Mined Rock and Overburden Piles

Investigation and Design Manual

Interim Guidelines

May, 1991

British Columbia
Mine Waste
Rock Pile
Research
Committee

INVESTIGATION AND DESIGN OF MINE DUMPS

INTERIM GUIDELINES

Prepared for the:

British Columbia Mine Dump Committee with funding provided from the Provincial Sustainable Environment Fund

Prepared by:

Piteau Associates Engineering Ltd.
215 - 260 West Esplanade
North Vancouver, B.C. V7M 3G7

MAY 1991

Canadian Cataloguing in Publication Data
Main entry under title:
Investigation & design of mine dumps

Includes bibliographical references: p.
ISBN 0-7718-9118-0

1. Coal mines and mining - Waste disposal - British Columbia. 2. Coal mines and mining - Waste disposal - Environmental aspects - British Columbia. 3. Mineral industries - Waste disposal - British Columbia. 4. Mineral industries - Waste disposal - Environmental aspects - British Columbia. I. British Columbia Mine Dump Committee. II. Piteau Engineering Ltd. III. British Columbia. Ministry of Energy, Mines and Petroleum Resources.

TD899.M5I58 1991 622'.334 C91-092314-0

FOREWORD

Mine waste rock and overburden dumps are massive structures, for example, mountain top coal mines in British Columbia are constructing the largest man-made structures on the face of the earth. These immense waste dumps are often up to 400 meters high, designed to contain in excess of 1 billion cubic meters of material and often form mid-valley fills or rock drains. Instability of the structures has caused increased concern by the mine operators and the government regulators because of impacts on the environment and risk to the safety of personnel, equipment and infrastructure.

In mid 1990 representatives of industry, CANMET and the ministries of Environment and Energy, Mines and Petroleum Resources formed a committee to foster research work and ensure a common understanding of these waste dumps.

These Interim Guidelines form one of a series of studies undertaken by the committee. Prominent geotechnical consultants and industry representatives have reviewed the guide and many of their suggestions have been incorporated.

I would like to stress that this document is purely for guidance and to assist in developing a standardization of approach in pre-design investigation and also in design analysis.

Over the course of the next year it is the intent of the committee to evaluate and verify the innovative classification system developed by the authors and also to encourage constructive comment from industry, regulatory personnel and consultants. In early 1990 the committee is proposing to sponsor a series of workshops to introduce all of the studies to key industry personnel and capture the practical experience of a year of using the guidelines so that a planned rewrite can incorporate that experience.

The guidelines are being widely distributed by the Ministry of Energy, Mines and Petroleum Resources in the hopes that all concerned with mine dumps will find them useful in establishing dumps that are stable, safe and economically feasible, as well as to solicit your comments.

R.W. McGinn, P.Eng.
Chairman, Waste Dump Research Committee May 21, 1991

EXECUTIVE SUMMARY

INTRODUCTION

This report presents the results of a study commissioned by the B.C. Ministry of Energy, Mines and Petroleum Resources to review the current practice and develop practical guidelines for geotechnical investigation, analysis and design of mine dumps in British Columbia. It is recognized that environmental, land use and related issues must also be addressed in the investigation and design process; particularly in view of the potential impact that mine dump instability may have on the environment. However, the primary focus of this study is the geotechnical stability of mine dumps. Where preliminary investigations indicate that serious environmental impacts could occur, such as acid rock drainage, runout of failures into sensitive habitats, impacts to private or public lands or facilities, etc., detailed, focussed assessments of these aspects will also be necessary.

Results of this study are presented as an interim working document. Certain aspects of the study will be subject to review and revision as new conditions or technology comes to light, or as new legislation is enacted. In particular, verification and calibration of the mine dump classification scheme proposed in Section 5 is required before it can be finalized and adopted for widespread use. A revised document will be prepared in due course, and periodically updated.

As part of the study, a survey of dumps at 31 active mines in the province was undertaken, and synopses on 83 individual dumps were prepared and are given in Appendix A. Contributions to the guide were solicited from mine operators, regulatory agencies, research and industry groups and geotechnical consultants. Much relevant information has been abstracted from the literature, and an annotated bibliography is provided in Section 9.

This guide has been developed to meet the needs of a wide range of interests throughout the mining industry, including those of mine proponents, regulators and consultants. Individual sections of the guide address pertinent aspects of the investigation, analysis and design procedure as described in the following.

PLANNING

Section 2 reviews the current regulatory requirements for mine dump development in B.C. A recommended investigation, analysis and design procedure which complements the current Mine Development Review Process (MDRP) is described and illustrated in a series of flow charts. Factors which must be considered in the design process are classified into five basic categories: Mining Factors, Physical Constraints, Environmental Impacts, Stability and Socio-Political Considerations.

SITE CHARACTERIZATION AND FIELD STUDIES

Section 3 describes the range of site investigation studies required to define the physical characteristics of a proposed dump site. Six areas of study are recognized: Physiography and Geomorphology, Hydrology and Climate, Bedrock Geology and Tectonics, Surficial Geology and Soils, Hydrology, and Environment and Culture. For each of these study areas, key characteristics are identified, and their implication in site selection and design, sources of available information and field methods for obtaining the relevant data are described.

MATERIAL PROPERTIES AND TESTING

The important physical and geochemical properties of the bedrock and soils in the dump foundation, and mine rock and overburden materials used to construct the dump, and their application in the design process are described in Section 4. In situ and laboratory techniques for defining the various properties are also described. In addition, recommendations for baseline surface water and groundwater quality sampling and testing are given.

MINE DUMP CLASSIFICATION

Section 5 reviews the various factors which influence dump stability and presents a comprehensive stability rating and classification scheme. Dump Stability Ratings (DSR) and Classes (DSC) provide a semi-quantitative measure of the complexity and hazard of a given dump configuration. They may be used to compare alternative dump configurations and sites, and provide an indication of the relative level of effort which should be applied throughout the investigation and design process. Recommendations regarding the level of effort, and two examples illustrating the classification system are given. A discussion of the various risks associated with dump development is also included.

STABILITY ANALYSIS

Possible modes of dump failure and key factors which could contribute to each mode are described in Section 6. In addition, alternative analysis techniques and their advantages and limitations are described and referenced. Factor of Safety and Probabilistic approaches to evaluating stability analysis results are presented. Interim guidelines for minimum design factor of safety are also given.

CONSTRUCTION

Section 7 reviews various aspects of mine dump construction and development which should be considered during the design process. Various alternatives for foundation preparation, control of surface water, snow control, construction methods, and possible hazard mitigation measures are described. The importance of considering reclamation objectives in the initial design process, and updating the design based on documented performance is also discussed.

CONTENTS

CONTENTS (cont'd.)

CONTENTS (cont'd.)

CONTENTS (cont'd.)

FIGURES

TABLES

1. INTRODUCTION

1.1 GENERAL

1.1.1 Background

Disposal of mine rock and overburden is a very important, and sometimes critical, aspect of mine development in British Columbia. Rock and overburden dumps at some open pit mines in B.C. are amongst the largest man-made structures on earth. Costs associated with mine rock and overburden disposal can account for a substantial portion of a mine's development, operation and reclamation expenditures. Equally important are the immediate and long-term effects that mine dumps may have on the physical environment.

Since the early 1970's, development of large surface coal mines has resulted in a significant increase in the number and size of mine dumps in British Columbia. Golder Associates (1987) has reported a corresponding increase in the incidence of mine dump instability. This trend towards more frequent and larger dump failures, and a general increase in environmental awareness, has given rise to concerns about the safety and environmental consequences of mine dumps, both during mining and following mine closure.

1.1.2 Study Objectives

Current legislation in B.C. (Mines Act, S.B.C. 1989, C.56) requires that plans and designs for proposed mine dumps (or for significant modifications to existing or approved dumps) be submitted to the B.C. Ministry of Energy Mines and Petroleum Resources (MEMPR) for approval prior to issuance of a permit and commencement of mining. While geotechnical design is a component of most new major dump plans, no standardized approach to investigation and design currently exists. Also, the expectations of regulators regarding the level of effort and content of submissions have not been well defined.

