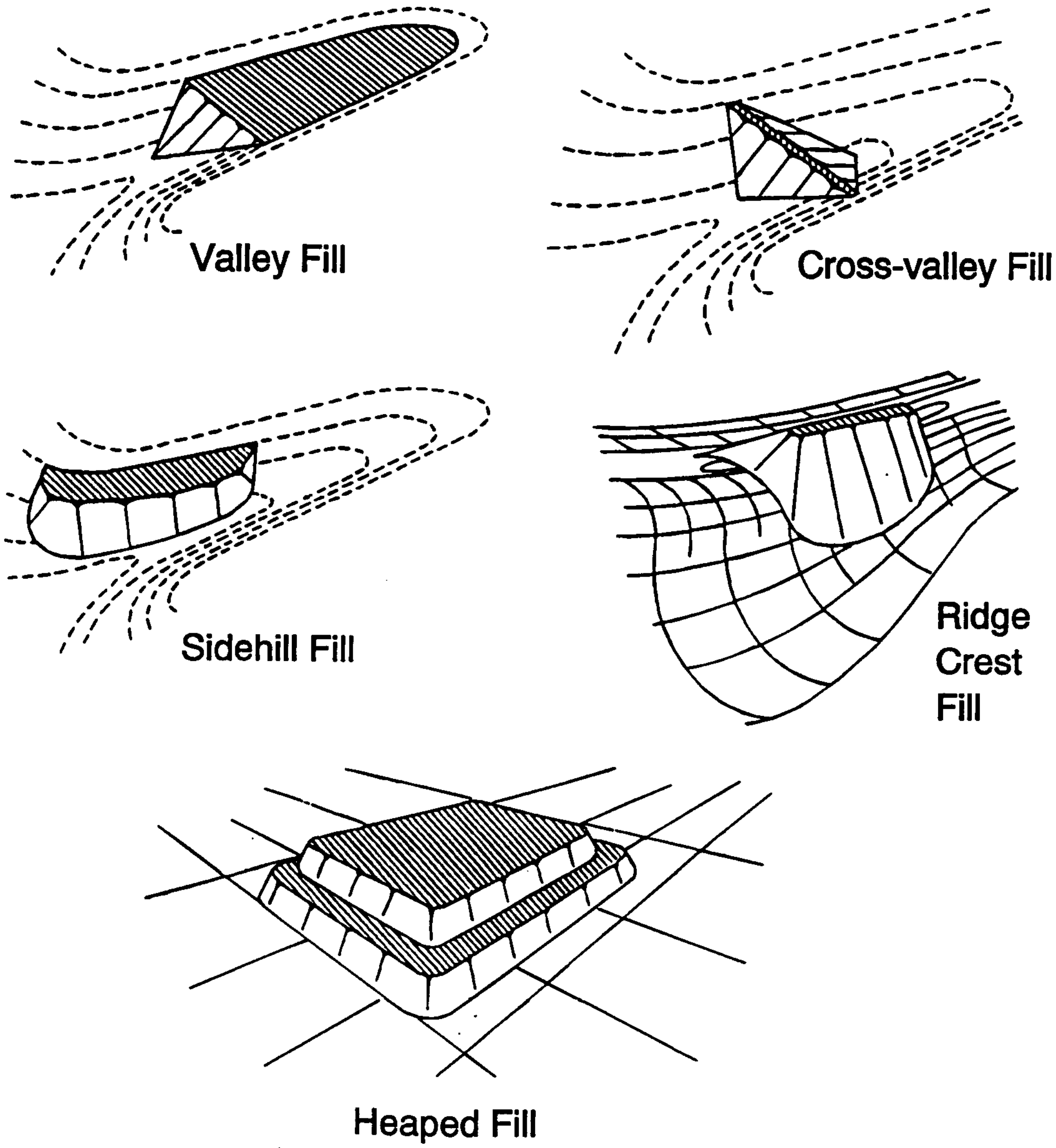
RCRA REGULATION IMPACT
ON ALASKA MINERAL DEVELOPMENT
WASTE ROCK MANAGEMENT



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

BUREAU of MINES
T S Ary, Director

OFR 95-92

RCRA REGULATION IMPACT ON ALASKA MINERAL DEVELOPMENT
- WASTE ROCK MANAGEMENT -

Prepared for
U.S. BUREAU OF MINES, ALASKA
Field Operations Center - Juneau
P.O. Box 20550
Juneau, Alaska
99802 - 0550

Prepared by
STEFFEN, ROBERTSON AND KIRSTEN INC.
Denver, Co.
Vancouver, B.C.

Technical Review by
Alan Krause
ACZ, Inc.
Steamboat Springs, Co.

MAY, 1992

RCRA REGULATION IMPACT ON ALASKA MINERAL DEVELOPMENT WASTE ROCK MANAGEMENT

By M. John Brodie,[1] Fred R. Banta,[2] and Nigel A. Skermer[3]

ABSTRACT

This report reviews the regulatory environment as it pertains to waste rock 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 waste 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 waste rock 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.

---

[1]Senior Geotechnical Engineer
Steffen Robertson and Kirsten (Canada) Inc.

[2]Division Head, Permitting and Environmental Affairs
Steffen Robertson and Kirsten (USA) Inc.

[3]Corporate Consultant
Steffen Robertson and Kirsten (Canada) Inc.

RCRA REGULATION IMPACT ON ALASKA MINERAL DEVELOPMENT WASTE ROCK MANAGEMENT

CONTENTS

LIST OF FIGURES

LIST OF TABLES

RCRA REGULATION IMPACT ON ALASKA MINERAL DEVELOPMENT WASTE ROCK MANAGEMENT

1.0 INTRODUCTION

1.1 Background

Waste rock, as addressed in this report, is the rock material that is excavated to recover material from the ore bearing zone.

Most waste rock piles are constructed by dumping from trucks, although discharge from railcars and conveyors may occur. The geometry of waste rock piles is primarily dependent on the construction method and local topography. They can be constructed in lifts, which results in a terraced configuration, or end-dumped at an advancing crest, which results in a continuous, uniform slope from the crest to the toe. Dumped rock will form a slope at the angle of repose of the material. Terraced piles have overall slopes that are flatter than end dump piles.

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 determination, 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 II has been directed toward the expanded scope of the regulatory program. Some materials included under

Strawman, which are identified below, are not traditionally considered mining waste, and are activities that have been regulated under other state and Federal programs. Specifically, these materials include:

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

The Strawman II definition that expands the scope of material included under the conceptual program 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 issue regarding the potential scope of a RCRA mine waste program, it is useful to know the definitions of processing and beneficiation as defined by EPA. The definition is 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.

Waste rock is not specifically defined in Strawman II or by EPA. For the purpose of this report, waste rock is waste generated during the process of removing ore from the earth, or generated from the process of segregating excavated material. It is not material that has been subject to processing, and only includes rock material subject to beneficiation that is waste through sorting or sizing. Concepts addressed in this report would apply to lowgrade stockpiles.

It is recognized that the management of waste rock 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 should be drafted with an understanding of the special conditions present in Alaska and 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 waste rock pile in Alaska than one in Arizona.

1.2 Objectives

This report reviews the regulatory environment as it pertains to waste rock management and disposal, delineates the unique conditions in the State of Alaska as they relate to waste rock management, discusses the special practices these conditions necessitate, and estimates the cost to the mining industry of potential regulatory actions.

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

1.3 Alaska's Mineral Industry

Mining is the third largest industry in Alaska. After fishing and oil production, it 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 mineral production in the USA, Alaska currently produces about 2% of the gold, 55% of the zinc, and 18% of the silver.

Essentially all mines excavate material, either on both of rock waste or overburden, that is not economic to process for mineral extraction, in order to gain access to, or expose underlying ore. These materials are placed in piles, generally as near to the point of excavation as possible.

The total waste rock production from all previous operations is estimated to be about 25 million tons. Most of this waste rock, generated by underground mines local to Juneau, has been used for landfill. Total tailings production in the state, excluding placer mining, is less than about 150 million tons, of which about 100 million tons was discharged to the channel.

There are roughly 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. The Red Dog mine is the first large open pit mine in Alaska.

2.0 ALASKAN MINING CONDITIONS

2.1 General

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

- The sheer size of the state; it is almost one fifth the rest of the U.S., and by far the largest. This is brought home by glancing at the sketch shown inset on Figure 2.1, with Alaska overlaying the entire lower 48 states.

- Its variety of environmental conditions and northern latitude, the bulk of the state lying north of 60° with roughly one quarter lying within the Arctic Circle.

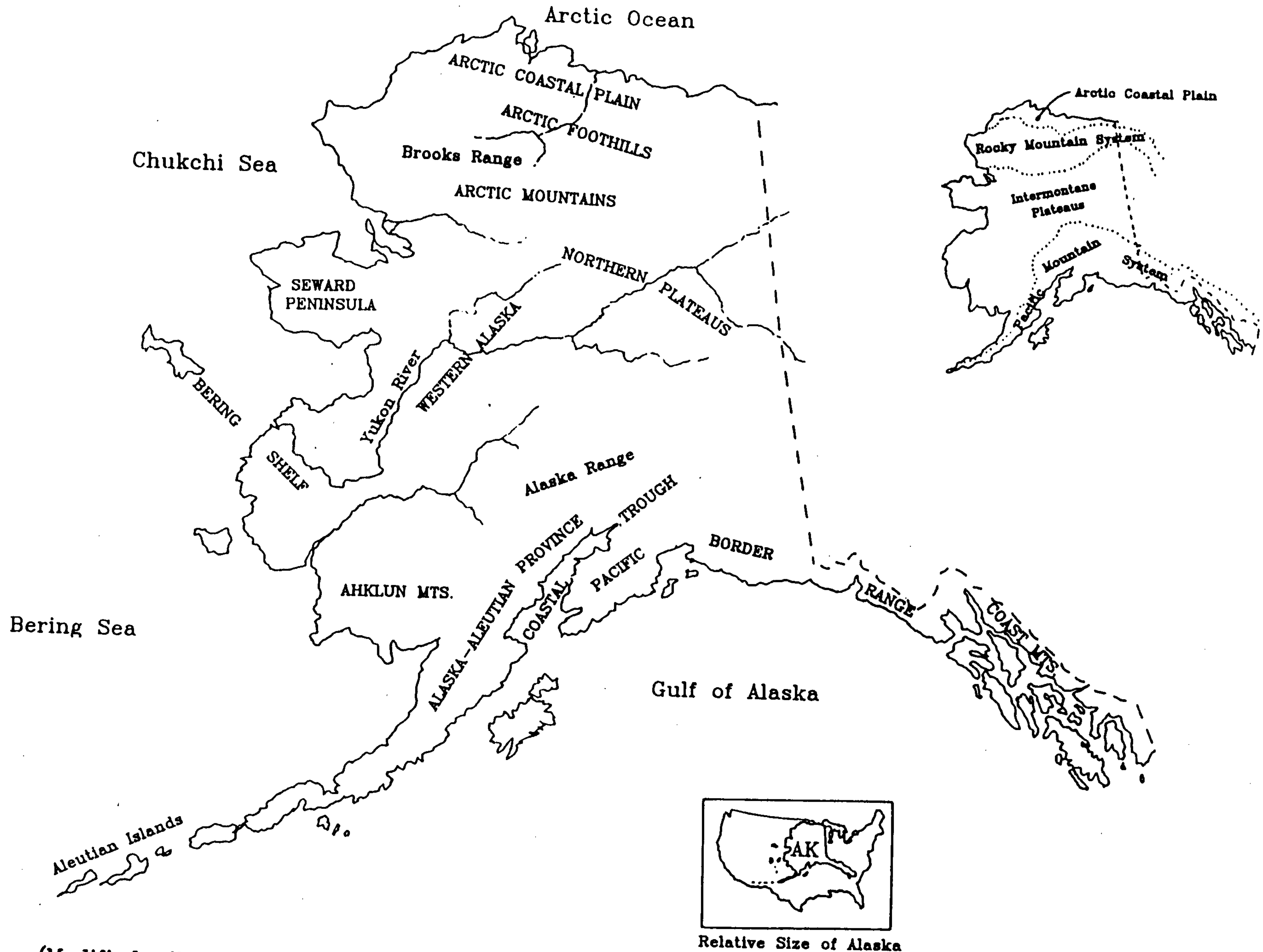
These two facts may well dictate unique solutions to waste rock disposal, in many instances. Concerns and technical solutions applicable to the other states could be inappropriate in Alaska. Similar conditions are more likely to be met in the Yukon and the Coastal Range of British Columbia in Canada. It is important therefore to have a clear appreciation of the physiography of the region before 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 waste rock disposal. This is a fundamental concept that 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 waste rock 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 covers 587,757 sq miles yet has one of the smallest populations of around half million. The environment of Alaska is complex and hostile, in many ways. Because of its size, it encompasses physiographic divisions of quite diverse character. In general there is a fourfold division, see Figure 2.1:

- Pacific Mountain System in southern Alaska;
- Intermontane Plateaus of the Yukon River and Kuskokwin River basins;
- Rocky Mountain (or Arctic Mountain) System north of the Yukon River basin;
- 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 Intermontane 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 wide are found in the Intermontane Plateaus. The Arctic Mountains are dominated by the Brooks Range rising to 6000 - 8000 ft. 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, with mountains of 8000 - 12,000 ft 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 physiographic provinces are shown on Figure 2.1.

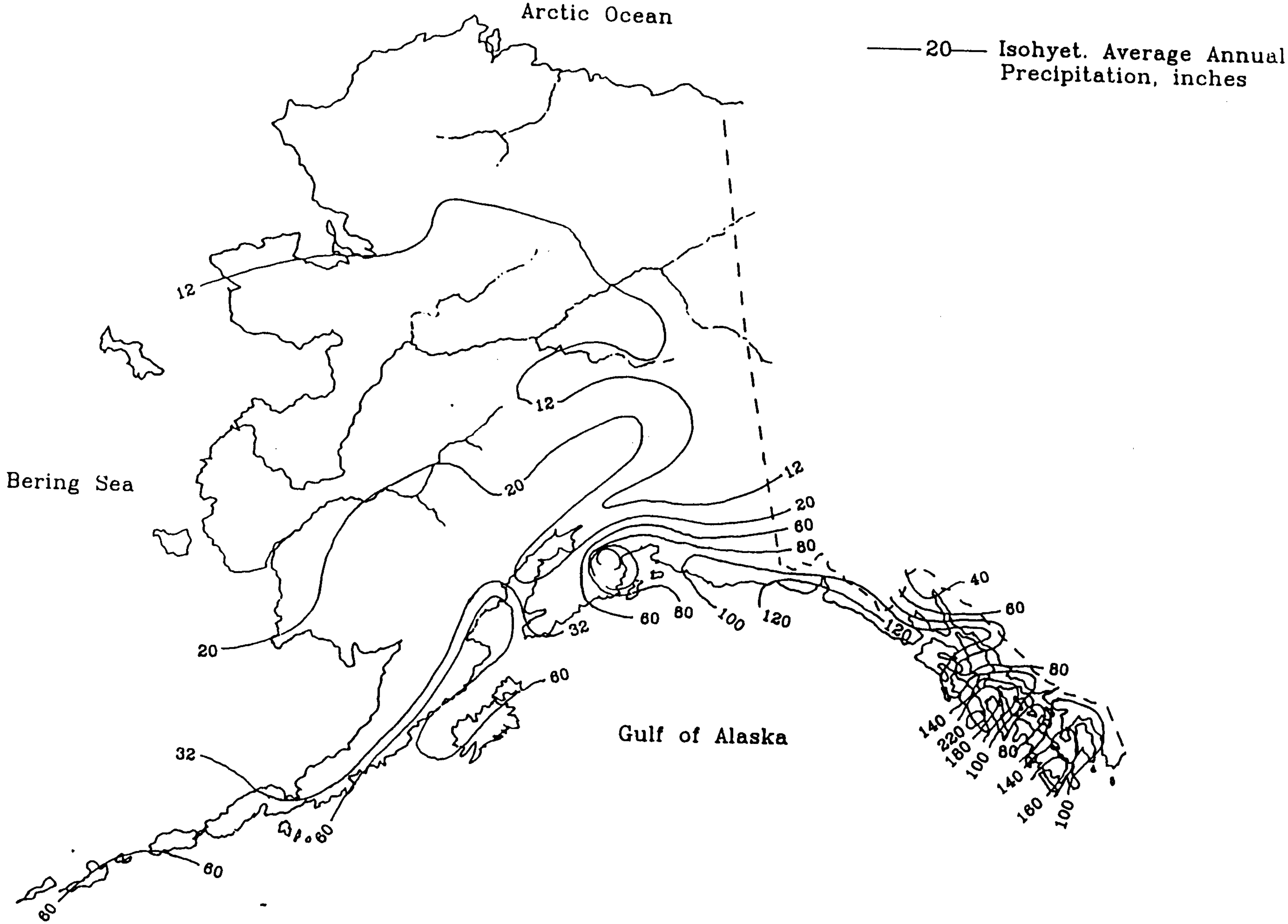
The Intermontane Plateau between the Arctic Mountains and the Pacific Mountain System consists of flat plains and rolling uplands with occasional groups of low mountains. It declines in relief and altitude westward. It is dominated by the Yukon River, by far the largest in the state.

2.3 Climate, Glaciation and Permafrost

Temperatures vary over a large range throughout the state, the coastal regions being more moderate. Extreme temperature variations occur around the Yukon River system close to the Canadian border, where mean daily minimum temperatures in January fall to about -30°F and mean daily maximum temperatures in July rise to about 75°F. In southeastern Alaska, corresponding temperature means range between roughly 20°F and 60°F. 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 annually, see Figure 2.2. The North Slope of Alaska and the upper Yukon Basin receive less than 10 ins 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 Intermontane 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 had an important bearing on soil conditions relevant to mine waste disposal because of the effects which glacial process have on the physical properties of soils.



