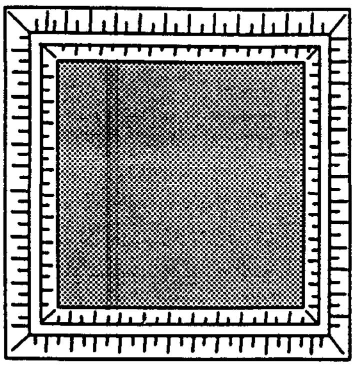
RCRA REGULATION IMPACT ON ALASKA MINERAL DEVELOPMENT

TAILINGS MANAGEMENT



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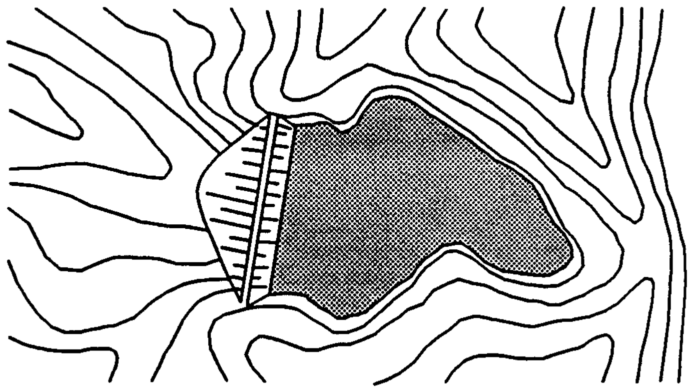
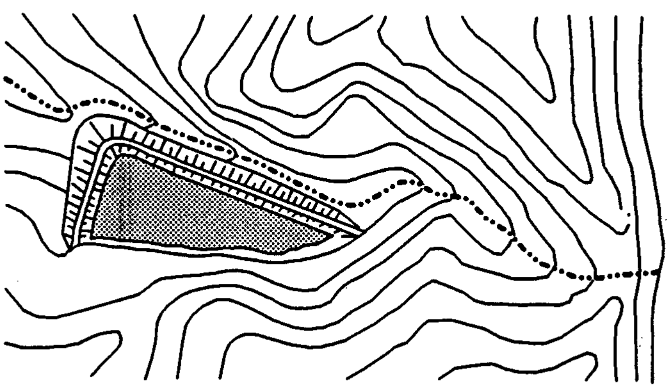
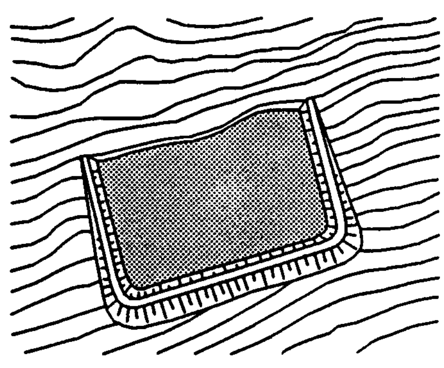


Cross-valley Impoundment



Diverted Stream Channel



Sidehill Impoundment

U. S. DEPARTMENT of the INTERIOR
Manuel Lujan, Jr., Secretary

BUREAU of MINES
T S Ary, Director

OFR 94-92

RCRA REGULATION IMPACT ON ALASKA MINERAL DEVELOPMENT
- TAILINGS MANAGEMENT -

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RCRA REGULATION IMPACT ON ALASKA MINERAL DEVELOPMENT TAILINGS MANAGEMENT

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ABSTRACT

This report reviews the regulatory environment as it pertains to tailings management and disposal from mining operations, excluding coal and placer gold operations, in the state of Alaska. It is based on the EPA's staff position on an effective program to regulate mining wastes as presented in the May, 1990 Strawman II document. The unique conditions which occur in parts of the state, including a fragile environment, high seismicity and permafrost, are identified. The special waste management practices which are necessitated by these conditions are delineated. The report provides a detailed outline of the current technologies that are suitable for designing, constructing, operating and closing a tailings disposal facility to meet environmental protection objectives. Cost implications to the mining industry of potential regulatory actions, such as the degree of groundwater protection are examined.

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RCRA REGULATION IMPACT ON ALASKA MINERAL DEVELOPMENT TAILINGS MANAGEMENT

CONTENTS

LIST OF FIGURES

LIST OF TABLES

RCRA REGULATION IMPACT ON ALASKA MINERAL DEVELOPMENT TAILINGS MANAGEMENT

1.0 INTRODUCTION

1.1 Background

Tailings are the remaining fraction of an ore after removal of the recoverable economic minerals. They are sand and silt materials which are usually handled in a water slurry. After processing they are discharged to an impoundment area designed and constructed with the objectives that the environment is protected from the physical and chemical impacts of the tailings. In some cases, where there is low impact and public acceptance, the tailings can be discharged into a natural water body, such as a lake or an inlet, however, this is not an accepted practice in the United States or Alaska. Generally, tailings are discharged into constructed impoundments, which use the natural topography and an embankment to control the deposition area of the tailings.

In December, 1985, the Environmental Protection Agency (EPA), under the direction of Congress, produced a report which described the characteristics and management of waste from the extraction and beneficiation of metallic ores, uranium overburden, asbestos, phosphate rock, and oil shale. In 1986, the EPA determined that classification of extraction and beneficiation wastes as hazardous under the Resource Conservation and Recovery Act (RCRA) Subtitle C may be economically impractical and unnecessary for protection of human health and the environment. At that time EPA also determined that RCRA Subtitle D criteria are not adequate to fully address mining waste concerns and recommended that a separate approach be developed under Subtitle D to deal with the unique characteristics of mining waste. After making this decision, EPA initiated a public dialogue that became known as the "Strawman Process".

The Strawman process was an effort by EPA to develop model regulations to address mining waste under Subtitle D. These model regulations were put forward to stimulate public discussion about the regulation of mining waste (see Section 3.0). In addition to extraction and beneficiation waste addressed in the 1985 Report to Congress, the Strawman approach addressed the regulation of mineral processing wastes that are excluded from classification as "hazardous" under Subtitle C and are co-located and co-mingled with materials generated by extraction and beneficiation.

It is important to note relative to this report that much of the controversy regarding the EPA Strawman has been directed toward the expanded scope of the regulatory program. The materials identified below are not traditionally considered mining waste, and are activities that have been regulated under other state and Federal programs. This report does not address these materials, but one should be aware of their inclusion under Strawman. Specifically, these solid waste materials would include:

- Heap and dump leach materials;
- Water or other liquids that have the potential to accumulate as wastes in open pits, mine shafts, tunnels, or other structures;
- Stockpiled ores and subgrade ores.

The Strawman II definition that expands the scope, is as follows:

> "Regulated units" are new or existing units in which regulated materials are placed or accumulate on or after the effective date. Regulated units include, but are not limited to: free-standing processing units that generate Bevill wastes that are not subject to Subtitle C; surface impoundments, tailings ponds, and waste piles containing mining waste; active heap and dump leaching units; any production unit such as an open pit, mine shaft or tunnel which has the potential for release of hazardous constituents; units containing mine tailings used in a manner constituting disposal or through land-application; areas and units where overburden is stored during the active life of the facility and where overburden is placed or disposed during closure or post-closure; piles containing stockpiles ores or subgrade ores; and ancillary structures that are used for the collection, treatment, or storage of leachate generated from any of these units.

To understand the issues regarding the RCRA mine waste program, it is useful to know the definitions of processing and beneficiation as defined by EPA. The definitions are presented below (54 FR 36628):

Final Criteria for Defining Bevill Mineral Processing Wastes

Definition of Mineral Processing Wastes:

For purposes of this rule, mineral processing wastes are generated by operations downstream of beneficiation (as codified by today's rule) and originate from a mineral processing operation as defined by the following elements:

1. Excluded Bevill Wastes must be solid wastes as defined by EPA.
2. Excluded solid wastes must be uniquely associated with mineral industry operations.
3. Excluded solid wastes must originate from mineral processing operations that possess all of the following attributes:

    - Follow beneficiation of an ore or mineral (if applicable);

- Serve to remove the desired product from an ore or mineral, or from a beneficiated ore or mineral, or enhance the characteristics of ores or minerals, or beneficiated ores or minerals;
- Use mineral-value feedstocks that are comprised of less than 50 percent scrap materials;
- Produce either a final mineral product or an intermediate to the final product; and
- Do not combine the product with another material that is not an ore or mineral, or beneficiated ore or mineral (e.g., alloying), do not involve fabrication or other manufacturing activities, and do not involve further processing of a marketable product of mineral processing.

4. Residuals from treatment of excluded mineral processing wastes must be historically or presently generated and must meet the high volume and low hazard criteria in order to retain excluded status.

Beneficiation operations include crushing, grinding, washing, dissolution, crystallization, filtration, sorting, sizing, drying, sintering, pelletizing, briquetting, calcining, roasting in preparation for leaching (to produce a final or intermediate product that does not undergo further beneficiation or processing), gravity concentration, magnetic separation, electrostatic separation, floatation, ion exchange, solvent extraction, electrowinning, precipitation, amalgamation, and heap, dump, vat, tank, and in situ leaching.

Processing operations generally follow beneficiation and include techniques that often destroy the ore or mineral, such as smelting, electrolytic refining, and acid attack or digestion. EPA also wishes to emphasize that operations following the initial "processing" step in the production sequence are also considered processing operations, irrespective of whether they involve only the techniques defined above as beneficiation. Therefore, solid wastes arising from such operations are considered mineral processing wastes, rather than beneficiation wastes.

It is recognized that the management of solid waste materials from mining activities in certain parts of the country present unique problems due to severe climates, high precipitation, permafrost, etc. In Alaska, the fragile environment, short production season, high levels of precipitation and run-off in some areas, low precipitation and permafrost in others, etc., complicate the management of solid waste from mining activities. Future regulations proposed by EPA and aimed at management of mining wastes in Alaska should be drafted with an understanding of the special conditions present in the state as well as the effect these regulations will have on the mining industry.

A concern about a RCRA regulatory program for mine waste is that the rules, which are applied on a national basis, will not sufficiently allow for site-specific design and engineering. This could result in design and construction of waste disposal facilities which are not appropriate for the site or the environment in Alaska. Techniques and methods for disposal of waste rock from an Arizona copper mine, or a Florida phosphate mine are not the same as those for an Alaskan open pit gold mine. The analytical process for selecting the design and method of placement may be similar, but the appropriate design and method of placement may be vastly different for a tailings disposal facility in Alaska than one in Arizona.

1.2 Objectives

This report will review the regulatory environment, delineate the unique conditions in the State of Alaska as they relate to tailings management, discuss the special practices these conditions necessitate, and estimate the cost to the mining industry of potential regulatory actions.

This report has been prepared in conjunction with a complimentary report which deals with waste rock.

1.3 Alaska's Mineral Industry

Mining is the third largest industry in Alaska, after fishing and oil production, and contributes about $600 million to the state economy. Approximately one sixth of this is from placer mining, which accounts for 85% of the gold production in the state. In terms of the total production in the USA, Alaska produces about 2% of the gold, 55% of the zinc, and 18% of the silver.

There are about 220 placer operations in Alaska, of which the 10 largest producers account for 50 to 60% of the placer gold production. There are two operating metal mines in the state: Greens Creek, which is the largest silver producer in the USA, and Red Dog, which is expected to soon be the largest zinc producer in the world. Only one coal mine is operated in the state.

The Red Dog mine is the first significant open pit mine in Alaska. The total waste rock production from all previous operations is estimated to be about 25 million tons. Most of this waste rock has been used for landfill in Juneau. Total tailings production, excluding placer mining, in the state is less than about 150 million tons, of which about 100 million tons was discharged to the channel.

Alaska is divided into seven mining regions as shown on Figure 1.1.

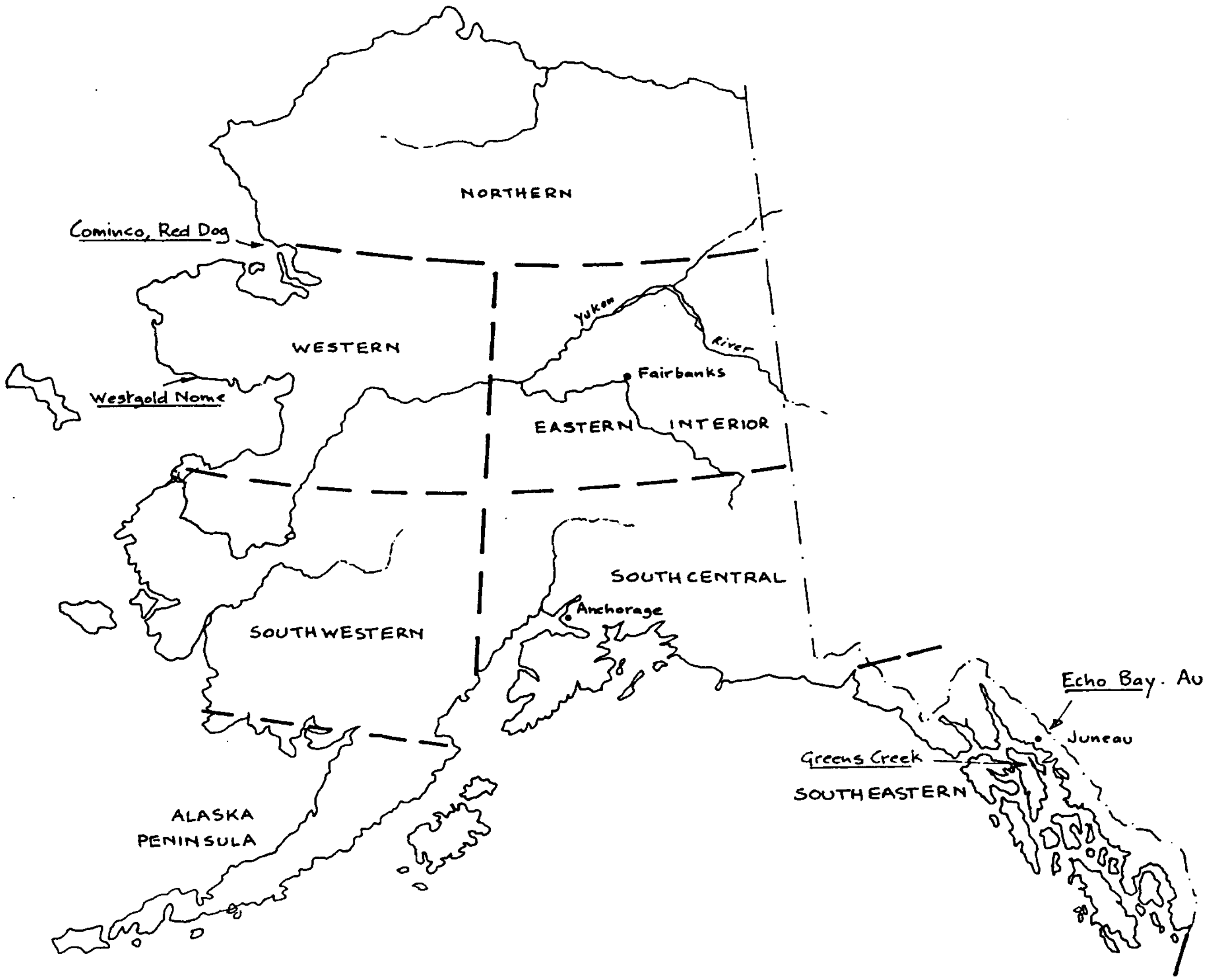


Figure 1.1 Alaska Mining Regions
(After Swainback et al, 1990)

2.0 ALASKAN MINING CONDITIONS

2.1 General

Alaska differs from the other states in two important physiographic ways.

- The size of the State is nearly one fifth the rest of the U.S., and by far the largest State. This is graphically presented in the sketch shown inset on Figure 2.1, with Alaska overlaying the entire lower 48 states.

- Its northern latitude with the bulk of the state lying north of 60°. Roughly one quarter of the State lies within the Arctic Circle.

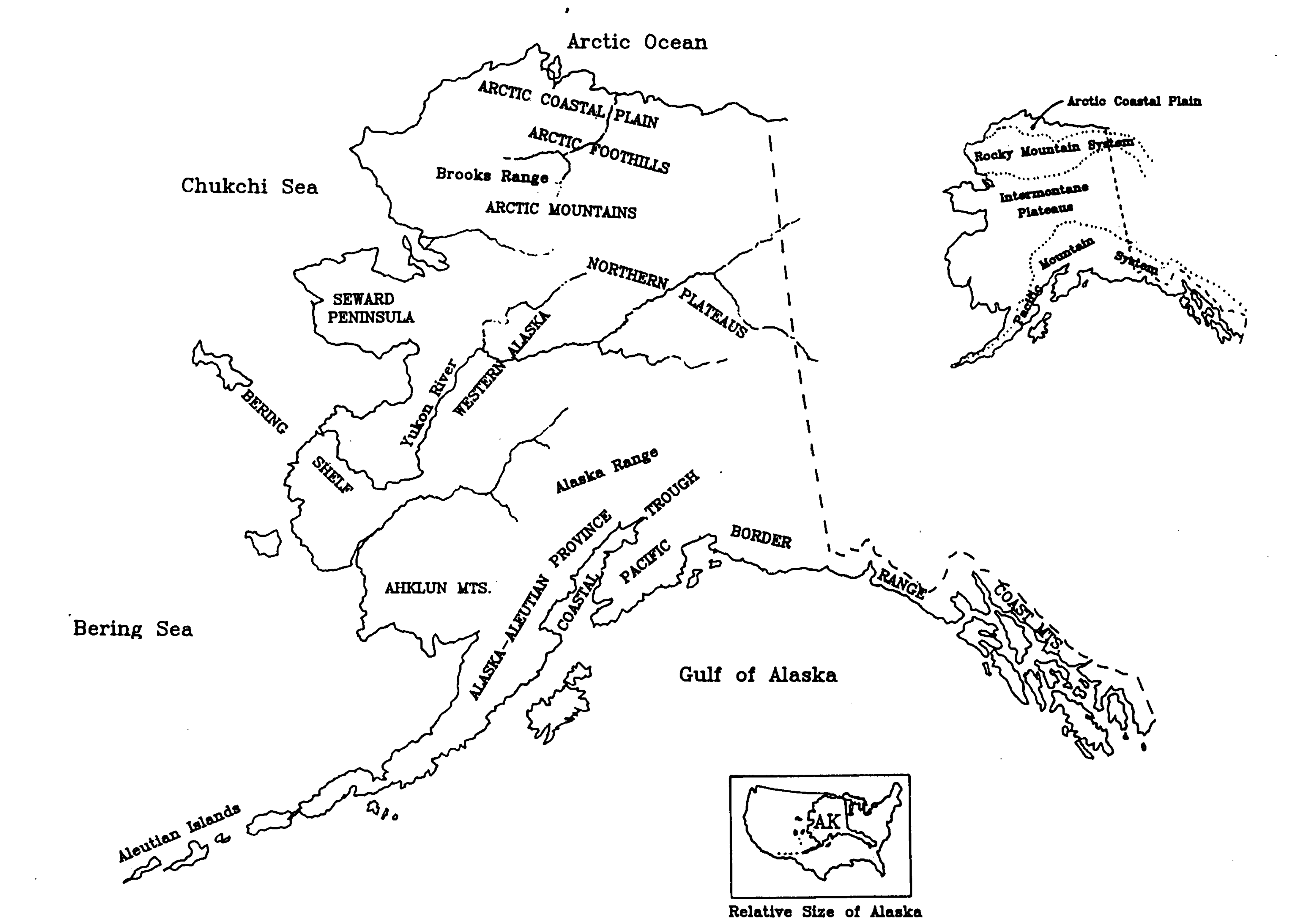
These two facts may well dictate unique solutions to mine waste disposal, in many instances. Concerns and technical solutions applicable to the other states could be inappropriate in Alaska. Similar conditions are more likely to be met in the Yukon and the Coastal Range of British Columbia in Canada. It is important therefore to have a clear appreciation of the physiography of the region when discussing mine waste disposal and the regulatory approach. The physiographic differences within the state clearly demonstrate the need for a site specific, waste specific and waste management specific design and engineering approach to tailings disposal. This is a fundamental concept and should be included and followed in RCRA regulation of mine waste. For this reason the discussion presented below will familiarize the reader with basic Alaskan environmental conditions that bear upon tailings disposal. A more detailed description is given by Wahrhaftig (1965) based largely on the work of the U.S. Geological Survey.

2.2 Physiographic Division

Alaska has an area of 587,757 sq miles (1527 464 sq km) yet has one of the smallest state populations, approximately one half million people. The Alaskan environment is complex and hostile in many ways. Because of its size, it encompasses physiographic divisions of quite diverse character. In general there are four divisions, see Figure 2.1:

- the Pacific Mountain System in southern Alaska;
- the Intermountane Plateaus of the Yukon River and Kuskokwin River basins;
- the Rocky Mountain (or Arctic Mountain) System north of the Yukon River basin; and
- the Arctic Coastal Plain.

Each division is a northwesterly extension of the major physiographic division of Canada and co-terminus United States. The Rocky Mountain System, the Intermountane Plateaus, and the Pacific Mountain System



(Modified after Wahrhaftig, 1965)

Figure 2.1 Physiographic Regions of Alaska are the Alaskan extensions of the North American Cordillera. The Arctic Coastal Plain is really the continuation into Alaska of the Interior Plains.

Most of the state is mountainous, although plains up to 100 miles/(160 km) wide are found in the Intermountane Plateaus. The Arctic Mountains are dominated by the Brooks Range rising to 6000 - 8000 ft(2400 m). Apart from a few small cirque glaciers in the eastern Brooks Range, there are no glaciers in the Arctic Mountains. The entire system is, however, underlain by continuous permafrost. The Pacific Mountain System is a pair of ridges separated by the Coastal Trough depression. The northern ridge is the Alaska-Aleutian province and the southern ridge is the Pacific Border Range Provinces. Here the highest peaks in the continent rise to more than 20,000 ft.(6000 m), with mountains of 8000 - 12,000 ft (2500 - 3600 m) being common. Large portions of the Pacific Border Range remain covered with glaciers, some of which extend to sea level. Discontinuous permafrost is widespread.

The Intermountane Plateau between the Arctic Mountains and the Pacific Mountain System consists of flat plains and rolling uplands with occasional groups of low mountains. It declines in relief and altitude westward. It is dominated by the Yukon River, the largest river in the state.

2.3 Climate, Glaciation and Permafrost

Temperatures vary over a large range throughout the state, with the coastal regions being more moderate. Extreme temperatures variations occur within the Yukon River system near the Canadian border. The mean daily minimum temperatures in January fall to about -30°F (-34°C) and mean daily maximum temperatures in July rise to about 75°F (24°C). In southeastern Alaska, corresponding temperature means range between roughly 20°F (-7°C) and 60°F (16°C). Coastal temperatures are moderated by the Japan Current.

Precipitation varies widely and comparatively small amounts of precipitation fall in many parts of the state. Except for southeastern Alaska and the southern coast from Yakutat west to Aleutian Islands, few areas receive more than 30 ins (76 cm) annually, see Figure 2.2. Higher precipitation may occur locally near mountains or parts of the coast. The North Slope of Alaska and the upper Yukon Basin receive less than 10 ins (25 cm) annually. The prolonged period of freezing temperatures causes streamflows to decrease drastically during the long winter months. In northern regions, flows in small streams cease entirely and shallow lakes generally freeze to their bottom by midwinter.

Since frost conditions prevail in Alaska, the dominant geomorphic processes are either glacial or periglacial. During Pleistocene time, the Pacific Mountain system was almost entirely covered by the vast Cordilleran ice sheet. The Arctic Mountains were also extensively glaciated. In complete contrast, most of the Intermountane Plateaus, Arctic Foothills and the Arctic Coastal Plain were never glaciated. Similar conditions prevailed eastward into the Yukon. The limits of the Pleistocene glaciation are shown on

Figure 2.3. Glaciation has an important bearing on soil conditions relevant to mine waste disposal because of the effects which glacial processes have on the physical properties of soil.

deserts. Vegetation and controlling climatic factors are discussed by Sigafoos (1958) and Hopkins (1959). Vegetation can have a significant influence upon the reclamation of mine waste by its control of long-term erosion, especially on critical structures such as cover for control of contaminant production and migration.

2.4 Geology, Seismicity and Geologic Hazards

Most of the state of Alaska is included in the North American Cordillera. It is a region of intense orogenic activity and the site of geosynclined sedimentation. An understanding of bedrock types is important in considering the chemical behavior as well as the physical stability of mine wastes. The geology of Alaska is described by Miller et al (1959), and a statewide geologic map is available, see Dutro and Payne (1957).

Interbedded carbonate and well-sorted clastic rocks are found in the Arctic Mountains and the northern part of the Intermountane Plateaus. The Brooks Range consists largely of limestone, sandstone and shale, or their metamorphic equivalents, quartzite and slate. They are of Paleozoic age (300 - 600 million years) and have been folded and thrust northward, away from the Pacific.

Central Alaska is underlain largely by limestone, sandstone and shale, with chert, volcanic rock and graywacke interbedded with the other rocks.

Interbedded volcanic and poorly sorted clastic rocks are found in the Pacific Mountain System and the southern part of the Intermountane Plateaus. Graywacke and volcanic rock are common throughout the sequence interbedded with limestone, slate, schist and nonmarine red sandstone. Ancient basalt flows constitute the greenstone formations common in southern Alaska, such as in the Kennecott Copper district.

The main period of orogenic activity began in Jurassic time (200 million years) culminated in the Cretaceous (136 million years ago) and waned in the Tertiary (60 million years ago). Enormous granitic batholiths were intruded in the Talkeetna Mountains, the Alaska Range, the Interior Plateau, the Kodiak and Chugach Mountains and the Coast Range. At the same time rapid uplifting of the mountains of southern Alaska was accompanied by erosion and accumulation of sediments in adjacent basins, forming the graywacke, argillite and conglomerate that make up large parts of southern and central Alaska. Igneous activity decreases across the cordillera away from the Pacific with relatively little occurring in the north front of the Brooks Range. The structures produced by the mountain building activity are great arcuate belts more or less parallel to the shore of the Gulf of Alaska. Structural trends are generally northwestward in southeastern Alaska, due west throughout central and northern Alaska, and southwestward in western and southwestern Alaska.

Seismic activity is an important consideration in the design of control structures for tailings impoundments because of the potential for major deformation of the containment facilities during an earthquake. Such deformation has resulted in catastrophic outflows of tailings at sites around the world.

Active volcanoes occur in the great chain of the Aleutians, in the Alaska Peninsula and the Wrangell Mountains. Both the Aleutians and the Gulf of Alaska have experienced, and continue to experience, major earthquakes. Seismic activity decreases in western and northern Alaska. Contours of horizontal ground motions on bedrock are shown on Figure 2.4, taken from current work by the U.S. Geological Survey. These are probablistic estimates based on historic seismicity data. Also shown on Figure 2.4 is the principal inland fault system in Alaska, the Denali fault. Its southeastern arm is postulated to follow the Chatham Strait fault, however, this fault appears to be inactive (Rogers and Horner 1990). The Denali fault system is characterized by horizontal movement essentially all of which occurred during Tertiary and Quaternary time. Holocene (within the last 10,000 years) displacement has taken place on the McKinley and Totschunda segments and the western part of the Shakwak segment. The Dalton segment may also be active.

The coastal zone is active along the Fairweather - Queen Charlotte fault on the margin of the Pacific Plate. The Fairweather fault has undergone major strike-slip displacement in Holocene time. The most recent event was the 1958, M 7.9 earthquake at Lituya Bay. Documentation of movement along this fault is presented by Plafker et al (1978), while that along the Denali fault system is presented by Lanphere (1978). In southeastern Alaska the rate of seismicity on the Denali fault system is an order of magnitude lower than in the coastal zone, see Rogers and Horner (1990).

Besides earthquakes and active faults, other geologic hazards can affect the stability of waste disposal schemes. These include flooding, erosion and deposition, slope instability, landslides, snow avalanches, volcanoes and possibly tsunamis at coastal sites. The most common hazards are landslides and flooding. Earthquake induced ground failures can include rockfalls and rock avalanches, and liquefaction of saturated fine-grained sediments often present in the lower regions of flood plains. Saturated silt and clay will slide or flow on slopes of 10° or less. Undercutting of slopes either naturally by stream flow or human activity can cause landslides. Alternatively overloading a slope by deposition of mine waste can lead to landsliding. Flooding in Alaska can result from high intensity rainfall during a cloudburst, prolonged rainfall, rapid snowmelt, river ice jams, glacial outbursts and coastal storm surges. Physical instability of mine waste impoundments can result from short period catastrophic events or slow insidious events over a long time frame, see Robertson & Skermer (1988). Geologic hazards in Alaska are reviewed in Combellick (1985) and Péwé (1982).

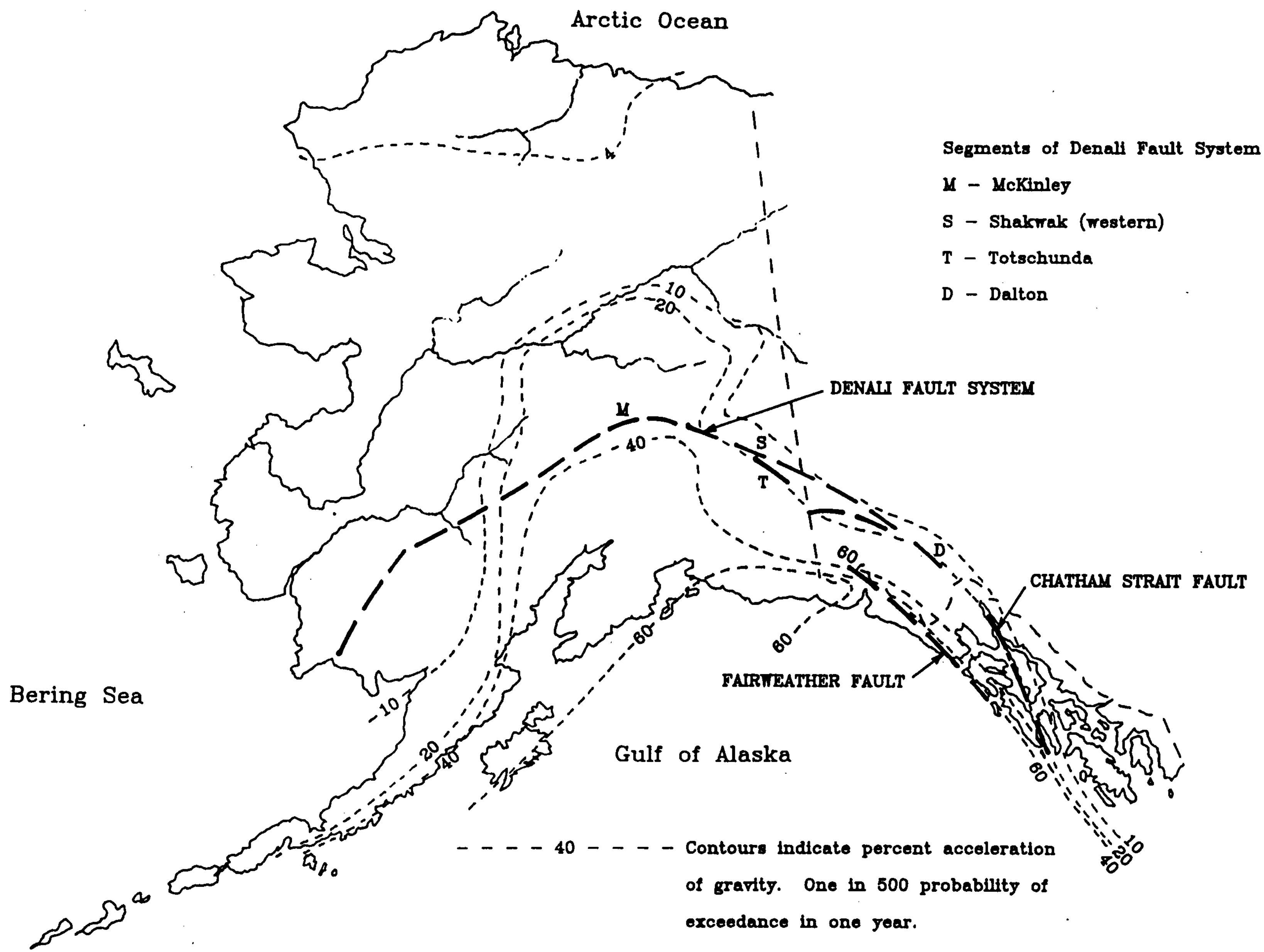


Figure 2.4 Seismicity and Faults of Alaska
(After Coonrad, 1982)

2.5 Federal Agencies

Alaska covers 376 million acres, much of it managed by one or other of the following Federal land management agencies which have responsibilities related to metallic mineral development and in particular mine waste disposal.

The U.S. Geological Survey (USGS) has programs for earthquake and volcanic hazards reduction which provide data for land-use planning, engineering and emergency preparedness. The USGS also operates a Geologic Framework Program involving both general and specialized research on the regional geology of Alaska. The USGS research includes geohazards and toxic waste studies. Economic geologic information for mineral occurrences is available through the USGS Mineral Resources Data System computerized files. More than 2000 metallic mineral entries for Alaska are on file.

The U.S. Bureau of Mines (USBM) operates the Minerals Availability System which, amongst other things, addresses environmental constraints on mining. The USBM is also concerned with policy analysis using technical, institutional, political, social, and economic parameters to identify mineral issues. The USBM also operates the Alaska Technology Transfer Office in Anchorage which is responsible for working with Federal agencies, the state, universities and industry on technology issues and needs.

The Bureau of Land Management (BLM) is concerned with planning and environmental review of mining operations on public lands and the regulation of mining activities to ensure environmental protection. The BLM is responsible for multiple-use management of both surface and subsurface of roughly 200 million acres of Federal lands in Alaska. Maps showing Federal land ownership in Alaska are put out by the BLM.

The Fish and Wildlife Service (FWS) ensures that mineral development on FWS land in Alaska is compatible with the protection of fish and wildlife and their habitats. The FWS is responsible for 77 million acres of land and has an environmental contaminants program that includes sampling and reporting on contaminants in waters, sediments and organisms affected by mining activities.