The purpose of this study is to review and summarize the state-of-the-art and current practice, and develop practical guidelines for geotechnical investigation, analysis and design of mine dumps in B.C. Where appropriate, reference is made to environmental, land use and related issues; however, the primary focus on this study is the geotechnical stability of mine dumps.

It is envisaged that the results of this study will be used by mine proponents to help them determine the various steps to be taken, and the appropriate level of effort which should be allocated to geotechnical investigation and design for proposed mine dumps. Study results will also assist regulators when reviewing and adjudicating submissions.

Results of this study are presented as an interim working document. Certain aspects of the study will be subject to review and revision as new conditions or technology come to light, or as new legislation is enacted. In particular, verification and calibration of the dump classification scheme proposed in Section 5 will be conducted. In addition, it is envisaged that periodically updated versions of this document will be produced which incorporate the results of the classification scheme verification/calibration, as well as results of other ongoing or future studies.

1.1.3 Scope of Guidelines

It is recognized that each site and proposed dump are unique, and that specific conditions may dictate a wide range of geotechnical investigation or design requirements. While the guidelines proposed in this report have been developed to cover a wide range of conditions, it is impractical to consider all possible situations. Scenarios may arise in which the guidelines conflict or are inadequate. This guide is not intended as a detailed design manual, nor should it be used as a substitute for experienced engineering judgement.

This guide is intended to cover soft rock, hard rock and overburden dumps for open pit and underground mines. As virtually all of the active mine dumps in B.C. are being constructed using haul trucks and bulldozers, the guidelines proposed herein have been developed primarily for dumps constructed using this type of equipment. Although many of the investigation and design principles may be similar, caution is advised when extending the guidelines to cover other methods of dump construction, such as dragline or bucket wheel/conveyor spoiling.

It is recognized that environmental and related aspects may influence, and in some cases control, investigation and design requirements for mine dumps. Where preliminary investigations indicate that serious environmental impacts could occur, such as acid rock drainage, runout of failures into sensitive habitats, impacts to public or private lands or facilities, etc., detailed, focussed assessments of these aspects will be necessary, in conjunction with geotechnical evaluations.

1.1.4 Terms of Reference

Terms of reference for the study were outlined in a Request For Proposal issued in July 1990 by the B.C. Mine Dump Committee (BCMDC), under the auspices of MEMPR. A contract to conduct the study was awarded to Piteau Associates Engineering Ltd. in August 1990. A draft report was issued for review by BCMDC and selected technical reviewers from industry, consultants and regulators in February 1991. This interim guide was issued in May 1991. Funding for the study was provided by MEMPR.

1.2 RELATED STUDIES

Several other related studies are currently being conducted.

1.2.1 Operation and Monitoring of Mine Dumps - Interim Guidelines

A technical guide for operation and monitoring of mine dumps in B.C. is currently being prepared by Klohn Leonoff Ltd., under contract to MEMPR. Completion of this study and preparation of an interim working document is also expected by May 1991. The Operation and Monitoring Guidelines are intended to sere as a companion document for the Investigation and Design Guidelines. Funding has been provided by MEMPR.

1.2.2 Major Mine Dump Failures

A review of major mine dump failures in B.C. and creation of a data base is being conducted by Mr. S. Broughton, P.Eng. as part of a Master of Engineering program in the Department of Mining and Mineral Processing at the University of British Columbia. Funding for this study is being partially provided by MEMPR, and results are expected by August 1991. Results of this study will be incorporated into an updated version of the Investigation and Design Guidelines.

1.2.3 Runout Analysis

In December 1990, Energy, Mines and Resources Canada (EMRC) requested proposals for a study of "Runout Characteristics Of Debris From Dump Failures In Mountainous Terrain". This study was awarded to Golder Associates, and the anticipated completion date is March 1992.

1.2.4 Mine Dump Monitoring

EMRC also requested proposals for a review of "Monitoring Technology For Waste Dumps In Mountainous Terrain". This study was awarded to Hardy BBT Ltd., and was completed in April 1991.

1.3 MINE DUMP SURVEY

As part of the study, a survey of mine dumps at most active mines in British Columbia was carried out. The main objectives of this survey were to document the current practice for investigating and designing mine dumps, and establish the range of dump types and construction strategies in current use in B.C. Questionnaires regarding the configuration and history of current and previous mine dumps were sent to 21 active mine operators in B.C., representing 31 different mines. Completed or partially completed questionnaires were received for 83 separate mine dumps, which represented a wide range of sizes and types.

Synopses of each of the dumps surveyed were prepared and compiled into a readable spread sheet data base, which is included as Appendix A to this report. Due to the large number and variability of responses, summarizing the information on the questionnaires required considerable synthesis and editing for consistency. In some cases, information in MEMPR files was used to supplement the data contained in the questionnaires. Preliminary compilations were forwarded to the participating mines and the District Mines Inspectors for review prior to finalizing.

The identity of the various mines and dumps has been preserved in Appendix A. We believe this policy, together with the consultative process by which the synopses were prepared, adds credibility to the data base and provide useful precedence for mine dump designers, mine proponents and regulators. This approach is also designed to encourage dissemination of current and past experiences throughout the industry.

Updating and refinement of the data base will be conducted in conjunction with ongoing studies and periodic updates of the Guidelines.

1.4 CONSULTATIONS WITH INDUSTRY AND REGULATORS

Mine operators and other interested parties were also invited to comment on any aspect of the proposed guide. The following groups/individuals were consulted:

- B.C. and selected Alberta Mine Operators
- Government/Regulatory Agencies:
  - MEMPR
  - B.C. Ministry of Environment (MOE)
  - Alberta Energy Resources Conservation Board (ERCB)
  - Energy, Mines and Resources Canada (EMRC)
  - U.S. Bureau of Mines (USBM)
- U.B.C. Department of Mining and Mineral Processing
- Mining Association of B.C.
- Coal Association of Canada
- Geotechnical Consultants:
  - Golder Associates Ltd.
  - Hardy BBT Ltd.
  - Klohn Leonoff Ltd.
  - Mr. Graham Morgan, P.Eng.
  - Piteau Associates Engineering Ltd.
  - Steffen Robertson & Kirsten (B.C.) Ltd.
  - Stewart-EBA Consulting Ltd.
  - Thurber Engineering Ltd.

1.5 LITERATURE REVIEW

As part of the study, a comprehensive literature search was conducted. Particular emphasis was placed on determining the existence of similar guides or relevant design manuals. Computer data base searches were conducted through CANMET in Ottawa and the Alberta Research Council in Devon. In addition, library facilities at the University of B.C. were utilized, and in-house resources were reviewed.

Several general references on mine dump investigation and design were identified, including:

- Engineering Design Manual for Disposal of Excess Spoil (OSM, 1989)
- Design of Non-Impounding Mine Waste Dumps (SME, 1985)
- Development of Systematic Waste Disposal Plans for Metal & Nonmetal Mines (USBM, 1982)
- Pit Slope Manual, Chapter 9 - Waste Embankments (CANMET, 1977)

- Engineering and Design Manual for Coal Refuse Disposal Facilities (MESA, 1975)

A full list of publications reviewed is given in the annotated bibliography in Section 9.

1.6 PROJECT PERSONNEL

This study was conducted by Piteau Associates Engineering Ltd. Mr. P.M. Hawley, P.Eng. was Project Engineer. The bulk of the assessments and report preparation were conducted by Messrs. Hawley, F.B. Claridge, P.Eng. and H.W. Newcomen, P.Eng. Additional assistance and review was provided by Mr. D.C. Martin, P.Eng., Mr. A.F. Stewart, P.Eng., Mr. J.D. Tod, P.Eng., Mrs. E. Foster and Mr. M.C. Leir.