(After Wahrhaftig, 1965)

Figure 2.2 Precipitation in Alaska

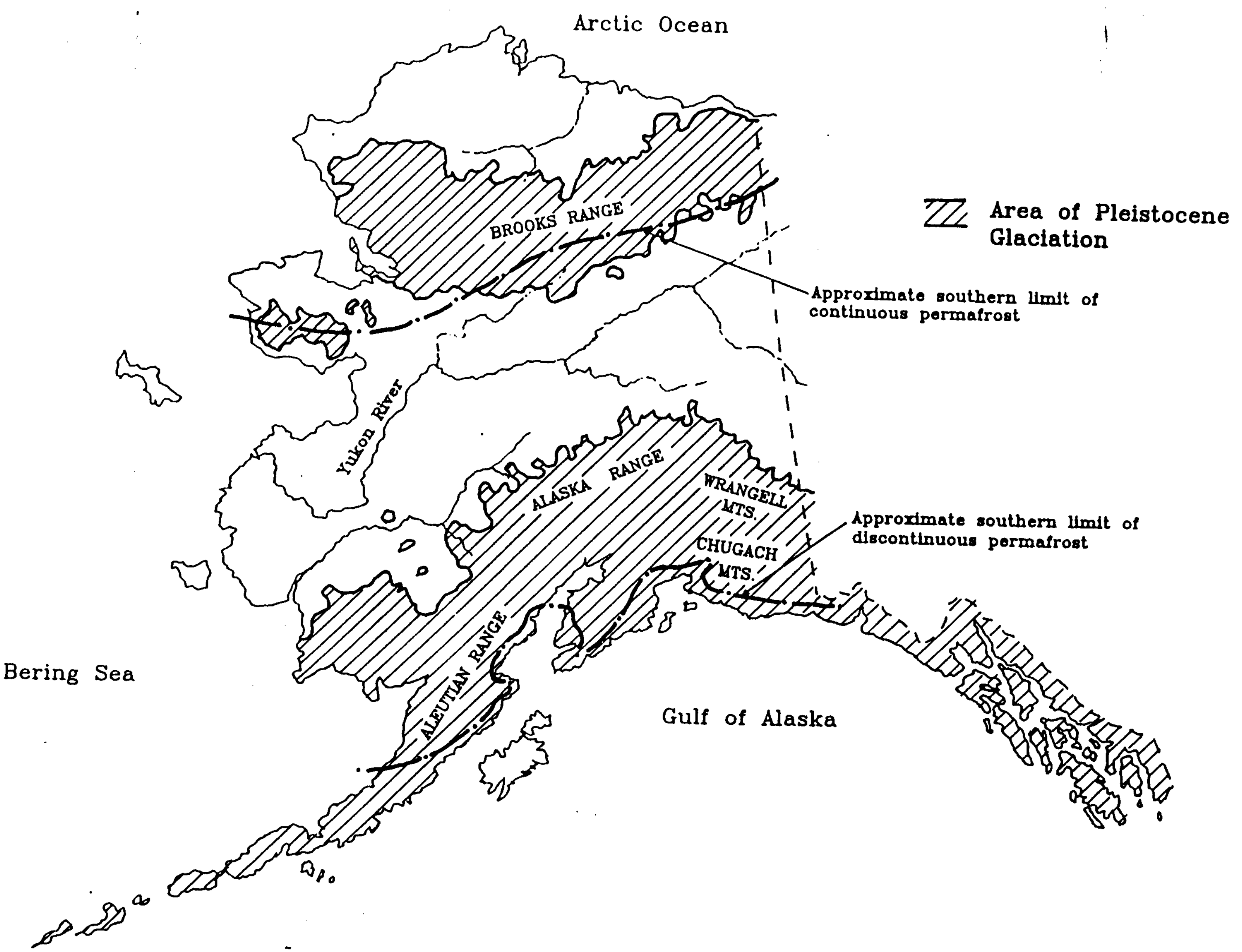


Figure 2.3 Glaciation and Permafrost in Alaska
(After Wahrhaftig, 1965)

Glaciated uplands that were buried by icecaps were eroded into blocks of mountains with rounded hummocky summits, isolated by broad, steep-sided, U-shaped valleys blanketed with colluvium. Where peaks rose above the icecap they are sharp and jagged, with extensive bare rock slopes. Such ranges have extreme relief, and their valleys head up in steep-walled, glacier-filled cirques. Glaciated lowlands consist of end and ground moraines, drumlins, irregular hills and hollows representing stagnant ice topography, kames, eskers and glacial lake plains. Rock basins and moraine-dammed lakes are common on the margins of the glaciated lowlands.

Unglaciated uplands have been formed largely by creep and solifluction under permafrost conditions. Patterned ground and solifluction lobes are common. Ridges of the unglaciated uplands have broad rounded summits and gentle convex sides, commonly mantled with windblown silt-loess. This material is susceptible to collapse on wetting, and frozen loess can collapse when the protective vegetative cover is stripped off. Loess has accumulated to great thickness in places. Unglaciated lowlands are generally broad, silt plains marked by thaw lakes and sinks, and pingos. Near the margins of the Pleistocene glaciation extensive outwash fans and aprons of sands and gravels exist, commonly trenched by shallow terraced valleys. In some areas wind action has formed extensive sand dunes, some stabilized with vegetation while others are still active. These conditions affect waste disposal by their effect on foundation conditions, surface and groundwater hydrology, and long-term stability of wastes.

Most of Alaska north of the Pacific Coastal belt is underlain by permafrost, either continuous or discontinuous. Permafrost can exist either in bedrock or soil, and it can act as an impermeable barrier to the movement of groundwater. The boundaries of the continuous and discontinuous permafrost are shown on Figure 2.3. The lines marking these boundaries correspond respectively to the 16°F and 36° isotherms of mean annual air temperature uncorrected for topography. Permafrost can exist at high altitude in mountains well down into the Coast Range, far south of the limit shown on Figure 2.3. The continuous permafrost zone in Alaska occupies the area draining to the Arctic Ocean and Chukchi Sea, where it is present nearly everywhere to recorded depths of as much as 1,330 feet. The discontinuous zone occupies much of the area draining to the Bering Sea and the Pacific Ocean, where it is at least 600 feet thick locally. Unfrozen areas in this zone become progressively more extensive southward. Local variations in the thickness, areal extent and temperature of permafrost depend on variable thermal properties of soils and rocks, local differences in the rate of heat flow from within the earth, climate, topography, slope aspect and vegetation. Permafrost is generally thickest and more extensive beneath terraces than beneath river flood plains. Permafrost conditions influence waste rock disposal by influencing the physical and chemical properties of wastes as well as materials which are used in the construction of waste disposal facilities.

As well as its effect on glaciation and permafrost, the arctic and subarctic climate of Alaska has an effect on erosion by virtue of its control on vegetation. Much of Alaska is above the timberline, and the ground surface is covered by a dense mat of low bushes, grasses and moss which acts as protective cover to the permafrost. Parts of the state, however, are so high and cold that they are barren rock deserts. Vegetation and controlling climatic factors are discussed by Sigafoos (1958) and Hopkins (1959). Vegetation can play an important part in the reclamation of mine waste areas by its control of long-term erosion, especially on critical structures such as covers 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 Intermontane 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 Intermontane 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 ago) and 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 waste disposal facilities because of the potential for major deformation of those facilities during an earthquake. Such deformation can result in

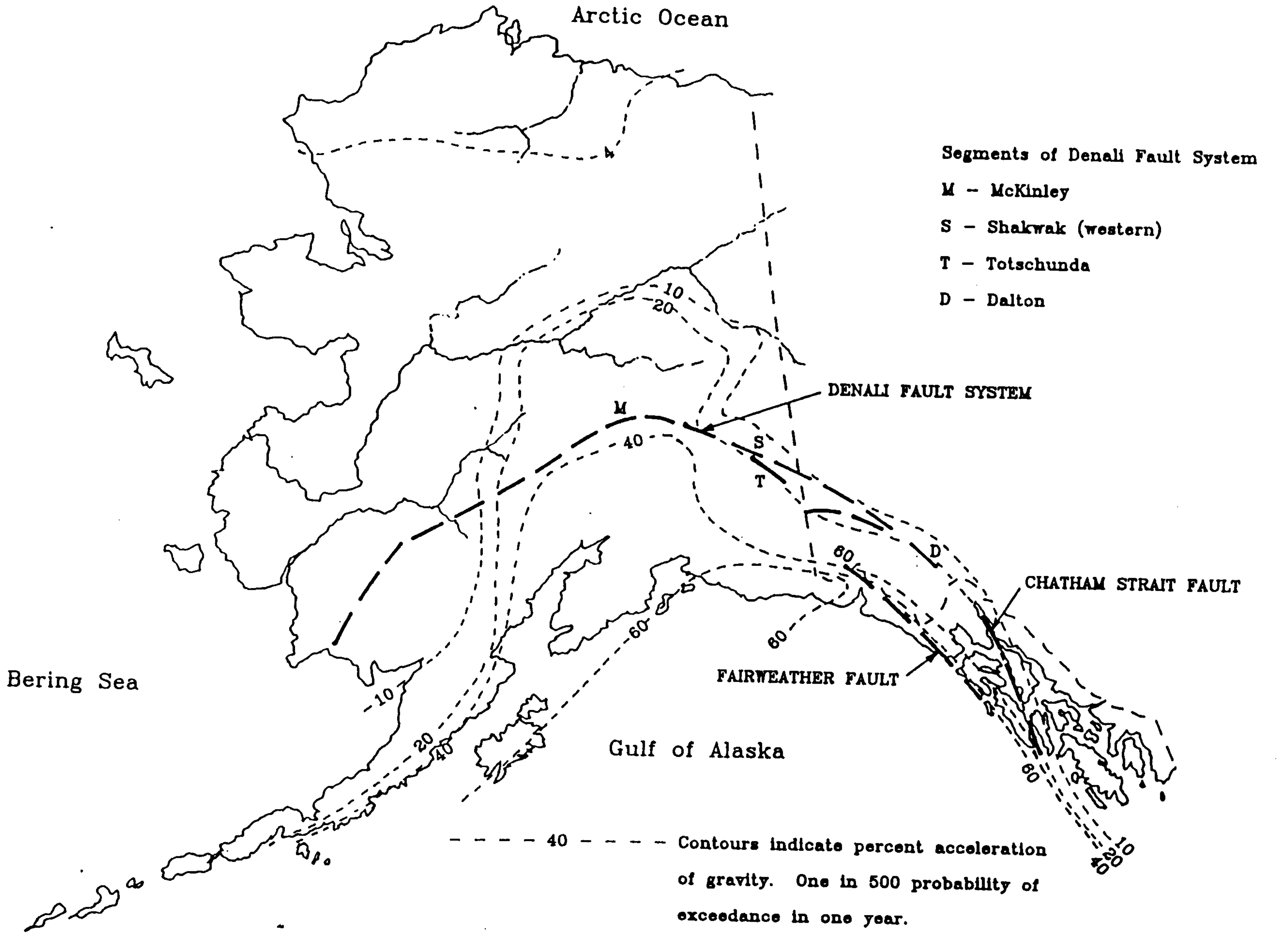


Figure 2.4 Seismicity and Faults of Alaska
(After Coonrad, 1982)

loss of land use, accelerated erosion, and potential damage to critical structures such as covers for control of contaminant production and migration.

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. The Southern Alaska-Yukon range is one of the most hazardous areas in the world for glacier dams and outburst floods. These can lead to sudden abnormally high peak flows and wave height coupled with unusually high sediment transport, and they are factors that need to be considered in siting waste facilities in river valleys. Physical instability of mine waste facilities 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).

These types of local and site specific conditions emphasize the need for site specific design of waste rock disposal areas.

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 waste rock. Waste rock, as defined within the concept of the Resource Conservation and Recovery Act (RCRA), is 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 waste rock, 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 corrosivity ignitability, reactivity or toxicity. This is important to note where hazardous waste is mixed with waste rock and disposed in the same waste disposal structure.

With respect to the practice of mixing waste, a waste rock disposal 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, non-detoxified leach material and other material exhibiting hazardous characteristics.

Waste disposal facilities that contain waste rock mixed with hazardous processing waste or other hazardous waste would be regulated under Subtitle C. Two paths to this result are apparent. First, if a listed hazardous waste is mixed with waste rock, then the disposal facility would be regulated as a Subtitle C hazardous waste facility. Second, if a non-listed waste which exhibits the characteristics of a hazardous waste is mixed with waste rock, 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 a 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 waste rock management, mixing of non-exempt processing waste or any other hazardous waste with the waste rock would result in a RCRA Subtitle C regulation of the waste rock 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 waste rock, processing waste and other hazardous wastes. This may eliminate past practices of mixing wastes, such as industrial waste. 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 where a State has elected to adopt their own non-hazardous waste program. 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 disposal 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 2.4 and 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 waste rock. Information is provided in this section about the Bevill Amendment to provide background and history regarding the development of regulations governing the management of waste rock.

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 waste rock was 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 2.2. With respect to waste rock management, waste rock continues 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, waste rock disposal operations conducted on lands administered by the BLM and the USFS 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 next 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, mines 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 the 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 been 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.

4.0 STRAWMAN II - TECHNICAL CRITERIA

As stated in previous sections, 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 a RCRA mine waste program because it is the most complete RCRA based 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 waste rock facility are driven by the performance standards. Under Strawman II the applicant or operator of a waste rock disposal facility must demonstrate that the design and methods of operation will meet the performance standards. With few exceptions, conventional methods of disposal for waste rock 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 waste rock management. Strawman II would not ban the disposal of waste rock 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 Alaskan waste rock.

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 waste rock are designed to address the broad range of risks posed by units 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 waste rock in Alaska using Strawman II technical criteria.

The process of physical characterization of Alaskan waste rock 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 waste rock disposal facilities under conditions such as permafrost and freeze/thaw cycles.

Methods and procedures for chemical characterization required 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 waste rock. 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 waste rock disposal facility 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 Groundwater (40 CFR XXY Subpart C.B.)

The United States does not have a national groundwater program of the same nature of the programs designed to protect surface waters under the Clean Water Act. Protection of groundwater is the responsibility of the states. The Strawman II technical criteria for groundwater is designed to allow for implementation of a groundwater 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, the disposal of waste rock is regulated by the Alaska Department of Natural Resources (DNR) under Alaska Statute 27.19. The regulations address long term reclamation, stabilization and prevention of acid rock drainage. Groundwater is protected by the implementation of these regulations, but specific standards for contaminants from waste rock have not been established. This is done on a site specific basis. The regulation was implemented on July 30, 1992, and further evaluation would be necessary at this point to determine if it fulfills the Strawman II concept for protection of groundwater.

The appropriateness of the designs and methods of waste rock disposal discussed in this report depend upon the specific site conditions and the characteristics of the groundwater 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 groundwater 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 waste rock 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. Effluent migration control measures, such as those discussed in Section 5.6.4, may be required for development of a waste rock disposal facility.

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

Discharge from waste rock disposal 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. Some methods may be precluded based upon the surface water standards and specific site conditions.

Disposal of waste rock 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 waste rock, but the performance standards and the uncertainty of some chemical reactions 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 waste rock 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. Again, there are no requirements that would categorically preclude the use of any of the waste rock 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 waste rock 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 methods 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 waste rock 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 waste rock 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 influences that these climatic and geologic regions have upon the behavior of waste rock 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 waste rock 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 WASTE ROCK DISPOSAL, PRE-MINE PLANNING

5.1 Waste Rock Characterization

Characterization of waste rock can be conducted in two parts, physical and chemical properties which are described in the following sections.

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

The gradation of the waste rock affects the shear strength and permeability characteristics of the dump. The gradation depends on the lithology, durability, frequency and character of discontinuities of the rock in the mines, technique for blasting, excavation and handling, and placement method. Gradation can change with time, due to mechanical or chemical breakdown (e.g. freeze-thaw, swelling of clay minerals, oxidation, etc.).

In general, coarse durable materials, with few fines, have higher strength and hydraulic conductivity than materials with appreciable fines. Where mine rock contains less than about 10% fines (finer than No. 200 mesh), hardness and compressive strength of the rock fragments control the gradation.

Where fine-grained materials form a significant percentage of the dump materials, the characteristics of the fines control or strongly influence overall dump material properties, such as shear strength, hydraulic conductivity, and exposure of potentially acid generating minerals. In this regard, sampling and gradation testing of dump materials with a maximum particle size of about 6 inches diameter should be conducted.

This is especially important for potentially acid generating rocks because a factor influencing acid generation is surface area of exposed sulphides. On a mass basis, greater than 90% of the surface area in a rock pile may occur on the particles which are smaller than 4 inches diameter.

Materials tend to segregate when placed by end-dumping techniques (dumping from a truck directly onto the dump face as opposed to push-dumping, where rock is dumped on the top of the dump and then pushed over the crest with a dozer). The result is to create a zone of coarse, durable rocks at the base of the dump, which may provide an effective underdrainage layer. The effects of various construction methods on segregation are described by Nicholas (1986), who also describes an approach for evaluating segregation. The amount of segregation depends on lift height, durability, initial bulk gradation and placement technique. In general, end-dumping directly over the crest results in more segregation than dumping short and pushing material over the crest using a bulldozer.

5.1.1.2 Shear Strength

The effective shear strength of dump materials depends upon intact particle strength angularity, gradation, surface roughness and frictional properties, and lithologic composition. Shear strength may change with time due to consolidation, degradation due to freeze-thaw, swelling or slaking, oxidation, leaching or other chemical changes, and also strains induced by foundation or internal adjustments. Plasticity of the fines influences the shear strength characteristics of the dump material.

Empirical methods for estimating shear strength of rock fills (e.g. Barton and Kjaernsli, 1981) require a knowledge of the intact material strength. For smaller dumps, where dump materials will be subject to relatively low levels of stress (i.e. less than about 25 to 50% of the unconfined compressive strength of the intact rock), or where rock materials are very strong, intact strength for preliminary investigations may be estimated based on empirical correlations with rock type (Goodman, 1980), field hardness tests (Piteau, 1970), and Point Load Index testing on drill core or hand specimens. For large dumps where dump materials will be subjected to relatively high levels of stress, or where dump materials are weak, interparticle point stresses may reach or exceed the intact strength of the rock, resulting in crushing and breakdown of rock particles. Detailed evaluations of intact strength, consisting of laboratory uniaxial compressive testing can be conducted.