The U.S. Forest Service (USFS), Department of Agriculture, under an agreement with the BLM, jointly administers the general mining laws on its own lands in Alaska. It assures mitigation of surface impacts of mine lease activities. In Alaska 23 million acres of land are administered by the USFS, most of it in the southern and southeastern parts of the State. The USFS also provides research information and technology to assist with post-mining reclamation.

The National Park Services does not manage minerals in the same way as other Federal agencies, since the vast majority of park units are closed by law to mining.

3.0 REGULATORY FRAMEWORK, POLICY DEVELOPMENT AND MINE WASTE MANAGEMENT TRENDS

3.1 RCRA Subtitle C

The scope of this report is limited to addressing the management of tailings. Tailings, as defined within the concept of the Resource Conservation and Recovery Act (RCRA), are a solid waste resulting from the beneficiation of ores. Under a 1980 amendment to RCRA, known as the Bevill Amendment, solid waste from the beneficiation of ores were excluded from regulation as a hazardous waste under Subtitle C, pending the completion of studies by the Environmental Protection Agency (EPA) and a determination by the EPA as to the appropriate regulatory response to management of these wastes (Section 3001 (3)(A) of Solid Waste Disposal Act (SWDA)). The regulatory determination, made on July 3, 1986, concluded that regulation of beneficiation waste as a Subtitle C hazardous waste was not appropriate (51 FR 24496, July 3, 1986). At this time the disposal of tailings, in itself, is not regulated under Subtitle C.

The Bevill Amendment also exempted mineral processing waste in the same manner that extraction and beneficiation waste were exempted. Consideration of whether to regulate processing waste under Subtitle C was conducted under a separate process. EPA determined that specific processing waste is to be exempt from Subtitle C regulation (56 FR 27300, June 13, 1991). Processing waste not specifically identified for exemption may be regulated as a hazardous waste if it exhibits the hazardous waste characteristics of being corrosive, ignitable, reactive or toxic. This is important to note where tailings and processing waste are mixed and disposed in the same waste disposal structure.

With respect to the practice of mixing waste, a tailings facility could become a hazardous waste facility if it contains hazardous materials. Hazardous waste is defined as:

> A solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical or infectious characteristic may:
>
> (A) cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or
>
> (B) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed. (Section 1004(5) of SWDA)

Hazardous waste found at mine sites can include solvents, petroleum based waste, metallurgical laboratory waste, sludge and other material exhibiting hazardous characteristics.

Waste disposal facilities that contain tailings mixed with hazardous processing waste or other hazardous waste would be regulated under Subtitle C. Two paths to this result are apparent. First, if tailings are mixed with a listed hazardous waste, then the tailings facility would be regulated as a Subtitle C hazardous waste facility. Second, if the tailings are mixed with a non-listed waste which exhibits the characteristics of a hazardous waste, it would be regulated as a hazardous waste facility.

The rationale for this policy is to prevent the avoidance of hazardous waste regulation by disposing of hazardous material in a non-hazardous solid waste facility. This policy prevents the use of mixing to reduce toxicity to a non-hazardous level as a means of reducing the regulatory requirements. However, as a result of recent federal court decision, EPA will reopen the mixing rule to public comment and further consideration (Shell Oil Co V. Environmental Protection Agency, U.S. Court of Appeals, D.C. Circuit, 90-1532).

In the case of Alaskan tailings management, mixing of non-exempt processing waste or any other hazardous waste with the tailings would result in a RCRA Subtitle C regulation of the tailings disposal facility. This would require a facility to be designed, engineered and operated as a hazardous waste storage facility. The material would have to be handled, transported and stored in accordance with the Subtitle C regulatory requirements. With respect to storage, the requirements would address site selection, site preparation, liner installation, material placement, closure and monitoring. The flexibility to design for specific site characterization and risks is greatly reduced because the objective of hazardous waste management is containment.

As a result of the mixing policy, it may be prudent for Alaskan mine operators to develop separate waste storage units for tailings, processing waste and other hazardous wastes. This may eliminate past practices of mixing wastes, such as sludge from waste treatment facilities and processing plants. Separation of waste products from different production streams may be most practical from both an engineering and cost perspective.

3.2 RCRA Subtitle D

Subtitle D applies to mining waste by virtue of the July 3, 1986 determination. EPA has not initiated the rule-making process to develop solid waste regulations for the management of tailings and waste rock. EPA determined that the current Subtitle D solid waste program is not designed to address the unique character of mining waste, principally the high volume characteristic. EPA declared its intent to develop a specific program for mining waste which it has described as a Subtitle D+ program. The D+ notation implies that it would be a regulatory program that is more stringent than the Subtitle D solid waste program which is oriented mostly toward municipal landfills. The development of the D+ program EPA envisions would require a statutory change. One authority that EPA would seek is direct enforcement authority for the regulation of mining waste units. Currently, EPA does not have enforcement authority under Subtitle D. Enforcement authority is reserved to the states. EPA's role in non-hazardous waste management is to provide technical guidance. In the interim, EPA is relying upon section 7003 of RCRA and section 104 and 106 of CERCLA to address major problems associated with mining waste. These are statutory enforcement provisions providing for EPA response to instances of substantial threat or imminent hazard to human health and the environment.

Given EPA's current position, there are two principle scenarios for the development of a mining waste program under Subtitle D. If no new statutory authority is granted by Congress, then regulations would be developed for mining waste under the existing statutory authority. The regulatory framework would be similar to that for municipal land fills and other solid waste disposal programs under Subtitle D. Under these regulations, state and local governments that adopt programs would have the authority to approve mining waste disposal facilities and to enforce solid waste laws. EPA would provide technical guidance and produce guidelines. It is important to note that EPA would still retain its authority to regulate certain activity at a mining waste facility under the jurisdiction of the Clean Water Act, the Clean Air Act or other laws that it administers.

The other regulatory development scenario is that Congress grants new authority under Subtitle D of RCRA to address mine waste. EPA would develop regulations under the new and expanded authority. The Strawman II rules, discussed in Section 3.0 of this report, are based upon the presumption that EPA acquires new statutory authority, including the authority to oversee state programs, to substitute Federal authority where a state does not perform at a minimum level, and to take enforcement actions.

It is anticipated that the direction that EPA will take will be determined during 1992 as a result of Congressional review and reauthorization of RCRA.

3.3 The Bevill Amendment Exclusion

The requirements of the Bevill amendment have been fulfilled, and no longer have a direct bearing on the management of tailings. Information is provided in this section about the Bevill Amendment to provide information and history regarding the development of regulations governing the management of tailings.

When RCRA was originally passed in 1976, mine wastes were eligible to be regulated under Subtitle C. EPA had the authority through section 3004(x) of RCRA to develop hazardous waste regulations that would fit the unique characteristics of a group of wastes, known as special wastes, which included mining waste. On May 19, 1980, EPA promulgated regulations under Subtitle C of RCRA which addressed mining waste, but did not provide full consideration of the special waste provisions. After representatives of the mining industry raised concerns about the regulation of mining waste under the Subtitle C hazardous waste program, Congress exempted mining waste from regulation under Subtitle C pending completion by EPA of a study (sections 8002(f) & (p)) and a regulatory determination (section 3001(b)(3)(C)). The statutory exclusion, passed in 1980, became known by the name of its Sponsor, Thomas Bevill of Alabama, as the Bevill Amendment. The solid wastes that were subject to the Bevill amendment continue to be known as "special wastes". Specifically, the Bevill amendment prohibited EPA from regulating solid waste from the extraction, beneficiation, and processing of ores and minerals, including phosphate rock and overburden from the mining of uranium ore, as hazardous waste under Subtitle C of RCRA.

The study required under the Bevill amendment was submitted to Congress on December 31, 1985. The regulatory determination was made on July 3, 1986 (51 FR 24496). EPA determined that waste from the extraction and beneficiation of ores should not be regulated under Subtitle C. As relevant to this study, this meant that tailings were not to be regulated under Subtitle C.

Once EPA made the regulatory determination, the requirements of the Bevill amendment had been satisfied. The Bevill amendment did not direct EPA to undertake any particular steps if it determined that mining waste should not be regulated under Subtitle C. When making the regulatory determination that waste should not be regulated under Subtitle C, EPA also stated that the current solid waste regulatory system under Subtitle D was not sufficient. EPA proposed the development of the D+ program, as discussed above in Section 3.2. With respect to tailings management, tailings continue to be recognized as special waste.

For more information regarding the Bevill Exclusion, see 51 FR 24496, July 3, 1986 and 56 FR 27300, June 13, 1991.

3.4 Strawman II Process and Concept

The purpose of the Strawman Process was to initiate public dialogue about mining waste regulatory issues in response to the RCRA provisions, the Bevill amendment exclusions and the EPA regulatory determination. The means for doing so was the creation of a model regulatory proposal, known as the Strawman, that could be reviewed by interested parties and government agencies. This model was to be critiqued publicly and refined prior to the development of a proposed Federal rule. The original Strawman document was released on June, 1988. The document provoked considerable public discussion. EPA accepted the comments and drafted a second document in response which became known as Strawman II.

Strawman II is not a complete regulatory concept. Within the document, EPA identifies areas where there are policy issues that need further discussion. The document presents the EPA staff concept of what critical elements should be included in a RCRA mining waste program.

The crucial concept of Strawman II is that it provides flexibility for site specific and waste specific regulation of mine waste. There are technical criteria that are to be followed to allow for site specific and waste specific design and engineering. This is particularly important in the northern climes where great variability exists from site to site depending upon latitude, altitude and other environmental factors. The technical criteria are discussed further in Section 4.0 of this report.

The regulatory program proposed under the Strawman II would not preclude the implementation of a regulatory program appropriate for the State of Alaska. The flexibility of the proposed program is intended to provide for the development of standards appropriate to the Alaskan environment. The State of Alaska could establish technical criteria that are more stringent than those in the Strawman II, if it chooses.

One of the issues is that the performance standards and the design and operating criteria could vary depending upon who administered the Strawman II program, the state or the Federal government. If Alaska did not obtain an approved program, then the EPA would have to develop a program for the state of Alaska. A Federal program would be developed that would consider existing state regulatory programs and impose federal requirements as required under RCRA. The EPA program would apply to all lands in the state. As such, tailings disposal operations conducted on lands administered by the Bureau of Land Management and the United States Forest Service would be subject to the EPA regulatory program.

The Strawman process is completed. It is likely that some of the concepts contained in the Strawman II document will carry through to the development of a mining waste program. The discussion regarding the development of a mining waste program has moved to new forums, the Policy Dialogue Committee and Congress.

3.5 The Policy Dialogue Committee

The Policy Dialogue Committee (PDC) convened under the authority of the Federal Advisory Committee Act (FACA). The committee consists of representatives of the major public interest groups and government agencies. The participation is limited to twenty-one individuals who have been designated as representatives of these groups and agencies. According to the minutes of the first meeting of the PDC, the EPA goals of the PDC process are: 1) to provide a forum for the exchange of ideas; 2) to develop innovative approach for the regulation of mine waste; 3) to create the principal mechanism for input to EPA on mine waste regulatory policy; 4) to develop consensus to the greatest extent possible; and 5) to sharpen the understanding of disagreements.

The scope of deliberation by the PDC is to address RCRA related issues while recognizing some options considered may extend outside RCRA statutory authorities; to focus on hard rock and phosphate mining wastes, excluding coal, sand and gravel, crushed stone and quarry rock; to address activity from exploration through mineral beneficiation and processing wastes not covered under RCRA Subtitle C hazardous wastes; and to address abandoned mines within the context of RCRA.

Meetings were held by the PDC through January, 1992. The PDC charter under the FACA expired on March 30, 1992, but was extended for a brief period. The PDC process, to some degree, was eclipsed by the activity of a congressional working group that was developing legislation for mining waste. This is briefly discussed in the following section.

3.6 Reauthorization of the Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act is to be reauthorized by Congress in the near future. At the time of this report, over 120 bills have been introduced to amend RCRA. While the PDC was undertaking its discussions, a separate meeting process with interest groups and state and federal government representatives is being undertaken with Congressional Representatives. The purpose of the meetings is to discuss legislation for mine waste that would be included in the RCRA Reauthorization bill. During hearings in the U.S. House of Representatives held in September, 1991, Committee Representatives, including Chairman Swift (D) Wash., expressed interest in the PDC discussions. The result of the process was a bill introduced by Rep. Swift.

3.7 Mine Waste Management Trends

Several significant legislative and regulatory initiatives have been undertaken at both the federal and state level to address the management of mining waste.

3.7.1 Federal Trends

At the federal level, in addition to the RCRA mine waste initiative, there has been increased attention given under the Clean Water Act and the Federal land management laws to the management of mine waste. Unlike coal mines which have been subject to the comprehensive Surface Mining Control and Reclamation Act (SMCRA) and regulated by the Department of the Interior's Office of Surface Mining, Reclamation and Enforcement, environmental regulation of hard rock mines have been principally regulated by EPA through the Clean Water Act and other media laws. In addition, those that have been operated on federal lands have been regulated through the statutory authority vested in the land management agency, the two principle agencies being the BLM and USFS.

There has been substantial controversy about the regulation of hard rock mines on federal lands. The Mining Law of 1872 gives the miner the right to enter and explore for minerals on federal lands. Many have complained that the 1872 mining law is either weak or has not been enforced with respect to environmental protection and reclamation. The miner has the obligation to perform certain tasks, including reclamation, in accordance with the regulations of those agencies as promulgated under their respective statutory authorities, which include the Federal Land Management and Policy Act (FLPMA) for the BLM and the Organic Act for the USFS. As questions have been raised about the effectiveness and implementation of these regulations federal land management agencies have become more aggressive in imposing requirements upon mines on federal lands. For example, the BLM has taken initiative to remove individuals from public lands who are not fulfilling the requirements for exploration under the 1872 Mining Law, to establish guidelines for heap leaching operations and to improve its bonding requirements. The USFS has also increased its scrutiny of hard rock mining operations. Notable examples include greater intensity in heap leach reviews and the imposition of quality assurance/quality control on operations.

The Clean Water Act has spawned several activities in the past few years impacting mining operations and management of mine waste units. The non-point source program (Section 319) has identified mining operations as significant source of non-point pollution. The stormwater regulations, which require management of all water coming into contact with mine waste, have forced mining operations to give greater consideration to total water management. Strict water quality standards have required significant increase in treatment to meet standards.

3.7.2 State and Local Government Activity

Several states have begun actively modifying mining, reclamation, water quality, and waste management laws in response to increased social expectation about preventing impacts to the environment and in anticipation of the development of a federal mining waste management program.

States recently passing mining and reclamation legislation which have a direct bearing on the management of mining waste include Alaska, Oregon, California, Nevada, and Colorado. States considering legislation include Washington and New Mexico. The common themes among these laws include the opportunity for public participation, the establishment of fee based programs, increased stringency for reclamation performance bonds, more substantial monitoring and verification of performance.

States have been responding to the implementation requirements of the Clean Water Act pertaining to stormwater. Operators having NPDES permits will need to modify those permits to include stormwater requirements. New operators will need to address stormwater management as well as point source discharge from treatment facilities and conveyances.

Groundwater protection is an area where the federal government does not have direct authority. States have been developing laws for the protection of groundwater resources, some with particular regard to discharges from mine waste facilities. Among others, Arizona and Colorado are implementing groundwater protection programs.

In summary, the trends indicate greater public involvement in the development of mining operations. The public expectation of performance has increased, and the demand to not repeat the historical impacts of mining is increasing the standards placed upon today's operations. In addition, the government employees are becoming increasingly sophisticated in the understanding the technology and capability of mining companies to comply with requirements.

4.0 STRAWMAN II - TECHNICAL CRITERIA

As stated in previous section, the Strawman II is a regulatory concept. It is used in this report as the point from which to assess the regulatory implications to Alaska of RCRA mine waste management program because it is the most complete RCRA model to date. The technical criteria of Strawman II are found in Section 40 CFR XXY of the Strawman II document. The concept behind the technical criteria is to allow for a tailored, risk-based strategy to respond to site-specific conditions. The key provisions in the Technical Criteria are the performance standards. Generally, design and methods for operations of a tailings facility are driven by the performance standards. Under Strawman II the applicant or operator of a tailings disposal facility must demonstrate that the design and methods of operation will meet the performance standards. With few exceptions, conventional methods of disposal for tailings for the State of Alaska are acceptable provided that the performance standards can be met. The exceptions may include lake disposal and marine disposal.

Technical criteria for specific locations have particular applicability to Alaskan tailings management. Strawman II would not ban the disposal of tailings in these special locations, but would require demonstrations be made to the regulatory authority to assist in the determination whether performance standards can be met. These special locations include floodplains, wetlands, seismic impact zones, unstable areas, karst terrain, fault areas and permafrost. Except for karst terrain, almost any disposal site found in Alaska would involve one of these special locations.

With respect to this report, the technical criteria for Performance Standards, Design and Operation, and Closure and Post-Closure Care are the applicable sections to review as they may have implications unique to Alaska. The sections addressing Monitoring and Verification Criteria, Corrective Action Criteria, and Financial Responsibility address activity that is based upon meeting the Performance Standards, following the Design and Operation plans and performing Closure and Post-Closure Duties.

The following sections discuss the applicability of the technical criteria to the management of tailings in Alaska.

4.1 Performance Standards (40 CFR XXY, Subpart C)

4.1.1 Performance Standards for Characterization of Regulated Materials and Site Factors (40 CFR XXY, Subpart C.A.)

The Strawman II technical criteria for characterization of tailings are designed to address the broad range of risks posed by facilities and materials that would be regulated under a mining waste program. The materials, methods and procedures discussed in subsequent sections of this report would be acceptable for physical and chemical characterization of tailings in Alaska using Strawman II technical criteria.

The process of physical characterization of Alaskan tailings is oriented toward the unique environmental conditions involving extreme changes in weather. It is necessary to evaluate characteristics that will assist in the prediction of the behavior of tailings impoundments under conditions such as permafrost and freeze/thaw cycles.

Methods and procedures for chemical characterization under the Strawman II allow for the methods and procedures identified in this report. In particular, Strawman II did not specify appropriate methods to measure acid generation potential. The methods recommended in this report would be appropriate for Alaskan conditions and should be included as acceptable under a regulatory program.

The Strawman II characterization requirements were not complete as indicated in the EPA discussion sections within the regulation. The minimum requirements proposed for total constituent analysis using SW-846 is acceptable for Alaskan tailings. Other requirements under this section are broad in nature and would allow for procedures and methods appropriate to a specific site in Alaska.

Site characterization necessary to predict the physical and chemical behavior of a tailings impoundment is required under the Strawman II concept and is appropriate for Alaska. Where there would be a release to the environment of leachate or material, an identification of environmental receptors would be appropriate.

4.1.2 Performance Standards for Ground Water (40 CFR XXY Subpart C.B.)

The United States does not have a national ground water program of the same nature of the programs designed to protect surface waters under the Clean Water Act. Protection of ground water is the responsibility of the states. The Strawman II technical criteria for ground water is designed to allow for implementation of a ground water protection scheme established by the state. However, of critical importance, groundwater tributary to surface water must be protected in a manner that will protect surface water uses and meet surface water standards.

In Alaska, tailings disposal could be regulated under the Alaska Statue 46.03, Water Pollution Control and Waste Disposal, administered by the Alaska Department of Environmental Conservation. This law is oriented toward municiple land fills, and generally tailings have not been regulated under this law. The DEC has given notice that they intend to issue permits to some lode mill tailings impoundments using this authority. The protection of groundwater under this authority is by use classification. Performance standards are established for each class.

The appropriateness of any designs and methods of tailings disposal discussed in this report depend upon the specific site conditions and the characteristics of the groundwater resource. With respect to the disposal of tailings, the appropriateness of any of the designs and methods of disposal discussed in this report depend upon the specific site conditions and the characteristics of the ground water resource. If a situation exists where no discharge to groundwater is allowable then some methods of disposal that discharge elevated levels of metals or other constituents would not be allowable. However, use of liners and the operation of a water treatment facility to prevent migration of any pollutant may result in a project not being economically feasible.

Strawman II requires that the point of compliance for discharges to ground water be as close to the boundary of the mine waste unit as practicable. Alternative points of compliance may be designated based upon site specific conditions. In no case can the point of compliance be further than the facility's property boundary. In Alaskan situations, this would only preclude the development of a particular tailings disposal design or method of operation on a site specific basis.

Generally, the Strawman II criteria for protection of groundwater may result in a high ranking of geologic conditions in the site selection process. Seepage control measures, such as those discussed in Section 5.5.4, may be required for development of a tailings impoundment.

4.1.3 Performance Standards for Surface Water (40 CFR XXY, Subpart C.C)

Discharge from tailings facilities to surface water must be in compliance with the Clean Water Act. If the materials characterization indicates specific parameters of concern for which standards have not been established, then a standard shall be set for those of concern. Strawman II sets out a hierarchy for establishing standards, which includes the use of background and risk based standards. With respect to the dry land tailings disposal methods discussed in this report, there is nothing resulting from the surface water requirements that would categorically preclude the use of the methods presented. Some methods may be precluded based upon the surface water standards and specific site conditions.

Disposal of tailings in lakes or marine waters (aqueous disposal) most likely is not allowable under the Strawman II concept. As is discussed in Section 5.4.2, aqueous disposal may be an effective means for control of acid generation and long term management of tailings, but the performance standards and the uncertainty of some chemical reaction would likely prevent approval of an aqueous disposal plan. The development of an Alaskan program will need to examine the merits of aqueous disposal.

4.1.4 Performance Standards for Air Quality (40 CFR XXY, Subpart C.D)

Performance standards for air quality would be established based upon the results of the materials and site characterization. The determination will be based upon the potential for air migration through fugitive dust. If it is determined that there is a potential for adverse impact to human health, then a numerical standard may be set for a particular parameter. A management practice for controlling emissions can be used in lieu of a numeric standard. A point of compliance needs to be selected. Again, there is nothing in the performance standards for air quality that would categorically preclude the use of specific tailings disposal methods and practices.

4.1.5 Performance Standards for Soils and Surficial Materials (40 CFR XXY, Subpart C.E.)

Standards can be set for concentration of elements allowed for soils and surficial materials. These standards are to be based upon the materials and site characterization. Management practices can be established as standards in lieu of numeric standards. Points of compliance are to be the point of contact exposure to the soils. There are no requirements that would categorically preclude the use of any of the tailings disposal methods discussed in this report in Alaska. Determinations of preferred methods of operation and controls would be made on a site specific basis.

4.2 Design and Operating Criteria (40 CFR XXY, Subpart D)

4.2.1 General Criteria (40 CFR XXY, Subpart D.A.)

This section requires that tailings disposal units be designed and operated in a manner that meets the performance standards. Since the performance standards are based upon the materials and site characterization under Subpart C, and since the characterization drives the numeric standards or management practice, then the design and operations are dependent upon the site specific conditions. Structures must be stable and not release in excess of the performance standards, and operators must ensure that catastrophic failure does not occur.

With respect to prevention of catastrophic failure or discharge in excess of the standards, performance is highly dependent on the ability of water management facilities to cope with extreme events. This is discussed in detail in Section 6.0 as the requirement pertains to Alaskan conditions.

This section addresses requirements for run-on and run-off controls, co-mingling or mixing of hazardous and non-hazardous waste, unauthorized access, human contact, surface impoundments, land application of waste and protection of biological resources. With the exception of co-mingling, none of the design and operating criteria would categorically preclude the methods discussed in this report. The standards in this criteria are all site specific, and as such, specific design and operation standards have not been set.

Co-mingling or mixing of hazardous and non-hazardous waste streams, which may be cost effective in Alaska, is not allowed under this provision, unless the facility is designed and operated as a hazardous waste facility. This report does not address the operation and design of tailings facilities to handle hazardous waste.

4.2.2 Criteria Applicable to Regulated Units in Specific Locations (40 CFR XXY Subpart D.B.)

Strawman II does not ban the installation of tailings in specific locations which are considered environmentally sensitive. For such areas it requires demonstrations specific to the location that would assist regulators in making determinations that the facility will meet the performance standards. Specific locations pertinent to Alaska include floodplains, wetlands, seismic impact zones, unstable areas, fault areas and permafrost. The only additional specific location presented in Strawman II is karst terrain which is not evident in Alaska.

These specific locations and the design and operating criteria applicable to them would be a consideration in most any tailings facility development in Alaska. As discussed in the preceding section, Alaska has very diverse climatic regions, and much of the mine development is in or near floodplains, wetlands, seismic impact zones, unstable areas, fault areas and permafrost. Section 5.0 discusses the influence that these climatic and geologic regions have upon the behavior of tailings disposal facilities, and identifies the appropriate design and methods of disposal for specific locations.

Again, no specific design or operating method is precluded by the criteria, but some may be eliminated by virtue of their inability to meet the performance standards. Some conditions may enhance performance of the structure. An example of such a situation is in permafrost conditions as discussed in Section 5.3.2.

Seismic impact zone criteria contained in Strawman II may not be sufficient for Alaskan conditions. Given the long term performance requirement and the requirement to prevent catastrophic failure, the design criteria for potential forces which could result in catastrophic failure should be based on the maximum credible event. Strawman II performance is based upon the maximum horizontal acceleration as defined in sub-part D.B.C.3. This is discussed in detail in Section 5.5 of this report. The regulatory authority is not precluded from modifying the requirements to meet site specific or regional circumstances.

4.3 Closure and Post-Closure Care Criteria (40 CFR XXY Subpart G)

4.3.1 Closure Plan (40 CFR XXY Subpart G.B.) and Post-Closure Care Plan (40 CFR XXY Subpart G.F.)

At the time of initial approval of a tailings disposal facility, the owner or operator must prepare a detailed plan for closure. In Alaska this means that consideration at the time of the initial application of the specific locations conditions at closure is extremely important. The long term regulatory performance requirement for some specific locations needs to be carefully evaluated.

The operator must also prepare a detailed post-closure care plan. This plan is implemented immediately after the facility is certified as closed and remains in effect for 30 years. Upon completion of the post-closure period, the facility is certified as completed, however, the owner operator is not released from future corrective action or liability. This has implications for the design and construction of Alaskan tailings facilities because of the need to anticipate maintenance needs during this extended period of care and the long term stability of the facility. Permafrost and other conditions may require unique maintenance requirements.

A major consideration is the cost of post-closure care and the cost of carrying a financial warranty during that period. Some less expensive design and operating methods may lead to a more expensive post closure care period than those requiring higher initial capitalization or costs. From a long term perspective, considerations such as designing for the probable maximum flood (PMF) may be appropriate to reduce the maintenance requirements.

These issues are addressed in detail in Sections 5.0 and 6.0.

5.0 TAILINGS DISPOSAL OPTIONS

This section discusses the critical elements of tailings disposal options and factors pertaining to the unique Alaskan environment. Material characterization, disposal methods, facility design and engineering, and environmental factors are addressed.

5.1 Tailings Characterization

The properties of tailings are well described by SRK et.al., 1987 and Vick, 1990, and only a brief overview is provided here. Characterization of tailings can be conducted in two parts, physical and chemical.

5.1.1 Physical Characteristics

COMMENT

The Strawman II requires the physical characterization of waste materials (40 CFR XXY Sulpart C.A.). It also includes clear criteria on the post-closure care and continued structural stability of regulated units in Subpart D: Design and Operating Criteria, A.1 and A.2. The physical properties of materials used in constructing or contained within a regulated unit must be understood in order that physical impacts such as sediment release or slope failure are not in exceedance of performance standards. In addition, where materials are used to provide physical means for meeting performance standards for surface and groundwaters, such as an embankment to maintain a water cover over potentially acid generating material, then the physical properties of the construction materials must evaluated. Grain size, shear strength, durability, and hydraulic conductivity are the most important physical properties to identify. Unfavorable materials for construction, which are typical of rock in some areas of Alaska, are soft degradable rocks such as mudstone or shales or weathered rock masses. Strawman II requirements would allow for the methods described herein.

5.1.1.1 Grain Size, Type and Permeability

Grain size distribution and type is normally determined by the ore type and the milling process and is beyond the control of the impoundment design engineer. It is the most fundamental property of the tailings and, controls the basic engineering property of permeability. A first estimate of permeability can be made from the grain size distribution using Hazen's formula as described by Blight, 1987.

Of greater importance in any tailings impoundment is the variation in permeabilities resulting from grain size variations caused by segregation during tailings placement. Variations in permeability between the sand and slime zones of a tailings impoundment may be as much as three orders of magnitude. Thus the sand zone from a cyclone split tailings, or at the top of a well segregated spigot discharge placed beach, may be one to two orders of magnitude greater in permeability than the average (unsegregated) tailings.

Layered beach deposited tailings are highly anisotropic. The permeability parallel to the layering can be one to two orders of magnitude greater than permeability perpendicular to the layering. Such layering is adversely oriented for drainage purposes and is therefore undesirable. Ice layers that form in the beaches, as occurs in Alaska, are barriers to drainage. Thin layer spigotting (Section 5.6.3) is sometimes practiced to increase the settled density and reduce anisotropy, however, it does not appear to work well in cold climates.

5.1.1.2 Consolidation Characteristics and Density

During consolidation, the effluent in the pore spaces is squeezed out resulting in a closer spacing of the grains. Consolidation under an increase of stress results in a decrease of the void ratio and an increase in the dry density of the tailings which causes a decrease in the permeability as shown in Figure 5.1. Consolidation is stress history dependent, and for each tailings sample there is a void ratio effective stress relationship, as described by Blight and Steffen, 1979. Effective stress increases causing consolidation can result from any of the following:

i) additional layers of incumbent tailings;
ii) drawdown of water table due to underdrainage; and
iii) pore suction due to evaporative drying.

5.1.1.3 Shear Strength

The shear strength of tailings is generally of importance only where tailings are used for embankment construction, or when operation of construction vehicles is anticipated on the surface of the tailings. The shear strength of tailings is described by the equation:

$$s = c' + (\sigma - u) \tan \phi'$$

where:

- s is the shear strength of the tailings,
- c' and ø' are the effective cohesion and friction angle of the tailings as defined in classical soil mechanics theory,
- σ is the normal stress on the failure surface, and
- u is the porewater pressure on the failure surface.

The effective cohesion is usually very small in under or normally consolidated tailings. Thus the shear strength exhibited by tailings is mainly due to the effective friction angle, ø'. The term in which ø'

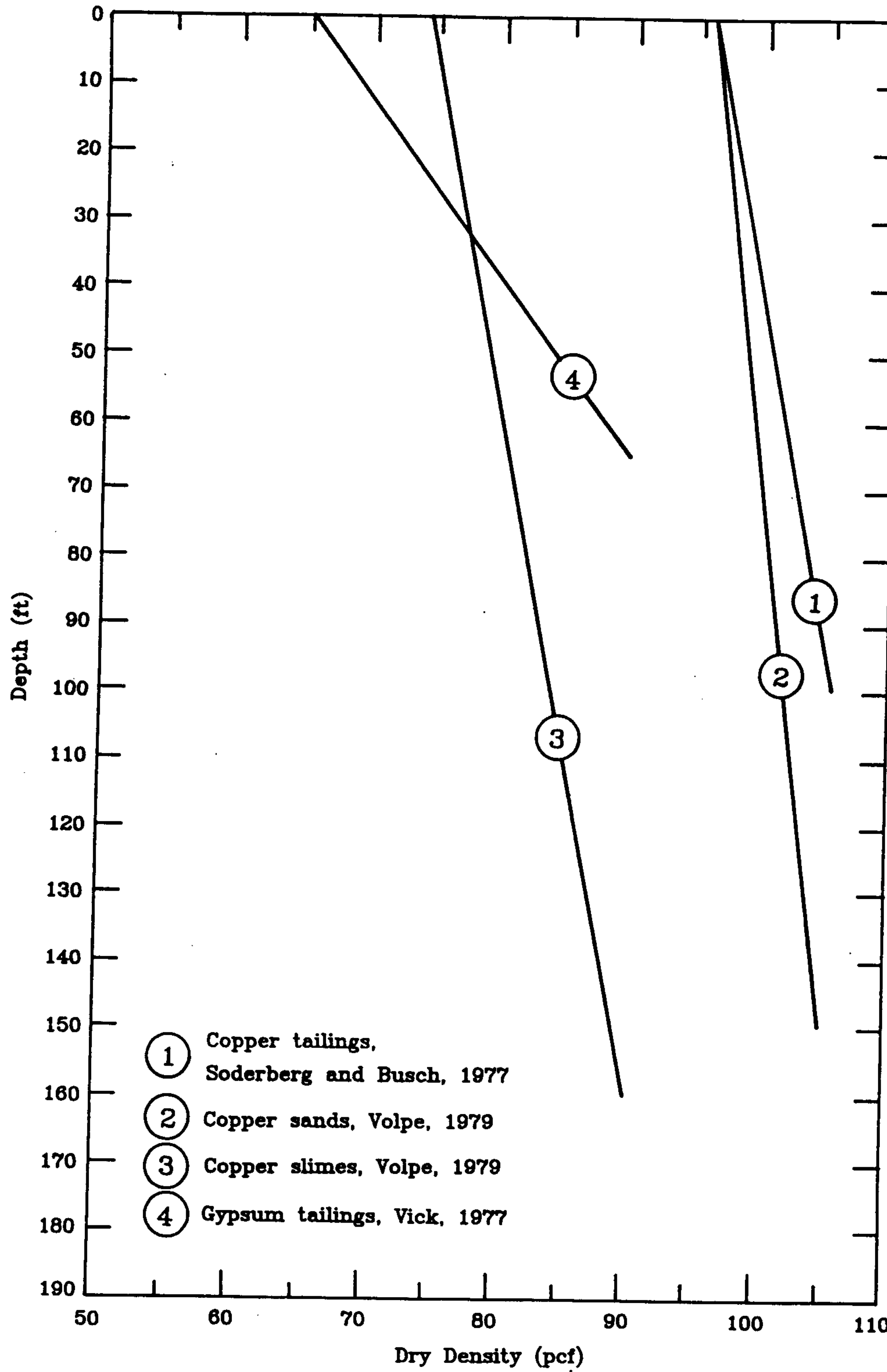


Figure 5.1 Tailings Density Variation With Depth (From Vick, 1990)

appears includes the sum of the normal stress less the effective pore pressure. If the tailings are dry then u is zero and the tailings have an appreciable shear strength. Thus it is possible for construction vehicles to travel on the dry beach areas of tailings impoundments. In the saturated areas, the application of a load causes pore pressures to rise resulting in low shear strengths. Thus it is not possible to travel with construction equipment on wet tailings fines. Where tailings are very coarse, the rate of drainage and pore pressure dissipation is sufficiently fast to allow significant loads to be applied to the tailings. Thus it is possible to construct embankments on the coarse beach tailings even though they may be saturated.