2. PLANNING

2.1 MINE DEVELOPMENT REVIEW PROCESS

The Mine Development Review Process of British Columbia (MDRP) is a review procedure sponsored and administered by the Province of British Columbia for all new mining projects, or for major expansions or modifications of existing mines (MEMPR, 1989). The MDRP was initially established as a non-legislative working policy by the Environment and Land Use Committee (ELUC) of the B.C. Cabinet in 1976, and was subsequently streamlined in 1984. In July 1990, the Minister of Energy, Mines and Petroleum Resources introduced new legislation to formalize the process (i.e. Mine Development Assessment Act, S.B.C., 1990, C.59). Currently, the Cabinet Committee on Sustainable Development (CCSD) has the ultimate responsibility for granting approval-in-principle of mining projects in B.C. (MEMPR, 1990b). Following enactment and proclamation of the Mine Development Assessment Act, approval-in-principle will be replaced by a mine development certificate issued by the Minister of Energy, Mines and Petroleum Resources, with the concurrence of the Minister of Environment.

The main objective of the MDRP is to provide a comprehensive, coordinated, consolidated and consistent review process whereby the environmental and socio-economic implications of new, expanded or modified mining projects can be rationally assessed prior to allowing them to proceed, or rejecting them. The process establishes a procedural framework and guidelines for technical submissions by mine proponents on various aspects of the proposed mine, including mine dumps, at various stages in the review. Depending on the complexity or potential implications of a proposed mining project, the level of design and reporting required may vary, and several alternative review tracks may be applied, as illustrated in Fig. 2.1.

In its current format, the MDRP commences with the filing of a Prospectus or Letter of Intent with the Mine Development Steering Committee (MDSC). This is a brief description of the proposed project, and would normally be filed by the mine proponent following preliminary exploration and prefeasibility studies.

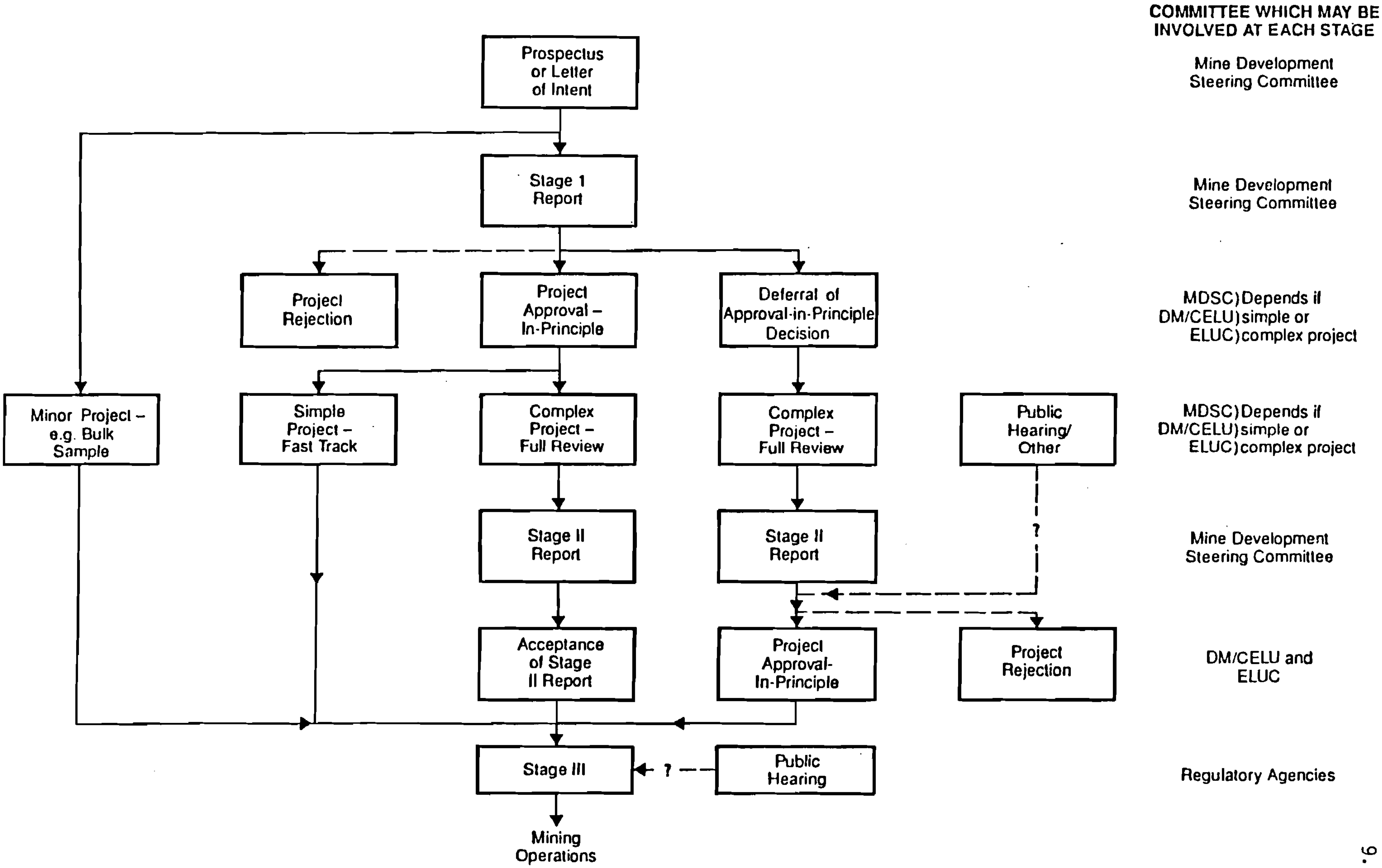


FIG. 2.1 MINE DEVELOPMENT REVIEW PROCESS (modified after MEMPR, 1989)

Except in the case of a very minor project (e.g. bulk sample), the MDSC then develops terms of reference for a Stage I study, to be carried out by the mine proponent to address areas of perceived impacts. Following submission and review of the Stage I report, the MDSC decides if significant unresolved issues remain, or if more details on specific aspects of the project are required, before an informed judgement on the project can be made. If required, the MDSC will then formulate terms of reference for Stage II studies, to be carried out by the mine proponent to address unresolved issues or details. Approval-in-principle (or a mine development certificate) may be granted, or the project may be rejected at various stages in the process as indicated in Fig. 2.1.

2.2 RECOMMENDED DESIGN SEQUENCE

Figures 2.2. 2.3 and 2.4 are flow charts which illustrate the recommended steps in the mine dump design process. These flow charts have been specifically devised to meet the requirements of the MDRP.

2.2.1 Exploration

Specific investigations and designs for mine rock and overburden disposal facilities are generally not conducted during the initial exploration phase of a mining project. However, much of the information which is collected as a matter of course during exploration, such as topography, geology, hydrology, climate, etc., may be valuable for subsequent mine dump assessments. In many cases, if exploration personnel are made aware of the basic site information which may ultimately be required, it may be possible to establish an initial data base at relatively little cost (Stewart and Martin, 1988).

