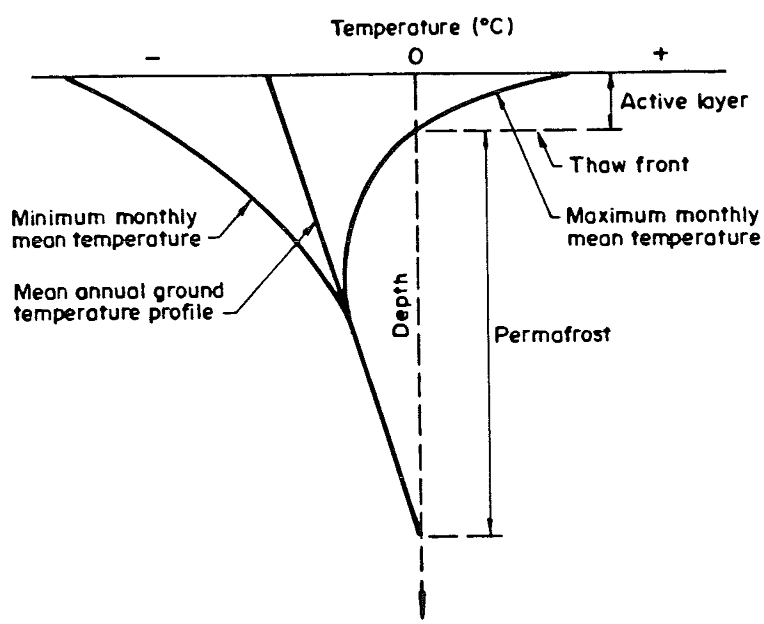
TYPICAL GROUND TEMPERATURE PROFILE
IN PERMAFROST

FIGURE 3

IDEALIZED SURFACE TEMPERATURE
WITH TIME



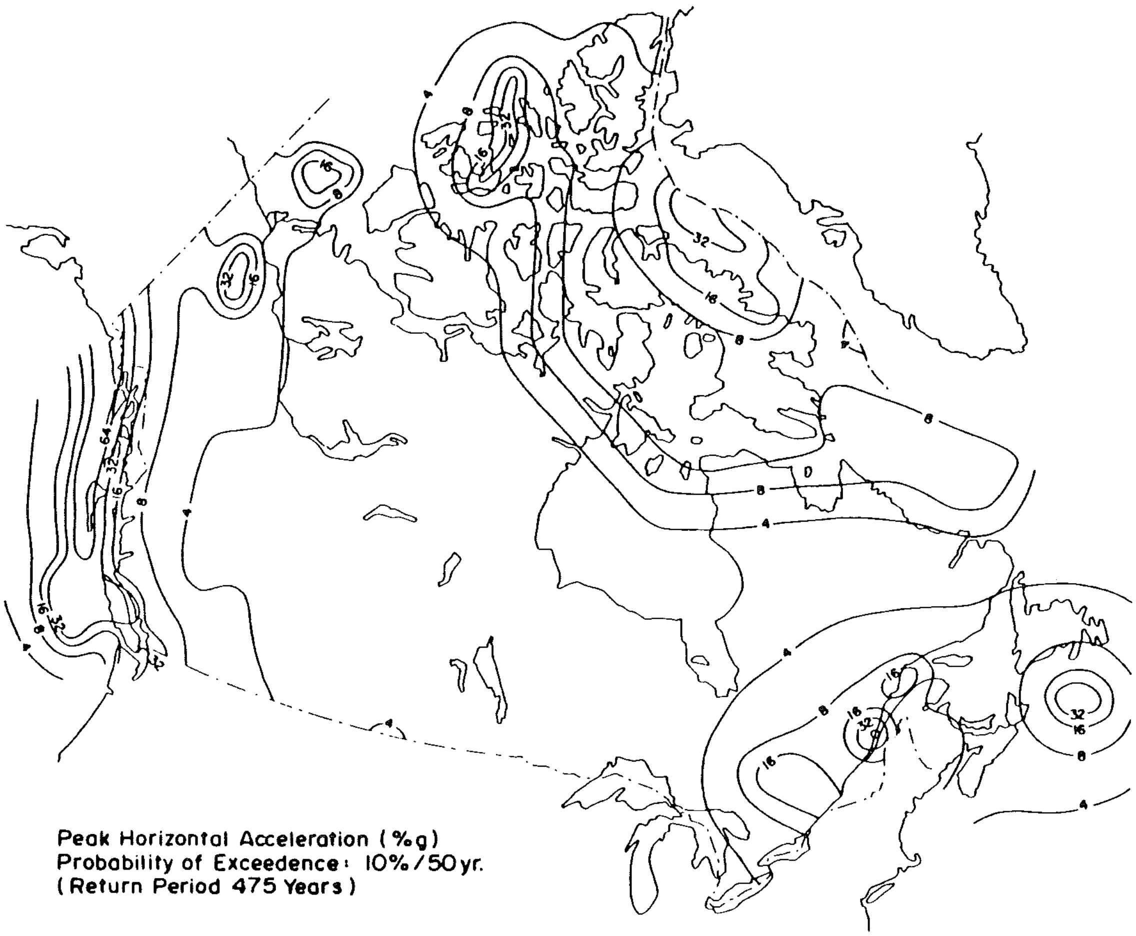
IDEALIZED GROUND TEMPERATURE
PROFILE IN PERMAFROST TERRAIN