5.1.1.4 Liquefaction Potential

Hydraulically placed tailings sands and silts are usually in a state of low relative density (less than 60%) and if saturated are susceptible to liquefaction under dynamic (seismic) loadings. During dynamic events, such as earthquakes, the tailings are subjected to rapid reversals of shear loads. Under these loads relatively low density tailings may consolidate, resulting in the generation of high pore pressures and a large loss in shear strength. Discussions and texts on appropriate evaluation and design methodologies are provided elsewhere (ASCE, 1982, Vick, 1990, and Vick et al 1985). In areas subject to seismic risk, it is usually necessary to design to allow for the potential for liquefaction. This generally means the avoidance of upstream construction methods.

5.1.1.5 Frost Action

The effect of freezing tailings is to prevent consolidation and drainage for as long as the tailings are frozen. In northern Canada large accumulations of frozen tailings have occurred under the beach areas of annually layered tailings impoundments. About 20% of the impounded volume was ice at one Canadian site located south of the discontinuous permafrost line. At another site the ice was still present 50 years after deposition. The zones under the pond tend to not freeze. On thawing the low density frozen tailings will consolidate resulting in large surface settlements. Such settlements would disrupt surface drainage and capping layers. During freezing the ice crystal formation forms interconnecting voids in the tailings mass resulting in a modified soils structure and a very large increase in permeability upon thawing.

In permafrost regions, the tailings will remain or become frozen. Only the active layer will thaw and be continually modified by frost action.

Cycles of freezing and thawing of the final surface are generally prevented in a tailings impoundment which has a water cover.

5.1.2 Chemical Characterization

The chemical aspects of tailings and tailings pore water are key issues in trying to understand and predict the environmental impact in terms of surface and groundwater quality. Primary considerations are:

i) potential for chemical changes of the tailings solids by oxidation (acid drainage) or metal leaching; and,

ii) potential for release of soluble products from the pore water upon or following deposition.

COMMENT

Strawman II approach requires the chemical characterization of waste materials as outlined in subpart C: Performance Standards A.2.

5.1.2.1 Prediction of Acid Rock Drainage

Acid rock drainage (ARD) is contaminated drainage resulting from oxidation and metals leaching of sulphide bearing rock when exposed to oxygen and water. Oxidation and flushing of the sulphide minerals results in drainage water with elevated acidity and sulphate levels, and low pH which can leach metals from the surrounding rock. Neutralization of the acid and complexing precipitation reactions along the drainage water flow path can further alter drainage water quality upstream of the receiving environment. These are naturally occurring weathering reactions which are accelerated by mining excavation and construction activities. The milling process results in exposure of large quantities of sulphide bearing material in a short period of time with greatly increased surface area compared to natural (insitu) conditions. The comprehensive Draft Acid Rock Drainage Technical Guide (SRK et.al., 1989) provides a complete reference on the processes, prediction, control, remediation and monitoring of acid rock drainage, and only a brief review of prediction is provided here.

Geochemical static tests, often called acid-base account (ABA) tests, are relatively simple, inexpensive tests used in the initial evaluations and material characterization. The U.S. EPA standard methods are described in the literature, specifically, "Field and Laboratory Methods Applicable to Overburden and Minesoils" EPA 600/2-78-054, 1978. A static test defines the balance between potentially acid generating materials (reactive sulphide minerals) and acid consuming minerals (generally carbonate minerals). A sample of tailings will theoretically generate net acidity at some point in time only if the potential acidity exceeds the neutralization potential. Static tests are limited in prediction of acid generation potential in that they assume all sulphide and alkali is available and do not account for relative reaction rates.

Kinetic test procedures have been developed to simulate natural weathering processes, under controlled laboratory or field conditions, to predict the relative rates of oxidation, acid generation, depletion of neutralization potential and metal release.

Whereas static tests can be used for material characterization of the overall potential for acid generation independent of time, kinetic tests define reaction rates and are necessary to predict drainage water quality. These tests are used to evaluate the tailings under uncontrolled conditions (as disposed) and alternative control measures.

Kinetic test procedures commonly used for prediction include small scale humidity cells, column testing and field test plots. A range of flushing rates, and water quality (eg. pH, oxygen concentration) of the flushing solution may need to be tested to simulate site conditions.

There are three approaches to the control of acid rock drainage:

i) control of acid generation reactions;
ii) control of migration; and
iii) collection and treatment.

In the case of a tailings impoundment, control of the acid generation reactions is best provided by exclusion of oxygen with a water cover. However, migration of water through the material, as well as oxygen diffusion, will import some oxygen and therefore, very slow oxidation of sulphides will occur. The solubility of oxygen in water is very low and is generally rapidly depleted, which results in anaerobic conditions within the tailings solids. Note that saturated tailings consolidate more slowly than unsaturated tailings and settlement will occur for many years after the end of operation. Where a water cover is used to control acid generation this is not usually an issue because settlement only results in increasing the depth of the water cover.

The rate of oxidation is dependent upon the rate of oxygen entry into the tailings or waste which is governed partly by the seepage path and rate. Figure 5.2 shows four potential seepage paths through a tailings impoundment. Predictions of discharge water quality resulting from each of these potential seepage paths may need to be conducted for sensitive sites. Where contamination of the pore fluids occurs as a result of oxidation and metals leaching it is usually necessary to model the diffusion and/or seepage rates into the water cover or underlying soils, to determine environmental impact and requirements for control of migration and/or collection and treatment.

The conclusions that can be drawn from the currently available technology for acid generation control can be summarized as follows:

1. Prevention of the acid generation reactions is the most preferable form of control and should, if at all possible, be the primary long-term approach. The design for ARD prevention at proposed facilities should aim to exclude one or more of the principal ingredients in the acid generation reactions.

2. The exclusion of oxygen from reactive wastes by means of a water cover is currently the most effective acid generation control measure. Water cover (underwater disposal or a saturated soil/bog cover) for preventing acid generation should be evaluated first. Care should be exercised when considering flooding existing waste deposits due to potential high loads of stored oxidation products within the waste. Proposals to dispose mine wastes, such as tailings, into natural water bodies are often opposed by regulatory agencies and the public for environmental and political reasons. The cost of on-land disposal under water cover, relative to lake or marine disposal, and the environmental implications associated with all methods need to be investigated in full.

3. Control of the acid generation process for abatement of ARD at existing facilities is often not practical, has limited success, or is extremely costly. In these cases, acid generation control techniques may be used to reduce the rate of acid generation in conjunction with control of ARD migration and, if necessary, collection and treatment of ARD.

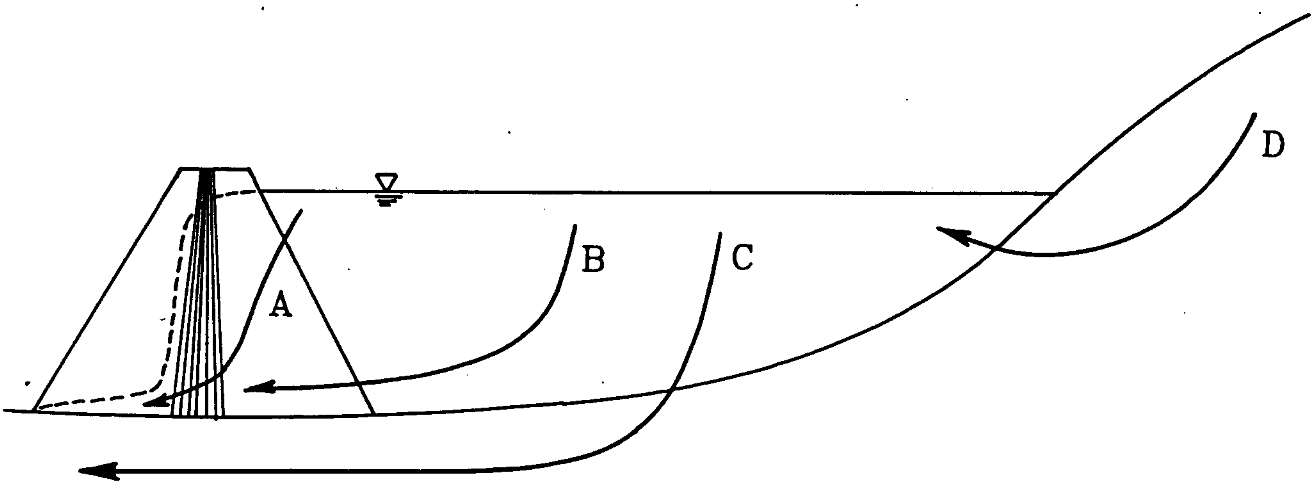
4. A combination of various measures may produce the most efficient control of ARD for both existing and proposed facilities and in the short or long term. Measures of the control of acid generation should be evaluated in conjunction with control of ARD migration and collection and treatment.

5. Construction methods and extraction processes that result in conditions favorable for preventing acid generation, such as bulk sulphide flotation of tailings should be considered for proposed facilities. However, additional control measures are likely to be required for the separated material.

6. Covers and seals show promise as inhibitors of migration of oxidation products and, to a lesser degree, of acid generation reactions provided these are maintained in good order as designed. Certain types of covers and seals are very effective in reducing infiltration of precipitation. Soil covers, in particular, are suitable for re-vegetation purposes.

7. The use of bactericides might be a suitable short-term acid generation control measure. It should be remembered that bactericides have a limited life and control only the biological oxidation processes and not chemical oxidation of the sulphides. Additional controls are necessary if the waste has insufficient natural potential to neutralize acid generated by chemical oxidation.

8. Base additives are generally a suitable short-term control measure. In some cases, base additives may be suitable in the long-term, depending on the quantity, type and reactivity of the sulphide minerals. Blending of mine wastes is a form of base addition in areas



A: Seepage of supernatant through embankment

B: Seepage of pore water through embankment

C: Seepage of pore water through foundation

D: Seepage of groundwater through tailings

Figure 5.2 Potential Seepage Pathways Through a Tailings Impoundment

(After SRK, 1991b)

where limestone or other alkaline strata occur in the overburden. This method has been successfully used in the coal mining industry.

In addition to the above general points regarding ARD control, cold temperatures and permafrost can be used as a control measure in tailings:

- if voids are filled with water when frozen there is no oxygen;
- within permafrost the transportation mechanism has been removed providing control of migration;
- both chemical and biological oxidation rates are reduced at low temperatures;
- measures can be taken to induce permafrost such as coarse rock covers, heat pumping (cryopiles); and
- there will still be a surface depth of thawing which should contain non-acid generating material.

5.1.2.2 Leaching Of Metals

Leachates, in this document, refer to drainage water that has been chemically contaminated by soluble constituents from tailings, pore water, or the materials contained in constructed facilities including embankments and spillways. Removal of soluble constituents may include dissolution of precipitates from other solids such as water treatment sludge which may have been co-disposed with the tailings (See Section 2.1 for discussion of regulatory implications of co-disposal.).

The main contaminants of concern in seepage, drainage water or surface water decants would include:

- oxidation products or other soluble products such as sulphate and acidity;

- soluble metal salts stored within the wastes from oxidation, leaching and precipitation reactions. The metals will be specific to the waste type mineralization, but typically include iron, zinc, copper and lead; and

- metals released by continued oxidation.

Other sources of contaminants may include:

- mill reagents including, pH modifiers, flotation reagents, leaching agents such as acids or cyanide, or flocculants or dispersants; and

- nitrogen species (nitrates, ammonia) from explosives.

Leach Extraction Tests

Short term leach extraction tests are used to determine the readily soluble component of a sample. There are a number of different test procedures which vary primarily in the duration of the test and the nature of the extractant. These tests are useful in the initial phases of testing program to indicate the short term leaching characteristics and potential for metal release from a sample. This can also indicate the extent to which oxidation has occurred in a sample if the flushing regime is known. These tests are particularly useful for the evaluation of existing tailings, and for samples which contain readily soluble contaminants as the tailings are produced.

There are a number of procedures used for these extractions which vary primarily in the nature of the extractant and the duration of the test. The sample is combined with water or a weak acid in a 1:20 ratio and gently agitated to maintain the solids in suspension for 18 to 24 hours. Solution pH may be monitored or adjusted periodically, and the final leachate analyzed for such parameters as pH, Eh, conductivity, sulphate, alkalinity, acidity, and metals. These tests provide an indication of the readily soluble load in a material, and of the extent of acid generation that has already occurred in the sample. This load would be primarily a short term water quality concern, released from the tailings soon after placement in the impoundment and exposed to precipitation.

Numerous laboratory test procedures have been introduced in Canada and the United States over the years, all of which have the objective of quantifying the mobility of the contaminants and thereby enabling the classification of the waste for the appropriate method of disposal and containment requirements. Such tests have a variety of names such as B.C. Special Waste Extraction Procedure, TCLP, EPA 1312, ASTM 3987, SWEP Test and so on. While the objective of each of the tests is the same, the procedure and thus the relevance of the results of mine wastes varies for each test. Some of the more commonly used tests include:

- ASTM D3987 distilled water extraction;
- B.C. Special Waste Extraction Procedure (SWEP) using an acetic acid extractant;
- U.S. EPA 1312 procedure using a nitric/sulphuric acid extractant;
- U.S. EPA 1312 or TCLP leach test using acetic acid based extractant.

Most of the studies evaluating the relative merits and applicability of each test have concentrated on the hazardous waste applications. Two such studies are documented in the literature, and a study is currently in progress in British Columbia to evaluate the use of the above mentioned tests for use on mine rock and tailings. At this time it appears that the EPA 1312 test (designed for mine soils and overburden) and a distilled water or site water shake flask extraction procedure similar to the ASTM 3987 are the most applicable tests. There is growing recognition that acetic acid leachant may not be appropriate for arsenic, copper and lead extraction. However for all of these procedures it must be recognized that the fine sample particle size and short duration of the test do not represent field conditions. The results of these test indicate a total soluble load for the sample.

The prediction of potential leachability must also consider the effects of dilution within the tailings impoundment, and water cover over the waste material. Generally, strong acid based tests are inappropriate for prediction of leachates from tailings impoundments, although in areas where acid rain is a concern, leaching tests using solutions with pH as low as 4.5 may be appropriate. Acid rain is not a concern in Alaska.

5.1.2.3 Flushing Of Pore Water

The effects of many of the flotation and milling reagents cannot be quantified by direct analysis. The effects of reagents used in the mining and milling processes can be evaluated with bioassay tests which determine the effect of effluent water on aquatic biota.

5.1.2.4 Oxidation Of Thiosalts

When iron sulphides, such as pyrite, pyrrhotite and marcasite are processed in highly alkaline solutions a small quantity of the iron sulphide reacts to produce thiosulphate and polythionates. When these reduced sulphur compounds are placed in the tailings impoundment, oxidation takes place resulting in the formation of sulphuric acid. This process has resulted in a pH decrease from 10 to as low as 4 from the point of tailings discharge to the pond decant point. Prevention of environmental impact by the thiosalts can be achieved when they are destroyed during warm weather. This requires that the retention time in the ponds is sufficiently long and the acidity is treated prior to discharge from the impoundment. In cases where thiosalts may be present in the tailings pore water it may be necessary to add an alkaline cover over the tailings to consume the acidity.

The primary chemical concern with tailings is the potential for ARD. Acid base accounting, should be conducted for all tailings, using EPA methods described above. Where these tests indicate there is a potential for acid generation then kinetic tests should be conducted except possibly in cases where immediate and long-term underwater disposal is to be used. Notwithstanding the results of ARD prediction results, leach extraction tests should be conducted on samples of the tailings and process water as the are expected to be produced at the site. Methods such as AS7M 1312 appear to be the most suitable.

5.2 Placement Methods for Tailings

There are several methods for the placement of tailings. They can be divided into two categories; wet or slurry methods, and reduced moisture content methods such as thickened and dewatered tailings.

The tailings slurry is usually thickened to 35 to 40% solids and discharged by either point or line discharge. Discharge can be either onto a beach which is called sub-aerial discharge or underwater which is called sub-aqueous discharge. Sub-aerial and sub-aqueous discharge are generally the lowest cost methods of tailings placement but they also result in the lowest final density, which can effect storage capacity and shear strength.

5.2.1 Sub-aerial Discharge

Tailings can be discharged onto a beach which tends to give slopes in the range of 1/2 to 1°. Beach discharge results in segregation of the tailings and a settled density which is higher than for underwater discharge. Beach discharge can result in excessive ice lens formation during winter in cold climates. Up to 20% of the total contained volume has been found to be ice at some sites in Canada, not necessarily north of the permafrost line. Many northern sites use beach discharge in the summer months only. Point or subaqueous discharge is used in the winter months.

Grain size segregation during discharge will affect the beach geometry. The resultant shape of the beach is important because it determines the spacing of spigot points to prevent fines accumulation in hydraulic fill embankments, and the depth of flooding needed at the dam to provide a complete water cover where ARD control is required. The grain size classification that occurs along the beach of a tailings deposit has been examined by a number of researchers (Vick 1985, Melent'ev et.al. 1973, Blight 1987, Blight et, al. 1985, Wates et.al. 1987 and Williams and Morris 1987, Geocon 1986) and is summarized below. Further work on tailings beach slopes is presented by Conlin, 1989.

It has been shown that the profile of a hydraulic beach can be described by a dimensionless master beach profile, see Figure 5.3. This profile is the same for all beaches composed of a particular tailings material deposited at a specific solids concentration. The equation for the master beach profile, shown on Figure 5.3, contains an exponent, n, which characterizes each material and slurry solids content. Since the equation is dimensionless, the parameter can be established from small-scale laboratory flume tests.

The hydraulic sorting that occurs along the beach can also be predicted from a grain size equation. This enables the permeability to be estimated, see SRK et.al., 1987a. Since particle size and permeability decreases towards the pond, the phreatic surface in the embankment is lower than would be predicted assuming constant isotropic permeability. The permeability and settled density are important because they determine the long term consolidation characteristics and the rate of pore fluid release and diffusion out of or into the tailings. This directly effects the contaminant migration into surface or groundwater as well as physical properties of the tailings mass relating settlement and resistance to liquefaction.

It is apparent that different mechanisms cause the classification that is observed in tailings deposits. The first basic mechanism depends on slurry density. At very high slurry densities interference occurs (hindered settling). Coarse particles cannot settle out during flow, and this reduces the amount of

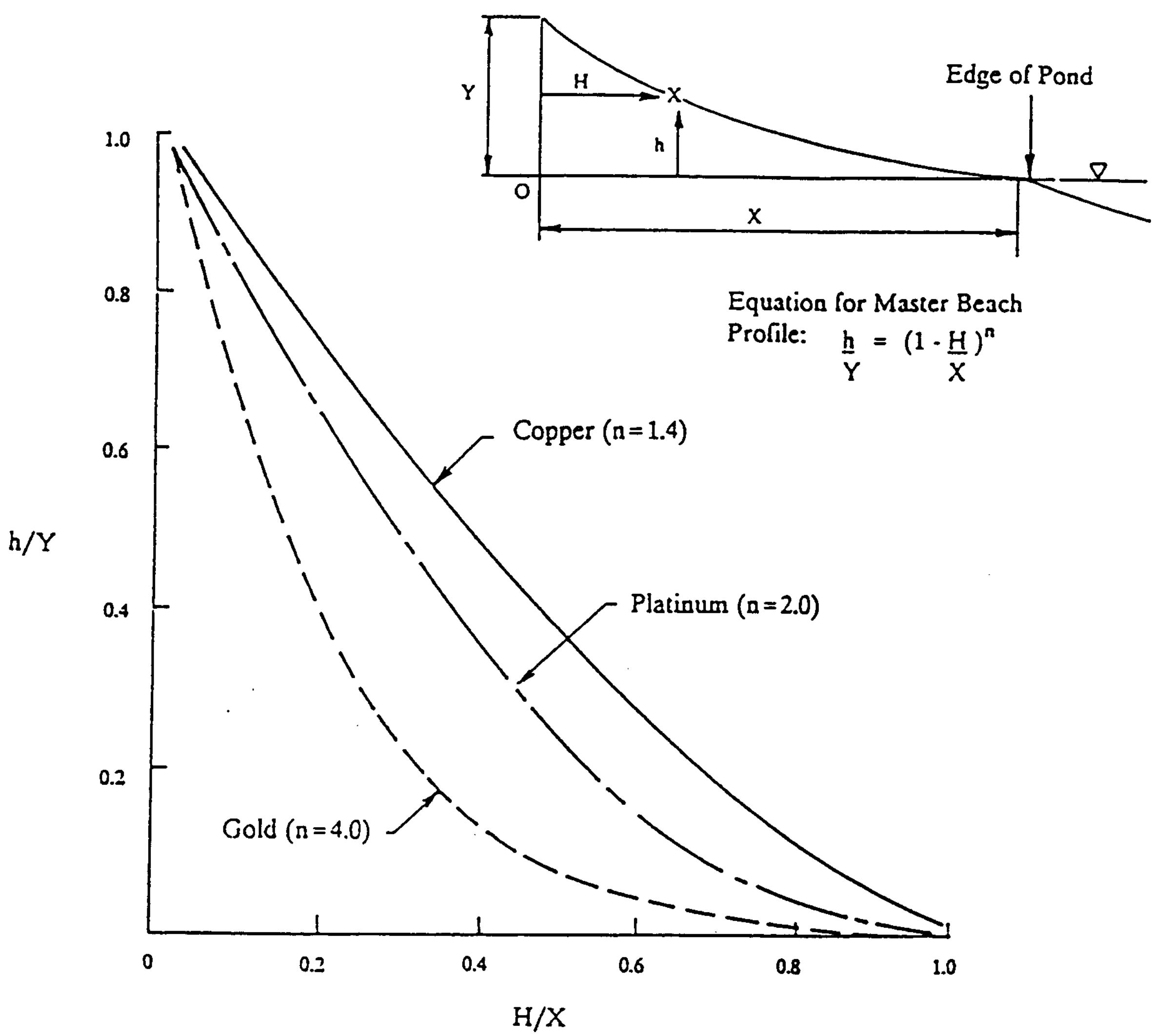


Figure 5.3 Master Beach Profiles (From SRK, 1987a)

classification and segregation along the flow path. Segregation tends to be prevented at solids to water ratios varying between 30 to 60% by weight depending on the grain size of the material. The second basic mechanism depends on the thickness of the flow. It is observed that if slurry of a given density is discharged as a shallow wide flow it tends to develop steeper beaches with less segregation than if it is discharged as a concentrated flow. Such wide shallow discharges, spreading out over the beach tend to have laminar flow, in contrast to the turbulent conditions developed in concentrated discharges.

5.2.2 Sub-aqueous Discharge

Since deposition is below water, consolidation is due to the buoyant weight of incumbent layers only (effective vertical stress not total vertical stress), resulting in very low density deposits, particularly near the upper surface of the tailings. In soils mechanics terminology these deposits are called either under or nominally consolidated. Such deposits are typical of the pond area of many tailings impoundments, which also represents a concentration of the finest grained portion of the tailings. Such deposits are characterized by a high void ratio, high compressibility and low permeability.

Tailings which are discharged sub-aqueously are normally ice free because of the water cover. Laminar flow down a beach and then into a pond results in a submerged slope typically in the range of 5 to 8°. Sub-aqueous discharge tends to produce slopes considerably steeper than on beaches. In cases where the tailings are potentially acid generating and where a single discharge point is used, then allowance for flooding the highest point of tailings should be made in the embankment design. An alternative is to use a moving discharge point on a raft or have multiple discharge points.

5.2.3 Thickened Discharge

Adapted from Vick 1990.

The thickened discharge method of tailings disposal stems from a concept first described by Shields (1974) and further developed by Robinsky (1979). Essentially the thickened discharge method relies on thickening the whole tailings to a high pulp density, about 60%, at which the tailings-water mixture behaves more like a highly viscous fluid than a liquid-type slurry. When normally discharged, liquid-type slurry has pulp densities of about 40 to 45%. At high pulp densities, the thickened tailings assume a slope of about 5% upon discharge, allowing the deposit to form the shape of a conical pile. Water remaining after deposition of the tailings is collected in a small dam at the toe of the pile.

The principal advantage of the thickened discharge method is that impoundment dams or embankments are largely eliminated, and return-water pumping is reduced. Reclamation of the tailings pile may be simplified by the flatter and more uniformly graded pile slopes, and seepage may be reduced by essentially eliminating the decant pond. There is no risk of embankment failure under static loading conditions, although there is potential for liquefaction of the tailings.

Although costs for embankment construction are largely eliminated by the thickened discharge method, the savings are partially offset by higher costs for thickener construction and operation. Also, pumping of the thickened slurry may be more costly and difficult because of higher energy requirements and possibly greater pipe wear. More surface area may be disturbed than for conventional impoundments, resulting in larger areas to be reclaimed.

Management of runoff in the area and seismic risks must be carefully considered for the thickened discharge method. If all flood runoff is not completely diverted around the pile, erosion and transport of tailings at the toe can result. Jeyapalan (1982) concludes that tailings deposited by the thickened discharge method are susceptible to liquefaction and flow sliding under moderate to high levels of seismic shaking.

In summary, the thickened discharge method appears to be best suited to disposal sites located in relatively flat topography where concentrated runoff does not occur, at sites close to the mill where pumping costs are minimized, and in low seismic risk areas. In this regard, the thickened discharge method shares many of the siting restrictions of upstream-type embankments. Also, like upstream methods, thickened discharge disposal is only applicable for tailings containing a reasonable sand fraction and without a major proportion of clayey fines.

5.2.4 "Dry" Disposal (Dewatered tailings)

Adapted from Vick 1990.

The use of belt filtration to remove water to produce "dry" tailings has recently been advocated. This method produces a more solid form of tailings which reduces seepage from tailings disposal areas.

Belt filtration is an integral part of some European uranium milling processes that have been used extensively in France and South Africa. It is currently being used at the Greens Creek Mine in south-east Alaska and the Barton Mine in New York. The operation of the belt filter device is simple in principle; the liquid is drawn from the tailings by a vacuum box as they move on an elastomer-supported filter cloth belt. The moisture content of the tailings is reduced from approximately 50% to 20-30%. Tailings come off the belt as an easily handled cake, often referred to as "dry cake," leading to the commonly used (but incorrect) nomenclature of "dry" tailings disposal. In areas of high seismicity, such as southeast Alaska, it may be necessary to place and compact the tailings in thin lifts to provide resistance to liquefaction. Erosion and the potential for buildup of a water table must be considered in any plan using "dry" tailings. "Dry" tailings disposal is not suitable for potentially acid generating tailings.

There remains considerable controversy over the economics, feasibility, and advantages of belt filtration for tailings disposal. Factors such as ore grind and gypsum content affect the efficiency of the filtration process. For some ores of high clay content the process may not work at all.

COMMENT

The climate of Alaska, and especially northern Alaska where sub-freezing temperatures can prevail for much of the year, can have a significant impact on the placement of tailings. Tailings placement methods should consider the potential effects of ice build-up on impoundment storage, water balance, and long-term consolidation.

5.3 Facility Management

5.3.1 Temporary Storage

Temporary storage of tailings is rarely practiced, except where small quantities are stored prior to use as underground backfill. These quantities would rarely exceed the total tailings production for several months. Storage may be in specially constructed tanks or ponds.

5.3.2 Permanent Storage - Site Selection

5.3.2.1 General

Site selection is concerned with the identification of potential sites for a tailings disposal site, as opposed to site layout which is concerned with the structures to be built. It should be recognized that these factors are not independent; however, in order to simplify this report they are discussed separately.

Site selection is a screening process for finding the most favorable site from a potentially very large array of alternatives. This process involves the application of various constraints to the initial array in order to reduce it to a small number of possibilities which can then be evaluated in detail. The constraints include: mill location, topography, surface hydrology, geologic conditions, natural hazards, and current land use.

The first step in site selection should be regional screening to identify all potential sites within a radius of up to 15 km from the mine site, though sites within 5 km are generally preferred. Any areas which are obviously unsuitable should be eliminated. Some of the factors which may eliminate an area are listed below (after Caldwell et al, 1983, Robertson et al, 1981, and SRK 1987a). These references also provide further information on ranking and optimization methods for selection of a tailings disposal site.

- Topographic features such as side slopes steeper than 15% or where access is difficult.

- Land use or ecological features such as:
  - important recreational areas;
  - sensitive breeding areas or exceptional animal habitat;

- areas with sensitive ecosystems or endangered species;
- other mining operations in the area;
- areas of historical or archaeological importance; and
- areas of alternative use such as oil fields.

• Hydrological conditions, such as areas with a large upstream catchment which will result in the requirement for perpetual control of large flows through the impoundment or floodplain areas where embankments could be eroded.

• Hydrogeological conditions, such as groundwater recharge areas near current or potential water supply sources, or high permeability soils such that excessive seepage losses would occur.

• Geological conditions, such as active faults, previous landslides, karst topography, foundation materials which have a high potential for liquefaction, or zones of potential mineralization.

This list of factors, except for topographic and hydrological conditions, can be considered as fatal flaw screening criteria. A fatal flaw is any site characteristic which is sufficiently unfavorable or severe that, taken singly, it would eliminate that site as a potential tailings impoundment site.

5.3.2.2 Mill Location

The first constraint applied to the range of possible sites is distance from the mill and relative elevation with respect to it. This arises from the construction and operating costs for transportation of rock waste and/or tailings slurry and reclaim water. Considering that the initial cost of access roads or tailings and reclaim water pipelines alone may be as much as $0.5 million or more per mile, a significant cost penalty quickly accrues to more distant sites. Haulage and pumping costs can substantial increase operating cost. Consequently, it is ordinarily desirable to locate the tailings impoundment as close as possible to the mill. As a general guideline, initial site screening should consider an area within a radius of up to about 10 miles from the mill, except in unusual cases involving very large tailings storage requirement or where there are unique geologic conditions. Typically, sites should be no more than 3 miles from the mill.

While sites located at elevations moderately higher than that of the mill should not be ruled out, it is desirable that the impoundment be located downhill from the mill to allow for gravity flow of the tailings slurry, or at least to minimize slurry pumping costs. Average downgrades of one to three percent are usually optimal. Steeper gradients may require drop-boxes in the tailings pipeline for energy dissipation and will also increase pumping costs for return of reclaim water to the mill. In most cases, screening for sites on the basis of proximity to the mill and relative elevation will considerably narrow the initial range of siting possibilities. (Vick, S., 1990).

Sites which are within a few kilometers of the mine, especially open pit operations, should be given special consideration because it may be possible to use mine waste, overburden and/or rock, in the construction of embankments and the resulting cost saving can offset other deficiencies of the site. However, construction of the external shell or non-submerged parts of an embankment with potentially acid generating material is not acceptable.

5.3.2.3 Topography

Topography is the second most important variable in site selection after position relative to the mill. Topographic maps at 1:25,000 scale with at least 50 foot contour intervals, or smaller scale maps, should be used for evaluation of potential sites. The objective is to locate the site which provides the maximum amount of storage with the minimum amount of embankment construction. This is usually evaluated by the ratio of stored volume to embankment volume and the following list gives typical values.

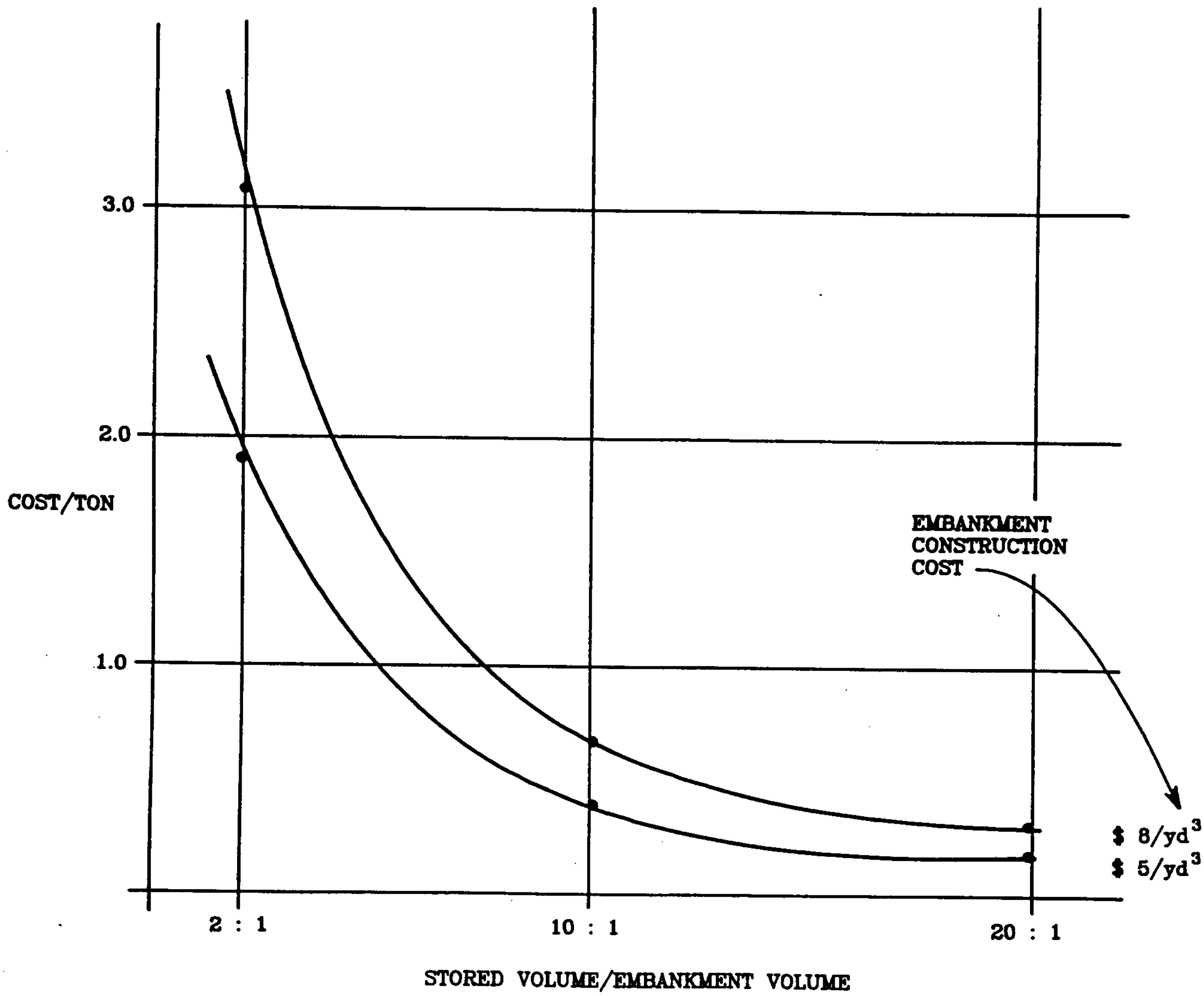
Stored Volume/Embankment Volume	Efficiency of Storage
< 3:1	Poor
3 - 15:1	Moderate
> 15:1	Good

Figure 5.4 illustrates the cost per tonne of tailings disposal versus impoundment storage ratio for total embankment construction costs ranging from \$5 to \$8/yd^3 of embankment volume and based on disposal volume of 1×10^6 yd^3.