2.2.2 Prefeasibility

Once a project advances beyond the basic exploration stage, it is necessary to establish the basic mine rock and overburden disposal requirements. How much and what type of materials must be disposed? Where will these materials originate? What methods of materials handling

EXPLORATION / PREFEASIBILITY

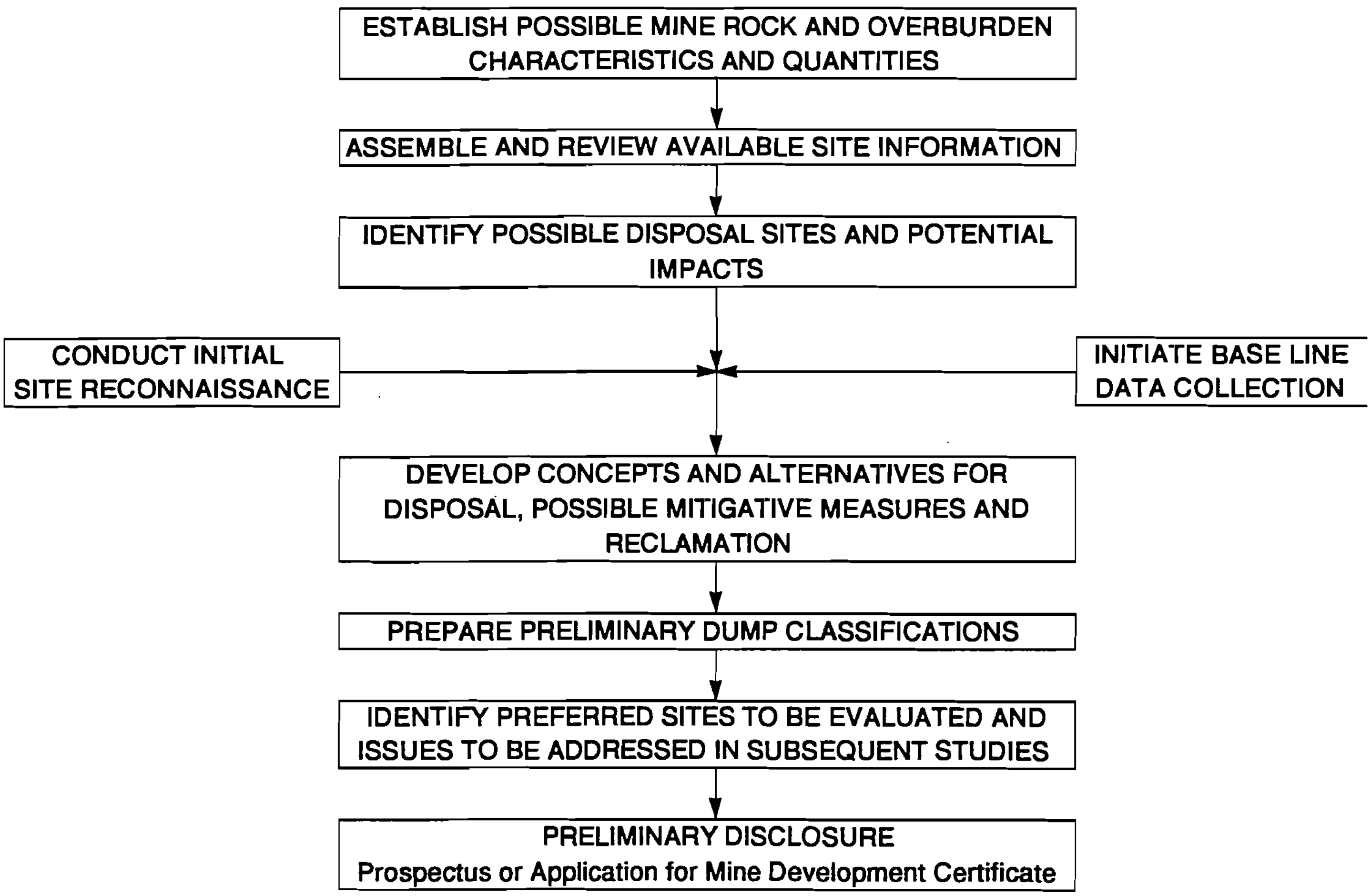


FIG. 2.2 RECOMMENDED MINE DUMP INVESTIGATION AND DESIGN SEQUENCE – EXPLORATION AND PREFEASIBILITY

FEASIBILITY / PRELIMINARY DESIGN

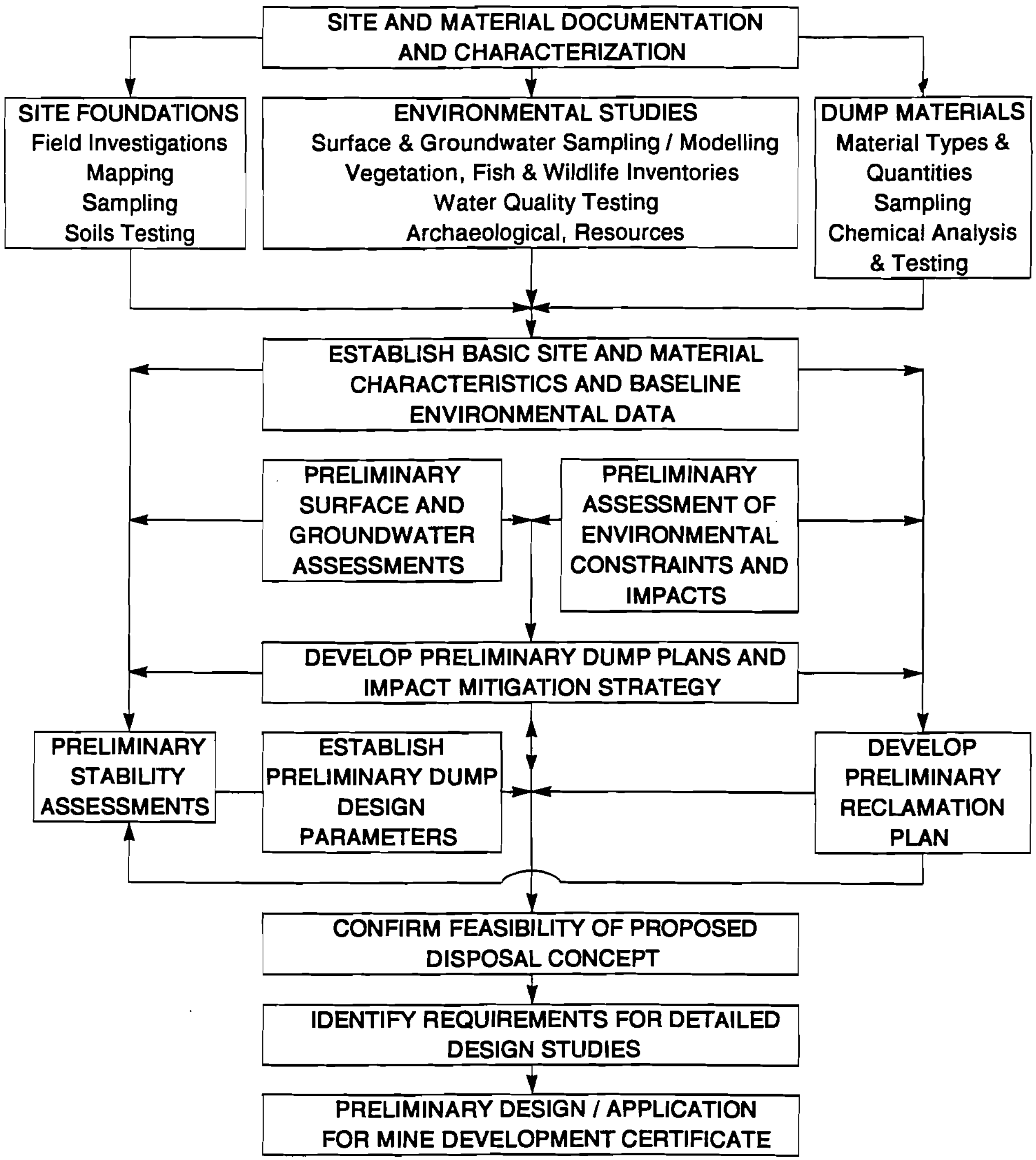


FIG. 2.3 RECOMMENDED MINE DUMP INVESTIGATION AND DESIGN SEQUENCE – FEASIBILITY / PRELIMINARY DESIGN

DETAILED GEOTECHNICAL STUDIES

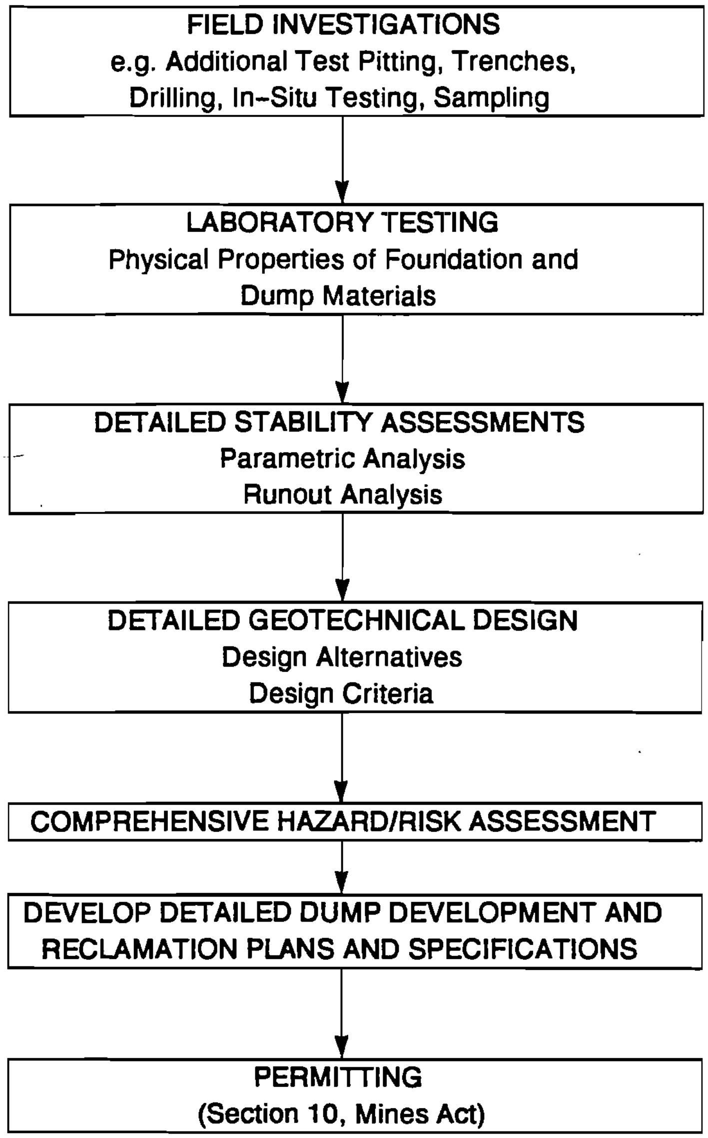


FIG. 2.4 RECOMMENDED MINE DUMP INVESTIGATION AND DESIGN SEQUENCE – DETAILED STUDIES / PERMITTING

and placement will likely be employed? Available site information, such as the basic geology, topography, vegetation, hydrology, climate, archaeological information, and any other data available from the exploration program, other relevant projects or publications (e.g. air photos, geologic maps, climatic station reports, etc.) is then assembled and reviewed. Alternative disposal sites and potential environmental and other impacts are identified for further consideration.

Following this initial review and selection of possible sites, a preliminary reconnaissance of identified sites would normally be conducted. Baseline data collection would also be initiated (e.g. stream flow monitoring, water quality sampling, etc.).

Preliminary evaluations of mine rock and overburden characteristics and quantities, and site characteristics would be used to develop alternative conceptual disposal schemes, possible measures to mitigate potential impacts, and a conceptual reclamation plan. At this stage, preliminary dump classifications for each of the various alternative sites and dump development schemes should be prepared, as outlined in Section 5. Classifications will provide a mechanism for comparing possible alternatives, and identifying site or dump specific factors which may ultimately have to be addressed in more detailed studies.

Based on results of prefeasibility studies for mine dumps and other aspects of the project, a decision would be made by the mine proponent whether to proceed with a detailed feasibility assessment or not. If a decision is made to proceed, the proponent would file a Prospectus or Letter of Intent (or an application for a Mine Development Permit as described in the pending legislation) outlining the proposed project and basic approach to development.

2.2.3 Feasibility and Preliminary Design

Feasibility and preliminary design studies would be conducted to advance project planning and address specific issues raised by the MDSC and outlined in the Stage I terms of reference. Additional documentation and characterization of the site and dump materials would be conducted. Field investigations, such as additional reconnaissance, test pitting, etc., would be conducted to further assess site conditions and suitability. Samples of foundation soils would be collected for classification and laboratory testing. Baseline environmental sampling and habitat monitoring programs may be initiated or expanded. Estimates of mine rock and overburden material quantities and composition would be refined, and samples collected for laboratory testing.

Laboratory studies of foundation and dump materials would be conducted to establish basic material characteristics, such as shear strength, durability and chemistry. Surface water and groundwater samples would be tested to establish baseline water quality. Based on initial laboratory testing results, sampling and monitoring programs may require adjustment.

A preliminary assessment of the surface and groundwater flow systems, and a tentative site water balance would be prepared. An initial evaluation of environmental constraints and potential impacts would be prepared, and conceptual disposal schemes would be refined and revised accordingly.