Shear strength is also a function of stress level. The common practice in assessing the shear strength of dump materials for analysis and design is to assume a linear failure criteria, with zero cohesion and a friction angle represented by the natural repose angle of the materials. Repose angles of mine dumps typically range around 37° (4H on 3V). For relatively small to moderate size dumps where internal stresses are low in comparison to the intact rock strength, dump materials contain only limited amounts of fines and dump materials are not subject to degradation, this approach to shear strength is adequate.

For larger dumps, where internal stresses are higher, strains due to consolidation or internal shearing and adjustments are large, and dump materials contain a significant proportion of fines or are subject to degradation, laboratory testing for shear strength is recommended.

Tests should be conducted at various initial densities and confining stresses to simulate the range of values likely to occur within the dump. Testing should be sufficient to determine both peak and residual shear strengths. Testing should also be conducted on degraded materials, if degradation is likely to occur.

5.1.1.3 Durability

Durability of the rock and the potential for degradation influence the long-term shear strength and hydraulic conductivity of the dump. Slaking characteristics can affect sulphide exposure and acid generation, as well as physical stability of the dump surface in terms of slumping and erosion. The fines produced by slaking can reduce permeability causing the phreatic surface to rise and the overall slope stability to decrease. Weathering and mechanical breakdown of dump materials may be accelerated by stress conditions in large, high dumps.

Qualitative observations of durability can be based on weathering, ponding and trafficability of existing dumps, mine rock outcrops and drill core. If qualitative assessments indicate the mine rock may be susceptible to weathering and degradation, laboratory tests, such as slake durability, Los Angeles abrasion, sulphate soundness, or freeze-thaw, may need to be conducted. This may be important for long-term performance of rock drains.

5.1.1.4 Hydraulic Conductivity

Estimates of the hydraulic conductivity of dump materials may be required for seepage analysis and for release rates of oxidation or leaching products, which will be partially influenced by water flux through a dump.

Hydraulic conductivity can vary widely. It should be noted that dump construction in lifts generally results in the development of lower permeability layers at the top of each lift due to the compaction effect of the mine equipment. Hydraulic conductivity can also change with time due to migration of fines or slaking and weathering of dump materials. Preliminary estimates of hydraulic conductivity are commonly based on empirical correlations with gradation (CANMET, 1977). Where dumps contain substantial components of fine-grained materials, or materials subject to slaking or degradation, lower-bound estimates of hydraulic conductivity should be based on compaction permeameter tests conducted on the fine fraction of the mine rock.

5.1.2 Chemical

Chemical stability issues of waste rock dumps include acid rock drainage (ARD) and leaching of metals.

COMMENT

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

5.1.2.1 Acid Rock Drainage

Waste rock is generated throughout the mining process and remains on site long after mining operations cease. Acid rock drainage (ARD) and metal leaching in drainage water may not become apparent for many years, but once initiated can continue for hundreds of years. Produced in high volumes, particularly from open pit operations, acid generating waste rock can require extensive control and remediation measures to prevent adverse environmental impacts. There are a number of physical, chemical, geochemical and biological factors which influence the potential for contaminant release from a sample, and which therefore influence the technology for prediction and handling of such rock. Appropriate mine rock management plans for handling and control of drainage water quality can only be developed with proper classification of the material and an understanding of the current technology.

The processes of ARD are described in detail in SRK et. al., 1989. Where rock dumps contain sulphides, the potential for ARD is usually the greatest operational and closure concern. Measures to protect the environment from the effects of acid generation can have a significant influence on mine planning and economics. Contaminated drainage from sites where adequate control measures have not been implemented can continue for many hundreds of years. Where sulphide minerals are identified in materials to be stripped, then testing should be conducted to determine the acid generation potential through static and, if necessary, kinetic tests, as outlined below. Generally, soils and topsoil do not have the potential to generate acid, however those that have been contaminated by acidic drainage from other materials may contain significant levels of leachable metals.

Current technology for prediction of ARD from rock dumps suggests that the main parameters are net neutralization potential (NNP) and the ratio of neutralization potential to acid generation potential (NP:AP). Other parameters such as nature and surface area exposure of the sulphides and neutralizing minerals also influence ARD characteristics.

It is critical to recognize that acidic (or low pH) drainage is not the key ARD issue, but rather the potential elevated metal levels in the drainage. Elevation of some of the metal levels (zinc for example) will occur if there is local and temporary depression of pH. Thus, while most current ARD potential testing tends to focus on overall acid generating potential, the real interest is local pH variations that will allow mobilization of metals into the drainage water and thus determine drainage quality.

Static Testing

NP and AP are generally determined in a laboratory analysis of a five ounce sample. Such an analysis, or acid base account (ABA), is called a static test because it does not consider the rates of acid generation or neutralization. Therefore, it should be treated as a qualitative predictive method. The subtraction of AP from NP yields the NNP. Theoretically, a sample can be expected to generate net acidity at some point in time if the NNP is less than zero, however, this may not be the case in practice. 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.

Based on general experience with laboratory tests and field data on a wide range of sulphidic rock types, there appears to be a low potential for acid generation for rock samples with a NP:AP ratio greater than 3:1, as indicated on Figure 5.1. Rock samples with a negative NNP and a ratio of NP:AP less than 1:1 have a high potential for acid generation. There is a "marginal" zone between these two categories in which the "other" parameters influence results and it is difficult to predict the short and long-term acid generation characteristics and associated runoff water quality purely from static testing.

Kinetic Testing

The objective of static tests is to identify the geologic units at a site that may have the potential to generate net acidity. The objective of kinetic testing is to predict the short-term and long-term drainage water quality in the field. Geochemical kinetic tests involve weathering under laboratory controlled or on-site conditions of samples of these units in order to confirm the potential to generate net acidity, determine the rates of acid generation, sulphide oxidation, neutralization, and metal depletion and to test control/treatment techniques.

Current ARD prediction methods are reasonably able to predict the formation of ARD and, to a lesser extent, the associated drainage water quality from homogeneous materials such as mine tailings. In order to do the same for rock piles, a prediction method must account for the following factors:

- the spatial variations in type and concentration of sulphide and alkali minerals in individual rock units and throughout the rock pile,

- the range and spatial variations of particle size in rock piles and the associated surface area exposure of sulphides and alkali minerals in the rock particles,

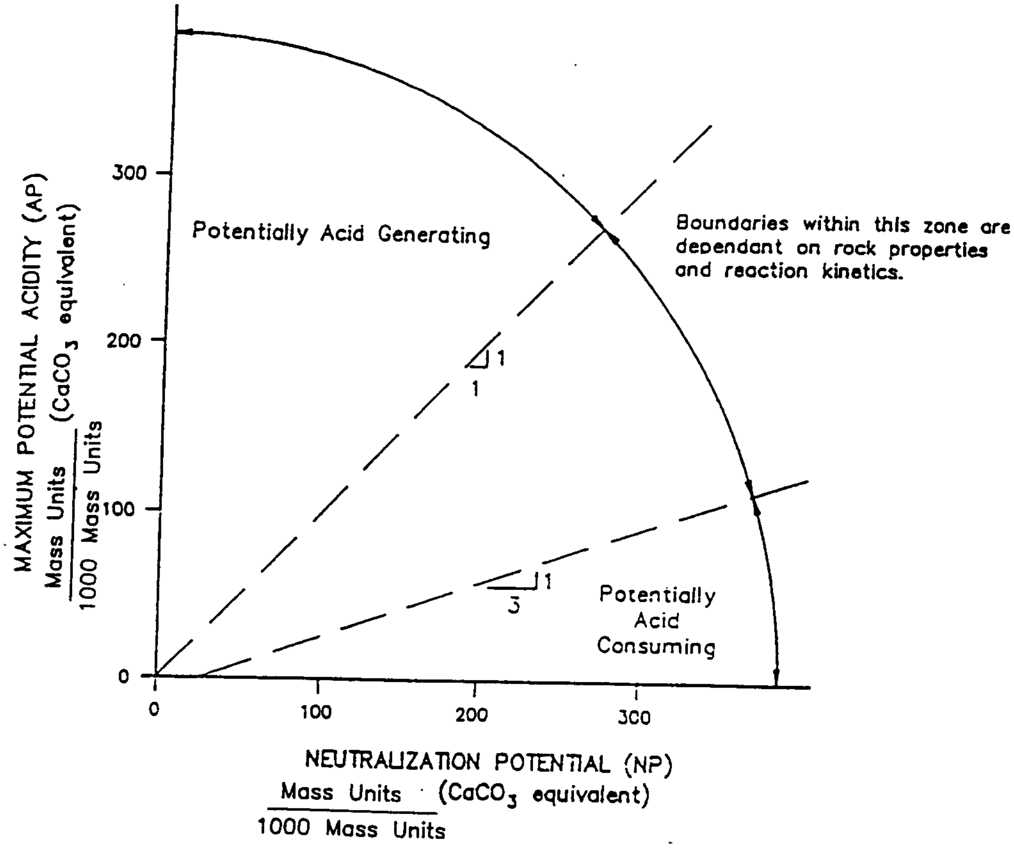


Figure 5.1 Conceptual Waste Rock Classification For Waste Management Planning
(After Brodie et al, 1991)

- the time dependent change in particle size, and hence exposed surface area of sulphide and alkali minerals, as a result of slaking or chemical breakdown in a rock pile,

Other factors such as availability of oxygen, water, temperature and bacterial activity may also influence the rate of acid generation and character of drainage water.

Rock samples which are not clearly acid generating or acid consuming [based on their acid/base account (ABA)] are often further evaluated in kinetic testing, with sample selection being based on a consideration of the physical and geochemical characteristics of the rock. A conceptual rock classification system of the physical and geochemical nature of rock samples is described by Brodie et al, 1991.

A preliminary guide for determining which materials can be safely placed in on-land piles is: 1) no net acid generating materials, 2) blended acid generating and non-acid generating pile materials should generally have an overall ratio of NP:AP of 3:1 or greater, and 3) the pile should be homogeneous with no zones or significant concentrations of individual acid generating rock types. Where mine plans call for on-land disposal of waste rock which has an NP:AP < 3:1, then kinetic testing should be conducted to examine the rate of acid generation/neutralization and the resulting drainage water quality under conditions representative of those expected at the site.

Kinetic testing of rock samples is often conducted when the acid generation potential cannot be confidently predicted from static testing, or where it is necessary to predict the associated drainage water quality. The latter may occur where mine plans call for blending of net acid consuming rocks with acid generating rocks. The most suitable methods for kinetic testing of mine rock include columns/lysimeters and modified humidity cells. These tests are further described by Coastech, 1990 and Brodie et al, 1991, respectively.

Sampling for ARD Testing

Most geologic units exhibit variability in their geochemical properties. In many cases a unit is composed of a number of sub-units, each with a distinctive geochemical character. Therefore, sampling should be conducted so that representive samples of each geochemically similar unit are obtained. Guidelines for the number of static test samples of each geologic unit can be found in SRK et. al., 1989. Generally, static test samples are smaller than 2 lbs. Kinetic test samples may range in size from 100 lbs for modified humidity cells up to several tons for large columns or field plots.

5.1.2.2 Leaching to Metals

Leachates, in this document, refer to drainage water that has been chemically contaminated by soluble constituents from waste rock. The main contaminants of concern in seepage, drainage water or surface water decants 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.

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 that vary primarily in the duration of the test and the nature of the extractant. The tests described below are useful in the initial phases of testing program to indicate the short term leaching characteristics and potential for metal release from a sample. They can also indicate the extent to which oxidation has occurred in a sample if the flushing regime is known. The tests described below are particularly useful for the evaluation of existing tailings, and for samples which contain readily soluble contaminants as the tailings are produced.

In these tests, 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.

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. While the objective of each of the tests is the same, the procedure and thus the relevance of the results to 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 1311 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, (Environment Canada, 1990 and Erickson et al, 1991) and a study is currently in progress in British Columbia (SRK, 1992b) to evaluate the suitability of the above mentioned tests for use on mine rock and tailings. At present 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 D3987 are the most applicable tests. There is growing recognition that acetic acid leachant may not be appropriate for arsenic, copper and lead extraction. Generally, strong acid based tests are inappropriate for prediction of leachates from tailings impoundments. 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 prediction of potential leachability must also consider the effects of dilution within the tailings impoundment, and water cover over the waste material.

COMMENT

The primary chemical concern with mine rock is the potential for ARD, however, prediction methods for evaluating the ARD potential of mine rock are evolving. Generally, acid base accounting should be used for initial screening of mine rock, using EPA methods as noted above. The SW-846 is a compendium of analytical methods, however, for rocks of uncertain ARD characteristics (1:1 < NP:AP < 3:1) these methods should be supplemented with kinetic tests, such as columns or modified humidity cells, as they may give a more accurate indication of drainage water quality under field conditions.

A less common chemical concern is the potential for leaching of metals from mine rock under neutral conditions. This should be evaluated for non-acid generating rocks. Acetic acid and strong acid based tests should be avoided. Methods such as the ASTM 1312 appear to be the most suitable.

5.2 Facility Management

5.2.1 Temporary Storage

Temporary storage of mine rock may be used in two cases and would be regulated under the Strawman II approach (see definition of regulated materials Section 1.1): stockpiling of low grade ore for future milling, or stockpiling prior to permanent disposal such as in a pit at the end of mining. In either case, if the material is potentially acid generating then measures to provide environmental protection will be required. These measures may be: control of acid generation, control of effluent migration, or collection and treatment. A proposed temporary storage facility for potentially acid generating rock is described by City Resources Ltd., 1988.

5.2.2 Permanent Storage - Site Selection

5.2.2.1 Physiography and Geomorphology

The physiography of the site refers to its location, shape, size and topography. Location of the site and proximity to the source of the waste directly affects haulage costs. Generally, locations slightly downhill and closest to the source are the most economical. Other mining activities such as blasting, access development, or layout of mine facilities may affect site selection, development and dump stability considerations. The size and shape affect the suitability of the site in terms of available capacity, type of dump and construction alternatives. Topographic constraints, such as steep slopes, major drainages or divides, may place additional physical limitations on the site, and may also affect selection of the type of dump and construction methodology.

Where it is determined that it will be necessary to provide environmental protection measures, such as covers or seepage collection for control of ARD, it is possible that these requirements will take a high priority in evaluation of alternative sites.

The geomorphology of the site refers to the geological origin of various landforms and active geologic processes. Understanding the geomorphology provides insight into the nature of site soils. For example, colluvial deposits might be expected in the lower sections of moderately steep bedrock slopes, or terrace deposits might be expected on the slopes of large valleys. The occurrence of landslides, or other geologic hazards such as debris flows, debris torrents or avalanches, may require stabilization or construction of mitigative works. Some landforms, such as river or kame terraces and gullies, may have positive influences on dump stability, and can often be used to advantage during dump construction, although special seepage control measures may be required.

Preliminary field investigations of site physiography and geomorphology would normally consist of a terrain analysis based on available maps and air photos. This would be followed by ground reconnaissance and mapping of significant terrain features. Depending on the detail of available mapping, and complexity of the site, photogrammetric mapping and/or ground surveys might be required at later stages of the study to prepare more detailed maps.

5.2.2.2 Hydrology

The hydrology of a particular dump site may limit its use. Dump sites with defined drainage courses may require construction of diversions or flow-through rock drains. Climate patterns, frequency and severity of storm events, snow packs, temperatures and the size of catchment basins all influence runoff and stream flows, and may affect dump stability and flushing of metals or oxidation products. Areas with high precipitation may require special construction methods to control runoff and minimize infiltration into the dump. Heavy snow accumulations may lead to seasonally adverse conditions within the dump and foundations, and limit operations. On the other hand, prevailing winds may prevent significant snow accumulations. Mining and dump construction may also significantly change the amount of infiltration and distribution of runoff, with a consequent impact on surface water resources.

Topographic maps and air photos provide useful information on drainage patterns and catchment basins.

Field investigations should include basic ground reconnaissance and stream mapping. A program of periodic measurement of streams which may be affected by the proposed dumps, should be initiated early in the investigation. Flow monitoring should be conducted utilizing staff gauges, weirs or current metering on measured cross sections. It is generally good practice to establish a climatological station at the mine site. Detailed ground surveys should be conducted for design of diversions and/or flow-through rock drains and contaminated seepage collection systems.

5.2.2.3 Geology

The geological setting of a dump site should be considered during the site selection and design stage. Adversely oriented geologic structures, such as faults, bedding planes or joints, may affect the stability of the foundation. Competency and durability of the foundation materials may limit allowable bearing loads, or influence dump configuration and construction concepts. A knowledge of the geology of the dump site will also be required to assess the possibility of economic mineral deposits occurring beneath the site. Available exploration reports and drill logs should also be reviewed. Air photos and topographic maps may provide some insight into the bedrock geology and structure.

An understanding of regional tectonics is important in evaluating seismic risk. Proximity to major tectonic faults and earthquake epicenters may influence the types of stability analyses, factors of safety, and design approaches deemed appropriate for a given site.

An understanding of the surficial geology of the site is essential to be able to evaluate foundation conditions and overburden material characteristics for stability analysis and design, and to determine foundation preparation requirements. It is necessary to determine the origin, nature, distribution and stratigraphy of site soils, and the depth to bedrock or competent soil strata. Particular emphasis must be placed on determining the characteristics and extent of soft, loose or incompetent soils which may affect foundation stability or which may be incorporated into the dump.

Surficial geology investigations commonly begin with a preliminary interpretation of black and white and/or color air photos, followed by ground reconnaissance and mapping of soil exposures in road cuts, stream channels, etc. Depending on the sensitivity of the proposed dump to foundation condition trenching and test pitting may be required to further define and classify soil types and distribution, and to obtain representative samples for laboratory index testing. Soft soil deposits, such as peat or organic rich soils, should be probed to determine depth and extent. In situ testing, such as hand-held vane shear or pocket penetrometer testing should be conducted in test pits and trenches, where practical, to provide an initial indication of soil strength properties. Permafrost may thaw, resulting in a decrease in foundation strength with time. If significant deposits of potential problem soils are identified during the preliminary investigations, more detailed field studies should be carried out. Such studies would likely include geotechnical borings.