Topographic features may result in sites involving very high embankments or very large impoundment areas. There are practical limits, however, to the total potential volume of such sites that can or should be developed for tailings disposal. On the basis of stability, hazard, and economic factors, embankments less than about 100-200 ft high usually prove to be optimal, and very high embankments (greater than 400-500 ft) almost always pose special design and construction problems that may better have been avoided during siting. On the other hand, very shallow and large impoundments may result in excessive seepage, land disturbance, and land acquisition costs by virtue of their area (Vick, S. 1990). If environmental or water supply conditions require that a zero discharge impoundment be operated then this condition may eliminate most sites for reasons of excessive inflow.

5.3.2.4 Surface Hydrology

The annual precipitation determines the extent and need for diversion works and wind and water erosion controls. Extreme rainfall events have a large effect on the design of a tailings impoundment. Generally, during operation it is desirable to divert as much natural runoff around the impoundment as possible, hence extensive diversion ditches may be necessary. At the end of operations the situation generally



Based on disposal volume of 1×10^6 yd^3

Figure 5.4 Disposal Cost/Ton vs. Impoundment Storage Ratio

(After SRK, 1991b)

reverses, where control of ARD or dust release is to be achieved with a water cover, then surface runoff is allowed to flow through the impoundment to the spillway. Consequently, for closure, the spillway must be designed to pass the flood flow of the entire upstream catchment, unless permanent diversion works are provided. Diversion of large flows requires major erosion protection works and provision for long-term maintenance.

Typically, the best method for minimizing the construction implications of these requirements is to locate the tailings impoundment as near as practicable to the head of the catchment or valley in which the impoundment is contained. If the tailings are potentially acid generating then the water balance for the impoundment should be such that an adequate depth of water cover is maintained in the event of a succession of dry years which may occur during a 100 year period. Standard hydrologic evaluation techniques are available for predicting the precipitation during such dry periods.

5.3.2.5 Geologic Conditions

Generally, the siting constraints of mill location, topography, and hydrology reduce the number of potential sites to a preferred list of three or four, and often only one. Evaluation of geologic conditions for a tailings impoundment must consider the availability of borrow materials for construction and two aspects of the foundation materials; strength and hydraulic conductivity. Initial geologic evaluation of sites should be made with a regional terrain analysis map which shows the type and distribution of surface soils and the location of natural hazards.

Soft foundations can limit the allowable rate of embankment height increase as a consequence of inadequate pore pressure dissipation. This can also result in settlement induced stress in the embankment. Weak foundation materials will generally result in a more costly structure because the materials must be excavated and replaced with suitable material. If they are not excavated then flatter embankment slopes will be required. Generally, rock foundations or dense glacial till type deposits provide the strongest foundations. Sand and gravel foundations can provide sufficient strength; however, excessive seepage may occur if a liner or cutoff trench is not used. Also sands and gravels may be prone to liquefaction if their relative density is below 60%. Silt or clay foundations can be used; however special care must be taken in assessing the material strength and controlling the rate of construction.

The presence of permafrost, either continuous or discontinuous, should be identified. Development of a tailings impoundment over permafrost may result in upward migration of the permanently frozen zone and thawing of some horizons. In the case of most soils and some highly weathered rocks this can result in differential settlement which may effect embankment stability and the performance of covers on the tailings surface. These effects may need to be modelled to predict facility performance. As a general rule, structures which may be adversely effected by differential settlement should not be located on geologic units which contain more than 10% ice by mass. Alternatively, these geologic units could be removed, or the design modified to allow for strength reduction and settlement in the foundation.

Seepage from a tailings impoundment is primarily controlled by the hydraulic conductivity of the foundation materials. Seepage through embankments is discussed in Section 5.5. Generally, because of the potential for excessive seepage, materials with a hydraulic conductivity of 10^{-5} cm/sec or greater are not favorable for a tailings impoundment without some type of seepage barrier. Preferential seepage zones can result in piping of fines out of the foundation. If this occurs under the embankment then failure will ultimately occur. Soil types which can be prone to piping are loose silts, sands and gravel from fluvial or alluvial sources.

The interrelationship of the waste embankment and the permafrost foundation soil is complex. The embankment has an effect on the permafrost below, and the presence of the permafrost affects the thermal regime within the embankment. Detailed analysis is required before the transient effects and long term results may be evaluated. Computer simulation is useful in performing this analysis.

Permafrost

Permafrost is prevalent over wide areas of Alaska, as shown in Figure 4.4. Placement of structures on permafrost has the effect of upsetting the natural thermal equilibrium.

Permafrost may be defined as any soil type which is perennially frozen. The soil may be solid rock, gravels, sands, silt, organic material or clay. Those soils which have high moisture content are particularly important. A sub-surface soil layer receives heat from geothermal sources below. It also receives heat from the atmosphere during the summer period, and in general it loses heat to the atmosphere during the winter. Permafrost reflects an equilibrium or balanced state of a stable, permanent nature in which the sum of heat losses and gains must equal zero.

The modes of energy transport include convection, solar and atmospheric radiation, moisture accumulation and evaporation. These all occur at the surface, with thermal conduction and possible moisture flow convection) occurring below the surface. Annual freeze-thaw cycling takes place in the upper regions of the soil, referred to as the active layer. Below the soil surface, the seasonal variations in temperature are attenuated and delayed in time. The depth of active layer penetration, which varies, leaves the physical properties of the permanently frozen portions largely unaffected, even though they are functions of temperature. The depth of penetration is dependent on the extent of seasonal variations and on soil thermal properties.

Permafrost can be classified into two groups as either dis-continuous, occurring in limited areas usually as a result of terrain features and micro-climatic conditions, or continuous, occurring over a widespread area. It may be further classified as either cold or warm.

Warm permafrost is that which has a temperature close to 32°F (0°C). It exists commonly in areas of discontinuous permafrost. Warm permafrost is typified by large active layers. An upset in the equilibrium, unless compensated by some artificial means, results in irreversible degradation of the frozen state of the soil. When this occurs in soils of high moisture content, the resulting subsidence creates a hazardous condition.

Cold permafrost is found in regions of continuous permafrost such as Arctic Alaska. It commonly has a shallow active layer and is considered more stable; however, the same care must be taken in assessing the effects of disturbances.

Although groundwater in permafrost regions in Alaska occurs according to the same geologic and hydrologic principles prevailing in temperate regions, subfreezing temperatures result in profound modification of ground water flow systems. Frozen ground is an impermeable layer which: (1) Restricts recharge, discharge, and movement of ground water; (2) acts as a confining layer; and (3) limits the volume of unconsolidated deposits and bedrock in which liquid water may be stored. Although little is known about the effect of permafrost and low water temperatures on quality of groundwater, the restricted circulation imposed by permafrost boundaries may increase the concentration of dissolved solids in ground water in some areas. Low ground temperatures above and below permafrost result in ground water temperatures ranging from 0° to 4.5°C (Celsius). At these temperatures, ground water is more viscous and moves more slowly than in temperate regions (Williams, R.J., 1970).

Site Investigations In Permafrost

To accomplish a site investigation in permafrost, information is required to establish the effects of the mine facilities on the sub-surface strata and to evaluate the performance of the structure itself. A preliminary assessment of the site as to type and extent of permafrost may be obtained from existing literature such as permafrost maps, climatological data and reports on surficial geology. This preliminary investigation should be conducted before any on-site programs are planned in detail. It will provide information as to whether the site is located in a region of continuous or discontinuous permafrost, as well as depth of the active layer, probable ice content and distribution of ice. If the site is located in an area where permafrost is discontinuous or sporadic and is relatively warm permafrost, then a more comprehensive on-site investigation should be planned. In addition, if existing information indicates the presence of massive formations of ice in the soil, or that soil conditions are conducive to their existence, then an extensive on-site investigation is indicated with a very comprehensive borehole program.

The planning of site investigations, and particularly of extensive on-site investigations, should include some or all of the factors in the following two major categories: (1) the location and identification of the extent of permafrost soils and potential permafrost-associated hazards; and (2) obtaining specific data to aid in design and location of the embankment.

5.3.2.6 Natural Hazards

There are three types of natural hazard which can adversely affect the performance of a tailings impoundment: rockfall or landslide, avalanche, and flooding. Blockage of the spillway by any of rockfall, landslide or avalanche can result in flow of water over the embankment which can result in downcutting of the crest with potentially disastrous consequences. For these reasons the spillway and other permanent water management facilities should be located out of the path of these hazards. Mass flows into the reservoir can result in wave formation and subsequent overtopping, which must be considered in the determination of adequate embankment freeboard.

A completely separate consideration from control of inflow into the impoundment is the need to account for floods that may pass at the toe of the embankment. This situation may result in erosion, undercutting, and eventual failure of the downstream face of the embankment, and it is especially critical for impoundments located in low-lying river floodplain areas or narrow canyons. (Vick, 1990).

5.3.2.7 Current Land Use

The current land use of potential sites should be identified so that the impact on the regional ecosystem and land users can be evaluated. This information can then be used in a site selection ranking, as described by Caldwell et al 1983, Robertson et al 1981 and SRK 1987a. In addition, after a site has been selected then current land use data can be used to refine the objectives for reclamation of a tailings impoundment. For example, a tailings impoundment developed near a community may be reclaimed as a recreational water body whereas one near a wilderness area may be reclaimed as wildlife habitat.

COMMENT

Site selection and evaluation of the baseline or pre-mining condition are essential factors in developing an acceptable waste management plan from the perspective of meeting performance standards, closure and post closure care. Specific aspects of a site which should be assessed are described in Strawman II Subpart C, Section A.3. Assessment of permafrost conditions, which is described in Strawman II Subpart D, Section B.7., is essential for northern Alaska and some areas at high elevation in southeast Alaska. Land use assessment is to be conducted as part of a site characterization under the Strawman II approach.

5.3.3 Permanent Storage, Design for Closure

5.3.3.1 Design For Closure and Post-Closure Care

Strawman II is based on the "Design for Closure and Post-Closure Care" concept. The concept of designing for closure merges two separate objectives: that reclamation activities be incorporated during design and into the operation of the facility rather than delayed until closure and the requirement that the facility provides secure long-term containment, This requires that the developer look well into the future, and identifies those processes and forces which will come to act upon the proposed facility and then designs and operates the facility so that it will not deteriorate under those forces. If deterioration is inevitable, then provision for the required maintenance should be made. It is desirable to the extent to which it is practicable, that there be no ongoing intervention or operating activities other than periodic inspections and minimal maintenance after closure. Closure of the facility must begin 24 months after the most recent receipt of regulated materials at that unit for treatment, storage or disposal.

5.3.3.2 Broad Objectives for a Tailings Impoundment

In developing the design of a tailings impoundment the assessment of design objectives should be made in three broad categories (SRK, 1991) as follows:

- Physical stability,
- Chemical stability,
- Land use and aesthetics.

Physical Stability

A permanent tailings impoundment should be physically stable such that it does not impose a hazard to public health and safety as a result of failure or physical deterioration and should continue to perform the function for which it was designed. It should not erode or move from its intended location under the extreme events or perpetual disruptive forces to which it will be subjected after closure.

Chemical Stability

A tailings impoundment, including the impounded waste, that remains after mine closure should preferably be chemically stable and not releasing chemicals into the environment. A less preferable case occurs where there is some chemical instability and leaching of chemicals into the environment, after closure. If this occurs the resulting water quality should not endanger public health or safety, or result in the exceedance of water quality objectives in downstream waters.

Land Use and Aesthetics

The rehabilitation required at a project site shall be determined by considering:

- the naturally occurring physical hazards;
- the level of environmental impact;
- the expected post-operational use of the land; and
- the productivity of the land surrounding the site.

In its closed-out condition, the rehabilitated site should be compatible with that of the surrounding lands, to the extent possible.

COMMENT

The Strawman II requirements are essentially targeted at physical and chemical stability of a tailings deposit and its associated containment structures for the protection of human health and the environment.

5.4 Containment Site

5.4.1 On Land Disposal

5.4.1.1 Cross-Valley Impoundments

Cross-valley impoundments, illustrated in Figure 5.5, differ little in layout from a conventional water-storage reservoir. As the name implies, the cross-valley impoundment is confined by a dam extending from one valley wall to another. Cross-valley type layouts can be nearly universally applied to almost any natural topographic depression, in either single or multiple-impoundment form, as shown in Figure 5.4b, accounting for the prevalence of this layout for tailings disposal. Paramount in the use of the cross-valley layout is that the impoundment be located near the head of the drainage basin to minimize flood inflows. While sidehill diversion ditches can be used to reduce normal runoff accumulation in cross-valley impoundments, larger diversion channels to pass peak flood flows around the impoundment are often not feasible because of steep valley sidewalls. Flood runoff from large drainage catchment areas can often be handled for cross-valley impoundments only by storage, spillways, or separate water-control dams upstream from the tailings impoundment.

5.4.1.2 Sidehill Impoundments

The sidehill impoundment layout is shown in Figure 5.5. This layout type encloses the impoundment by embankments on three sides and therefore generally requires more fill than the cross-valley option. This type of impoundment, however, can be used where no incised drainages suitable for cross-valley impoundments are available, for example, on mountain-front alluvial pediment deposits or where the available incised drainages would have an excessive catchment area. This type of layout is best suited for sidehill slopes of less than about 10% grade; on steeper slopes, fill volumes may become excessive in relation to storage volume achieved, and for downstream-type embankments, the upstream portion of the embankment itself may occupy a significant proportion of what would otherwise be impoundment storage volume.

5.4.1.3 *Valley-Bottom Impoundments*

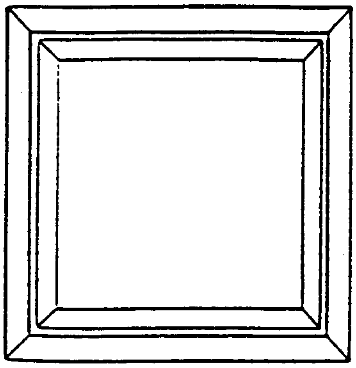
Valley-bottom impoundments, depicted in Figure 5.5, represent a compromise between cross-valley and sidehill layouts. The valley-bottom option in well suited for cases where the drainage catchment area would be too large for cross-valley layouts, but hillside slopes are too steep for practical application of the sidehill option. Since the impoundment is enclosed by embankments on two sides, fill requirements are generally intermediate between those for cross-valley and sidehill layouts. Valley-bottom impoundments are often laid out in multiple form, in order to "stack" the impoundments one above the other as the valley floor rises, thereby achieving greater total storage volume.

Central to the use of the valley-bottom layout is a diversion channel to carry the full peak flood flow around the impoundment. Diversion is usually necessary since these impoundments, commonly located in relatively narrow valleys, are often constructed across the original stream channel. The diversion channel usually corresponds to the gradient of the original stream channel but is constructed tight against the opposing valley wall. The main long-term concern with this arrangement is erosion of the diversion channel and subsequent erosion of the toe of the embankment. Durable erosion protection is required. During initial layout, if sufficient space is not allocated for the diversion channel, costly excavation in valley sidewall rock may be required to achieve necessary channel widths.

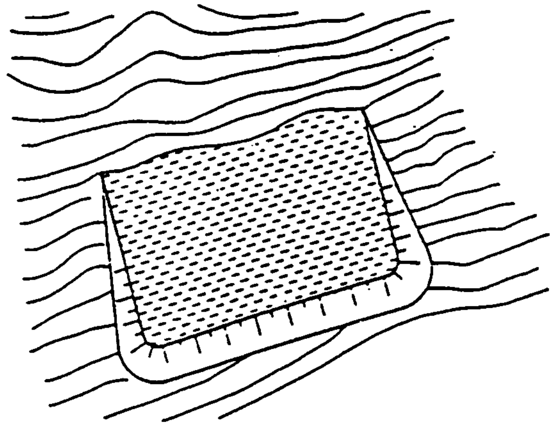
Because peak flows under PMF or similar flood conditions are usually large, widths for diversion channels associated with valley-bottom impoundments are often considerable. Excavated material, however, can often be conveniently used as starter dike fill. In addition, it is frequently the case that high-velocity flow will occur against the outer embankment face under design flood conditions, requiring that lower portions of the embankment be protected by riprap. This can make the use of centerline or downstream embankment raising methods awkward because of the need to continually replace the riprap as the embankment face moves outward with progressive raises.

5.4.1.4 *Ring Dikes*

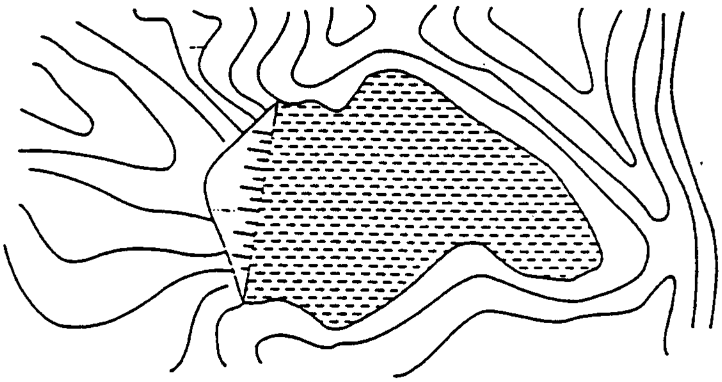
The ring dike impoundment layout is shown schematically in Figure 5.5. Best suited for flat terrain in the absence of natural topographic depressions, the ring dike layout requires a relatively high quantity of embankment fill in relation to the storage volume produced,. Since all sides of the impoundment are enclosed, runoff from external drainage areas is eliminated, and accumulated water results only from that which falls directly on the impoundment surface. Ring-type impoundments are usually laid out with regular geometry, resulting in a uniform configuration easily adapted to various types of liners.



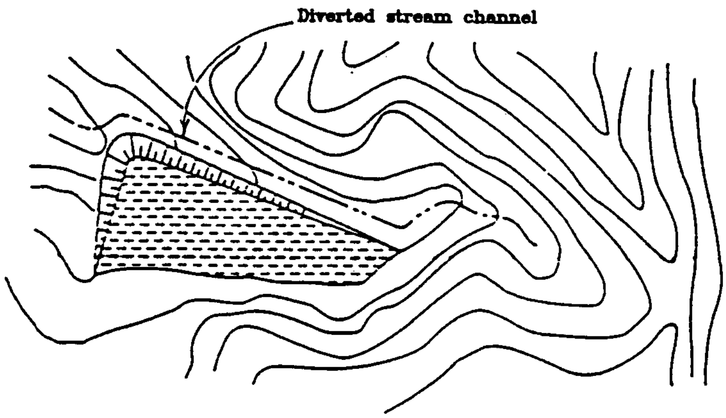
Ring Dyke Configuration



Sidehill Impoundment



Cross-valley Impoundment



Valley-bottom Impoundment

Figure 5.5 Tailings Impoundment Configurations
(After Vick, 1990)

The impoundment can be segmented using internal dykes, with each segment constructed sequentially as the previous segment is filled with tailings. While this may produce a number of benefits, including seepage reduction, concurrent reclamation, and deferral of construction cost, segmented-type; impoundments require greater embankment fill volumes.

5.4.2 Aqueous Disposal

5.4.2.1 Marine and Lake Disposal

Marine and Lake disposal are sub-aqueous methods of disposing of mine waste into an existing natural system. Fjords and lakes have been used in the past for the disposal of both acid generating and non-acid generating tailings. There are few examples of this practice in the USA, although marine disposal has been used in past int he Juneau district. This approach is not likely to be acceptable in Alaska and is only briefly reviewed here.

General case histories of marine disposal include Island Copper near Holberg Inlet (Poling, 1979) and Kitsault near Alice Arm (Snow, 1978). Other marine disposal locations include a copper mine in Chile (Castilla and Nealler, 1978) and Norway (Asmund, et al, 1988). General case histories of lake disposal of tailings can be identified for the Westmin Mine near Buttle Lake, B.C. (Pedersen, 1983), Surf Inlet Mine near Bear Lake (Errington and Ferguson, 1987), the Mandy Mine near Mandy Lake, Manitoba (Hamilton and Fraser, 1978), a copper mine near Benson Lake, B.C. (Hallam et al., 1974), and the Bluebell Mine near Kootenay Lake, B.C. (Daly et al., 1981). The research at these sites suggests negligible impact has occurred on lake water quality from the disposal of the tailings due to acid generation during and after operations have ceased. However, lake disposal of tailings also presents other problems related to turbidity and metal mobilization which may affect the biological communities in the lake (Arnesen et al. 1988). Consequently, the environmental concerns related to lake disposal include:

- toxicity of reagents and heavy metals from the mill process;
- increased turbidity due to suspended solids causing a reduction in light penetration; and
- direct physical impact from the placement of wasted on the habitat.

COMMENT

Disposal of tailings into natural waterbodies is not likely to be acceptable in the USA. It is mentioned here because research indicates that it may be technically acceptable during operation and in the long-term, even for potentially acid generating tailings. Marine disposal of tailings is currently being reviewed by the USBM, Field Operations Center - Juneau.

5.4.3 Underground Disposal

In many mines around the world underground disposal of tailings is practiced, primarily for aiding in the recovery of the ore by providing support in mined out areas and a working floor in active areas. Generally, the cost of tailings placement underground simply for disposal is more costly than placement in a surface impoundment and as such is not commonly practiced for this purpose alone. It is employed at some European coal mines where land use considerations have a high priority. Underground disposal may be an effective method to stabilize underground workings and reduce subsidence or to provide long-term containment of potentially acid generating tailings in a facility which does not require maintenance. Backfilling above the groundwater table would not be acceptable in this case. Any plan for underground tailings disposal would have to consider the potential impacts on groundwater. In past, underground disposal has been encouraged in Alaska. Wheeland, 1991, presents preliminary criteria focused on spontaneous combustion and backfill considerations for underground disposal of acid generating materials.

5.4.4 In Pit Disposal

Worked-out mine pits can be used for tailings disposal. The method varies considerably depending on the climate, the depth and variability of groundwater, the proximity to streams, the susceptibility of the pit to flooding, the permeability of the wall rocks in the pit, the mining program adopted, whether wet or dry tailings management is practiced, and the characteristics of the tailings. It is clearly site-specific and must be designed in accordance with the conditions prevailing at the site, particularly groundwater.

The technique depends on the mining program adopted. It can be used where there is an existing worked-out mine pit, or where the orebody is mined completely before milling commences. Where a low overburden stripping ratio exists, or where the pit is located in sloping topography the tailings volume may exceed the usable storage volume in the pit. The pit configuration, of course, is independent of tailings disposal requirements and depends on the nature of the orebody and topography.

Disposal of tailings in open-pit mines is best implemented where one or more separate worked-out pits are available. Disposal procedures in worked-out pits are relatively straightforward. Highland et al. (1981) describe operating procedures for a typical mine pit disposal system. Tailings are discharged into the pit either using peripheral discharge around the pit walls or by a simple single-point discharge system. Because the surface area of most mine pits is comparatively small, the area available for the decant pond is usually restricted. In some cases where more water is discharged with the tailings than can be used as mill-water recycle, notably acid-leach uranium processes, excess water must be decanted from the pit and either pumped to surface evaporation ponds or treated prior to release. Disposal of tailings in mined-out pits may be cost-effective if pit backfilling is required by reclamation regulations, or simply to reduce the area and cost of surface impoundments.

Simultaneous tailings disposal and mining in a single pit is much more complicated. For orebodies that are essentially linear, an initial pit is often excavated to the full depth of the orebody and then advanced to follow the trend of the ore. In theory, a series of water-retention type or downstream raised embankments could be constructed in the pit behind the advancing face to retain discharged tailings. Problems of seepage through the dam abutments, with adverse effects on dam stability, pit wall stability, and mine dewatering, can be serious. For these reasons among others, simultaneous tailings disposal and mining in the same pit has been proposed but seldom implemented in practice.

5.5 Containment Structures

Long-term physical and chemical stability, which are the main objectives of the Strawman II approach, of a tailings disposal facility are primarily provided by the containment structures. Consequently, the performance of these structures during operation and int he long-term is essential to meet the Strawman II objectives. Permafrost in norther Alaska and seismicity in southeastern Alaska are potential major destabilizing factors and must be carefully evaluated during the design of containment structures.

5.5.1 Types of Structures

The embankments which confine the tailings are the single most important part of a secure tailings disposal system. The location of the phreatic surface, or water level, within an embankment exerts a fundamental influence on the behavior of the embankment, and consequently is of primary important in its design. Stability during both static and seismic conditions, as well as seepage related problems are primarily influenced by the location of the phreatic surface and the resultant pore water pressure. The design objective is to keep the phreatic surface as low as possible in the vicinity of the embankment face. Embankments can be classified, with respect to the flow of water through them, as water retaining, pervious and leaky.

Water retaining embankments control the phreatic surface through incorporation of a low permeability core with a high permeability downstream shell. This type of embankment requires that there be a local source of low permeability natural soil. Soil enrichment with bentonite (3-5% by weight - bentonite) is sometimes used. This may increase the cost of the low permeability product by up to $0.75/yd^3 in Alaska. A core of some type is usually necessary where water will be impounded directly against the upstream face of the embankment. As discussed in Section 5.2, tailings deposition onto beaches may need to be avoided in cold climates because of excessive ice formation, and discharge under water may be necessary. Therefore, water retaining type embankments may be necessary for much of northern Alaska.

Unlike water retaining embankments, which perform essentially independent of the impounded material, pervious and leaky embankments require zones of successively greater permeability towards the downstream face. Pervious embankments are generally constructed with sand cycloned from the tailings stream. Leaky embankments are generally constructed with a rock-fill downstream section with cycloned sand and slimes successively further upstream. Leaky embankments may be used where there is ample rock available and insufficient sand for a pervious embankment. Neither of these types of embankments can be used where the tailings or rock are potentially acid generating.

Slope stability is the main issue of physical stability for tailings embankments. This includes deep seated failure, surface slumping and erosion.

Deep seated failure may occur as a result of earthquake induced changes in strength of the embankment or foundation material, or changes in the phreatic surface elevation in the embankment.

Surface slumping may be caused by dynamic (earthquake) loads, strength changes due to slaking of the rock fill, or frost action.

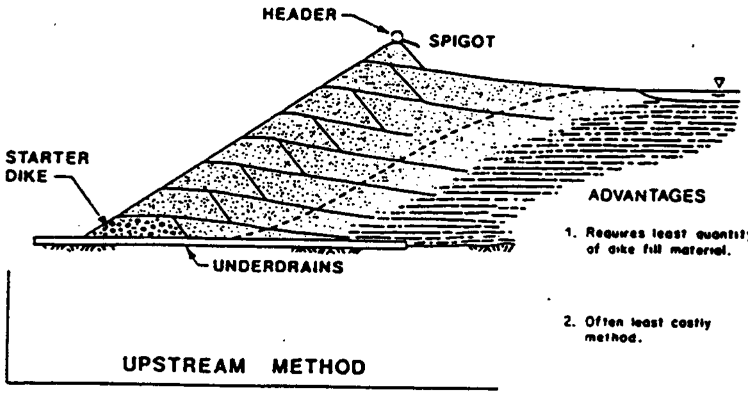
Erosion may occur gradually as a result of water and wind action, or catastrophically due to overtopping of the embankment by flood waters. Most embankments have a relatively narrow crest width, in the order 5 m, therefore, rip-rap protection composed of sound and durable rock must be placed on the upstream face of the embankment over the full range of potential water level fluctuation.

All embankments which are constructed for the long-term containment of potentially acid generating material should incorporate a low permeability core which is keyed into a basin liner or lower permeability foundation layer to reduce seepage losses and ensure that the material remains submerged.

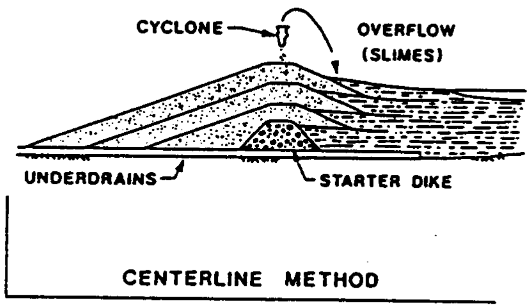
5.5.2 Embankment Construction Method

Embankments may be constructed with either a sand material which is derived from the tailings by cyclone separation or imported fill such as till or quarried rock. There are three basic types of tailings embankments, based on their construction method: upstream, centerline, and downstream. These are illustrated in Figure 5.6. These methods are compared in Table 5.2, after Vick, 1990.

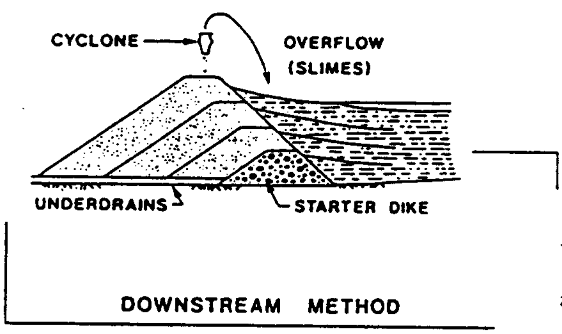
Generally, upstream is the least expensive to construct because it requires the least amount of material; however, it also has the lowest overall stability, other factors being equal. The upstream method requires construction over previously deposited tailings and if these tailings are deposited during freezing conditions then ice lenses may develop. If permafrost conditions are not likely to be maintained then future loss of strength and settlement may occur. These factors may render upstream construction unsuitable for most parts of Alaska.



ADVANTAGES	DISADVANTAGES
1. Requires least quantity of dike fill material.	1. Requires careful attention and control of tailings discharge and water decanting.
2. Often least costly method.	2. Rate of height increase may be limited.
	3. Not well suited to large runoff inflows or water storage.
	4. May be susceptible to liquefaction in high-seismic areas.



ADVANTAGES	DISADVANTAGES
1. May be used on flat ground or valleys.	1. Suitable only for coarser tailings.
2. May be raised faster than U/S system.	
3. Has a smaller volume for a given height than D/S embankment.	
4. Tailings sand may be compacted.	



ADVANTAGES	DISADVANTAGES
1. Compatible with any type of tailings.	1. Requires greatest quantity of dam fill.
2. Can be used for water storage.	2. Dam fill volumes increase for each successive raise.
3. Good seismic resistance.	3. Often most costly method.

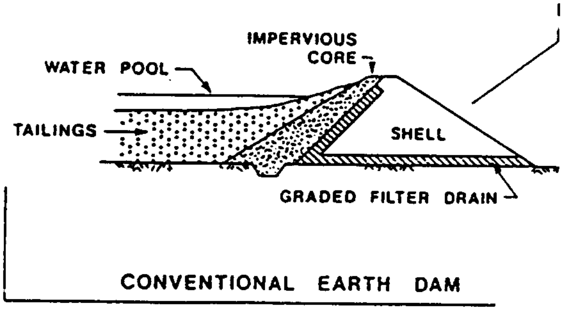


Figure 5.6 Types of Embankments (from Caldwell et al,1983)

TABLE 5.1

Comparison of Surface Impoundment Embankment Types

Embankment Type	Mill Tailings Requirements	Discharge Requirements	Water-Storage Suitability	Seismic Resistance	Raising Rate Restrictions	Embankment Fill Requirements	Relative Embankment Cost
(1) Water-retention	Suitable for any type of tailings	Any discharge procedure suitable	Good	Good	Entire embankment constructed initially	Natural soil borrow	High
(2) Upstream	At least 40-60% sand in whole tailings. Low pulp density desirable to promote grain-size segregation	Peripheral discharge and well-controlled beach necessary	Not suitable for significant water storage	Poor in high seismic areas	Less than 15-30 ft/yr most desirable. Greater than 50 ft/yr can be hazardous	Natural soil, sand tailings, or mine waste	Low
(3) Down-stream	Suitable for any type of tailings	Varies according to design details	Good	Good	None	Sand tailings or mine waste if production rates are sufficient, or natural soil	High
(4) Center-line	Sands or low-plasticity slimes	Peripheral discharge of at least nominal beach necessary	Not recommended for permanent storage. Temporary flood storage acceptable with proper design details	Acceptable	Height restrictions for individual raises may apply	Sand tailings or mine waste if production rates are sufficient, or natural soil	Moderate

after Vick, 1990.

Downstream construction usually results in the most expensive structure and has the highest overall stability. Downstream construction with compacted rockfill provides a structure with very high seismic and erosion resistance. For these reasons this method is well suited to southeast Alaska.

Embankments which are constructed with cyclone separated tailings typically have downstream slopes of 4 to 5 horizontal to 1 vertical. Those constructed of imported fill, till and/or rock are typically 3:1, and rock fill embankments can have slopes steeper than 2 horizontal to 1 vertical, if they are constructed on a suitable foundation. Tests should be conducted to verify that the rock material is not potentially acid generating and that it is durable and sound.