Results of all the above studies would be used to develop preliminary dump plans and an impact mitigation strategy. Preliminary stability assessments would be conducted to establish appropriate design parameters. A preliminary reclamation plan would also be developed. Iteration of this process may be required to establish an economical and environmentally sound disposal concept. Requirements for subsequent, detailed design studies would also be identified.

Results of the feasibility and preliminary design studies would be compiled into a preliminary design (Stage I) report for review by the MDSC. If no outstanding technical, social or environmental issues are identified, approval-in-principle would be granted (or a Mine Development Permit issued). If concerns are identified during review, the project could be rejected, or approval withheld, pending more detailed studies to resolve outstanding issues (i.e. Stage II). Detailed design studies may also be required for permitting (i.e. Stage III).

2.2.4 Detailed Geotechnical Studies

Detailed geotechnical investigation and design studies would be tailored to the individual project, and the scope of such studies would generally be determined in consultation with government. As illustrated in Fig. 2.4, detailed studies could consist of additional geotechnical field investigations to supplement existing information and provide samples for additional laboratory testing. Additional laboratory testing may be required to confirm and/or refine geotechnical parameters.

Detailed stability assessments, including parametric or sensitivity and runout studies, may be required. Detailed assessment of design alternatives and refinement of design criteria may be necessary, as well as detailed design of mitigative measures and comprehensive hazard and/or risk evaluations. Advanced reclamation planning may also be needed. Many of the factors involved are interrelated; hence, several iterations may be required to determine the optimum design.

At Stage III (permitting), a comprehensive report summarizing the detailed studies would be prepared for submission to government. Provided all dump design issues have been addressed to the satisfaction of the various regulatory agencies, a permit would be granted under Section 10 of the Mines Act.

2.3 BASIC DESIGN CONSIDERATIONS

Basic factors which must be considered in the design of a mine rock and overburden disposal scheme can be divided into five general categories: Mining Factors, Physical Constraints, Environmental Impact, Short and Long Term Stability, and Social/Political Considerations. These factors are interrelated, and at times conflicts occur. The challenge to the designer is to strike an acceptable balance between these diverse factors. Conflicts can usually be resolved, and a balance achieved, through economic analysis, comparative hazard and/or risk assessments, and engineering judgement.

2.3.1 Mining Factors

Mining factors include those aspects related to materials handling and mine scheduling. Transportation, for example, commonly accounts for a large portion of mine rock and overburden disposal costs; hence, it is usually desirable to locate the dump as close to the source as possible, with level or downhill hauls to the dump. Scheduling flexibility can also be an important factor, particularly for large mines where several dumps may be required or are desirable. Equipment requirements may also vary, depending on the type and location of the dump.

2.3.2 Physical Constraints

The quantity of dump materials and the basic configuration, location and capacity of a given dump site may be important physical constraints on design. Sites may be limited by topographic features such as streams or excessively steep foundation slopes. Access to some sites may be impractical or too costly to develop. Depending on the site geometry, several smaller dumps may be preferable to one major dump. Configuration and location of the site may also define the optimum construction technique.