The hydrogeology of the site can influence the foundation conditions, stability and requirements for underdrainage or liners. In addition, mine dump construction can have a significant impact on the groundwater and surface water resources. To be able to evaluate the potential impacts, it is first necessary to develop an understanding of the groundwater flow systems and the basic hydrogeologic characteristics of the site.

Sources of information on site hydrogeology are generally scarce, and site specific studies will be required to develop the necessary data.

If significant aquifers are identified beneath the site, or potentially adverse groundwater conditions are encountered, more detailed hydrogeological investigations would be required. Open standpipes and/or sealed piezometers would be installed in existing boreholes or holes drilled specifically for hydrogeological investigations. In situ permeability testing of sealed piezometers and pump testing of major aquifers may need to be conducted.

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 groundwater flow systems. Frozen ground is an impermeable layer which: (1) Restricts recharge, discharge, and movement of groundwater, (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 groundwater in some areas. Low ground temperatures above and below permafrost result in groundwater temperatures ranging from 32° to 40°F. At these temperatures, groundwater is more viscous and moves more slowly than in temperate regions (William, R.J., 1970).

Groundwater flow may also influence ARD. Seasonal fluctuations in the water table result in intermittent drying and wetting conditions which facilitate mineral weathering. Moreover, the discharge of groundwater enriched in reduced iron can maintain an acidic flow at the base of the waste rock dump throughout the year (Kwong, 1991).

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.

5.2.3 Permanent Storage, Design for Closure and Post-Closure Care

5.2.3.1 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.

5.2.3.2 Broad Objectives for a Rock Dump

In developing the design of a rock dump 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 rock dump 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 that it continues 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 rock dump 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

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

Strawman II requirements are essentially targeted at physical and chemical stability of a rock dump for the protection of human health and the environment.

5.3 Containment Site

(After Piteau, 1991)

Dumps generally classify into five typical types, on the basis of overall foundation and dump configuration. Typical dump types based on this approach are briefly described in the following and illustrated in Figure 5.2. It should be recognized that in practice a dump may be a combination of several of the following simplified dump types.

In addition to the typical dump type, a basic description of a dump should include some reference to the overall shape and height of the slope, or volume of the dump.

5.3.1 Valley Fills

As illustrated in Figure 5.2a, valley fills partially or completely fill the valley. The surface of the dump is usually graded to prevent impoundment of water at the head of the valley. Valley fills which do not completely fill the valley may require construction of culverts, flow-through rock drains or diversions, depending on the size and characteristics of the upstream catchment. Valley fills which completely fill the valley are sometimes referred to as "Head-of-Hollow" fills. Head-of-Hollow fills are common in the coal fields of the southeastern U.S., and often incorporate chimney drains for collection and conveyance of seepage and runoff.

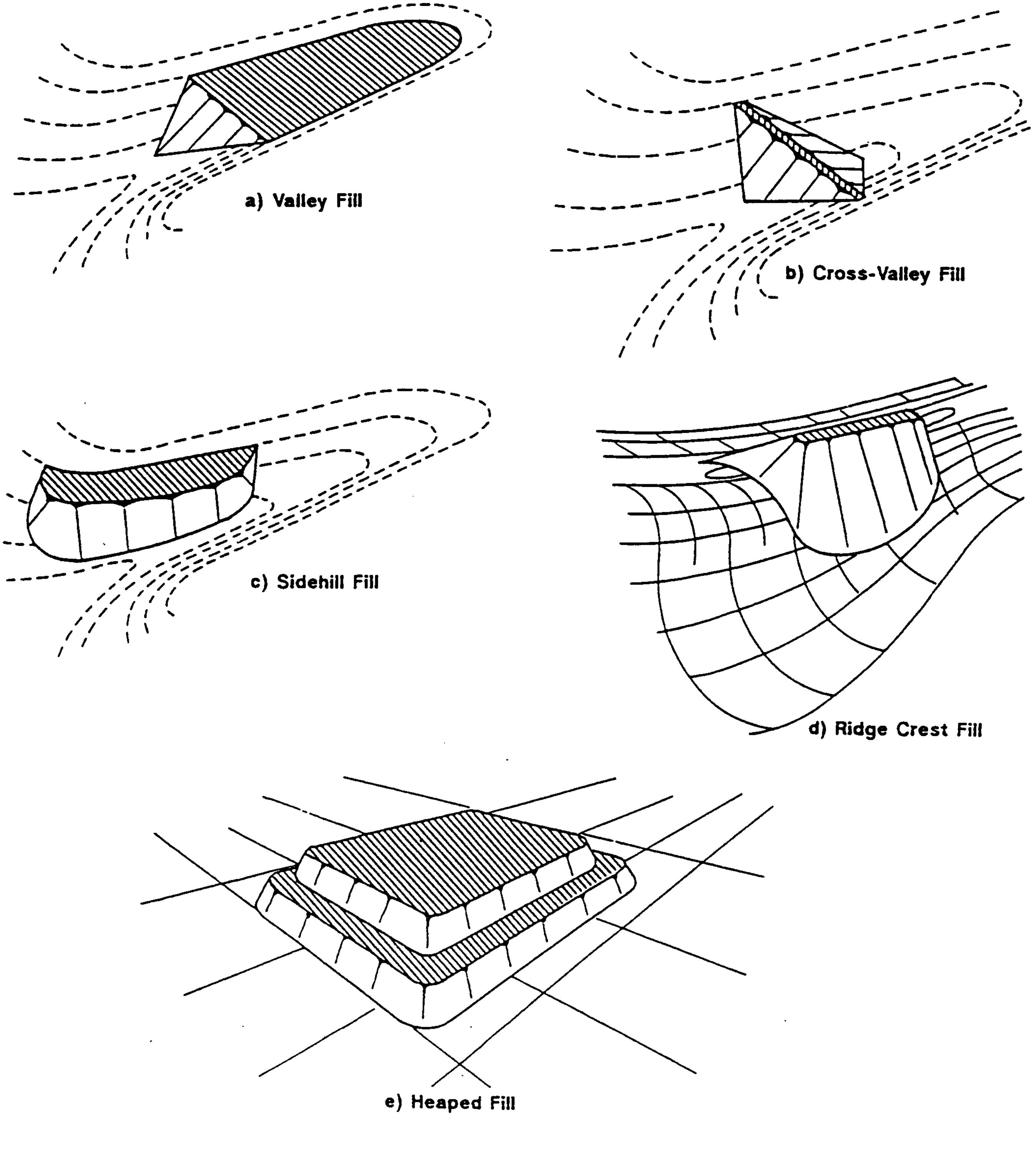


Figure 5.2 Basic Mine Dump Types
(Modified after Wahler, 1979)

5.3.2 Cross-Valley Fills

The cross-valley fill is a variation of the Valley fill. As illustrated in Figure 5.2b, the embankment extends from one side of the valley, across the drainage, to the other side of the valley. The upstream portion of the valley is not completely filled, and fill slopes are established in both the upstream and downstream directions. To avoid impounding water, cross-valley fills usually require specific provisions for conveying water through or around the fill (e.g. diversion and/or culverts or flow-through rock drains).

5.3.3 Sidehill Fills

Sidehill fills are constructed on sloping terrain and do not block any major drainage course, as illustrated in Figure 5.2c. Dump slopes are usually inclined in the same general direction as the foundation. Toes of sidehill fills may be located on the slope or on flat terrain in the valley bottom.

5.3.4 Ridge Crest Fills

Ridge crest fills are a special case of sidehill fills, wherein fill slopes are formed on both sides of the ridge line or crest. Figure 5.2d illustrates the ridge crest fill type.

5.3.5 Heaped Fills

Heaped fills, illustrated in Figure 5.2e, and also referred to as area, stacked or piled fills, consist of mounds of waste with slopes formed on all sides. Foundation slopes are generally flat or gently inclined.

5.4 Options for Control of Physical Stability

The stability of a mine dump is controlled by the following factors:

5.4.1 Dump Configuration

The layout and size of a dump have a direct bearing on stability and the potential size of failures (Lau et al, 1986; Taylor and Greenwood, 1981; Nicholas, 1981; and Blight, 1981). The primary geometric variables are:

a) **Height** - defined at the vertical distance from the crest to the ground surface at the toe of the dump. Heights typically range from about 50 ft to in excess of 1300 ft.

b) **Volume** - usually expressed in terms of in-place volume prior to excavation. Small dumps are considered to contain less than about 1 million cu yd, while large dumps have more than 50 million cu yd. Some dumps are designed to contain in excess of 1 billion cu yds.

c) **Slope Angle** - the overall angle measured from the crest of the uppermost platform of the dump to the toe. The normal range is between 26° (2H:1V), which is a common angle adopted for reclamation, and 37° (4H:3V), the average angle of repose of free-dumped cohesionless rockfill. Slopes steeper than 37° may occasionally develop if the material contains appreciable fines or cohesive material, or consists of very large, angular boulders.

5.4.2 Foundation Slope and Degree of Confinement

Both the foundation slope and degree of confinement afforded by the shape of the foundation will affect dump stability (Golder Associates, 1987; Tassie, 1987; Campbell, 1981; Blight, 1981). Steep foundation slopes and/or lack of confinement have been contributory factors in several failures of dumps. The least desirable situation is where the slope angle increases towards the toe, i.e. a convex slope. If a failure occurs in this situation, it may gain considerable momentum as it slides downslope. The most favorable situations are a decreasing slope towards the toe, i.e. a concave slope. In the event of a flow developing, confinement in a valley may actually increase the flow distance.

5.4.3 Foundation Conditions

Foundation conditions are a key factor in overall dump stability (Golder Associates, 1987; Robertson, 1986; Nicholas, 1981; Caldwell and Moss, 1981). Poor foundation conditions are the most frequent cause of instability. Foundation types fall into three general categories:

a) **Competent** - highly competent bedrock or soil of equal or greater strength than the dump materials, and which is insensitive to pore pressure generation and strength reduction due to loading.

b) **Intermediate** - intermediate material that will consolidate to gain strength with time, but which may be subject to pore pressure generation and strength loss if stressed too rapidly. Thawing permafrost foundations might fall into this category.

c) **Weak** - weak material that cannot safely be loaded beyond a limiting level of shear stress, and material that does not gain strength at a significant rate by consolidation. This is frequently the case where clay layers occur within the foundation soils. Saturated fine sand foundations subject to liquefaction or high pore pressures are also included in this category.

Often a weak surface base layer exists, possibly only a few feet thick in a dump hundreds of feet high. In this case shear stresses near the toe of the dump exceed shear strengths, and a spreading failure occurs (Vandre, 1980 and Blight, 1981).

COMMENT

The most common source of dump instability is foundation conditions. In southeast Alaska much of the topography is mountainous and steep slopes are common. Attention to other factors in dump development such as geometry and rate of construction may be needed to ensure a stable facility. In northern Alaska, permafrost is prevalent and its thawing may destabilize a dump. If permafrost develops within a dump, then stability may be improved because the cohesion provided by the ice.

5.4.4 Dump Material Properties

Properties such as gradation, shear strength, durability, etc. (see Section 5.1) are key factors in overall dump stability (Singhal, 1988; Golder Associates, 1987; Tassie, 1987; Robertson, 1986; Caldwell and Moss, 1981; Blight, 1981). The most favorable dump materials are composed of hard, durable coarse rock, with little or no fines. Dump materials of this type are commonly, but not exclusively associated with metal mines. The least favorable materials are overburden or soft, degradable rocks with significant fines, such as mudstones or shales, which are commonly associated with coal measures, or heavily weathered or altered rock masses.

5.4.5 Method of Construction

Dump stability is related to how the dump is constructed (Singhal, 1988; Golder Associates, 1987; Claridge et al, 1986; Gold, 1986; Campbell, 1981). Dumps are usually constructed in a series of lifts or platforms in either descending or ascending sequence. Upslope (ascending) construction is advantageous, as the toe of each lift is supported on the preceding lift. The method of construction is based on minimizing haulage distance, accessibility, and available capacity. Dump stability is usually critical during and shortly after construction. Stability can be enhanced by the use of wrap-arounds, terracing, restricting lift heights to limit shear stresses on the foundations and the length of potential runout. Dumping should generally be in the direction of valley contours, rather than downslope, and other techniques.

5.4.6 Piezometric and Climatic Conditions

Piezometric conditions in the dump foundation and within the dump can affect the stability of a mine dump (Singhal, 1988; Golder Associates, 1987; Zavodni, 1981; Caldwell and Moss, 1981). Climatic conditions, notably precipitation in the form of rainfall and snowfall, may have a direct influence on the piezometric conditions (Tassie, 1987; Golder Associates, 1987). Water may enter a dump either by direct infiltration, by flowing on surface topography (run-on), or as groundwater seepage (Zavodni, 1981).

Potential inflow of water and piezometric conditions within the dump should be estimated, based on hydrogeological and hydrologic information obtained during field studies and estimated material properties. Where preliminary studies indicate that development of phreatic surface within the dump may occur, modelling of the groundwater flow system is recommended.

High pore pressures in foundation soils generated by dumping have been identified as contributing to instability in many of the failures reported in British Columbia. The potential for pore pressure generation and dissipation rates must be evaluated, and results incorporated into analysis and design. Foundation materials which are particularly susceptible to adverse pore pressure generation include fine grained soils, softened tills and, in some cases, dense tills.

Incorporation of ice or snow in dumps may result in formation of perched water tables and development of instability due to high water pressures. Some dump failures have been attributed to residual snow and ice concentrations from the previous winter, in combination with relatively fine rock sizes. Climatic information should be analyzed and consideration should be given to the extent of potential snow accumulations on dump surfaces, especially in the leeward aspects of the dump sites.

COMMENT

High snowfall occurs in southeastern Alaska and mines in this region which produce soft low-durability rock (which degrades to yield a high fines content) need to design and operate their rock piles in a manner to avoid failure. This may require developing dumps on the windward side of the mine or constructing large flat dumps with shallow overall slopes for critical sites. In mountainous terrain this may necessitate siting dumps in the valley bottom.

5.4.7 Dumping Rate

The influence of dumping rate or crest advancement on stability has been recognized by several workers (e.g. Golder Associates, 1987; Tassie, 1987; Campbell and Shaw, 1978). High dumping rates have been considered a contributing factor in several of the dump failures reported in B.C. High rates of dumping may result in generation of excess pore pressures as described above. In such cases, dumping rates may have to be controlled and pore pressures monitored during construction, to ensure that excess pore pressures are effectively dissipated and foundation stability maintained. In addition, the shear strength of dump materials is influenced by density. Consequently, where filling or dump advancement is rapid, the dump material may not have an opportunity to consolidate and develop adequate shear strength to ensure stability.

It is clear from studying histories of dump failures that an important relationship exists between crest loading rates and stability. Other key factors include dump height, foundation material and slope, piezometric conditions and dump material quality. Piezometric conditions, dump height and material quality are interrelated:

- **Piezometric Conditions** - Rapid loading of saturated fine-grained material increases pore pressures, resulting in a decrease in effective stress. Given time, or slower rates of loading, the soils consolidate, allowing dissipation of pore pressures and transfer of stress to soil particles, thereby increasing effective stress and stability. This factor has been documented as contributing to failure in some dumps.

- **Dump Material** - End-dumped material will initially settle in a fairly loose state on the dump face, to be buried and loaded by subsequent dumping. As dumping continues, overburden stresses increase and the material will invariably assume a somewhat denser condition. This denser state tends to be more stable leading to higher shear strength. High stresses at great depths can, however, reduce shearing resistance.

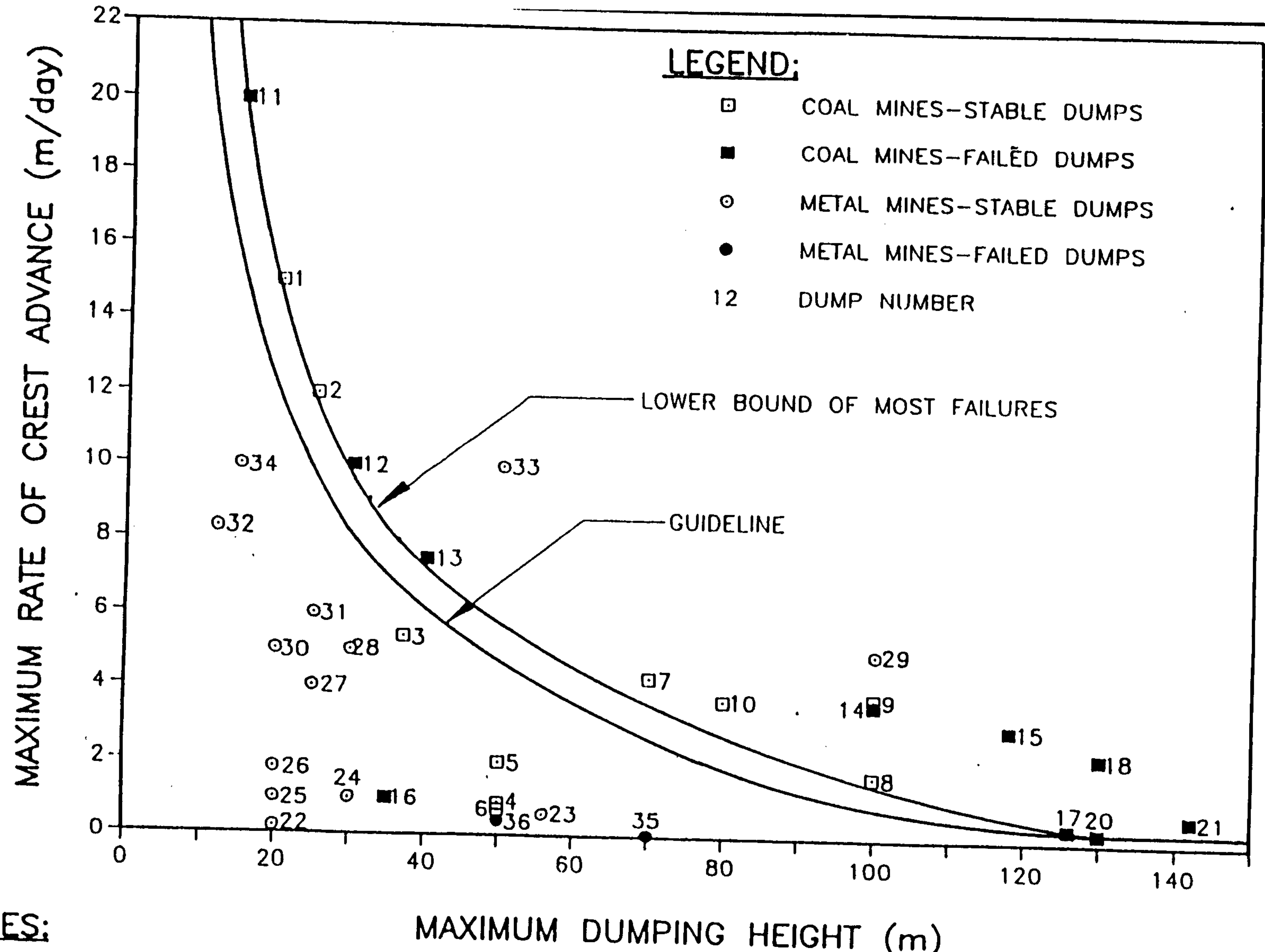
  If dumping is carried out at high rates, the dump material may not have adequate time to develop a sufficiently dense condition and consequent strengthening to withstand the increasing shear stresses that develop in the slope. With some materials this factor may contribute to failures associated with high rates of crest advance.