5.5.3 Embankment Stability - Design Criteria

Tailings embankments need careful consideration for longevity. Often they are constructed of highly erodible materials such as tailings sands. Although immediate static conditions may be satisfactory, long-term dynamic forces may suggest the need for extensive protective measures. Since gradual deterioration of materials can take place with time, conservative values of strength properties should be selected.

The other major parameter in the static stability of tailings embankments is the influence of pore water pressures and the location of the phreatic surface. If base drainage is utilized in the design, consideration should be given to the effect of clogging of drains with fines or precipitates in time, thus leading to rise in water pressures and reduction in stability. Again, conservative assumptions need to be made in estimating the position of phreatic surfaces.

In engineering analysis, uncertainty regarding engineering parameters is usually taken into account by use of the factor of safety based on effective stresses. In a tailings dam the stability of the downstream slope is usually the prime consideration. Analyses should consider failure through the embankment materials themselves and also failure through the foundations. If weak foundation soils are present, the latter failure mode is likely to be the critical condition. Various methods of stability analysis and computational techniques are available, but it is important to realize that the reliability of the analysis depends primarily on the accuracy of the input parameters. The extent to which these are representative of the real conditions in the embankment and foundations over the long term determines the true value of the factor of safety. Recommended minimum values of factor of safety by CANMET, shown in Table 5.3, are based on input parameters, known with reasonable certainty to be representative of actual conditions".

TABLE 5.2

Minimum factors of safety for the downstream slope

Assumptions	I*	II**
Using peak shear strength parameters	1.5	1.3
Using residual shear strength parameters	1.3	1.2
Including the loading for a 100-year***earthquake	1.2	1.1
For horizontal sliding on the base of embankment retaining tailings in earthquake areas assuming shear strength of tailings behind the dam reduced to zero	1.3	1.3

I* Where it is anticipated that severe damage would occur as a result of embankment failure.

II** Where it is anticipated that severe damage would not occur as a result of embankment failure.

*** Note that the factor of safety should not be less than 1.0 for the maximum credible earthquake.

after CANMET (1977)

Factors of safety used in water storage dams should also be considered, see USBR (1977). These vary according to loading conditions, defined as normal (usual), unusual and extreme events. Corresponding factors of safety vary from 3.0 to 1.0 for large gravity dams, and 2.0 to 1.25 for small gravity dams less than 12 m height for sliding stability.

Settlement analyses may also need to be made for:

- foundation consolidation if weak, soft soils exist that could lead to settlement and cracking of the impervious core of the dam, this could lead to internal erosion; and
- settlement of tailings within the impoundment after operations cease that could cause damage to covers.

While conventional soil mechanics theory can predict foundation settlement reliably enough, in the case of tailings settlement, finite strain theory needs to be applied.

Settlements of the tailings embankment, and in the tailings deposit can rupture pipes installed in or beneath embankments. When large settlements are anticipated decant pipes should not be located through the dam.

Perpetual forces and control technologies are summarized in Table 5.4.

5.5.4 Seepage Control Structures

5.5.4.1 General

Once a site has been selected for a tailings impoundment, geohydrological conditions and the tailings pore water quality will dictate whether a liner or seepage cutoff is necessary. The requirements are highly site and impoundment specific. Seepage control structures are classed as either seepage barriers or liners. Seepage control may also be achieved with a collection system as shown in Figure 5.7. Seepage barriers are cutoff structures located under the low permeability core of the embankment. These may be cutoff trenches, slurry walls or grout curtains as shown in Figure 5.8. Liners are normally used where the permeability of the natural rock or soil strata underlying the impounded area is unacceptably high. Liners can be tailings slimes, clay liners or synthetic geomembrane liners. Seepage barriers such as cutoff structures or basin liners are generally not compatible with upstream type embankments because these embankments cannot contain an impervious zone in the embankment.

5.5.4.2 Cutoff Barriers
(After Vick, 1990)

Cutoff barriers function by restricting lateral migration of seepage. As a consequence, they are fully effective only when pervious foundation materials are underlain by a continuous low permeability ($<10^{-6}$ cm/s) stratum of natural material that prevents vertical flow. As shown by Cerdergren (1967), a seepage barrier must completely penetrate the pervious foundation layer with a tight seal to the low permeability stratum in order to reduce seepage significantly. For example, a barrier that penetrates 90% of the pervious stratum reduces seepage by less than two-thirds.

Cutoff Trenches

Usually relatively economical to construct when natural clays are present for use as compacted trench backfill, cutoff trenches are perhaps the most widely used seepage-control method for tailings embankments. Cutoff trenches are commonly installed to depths ranging from 5 to 20 ft, depending on the depth to the impervious layer, but they have been extended to as much as 60 ft beneath some tailings embankments. A major limitation of cutoff trenches is that their excavation more than about 10-15 ft below the water table quickly becomes impractical unless expensive and time-consuming construction dewatering methods are used. However, cutoff trenches, unlike other types of barriers, are not limited by

TABLE 5.3

Perpetual Disruptive forces:
Consequences and Control Technology*

Perpetual Disruptive Force	Consequence	Control Technology	References
Wind Erosion	• Erosion of embankments	• long-term - establish and maintain vegetative, mine rock or till cover	Steffen, Robertson and Kirsten (B.C.) Inc., (1986a).
Water Erosion	• Erosion usually occurs during extreme precipitation and flood events	• Locate critical structures away from stream channels and flood plains, where practical • Sedimentation, ice, vegetative growth, debris blockage difficult to avoid - cleaning and maintenance required • design diversion structures to accommodate extreme events • use of heavy rip-rap	Steffen, Robertson and Kirsten (B.C.) Inc. (1986a); (1986b); Walters and Skaggs (1984).
	• Sheet and rill erosion of impoundment surfaces, covers and embankment	• experience indicates slopes flatter than 3H to 1V are usually required for erosion resistance and establishment of vegetation	United Soil Loss Equation Wischmeir and Smith, (1978). Steffen, Robertson and Kirsten (B.C.) Inc. (1986a).
	• Gully erosion major cause of instability of tailings surface, covers and embankments	• rip-rap	Falk et al (1985).
• Frost Action	• Major cause of long-term instability of tailings covers and their containment structures	• insulating layer • frost resistant layer	Knight and Piesold (1986); Geocon (1986); Steffen, Robertson and Kirsten (B.C.) Inc. (1987).
• Annual Ice Accumulations	• Blockage of diversion structures and outlet works • Freezing of drains in embankments cause slope failures • Thawing of deposited tailings can cause large settlements after close-out and cracking of covers	• no specific control technology, designers and proponents must be aware of the consequences and allow for when considering closure-plans	Clifton Associates (1986); Robertson, (1987a).
• Seasonal Frost Penetration	• Modifications to soil structures to increase permeability.	• insulating layer • frost resistant layer	

TABLE 5.4 continued

Perpetual Disruptive Forces:
Consequences and Control Technology*

Perpetual Disruptive Force	Consequence	Control Technology	References
• Physical/Chemical Leaching	• Decomposition or breakdown of intact rock particles in embankment or spillways.	• Run laboratory tests to evaluate decomposition of rocks used for long-term stability - only use rocks not susceptible to weathering in permanent structures	
Biological Activities			
• Root penetration generally beneficial effect on covers	• Roots may penetrate drains and clog • penetrate low permeability layers, rot and provide air or seepage channels	• Ensure drains in flooded conditions • Use of larger drains with surplus drainage void space Monitor and maintenance	
• Burrowing Intrusion	• Burrowing along phreatic line in fine material may induce piping failures; penetrate low permeability layers	• Monitor and maintenance • Use materials animals cannot penetrate	
• Beaver Dams	• Disrupt drainage of diversions ditches and spillways	• Monitor and maintenance	

* Adapted from SRK 1991.

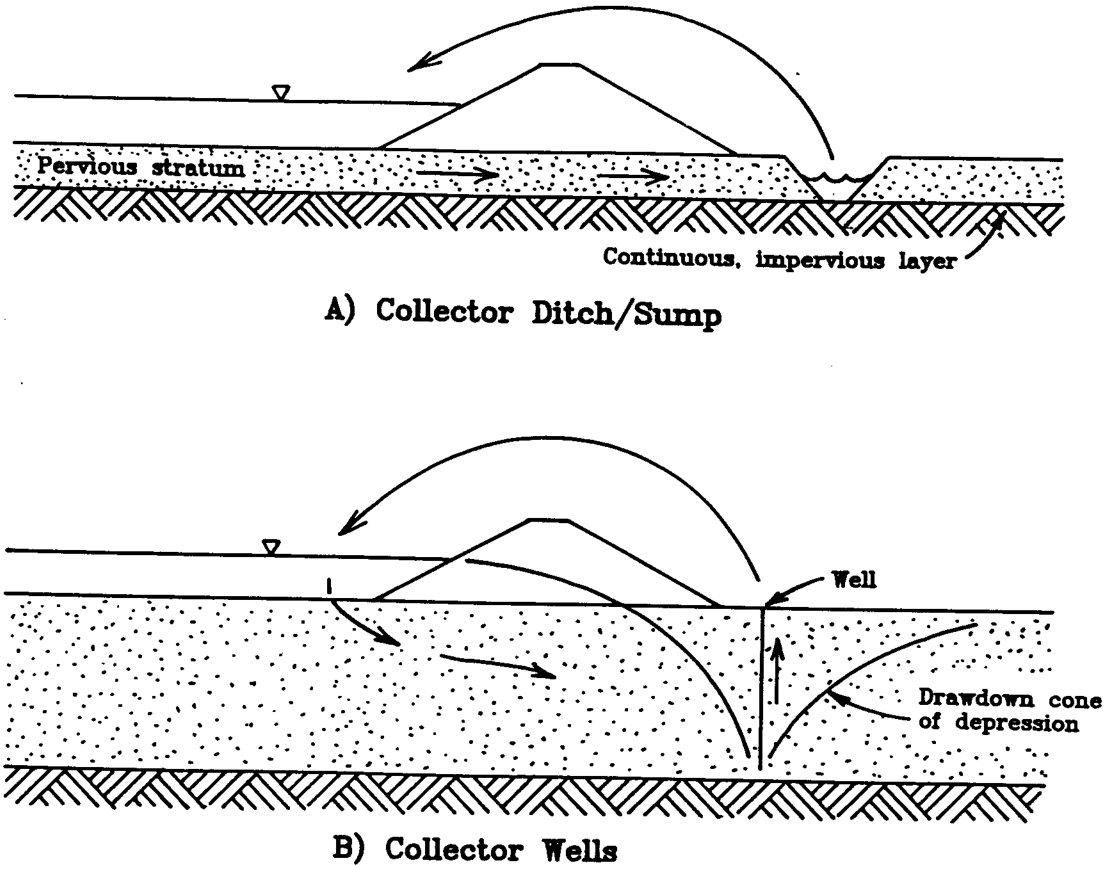


Figure 5.7 Seepage Return Systems (from Vick, 1990)

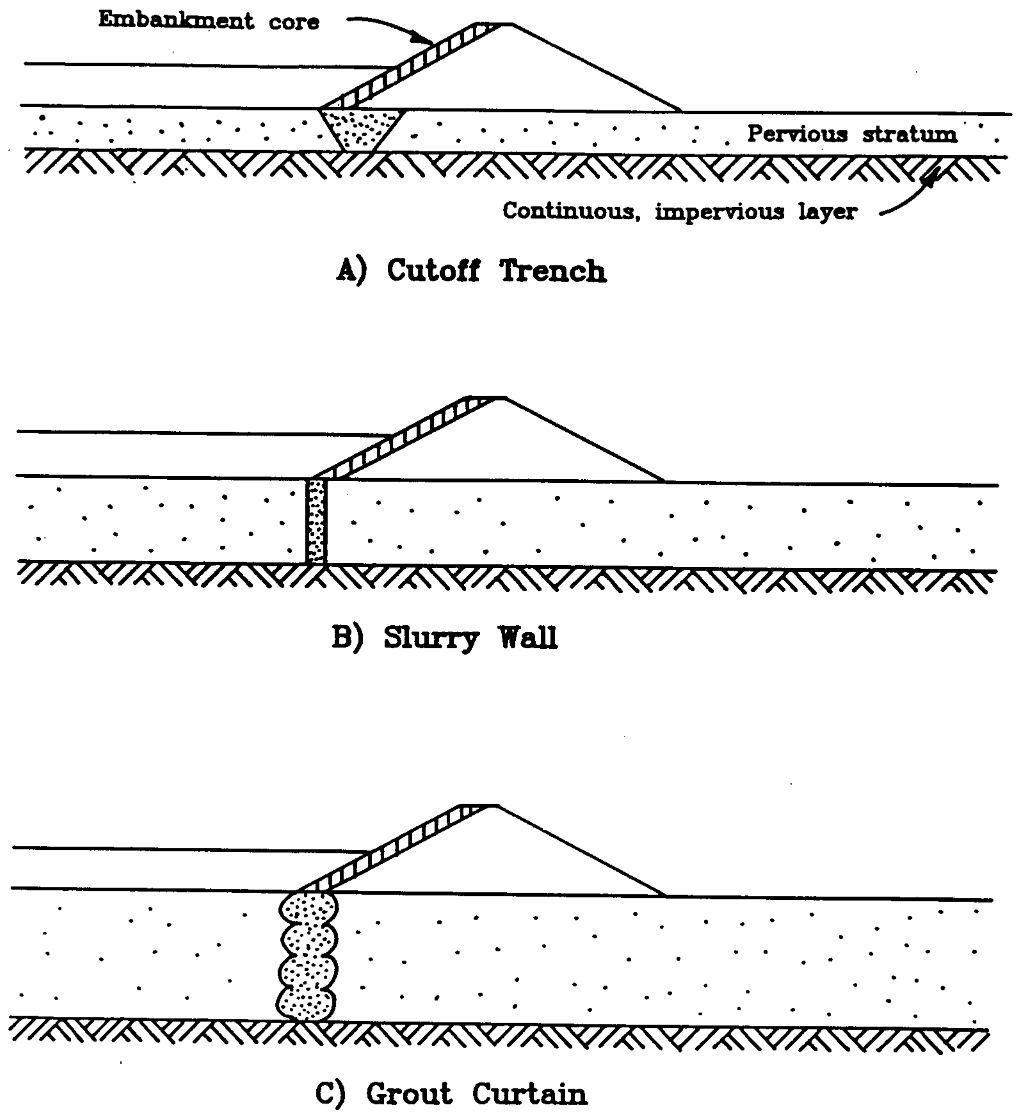


Figure 5.8 Seepage Barriers (from Vick, 1990)

the type of material present in the foundation; bouldery soils such as glacial tills and weathered or fractured bedrock can be excavated relatively easily. Also, the bottom of the trench can easily be inspected to ensure that all pervious materials have been penetrated and that the backfill achieves a good bond with the underlying impervious stratum.

Slurry Walls

Slurry walls can also be used to penetrate a pervious foundation stratum. The technique involves excavating with a backhoe a narrow trench whose sides are supported by a bentonite slurry. The trench is backfilled either with a slurry of soil and bentonite or with bentonite containing cement additives. Permeabilities of 10^{-7} cm/sec can be achieved with soil-bentonite walls (D'Appolonia, 1980), with permeabilities in the range of about 10^{-5} cm/sec for cement-bentonite cutoffs. Slurry wall cutoffs have been used for both tailings embankments and conventional water-retention dams (Engineering News Record, 1976, 1978). While slurry wall cutoffs have been constructed to depths as great as 100 ft, time and economic considerations usually limit practical depths to about 40 ft for tailings embankments.

A major advantage of slurry walls is that they can be constructed in saturated foundations where cutoff trenches would be impractical to excavate. Low permeabilities can be achieved with a soil-bentonite slurry trench beneath it.

On the other hand, slurry walls are relatively costly and cannot easily penetrate fractured bedrock or more than occasional boulders, limiting their usefulness in many types of coarse or highly fractured materials where barriers are most needed. The slurry wall barriers are best suited to reasonably flat sites where the pervious material to be cut off is saturated, relatively shallow and relatively fine grained.

Grout Curtains

Grout curtains have long been routinely constructed to reduce foundation permeability for major water-retention dams and can be installed to depths well in excess of 100 ft. Grouting techniques, while largely an art, are well developed (Albritton, 1982). The purpose of conventional grouting of dam foundations is structural rather than environmental. That is, grouting is intended to reduce foundation permeability to the extent that foundation pore pressures are not excessive; the quantity of foundation underseepage is of secondary importance in conventional water dam applications.

Grouting seldom reduces the permeability of the grouted material to less than about 10^{-5} cm/sec (Einstein and Barvenik, 1975), a value that, although adequate for water dam purposes, is not often sufficient to restrict seepage from tailings impoundments to an acceptable degree. Other problems include the high cost of grouting, its limitation to only coarser materials, and the potential for acid and sulfate attack of the grout by many tailings effluents. For these reasons, grouting does not ordinarily find wide application to tailings impoundment seepage control.

Several types of grout are available, ranging from portland cement to such chemical grouts as sodium silicate and acrylic resins. The type of grout required depends on the size of the voids that must be penetrated. However, economic considerations seldom allow the use of other than cement grout for dam foundation cutoffs. In order for grout particles to penetrate voids in soils, the ratio d_{15} of the soil to d_{85} of the grout particles must be greater than 25 in practice this limits cement grout applications to soils in the medium sand to gravel range with initial permeabilities greater than about 5 x 10^{-3} cm/sec (Einstein and Barvenik, 1975). Similarly, groutable fissures in rock must be wider than about 0.75 mm for cement grouting to have appreciable effect. Thus, cement grouting is usually effective for only relatively coarse soils and fractured rock with continuous, open joints.

5.5.4.3 Basin Liners

Liners may be used if there are stringent groundwater protection requirements and relatively high concentrations of toxic constituents in the mill effluent. Liners of any type are costly to install. Their effectiveness is less in doubt than high-cost barrier systems, principally because a liner is a surface installation that can be constructed under controlled conditions and inspected. This does not guarantee, however, that even a properly constructed liner will function as intended during actual operation or that any lined impoundment will be a "zero discharge" facility. Liners, however, must be resistant to both chemical attack by the retained effluent and a variety of types of physical disruption.

Three types of basin liners are described below: tailings slimes, clay liners and, synthetic liners.

Tailings Slimes

Tailings slimes are spigotted in the impoundment, and seepage reduction is achieved by virtue of the low permeability of the tailings themselves. Slimes liners constitute a legitimate and comparatively inexpensive seepage-control method for certain types of tailings, with effectiveness that can be comparable to or better than clay or synthetic liners. Slimes liners also have certain unique advantages not offered by other types of liners.

It goes without saying that, for a slimes liner to be constructed, slimes must constitute a considerable fraction of the whole mill tailings. Usually, more than 40% passing the No. 200 sieve would be sufficient. This criterion is generally met for the majority of mill tailings. Slimes liners generally require that the fine fraction be separated from the whole tailings by cycloning. A second criterion is that to have an effectiveness comparable to other types of liners on pervious foundations, the slimes must have a consolidated permeability approaching 10^{-6} cm/sec.

Slimes liners have several disadvantages. First, normal spigotting procedures must be modified to distribute the slimes around the entire perimeter of the impoundment, and ponded water must be carefully controlled and minimized. Second, the sands separated from the whole tailings must also be disposed of, requiring a smaller conventionally lined impoundment. However, if the cycloned sands can be used in embankment construction, this disadvantage is easily overcome. Finally, a slimes liner offers no opportunity for attenuating contaminant movement by geochemical processes within the liner itself.

On the other hand, other types of liners, both clay and synthetic, may be susceptible to cracking or rupture from foundation settlement, which may be considerable under loads imposed by typical tailings depths even for moderately dense foundation soils. This is not the case for slimes liners, which can easily withstand major foundation settlement or even seismic liquefaction without impaired effectiveness. Similarly, because the slimes are spigotted continuously, damage due to desiccation cracking or physical exposure is not of concern.

Clay Liners

Clay liners have long been used to reduce seepage from water storage reservoirs and toxic waste impoundments, and their application to tailings impoundments is straightforward. The term "clay" is not exclusive; satisfactory liners have been constructed using a variety of soil types, including CH, CL, ML, and SC in Unified Soil Classification terminology. Also, clay liners include compacted soils that incorporate additives.

The most common such additive is commercial bentonite. Blended with natural sandy soils in a travelling pugmill or central plant in proportions ranging from about 2% to 6% by weight, bentonite additives, where economically available, can provide a satisfactory liner material with permeabilities on the order of 10^{-6} cm/sec. However, the practices of spreading dry bentonite on the ground surface or mixing in place with a disc harrow are seldom suitable.

Another form of additive consists of chemical dispersants. Laboratory evidence and field experience indicate that clay permeability can sometimes be reduced about one order of magnitude if thorough and complete mixing is achieved (Dane, 1976; Lambe, 1974). Chemical dispersants modify the structure of a clay by producing a dispersed (face-to-face) structure of individual particles. An important question is the degree to which the effects of dispersants may be reversed by low-pH effluents.

The properties of compacted clays, either in a natural state or with any of the above described additives, are largely a function of placement and compaction procedures. Properties of primary concern in liner applications are permeability, volumetric stability, flexibility, and piping resistance. These properties are strongly influenced by the placement moisture content. The degree and also the method of compaction in the field determine the density and the structure of the clay fill. In general, the kneading-type action produced by sheepsfoot compactors is most effective in breaking down agglomerations of clay particles and producing a dispersed and therefore lower-permeability structure.

Synthetic Liners

Although synthetic liners have been used for some time, their introduction as a tailings impoundment seepage-control method is relatively new. Koerner (1980) provides a good overview of synthetic liner fabrication and manufacture, while Small (1980) and Kays (1978) describe the application of traditional liner design and selection methods to tailings impoundments.

The various types of synthetic liners include:

- rigid liners;
- sprayed membranes;
- synthetic rubber membranes; and
- thermoplastic membranes including;
  - Polyvinyl chloride (PVC),
  - Chlorosulfonated polyethylene ("Hypalon"),
  - Chlorinated polyethylene (CPE),
  - High-density polyethylene (HDPE), and
  - Elasticized polyolefin (EP).

The chemical formulation of different thermoplastic materials results in differences in their ability to withstand weathering, sun-light exposure and chemical attack by the effluent. Nearly all thermoplastic membranes have good resistance to acids, bases and salts in concentrations normally encountered in mill effluent. Aromatic hydrocarbons, such as toluene and benzene, which are highly damaging to many thermoplastic membranes, are not usually present in mill effluent. Some petroleum-derived flotation reagents, such as kerosene, may be moderately detrimental to some types of liner material, but these reagents are usually present in such low concentrations that they do not pose a major problem. The exception is where the liner is exposed to direct contact with floating oils, such as on impoundment sideslopes. With these generalizations, some of the specific characteristics of the various materials are described below.

Polyvinyl Chloride (PVC). PVC is among the least expensive liner materials, perhaps one of its major attributes. However, its weathering resistance is poor, and it must be protected by a water, tailings, or soil cover to avoid degradation by sunlight. PVC is relatively sensitive to petroleum derivatives unless an oil-resistant resin formulation is used. PVC in tailing impoundment applications is commonly used in 20-30 mil thicknesses.

Chlorsulfonated Polyethylene ("Hypalon"). "Hypalon" is perhaps the most common membrane in tailings impoundment applications. Available and commonly used in 30 and 36 mil thicknesses, it is resistant to most chemicals in mill effluent, including petroleum derivatives in low concentrations. It has good aging characteristics, and, significantly, it can undergo direct sunlight exposure, precluding the need for a soil cover on exposed sideslopes. Its cost per unit area is very roughly twice that of PVC.

Chlorinated Polyethylene (CPE). CPE is similar to "Hypalon" in most characteristics, but at a cost intermediate between that of "Hypalon" and PVC.

High-Density Polyethylene (HDPE). Another relatively new material, HDPE has good chemical, weathering and sunlight resistance. It is available in thicknesses ranging from 20 mils to 140 mils. Where thicker materials are used (80-100 mils), puncture and tearing resistance is improved compared to other thinner liners, but at a proportionally higher cost per unit area.

Effectiveness of Membrane Liners

Leakage through membranes results from two sources: leakage due to pinholes and porosity in the material itself, and leakage through tears or seams joining individual sheets. Leakage through tears and seams is usually assumed to be the major source of seepage loss, and the quantity of seepage is primarily a function of the quality of field seaming procedures and the care taken to prevent punctures during installation. Even for well-constructed membranes, some leakage through seams undoubtedly occurs, but the quantity is impossible to predict. Liners should meet chemical compatibility-type test. EPA Method 9090.

5.5.4.5 Composite Liners

It is typical to refer to liner systems as single liners, double liners, or triple liners. Composite liners are double or triple liners which are described below.

- Double liners are those where two low permeability liners are present, e.g. a geomembrane overlying a clay liner or two geomembrane liners separated by a leakage collection system; and

- Triple liners are those where three low permeability liners are present, e.g. two geomembranes separated by a drainage layer and underlain by a clay liner. EPA refers to this type of section as a double composite liner.

A detailed discussion on the aspects design and construction of composite liner systems is beyond the scope of this report and the reader is referred to SRK et. al., 1987 and Vick, 1990. Only some key aspects as they may pertain to Alaskan conditions are provided here.

For a double liner system, the upper liner is often a synthetic material and the lower liner is a soil material, however suitable materials must be available. The seepage detection/collection system between liners is commonly a suitable sand or gravel, if available, or a geofabric. If a geofabric is used, its permeability should not change significantly under the loading of the overlying tailings. Geofabrics are commonly used for the leak detection system between synthetic liners on the side slopes of collection ponds, where sands or other natural materials would slide on the synthetic liner. In southeastern Alaska, where steep topography prevails, geofabric leak detection systems may be the only practical option.

Installation considerations include the duration and time of year that construction is to take place. This is an important aspect for Alaskan sites because of the extreme annual range in temperature. A geomembrane installed during the summer can undergo significant shrinkage during colder weather. This effect must be compensated for by providing slack in the liner during construction.

Liners cannot tolerate any appreciable horizontal extension (or cracking) in the foundation strata as may be associated with considerable differential settlements. Large differential settlements would be associated with substantial depths of unconsolidated alluvium in valleys and potential thawing of permafrost. For sites in northern Alaska, this concern should be addressed during the design stage.

Liners applied to steep-sided impoundment walls (>30°) may be subject to large shear stresses as the tailings settle within the impoundment. Liner installation may be limited to slopes not steeper than 3 horizontal to 1 vertical. In southeastern Alaska, where steep topography prevails, this may limitation may substantially reduce the potential number of sites for lined impoundments such that this could become the most important factor in a site selection study. Many projects could be unfeasible if lined impoundments are required.

COMMENT

If RCRA performance objectives for the protection of groundwater were to be rigorously applied to all sites by either groundwater quality objectives which are equivalent drinking or aquatic water quality objectives, or by making the point of compliance within, say, 1 foot of original natural ground surface, then many projects in Alaska would become practically and/or economically unfeasible. An alternative approach may be to evaluate the required level of groundwater protection based on site specific evaluation of groundwater resource value, its current and potential future uses, potential impacts at the point where it emerges into the surface flow system, and the socio-economic aspects of any groundwater protection measure.

5.5.4.6 Seepage Collection

Unlike seepage barriers, return systems do not attempt to restrict seepage flow but rather to collect it, thereby eliminating or minimizing migration of contaminants in the groundwater. Two basic forms of return systems operate on this principle; collector ditches-sumps and collector wells (see Figure 5.7).

Collector Ditches

Collector ditches are often effective and inexpensive, making them a first line of defense for seepage control, whether used alone or as a backup for other seepage-control measures. Collector ditches are usually excavated along the downstream toe of an embankment, draining to one or more sumps, where collected seepage is pumped back to the impoundment. For narrow cross-valley impoundments, sometimes only a sump or collector pond is constructed.

Collector ditches are similar to cutoff trenches insofar as they are most effective for a relatively shallow pervious zone that is underlain by a continuous low-permeability stratum. To be fully effective, the ditch must completely penetrate the pervious stratum, but even if this is not possible, the ditch will still collect and return that portion of the seepage passing through the embankment itself. Collector systems do not require that the embankment contain an impervious zone, and they are useful for pervious embankments of upstream, downstream or centerline type.

Collector ditches may function poorly during spring runoff in cold regions because ice and snow in the ditch may impede flow and result in overtopping flow.

Collector Wells

Collector wells incorporate the same principles as collector ditches. Contaminated seepage is intercepted by a line of wells at or near the embankment toe, pumped out, and returned to the impoundment. An impervious lower layer is desirable but not essential if the wells penetrate deeply enough to intercept the contaminant plume.

Collector wells are expensive and not a method of choice for seepage control. Their effectiveness may be limited in foundations of low or variable permeability. However, they may be a remedial measure of last resort to prevent further damage to an already contaminated aquifer, or as an aquifer cleanup measure.

5.6 Deposition Method

5.6.1 Point Discharge

Point discharge involves tailings discharge at a single point into the impoundment, typically from an opened pipe. The discharge point may not be moved for the life of the mine, it may be moved seasonally, or when the beach rises to the discharge point. Many northern mines use multiple point beach discharge in summer months and single point underwater discharge in winter months. Differences between concentrated or point discharge and non-concentrated flow are described in Section 5.2.2.

5.6.2 Spigotting

Spigotting involves separating the tailings discharge stream into multiple discharge points. This method is commonly used in conjunction with cycloning to construct upstream and centerline embankments. Spacing of the discharge points will influence the amount of fines which are deposited in the beach area which can influence stability. This is controlled by the beach profile which is described in Section 5.2.2.

5.6.3 Thin Layer Spigotting

Thin layer spigotting, which is often called sub-aerial deposition, involves the systematic deposition of tailings in thin layers and allowing each layer to settle, drain and partially air dry prior to covering with another layer. Discharge is from spray bars and results in layers 4 to 6 inches thick before the discharge point is moved to another area of the pond. This method is not recommended for potentially acid generating tailings because the tailings are not saturated at the end of operations. Liquefaction resistance of these tailings is greater than point or spigot discharged tailings. Thin layer spigotting requires good operations management to prevent excessive layer thickness or formation of a large decant pond. At decommissioning, the tailings are fully drained and consolidated allowing immediate reclamation. Cold climates can result in ice formation and a high retained moisture content, which can adversely affect settlement and liquefaction resistance.

5.6.4 Cycloning

The use of cycloned tailings in embankment design presents an attractive design option when natural soils of suitable type or quantity are unavailable. Reasonably clean sand tailings can be produced from most mill tailings having less than about 60% passing the No. 200 sieve, provided the tailings are essentially non-plastic and free of clay minerals. The resulting cycloned sand has high effective strength and permeability, making it an ideal material for providing drainage and phreatic surface reduction in downstream zones of the embankment.

Tailings discharged to the impoundment after removal of the cycloned sands are finer than the whole mill tailings that would otherwise have been deposited and typically have an overall permeability about one to two orders of magnitude less.

5.6.5 Co-disposal With Rock

Co-disposal of tailings with rock can take two forms: on-land disposal of tailings in a rock pile, or rock addition to a tailings pond. The latter is really sub-aqueous disposal of rock. The concept of on-land co-disposal with rock is for the tailings to be stored in the voids between the rock fragments. It is best suited to high stripping ratio operations. The method is untried because of economics.

COMMENT

Climatic conditions may dictate that point discharge is used extensively in northern Alaska. Similarly, thin layer spigotting may be impractical in this area. There is greater flexibility on deposition method for southeastern Alaska, however winter conditions should still be carefully evaluated when developing a tailings disposal system.

5.7 Decant Methods

After tailings are discharged into the impoundment, the particles settle and a pond of water will be formed. Where possible, this water is returned to the mill for reuse. Pumps or siphons mounted on floating barges can be used for this purpose. Decant towers can also be used. Decant by spillway is not common because the tailings embankment is progressively raised through the mine life which would require continual relocation of the spillway. A decant tower is generally a concrete or steel conduit composed of two sections: a vertical riser through the tailings which is extended as required, and flatlying section which passes through the embankment to its toe. Damage or deterioration of this flatlying section during operation or after closure has resulted in internal erosion of embankments, therefore, decant tower systems are not the preferred method for removal of pond water. Barge mounted pumps or siphons do not have the disadvantage of decant towers, however, their operation can be hampered in cold climates where there is substantial ice formation on the pond. The current trend in northern Canada is towards the use of barge mounted decant systems.

5.8 Tailings Water Treatment

5.8.1 Treatment of Cyanidation Waters

5.8.1.1 Hydrogen Peroxide Process

In recent years two processes have been developed and patented which utilize hydrogen peroxide for the oxidative destruction of free and metal complexed cyanides. The first process, known as the Kastone process, developed by scientists at Dupont, utilizes chemically stabilized hydrogen peroxide solutions in conjunction with formaldehyde and/or copper to initiate the oxidation of cyanide. The second process, developed by Degussa, utilizes concentrated hydrogen peroxide solutions and a copper catalyst supplied as copper sulphate if insufficient copper is present in solution. A full scale treatment facility utilizing the Degussa process is in operation at the OK Tedi Mine located in Papua New Guinea. In addition, the Kastone process has been successfully pilot plant tested for over a year at the Homestake Mine in Lead, South Dakota (USA).

Hydrogen peroxide in the presence of formaldehyde and/or copper oxidizes free cyanide to cyanate. The cyanide bound to copper, nickel, and zinc (the weak acid dissociable (WAD) forms of metal complexed cyanides) is also oxidized during the process. The metals released during oxidation are precipitated as hydroxides to a final concentration dependent upon the pH of the process. The iron cyanide compounds combine with the free copper in solution to form an insoluble complex. The optimal pH for the process is 9.0 - 9.5, although the process operates over a wide range of pH values. This pH range is chosen as it represents the minimum concentration range for copper and the iron complexed cyanides. The optimal copper concentration ranges from 10 mg/L to 20 mg/L, depending upon the initial cyanide concentration. The hydrogen peroxide concentration required varies according to the initial total cyanide and total suspended solids concentrations and is determined through laboratory and/or pilot plant studies. The reaction period required to complete the oxidation ranges from 2.0 to 2.5 hours. The cyanate produced in the process is hydrolysed in part to ammonia, which is not removed. Thiocyanate, which is present in most decant and barren wastewaters in varying concentrations, is oxidized only slightly. Reductions in the initial thiocyanate levels are usually less than 10% based upon experimental results.