2.3.3 Environmental Impact

Potential environmental impacts influence, and in many cases control, dump design. Requirements for sedimentation facilities may favour one site over another. When acid rock drainage is predicted, required mitigative measures may vary considerably between alternative sites. The potential impact of waste dump failures may also influence design and must be evaluated. In addition, reclamation requirements and aesthetics may vary between sites, and must be considered in the design process.

2.3.4 Short and Long Term Stability

Stability of a mine dump depends on the dump configuration, location, foundation shape and conditions, foundation and dump material characteristics and their variation with time, construction methodology and other factors. Stability considerations may vary depending on the perceived level of hazard or period of exposure of the dump (i.e. short term (during construction) vs. long term (abandonment)). Hence, the potential for various types of instability which may impact the safety of the operation or the environment must be evaluated. Appropriate measures must then be taken to reduce the risk of instability to an acceptable level. Overall dump stability, as well as the potential for surface erosion of reclaimed slopes, must be addressed.

2.3.5 Social/Political Considerations

Resource development projects in British Columbia and elsewhere are being subjected to increasingly more stringent permitting and regulatory requirements. Issues such as environmental protection, resource conservation, native land claims, archaeological significance, aesthetics, and competing land uses are receiving more attention in the public and political arenas. Mine proponents must evaluate the public perception and political acceptability of proposed mine rock and overburden disposal alternatives early in the design process.

3. SITE CHARACTERIZATION AND FIELD STUDIES

3.1 GENERAL

Rational mine dump site selection and design requires a thorough knowledge of the physical and biological characteristics of the site and potential dump materials. Those characteristics which are considered most important are described in the following and summarized in Table 3.1. For discussion purposes, key site characteristics have been grouped into six broad categories or study areas. The primary impacts that each of these study areas has on the site selection and design process are also described.

The first step in site characterization is to assemble available information from government publications, maps, basic environmental data and public and private company reports. Much of the required information may already have been collected in connection with other aspects of the project or related or adjacent studies. Some of the available sources of information which may be useful are described in the following and summarized in Table 3.1.

Field investigations are then planned and executed to define and confirm the key site characteristics. The scope of field investigations may vary from a preliminary site reconnaissance, to detailed drilling, geophysical surveys, sampling and instrumentation programs. The design of field investigation programs will depend on a wide variety of factors, including site conditions, the size of the proposed dump and the amount of information already available. Typical field investigation techniques are described in the following and summarized in Table 3.1. Some useful references which describe some of the typical field investigation techniques in greater detail are also given in Table 3.1.

Information requirements commonly change as a more thorough understanding of site characteristics evolves during the course of the study. Hence, it is important that field investigation programs be comprehensive yet flexible. A

TABLE 3.1

SITE CHARACTERIZATION AND FIELD METHODS

STUDY AREAS	IMPORTANT CHARACTERISTICS	SITE SELECTION AND DESIGN IMPLICATIONS	AVAILABLE INFORMATION SOURCES	FIELD METHODS		
				PRELIMINARY STUDIES	DETAILED STUDIES	REFERENCES
Physiography and Geomorphology	-Site location, size, shape, topography -Geologic hazards (eg. landslides, debris flows, etc.) -Landforms (eg. terraces, gulleys, etc.) -Glacial history	-Overall site suitability -Haul distance, grades -Stabilization or mitigative works -Topographic constraints -Dump type, construction method	-Topographic maps -Air photos	-Air photo interpretation, terrain analysis (1) -Ground reconnaissance, terrain mapping (2)	-Photogrammetric mapping (21) -Ground surveys (22)	-Martin (1991): 1,2,5-14, 17,21,22,24-26,28,32 -Piteau Associates (1990): 12-15,18,29,30 -OSM (1989): 6-12,26-29 -Environment Canada (1988): 23 -CCREM (1987): 16,18, 19,35 -Fisheries & Oceans (1987): 18,19,34,35 -CGS (1985): 1,8-10,21, 26-28 -Environment Canada (1983): 16,18 -USBM (1982): 1,2,5-9, 11,26,27 -Welsh (1981): 1,2,22,26 -Freeze & Cherry (1979): 15-17,29,31-33 -Naismith & Gerath (1979): 1 -ELUC (1978): 1 -CANMET (1977): 6,8,12, 26,27 -Goodman (1976): 1,7,21, 24 -Keser (1976): 1 -Dept. of the Navy (1975): 6,8-11,16,26-28,31-33 -Linsley et al (1975): 4 -MESA (1975): 2,3,5-7,11, 16,18,22,26-28,30-32 -Peck et al (1974): 8-11, 27,28 -Compton (1962): 5,22
Hydrology and Climate	-Precipitation (rainfall and snowfall) -Temperature -Prevailing winds -Runoff/infiltration characteristics -Locations of streams -Size of catchment basins	-Diversions and rock drains -Snow accumulation/removal -Flooding potential -Freeze-thaw degradation potential -Avalanche hazards -Impact on surface water resources	-Topographic maps -Air photos -Climatological station records -Water license records	-Ground reconn, stream mapping (3) -Stream flow measurements (eg. weirs, staff gauges, current metering) (4)	-Ground surveys (22) -Establish climatological station (23)	
Bedrock Geology and Tectonics	-Geologic structure -Rock competency, durability -Potential mineral resources -Seismicity	-Foundation conditions, stability -Impact on potential mineral resources -Seismic stability -Characteristics of mine rock materials, stability	-Air photos, topographic maps -Geologic maps or open file reports -Regional geology studies, theses -Exploration drill logs, reports -Seismic zoning maps	-Air photo interpretation (1) -Ground reconn, outcrop mapping (5) -Trenching, test pitting (6) -Exploration drilling (7)	-Geotechnical exploration drilling (24) -Additional trenching, test pitting (6) -Geotechnical core logging (25)	
Surficial Geology/Soils	-Soil types, distribution, stratigraphy -Depth to bedrock or competent soil -Insitu soil characteristics	-Foundation conditions, stability -Foundation preparation, remediation -Characteristics of overburden materials, stability	-Air photos, topographic maps -Surficial geology or soils maps, reports -Exploration drill logs	-Air photo interpretation (1) -Ground reconn, soils mapping (8) -Trenches, test pits, grab sampling (6) -Soil classification (9) -Soft soil probing (10) -Insitu testing (eg. vane shear, pocket penetrometer, etc.) (11)	-Additional trenching, test pitting (6) -Geotechnical boreholes (eg. mud/air rotary, Becker, auger, etc.) (26) -Downhole/insitu testing (e.g. SPT, CPT etc.) (27) -Split spoon, thin wall, block sampling (28) -Geophysics (29)	
Hydrogeology	-Location of springs, seeps, perched water tables, phreatic surface -Piezometric pressures -Groundwater flow system -Existing groundwater useage	-Foundation conditions, stability -Underdrainage requirements -Impact on groundwater resources	-Air photos, topographic maps -Geologic maps, reports -Exploration drilling records water level measurements, piezometers -Well logs -Water licenses	-Air photo interpretation (1) -Ground reconn, hydrogeologic mapping (12) -Inflows to trenches, test pits (13) -Shallow standpipes in test pits (14) -Groundwater sampling (15) -Field testing of phys. properties (16) -Perc tests (17)	-Geotechnical boreholes with open standpipes and/or sealed piezometers (30) -Geophysics (29) -Pump testing (31) -Insitu permeability testing (32) -Infiltrometer testing (33)	
Environment and Culture	-Surface and groundwater quality -Air quality -Fish and wildlife habitat -Plant, forestry resources -Present land use -Aesthetics -Land ownership, native land claims -Archeological resources	-Establish baseline data for impact assessments -Mitigative measures -Establish future land use objectives -Political, legal considerations	-Air photos, topographic maps -Forestry, land use maps -Land registries -Local population, Indian bands	-Surface and groundwater sampling (18) -Field testing of physical properties (16) -Fish, wildlife and plant inventories (19) -Archeological reconnaissance (20)	-Wildlife habitat studies (34) -Biophysical monitoring (35) -Air quality monitoring (36)	

NOTE: Numbers in parentheses refer to the selected references listed on the far right which contain detailed descriptions and/or specifications for the various field tests.

phased investigation usually provides the most cost effective and efficient method of obtaining the required information. In cases where the project schedule does not enable a phased approach, delays may occur during later stages of project development, while critical missing information is collected. Increased investigation, design and construction costs may also be incurred if field investigations are compressed or truncated.