- **Dump Height** - For a given rate of crest advance (ft/day), a higher dump involves a greater rate of material placement. Hence, the stress increase and the rate of change of stress in both the foundation and dump material are higher.

Dumping is described in terms of volume dumped per linear ft of crest per day (ft^3/ft/day) or in meters per day (ft/day) of crest advance. Generally, ft/day of crest advance is a more useful figure and should be adopted as the reported value.

Figure 5.3 is a plot of crest rate advance (ft/day) versus maximum dumping height for dumps in British Columbia. There is no obvious separation of stable and unstable dumps. However, it is possible to draw a curve (labelled "lower bound of most failures") such that most (all but three whose causes can be attributed to other extreme conditions) failed dumps fall above and most stable dumps fall below the line.

As a guideline for new mines or dumps with no performance history, the initial relationship of dumping rates and dump height should be governed by the second curve, labelled "guideline" on Figure 5.3 (Klohn Leonoff, 1991). This curve has been offset from the lower bound curve to offer a degree of extra safety. As more data becomes available, it may be possible to revise the criteria on proven performance.



NOTES:

16. FAILURE DUE TO WET MATERIAL, NO TOE SUPPORT AND POSSIBLE SNOW ON FOUNDATION.
35. FOUNDATION FAILURE IN RAPIDLY LOADED, NORMALLY CONSOLIDATED, MARINE CLAY (MARINE DUMP).
36. REACTIVATION OF OLD LANDSLIDE. HIGH PORE PRESSURES IN FOUNDATION.

Figure 5.3 Plot of Crest Rate Advance vs. Dumping Height (After Klohn Leonoff, 1991)

5.4.8 Seismicity and Dynamic Stability

The possible effects of earthquakes on the stability of mine dumps is discussed by Glass (1981) and Caldwell and Moss (1981). Generally, deep seated or overall stability is the primary concern, however surficial sloughing is important where dumps are covered or have seepage collection facilities for control of ARD. Liquefaction of susceptible foundation materials is important, however, saturated fine grained dump materials may also be subject to liquefaction. Dynamic ground motions induced by nearby blasting associated with mining can also affect dump stability, although the work done by Stuckert et. al. (1989) suggests that blasting is unlikely to be a significant factor in dump stability, except possibly in the case of liquefaction. The magnitude of surface creep should be evaluated with dynamic analysis techniques such as Newmark (1965).

Some of the measures to achieve long-term physical stability and closure objectives include:

- Siting dumps to avoid low strength foundations or removal of these materials prior to construction.

- Dump construction using lifts and providing adequate terraces to reduce rehabilitation costs (Golder Associates, 1986 and Norecol, 1986).

- Constructing the rock and overburden dumps with a high permeability foundation layer to prevent build-up of pore pressures. This may be achieved by either end dumping to achieve gradation sorting and placing a coarse base zone or pre-construction of underdrains. These methods may not be effective for soils or materials that degrade with time unless the drains include filters to prevent blocking by fines.

- Construction of toe berms to reduce the overall slope of the dump.

- Slope flattening by dozing down the crest. This option can be very costly for large dumps.

Measures to achieve the closure objectives pertaining to surface slumping include:

- Slope flattening as described in Section 6.0

- Construction of covers and soil layers with appropriate underdrainage and vegetation.

Control technology to achieve closure objectives relating to erosion include:

- Contouring of the upper surfaces of dumps to enhance runoff and installing ditches with appropriate rip-rap erosion protection to drain runoff from the dumps.

- Developing vegetation or constructing rip-rap covers to control both wind and water erosion from surfaces.

Where erosion cannot be controlled due to technical or economic factors, provision should be made for runoff collection and sediment removal in settling ponds prior to release to the environment. The long-term maintenance and operation of the sediment ponds need to be addressed.

COMMENT

Seismic stability may be a major concern for developments in southeast Alaska. Sites with soft foundations, dumps which contain appreciable fines, or dumps where a water table can develop are all conducive to failure during a seismic event. Stability analyses should be conducted for such sites using 500 year or greater return period seismic event, depending on the potential impacts. Runout distance estimates may be required in special cases. Where dumps are to be constructed of hard durable rock on a competent foundation and without the development of a water table then stability analyses for seismic events should be conducted using displacement methods such as that developed by Newmark, 1965. In these cases deformation during a seismic event is usually limited and measures to improve stability are not warranted.

5.5 Options For Control Of Chemical Stability

5.5.1 Introduction

The objective of control technology for chemical stability is to develop the control necessary to achieve environmental objectives using the most cost effective technique. There are at present three generally accepted stages in control, as described by Barton-Bridges and Robertson (1989), and in the Draft Acid Rock Drainage Technical Guide (SRK 1989):

1. Control of generation of the contaminants which yield unacceptable drainage;
2. Control of contaminant migration; and
3. Collection and treatment of contaminated drainage.

The above three control categories are listed in order of preference. If the reactions creating the contaminants are prevented, there is no risk of the contaminants entering the environment. Where the reactions cannot be prevented, control of contaminant migration should be implemented. If neither of these control measures are in effect, it is necessary to collect and treat the drainage. Clearly, the least risk of environmental impact exists if the contaminants are never generated. The greatest risk results when there is a continuous and long-term need to operate and maintain collection and treatment systems. A combination of control measures from one or more of these categories may be necessary to provide adequate control.

Control technology for chemical stability includes both prevention and abatement techniques. Prevention refers to measures designed before mining starts and with the intent of preventing contaminated drainage from developing. Abatement refers to measures implemented either at facilities where contaminated drainage is occurring which was not anticipated, or at facilities where control measures are not sufficiently effective, in order to reduce the potential environmental impacts.

5.5.2 Control of Acid Generation

The objective of acid generation control is to limit the formation of acid at the source by inhibiting sulphide oxidation. The available control measures are summarized in the Draft Acid Rock Drainage Technical Guide (SRK 1989), and Table 5.1.

TABLE 5.1

Summary of Available Acid Generation Control Measures

Objective of Control	Control Measure	References
Sulphide removal or isolation	• Conditioning of waste	Broman, 1988 Hester & Associates, 1984 Knight & Haile, 1983 Steffen Robertson & Kirsten, 1987(b)
Exclusion of water	• Covers and seals	as below
Exclusion of oxygen	• Subaqueous deposition	Nolan, Davis & Associates, 1987 Steffen Robertson & Kirsten, 1988(c) Ladwig et al, 1984 Pedersen, 1983 Errington & Ferguson, 1987 Hallam et al, 1974 Daly et al, 1981
	• Covers and seals	Steffen Robertson & Kirsten, 1988(c) NTDME, 1986 Magnusson & Rasmuson, 1983
pH control	• Waste segregation & blending	Sturm, 1987 Milner, 1987
	• Base additives	Morin and Cherry, 1986 Dubrovsky, 1986 Helz et al, 1987 City Resources, 1988
Control of bacterial action	• Bactericides	Kleinmann & Erickson, 1983 Sobek, 1987

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

1. An essential first step in achieving control of acid generation is a thorough prediction program so that all potential problem materials are identified. Appropriate ARD sampling, testing and prediction methods are described in Section 5.1 and the Draft Acid Rock Drainage Technical Guide (SRK 1989).

2. 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 at excluding one or more of the principal ingredients in the acid generation reactions.

3. The exclusion of oxygen from reactive wastes by means of a water cover is currently considered to be one of the most effective acid generation control measure. Water cover (underwater disposal or a saturated soil/bog cover) for preventing acid generation should be evaluated for any closure plan. Care should be exercised when considering flooding existing waste deposits due to potential flushing of high loads of soluble oxidation products within the waste.

4. Complex soil covers and caps with geomembranes which prevent oxygen entry show promise as inhibitors of acid generation provided these are maintained in good order as designed. To achieve sufficiently low rates of oxygen transport through complex soil covers generally requires a saturated layer or perched water table in the cover. Provision for long-term maintenance of covers is usually required.

5. Construction methods such as blending of rock waste or segregation, such as separating high sulphide rock from non-acid generating rock, etc., should be considered for proposed facilities. However, the intimacy, variability and reliability of blending or separation are concerns, and additional control measures are likely to be required.

6. Control of the acid generation process for abatement of ARD at existing facilities does not remove need for the control of acid products already in storage in the waste. In these cases, acid generation control techniques could be used to stop or reduce the rate of future acid generation in conjunction with control of existing acid product migration and, if necessary, collection and treatment of ARD.

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, are difficult to apply

effectively, and, at best, control only the biological oxidation processes and not chemical oxidation of sulphides.

8. 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 where limestone or other alkaline strata occur in the overburden. This method has been successfully used in the coal mining industry. The adequate blending of alkaline materials with coarse hard rock waste may require crushing and intimate blending and adequate appropriate laboratory or field trials to demonstrate its effectiveness.

In addition to the above general points regarding ARD control, Alaskan conditions including sub-zero temperatures and permafrost can influence the control of acid generation. This may include the following:

- if the voids are filled or partially filled with water and frozen, then the infiltration of oxygen is reduced;
- within permafrost, there is essentially no water movement, which provides control of migration;
- at low temperatures, both chemical and biological oxidation rates are reduced, which may reduce the loading of oxidation products in an effluent stream;
- measures such as coarse rock covers which trap cold air can be used to induce permafrost; and
- there is a zone of surface thawing which should contain non-acid generating material where sub-zero temperatures are relied upon for control of acid generation or migration.

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.

5.5.3 Underwater Disposal of Rock

The only two cases where mine rock has been placed underwater are as follows:

- Island Copper Mine on Vancouver Island in British Columbia has been dumping mine rock into Rupert Inlet since 1971. Activities at this site are not directly applicable to this manual because the rock was dumped into a natural water body from a single advancing crest. For the durable waste rock at Island Copper, the dump slope angles both above and below water are about 34°.

- Skorovos Mine in Norway has completed removal of an oxidized rock pile to a nearby lake.

As noted earlier, disposal of mine waste into natural water bodies is unlikely to be acceptable and therefore, the above examples are not directly applicable to waste disposal in Alaska. Consequently, most of the contents of this section are based on current methods for development of on-land rock piles, and conceptual plans for underwater placement of mine rock in impoundments or in a tailings pond for proposed mines.

Rock placement into water can generally be carried out by one or two methods; dumping from trucks and spreading with dozers, or barge dumping. Conveyor discharge into a tailings impoundment using mobile stackers was evaluated for an operation in British Columbia involving up to 60 million tons of rock and was found to be too costly. The capital cost of this method makes it even less viable for smaller operations.

It is expected that for most sites, rock placement into an impoundment will be in multiple lifts rather than dumped from a single crest which advances into the impoundment. The basis for this is that economics generally dictate that the embankments be raised gradually over the mine life and the upper portion of the placed rock would not be submerged until late in the mine life if a single life were developed.

Placement of mine rock in a tailings impoundment is essentially the same as the construction an on-land dump for mine rock, except for two important differences. Placement of mine rock in a tailings impoundment will result in a rock pile which is partially submerged and consequently the side slopes of the pile will have a lower factor of safety against failure than if the pile were not submerged. The second difference is that the process of dozing rock off the crest into the water will result in an increased sediment load in the water. This sediment load may effect the ability to release surplus water from the impoundment during operation.

Some aspects of waste disposal which may be considered in developing plans for underwater placement of rock are as follows:

- There may be a cost savings if the mine rock can be used in the upstream section of embankments.

- Stability may be improved by constructing the pile with a terraced configuration.

- The thickness of each lift of mine rock should be roughly equal to the increase in pond elevation in the year which the rock is placed. For most sites this will result in a small dump area with thick lifts initially and a large dump area with thin lifts towards the end of the mine life.

- In cases where it may be difficult to submerge the mine rock before the onset of ARD then it may be delayed by adding a small amount of alkaline material, such as crushed limestone, to the rock. Some guidance on testing to determine the amount of alkaline material to add and methods for addition of crushed limestone can be found in City Resources June 1988, March 1989, and August 1989.

- Where rock is dumped into tailings or placed in lifts over tailings, it is possible that slumping of the crest area of the dump will occur. In this case dump monitoring may be necessary to ensure the safety of trucks. It may be necessary to dump the rock some distance back from the crest area, say 50 ft, and push it to the edge with dozers.

- Placement of oxidized rock in a tailings impoundment may result in poor water quality and the requirement for water treatment. Experience in Norway has shown that layering wastes with alkali materials can limit the release of stored oxidation products. The details of this work, such as degree of mixing and ratio of added neutralization to mine rock, are being investigated by the B.C. AMD Task Force and is expected to be available in 1992.

COMMENT

Disposal of rock underwater in an impoundment will require that design, operation and decommissioning of the facility be conducted consistent with the approach for surface impoundments, as per Strawman II, subpart D. These aspects are addressed in the report "RCRA Regulation Impact On Alaska Mineral Development - Tailings Management". Furthermore, because there is limited precedent on underwater disposal of rock, any such plans should be based on conservative criteria for physical and chemical stability, and operational logistics.

5.5.4 Control of ARD Migration

Where acid generation is not prevented, the next level of control is to prevent or reduce the migration of ARD to the environment. Since water is the transport medium for contaminants, the control technology relies on the prevention of water entry to the dump. Control of water exit is of little value since in the long-term all water entering the dump must exit, long-term storage being negligible. Water entry may be controlled by:

- Diversion of all surface water flowing towards the dump;

- Prevention or interception of groundwater flow into the dump;

- Prevention of infiltration of precipitation with covers and caps on the dump;

- Controlled placement of acid generating waste to minimize infiltration.

The conclusions that can be drawn regarding current technology for control of ARD migration may be summarized as follows:

1. Diversion of surface water is best achieved during operation (short term) by means of diversion ditches or berms. For the long-term, appropriate site selection to avoid drainage channels and to minimize contact with surface water runoff is the most cost effective design measure. If necessary, ditches, berms and other structures may be used in the long-term, however, a certain level of ongoing inspection and maintenance will be required.

2. Interception of groundwater by means of ditches, wells and pumps may be suitable in the short term only. Impermeable cut-off walls and gravity drains may be suitable in the long-term but may require on-going monitoring and maintenance.

3. Infiltration control is essential for controlling ARD migration. This is best achieved by means of complex covers constructed with soils and/or synthetic materials or a combination of these.

   - Single layer soil covers may not reduce infiltration sufficiently for migration control purposes. Soil structure modification with time as a result of frost and root action, burrowing animals, settlement and erosion may increase hydraulic conductivity and infiltration with time.

   - Complex, multiple soil layers, possibly in combination with synthetic membranes, may be required to control both infiltration and surface erosion. The design of soil covers must consider cost, the degree of infiltration control required, the requirements for revegetation, long-term disruptive forces and maintenance requirements.

   - Synthetic membrane liners are most suitable in the short term to cover, for example, temporary stockpiles.

   All types of covers require some form of long-term monitoring and maintenance. Factors which should be considered in cover design are: erosion, desiccation, frost and root action, burrowing animals, settlement, disruption by uprooted trees or human activity, and capillary rise and root uptake of metals.

4. Methods of placing waste rock to minimize infiltration should be considered as part of planning waste management operations, in conjunction with other control methods.

5.5.5 Collection and Treatment of ARD

5.5.5.1 Introduction

Collection and treatment of ARD is to date the most widely applied ARD control measure. This is largely due to the fact that at many existing operations, where ARD was not anticipated or adequately controlled, collection and treatment is the only practical option available.

Collection systems may be required to recover both surface waters and groundwater contaminated by ARD. Collection of surface flows is usually fairly readily achieved by means of surface ditches. The collection of subsurface flows requires the installation of collection trenches, wells, or cut-off walls to force groundwater flow to the surface where it can be collected. Most collection systems require long-term maintenance.

Treatment measures may be classified as either active systems that require continuous operation, such as a chemical treatment plant, or passive systems that are intended to function with only occasional intervention by man, such as a wetland or an alkaline trench.

The objective of acid rock drainage treatment is to eliminate acidity, precipitate heavy metals and remove deleterious substances such as suspended solids, arsenate and antimonate.

5.5.5.2 Chemical Treatment

Chemical treatment involves technology which is well established and is working effectively at a number of mines. Details on water treatment for ARD can be found in a number of references (Mine & Mill Waste Water Treatment - EPS 1987, and Tailings Management, Ritcey, 1989).