The optimal pH for metals removal after cyanide destruction is 9.0 - 9.5, although the process operates over a wide range of pH values. A pH below 9.0 is optimal for precipitation of iron cyanides. Since metals removal is usually of more importance than iron cyanide removal, the higher process pH is preferred. Generally, no adjustment in pH is required, as with other chemical treatment processes. The residual copper concentrations achieved are dependent upon the initial Wad cyanide concentration.

Copper sulphate pentahydrate (i.e. $CuSO_4.5H_20$) is added to the untreated wastewater to produce an initial copper concentration of about 10 - 20% of the Wad cyanide concentration. The hydrogen peroxide concentration required varies according to the initial total and Wad cyanide levels in the untreated wastewater. In general, a hydrogen peroxide excess of 200 - 450 percent of theoretical is utilized in the full-scale applications. The reaction period required varies according to the initial Wad cyanide concentration, as well as the copper and hydrogen peroxide levels utilized. The reaction periods range from about 20 minutes to 4.0 hours, depending upon the copper to cyanide ratio, the cyanide levels and the quantity of hydrogen peroxide used. The reaction rate is increased sharply as the copper concentration is increased. However, increasing the copper concentration also increases the eventual problems associated with removing the metal from solution.

The actual reaction period, copper concentration and hydrogen peroxide dosage used, are determined through a series of laboratory and/or pilot plant investigations. The cyanate produced during treatment is slowly hydrolysed to ammonia as shown in equation 6.15. About 10 - 20 percent of the cyanide is converted to ammonia during treatment. The process does not preferentially attack thiocyanate, although about 10 - 15 percent is oxidized during treatment.

As mentioned before, the process operates effectively over a wide pH range. One operational parameter which must be evaluated during testing involves the effluent pH. Since the optimal pH for copper removal is about 9.5 and for iron cyanide removal is <9.0, a decision must be made initially to optimize removal of one or the other of these. Since the toxicity of iron cyanide is very low, the choice is usually made to optimize copper removal. It should be recognized that copper and cyanide are intimately related and removal of copper is dependent upon removal of wad cyanide and not iron cyanide.

5.8.1.2 *Cyanide Recovery Process, AVR Method*

The recovery of cyanide from mining solutions through acidification, air stripping and reabsorption was originally known as the Mille Crows Process. The process was utilized for economic, not environmental reasons and was limited to the stripping of cyanide from clarified barren solutions, not slurries.

In the 1970s the process was reinvestigated and modernized by CANMET and McNamara (1978). The renewed interest in the process was due to the increasing costs of both cyanide and its treatment. In the CANMET study, a bench-scale laboratory apparatus was employed to investigate the recovery of cyanide from six actual barren waters. The study summarized for the first time the various chemical reactions associated with the process. The process was referred to as acidification, volatilization and reneutralization or the AVR process, which is the current terminology for cyanide recovery and regeneration from solutions.

The study advocated the use of single complete mix aeration basins about 1.5 m in depth instead of stripping towers, to minimize the mechanical problems associated with scaling and plugging of media or internals, and to minimize pressure drop and horsepower requirements. It was recommended that aeration in a full-scale operation be accomplished using multiple rows of fine bubble diffusers.

The AVR process was evaluated as a primary wastewater treatment alternative, utilizing pH values below 2.0 to facilitate removal of total and iron complexed cyanides through precipitation. Greater than 99 percent removal of total cyanide was achieved in the studies, with treated effluents containing total cyanides ranging from 0.10 to 4.0 mg/L. In addition, the investigation of metals precipitation was undertaken, demonstrating that excellent removal efficiencies were achievable following reneutralization with lime. However, the process was confined to solution treatment as it was considered not feasible for treatment of tailings slurries. In addition, the use of basins and fine bubble diffusers increased the horsepower requirements compared to towers, due to the increased pressure losses encountered in the system.

A full-scale packed tower cyanide recovery system was designed and operated from 1985-1987 by Golconda Engineering and Mining Services at the Beaconsfield Gold Mine in Tasmania (Kitney, 1988). The process was termed the C.R.P. or Cyanide Regeneration Process. Initially, a continuous flow pilot plant operation was conducted to establish the appropriate air to liquid ratio, stripping time and caustic requirements for the absorber. The full-scale facility was designed to treat 1,200 tonnes/day of clarified barren water using a system of multiple packed aeration towers.

The plant was designed using the most modern mass transfer technology, plastic media and cyanide monitoring equipment. The system was designed for maximum safety incorporating an enclosed negative pressure system. Fan exhausts were monitored routinely for HCN with typical values of <1.0 mg/m^3, which were 1/10 of the 8-hour 10.0 mg/m^3 TLV for free cyanide. Cyanide recoveries of nearly 95 percent were reported in the full-scale system.

The various laboratory, pilot plant and full-scale cyanide recovery facilities described have demonstrated that application of mass transfer technology coupled with state-of-the-art monitoring equipment and engineering design approaches can be employed in the construction and operation of full-scale cyanide recovery systems. However, it has been widely believed that the cyanide recovery process cannot be extended to slurries, due to the problems associated with the chemical and physical properties of low pH slurries and the lack of adequate materials and equipment.

5.8.1.3 INCO/SO_2/Air Process

INCO research has recently developed a process for the destruction of cyanide in industrial wastewaters. The process involves the use of sulphur dioxide or sulphite and air in the presence of a copper catalyst. The process has been evaluated in bench, pilot, and full scale operations for the treatment of several Canadian gold mining and metal finishing wastewaters. The process has been shown effective in the removal of free and metal complexed cyanides and metals. At this time insufficient research has been conducted to completely elucidate the reaction mechanisms.

Cyanide removal is catalyzed by the presence of copper ions in solution, while thiocyanate removal is catalyzed by the presence of nickel ions in solution. In general, the removal of thiocyanate is relatively slow and does not occur to any great extent. The optimum pH for the process is 9.0. Sulphur dioxide can be supplied either as SO_2 gas, sodium sulphite, or sodium metabisulphite. The metal cyanide complexes are removed in the preferential order of Zn, Fe, Ni, and Cu. The iron remains in the reduced form and combines with other metals in solution to yield insoluble metal ferrocyanide complexes as shown in equation 26. Metals liberated from the complex of Cu, Ni, and Zn which are not utilized in the precipitation of the metal ferrocyanide complex are precipitated as the metal hydroxides. The theoretical reagent requirements for sulphur dioxide and lime are 2.5 g SO_2/g CN^- and 2.2 g CaO/g CN^-, respectively. However, in practice the reagent consumption is usually higher. The minimum copper concentration required is 50 mg/L which is supplied as copper sulphate, although in practice the required concentration may be considerably higher. The reaction period required varies from 30 to 60 minutes.

Recently, INCO scientists had the opportunity to install and operate a well designed treatment system at the McBean Mine in Ontario. The system consisted of a modified four compartment flotation cell which was employed as the reactor. During the study >99% removal of total cyanide was achieved resulting in an average effluent total cyanide concentration of <1 mg/L. Mean removal efficiency for metals removal including iron was >90%. The average effluent copper concentration was 1.2 mg/L.

The approximate consumption of sodium metabisulphite, lime, and copper sulphate per gram of cyanide was 5.4 g/g, 3.9 g/g, and 0.2 g/g, respectively. The influent wastewater total cyanide concentration to the treatment facility averaged 366 mg/L. The advantages and disadvantages of the SO_2/AIR process are presented in Table 5.5.

5.8.1.4 Ferrous Sulphate

When an excess of ferrous ion is introduced into a mining solution containing elevated free cyanide levels, the ferrous cyanide complex is formed. The complex is so stable it gives none of the common qualitative tests for ferrous or free cyanide ions. The addition of ferrous ions to solutions containing ferric cyanide yields a blue precipitate known as Turnbull's blue. Ferric ion on the other hand reacts with ferrous cyanide ions to form the familiar insoluble Prussian blue.

TABLE 5.4

Advantages and Disadvantages of the Inco SO_2/Air Process

ADVANTAGES

1. The process has been proven in bench, pilot, and full scale applications and has been proven effective in the treatment of cyanide and metal containing wastewaters.
2. The process is effective in treatment of pulps as well as clarified barren and decant solutions.
3. The process is suitable for batch or continuous treatment.
4. Technical support is available from INCO personnel.
5. All forms of cyanide are removed including the stable iron complexed cyanides.
6. Capital costs are comparable with other chemical treatment processes.
7. Heavy metals are removed through precipitation.

DISADVANTAGES

1. The reagent costs and consumption for the process (SO_2, lime, and copper sulphate) can be excessive.
2. Cyanide is not recovered.
3. Large quantities of sludge may be produced which may be considered hazardous.
4. A royalty payment is required for the patented process.
5. Additional treatment may be necessary for removal of total cyanide, thiocyanate, cyanate, metals, and ammonia if stringent effluent requirements and water quality criteria must be met.

6. The process creates relatively high effluent dissolved solids concentrations which may exhibit undesirable environmental effects.

The two mixed iron cyanide precipitates are evidently the same and have the approximate composition KFe $[Fe(CN)_6]$-H_2O, which exhibits the deep blue color. The knowledge of this chemistry led to the development of process for removal of free cyanide (Kuit and Babcock, 1981). The process of precipitating cyanide as an insoluble iron complex was first examined on a full scale at the 700 metric tpd Cominco Limited gold mining and milling operation located on the shores of the Great Slave Lake. Before adopting the hydrogen peroxide process for cyanide destruction, the mine employed a cyanide removal system based upon the adsorption of cyanide and metal cyanides on freshly prepared ferrous sulphide.

Finely divided insoluble ferrous sulphide was prepared in a mill by mixing ferrous sulphate with sodium sulphide, and adding the slurry to the barren bleed. The reaction which was pH dependent, was conducted at a pH of 7.5 at a flow of about 90 l/min. with a retention period of about 15 minutes. The ratio of ferrous sulphide to cyanide was maintained near 3:1.

The treated effluent from the process was discharged to the mill tailings launder. Ferrous sulphate was also added to the launder to remove arsenic through precipitation. The removal of cyanide was not intended to achieve an effluent guideline. Rather, it was to enhance the process of natural attenuation in the tailings impoundment by lowering the total cyanide content.

The process is best suited as a pre-treatment step for removal of free cyanide from a mill tailings slurry or heap leach pad rinse solution, or an emergency removal system for free cyanide contained in a spill.

The process works only for free cyanide, although there is evidence that if the pH of the solution following ferrous addition is decreased below 4.5, precipitation of other metal cyanides as their neutral complexes is possible. Therefore, Wad forms of cyanide, other than free, are not removed through addition of ferrous ion. The process is not generally suitable as a primary treatment process.

5.8.1.5 Alkaline Chlorination

Alkaline chlorination is a chemical process involving the oxidation and destruction of free and wad forms of cyanide under alkaline conditions (pH - 10.5-11.5). The chlorine is supplied either in liquid form or as solid sodium or calcium hypochlorite. The solid forms are prepared in concentrated solutions prior to use in the oxidation process. The chlorine or hypochlorite can also be generated on-site (in-situ) electrolytically.

Alkaline chlorination is the oldest and most widely recognized cyanide destruction process based upon operational experience and engineering expertise. The first industrial applications of alkaline chlorination were in the treatment of metal plating and finishing wastewaters, which also contained cyanides and metals. The use of alkaline chlorination in mine wastewater treatment resulted from the chemical similarity noted between metal plating and mine wastewaters. A few mining applications still exist, although the trend is toward other oxidation processes for the treatment of excess metallurgical and tailings impoundment wastewaters.

The first stage of cyanide destruction utilizing either hypochlorite or chlorine gas involves oxidation of cyanide to the intermediate cyanogen chloride (CNCl). At the elevated pH of the oxidation the intermediate cyanogen chloride is rapidly hydrolysed to cyanate. The entire first stage of the oxidation requires approximately 15 minutes at a pH - 10.5. The second stage of the oxidation involves hydrolysis of the cyanate in the presence of chlorine or hypochlorite to ammonia and carbonate.

The hydrolysis requires approximately 1.0 to 1.5 hours, although reaction periods of several hours have been employed. If excess chlorine or hypochlorite is added, the ammonia will react further through the process of breakpoint chlorination to yield nitrogen.

The process is not conducted to the breakpoint stage normally due to the increased chlorine demand and to the excessive reaction period required at the elevated pH utilized in the process. The oxidation of cyanide to cyanate requires approximately 2.75 parts of chlorine per part of cyanide, although in practice the chlorine consumption is much higher. One compound contributing to the overall chlorine demand is thiocyanate (SCN^-), which is found in varying quantities in most mine wastewaters. Thiocyanate is oxidized in preference to cyanide and in theory requires 4.9 parts of chlorine for each part of thiocyanate.

Cyanide is present in several forms in mine and tailings impoundment wastewaters including free cyanide (HCN/CN^-) and metal complexed cyanides. The metal-complexed cyanides are present in two forms including the extremely stable iron and cobalt cyanide complexes and the weak acid dissociable metal complexes of cadmium, nickel, zinc and copper. Alkaline chlorination will remove, under ambient conditions, all forms of cyanide except the extremely stable iron and cobalt cyanide complexes. The concentration of iron complexed cyanides can be reduced by alkaline chlorination through employment of elevated temperatures or the addition of ultraviolet light, both of which are relatively impractical and increase the cost of the process significantly. As a result, the applications of alkaline chlorination are limited to those wastewaters containing insignificant levels of the iron complexed cyanides. Since the process is operated at elevated pH values precipitation of metals as their hydroxides also occurs.

The design of the process is straight forward with process design information usually obtained through bench-scale and/or a pilot plant testing programme. The chemical feed equipment and monitoring systems are commercially available and reliable. The alkaline chlorination process has been employed on a full-scale basis at about eight mining operations in Canada and the United States.

5.8.1.6 *Biological Treatment*

Although historically biological processes have been proven effective in the treatment of high concentrations of free cyanide, it is only recently that they have been utilized in the treatment of barren or tailings impoundment wastewaters containing elevated concentrations of metal complexed cyanides. A full scale biological treatment facility was designed and placed into operation at the Homestake Mine in Lead, South Dakota (USA), in late 1984. Currently, the facility is treating approximately 20,000 M^3/day of combined decant and mine wastewaters. All forms of metal completed cyanides are removed including the stable iron completed forms, which are removed through a combination of oxidation and adsorption. In addition, the process removes heavy metals through a combination of biological adsorption and chemical precipitation. Thiocyanate and ammonia are also removed to very low levels. The treated effluent is discharged to a stream serving as a marginal stocked trout fishery. The effluent has been shown to be environmentally acceptable through extensive toxicological testing. Effluent concentrations of total cyanide, ammonia, copper, and thiocyanate are consistently below 0.5 mg/L.

The chemical requirements for the process include phosphorous and soda ash in minimal quantities. The phosphorous, which serves as a trace nutrient, is added in the form of phosphoric acid. The addition of soda ash is required to aid the microorganisms involved in nitrification process.

The process is an attached growth biological system involving the use of several strains of bacteria. The facility incorporates the use of forty eight rotating biological contractors on which the bacteria reproduce forming an active biofilm. The rotating biologica contractors consist of circular sheets of corrugated plastic attached to a metal shaft. The shaft rotates partially submerged in the wastewater, alternately exposing the biofilm to the air and the wastewater. It is within the active biofilm that the actual degradation and adsorption processes occur. The oxidation and adsorption of cyanide, thiocyanate, ammonia, and metals requires approximately 2.5 hours.

The biological solids which continuously slough from the biodiscs are removed through secondary clarification and disposed of in the tailings impoundment or placed in drying beds. The advantages and disadvantages of the biological treatment process are presented in Table 5.6.

TABLE 5.5

Advantages and Disadvantages of the Biological Treatment Process

ADVANTAGES

1. The process is simple in design and process control is minimal.

2. Reagent costs for phosphoric acid and soda ash are very low in comparison to other treatment processes.
3. All forms of cyanide are treatable including the stable iron complexed cyanides.
4. Heavy metals are removed through a combination of adsorption and precipitation.
5. Thiocyanate and ammonia are oxidized and removed.
6. The effluent from the biological treatment process has been shown to be environmentally acceptable.

DISADVANTAGES

1. Capital costs are similar to those of other treatment processes.
2. The biological treatment process, as with other treatment processes, has not been widely applied or accepted in the treatment of mine wastewaters or metallurgical solutions.
3. Suitable microbial populations may not be found locally, requiring obtainment of commercial or patented bacteria for which a fee may be charged.
4. Additional treatment may be required if residual effluent metals concentrations exceed environmentally acceptable levels.
5. The performance of the process is affected more adversely by cold temperature than are other chemical or physical treatment processes.
6. Cyanide is not recovered.
7. The process is less suitable for batch treatment applications than the other chemical/physical treatment processes.

COMMENT

Chemical treatment may be required at some mine sites and is usually acceptable during operation. Cyanide naturally decays and long-term treatment is not likely to be required. However, at some sites it may be necessary to provide treatment for a temporary period after operations cease until sufficient decay has occurred and waters can be discharged without treatment. This would meet the Strawman II goals of low maintenance closure.

5.9 Wildlife Protection

Cyanide operations can pose a hazard to both wildlife and the environment if effective precautions are not taken. Ponds attract wildlife, notably migratory waterfowl but also: deer, cows, bats, rodents and reptiles. Killing migratory birds without a license or a permit is a criminal offense under the Migratory Bird Treaty Act. In Nevada about 90 percent of the reported wildlife deaths were of birds - mostly of migratory waterfowl.

Bird control at containment pond sites is achieved by two well known, but poorly understood aversion techniques: hazing systems (sound/visual) and stretch wire (Martin, 1992). The limiting condition of either approach is that resident birds rapidly adapt while some migrating species are totally unaffected. Hazing devices include techniques such as propane cannons, pennants, floating alligators, decoy owls, music, and other recorded sounds. However, hazing is an ineffective long-term solution. Mine operators report that migratory birds quickly become accustomed to the sound of propane cannon explosions and cease to be frightened away. Any bird control technique other than netting or other coverings on a containment basin should be considered as only part of a wildlife protection system. Alaskan conditions may further reduce the effectiveness of hazing devices. For example, on windy days only half of the propane canons will function properly and below freezing the firing rate will be extremely slow.

Trial and error have shown that preventing wildlife deaths requires either (1) restricting access to the cyanide solution by fencing the perimeter and covering the surface of cyanide ponds with netting or other materials or (2) diluting the solution to nonlethal levels with water or by chemical detoxification. Generally, solutions of 50 or fewer parts-per-million of cyanide are generally non-lethal while solutions of 100 or more parts-per-million are clearly lethal to birds.

The latest developments in research of deterrent devices is the use of radar and motion detectors to alert a remote sensing device that will automatically activate the propane canons or pyrotechnique devices located along the landing approach path. This approach to the use of deterrent devices would be useful on the 100 acre tailings ponds.

Bird net is available in a solid strand or chain-link configuration. Chain-link netting is a diamond mesh, stretch net. This net product is generally more expensive and more difficult to install over a containment basin than an equal weight of solid strand net. Abrasion caused by the wind is the paramount factor to consider in choosing a cable. Minimizing wind damage may be achieved by constructing a wind break along the side of the pond which is hit first by the prevailing winds, although this clearly could not be effective on a 100 acre pond.

Snow and ice build-up are the next most important variables to be dealt with. Snow will collect on a one inch mesh faster than on a two inch opening. Ice build-up will collapse any net regardless of mesh size. Most facilities in snow country have someone periodically "thumping" support cables to cause snow to fall through during a snow storm. Consider that the one inch net excludes all birds while a two inch net will allow small birds including some shore birds to pass through. Usually they become trapped under the net. In snow country the mesh size should be determined by the probability of small birds using the ponding basin. Snow and ice accumulation will be minor problem in northern Alaska. In southeastern Alaska, snow and ice build-up is likely to be a major issue and careful identification of the species to be repelled is necessary to avoid using a netting with overly small openings.

Comment

The use of cyanide for gold recovery and measures to protect wildlife have not been extensively developed for Alaskan conditions, consequently, any measures should be developed with flexibility for modifications as required and a monitoring system to evaluate the effectiveness of the overall system.

6.0 WATER MANAGEMENT

Water management is the term applied to the techniques used for ensuring that water occurring on and around the site is controlled for the benefit of the mining operation and the surrounding environment.

Some guidance on the typical main components of a water management plan are given in the following paragraphs.

6.1 Water Balance and Mass Balance

Water balance calculations enable the hydrological regime of a tailings impoundment to be understood by comparing the total inflows to the total outflows. A mass balance is an extension of a water balance to include volumes of solids which are added to or taken from a water body. Frequently it is useful to combine the water balance volumes with chemical loadings and thereby to develop a water quality model.

An annual water balance will determine whether the water body is in water surplus or deficit, and therefore whether provision needs to be made for additional inflows, for example to maintain a water cover over potentially acid generating tailings, or for reduced inflows to limit storage volumes and discharge quantities. Additional information, such as seasonal water level fluctuation and extreme water levels, can be derived from a monthly analysis.

The effects of unusually 'wet' or 'dry' years can be determined using statistically determined high and low precipitation quantities. This is done by a frequency analysis of annual precipitation data and choosing actual years having precipitation quantities which correspond closely to the statistically determined values, or by developing 'synthetic' precipitation data meeting the statistical criteria. For potentially acid generating tailings a minimum water cover of 1 m is recommended in the event of a 100 year return period dry year. Note that this minimum cover applies to the most elevated point, such as the head of a tailings beach.

Inflows to a tailings impoundment will generally include the following parameters:

- mill water discharge;
- direct precipitation of the water surface (no loss assumed);
- runoff from the surrounding catchment area;
- groundwater seepage;
- waste water; and
- seepage return.

Outflows to be incorporated in the water balance will include:

- Mill water reclaim;
- Water entrained in the voids of deposited solids;
- Evaporation;
- Seepage;
- Controlled discharges;
- Spill.

In the design stages of a proposed facility it is usually necessary to know the rate at which the embankments must be raised during the course of operations. Therefore a mass balance, incorporating all the solid and liquid inflows and outflows, is conducted, usually on a monthly basis for the projected operating life of the facility. Sensitivity analyses should be conducted so that the significance of the various assumptions can be assessed.

Mass inputs will include those mentioned above, tailings solids and possibly mine rock, plus water treatment plant sludge, incoming sediment and other deposited materials. If there are natural influent streams to the impoundment with a high bed load or suspended solids content, it is likely that some of the transported material will be deposited in the impoundment, forming a delta at the point of entry. The deposited sediments will occupy space that would otherwise be available for water storage and must therefore be accounted for in mass balance calculations and impoundment design.

6.2 Design Floods

6.2.1 Introduction

The selection and computation of design floods is an important part of the design for all tailings impoundments. It affects the design or upgrading of embankments, spillways and ditches.

The commonly used terminology for floods of different magnitudes is as follows. A *statistically determined flood* is one of a given return period, such as a 200 year flood, and it can be expected to occur, on average, once during that period. In any given year a 200 year flood therefore has a 0.5% chance of occurring. Similarly, a 100 year flood has a 1% chance of occurring. The smaller the return period, the smaller is the flood and the greater are the chances of its occurrence.

The *probable maximum flood* (PMF) is defined as the flood which may be expected from the most severe combination of meteorologic and hydrologic conditions reasonably possible in the region. Such an event may be due to the *probable maximum precipitation* (PMP), or an extremely severe snowmelt event, or a combination of rainfall and snowmelt.

Some guidance on the computation of design floods is given here and for more detail reference can be made to numerous hydrology texts (e.g. U.S. Bureau of Reclamation, 1977; Watt, 1989; Linsley Kohler and Paulhus, 1975; Chow, 1964). Computation of a design flood is normally undertaken by a professional engineer experienced in hydrology.

For drainage areas smaller than 2.5 square km the Rational method of calculation is adequate. This will require data on storm rainfall intensity, duration and frequency for the area. The Rational method is described in many texts (e.g. Haan and Barfield, 1978).

For drainage areas between 2.5 and 12.5 square km both the Rational method and a synthetic unit hydrograph method should be applied and engineering judgement used to determine the design flood flow. A synthetic unit hydrograph can be developed using empirical relationships between the hydrograph properties and the catchment characteristics (Linsley, Kohler and Paulhus, 1975) and the streamflow hydrograph is then synthesized by combining the unit hydrograph with the effective rainfall.

For drainage areas larger than 12.5 square km the preferred method is to conduct a frequency analysis of streamflow records on the watercourse in question, if available, or on other similar catchments in the region. In this way regional relationships can be developed between catchment size and flood flows of different return periods. The frequency analysis method should be supplemented by application of a synthetic unit hydrograph using a catchment model such as HEC-1 or OTTHYMO. These models can be used to apply a standard rainstorm, such as an SCS Type II storm, to the catchment. Again engineering judgement is required, both in the selection of parameters for the model and in choice of the peak flow value. In permafrost environments it has been observed (Woo, 1983) that spring melt released considerable meltwater which could not be accommodated by the thinly thawed active layer and high runoff has resulted.

6.2.2 Ditches and Spillways

Ditches and spillways will tend to block eventually by bank sloughing and growth of vegetation in the channel. Design of any permanent ditches should include oversizing the ditches to minimize maintenance. The design criterion should be the probable maximum flood (PMF), only where large environmental damage or risk to life could result. For moderate and low risk ditches, design events of 1,000 years and 200 years, respectively, are appropriate.

Velocities in ditches and spillways during the design event should be low enough to prevent erosion. Non-eroding velocities for channels in various materials are listed in several texts (e.g. Brater and King, 1976) Suitable design velocities range from 0.5 m/s for channels in fine sand to 1.8 m/s for shales and hardpans. Riprap lining will allow much greater velocities and will also provide some energy dissipation.

Side slopes should be trimmed back to stable angles where necessary; generally these slopes are between 1 vertical to 2 horizontal for soils and vertical for rock cuts. Redesigned channels require judicious choice of cross section, lining (if any), side slopes and gradient.

7.0 CLOSURE AND POST-CLOSURE CARE

7.1 Regulatory Requirements

Goals to consider in closure planning are pollution prevention, resource recover, source control and low maintenance closure. These can be addressed under the headings of physical and chemical stability using the design for closure approach, as described in Section 5.3.3.

The following sections describe some of the objectives and means for achieving an acceptable closure scenario.

7.2 Decommissioning Objectives and Measures

7.2.1 Physical Stability

Embankments

The objectives of embankment design, construction, and closure are:

- to leave a structure which has a minimum factor of safety against deep seated and surface slumping failure of 1.5 and 1.0, under static conditions and maximum seismic loading, respectively;
- to have slopes, both upstream and downstream, which are resistant to perpetual erosion forces; and
- to protect the structure from erosion due to overtopping flow.

Dufour et al (1987) describe some of the restoration alternatives for an abandoned tailings pond at a remote northern site.

Access onto tailings embankments is not considered to be a safety hazard because the slopes are relatively flat and measures to control access are not usually required. It may be necessary to control access to prevent the inducement of erosion along preferential flow paths resulting from hiking trails or ATV tracks.

Measures which may be used to achieve the objective of long-term stability include:

- initial site selection to avoid low strength foundations or removal of these materials prior to construction;

- constructing of the embankment with durable underdrains to prevent build up of the water table;
- constructing with low downstream slopes or flattening the overall slope by constructing a toe berm;
- placing a rip rap or establishing a vegetation cover on the surface of the embankment to control erosion;
- constructing of the embankment with sufficient freeboard (in conjunction with spillway design) that the maximum probable flood will not overtop the crest; and
- appropriate siting of the tailings impoundment and diversion of run-on water to limit large flows around the impoundment.

Tailings

The objective for physical stability of tailings is to prevent release or migration of the tailings either directly by wind action causing fugitive dust or by wind induced wave action. Fugitive dust can be controlled by as little as a 4 inch thick layer of gravel over the tailings (Barth 1986). Wind induced wave action is described below in Section 7.3.5.

Associated Structures

Structures associated with a tailings impoundment system include discharge lines, decant systems, and spillways. At closure, discharge lines should be flushed and then disposed of in an approved manner. Closure considerations for decant systems are discussed in Section 5.7. Long-term performance considerations for spillways are discussed in Section 6.0.

7.2.2 Chemical Stability

Chemical stability issues include: acid rock drainage (ARD), leaching of metals, and flushing of mill reagents or other chemicals. Potential control technologies for chemical stability are presented in Table 7.1. Generally, control measures must be specific to the type and source of contaminant. Prediction of the type, concentration and volume of an effluent is essential to identifying the most effective and economical control method. Prediction methods are described in Section 5.1.2.

TABLE 7.1

Chemical Stability
Potential Control Technologies

CONTROL OF REACTIONS

CONTROL TECHNOLOGY	ARD	METAL LEACHING	MILL REAGENTS
Conditioning of waste/ removal of deleterious mineral.	Yes	Yes	
Covers and seals for exclusion of water.	Yes	Yes	
Covers and seals for exclusion of oxygen.	Yes		
Blending/ base addition.	Yes		
Bactericides (short term only)	Yes		
Change mill process, change reagents.			Yes
Change mill process, add fixing or neutralizing agents.			Yes

CONTROL OF MIGRATION

CONTROL TECHNOLOGY	ARD	METAL LEACHING	MILL REAGENTS
Covers & seals to reduce infiltration.	Yes	Yes	Yes
Controlled placement to reduce infiltration.	Yes	Yes	Yes
Diversion of surface water.	Yes	Yes	Yes
Interception of groundwater.	Yes	Yes	Yes

COLLECTION & TREATMENT

CONTROL TECHNOLOGY	ARD	METAL LEACHING	MILL REAGENTS
Active treatment in chemical treatment plant.	Yes	Yes	Yes
Passive treatment using wetland.	Yes	Yes	Yes
Passive treatment using alkaline trench.	Yes		
Passive treatment using retention pond.			Yes

7.3 Design of Covers

7.3.1 Introduction

The transport medium for contaminants is water and the principal source of this water is infiltration of precipitation. The control of infiltration is therefore important in controlling migration of ARD or tailings pore water. Covers may also be used to control ingress of oxygen for control of ARD. The most practical way of controlling infiltration of precipitation is by means of low permeability covers or seals. Soil and synthetic materials are commonly used to construct covers. The length of time during which control is required is an important consideration in selecting the most appropriate cover material or combination of materials.

An important consideration in the design of covers for sites in Alaska is the potential for degradation of the cover by frost processes. These are discussed further in Sections 5.1.1.5 and 5.3.2.5. Rip rap covers may also be used to control wind and water erosion of tailings or embankments. A water cover of sufficient depth will prevent remobilization of deposited tailings due to the following causes:

- wind induced wave action; and
- eroding water velocities during flood events.

A water cover may also be required to minimize air-water gas transfer and hence limit the introduction of oxygen to the deposited tailings (Daniil and Gulliver, 1991).

An inert granular cover over the tailings and below the water surface, may be required as an alternative to a greater depth of water cover in situations where the required water depth is not attainable. The following discussion deals with determination of the minimum water depth for each of the above considerations.

COMMENT

Although mine wastes are not classified under RCRA Subtitle D, wastes which exhibit chemical instability may require covers for protection of the environment. Where covers are to be constructed over wastes in Alaska then special attention should be made to the specific conditions at the site. For example, in northern Alaska where extreme cold temperatures prevail, the number of freeze/thaw cycles are fewer than in many regions of continental USA and consequently freezing conditions may not be a major design factor in northern Alaska. RCRA guidance documents on cover design should be evaluated before being applied unilaterally to Alaska.

7.3.2 Soil Covers

Although soil covers do show promise as oxygen inhibitors, they are generally more effective in controlling infiltration of precipitation. The effectiveness of soil covers as inhibitors of infiltration depends on factors such as climate, cover design and construction. The mechanisms of infiltration, design of covers, and effectiveness of soil covers as barriers to infiltration are briefly described below. A more detailed discussion is presented in SRK 1989.

7.3.2.1 Mechanisms of Infiltration

Water Flow in Unsaturated Soils

Water transport in the cover material and in the waste underneath takes place under generally unsaturated conditions (Collin, 1987). This implies that the porous material is partly filled with air. Flow under unsaturated conditions is considerably smaller than under saturated conditions. Water statics and dynamics in the unsaturated zone are also of utmost importance for the diffusional transport of oxygen from the surrounding air since a high moisture content in the cover material is needed to restrict this transport.

When water is applied to the soil surface for a relatively short period of time, the water redistributes in the soil profile. The actual water content at a given depth and time is dependent on the soil water characteristic curve of the particular soil in question. This type of infiltration and redistribution would occur in a waste cover after a rainfall event.

Comparing the sand, loam and clay soils, we see that fine grained soils maintain higher water contents (therefore lower air filled porosity) than coarse grained soils drained for the same period of time. This is due to both the lower conductivity and smaller pores in the clay soil.

If vegetation was present on a cover, the plant roots would be extracting water from the soil to be transpired to the atmosphere. The combined effect of evaporation and transpiration is termed evapotranspiration. The presence of vegetation results in a greater loss of water from the soil and drying of the soil to a greater depth, dependent on plant type and time of year. It also tends to disrupt drainage and this increases ponding and infiltration. There are a number of other factors which influence the infiltrate rate, such as the texture and compactness of the soil surface, texture and irregularity and slope and the resulting ponding, duration and intensity of rainfall. Prediction of infiltration rates through uniform soils is therefore extremely complex. Cracks, root holes, burrows and soil variability makes this even more complex.

Modelling Infiltration

Modelling of water flow in unsaturated soils is complicated by the non-linear nature of the interrelationships of the soil water properties, and by the fact that steady-state flow conditions are seldom achieved in the field.

Alternative methods for the modelling of infiltration have been reviewed by Steffen Robertson and Kirsten (1986a).

The Hydrological Evaluation of Landfill Performance (HELP) model developed by the U.S. Army Corps of Engineers is an extremely useful tool for a first evaluation of the relative benefits of alternative cover layers with and without vegetation cover. The large potential differences in infiltration between the different cover types is apparent. The HELP model assumes saturated soil conditions at the commencement of precipitation. Clearly this is an approximation leading to considerable inaccuracies under certain circumstances.