3.2 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. Other mining activities such as blasting, access development, layout of mine facilities, etc. may affect site selection, development and dump stability considerations. Size and shape affect the suitability of the site in terms of available capacity, type of dump and construction concepts. 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.

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.

The main sources of available information on site physiography and geomorphology consist of topographic maps and air photos. Topographic maps at a scale of 1;50,000 are available for the entire province through the Surveys and Mapping Branch of EMRC. Air photo coverage at a variety of scales is available through the B.C. Ministry of Crown Lands - Surveys and Resource Mapping Branch (MAPS-

B.C.). In addition, larger scale and specialized maps (e.g. soils maps, terrain maps, etc.) are also available for some areas from MAPS-B.C., MOE, and the B.C. Ministry of Forests.

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.

3.3 HYDROLOGY AND CLIMATE

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. 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. Hydrologic records may be obtained from MOE or Water Survey of Canada. Climatological station records are available for many sites from Environment Canada. Water license records are also maintained by MOE. In addition, seasonal precipitation maps are available for some areas through MAPS-B.C.

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

3.4 BEDROCK GEOLOGY AND TECTONICS

The geological setting of the mine and dump should be considered during site selection and design. Adversely oriented geologic structures, such as faults, bedding planes or joints, may affect the stability of the foundation, and could influence surface drainage patterns and groundwater flow systems. Competency and durability of the bedrock 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.

A knowledge of the geological characteristics of the mine rock materials which will form the dump is also required. Key parameters such as lithology, alteration, weathering, geologic structure and rock fabric influence the strength, gradation, durability and other important characteristics of the dump materials.

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

Sources of available information on geology may include published and unpublished geologic maps, open file reports, regional and local geology studies, theses and journal articles. This type of information is commonly available through the Geological Survey of Canada (GSC), universities and public libraries. 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. Seismic zoning maps and hazard assessments are available through the GSC.

Preliminary field studies would normally include air photo interpretation, ground reconnaissance and outcrop mapping, supplemented by trenching or test pitting, if required. Drilling records and cores would be examined and geotechnical core logging may be conducted to supplement geologic logging and assist in characterizing the rock mass. If bedrock exposures are limited, and exploration drilling coverage is sparse, additional drilling may be required.

3.5 SURFICIAL GEOLOGY AND SOILS

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.

Sources of information on surficial geology and site soils include published surficial geology maps and reports, soil survey studies and soils maps, theses and journal articles. These are commonly available through the GSC, MAPS-B.C., and university and public libraries. In addition, geological maps and reports often make reference to, and describe, surficial soils. Air photos and topographic maps are also useful sources of information. Exploration reports and drill logs may include information on the general character and depth of surficial soils. Water well logs may also be a source of information.

Surficial geology investigations commonly begin with a preliminary interpretation of black and white and/or colour air photos, followed by ground reconnaissance and mapping of soil exposures in road cuts, stream channels, etc. Trenching and test pitting should be employed 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.

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 using mud or air rotary, Becker, hollow or solid stem augers, vibracore or other types of drilling rigs. The choice of the drilling rig would depend on cost, availability, types of soil deposits to be drilled and sampling objectives. Downhole in situ testing, such as standard penetration, cone penetrometer or pressuremeter would be used to assess the distribution, density, strength and stratigraphy of problem soils. Representative samples would be obtained, consisting of split-spoon or pitcher samples (i.e. disturbed) for basic stratigraphy and classification, or thin-walled (e.g. Shelby, piston) samples or block samples (i.e. undisturbed samples) for more sophisticated testing. In cases where a detailed knowledge of the in situ density, stratigraphy and/or depth to bedrock is required, geophysical methods, such as seismic refraction, resistivity and shallow radar, would be employed to supplement information from test pits, trenches or boreholes.

3.6 HYDROGEOLOGY

Foundation conditions, stability and requirements for underdrainage or liners are directly influenced by the hydrogeology of the site. 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. Basic information that is required includes the distribution of discharge and recharge areas, climatic conditions, geometry and hydrogeologic characteristics of the various soil and bedrock units, position of the water table and the occurrence of perched water tables, distribution of piezometric pressures and information on current groundwater usage.

Sources of information on site hydrogeology are generally scarce, and site specific studies will be required to develop the necessary data. Regional hydrogeologic maps or studies are generally not available. However, exploration drilling records which indicate drilling fluid consumption and returns, standing water levels in boreholes, and general groundwater conditions or drilling difficulties are useful sources of information. (Well logs, pumping tests on domestic or irrigation wells and water license records, all of which are available through MOE, are also useful.) In addition, topographic maps, air photos and agricultural or forestry maps and reports can provide useful insight into groundwater flow systems and usage. Some geologic and surficial geology maps and reports also make reference to groundwater conditions, the occurrence of significant aquifers, etc.

The first step in a hydrogeological investigation consists of a preliminary identification of possible groundwater discharge areas using air photos and topographic maps. This desk study is then followed by ground reconnaissance and basic hydrogeologic mapping (i.e. location of springs, seeps and other evidence of groundwater discharge). Groundwater levels in local wells, and inflows into trenches and test pits would be documented, and shallow open standpipe piezometers may be installed. Sampling of wells or drillholes and other sources of groundwater, and field testing of physical properties (e.g. temperature, pH and conductance) would also be conducted. Simple percolation tests would be carried out to gain an initial appreciation for the infiltration characteristics of the surficial soils.

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 would be conducted. In unusual cases, where a detailed knowledge of the flow systems is required, flow tracing with fluorescent dyes or radioisotopes, or geophysical methods (e.g. resistivity, refraction seismic, etc.) would be used to supplement borehole and piezometer information. More sophisticated infiltration testing (e.g. double ring infiltrometer) would also be carried out if evaluation and design of a contaminated seepage collection system was required.

3.7 ENVIRONMENT AND CULTURE

One of the prime objectives of a mine dump design is to minimize the impact of the development on the environment. Protection of cultural and other resources is also a priority. To be able to rationally assess potential impacts and develop mitigative measures, it is necessary to document environmental conditions and resources at the outset of the project. The important environmental characteristics which must be evaluated include surface water quality, groundwater quality, air quality, fish and wildlife habitat and productivity, and vegetation. Present land uses must be identified, and existing and potential forestry and agricultural resources evaluated. Archaeological and recreational resources must be identified, and the aesthetics of the site must be considered. Also, questions of land ownership and acquisition, and the potential for native land claims must be addressed.

Sources of information on environmental, cultural and other resources include forestry, agricultural and land use maps, which are available for many areas of the province through MAPS-B.C. Information on local fish and wildlife may be available through MOE, Fisheries and Oceans Canada, Parks Canada, Environment Canada and other government agencies. Air photos and topographic maps are also useful. Land registry offices and local government agents may provide relevant data. Consultations with the local population at an early stage of the project are strongly advised.

Baseline environmental investigations should include surface and groundwater quality sampling and field testing of basic physical properties (e.g. pH, temperature and conductance). Site reconnaissance, documentation of habitat, and inventorying of fish, wildlife and vegetation species must also be conducted. Archaeological reconnaissance should also be conducted.