Acidity, present as sulphuric acid in acidic rock drainage, is eliminated by neutralization with an alkali, primarily ground limestone (calcium carbonate, $CaCO_3$) and/or hydrated lime ($Ca(OH)_2$). Limestone is a cheaper reagent but has a number of limitations, mainly its inability to raise the pH to the level required for effective precipitation of some metals. It may be used in conjunction with hydrated lime in some cases. Lime can be supplied in two different forms, quicklime and hydrated lime. Quicklime is the product of the calcination of limestone, and consists primarily of the oxides of calcium and magnesium, while hydrated lime is a dry powder obtained by combining quicklime with a stoichiometric quantity of water to form hydroxide. Quicklime is generally hydrated prior to use.

Heavy metal ions hydrolyse and precipitate as their respective hydroxides during neutralization while anions such as arsenate and antimonate form insoluble compounds at neutral pH with many of the heavy metals (notably iron) present. Each species has an optimum pH (level of neutralization) for its removal.

During neutralization, the slurry is commonly aerated to oxidize any ferrous iron present to ferric iron and to precipitate ferric hydroxide.

The primary by-product of ARD neutralization using either limestone or lime is gypsum ($CaSO_4.2H_2O$), produced largely as a precipitate. Gypsum commonly forms scale on tanks and in piping which can require acid treatment and mechanical removal. Descaling can be a frequent high maintenance cost item where low pH ARD is being treated. It may also result in the unreliable performance of instruments used to automate plant operation. Proper design can reduce the severity of some scaling problems. Financial assurance for funding long-term chemical treatment must provide for the operating, maintenance and replacement costs and address long-term operating risks.

Other potential treatment processes which can be used prior to the neutralization circuit are primarily intended for metal recovery and may include carbon absorption, ion exchange or solvent extraction. Biological treatment using sulphate reduction is being investigated as an alternative treatment process for some sites.

Sludge Characteristics

Sludges resulting from neutralization of ARD can contain gypsum, heavy metal hydroxides, heavy metal arsenates, calcium arsenate, and heavy metal sulphides. Stability is gauged by the potential for various components of the sludge to re-enter the environment. ARD treatment sludges may be unstable if exposed to air or slightly acidic water movement over an extended time period. (Note that slightly acidic water may drain from the wetlands which are common in southeast Alaska.) Protective alkalinity in the form of excess lime and careful selection of the disposal site to avoid acidic leaching can enhance long-term stability. Leaching prediction tests such as SW-846 or specifically EPA 1312 should be conducted to classify sludges for waste disposal (see Section 5.1.2.2).

Sludges containing calcium arsenate in contact with carbon dioxide, bicarbonate, or carbonate can break down releasing arsenate ion. Alternatives resulting in precipitation of arsenic as ferric arsenates are preferred for long-term stability. Sludges containing sulphide precipitates must be given careful consideration due to the possibility of acid generation occurring in the sludge with time after consumption of the available neutralization potential.

5.5.5.3 Wetland and Other Treatments

Wetlands such as bogs, marshes, and swamps show promise in being able to provide final or polishing treatment of acid rock drainage and other wastewaters. Research to date has shown that the ability of wetland systems to treat wastewaters is dependent on water flow distribution, above and below ground, and residence time. These factors are more easily controlled in constructed rather than natural wetlands. The principal advantage of wetland systems is that they have the potential to be self-sustaining with low operational and maintenance costs. The main disadvantage of wetland systems is that their effectiveness has yet to be demonstrated in the field, particularly in the long-term. Factors which should be addressed in wetland evaluation are: winter operation, mean and peak flows, retention time, length to width ratio, and maximum water depth. Generally, retention time should not be less than 1 day under peak flow at a maximum water depth of 1 ft. Length to width ratios in the order of 10:1 or greater are favorable.

The use of wetlands for treatment of acid mine drainage is discussed in Girts and Kleinman, (1986). Wetlands may not be a viable treatment option for most of Alaska because of the short growing season and low temperature. It is, however, a potentially viable treatment option in southeast Alaska where conditions are well suited to the development of wetlands.

5.5.5.4 Alkaline Trenches

Alkaline materials placed in trenches constructed downstream of ARD sources are quickly coated, and clogged by insoluble precipitates such as gypsum, and have been found to be ineffective in the medium or long-term. They may be beneficial in the treatment of near neutral pH drainage when used at the inlet to a wetland.

COMMENT

Chemical treatment may be required at some mine sites and is usually acceptable during operation. One of the goals of the Strawman II is to achieve a low maintenance closure condition. At some sites it may be acceptable to provide for collection and treatment of ARD for a short period after operations cease, probably not more than ten years. However, perpetual treatment using a treatment plant does not achieve the Strawman II goals. Perpetual treatment using a wetland system may be acceptable, however, long-term performance of wetland systems is not known.

6.0 CLOSURE AND POST-CLOSURE CARE

6.1 Physical Stability

6.1.1 Slope Flattening

Most mine dumps are developed by end-dumping, resulting in intermediate slope angles equal to the angle of repose, or generally about 37°. Flattening of slopes to an overall slope angle of 26° is generally accepted as a suitable criterion for revegetation. However, steeper slopes have been successfully revegetated at some British Columbia mines. At 26° or flatter, water erosion will be limited, soil creep is reduced, and infiltration is enhanced.

Bulldozing material down from the crest in a balanced cut-to-fill is the method most often used to re-slope rock dumps. Practical aspects of slope flattening are discussed by Golder Associates (1986). The amount of material required to be bulldozed is proportional to the cube of the slope height. This results in a significant effort required to flatten high slopes built at the angle of repose.

To minimize material rehandling, it is desirable to develop dumps in lifts with intermediate berms or with wrap-arounds. The economics of this will depend on the mining geometry and sequencing, but should be considered whenever possible in the planning stage.

At many sites, the benefits of establishing vegetation on rock piles will not justify the effort required. However, the following factors may necessitate resloping.

1) The rock may be prone to slaking or strength reduction and the end of mining dump geometry should be developed in recognition of the long-term rock strength and phreatic conditions in the dump. Most waste materials, as well as dump foundations, will show increased stability with time. The critical time for development of sliding will be during dump construction, when high pore-water pressure is created by active loading. After completion, when pressures dissipate, the dump becomes safer. In these cases resloping may not be required.

2) If covers are required to control entry of water or oxygen for chemical concerns, then the dump may need to be re-sloped so that long-term stability of the covers can be achieved.

Reclamation of waste dumps is dependent on the land use selected for the dump area. Selection of end land uses may be constrained by the ability to establish a suitable vegetation cover, hence, selection of a revegetation prescription for a waste area must be developed in concert with the development of final land use objectives.

When open pit mining is carried out in mountainous terrain, wrap-around benches are commonly developed on dump faces to reduce the vertical difference in elevation between the level in the open pit where the waste rock is generated, and the level of waste rock disposal. Wrap-around benches also have the effect of reducing the overall inclination of a dump face and hence improving overall stability. Wrap-around benches on a dump face also result in a very significant reduction in the dump resloping costs.

If the width of wrap-around benches is such that a berm remains after resloping has been completed, these remaining berms will continue to serve as access ways for equipment, and can be of aid in establishing the revegatative cover on the slope.

Re-Sloping Over Rock Drains

Coal mine operators in eastern British Columbia are making extensive use of "flow-through" rock drains to carry surface drainage beneath dumps at locations where dumps cross drainage courses. This technique is well suited to development in mountainous areas such as southeastern Alaska. Surface flows are conducted through the void spaces between the coarse rock fragments comprising the rock drain.

Dump resloping operations result in transfer of the finer fraction of the waste rock from the upper to the lower region of the dump, see segregation effects in Section 5.1.1.1, and rehandling of the material is likely to result in reduction in particle size. Thus, resloping of the dump face above the outlet or the inlet of rock drains will probably reduce hydraulic conductivity at these locations, and impair the performance of the rock drain.

Therefore, resloping of dump faces above the inlet and outlet ends of rock drains should be avoided. Alternatively, if resloping of a dump face above the inlet or outlet ends of a rock drain is deemed to be imperative, the rock drain should be extended beyond the limit of the resloped toe before resloping commences. Placement of suitably graded filter zones may also be required over the zone of coarse rock fragments comprising the drain extension to preclude entry of finer grained waste dump material in the region of the resloped face.

Permafrost

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

Stepanek (1986), describes examples of waste dumps or embankments sited on permafrost that have undergone deep seated failures. These failures have occurred because of thawing and loss of shear strength, and possible development of excess pore pressure due to the development of a frozen "shell" on dumps. Progressive failure occurring over several years has been observed. Problems such as these occur mostly in dumps composed of finer grain size material or where the dump has caused thawing of the foundation. In permafrost regions these issues should be evaluated and where stability concerns exist, dumps should be developed with flatter slopes.

Seismic Stability

Measures to improve seismic stability to meet decommissioning objectives are described in Section 5.4.8.

6.1.2 Chemical Stability

ARD is the most common and usually most serious chemical stability issue for waste dumps. The control technologies which may be used are summarized in Table 5.1. Currently, underwater disposal is the favored control method because of its effectiveness of controlling ARD, and is described further in Section 5.5.3. Other control methods such as control of ARD migration with covers or seals may be used. Covers and seals are described further in Section 6.3. Collection and treatment of ARD is generally the least desirable method and should be avoided wherever possible. Collection and treatment of ARD is described in Section 5.5.5.

6.2 Design of Covers

6.2.1 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. 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.

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.

6.2.2 Soil Covers

Although soil covers 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 et. al., 1989, and is summarized in Sections 6.2.2.2 and 6.2.2.3.

6.2.2.1 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.

Comparing sand, loam and clay soils, it is observed 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 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 infiltration rate, such as the: texture and degree of soil compaction, slope texture and irregularity (and the resulting ponding), and duration and intensity of rainfall. Prediction of infiltration rates through uniform soils is therefore extremely complex. Cracks, root holes, burrows and soil variability make 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 Waterways Experiment Station with funding by the U.S. EPA. It 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 illustrated in Figure 6.1. The HELP model assumes saturated soil conditions at the commencement of precipitation. Clearly this is an approximation which may lead 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 model 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 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 (for construction materials),
- frost action effecting permeability and drainage,
- erosion,
- disruption of drainage by vegetation,
- clogging of drains due to frost or root action.

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

6.2.2.2 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 mainly a function of the climate but is likely to be not less than 3 ft, and up to 6 ft for regions such as southeast Alaska.

- 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 drawn 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.

6.2.2.3 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 6.1.

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). Their study incorporated field testing of these different methods and costs for the various stabilization procedures.

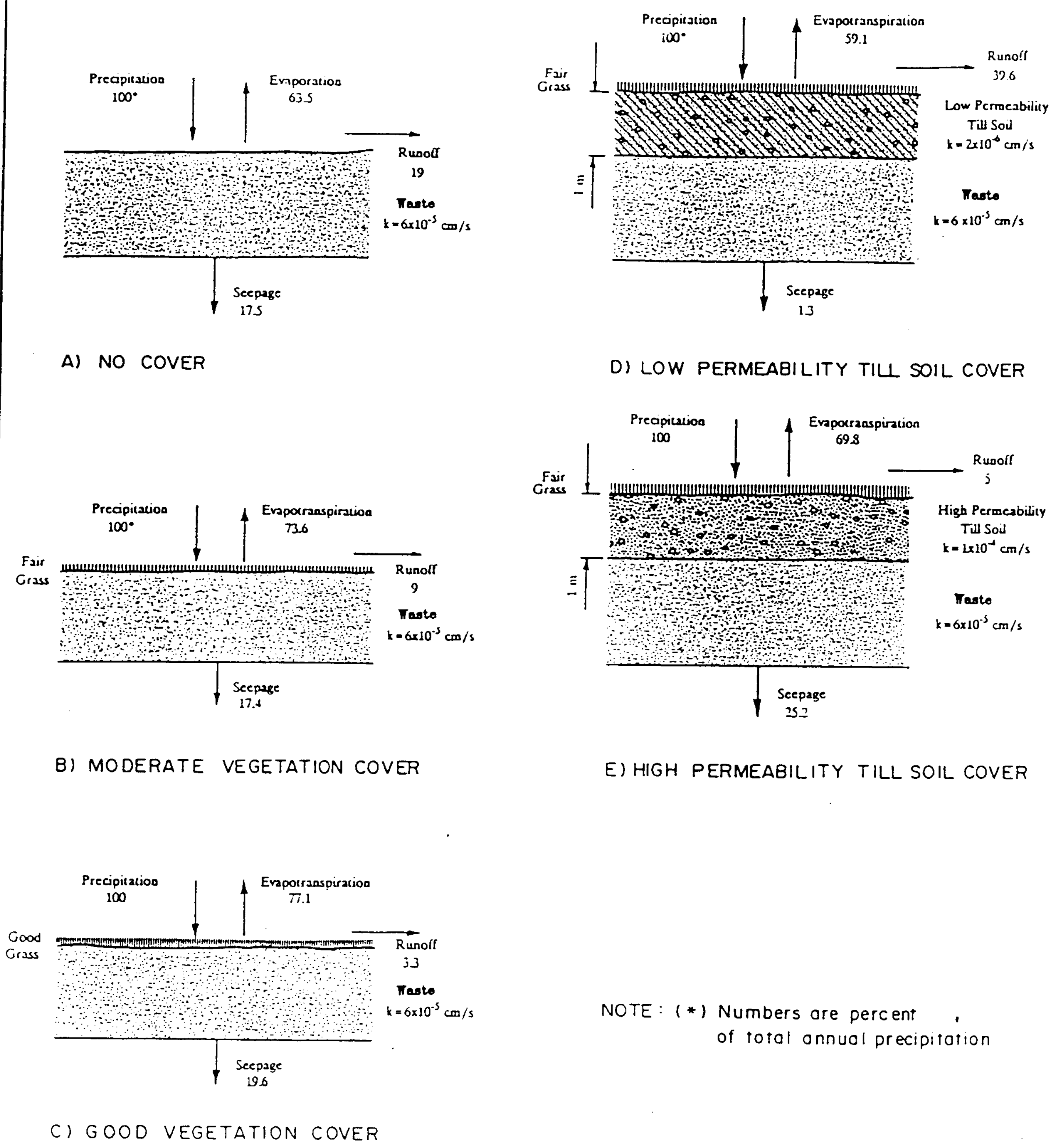


Figure 6.1 Effect of Cover Type on Infiltration Rate (After Steffen Robertson and Kirsten, 1988b)

Moisture Retention Zone

The purpose 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. This helps prevent desiccation cracking and reduces oxygen diffusion.

ii) By retaining moisture after a precipitation event, it helps support 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.

Upper Drainage/Suction Break Layer

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

i) It drains water laterally from the surface of the infiltration barrier, preventing ponding.
ii) It prevents moisture loss from the infiltration barrier due to upward capillary suction.

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 objectives of this layer are to provide a sufficient barrier to enable the overlying coarse-grained layer to drain infiltrated water and prevent ponding of water.

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.

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 through the infiltration barrier 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.

Soil covers have been placed at three mines in B.C. and are the proposed control measures at a number of other mines (Steffen Robertson and Kirsten, 1988a). While the placed covers appear to be effective to date, the period of monitoring is considered too short for valid conclusions. A till cover has been placed over waste dumps at the abandoned Mt. Washington mine on Vancouver Island. Instrumentation will be installed to monitor oxygen levels, temperature and infiltration of precipitation. Construction of the cover was completed in 1990. Monitoring of this facility indicates that cycles of wetting and drying by groundwater at the base of the dump can significantly influence drainage water quality and construction of low permeability covers may not be sufficient to control ARD (Kwong, Y., 1991).

The change in infiltration into a waste dump in B.C. was evaluated using the HELP model. The results of modelling are presented in Table 6.1. The results show that the only parameter which has a significant effect on the infiltration to the dump is the hydraulic conductivity of the cover. Line 1 in Table 6.1 represents the current condition of an uncompacted till cover. If the entire till cover was compacted to decrease the hydraulic conductivity from this level to $1x10^{-5}$ cm/s, infiltration into the dump may be reduced by approximately 50%. If the hydraulic conductivity could be reduced to $1x10^{-6}$ cm/s, infiltration may be reduced by 90%. Once compaction is achieved, the cover is vulnerable to cracking and loosening as a result of dump consolidation, frost and root action, gully erosion and burrowing. These effects are expected to increase the effective permeability of the cover with time.

It is unlikely that a hydraulic conductivity of the cover as low as $1x10^{-6}$ cm/s could be achieved in the long-term. Therefore, it is unlikely that any combination of cover compacting, recontouring, and vegetation will reduce the volume of dump effluent to very low levels. Line 5 in Table 6.1 may well represent the maximum realistic reduction in infiltration with a simple cover.

TABLE 6.1

Waste Dump Infiltration Estimates
Simple Cover

Waste Dump Parameters				Results, as Percentage of Precipitation			
Cover Thickness cm	Cover Hyd. Cond. cm/s	scs[1] curve number	Vegetation	Runoff	Evap.	Infiltration	Groundwater
50	$1x10^{-4}$	10	none	2	52	43	<1
50	$1x10^{-5}$	10	none	34	45	20	<1
100	$1x10^{-5}$	10	none	34	45	19	<1
50	$1x10^{-5}$	60	none	34	46	19	<1
50	$1x10^{-5}$	60	poor grass	32	49	19	<1
50	$1x10^{-6}$	10	none	63	32	5	<1

1. SCS = Soil Conservation Service

COMMENT

The Strawman II does not contain specific comments on re-vegetation and land use because the EPA wants to avoid duplication the reclamation requirements of Federal land managers and State mine reclamation programs. The guidelines in the following sections should be read as supplemental to Alaska *mine reclamation practices. They are brought out in detail here because long-term physical stability often depends on the establishment of self-sustaining vegetation.*

6.3 Revegetation

6.3.1 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 introduced 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 (Larkin, 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 mean daily minimum of 20°F (-7°C) in winter and a mean daily 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. Their 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 develop 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 mountains in other parts of the state. Dense stands of hemlock (Tsuga sp.) and spruce (Picea sp.) grow naturally on these mountain slopes and commercial forestry is 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 in the 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.

6.3.2 Rehabilitation Aims and Objectives

The principal aim of a rehabilitation program 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 program is 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 waste rock 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 program.