The TRUST model was developed at Lawrence Berkeley Laboratories and is well described by Reisenauer et al, (1982). This suite of programs has been extended to allow more effective and convenient applications to cover design by McKeon et al, 1983. While the program allows for partially saturated flow the determination of input variables to adequately allow for the seasonal and extreme variations found in practice still renders the accuracy of the answers questionable.

A model that simulates unsaturated conditions, called SOILMOIST, has been developed for the US Uranium Mill Tailings Remedial Action Program and this may yield more realistic results under certain circumstances.

A limitation that all the models suffer from is the inability to anticipate and include the effects of layer disruptions such as:

- settlement causing drainage disruption and ponding;
- cracking due to settlement or desiccation;
- root holes;
- burrowing channels formed by insects, animals and man;
- frost action effecting permeability and drainage;
- erosion;
- disruption of drainage by vegetation; and
- clogging of drains due to frost or root action.

These disruptions may be more severe with complex layered covers than with simple homogeneous covers.

7.3.2.2 *Simple Covers*

In the interest of minimizing cost, a simple, single layer, soil cover is preferred. A fine textured soil, such as clay or silt, is required to limit infiltration. To effectively limit oxygen transport it is necessary to maintain the layer at a high moisture content. A single soil layer, however, is limited in its effectiveness for the following reasons.

- Without capillary barriers, a simple soil cover is prone to large seasonal variations in moisture content. This could result in desiccation cracking and hence an increase in permeability. In addition, decreasing the moisture content of the soil increases the rate of oxygen diffusion. These seasonal variations are greatest near the surface and their effect is therefore greatest for thin covers. For single layer soil covers to be effective they need to be relatively thick to maintain a saturated zone during the dry season. The cover thickness required is primarily a function of the climate but is likely to be of the order of 2 m for regions such as southeast Alaska. This is based on the annual frost penetration. In permafrost regions this thickness should be greater than the depth of the active layer.

- The fine-grained soils required to limit infiltration may be frost susceptible. Ice segregation may result in degradation of the cover and increased permeability. Frost heave may also make the surface of the cover irregular, allowing ponding and increased infiltration.

- A simple soil cover does not have the ability to prevent moisture being sucked up from underlying tailings by capillary action. Likewise, it does not limit the migration of salts from the tailings to the surface due to surface evaporation and transpiration.

- A simple, single layer fine-grained soil cover may not be able to adequately withstand wind and water erosion or burrowing and root action. Some form of erosion protection, such as vegetation or rip-rap is normally required.

These limitations on the effectiveness of a single soil layer can be overcome by using complex covers, as described in the next section.

7.3.2.3 *Complex Covers*

The effectiveness of a soil cover is greatly improved by adopting a complex cover design consisting of several layers, each performing specific functions to improve water and/or oxygen exclusion and long-term stability. These layers and their specific functions are described below. A typical complex cover design is illustrated in Figure 7.1.

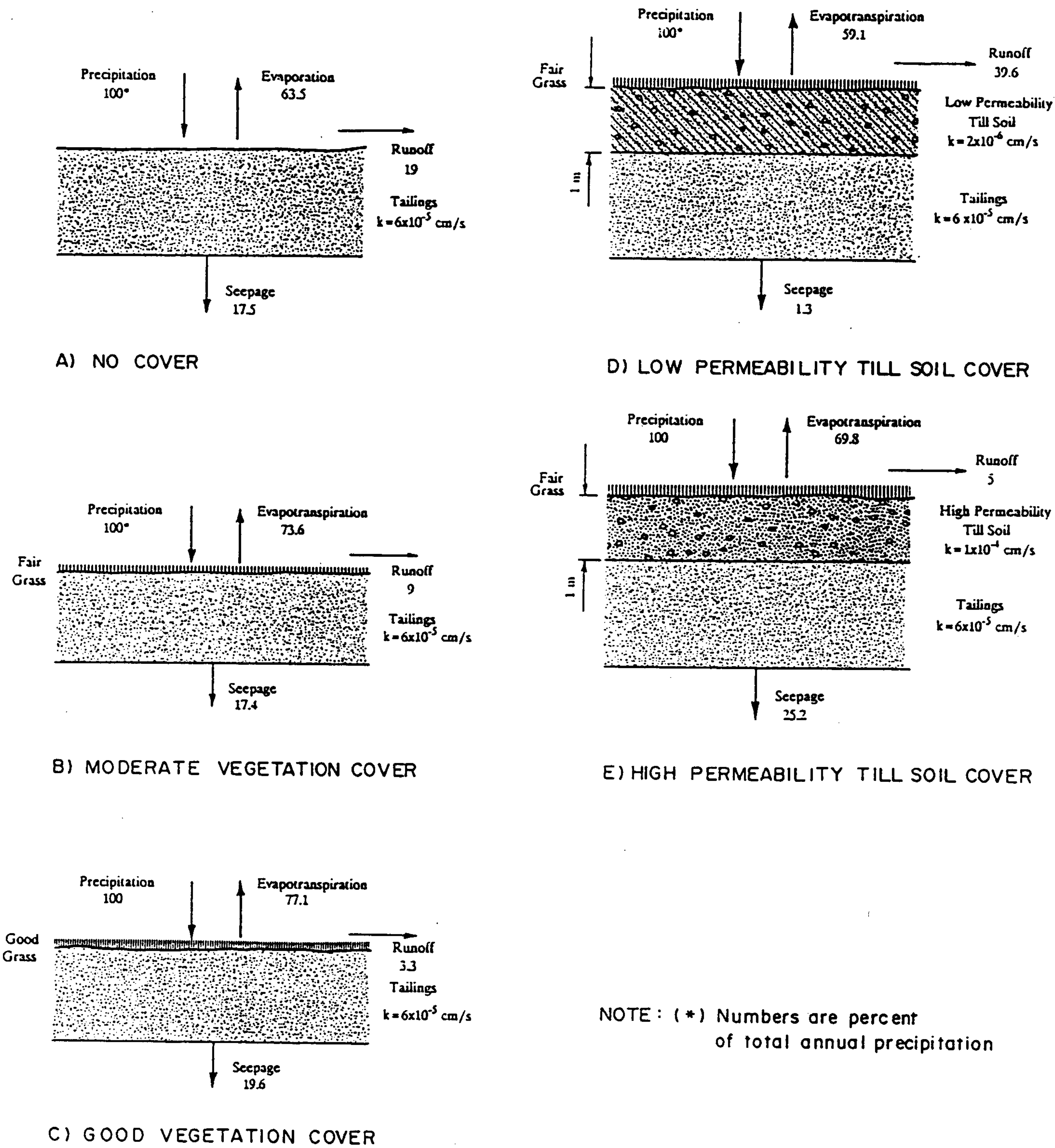


Figure 7.1 Effect of Cover Type on Infiltration Rate (After Steffen Robertson and Kirsten, 1988b)

1) Erosion Control Layer

Erosion protection can be provided by vegetation or by a layer of coarse gravel or rip-rap. The establishment of vegetation on the waste dumps is desirable for aesthetic and land use reasons. Therefore, revegetation is usually the most desirable method of providing erosion control. However, where revegetation is not practical or will not sufficiently control erosion, coarse gravel or rip-rap may be required.

Certain physical, chemical and vegetative stabilization methods have been evaluated for purposes of mine waste reclamation by the U.S. Bureau of Mines (Dean, et al, 1986). This study incorporated field testing of these different methods and costs for the various stabilization procedures.

2) Moisture Retention Zone

The purposes of the moisture retention zone is to provide a zone for moisture retention to limit desiccation of underlying layers. It also provides a growth medium to support vegetation. Moisture retention is therefore desirable for two reasons:

i) it helps to keep the infiltration/oxygen barrier moist which helps prevent desiccation cracking and reduces oxygen diffusion; and

ii) by retaining moisture after a precipitation event it supports vegetation and allows time for evapotranspiration to occur, thus reducing infiltration.

The soil used to construct the moisture retention zone would generally be a loam soil with a substantial sand fraction.

3) Upper Drainage/Suction Break Layer

The upper drainage/suction break layer serves two primary purposes:

i) to drain water laterally from the surface of the infiltration barrier, preventing ponding; and

ii) to prevent moisture loss from the infiltration barrier due to upward capillary suction.

Prevention of ponding reduces infiltration. Keeping the infiltration barrier moist helps to reduce oxygen diffusion and prevents desiccation cracking. This layer can also be designed to prevent intrusion by burrowing animals if it incorporates large gravel. For drainage to be effective it must be constructed with a cross fall of 1% or greater.

The effectiveness of this layer would be expected to decrease with time as it becomes clogged with roots and organic debris and fines, and as the drainage slope is modified by long-term settlement of the underlying tailings or rock waste.

4) Infiltration Barrier

This is a low-permeability layer consisting of fine-grained soil or synthetic materials (or a combination of both). Its purpose is to prevent the downward infiltration of moisture and the diffusion of oxygen into the waste. The lower the permeability of this material, the more effective it is as a barrier to infiltration. The objective of this layer is to provide a sufficient barrier to enable the overlying coarse-grained layer to drain infiltration and prevent ponding of water.

5) Lower Capillary Barrier

Rasmusson and Eriksson (1987) investigated the use of capillary barriers, beneath the infiltration barrier, to reduce infiltration. The principle is that, if negative pore-water pressure is maintained in the low permeability material at the interface with the underlying coarse grained capillary barrier, infiltration into the lower layer would be prevented. They found that this would only be effective if ponding on the low-permeability layer does not occur, which would be difficult to achieve in practice. However, for soil covers over fine grained waste deposits such as tailings, a capillary barrier beneath the infiltration barrier may be useful in preventing suction of contaminated pore water from tailings up into the cover in dry periods.

The long-term performance of a complex soil cover could be greatly reduced if fine-grained materials are allowed to migrate into the coarse-grained layers. Filter layers should be considered.

6) Basic Layer

A basic layer could be incorporated into the design to reduce the pH of infiltrating water and therefore acid generation rates. Alkaline materials such as limestone could be spread over the surface of the waste before placing the cover or mixed into the cover layers.

Limestone is commonly mixed with waste rock during placement at coal mines with great success and research is being done on the addition of phosphate rock (Chiado et al, 1988). The potential for acid generation control by surface applications of alkaline materials is less attractive than mixing them with the waste. Limestone has a low solubility in near neutral water, and the resulting alkaline charge is therefore small and may be insufficient to control ARD. Surface inflows tend to be concentrated at isolated locations such as depressions, cracks, permeable zones, etc. At these locations the available alkaline materials are quickly exhausted. The addition of a basic layer would not significantly reduce acid mine drainage where unsaturated conditions predominate. It would be more beneficial in saturated tailings, and might be usefully employed in tailings impoundment covers.

Acid flux reductions calculated by Steffen Robertson and Kirsten (1987) using the RATAP model (SENES and Beak, 1986) for some simple cover types are tabulated in Table 7.2, and illustrate the theoretical effects of rip-rap, soil and limestone covers.

TABLE 7.2

Effect of Cover Options on Acid Generation
(After Steffen Robertson and Kirsten, 1987)

Tailings Cover Type	Cover Thickness (m)	Sulphate Flux (moles/m^2/year)	Reduction of Acid Flux (%)
None	-	76.65	-
Waste Rock (inert)	0.6	59.37	22.5
Depyritized Tailings (soil)	2.0	21.06	72.5
Depyritized Tailings (plus)	2.0	7.9	89.7

The first cover type considered in Table 7.2 is to provide a non-acid generating waste rock (rip-rap) cover. The primary consequence of this option is a reduced annual summer temperature in the tailings. The results from the mathematical model show a corresponding reduction in acid flux. The effect of a soil cover, in the form of inert tailings, is to lower the temperature as well as raising the water table and hence reducing acid generation. The third type of cover demonstrates the use of limestone to control the pH and hence reduce acid generation. It is important to note that the above example is based on the results obtained from a specific mathematical model and are therefore subject to the assumptions, input and method of calculation adopted for that model. Nevertheless, the example serves as an illustration of how the relative effectiveness of different covers may be evaluated. Figure 7.2, developed from results using the RATAP model, illustrates the effect of depth of a till cover on typical tailings from the Elliot Lake project for various depths of unsaturated tailings (Steffen Robertson and Kirsten, 1987).

Figure 7.2 shows the effects of various types of covers on infiltration rates as predicted by the HELP model for acid generating tailings at Elliot Lake (Steffen Robertson and Kirsten, 1987). The results show considerable benefit of a complex cover design over simple covers, and benefit of adding a synthetic liner.

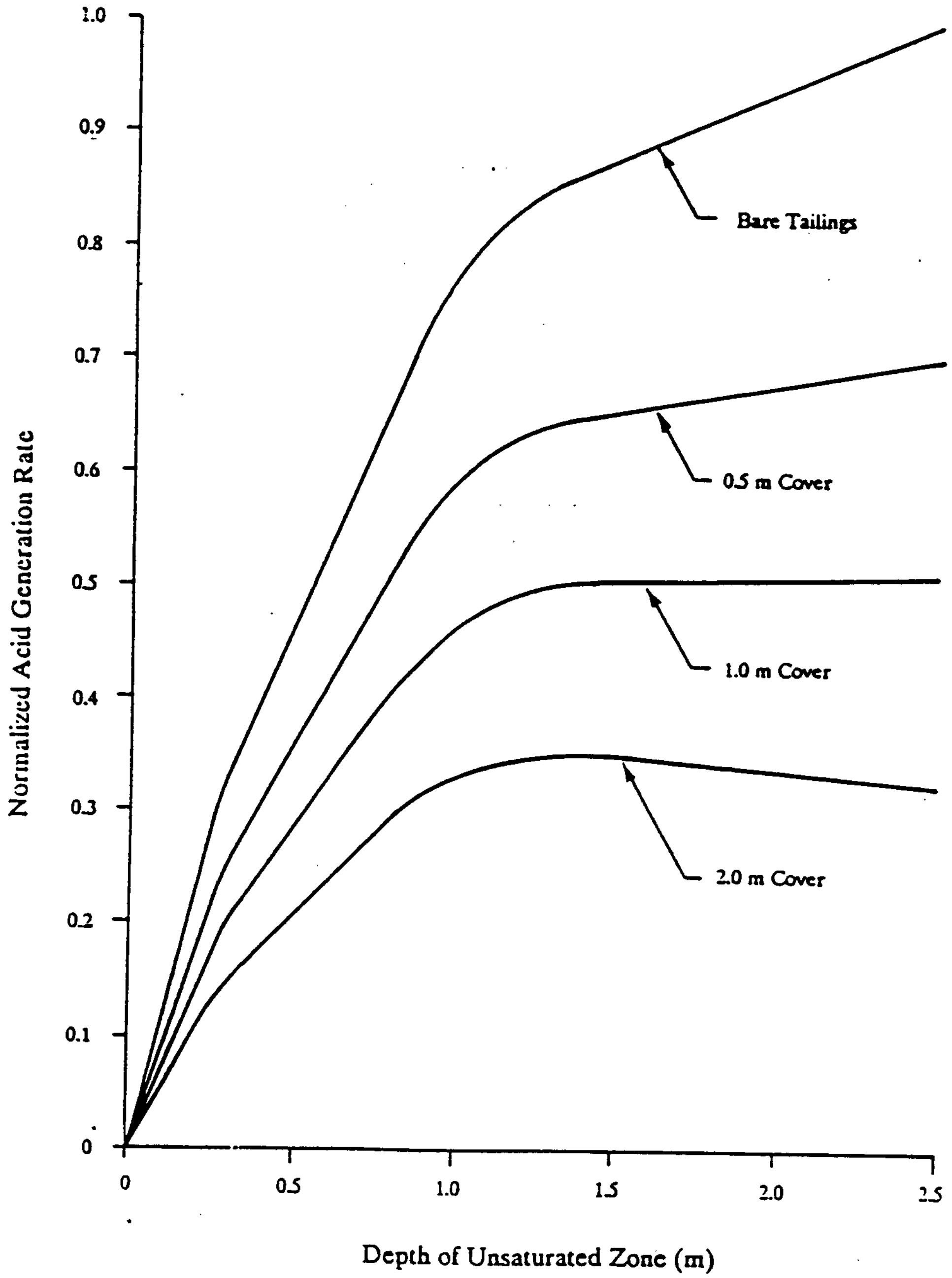


Figure 7.2 Effect of Till Cover Depth on Acid Generation Rate in Tailings (After Steffen Robertson and Kirsten, 1987)

Measurements of groundwater quality criteria beneath rehabilitated dumps at Rum Jungle indicate that the groundwater quality has not changed significantly during the four years since cover placement (Gibson and Pantelis, 1988). It would appear that there is a store of contaminants in the groundwater and within the dump. The response of downstream surface-water quality to cover placement may well be affected by the release of these stored contaminants. On-going monitoring is essential until trends in surface and ground water quality are established.

7.3.3 Synthetic Covers

The use of synthetic membranes for liners for tailings impoundments has been reviewed by Golder Associates, (1984) and are discussed in Section 5.5.4.3.

7.3.4 Cover Placement Considerations

The access, trafficability and stability of a tailings surface varies tremendously, depending on the nature and age of the tailings deposit and location on the impoundment surface. The effects of placement conditions on the properties of tailings deposits has been reviewed by Robertson (1987). The difficulties of placing covers on tailings and the deformations of tailings surfaces are reviewed by Steffen Robertson and Kirsten (1986a).

Wet unconsolidated tailings always represent difficult access conditions. Access improves as the tailings are drained and consolidate. Where tailings have been spigotted onto beaches, the sand fraction is deposited nearest the spigots and drain more freely than the slimes which accumulate near and in the pond. Drained sandy beaches may be trafficable within days of deposition, while pond areas may never achieve this condition. Thus it is possible to place and compact covers on the beach areas with little preparation. In the pond areas it may be necessary to apply drainage measures to remove free and near surface water, and to use geofabrics on the slimes followed by thin layers of the cover. These techniques have been successful in placing a cover over slimes which could not be walked on at the start of cover placement (Steffen Robertson and Kirsten, 1983). Covers may also be placed during winter when freezing conditions allow access, as was done for the cover placement over wet tailings at the Beaverlodge mine (Steffen Robertson and Kirsten, 1983; Eldorado Resources, 1986).

To prevent capillary suctions in covers it may be necessary to utilize capillary barriers over tailings fines and slimes as discussed in Section 7.3.

Prior to placing covers on tailings it is necessary to first develop a tailings surface which has an adequate slope and drainage pattern. Requirements are reviewed by Steffen Robertson and Kirsten (1987). Much can be done to achieve such slopes by adopting an appropriate tailings placement and management method (Robertson, 1987). Reshaping of tailings surfaces after closure, with earth moving equipment, may be difficult and prohibitively costly. Trafficability of dewatered tailings are reviewed by Robertson et al, (1982).

After closure, tailings continue to consolidate and settle as a result of dissipation of pore pressures and thawing of included ice. The effects have been reviewed for Canadian tailings impoundments by Steffen Robertson and Kirsten (1986a, 1987). These settlements can be a substantial portion of the total tailings depth and result is disruption of the drainage pattern, leading to extensive ponding on the tailings surface, and cracking of covers.

7.3.5 Erosion Covers - Wind Induced Wave Action

Currents caused by wind induced waves decrease exponentially with depth. However if the water is sufficiently shallow such currents may exceed the threshold velocity required to remobilize tailings particles. The threshold velocity is a function of the tailings particle size and specific gravity and may be determined analytically or experimentally. The maximum orbital velocity at the tailings surface due to wave action is a function of the water depth, the significant wave height and wave period The two latter parameters may be derived from the design wind speed and fetch (Lawrence et al, 1990).

The design parameters available to ensure that tailings remobilization does not occur are therefore the water depth and wind fetch. Fetch can be limited by construction of berms or dykes perpendicular to the prevailing wind direction. Minimum water depth can be determined using the approach outlined above.

For the Syncrude tailings pond in Alberta, which has a design fetch of 5 km, a design 10 year return period wind speed of 17 m/s and tailings particles with a threshold velocity of 0.034 m/s, the water cover depth to minimize resuspension was determined to be 6.4 m. A depth in the order of 1 to 2 m has been determined for a site in the Yukon using a fetch of 1.6 km, wind speeds of 10 to 15 m/s and threshold velocities of about 0.1 m/s.

7.3.3 Erosion Covers - Flood Events

Water velocities due to flow in water covers are very low, even during flood events, and are unlikely to exceed the velocities needed to mobilize tailings. Velocities would have to be in the region of 0.5 m/s before there was any likelihood of sediment movement. The only area which may be of concern is the spillway approach where the flow concentrates and velocities increase. In this area it may be necessary to provide a riprap cover to prevent erosion. Many standard texts relate required riprap size to design velocity (e.g. Environmental Protection Agency, 1976).

7.4 Revegetation

7.4.1 Natural Vegetation and Soils

The natural vegetation of Alaska mainly comprises species adapted to harsh arctic and subarctic environmental conditions. Its most remarkable features are its low diversity and high uniformity over large areas. In addition, it is relatively well preserved by virtue of the State's remoteness and sparse population, as well as the inability of most introduces species to survive.

There is a strong correlation between the nature of the vegetation and the climatic and soil conditions in the various regions of Alaska.

Climatic conditions prevailing in Alaska are outlined in Section 2.3. Conditions which have the most profound influence on vegetation are, according to Larking (1974), temperature, the length of the growing season, rainfall and wind.

Three types of environments - arctic, subarctic and temperate coastal environments - are encountered in Alaska and the vegetation in these environments is quite distinct (Larking, 1974).

The arctic environment is characterized by an absence of trees, low amounts of solar radiation and precipitation, and a short growing season. Evaporation rates are low due to low temperatures, and runoff through streams and rivers accounts for a large proportion of water loss in the hydrological cycle. Wind velocities at ground level are high due to the absence of protective shielding and surface friction.

In the subarctic environment, which extends from the south side of the Arctic Mountain to the Pacific Mountain System, the amount of radiation is considerably larger than in the arctic environment and precipitation is higher. More water is lost by evaporation from the ground surface and by evapotranspiration through vegetation, but the total evaporation is, however, still low and runoff in streams and rivers is high.

The temperate coastal environment in the southern regions of Alaska bordering on the Pacific coast supports dense vegetation and is characterized by relatively warm temperatures, ranging from a minimum of 20°F (-7°C) in winter and a maximum of 60°F (16°C) in summer, and high rainfall.

According to Dwight-Billings (1974), most vascular plants comprising tundra vegetation are herbaceous and almost all of these herbs are perennials with large underground root or storage systems. They are adapted to photosynthesize and respire at high rates for only a few weeks when temperature and light conditions are favorable and the optimum photosynthesis rates are at lower temperatures than for ordinary plants. Growth is very rapid at low positive temperatures and vegetative reproduction, particularly by rhizomes, is more common than sexual reproduction which is unreliable in severe environments because it necessitates the completion of the whole lifecycle from germination to seed production in a short cold growing season. Dormancy is triggered by photoperiod, low temperatures and drought and the dormant plants are extremely resistant to low temperatures and drought.

Flowering of tundra plants depends to a great extent on environmental conditions during previous summers and most plants flower buds a year before flowering. These pre-formed buds are highly resistant to cold winter temperatures and rapidly develop into flowers under optimum conditions. The flowers are pollinated by insects or wind and seed is produced if the weather remains favorable. Seeds remain dormant for long periods at low temperatures and require temperatures well above freezing for germination. Seedling establishment is rare and very slow - it is often several years before a seedling is established.

In addition to the coastal regions, tundra vegetation is found in the mountainous regions of Alaska. More specifically, it is found above the timberline, the limit of tall tree growth, on the mountains of the Arctic Mountain System and the Pacific Mountain System, as well as the mountains in the Intermountane Plateau region.

Tundra vegetation in the mountainous regions comprises cottonsedge tundra as well as dry meadows where Dryas and Carex species are common.

Dryas species such as D integrifolia and D drummondii are believed to be important contributors of nitrogen to the soils in Alaska. Some lichens are also believed to play an important nitrogen fixing role (Dwight-Billings, 1974).

The most severe environments in Alaska are the high mountainous regions, particularly the windswept ridges and plateaus in these regions. Called barrens, these environments do not support vascular plants but often support mosses and lichens. Moss carpets are found in sheltered moist areas and lichens - crustose, thallose and sometimes fruticose lichens - are found in the dry rock areas.

Lichens are better fitted to extremely cold, dry environments than vascular plants because they exist at the rock - or soil-air interface where daytime temperatures are highest - sufficiently high to produce meltwater and allow photosynthesis to operate more efficiently. In addition, lichens are extremely long-lived perennials - some such have life spans in excess of 1,300 years, and, therefore, do not need to produce new biomass each year (Dwight-Billings, 1974).

Land in the mountainous regions of Alaska is classified as rock land comprising rock, ice and some soil. Soils found in the rock land regions include Cryaquepts, Cryandepts, Cryorthods and Cryumbrepts.

While the mountains of southeastern Panhandle are classified as rock land and bear dry meadow and barren vegetation on high ridges and plateaus, they support much more vegetation on their slopes than the mountain sin other parts of the state. Dense stands of hemlock (Tsuga sp.) and spruce (Picea sp.) grow naturally on these mountain slopes and commercial forestry has been found to be economically viable throughout this region.

Well stocked, economically important, hemlock-spruce forests are not restricted to the Panhandle region, they also extend along the entire coastline bordering on the Pacific Ocean. The vegetational richness of this region may be attributed to the temperate climate conferred by the Pacific coastal waters.

Forests are also the predominant vegetation of the plateau region between the Arctic and Pacific Mountain Systems. The interior forests differ from the coastal forests in that Picea species, rather than Tsuga species, are dominant.

The soils of the forested plateau region include Cryaquepts, Cryochrpts, Cryorthents, Cryorthods, Cryumbrepts and Histols. Cryaquepts and Histols are found throughout the region, while Cryorthents and Cryorthods are mainly present int he basins of the Yukon, Tanana, Porcupine and kuskokwin Rivers and their tributaries. Cryochrepts are found in a relatively narrow band in the region between the Porcupine and Tanana Rivers and in the region where these rivers intersect to form the Yukon River. Cryorthents, Cryorthods and Cryochrepts are all well drained soils which are often used for crop farming, pasture and woodland. Cryumbrepts are found in the plateau regions between rivers. They are also well drained and are suited to woodland and range uses.

Forests in the basins of the Yukon, Tanana, Porcupine and Kuskokwin Rivers mainly comprise black spruce (Picea mariana) and are often sufficiently productive to justify commercial forestry. The grounds between the main rivers support less productive forests comprising mainly white spruce (Picea glauca) and white birch.

The almost continuous interior forests are interrupted in the region of low poorly drained basins which support open muskeg vegetation comprising a diversity of species. The most common muskeg species are Eriophortum and Sphagnum species. Betula species are fairly common in these muskeg regions too.

7.4.2 Rehabilitation Aims and Objectives

The principal aim of a rehabilitation programme is to reintegrate land which has been drastically disturbed by site operations into the surrounding landscape. It is intended that the quality and capability of the rehabilitated land will be equal to its pre-disturbance potential. Also, the rehabilitation plan should be devised so as to achieve the following objectives:

- meet prevailing legal requirements regarding environmental protection;
- optimize landuse options after closure;
- create an ecologically stable system in the long term;

In order to achieve these goals effectively, a stepwise approach to rehabilitation performed in phase with ongoing mining operations is recommended wherever appropriate and economically feasible. This is an essential aspect of the design for closure concept as described in Section 5.3. Such an approach is cost effective and enhances the quality of the working environment during the life of the mine. A four phase rehabilitation programme required. The phases are:

1. Rehabilitation during and immediately following the construction phase, where appropriate;
2. On-going active rehabilitation of waste dumps, topsoils stockpiles, spoil piles and other disturbed areas during the production phase;
3. Concurrent rehabilitation of open pits and coarse discard dumps;
4. Final rehabilitation upon closure of the operation.

Generally, factors which limit vegetation establishment differ between mining waste and soil types. Consequently, suitable ameliorative measures and appropriate stress and/or disturbance tolerant plant species must be carefully selected for the rehabilitation programme.

7.4.3 Vegetation Covers for Long-Term Land Rehabilitation and Pollution Control

Topsoil Requirements and Management

The establishment of vegetation cover in the restoration of land is facilitated by the replacement of topsoil. Topsoil should be removed from construction and mining sites prior to operations. The topsoil should be removed and stockpiled separately from overburden and waste rock. It is also necessary to remove topsoil and subsoil from arable land for separate storage and treatment. Ultimately, subsoil and topsoil should be replaced over backfilled areas so as to restore the original soil profile. In so doing, a soil moisture regime suited to arable production or ecological restoration will be reinstated.

The long-term bulk storage of topsoil causes its degradation particularly with regard to fertility, texture and structure. In particular, therefore, uncontrolled dumping in large high dumps for long periods (greater than 12 months) will create environmental hazards and a deterioration in topsoil quality as follows:

- increased erosion and, hence, siltation hazard;
- visual intrusion;
- degradation of soil structure;
- loss of nutrients;
- decline in essential biological activity.

These problems can be overcome by adopting certain management practices which are set out below as a series of guidelines:

- Topsoil depth should be carefully determined and stripping depth established to contain only the cultivable upper soil horizon (A horizon), or to permafrost depth;

- Topsoil should be stripped and stored with as little compaction as possible and not in wet weather. The clay content will lead to cementation if too much moisture is present.

- Stockpile dimensions should not exceed 2 m in height if practically possible as a higher profile will lead to compaction, anaerobic conditions in the center of the heap and gaseous loss of nitrogen.

- The life of a stockpile should be as short as possible and single handling should be practiced whenever possible.

- Stockpiles which are likely to remain undisturbed for 12 months or more should be revegetated using a seed mixture composed predominantly of quick growing desirable species including perennial leguminous species. In so doing, establishment of noxious weeds will be suppressed and soil nitrogen content will be maintained.

- Topsoil should be respread with as little hard compaction as possible using for example a Cat 623 self-propelled elevating scraper or front-end loader/truck combination, as appropriate; ideally it should be levelled with a 140 grader or equivalent. This should not be carried out in wet weather.

- For most revegetation situations at least 300 mm of topsoil are required. This should be ripped to 100 mm to provide an uncompacted seed bed prior to vegetation establishment.

Amelioration of Waste Materials

Common to each area or material in need of rehabilitation is a fertilizer scheme which will require decreasing maintenance over 3 - 5 years. Fertilizers should be cautiously applied because excessive application has promoted too much weed growth in some areas. Heavier seeding rates with nurse crop species seems to be more cost effective in stabilizing the surface and reducing weed infestations. Incorporation of organic material should provide a longer term and cost-effective source of nutrients as well as an effective metal-binding component. Here, the incorporation of sewage sludge or commercial organic amendments into the surface of the soil and topsoil stockpiles is an appropriate strategy, if available in sufficient quantities. For acidic mining wastes arising from the oxidation of pyritic materials, heavy application of acid-soluble phosphate and lime are usually necessary to allow establishment of vegetation cover.

Use of Surface Capping and Capillary Blockers

The revegetation of areas contaminated by potentially phytotoxic materials such as heavy metals and acid-sulphate solutions is often problematical. The addition of surface amendments such as subsoil and topsoil directly onto dewatered waste surfaces such as tailings can often be successful in the short term. However, the good initial vegetation cover regresses due to the upward migration of chemicals with capillary water from the buried waste into the topsoil. This is particularly important in dry periods when build up of potential plant toxins can occur in the surface rooting zone and lead to vegetation dieback which will then require expensive maintenance programmes which cannot cure the situation.

A system which has been established to overcome this attempts to physically isolate the surface plant rooting zone from the wastes using additional amendment layers. A wide range of materials can potentially be used and can be summarized functionally as either:

- allowing percolation of water downwards but preventing capillary rise of water upwards, eg: using coarse rock or crushed builders rubble;
- an impermeable layer, eg: a plastic liner or clay (glacial till) cap.

Plant Species Selection

Land rehabilitation by the establishment of persistent vegetation cover should be planned as a three-phase operation:

- the establishment of a rapidly growing but temporary cover of vegetation;
- the development of a slow growing and stress tolerant, but persistent, cover of vegetation;
- the diversification and stabilization of the vegetation cover by introduction of naturally occurring species.

This process is relatively straightforward where vegetation cover is required on subsoils or topsoils overlying innoxious wastes. Nevertheless, selection of appropriate plant species for the establishment of a long-term vegetation cover should be based upon a scientific evaluation of the germination and growth performance of species under variously topsoiled or ameliorated waste conditions. This is a two-phase exercise which involves firstly the simultaneous screening of a range of grass and tree species, and physical and chemical amendments, under controlled environmental conditions. The second phase of work requires rigorous testing of seemingly appropriate plant species and amendment combinations under more realistic, field environmental conditions. Following these exercises, relatively low-risk recommendations may be made for:

- Physical and chemical amelioration of adverse surface environmental conditions;
- appropriate grass species for temporary "nurse crop" cover and surface stabilization;
- suitable stress and/or disturbance tolerant grass and tree species for persistent, erosion-resistant cover.

The cover of vegetation should be erosion resistant, yet sufficiently open to allow longer term natural colonization of gaps by locally indigenous species. This process of natural colonization and succession may be accelerated by the application of selected land management practices. Of particular importance in this respect is the reduction of commercial fertilizer application in favor of the incorporation of organic material into the waste and soil surface, and the development a natural, mineral cycling system in the rooting zone within 3 to 5 years. In this context, the facilitation of nitrogen fixation and bacterial/decomposer activity in the rooting zone is essential.

Methods of Plant Establishment on Degraded Land

Three strategies are available for propagating vegetation cover on mining wastes and disturbed soils:

- agricultural sowing;
- hydroseeding;
- hand planting.

Agricultural Sowing

Agricultural sowing is probably the best means of establishing vegetation, but it is limited by slope gradients steeper than 1:4, is labor intensive and time consuming.

Once the seedbed has been prepared, a carefully chosen seed mix must be sown. The seed mix normally comprises grasses and trees which are indigenous to the area wherever possible. The choice of species will be determined by:

- chemistry of material (pH, salinity, nutrient availability and toxicity);
- physical characteristics of the material (drainage, texture, grading and surface transportation;
- means of plant propagation;
- climatic conditions of the region.