SEISMIC DESIGN ACCELERATIONS FOR CANADA

REFERENCE:
Basham et al, 1982

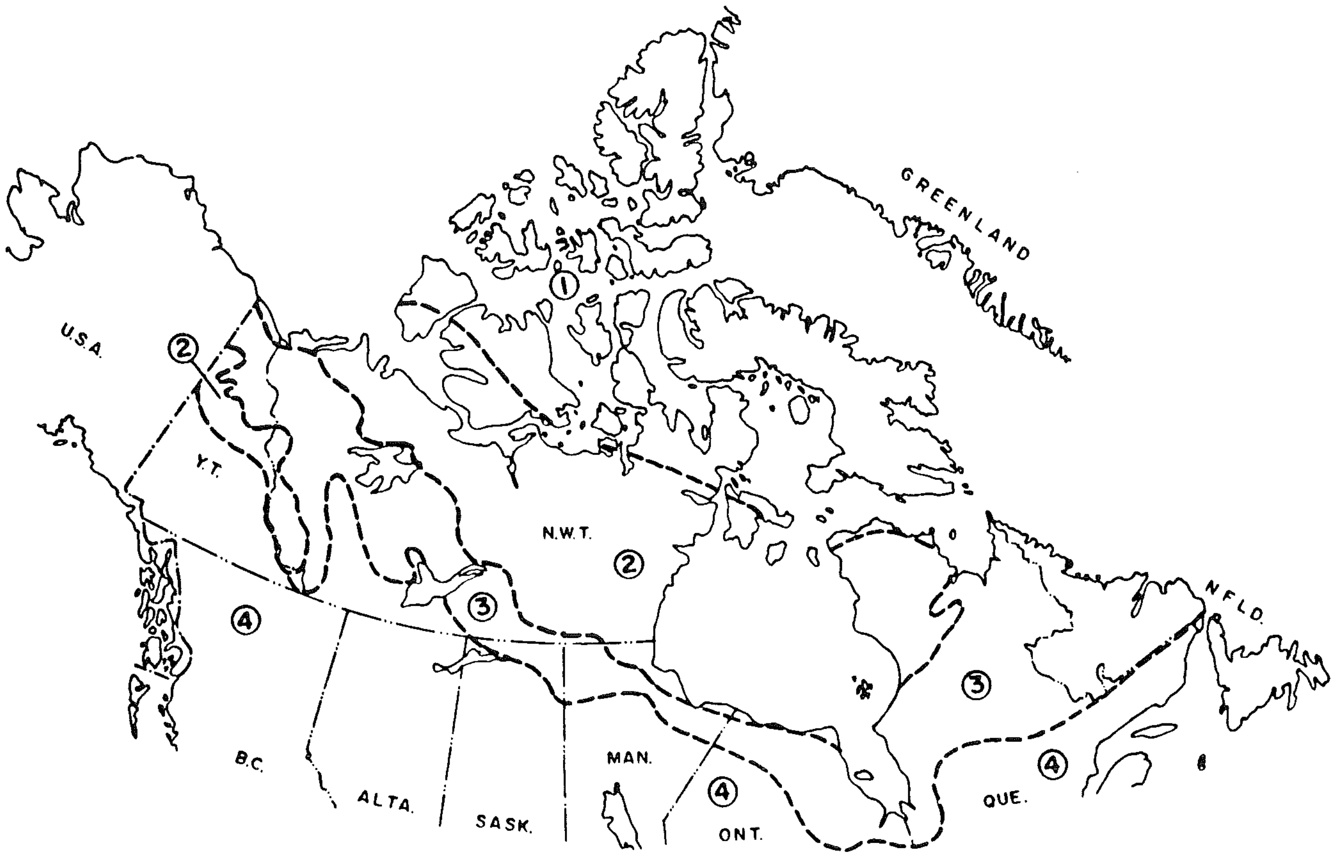
FIGURE 4



MAJOR VEGETATION ZONES IN CANADA

REFERENCE:
Fremlin, G. 1974

FIGURE 5



LEGEND:

1. POLAR DESERT
2. TUNDRA
3. WOODLAND
4. FOREST