6.3.3 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 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 6 ft in height if practically possible, as a higher profile will lead to compaction, anaerobic conditions in the centre 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 12 inches of topsoil are required. This should be ripped to 4 inches 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 to 5 years. 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 such that surface capping and capillary blocking layers, as described in Section 6.2.2.3, may be required.

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 include:

- 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 4H:1V, 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 may also contain cellulose fibres 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 hyroseed 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 about 300 feet 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 1.5H:1V is difficult. The range of commercial species which can be planted should be limited to indigenous trees.

6.4 Maintenance

Many reclamation programs have a program of reclamation maintenance associated with them. Maintenance of reclaimed areas is carried out to identify and correct problems which, if left unchecked, could threaten the success of the reclamation work conducted. Most maintenance programs seek to identify problems of excessive erosion, poor vegetation establishment and growth, lack of nutrients, and stability problems prior to becoming major problems. Maintenance of reclaimed sites is specific to both the site and the reclamation problem for which a remedy is sought.

In general, revegetation on steep slopes will require greater maintenance in the form of repair of erosion damage, and minor slope instabilities, and additional fertilization than would be required on flatter ground.

Development of productive forests is dependent on the availability of forest nutrient, moisture and an amenable climate. In addition, slopes must be stable.

Slopes to be reclaimed for reforestation should be between 3 and 35 percent (20°). Slopes flatter than 3 percent impede drainage required for optimum tree growth, hence the need for some slope to the land, and above 36 percent, difficulties are experienced in the planting of the trees. However, industrial disturbances with slopes in excess of 33° are being successfully reforested (Polster, 1986). In general, the physical stability of the surface of the slope is the key element to successfully establish vegetation. Slopes which are continually ravelling will not allow development of healthy trees. Downslope creep of the surface material can hinder seedling survival and may result in the development of tree stems which are curved, and of unequal diameter growth.

A mine adjacent to a fish bearing stream should aim to control sediment release while sediment control may not be important for a mine which is distant from such a stream. It should be noted that flattening of waste dump slopes will not always reduce the hazard for sedimentation. Alternatively, vegetation or other controls may be required. The appearance of the waste dumps may be an important criterion in certain circumstances. Appearance may be important where the mine is located in a highly used recreation area or near a population center.

7.0 MONITORING REQUIREMENTS

7.1 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 waste rock dump 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 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, 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 of years without periodic inspection and maintenance. Therefore, for critical facilities such as 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.*

7.2 Monitoring for Physical Stability

When a waste dump 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 dump slopes. Instrumentation, such as piezometers or settlement gauges, are commonly used for critical facilities. 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 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, and in determining temperatures to be used for laboratory testing of samples.

7.3 Monitoring for Chemical Stability

Monitoring for chemical instability consists of two parts: monitoring for leachate generation and monitoring for leachate migration. RCRA monitoring requirements include the use of up-gradient and down-gradient sampling points and these may be in addition to sampling points within a regulated unit. In cases where ongoing treatment is required, 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 piezometers, 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.

7.4 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 waste facility 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.

8.0 GENERIC CASE STUDIES

8.1 Introduction

To illustrate the potential impact of proposed RCRA regulations on waste rock management practices in Alaska, two generic case studies have been prepared. The first study typifies conditions characteristic of northern or arctic Alaska, while the second study typifies those of southeastern Alaska. For each of the two case studies, a general description of the project is provided, followed by a base case waste rock management plan and a cost estimate for that base case plan. The base case plan represents current engineering practices applicable in the respective regions of Alaska. The base case plan is followed by examples of change or additions to the plan that might be required if sections of Strawman II were to be rigidly interpreted and applied such as for meeting groundwater performance standards. Estimates of the incremental costs associated with the changes to the base case waste rock management plan are presented.

8.2 Case 1 - Northern Alaska, Waste Rock Management

8.2.1 Project Description

A generic base metals mine is located in rolling mountainous terrain in northern Alaska. Snow can be expected at any time of the year and will generally cover the ground from October to May in most years. The mean annual temperature is 18°F. Mean annual precipitation is between 20 and 30 inches which is partially influenced by its near coastal location. The maximum earthquake anticipated in a 500 year recurrence period is expected to produce a maximum horizontal bedrock acceleration of .11g. Permafrost is wide-spread, except on south-facing slopes.

A major creek runs through the centre of the proposed pit, and will be temporarily diverted around the pit during mining.

The open pit mine produces 3000 tons per day of ore, with reserves of 6,000,000 tons. Over its seven-year mine life, the mine will produce 5 million tons of waste rock (4.5 million tons of mudstone and 0.5 million tons of pyritic rock) and 4 million tons of overburden. The overburden consists primarily of glacial till (a well-graded mixture of clayey silt, sand and gravel). Both the mudstone and the pyritic rock are potentially acid generating. However, while the pyritic rock is highly acid generating, the acid generation potential of the mudstone is considerably lower. The primary concern in the waste rock management plan is to limit acid generation in the rock and subsequent release of heavy metals to receiving waters.

8.2.2 Base Case Waste Rock Management Plan

A number of different dump scenarios were investigated in the design phase. The first and least expensive option was to construct a dump in the creek valley on the downstream side of the pit. This was discarded when the acid generating nature of the rock was realized. The option also required maintaining a permanent diversion of the existing creek around the dump. As the valley slopes show signs of instability due to permafrost, maintaining this diversion was not considered practical.

Other alternative scenarios considered included the following:

- constructing an embankment across the valley below the pit to form a permanent impoundment, and placing all waste rock under a water cover within the impoundment;

- rehandling the waste rock back into the open pit, and constructing an embankment around the crest of the pit to maintain a water cover over the rock (The relatively shallow open-pit is located on a hillside, providing little capacity for waste rock storage without additional embankments), and

- segregation of the waste for disposal in till-covered cells.

These scenarios were evaluated on the basis of effectiveness (as predicted from water quality modelling), cost, and risk of failure. While establishing a water cover over the waste rock provides the best protection against acid generation, the alternatives were rejected on the basis of cost and risk of failure associated with the structures required to maintain the water cover. Both the costs and risk of failure of the embankments and their associated spillways are complicated by the presence of permafrost. These scenarios also allow little flexibility in the mine development plan. The construction season available for placing high-quality engineered fill is very short. An unusually short or wet summer could have a severe impact on the mining schedule.

The selected option was to segregate the waste rock and place it in cells within a till-covered dump located on the plateau adjacent to the pit. The cells would be separated by a till dividing berm and encapsulated in till to reduce oxygen transmission and water infiltration. The purpose of segregating the rock types was to prevent drainage from the highly acid-generating pyritic rock from leaching metals and accelerating acid generation in the moderately acid-generating mudstone. Drainage from the dump would be collected by a system of finger drains and collection ditches and treated prior to discharge. Till encapsulation alone would not be sufficient to prevent acid generation completely, and predictive test work indicated that collection and treatment would be required. The primary benefit of the till covers would be to reduce the total amount of drainage requiring treatment (by limiting infiltration). It should also be noted that a treatment facility was required regardless to treat drainage from the open pit during mining. Locating the dump on the plateau avoided construction on the areas of permafrost found in the valleys. The final dump will have a maximum height of 120 feet and a total surface area of approximately 60 acres.

Till berms will be constructed around the perimeter of the dump prior to waste rock placement, and raised as the dump rises. Side slopes will be constructed with an overall slope no steeper than 3 horizontal to 1 vertical. Till in the perimeter berms and dividing dyke will be placed and spread in lifts to achieve a minimum relative density of 90 percent Modified Proctor maximum dry density. A higher level of compaction would require more stringent controls on moisture content and placement methods, which would slow construction and interfere with the mining schedule. Till placement will, nonetheless, be restricted to summer months only to avoid placing frozen material.

Stability analyses indicate that the till berms would be safe against major instability. Under the relatively low design seismic accelerations anticipated for the area, only localized ravelling is expected on the slopes, without jeopardizing their overall stability. Shallow surface slumping during spring frost thaw is expected to pose more of a problem, particularly in the first few years after construction. Some localized repair work is anticipated on the side slope covers both during mine development and in the years immediately following end of mining. The frequency of inspections and repairs is expected to decrease with time, however. Also, as the till is well-graded, it is anticipated to develop a natural armouring of cobbles with time.

At the end of mining a 9-foot thick till cover would be placed over the top of the dump to reduce oxygen transmission and infiltration. the lower 3 feet would provide the main oxygen and infiltration barrier, with the upper 6 feet acting to prevent desiccation, reduce frost penetration, and provide a growth medium for vegetation. As such, the lower 3 feet will be compacted to at least 93 percent Modified Proctor maximum dry density, while the upper 6 feet will be only lightly compacted (to 90 percent Modified Proctor). Prior to cover placement the dump surface would be graded to prevent runoff from flowing over the dump faces. Some deterioration of the cover with time (due to settlement, root penetration, etc.) is anticipated. The resulting reduction in effectiveness was considered in the water quality model used to evaluate the effectiveness of the plan.

Construction costs associated with this case management plan are summarized in Table 8.1.

Table 8.2 summarizes the projected annual treatment costs. Note that without covering the dump the annual treatment cost of $64,000 would continue in perpetuity. Water quality in the dump seepage would be monitored on a regular basis as part of the normal operations of the treatment plant. The costs of this monitoring are included in the annual treatment costs. It is possible that the low temperatures at the site may be more effective at inhibiting acid generation than was anticipated in assessing the need for treatment. Should monitoring show that drainage water quality emanating from the cells is considerably better than predicted it may be possible to limit treatment to drainage from the pyritic rock cell only, or eliminate treatment altogether. The facilities would remain in place, however, as a contingency.

TABLE 8.1

Capital Cost Estimates for Base Case Mine Rock Management Plan, Northern Alaska

DUMP CONSTRUCTION Construction item	Units	Quantity	Unit costs	Cost
Berms and Divider Dyke				
Foundation Preparation	acre	120	$1,500	$180,000
Till Placement (Starter Dam)	yd^3	900,000	$2.00[1]	$1,800,000
Till Placement (Extensions)	yd^2	1,500,000	$2.00[1]	$3,000,000
Dump Cover (lower 1m)				
Till Haul	yd^3	300,000	$1.20	$360,000
Till Placement	yd^3	300,000	$3.00[1]	$900,000
Dump Cover (upper 2m)				
Till Haul	yd^3	600,000	$1.20	$720,000
Till Placement	yd^3	600,000	$2.00[1]	$1,200,000
Rock Drain				
Excavation of Ditch	yd^3	3,000	$2.00	$6,000
Supply & Install Filter and Drains	yd^3	6,000	$5.00	$30,000
Supply & Install Geotextile Filter Fabric	yd^2	10,000	$5.00	$50,000
Supply & Install 60 mil HDPE Membrane	yd^2	250	$20.00	$5,000
Selective Placement of Waste Rock	ton	4,500,000	$0.10	$450,000
Erosion Protection	acre	120	$3,000.00*	$360,000
Collection Ditches and Pond	l.s.			$500,000
Treatment Plant[2]				N/A
Total Cost				$9,561,000

1. This unit cost could be as low as $0.50/yd³ if till placement is incorporated into pit stripping
2. Treatment plant required as part of pit water management plan; cost not included.

TABLE 8.2

Water Treatment Costs for Base Case Mine Rock Management Plan, Northern Alaska

Treatment Period	Annual Treatment Cost
During Mining	$64,000/annum
After Cover Completed	$16,000/annum

Physical monitoring would include installation and monitoring of piezometers, to ensure that pore pressures do not build up behind the till perimeter berms, as well as an annual visual inspection by a geotechnical engineer. Thermistors would also be installed along the toe of the north side of the dump to detect the development of new zones of permafrost. Installation and monitoring costs are summarized in Table 8.3.

TABLE 8.3

Monitoring Costs, Northern Alaska Mine Rock Management Plan

Monitoring Item	Units	Quantity	Unit Cost	Cost
Piezometers	each	6	$2,000	$12,000
Thermistors	each	6	$1,000	$6,000
Instrument Reading (2 men, quarterly, 2 days)	hour	128	$30	$3,840 (annual)
Annual Inspection (2 days @ $800/day + travel and accom.)	each	1	$3,600	$3,600 (annual)

8.2.3 Changes to Base Case Plan

Rigorous interpretation of RCRA regulations may require additional measures to protect groundwater quality. While the plateau on which the dump will be situated is covered with a veneer of till, this till blanket is relatively thin in places (less than 10 feet thick) and some drainage is bound to seep into the underlying groundwater system with time. Because the facility is kept drained the driving head would be minimal, thereby minimizing the rate of seepage into the foundation.

The most effective way to prevent waste rock seepage from entering the groundwater system would be to place a synthetic membrane liner under the entire waste rock dump. Doing so, however, would require substantially flatter side slopes to provide stability, and would enlarge the footprint area of the dump beyond the area available on the plateau. The next most reliable alternative would be to work bentonite clay into the till beneath the dump. The estimated additional cost of doing so, assuming that an area of 80 acres would require treatment with 20 tons bentonite added per acre, is given below.

Bentonite Addition

Item	Units	Quantity	Unit Cost	Cost
Bentonite Supply	tons	1,600	$200	$320,000
Bentonite Addition	acres	80	$2,000	$160,000
Total Cost				$480,000

Groundwater sampling wells may also be required upstream and downstream of the dump. The cost of installing those wells, as well as sampling and testing are presented below.

Upstream and Downstream Groundwater Sampling Wells

Item	Units	Quantity	Unit Cost	Cost
Well Installation	each	6	$4,000	$24,000
Sampling Well Water (quarterly)	each	24	$4,200	$4,800 (annual)

8.3 Case 2 - Southeastern Alaska - Waste Rock Management

8.3.1 Project Description

This example illustrates a typical case of waste rock management in southeastern Alaska. The mine is an open pit gold producer with a life of 12 years at 3000 tons per day. It is located near the head of a major fjord in mountainous terrain.

A total of 50 million tons of waste rock will be produced over the mine life. Approximately 35 percent of the rock is highly acid generating while the balance is slightly acid consuming.

8.3.2 Base Case Waste Rock Management Plan

Blending or mixing of the rock in an on-land dump was considered in the early mine plans. However, laboratory testing showed that there was a net excess of potential acidity in the blended product and the drainage water quality would not be acceptable for release to the environment without treatment. The water treatment costs were considered unacceptably high, and the long-term maintenance requirements made treatment unattractive. The capacity of any treatment plant would have to be very large to accommodate the high precipitation at the site.

The approved mine plan calls for segregation in the pit of the waste rock types for on-land disposal of the acid consuming rock and underwater disposal of the acid generating rock in the tailings impoundment. Underwater disposal has been shown to be an effective method of providing long-term control of acid generation. Segregation of the rock types will be straight forward as all of the acid generating rock is greenstone, which is located in the footwall, whereas the acid consuming rocks are calcareous mudstones located in the hanging wall.

Based on 6.3 million yd^3 of tailings and 8.8 million yd^3 of waste rock, the required tailings pond capacity was increased by 2.4 times to accommodate the waste rock disposal plan.

A site selection study was conducted and showed that the best site for a tailings impoundment is located in a neighboring valley, north of the pit. The valley is U-shaped and approximately 3 miles long. The valley floor at the embankment is at 1000 feet elevation. A storage ratio of about 20:1 is achieved with a rock-fill embankment.

Because of the high seismic accelerations anticipated at the site, downstream construction methods were selected for the tailings dam, using conventional earth and rockfill dam methods. The acid-generating nature of the tailings made construction of a sand dyke inappropriate. Drainage of the tailings after closure would enhance acid generation.

As suitable earthfill materials for constructing the shells of the dam are lacking, and mine rock is readily available, mine rock will be used in the dam. The calcareous mudstone (352,000 tons) will be used in the downstream shell. Till will be used to construct a low permeability core (176,000 tons), and some of the acid generating rock will be used to develop the upstream section of the embankment. The height of the embankment will be about 150 feet including freeboard and 6 ft water cover over the rock and tailings. Upstream and downstream slopes will be 2:1 (horizontal to vertical). The acid-generating rock placed in the impoundment will help to buttress the upstream slope of the dam to enhance stability.

The incremental costs of rock disposal arising from this plan are as follows:

- haulage of rock 4 miles from the pit to the impoundment;
- controlled dumping and spreading of the rock so that it will become submerged within 6 months as the pond level rises;
- increasing the embankment volume by 440,000 yd^3, of which 20% is borrowed till, 40% is acid generating rock, and 40% is acid consuming rock.

To date, there has not been a requirement at this site to add neutralizing material to the waste rock for control of acid generation prior to submergence. This is due to the slow onset of acid generation in these rocks which is further aided by the cool temperature at the site.

A cost summary of the incremental costs for waste rock disposal is presented in Table 8.4.

TABLE 8.4

Cost Summary - Incremental Costs of Waste Rock Disposal

Item	Units	Quantity	Unit Cost	Cost
Waste Rock Haulage				
- Potentially Acid Generating	tons	17.6×10^6	$.15/ton/mile	$10,560,000
- Acid Consuming	tons	352,000	$.15/ton/mile	$211,200
Waste Rock Spreading				
- Potentially Acid Generating	tons	17.6×10^6	$.10/ton	$1,760,000
- Acid Consuming	tons	352,000	$1/ton	352,000
Till Borrow, Place & Compact	tons	176,000	$3.00/ton	$528,000
Total Cost				$13,411,200

8.3.3 Changes to Base Case Plan

As the plan calls for placing all potentially acid-generating waste rock within the tailings impoundment, potential environmental concerns, and any changes to the base case plan to address them, would be the same as for a tailings impoundment. RCRA regulation impact on tailings management in Alaska was addressed in SRK Report 96303, "RCRA Regulation Impact on Alaska Mineral Development, Tailings Management", May, 1992. Concerns included protection of groundwater resources, treatment of water in the impoundment, wildlife protection and monitoring. Only groundwater protection will be addressed here. Inclusion of the waste rock with the tailings is not expected to effect the tailings pond water quality. Wildlife protection concerns would be directly related to pond water quality. Monitoring requirements would be the same as for the tailings impoundment alone.