Hydroseeding

Hydroseeding is a method of applying grass seed and fertilizer to a slope by means of a pumped slurry. The hydroseed mixture also contains cellulose fibers and an erosion-resistant adhesive. The cellulose used in the mixture will help to reduce surface temperatures, aid infiltration and reduce evaporation from the soil surface. The adhesive is used to bind the components of the hydroseed mixture so that they adhere to the slope. This prevents the seed and fertilizer from blowing, washing or slipping. The adhesive is hygroscopic, thereby enhancing water availability for plant growth. Hydraulic placement of seeds is the most rapid and convenient method for steep slopes, but it is somewhat dependent on the accessibility of the machine to the crest or toe of the slope and the spraying distances involved. A spray range of 100 m is usual of hydraulic seeding equipment, although extension tubes may be used also. This facility is likely to provide an advantage when treating areas which are inaccessible.

Hand Planting

Hand planting either involves broadcasting seed and fertilizer by hand or hand planting runners into drills. Both hand-planting methods are cheap, but they are labor intensive and have a higher risk of failure attached to them. Access onto slopes greater than 1:1.5 is difficult. The range of commercial species which can be planted should be limited to indigenous trees.

7.5 Costing of Rehabilitation Measures

7.5.1 Description of Rehabilitation and Closure Measures

In the closure plan, the proponent should describe and illustrate, by the means of plans and diagrams, the rehabilitation activities that are scheduled both during mine operations and at the closure of mining. The proponent must indicate the test program and monitoring activities required to demonstrate the effectiveness of the conceptual rehabilitation work and the period over which monitoring will be carried out. Monitoring activities will be required to demonstrate both the physical and chemical stability of the site, as described in Section 8.0 of these guidelines. The schedule must indicate components of the rehabilitation work (if any) that will require perpetual monitoring, maintenance and/or operation.

The proponent should provide premature closure cost estimates for the rehabilitation activities that will be required at the commencement of mining and at the end of the projected mine life. In addition, depending upon the expected life of the mine, it may be necessary to provide the estimated premature closure costs for rehabilitation annually or at various stages or set times of the mine life to suit key dates in progressive rehabilitation activities.

7.5.2 Annual Costs and Three Year Window

The estimated planned closure and progressive reclamation costs in the closure plan and any update should be provided as the net current value cost at the time of closure or premature closure. Since changes in the closure plan and costs may occur with time detailed planning may be appropriate for only a limited time into the future. In the closure plan the proponent should provide a detailed schedule of proposed rehabilitation and progressive reclamation and premature closure cost estimates for each year for a three to five year period from the date of the closure report. For periods beyond this "window" the rehabilitation measures, schedule and cost estimates can be provided at a conceptual level sufficient to allow final and progressive costs to be estimated with sufficient confidence for the establishment of financial assurance. The costs estimates should include for the actual rehabilitation work, the physical and chemical monitoring required to demonstrate that the rehabilitation techniques have achieved their objectives, and any ongoing maintenance or operations required.

Rehabilitation performed after closure of the mine, and during the closure period, are referred to as the closure measures. In the design-for-closure philosophy, these closure measures are minimized to the extent practicable, social and economic factors being taken into account, by appropriate initial mine planning and scheduling and performance of progressive rehabilitation during operations.

7.5.3 Schedule and Cost Components

The quantity of rehabilitation work to be carried out should reflect the "neat line" quantity estimated from drawings, and where applicable field surveys. Cost estimates for closure work must be based on the cost of hiring a third party to conduct the work.

7.5.4 Decommissioning Schedule

The concept of "designing for closure" is discussed in Section 5.3. Acceptable conceptual closure plans should be prepared for all proposed and operating tailings impoundments. In reality, the closure plan which is submitted initially at the commencement of a project may change as a result of changes to the operation and advances in closure technology. The regulations require that any changes in the closure plan be included in the annual report.

7.5.5 Rehabilitation Performed During Mining Operations

The proponent is encouraged to carry out progressive rehabilitation at sub-sites throughout the life of the mine in order to avoid the payment of additional security into the fund. By this method, the amount of rehabilitation work remaining at the end of mining can be reduced, and monitoring of rehabilitated sub-sites during mining operations can demonstrate the success of the work, or identify the need for any necessary remedial work required to meet the closure objectives.

8.0 MONITORING REQUIREMENTS

8.1 Introduction

In general terms, closure monitoring is intended to evaluate the effectiveness of closure measures and to provide earliest possible warning if measures are unsuccessful. Monitoring must address physical stability, including effects of static and dynamic conditions, and chemical stability, including prevention, migration and treatment control measures. Biological response and impacts may also need to be monitored. Two types of monitoring stations have been defined: an effluent discharge point and the receiving environment. An effluent discharge point is generally, but not necessarily, located on the mine property (on site) while the receiving environment stations will generally, but not necessarily, be off-site.

Monitoring may consist of any or all of: visual inspections, surveying, instrumentation and sampling. Monitoring stations should be established in or near all environmentally sensitive areas potentially affected by the development including both surface water and groundwater stations.

Generally, the monitoring program for a tailings pond should be tied into the mine site closure monitoring plan. In the case of large mines or operations in sensitive areas many monitoring points will be required. Physical stability should be monitored on each structure and, for some facilities, at a downstream point to detect sediment release. Monitoring stations for chemical stability should be established upstream, within and downstream of each component for surface water and, in many cases, vadose zone and groundwater flow.

A long-term monitoring program implemented during and after closure would decrease in frequency of sampling as time from closure increases. If significant changes in environmental conditions are detected at any station then additional monitoring should be performed at that station and at other stations to confirm the presence and spatial extent of the change. If the adverse impact is confirmed, alternative control or treatment techniques must be designed, tested, and implemented. The monitoring program must then be revised to monitor the success of the new techniques. If no unacceptable impacts are detected over an acceptably long period of time then the site can proceed with abandonment.

Current technology does not generally allow design which can be expected to be continually effective for periods of hundreds or thousands of years without periodic inspection and maintenance. Therefore, for critical facilities such as tailings embankments or covers over potentially acid generating waste it should be anticipated that the monitoring program will be continued in perpetuity.

COMMENT

Many State and Federal regulatory agencies are going toward requiring designs which are continually effective for the long-term. However, it is important to recognize that a facility such as a cover to control *acid generation may be designed for the long-term but the consequences of its failure may be sufficiently high that provision for monitoring and maintenance is likely to be required. This is consistent with the Strawman II objectives of low maintenance closure of a regulated unit.*

8.1 Monitoring for Physical Stability

When a tailings impoundment ceases to be operated and enters a closed condition all associated components should be monitored for physical stability.

Four basic types of monitoring can be conducted: visual, survey, instrument, and sample. Visual monitoring may consist of inspections with supporting notes and/or photographs. Air photographs can also be used. Surveying includes all types of physical measurement such as topographic surveying, flow measurements of running water, or deformation measurements of unstable pit slopes. Instrumentation, such as piezometers, settlement gauges, or thermistors are commonly used for critical facilities such as a tailings embankments. Sampling would consist of stream flow collection and analysis for suspended solids to check erosion rates.

Information on the ground thermal regime at construction sites in frozen ground areas should always be collected. In some cases, only the position of the 0°C isotherm, which can be obtained by relatively simple methods, may be required. For most critical projects detailed information on ground temperatures and their fluctuation at various depths will be required for thermal design and for assessing the performance of structures during their service life. Temperature data will also assist in delineating unfrozen zones, particularly at sites in marginal permafrost areas, as may occur in southeast Alaska and in determining temperatures to be used for laboratory testing of samples.

8.2 Monitoring for Chemical Stability

Monitoring for chemical instability consists of two parts: monitoring for leachate generation and monitoring for leachate migration. In cases where ongoing treatment is required, such as at an existing mine, then monitoring for efficiency of treatment will also be required.

Monitoring for chemical instability consists of collection and analysis of water samples in all cases. Collection of water may utilize ditches, emergent seepage points, wells and/or piezometer, or lysimeters for vadose zone sampling. At some sites additional monitoring may consist of gas measurement such as oxygen under covers or temperature measurement in waste piles.

8.3 Monitoring for Environmental Impact

The objective of monitoring for environmental impact is to provide a check on the monitoring systems and the effectiveness of closure measures. Environmental monitoring is generally not required except where a tailings impoundment is located within or upstream of a sensitive environment. It may consist of monitoring biological species, drinking water supply, or vegetation growth. Environmental monitoring is not considered to be as reliable or rapid as physical and chemical monitoring for routine evaluation of the effectiveness of closure measures. Nevertheless, an annual biological survey of the minesite and surrounding off-site region is recommended as contingency monitoring to check for changes in vegetation or fisheries which may indicate, for example, the migration of acid drainage not detected by an established monitoring network. This situation could arise during a first flush event where acid products are released between sampling periods of the monitoring stations.

9.0 GENERIC CASE STUDIES

9.1 Introduction

Two generic case studies have been prepared to illustrate the application of tailings management practices in Alaska. One study represents northern or arctic Alaska and the second represents southeastern Alaska. Each case study has been prepared as a general description with a base case cost estimate. This case represents a conventional engineering current approach to tailings management in the respective region of Alaska. The base case is followed by examples of closure and environmental protection costs plus examples of potential changes to design and operation that may occur if sections of Strawman II were to be more rigidly interpreted and applied. Estimates of the incremental cost to tailings management are presented.

9.2 Northern Alaska Tailings Management Case Study

9.2.1 General Description and Base Case Costs

This is a tailings impoundment typical of arctic or Northern Alaska. It is based on a base metal mine producing about 3000 tons per day over a 22 year mine life. The site is characterized by long, severe winters and moderately warm, windy and somewhat wet summers due to its near coastal location. In general, average annual precipitation is between 20 and 30 inches with up to 50% of the precipitation in the form of winter snowfall. The mean annual temperature is 14°F.

Depth to bedrock ranges from zero feet on the west abutment to approximately 20 feet on the east abutment. The upper surface is a highly weathered zone which ranges in thickness from approximately 5 to 10 feet. Most of the surface deposits contain some percentage of ice-lensing to depths of approximately 15 feet. The site is in a region of low seismic activity and an earthquake acceleration of 0.05 g is used for the seismic design of dam structures.

The topography is undulating and relatively flat. Slopes within the impoundment are generally flatter than 5:1 (horizontal to vertical). Natural hazards other than permafrost are not a concern at this site. Several design concerns have been identified relative to specific site conditions. These concerns are based on the extreme climatic conditions, the poor properties of the near-surface foundation materials and the availability of construction material.

Climatic conditions at the site dictate that a strict construction schedule be followed. Foundation excavation and backfilling must be completed prior to spring thaw. Fill placement for the starter dam must be completed during relatively short summer construction season which normally runs June through September. Liner installation, on the upstream face of the dam only, must be performed during the warmer summer months.

The proposed embankment will consist of a homogeneous random rockfill with upstream and downstream side slopes of 2:1 and 4:1, respectively. It is shown in cross-section on Figure 9.1. The embankment will be a cross-valley type; a side-hill type was evaluated and found to develop insufficient storage capacity. The rock will be select mine rock which is identified as non-acid generating. The embankment will be increased in size through a series of construction stages, with the increase of any one stage limited by the availability of construction materials, embankment stability, and the length of the optimum construction season. The ultimate height of the dam will be about 130 feet above the elevation of the creek. A lined cutoff trench will be located along the upstream toe of slope to reduce the amount of potential seepage beneath the dam. The ice-rich, near-surface soils and ice-rich, highly weathered shales will be excavated under the entire foundation area of the starter dam. Tailing pond capacity will be for up to 45 million tons of tailings, potentially acid generating rock, and entrained ice. The pond area is about 550 acres.

The stability of the tailings embankment section may be affected under thawing conditions. Formation of ice on the tailing pond during the winter months creates a condition that could result in damage to the exposed liner on the upstream face of the tailing dam. A protective rockfill buttress with an upstream slope of 3:1 will be placed on the upstream face of the starter dam. Protection will be provided to the liner during subsequent stages of operation through the development of a tailing beach. In the event that some liner leaks occur, a 20-foot zone of processed filter drain material will be installed immediately behind the synthetic liner.

The tailing dam is to be constructed from relatively permeable mine waste rock materials, therefore a method to minimize the seepage through and under the dam is necessary. Various types of seepage barrier materials have been evaluated including:

- Asphaltic Concrete
- Steel
- Synthetic Membranes
  - High Density Polyethylene (HDPE)
  - Linear Low Density Polyethylene (LLDPE)
- Shale

HDPE's longer in-service performance history over LLDPE makes it the preferred liner alternative and therefore it was used in the design.

The long-term stability of both the seepage dam and the tailing dam is dependent upon pore water pressures in the foundation, the position of a phreatic surface, if any, and permafrost conditions. Piezometer and thermistors will be installed in the dams to monitor subsurface water levels and temperature variations to verify the design assumptions.

A tailings slurry pipeline will transport tailing from the mill to the tailing pond. Tailing discharge will be accomplished by point discharging from spigots. Cyanide is used in the mill process. There is no discharge to the environment as excess pond water is returned to mill via a water treatment plant. The recycle flow is 1500 USgpm.

COST SUMMARY
BASE CASE
NORTHERN ALASKA

Construction Item	Units	Quantity	Unit Cost	Cost $
Foundation Excavation	yd^3	150,000	5.00	750,000
Cutoff Trench Excavation	yd^3	150,000	5.00	750,000
Filter Blanket	yd^3	170,000	8.00	1,360,000
Synthetic Liner	ft^2	750,000	1.20	900,000
Fine-Grained Backfill (cutoff trench)	yd^3	150,000	6.00	900,000
Foundation Backfill	yd^3	100,000	6.00	600,000
Random Rockfill	yd^3	1,800,000	5.00	9,000,000
Select Rockfill	yd^3	100,000	6.00	600,000
Geotextile Filter Fabric	ft^2	1,000,000	0.25	250,000
Liner Cover	yd^3	5,000	8.00	40,000
Anchor Trench Backfill	yd^3	10,000	5.00	50,000
Total Cost				$15,200,000

9.2.2 Alternative A - Liners

This alternative examines the cost impacts of constructing a basin liner system to reduce seepage from the impoundment which may occur because of:

- excessive seepage volume due to high permeability foundation materials, or
- downstream water quality impacts resulting from high contaminants concentration in the seepage, or
- rigorous interpretation of RCRA for the protection of groundwater quality.

A liner system can be a single, double or triple system using soils or synthetic materials. Where synthetic liners are required for environmental protection, polyethylene either HDPE or LDPE is commonly selected because of its physical and chemical durability, and long service life. This alternative case assumes that HDPE is used. A single liner system may also incorporate a sub-drain system. A double or triple liner system would likely incorporate a leak detection system.

At this site there are essentially no clay rich soils which could be used to form a single liner or be part of a triple liner. Therefore two options are presented: a single, 80 mil HDPE liner with a subdrain, and, a double liner with leak detection. The pond area is 550 acres or 24 x 10^6 ft^2.

Single liner with sub-drain				
Item	Units	Quantity	Unit Cost	Cost[1]
HDPE	ft^2	24 x 10^6	$1.20	$28,800,000
Sub-drain	ft^2	24 x 10^6	$0.34	$8,070,000
			Total	$36,870,000
Double Liner with Leak Detection				
HDPE	ft^2	48 x 10^6	$1.20	$57,600,000
Leak Detection Layer	ft^2	24 x 10^6	$0.32	$7,680,000
			Total	$65,280,000

(1) Incremental cost to be added to base case costs

9.2.3 Alternative B - Water Treatment

Water treatment for removal of cyanide is highly dependent on the concentration of cyanide and any dissolved metals. The best method for a particular site can only be selected after detailed testing in light of the influent and acceptable effluent parameters. The capital cost of a treatment plant with a process rate of 1500 USgpm is expected to be in the order of $1,000,000. This cost is not expected to vary widely with different treatment methods. Operating costs may range from $500,000/year for readily treatable low concentration influents where the treatment objectives are low, such as for mill recycle, to as high as $3,000,000/year for high concentration influents which must be treated for discharge to the environment. The operating cost for this site is expected to be in the range of $1,000,000/year.

9.2.4 Alternative C - Wildlife Protection

Wildlife protection may require fencing to protect mammals or floating covers to protect migratory birds. The cost of these measures are presented below. It is assumed that the floating cover is 45 mil LDPE. It is unlikely that a floating cover would be a practical approach to wildlife protection on a pond of this size, especially in northern Alaska. This option is shown here simply to illustrate the economic significance of such a cover.

If fencing were insufficient to protect wildlife, such as birds, then a more practical approach would be to rely on water treatment to make the water of a quality acceptable to wildlife. Using the above treatment plant and assuming that a higher level of treatment was required, it is estimated that annual treatment costs would rise to a total of $2,000,000. The incremental cost of treatment for wildlife protection is $1,000,000 year. Based on an annual interest rate of 10% the present value of this treatment is $10,000,000 for the 22 year mine life, which is less than the cost of the floating cover.

Fencing

Item	Units	Quantity	Unit Cost	Cost
Fences	ft	17,500	5.00	$87,500

Floating Cover

Item	Units	Quantity	Unit Cost	Cost
Cover	ft^2	24×10^6	0.61	$14,640,000

9.2.5 Alternative D - Monitoring Costs

Monitoring of a tailings facility will generally require both physical monitoring of the embankments and water quality monitoring of the tailings liquor and any discharges to the environment. Groundwater monitoring is usually necessary. In this only settlement gauges are required on the embankment as it is a rockfill structure. Discharges to the environment are not proposed therefore quarterly sampling from the groundwater wells and tailings liquor are proposed. Cost estimates are as follows:

Stability Monitoring

Item	Units	Quantity	Unit Cost	Cost
Settlement gauges	each	8	$500	$4,000

Instrument Reading

Item	Units	Quantity	Unit Cost	Cost
(2 men, quarterly, 2 day)	hour	128	$30	$3,840 (annual)

Water quality Monitoring

Item	Units	Quantity	Unit Cost	Cost
Groundwater wells	each	6	$4,000	$24,000
Sampling well water, quarterly	each	24	$200	$4,800 (annual)
Sampling tailings, quarterly	each	8	$200	$1,600 (annual)

9.2.6 Alternative E - Cover for Reclamation

A cover may be required for reclamation of a tailings impoundment. The factors involved in cover design are highly site specific, as discussed in Section 7.3. Hence, there is a wide range of cover types and associated costs. Cyanide is not usually a problem after closure of a mine because new cyanide is no longer added to the pond and the existing cyanide will naturally decay. Water management may be required for a short period after mining ceases until sufficient decay has occurred. The site is frozen in the winter and typically wet during the summer so frigitive dust is not a concern. Therefore, no cover is proposed for this site. The range of cost for covers, if required, is \$2 to \$6/yd^2 for simple covers to, \$20 to \$30/yd^2 for complex covers.

Total costs for the project including both the base case costs and alternative costs are summarized below.

Cost Summary, Northern Alaska Case Study
Base Case and Alternatives

Alternative	Base Case Cost	Incremental Cost of Alternative	Total Cost (Base Case & Alternative)
A - Liner			
A-1 Single liner with sub-drain	$15,200,000	$36,870,000	$52,070,000
A-2 Double liner with leak detection	$15,200,000	$65,280,000	$80,480,000
B - Water Treatment	$15,200,000	$1,000,000 (+$1,000,000/year)	$16,200,000 (+$1,000,000/year)
C - Wildlife Protection			
C-1 Fencing	$15,200,000	$87,500	$15,287,500
C-2 Floating cover	$15,200,000	$14,640,000	$29,840,000
D - Monitoring	$15,200,000	$28,000 (+$10,240/year)	$15,228,000 (+$10,240/year)
E - Cover	$15,200,000	not included	N/A
All Alternative (A,B,C,D&E)	$15,200,000	$37,985,000 to $80,948,000 (+$1,010,240/year)	$53,185,000 to $96,148,000 (+$1,010,240/year)

9.3 Southeastern Alaska - Tailings Management Case Study

9.3.1 General Description and Base Case Costs

This is a tailings impoundment typical of the mountainous, high seismicity, high precipitation environment of Southeastern Alaska.

A gold mining project is envisaged producing 10,000 tons per day of tailings over a 20-year mine life. Cyanide treatment will be involved in the process and therefore water quality will be a prime consideration in the tailings disposal scheme. The mine is an underground operation.

The layout of the impoundment is shown on Figure 9.2. The tailings are approximately 200 ft thick.

The tailings are a silty fine sand with low to medium plasticity fines. The host rocks are greenstone and the tailings are potentially acid generating. For this reason the tailings will be placed behind an impermeable dam that will ensure permanent saturation of the tails. Dry tailings disposal will not therefore be an option.

Impoundment

The impoundment is in a steep mountain valley that has been heavily glaciated. It is at a mean elevation of about 800 ft ASL. The pond area is approximately 15.7 x 10^6 ft^2. The host rocks are tight and hydraulic gradients are inwards towards the tailings. Leakage out of the impoundment is not, therefore, expected to be an issue except at the damsite itself. There is therefore no need to consider lining the impoundment floor and valley walls. The valley walls are typically 2:1 (horizontal to vertical) or steeper, making placement of any type of liner, soil or synthetic is impractical. If liners were required then another impoundment site would have to be selected. Not including the cost of a liner, such a requirement would likely make the project uneconomic because of the reduction in storage efficiency and increased tailings transport costs.

However, the valley is geologically active (as are most valleys in the region) and careful consideration needs to be given to geologic hazards such as snow avalanches and rockfalls, possibly induced by earthquakes. Such events could trigger wave runup at the damsite with possible overtopping of the dam. As a result a geologic hazard evaluation of the flank of the impoundment was undertaken. A possible bedding plane controlled rockfall was identified on the right flank at an elevation of 500 ft above the final tailings level. This could break loose during seismic shaking and plunge into the impoundment, at a point roughly 1,000 ft upstream of the damsite. The likely volume was 25,000 cu yds. A shallow water cover would lie on top of the tailings, but depending on whether the slide occurred shortly after or a long time after finish of tailing deposition, the tails could be either more or less consolidated. Initially they might be semi-fluid. The possible induced wave is difficult to predict mathematically and so a physical scale model was built using techniques similar to those developed by the US Bureau of Reclamation in Denver. These showed that allowing for wave reflection of the opposite valley wall, the likely height of wave running at the damsite would be 12 ft. It was therefore decided to add an extra 12 ft of freeboard to the dam to handle this contingency. The extra cost in terms of dam fill and construction costs was about 4%.

Snow avalanches were also considered but found to be less likely to induce such a high wave as the possible rockfall.

Placement of Tailings

The tailings will be delivered to the impoundment in a pipeline and discharge from a barge on the lake behind the dam. Subaerial deposition was considered but not thought to be practicable in the high precipitation environment. In any case, the dam was designed to withstand the full dynamic forces resulting from complete liquefaction of the tails over their full depth in the event of a major earthquake. This approach is conservative but the resulting forces can easily be resisted by the type of dam envisaged.

Because of the fine-size, clay fraction in the tails, and the relatively uniform method of placement of the order of 1 x 10^{-6} cm/sec, and the tails are expected to seal the face of the dam and blind the valley floor immediately upstream of the dam. This is equivalent to the use of an upstream blanket in conventional water retention dam design. Some of the tails may be cycloned in the mill and the coarse fraction used for mine backfill, in which case even finer tails will be introduced to the impoundment.

Freezing conditions are not expected to be a problem during tailings placement. In those months when the water in the impoundment freezes, tails will be discharged from various locations by forming a hole in the surface ice, placing the discharge line in the hole and discharging through the water beneath.

Control Structures

The narrowing in the valley offered an attractive damsite with the possibility of tails storage to embankment volume ratios as high as 100 to 1. Because of the obvious economics of such a scheme efforts were concentrated on engineering a dam at the narrows.

An early decision was made not to utilize upstream tailings disposal methods because of the concerns for the stability of such structures under seismic loadings. Stability analyses indicated that failure of a centerline embankment towards the impoundment could occur if a major seismic event was to liquefy the tailings to a depth of 50 feet or more. Possible structures were an earthfill embankment with a clay fill core, an upstream faced rockfill dam, a roller compacted concrete dam or a conventional concrete arch dam.

The four alternative dam types that were considered are :

- earthfill with 2.5 to 1 side slopes and an embankment volume of 3,100,000 in yards,
- rockfill with 1.5 to 1 side slopes and an embankment volume of 1,400,000 in yards,
- roller-compacted concrete (RCC) with vertical upstream face and 0.75 to 1 downstream face and a volume of 400,000 cu yds,
- double curvature concrete arch dam with a volume of 110,000 cu yds.

Dam construction capital costs for the four alternatives are estimated to be:

- earthfill $21,000,000
- rockfill $17,000,000
- RCC $18,000,000
- Arch $23,000,000

The corresponding unit costs for earthfill, rockfill, RCC and conventional concrete were estimated to $4.50, $8.25, $36.00 and $162.00 per cu yd at this site. The additional costs are for clearing and grubbing, foundation treatment, creek diversion during construction, equipment mobilization and engineering.

Considerations in the selection of the dam type were as follows.

Earthfill embankments would be zoned with free-draining sand and gravel shoulders and a relatively impermeable core. Construction of the core, however, could prove difficult in the wet climate that prevails in this area. Very careful control of the moisture content of the material is necessary during placement in order to achieve a stable well-compacted core. If a well-graded glacial till can be located nearby, core placement would be less of a problem. If, however, the only core material available is a silt, or silty clay, placement of such material in wet weather would not be possible. As a result, raising of the embankment with a central core construction would have to be halted during rainy spells. This leads to costly delays in construction. One possible alternative is to build the core on the upstream face of the sand and gravel embankment. By this means the sand and gravel can be raised continuously independent of the core, the latter being placed later during spells of dry weather.

A further concern with an earthfill embankment is the steepness of the canyon walls, and the likelihood for differential settlement to take place between the core and shoulders. This can lead to cracking of the core and piping. To partly overcome the problem, trimming of the canyon walls would help as it would achieve a smooth, regular profile. In addition, to minimize settlement, heavy vibratory compaction would be required on the earth materials, particularly for dams of the heights envisaged in a moderately seismic region. This adds considerably to the cost of construction.

Similar concerns would exist with a rockfill embankment. In this case the design would be a similar zoned structure with rockfill in place of the sand and gravel in the shoulders. Again, settlements are a concern, although in recent years considerable progress has been made in the design and construction of compacted rockfill embankments. An alternative design uses a concrete or asphalt upstream face placed on rockfill, which replaces the fine-grained core. In rockfill dams it is important to have carefully-designed well-constructed filters of different gradations of sand placed between the core, the concrete face, and the rockfill. From both a technical and practical construction standpoint, a rockfill dam is considered preferable to an earthfill embankment.

Roller-compacted concrete, "rollcrete", is a relatively new development that has been used at a number of sites in recent years. Typically the material consists of silty, sand and gravel, or crushed rock mixed with about 5% cement and water, and compacted by rollers. It achieves economy by combining the relatively inexpensive earth compaction techniques with the smaller size of structure associated with concrete gravity dams. Roller-compacted concrete dams are virtually impermeable, but care has to be taken during construction particularly at the joints between lifts. Adequate jointing can be achieved by improving the workability of the mixture, and by scarifying the surface of each lift with a high pressure water spray prior to placement of the subsequent lift. To ensure water tightness and durability at the upstream face a layer of conventional concrete 3 ft wide can be place in 1 ft lifts. This construction method and material is considered to be particularly appropriate of the identified site and locally available materials.

Conventional concrete gravity and arch dams are also appropriate in seismically active regions provided that the foundation conditions are adequate. They have many of the advantages of RCC including the use of an overflow spillway. At this site, however, they are likely to be ruled out on the basis of cost alone. It is possible that instead of using a pure arch dam with concrete costs in place (including form work) of \$162.00 cu yd, a gravity arch dam could be utilized with concrete costing \$150.00 cu yd. Even so total costs may not be less, since a gravity arch will require rather more concrete than a pure arch design. In both cases it is assumed that local sources of aggregate would be used, but that the aggregate would require processing.

Although RCC is not the least costly choice, it has been selected for this site, because of the ease of construction and likely low maintenance costs associated with its future life after mine closure. The RCC dam is likely to possess the best overall long-term stability. Note this choice is very much a function of damsite geometry, since in other situations the rockfill dam may well prove to be the best overall choice both in terms of cost, longevity and ease of construction.

An overflow spillway is provided to handle the probable maximum flood, but freeboard at the dam is such that up to the 1 in 20-year flood can be handled by storage in the reservoir. Normal flows are handled by an outlet conduit that discharge directly to Mills Inlet on the coast at a mean annual rate of 15,000 USgpm. There are no diversion ditches around the impoundment. The quality of water discharging from the lake meets drinking water standards.

The use of perimeter ditches to divert surface flows around the tailings impoundment, on abandonment was considered. It is concluded that vegetation growth and debris would probably block the ditches in time and thereafter flood water would inevitably drain through the impoundment.

9.3.2 Alternative A - Liners

As described in Section 9.3.1, the site is not ammeable to liners and any requirement for liners would likely make the project uneconomic.

9.3.3 Alternative B - Water Treatment

The tailings stream is not processed through a cyanide destruction circuit before discharge into the impoundment. Dilution and natural degradation are expected to yield drinking water quality at the discharge point.

9.3.4 Alternative C - Wildlife Protection

Wildlife protection may require fencing to protect mammals or a floating cover to protect birds. Fences could be constructed however the cost would be very high because of the lack of perimeter access around the pond and the steep slopes involved. A floating cover is not required because the pond water quality is expected to meet drinking water standards.

9.3.5 Alternative D - Monitoring Costs

Monitoring of a tailings facility will generally require both physical monitoring of the embankments and water quality monitoring of the tailings liquor and any discharges to the environment. Groundwater monitoring is usually necessary. In this only settlement gauges are required on the embankment as it is a rockfill structure. Discharges to the environment are not proposed therefore quarterly sampling from the groundwater wells and tailings liquor are proposed. Cost estimates are as follows:

Instrument Reading

Item	Units	Quantity	Unit Cost	Cost
(2 men, quarterly, 2 day)	hour	128	$30	$3,840 (annual)

Water quality Monitoring

Item	Units	Quantity	Unit Cost	Cost
Groundwater wells	each	6	$4,000	$24,000
Sampling well water, quarterly	each	24	$200	$4,800 (annual)
Sampling tailings, quarterly	each	8	$200	$1,600 (annual)

9.3.6 Alternative E - Cover for Reclamation

A cover may be required for reclamation of a tailings impoundment. The factors involved in cover design are highly site specific, as discussed in Section 7.3. Hence, there is a wide range of cover types and associated costs. Cyanide is not usually a problem at closure of a mine. The site is frozen in the winter and typically wet during the summer so frigitive dust is not a concern. Therefore, no cover is proposed for this site. The range of cost for covers, if required, is \$2 to \$6/yd^2 for simple covers to, \$20 to \$30/yd^2 for complex covers.

Total tailings management costs, including the base case and alternatives, are presented below.

Alternative		Cost
Base Case	RCC Dam (including overflow spillway)	\$18,000,000
Alternative A	Liners	prohibitive
Alternative B	Water Treatment	not required
Alternative C	Wildlife Protection	not required
Alternative D	Monitoring	\$24,000 (+10,240/year)
Alternative E	Cover for Reclamation	not required
Total Cost, Base Case & Alternatives		\$18,024,000 (+10,240/year)

10.0 PERMIT COMPLIANCE DURING OPERATION AND CLOSURE

The fundamental concept for a national mine waste program is that the procedures for permitting and compliance will be based upon state and local needs. Under the Strawman II approach, the State of Alaska can develop a program that meets the Federal requirements, if it chooses to do so. If it does not do so, a Federal program would be implemented. A study was conducted for the State of Alaska by America North, Inc. which evaluated the existing state statutes to determine whether they contained sufficient authority to implement a Strawman II approach. The study concluded that the fundamental statutory authority exists, but some statutory modifications to specifically address mine waste would be necessary (America North, Inc., 1991).

In specific regard to tailings, compliance monitoring and verification of performance for groundwater, surface water, air and soils and surficial materials will be required. (see Strawman II Technical Criteria, Subpart E.)

Success of a Strawman II approach for permit compliance in the State of Alaska depends on two aspects. The first is that the operator responsible for a tailings disposal unit implements an effective internal monitoring and verification program based upon meeting the regulatory requirements. The second is that the regulatory compliance program, which includes monitoring, verification and corrective action procedures, be designed and implemented by the State of Alaska for the State of Alaska. The Strawman II concept allows for this approach.

It is important that the compliance requirements for any given tailings disposal unit be clearly defined in the permit, and be based upon the site and waste characteristics. In Alaska this includes consideration for unique characteristics such as permafrost and seismicity. Effort needs to be made to avoid imposition, under the Federal RCRA mine waste program, of compliance requirements that are not relevant to Alaska. Again, the Strawman II approach appears to allow for such a state based approach which is consistent with the Federal framework. The Strawman II requires the operator to establish a monitoring system based upon site conditions and the characteristics of the waste unit. Each of the potentially affected media are to be monitored; groundwater, surface water, air, and soils and surficial material.

A compliance program for a tailings disposal unit needs to be based upon the design and operating criteria described in this report. Failure on the part of an operator to construct a tailings disposal unit in accordance with the design criteria specified in the permits or approvals would lead to corrective action.

Corrective action is to be carried out to prevent future occurrence of the problem. Also, Subpart F-B of the Strawman II provides the regulatory authority to require corrective action to be taken where monitoring shows design and operating objectives are not being met, regardless of whether a performance standard has been exceeded.

Under Strawman II, correcting action plans are to be developed and implemented where non-compliance occurs. Again, it is imperative that the plans are site specific and waste specific.

The permit compliance activity is subject to the oversight of the Federal Environment Protection Agency (EPA) under the Strawman II approach. EPA can become involved under certain conditions; these include 1) a state request; 2) a failure of the state to follow the codified program; 3) imminent and substantial endangerment to human health and the environment, or threat thereof; 4) interstate or international issues involved; or 5) other triggers developed as part of the state plan.

If EPA disagreed with the State of Alaska regarding the development of a tailings disposal unit, it could intercede under the conditions identified above. However, in doing so, state and local conditions are to serve as the standard for any activity. As such, it is important in the case of Alaska that these conditions are clearly identified and characterized.

This report, 96303, RCRA Regulation Impact on Alaska Mineral Development Tailings Management has been prepared by:

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