Protection of groundwater quality may require constructing a basin liner system. 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 part of a multiple liner. Therefore, two options are presented:

- a single, 80 mil HDPE liner with a sub-drain; and,
- a double liner with leak protection.

The pond area, enlarged to contain the acid-generating rock, would be 190 acres or $83x10^6ft^2$. The incremental costs of placing a liner are presented in Table 8.5.

TABLE 8.5

Impoundment Lining Costs

Single Liner with Sub-drain

Item	Units	Quantity	Unit Cost	Cost[1]
HDPE membrane	ft^2	$8.3x10^6$	$1.20	$9,960,000
Sub-drain	ft^2	$8.3x10^6$	$0.34	$2,822,000
Total				$12,782,000

Double Liner with Leak-Detection

Item	Units	Quantity	Unit Cost	Cost[1]
HDPE membrane	ft^2	$16.6x10^6$	$1.20	$19,920,000
Sub-drain	ft^2	8.3×10^6	$0.34	$2,822,000
Total				$22,740,000

1. Incremental costs to be added to base case costs.

9.0 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 waste rock, 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 waste rock 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 waste rock 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. 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 waste rock 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 waste rock 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 waste rock 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, Number 96302, RCRA Regulation Impact on Alaska Mineral Development, Waste Rock Management has been prepared by:

STEFFEN, ROBERTSON AND KIRSTEN (CANADA) INC.

M. John Brodie, P.Eng.

Fred R. Banta

Nigel A. Skermer, P.Eng.

10.0 REFERENCES

America North, Inc., 1991. WGA Mine Waste Regulatory Development Program. Task 1: State Statutory and Regulatory Analyses. Prepared for the State of Alaska, Department of Natural Resources, February.

Barton, N. and Kjaernsli, B., 1981. Shear Strength of Rockfill. J. Geot. eng. Div. ASCE, Vol. 107. No. GT7, July.

Barton-Bridges, J.P. and Robertson, A. MacG., 1989. Geotechnical Considerations in the Control of Acid Mine Drainage. One Day Symposium on Acid Mine Drainage, Vancouver Geotechnical Society, Vancouver, May.

Blight, G., 1981. Failure Mode. Workshop on design of Non-Impounding Mine Waste Dumps. SME, November.

Brodie, M.J., Broughton, L.M. and Robertson, A. MacG., 1991. A Conceptual Rock Classification System for Waste Management and a Laboratory Method for ARD Prediction from Rock Piles. Second International Conference on the Abatement of Acidic Drainage, Montreal, September 16 - 18.

Broman, P.G., 1988. Sulphidic Mine Tailings Deposits in Sweden Past, Present and Future. Proc. of International Conference on Control of Environmental Problems from Metal Mines. Roros, Norway, June.

Caldwell, J.A. and Moss, A.S.E., 1981. Simplified Stability Analysis. Workshop on Design of Non-Impounding Mine Waste dumps. SME, November.

Campbell, D.B., 1981. Construction and Performance in Mountainous Terrain. Workshop on Design of Non-Impounding Mine Waste Dumps. SME, November.

Campbell, D.B. and Shaw, W.H., 1987. Performance of a Waste Rock Dump on Moderately to Steeply Sloping Foundations. Intl. Symp. Stab. Coal Min., Vancouver, December.

Canada Centre for Mineral and Energy Technology (CANMET), 1977. Pit Slope Manual - Chapter 9 - Waste Embankments. CANMET Report 77-01.

Chiado, E.D., Bowders, J.J. and Sencindlver, J.C., 1988. Phosphatic Clay Slurries for Reducing Acid Mine Drainage from Reclaimed Mine Site. Proceedings: Mine Drainage and Surface Reclamation

Conference, U.S. Dept. of the Interior and Amer. Soc. for Surface Mining and Reclamation, Bureau of Mines Information Circular IC 9183, Vol. I, pp. 44-51.

City Resources (Canada) Ltd., 1989. Cinola Gold Project, Stage II Review, Response to Government Comments, Report to British Columbia Ministry of Energy Mines & Petroleum Resources, March.

City Resources (Canada) Ltd., 1989. Cinola Gold Project, Stage II Review, Workshop Response Report, August.

City Resources (Canada) Ltd., 1988. Cinola Gold Project, Stage II Report, Volume II, Project and Facilities Description, June.

City Resources (CANADA) Inc., 1988. Cinola Gold Project, Stage II Addendum Report, Chapter 6.

Claridge, F.B., Nichols, R.S. and Stewart, A.F., 1986. Mine Waste Dumps Constructed in Mountain Valleys. CIM Bull., August.

Coastech Research Inc., 1990. Acid Rock Drainage Prediction Manual. Prepared for CANMET - MSL Division, November.

Collin, M., 1987. Mathematical Modelling of Water and Oxygen Transportation in Layered Soil Covers for Deposits of Pyritic Mine Tailings. Licentiate Treatise April 16, Royal Inst. of Technology, Sweden.

Combellick, R.A., 1985, Geologic-hazards Mitigation in Alaska: A Review of Federal, State and Local Policies. Alaska Division of Geological and Geophysical Surveys Special Report 35, 71 p.

Daley, R.J., Carmack, E.C., Gray, C.B.J., Pharo, C.H., Jasper, S. and Wiegand, R.C., 1981. The Effects of Upstream Impoundments on the Limnology of Kootenay Lake, B.C. Scientific Series No. 117. West Vancouver, B.C.: National Water Research Institute, Environment Canada.

Dean K.C., Froisland, L.J., and Shirts, M.B., 1986. Utilization and Stabilization of Mineral Wastes. USBM Bulletin 688.

Dubrorsky, N.M., 1986. Geochemical Evaluation of Inactive Pyrite Tailings in the Elliot Lake Uranium District. Ph.D. thesis, Department of Earth Sciences, University of Waterloo, Ontario.

Dutro, J.T., Jr., and Payne, T.G., 1957. Geologic map of Alaska: U.S. Geol. Survey, scale 1:2,500,000.

Environmental Protection Series (EPS), 1987. Mine and Mill Wastewater Treatment. Report EPS 2/MM/3, December.

Errington, J.C. and Ferguson, K.D., 1987. Acid Mine Drainage in British Columbia - Today and Tomorrow. Proc. of Acid Mine Drainage Seminar/workshop, Halifax, Nova Scotia, March.

Glass, C.E., 1981. Influence of Earthquakes. Workshop on Design of Non-Impounding Mine Waste Dumps, SME, November.

Gold, R.D., 1986. Performance and Operation of Waste Dumps on Steeply Sloping Terrain - Case at Fording Coal. Intl. Symp. Goetech. Stab. Sfc. Min., Calgary, November.

Golder Associates, 1986. A Practical Guide to Resloping of Waste Rock Dumps. Prepared for the Technical and Research Committee on Reclamation, December.

Golder Associates, 1987. Regional Study of Coal Mine Waste Dumps in British Columbia (Draft). Supply and Services Canada File No. 23440-6-9188/01SQ, June.

Goodman, R.E., 1980. Introduction to Rock Mechanics. Wiley.

Hallam, R., Kursat, R. and Jones, M., 1974. A Biological Assessment of Benson Lake Following Cessation of Deep Lake Tailings Disposal. Surveillance Report EPS-5-PR-74-2. West Vancouver: Environmental Protection.

Helz, G.R., Dai, J.H., Kipak, R.J., Frendinger, N.J. and Radway, J.C., 1987. Processes Controlling the Composition of Acid Sulphate Solutions Evolved from Coal. Applied Geochemistry, 2, pp. 427-436.

Hester, K.D. & Associates, 1984. Practical Considerations of Pyrite Oxidation Control in Uranium Tailings. Research Report prepared for National Uranium Tailings Program, CANMET, EMR, Ottawa.

Hopkins, D.M., 1959. Some characteristics of the climate in forest and tundra regions in Alaska: Arctic, Vol. 12, pp. 215-220.

Kleinmann, R.L.P., and Erickson, P.M., 1983. Control of acid drainage from coal refuse using anionic surfactants. U.S. Bureau of Mines Report of Investigations 8847.

Klohn Leonoff Ltd., 1991. Operation and Monitoring of Mine Dumps, Interm Guidelines. Prepared for the British Columbia Mine Dump Committee, May.

Knight, R.B. and Haile, J.P., 1983. Sub-Aerial Tailings Deposition. Proc. 7th PANAM Conference, Soil Mechanics and Foundation Engineering, Vancouver, Vol. II.

Kwong, Y.T.J., 1991. Acid Generation in Waste Rock as Exemplified by the Mount Washington Minesite, British Columbia, Canada. Proceedings of the Second International Conference on the Abatement of Acidic Drainage, September, pp. 175-190.

Ladwig, K.J., Erickson, P.M., Kleinmann, R.L.P. and Poslus, E.T., 1984. Stratification in Water Quality in Inundulated Anthracite Mines, Eastern Pennsylvania. U.S. Dept. of the Interior, Bureau of Mines Report RI 8837.

Lanphere, M.A., 1978, Displacement History of the Denali Fault System, Alaska and Canada. Canadian Journal of Earth Sciences, Vol. 15, pp. 817-822.

Lau, R.K., Perez, A. and Krahn, J., 1986. Design, Construction and Performance of Sidehill Waste Dumps at Byron Creek Collieries in Corbin, British Columbia. Intl. Symp. Geotech. Stab. Sfc. Min., Calgary, November. (Abstract).

Magnusson, M. and Rasmuson, A., 1983. Transportberakningar pd vittringsforloppet i gruvavfall. The National Swedish Environmental Protection Board, Report SNV PM 1689 (in Swedish).

McKeon, T.J., Tyler, S.W., Mayer, D.W., and Reisenauer, A.E., 1983. TRUST-II Utility Package: Partially Saturated Soil Characterization, Grid Generation, and Advective Transport Analysis, NUREG/CR-3443, PNL-4805, RU, Pacific Northwest Laboratory, Richland, WA, 99352.

Miller, R.D., and Dobrovolny, Ernest, 1959. Surficial geology of Anchorage and vicinity, Alaska. U.S. Geological Survey Bulletin 1093, 128 p., scale 1:63,360, 6 sheets.

Milner, T.E., 1987. Management Plan for Acid Mine Drainage for the Quinsam Coal Mine. Proc. 11th Annual B.C. Mine Reclamation Symposium, Campbell River, April.

Morin, K.A. and Cherry, J.A., 1986. Trace Amounts of Siderite Near a Uranium-tailings Impoundment, Elliot Lake, Ontario, and Its Implication in Controlling Contaminant Migration in a Sand Aquifer. Chemical Geology, 56, pp. 117-134.

Newmark, N.M., 1965. Effects of Earthquakes on Dams and Embankments. Geotechnique, Volume XV, pp. 139-160.

Nichols, R.S. 1981. Waste Dump Stability at Fording Coal Limited in B.C. Third Intl. Conf. Stab. Sfc. Min., Vancouver, June.

Nichols, R.S., 1986. Rock Segregation in Waste Dumps. Proc. Intl. Symp. Flow-Through Rock Drains. Cranbrook, September.

Nolan, Davis and Associates, 1987. Study of Acid Waste Rock Management at Canadian Base Metal Mines. Prepared for Energy, Mines and Resources Canada, (CANMET) DSS No.23317-6-1738/01-SQ.

Norecol Environmental Consultants Ltd., 1986. Mine Waste Dump Management (Resloping) Study. Prepared for the Technical and Research Committee on Reclamation, July.

NTDME (Northern Territory Department of Mines and Energy), 1986. The Rum Jungle Rehabilitation Project - Final Project Report. Darwin, Australia, June.

Pederson, T.F., 1983. Dissolved heavy metals in a lacustrine mine tailings deposit-Buttle Lake, British Columbia. Mar. Pollut. Bull. 14(7), pp. 249-254.

Pernichele, A.D. and Kahle, M.B., 1971. Stability of Waste Dumps at Kennecott's Bingham Canyon Mine. SME Trans., Vol. 250, December.

Péwé, T.L., 1982. Geologic hazards of the Fairbanks area, Alaska. Alaska Division of Geological and Geophysical Surveys Special Report 15, 109 p.

Piteau, D.R., 1970. Geological Factors Significant to the Stability of Slopes Cut in Rock. Symp. Planning Open Pit Mines. S. Afr. Inst. Min. Met., Johannesburg.

Piteau Associates Engineering Ltd., 1991. Investigation and Design of Mine Dumps, Interm Guidelines. Prepared for the British Columbia Mine Dump Committee, May.

Plafker, G., Hudson, T., Bruns, T., and Rubin, M., 1978, Late Quaternary offsets along the Fairweather fault and crustal plate interactions in southern Alaska. Canadian Journal of Earth Sciences, Vol. 15, pp. 805-816.

Polestar Environmental Services, 1986. Rogers Pass Project 1985: Environmental supervision, monitoring and reclamation. Unpublished report to C.P. Rail, Special Projects, Calgary, Alberta.

Rasmuson, A. and Eriksson, J., 1987. Capillary Barriers in Covers for Mine Tailings Dumps. Nat. Swedish Env. Protection Bd. Rep. 3307, Stockholm.

Reisenauer, A.E., Key, K.T., Narasimhan, T.N., and Nelson, R.W., 1982. TRUST: A Computer Program for Variably Saturated Flow in Multidimensional, Deformable Media. PNL-3975, (NUREG/CR-2360) Pacific Northwest Laboratory, Richland, Washington.

Ritcey, G.M., 1989. Tailings Management: Problems and Solutions in the Mining Industry. Elsevier, New York.

Robertson, A. MacG. and Skermer, N.A. 1988. Design Considerations For The Long-Term Stability of Mine Wastes. First International Environmental Workshop, Australian Mining Industry Council, Darwin, Volume 1.

Robertson, A. MacG., 1986. Mine Waste Disposal: An Update on Geotechnical and Geohydrogeological Aspects. Pro. 8th An. Symp Geot. Geohyd. Aspects Waste Mgmt., Fort Collins, February.

Rogers, G.C., and Horner, R.B., 1990. An Overview of Western Canadian Seismicity. Contribution of the Geological Survey of Canada for DNAG Volume on Neotectonics GSMV-1. 23 p.

Senes Consultants Limited and Beak Consultants Limited, 1986. Estimation of the Limits of Acid Generation by Bacterially- Assisted Oxidation in Uranium Mill Tailings. DSS File #15SQ.23241-5-1712.

Sigafoos, R. S., 1958. Vegetation of northwestern North America, as an aid in interpretation of geologic data. U.S. Geol. Survey Bull. 1061-E, pp. 165-185.

Singhal, R.K., 1988. Western Canada's Mountains Challenge Waste-Dump Planners. E&MJ, Vol. 189, No. 6, June.

Sobek, A.A., 1987. The Use of Surfactants to Prevent AMD in Coal Refuse and Base Metal Tailings. Proceedings of the Acid Mine Drainage Seminar/Workshop, Halifax, Nova Scotia, 23-26 March. Environment Canada Catalogue No. EN 40-11-7/1987.

Steffen Robertson and Kirsten (B.C.) Inc. in association with M. Wiber, Toronto and Actrex Partners Ltd., 1991. Rehabilitation of Mines, Guidelines for Proponents. Prepared for the Ontario Ministry of Northern Development and Mines, August.

Steffen Robertson and Kirsten in association with Norecol Environmental Consultants and Gormely Process Engineering, 1989. Report 66602/1, Draft Acid Rock Drainage Technical Guide, Volume 1. Prepared for the British Columbia AMD Task Force.

Steffen, Robertson and Kirsten, 1988. Report 66001/1 Acid Mine Drainage in British Columbia. Analysis of Results of Questionnaire from Acid Mine Drainage Task Force. Prepared for the Province of BC Acid Mine Drainage Task Force, June.

Steffen, Robertson and Kirsten, 1987b. Report 64701/1, Alternative Measures for Acid Mine Drainage Abatement at Norwegian Mines. November.

Steffen, Robertson and Kirsten, 1986a in association with Senes Consultants Ltd. and Melis Engineering Ltd. Report 58901, The Technology of Uranium Tailings Covers, DSS Report #15 SQ. 23241-5-1709. National Uranium Tailings Program, Department of Energy Mines and Resources, Canadian Centre for Mineral and Energy Technology (CANMET).

Steffen, Robertson and Kirsten (B.C.) Inc. and Clifton Associations Ltd., 1983. Report No. 53601/1 Technical Report Beaverlodge Tailings and Sludges Close-Out Engineering Feasibility Studies for Eldorado Nuclear Limited.

Stepanek, M., 1986. Stability of Waste Embankments In A Northern Environemnt. International Symposium On Geotechnical Stability in Surface Mining, Calgary, November.

Stuckert, B., Balfour, J., Fawcett, D., Sheehan, P. and Das, B., 1989. Study of the Dynamic Stability of Mine Waste Dumps. CIM Bull., July.

Sturm, J., 1987. Materials for Mine Spoils and Coal Refuse. Proc. of Acid Mine Drainage Seminar/Workshop, Halifax, Nova Scotia, March.

Swainback, R.C., Bundtzen, T.K., and Wood, John, 1990. Alaska's Mineral Industry 1990. Division of Geological and Geophysical Surveys Special Report 45.

Tassie, W.P., 1987. Waste Dump Management at Quintette Coal Limited. CIM Dist. 5 AGM, Ft. McMurray, Alta., September.

Taylor, M.J. and Greenwood, R.J., 1981. Classification and Surface Water Controls. Workshop on Design of Non-Impounding Mine Waste Dumps. SME, November.

U.S. Environmental Protection Agency, 1990. Strawman II: Recommendations for a Regulatory Program for Mining Waste and Materials Under Subtitle D of the Resource Conservation and Recovery Act. Working Document.

Vandre, B.C., 1980. Stability of Non Water Impounding Mine Waste Embankments. USDA Forest Service, Intermountain Region, Ogden, Utah 84401, March.

Wahrhaftig, C., 1965. Physiographic Divisions of Alaska. U.S. Geological Survey Professional Paper 482, 52p.

Zavodni, Z.M, Trexler, B.D. and Pilz, J., 1981. Foundation Investigation and Treatment. Workshop on Design of Non-Impounding Mine Waste Dumps. SME, November.