The above is intended only as a general discussion of the nature and scope of environmental and cultural studies which might be required. It is essential that appropriate government agencies (e.g. B.C. Ministry of Environment, Environment Canada, Fisheries and Oceans Canada, etc.) be contacted at an early stage of project evaluation to determine the specific requirements for documentation and baseline monitoring, as well as appropriate field procedures. It is important to note that comprehensive environmental, cultural and socio-economic studies relating to the overall site and surrounding lands are required for overall project approval. Detailed, dump specific investigations would be determined in the context of the overall environmental/cultural impact assessment.

4. MATERIAL PROPERTIES AND TESTING

4.1 GENERAL

The engineering properties of foundation and dump materials are required for design. It is equally important to establish baseline surface and groundwater quality data against which to predict the overall impact of the dump on the environment, and to provide a benchmark for ongoing monitoring.

Selecting and obtaining representative samples for materials testing, interpreting results and applying them to design requires a thorough understanding of the various components of the physical environment outlined in Section 3 above. The type and amount of testing required will vary, depending on: the complexity of site conditions; the location, type, size and configuration of dump; the environmental sensitivity of the site; and other factors. For large dumps, or dumps located on a complex and environmentally sensitive site, substantial detailed testing may be required. In cases where a probabilistic approach to design is adopted, a large testing program may be required to supply sufficient data for statistical analysis.

Many of the parameters required for analysis and design may be derived from empirical criteria based on qualitative classifications and descriptions. However, where testing programs are limited in scope, or critical parameters cannot be reliably determined using available and practical testing techniques, conservative assumptions and design approaches must be adopted.

4.2 FOUNDATION SOILS

Important properties of foundation soils, their application in the design process, and methods for measuring them in the field and laboratory are described in the following and summarized in Table 4.1. More detailed descriptions of the various soil properties are given in most introductory soil mechanics text books, such as Craig (1983), Peck et al (1974) and Terzaghi and Peck (1967). OSM (1989), USBM (1982) and MESA (1975) all provide good

TABLE 4.1

MATERIAL PROPERTIES AND TESTING FOR FOUNDATION SOILS

MATERIAL PROPERTIES	APPLICATION	IN SITU / FIELD TESTING	LABORATORY TESTING	REFERENCES
DESCRIPTION –Colour –Odour –Texture –Fabric, structure	–Soils mapping, classification, interpretation –Identification of problem soils –Weathering characteristics –Important structures, fabric –Various empirical correlations –Grouping samples for testing	–Field description (1)	–Microscopic examination (20)	–Martin (1991): 6,11,18 –BCAMD Task Force (1990): 32–34 –OSM (1989): 4,6,10,12,16,18, 19,21–30,32–35 –CGS (1985): 1–6,10,12,16,17 –Craig (1985): 1–6,8,12,14,16, 17,21–30,35 –USBM (1982): 6,10,12,26,27,29, 30,35 –Zavodni et al (1981): 7 –Freeze & Cherry (1979): 6–8, 26,33,34 –Hurlbut & Klein (1977): 20,31 –Kerr (1977): 20 –MESA (1975): 2,3,6,21–24, 26–29,35 –Peck et al (1974): 1–5,10,12, 16,18, 21–30,35 –Dept. of the Navy (1971): 1–3,5, 9,10,12,18,21–27 –Terzaghi & Peck (1967): 1,2,5,8, 9,10,12,14,16,18,21–30,35 –Lambe (1951): 21–30,35
INDEX PROPERTIES –Gradation –Plasticity –Moisture content –Unit weight –Specific gravity	–Classification –Empirical correlations with permeability, strength, consolidation –Volume/weight relationships	–Visual estimation of gradation (2) –Estimation of plasticity via dilatancy, toughness, dry strength (3) –In situ density/moisture testing (4) –Preliminary classification (5)	–Sieve (21) –Hydrometer (22) –Atterberg Limits (23) –Various direct and indirect methods of measuring volume/ weight parameters (24) –Lab classification (25)	
HYDRAULIC CONDUCTIVITY	–Estimation of seepage, drainage quantities –Prediction of piezometric conditions –Assessment of effectiveness of soils as natural liner	–Piezometer and borehole testing (6) –Infiltration testing (7) –Pumping tests (8)	–Permeameter (26)	
CONSOLIDATION	–Pore pressure dissipation –Settlement	–Survey monuments, settlement plates and piezometers in conjunction with test fill (9)	–Consolidation (27)	
STRENGTH	–Foundation stability –Bearing capacity –Strain to failure	–Empirical correlations with penetration tests (10) –Field hardness (11) –Vane shear (12) –Pocket penetrometer (13) –Back analysis of natural failures (14)	–Unconfined compression (28) –Direct shear (29) –Triaxial (30)	
MINERALOGY / SOIL CHEMISTRY	–Presence of swelling or low friction clay minerals –Neutralization, adsorption potential –Documentation of existing contaminant levels	–Acid test for carbonates (15)	–X-ray diffraction, scanning electron microscope (31) –Acid-base accounting (32) –Adsorption (33) –Other physical/chemical tests to to detect specific contaminants (34)	
IN SITU DENSITY	–Empirical correlation with strength, settlement, liquefaction potential	–Penetration testing (16) –Pressuremeter (17) –Geophysics (seismic, density logging) (18)	–Consolidation (27)	
COMPACTION	–Design of liners –Design of mitigative or remedial measures	–Volumeter, sand cone , nuclear densometer on test fills (19)	–Consolidation (27) –Standard, Modified Proctor (35)	

NOTE: Numbers in parentheses refer to the selected references listed on the far right which contain detailed descriptions and/or specifications for the various field and laboratory tests.

discussions on basic soil parameters, and field and laboratory testing methods. CGS (1985) and Dept. of the Navy (1971) describe in situ testing and sampling techniques. A comprehensive summary of the most common laboratory tests, ASTM testing specifications and guidelines for interpreting and correlating test results is given in Dept. of the Navy (1971). Detailed sample specifications and testing procedures are described by Lambe (1951), ASTM and BSI (1975).

4.2.1 Description

All significant soils units and weathering horizons occurring within the site should be described. Descriptions should generally include: colour, grain size, fabric or structure, odour, texture, etc., and are useful in identifying and classifying basic soil types and weathering characteristics.

Descriptions also provide a useful means for separating soil samples into representative groups for subsequent testing. As indicated above, many soil parameters required for analyses can be derived from empirical correlations based on descriptions of soil types and preliminary soil classification.

Preliminary soil descriptions are commonly prepared in the field, in conjunction with reconnaissance, test pitting and drilling. These descriptions are based on how the soil looks to the unaided eye or under a hand lens, and how it feels and smells. Field conditions are commonly not ideal, and some sampling techniques, such as thin walled piston samples, do not lend themselves to detailed descriptions in the field. Hence, a follow-up laboratory description of selected samples, possibly including microscopic examination, is recommended.

4.2.2 Index Properties and Classification

Index testing should be conducted on each of the major soil groups and weathering horizons identified during field investigations. Index properties such as gradation and plasticity are important for soil classification. Index properties also provide an indication of some of the key engineering properties, such as shear strength, permeability and consolidation. Parameters such as natural moisture content, unit weight and specific gravity, provide information on the volume-weight relationships of the soil, which are used in a wide variety of calculations including: consolidation rates, pre-consolidation pressures, porosity, stability calculations, etc. Natural moisture content also provides an indication of the in situ state of the soil in relation to its plastic and liquid limits.

Preliminary visual estimates of gradation are prepared in the field. The experienced geotechnical engineer can estimate the percentage of cobbles and boulders, gravel, sand, silt and clay. The consistency or plasticity of fine soils is qualitatively estimated using simple field tests such as dilatancy, dry strength or toughness.

Field descriptions and estimates of index properties are used to prepare a preliminary soil classification. Although numerous classification schemes are available, the Unified Soil Classification System (USCS) (Wagner, 1957) is the most widely used and accepted, and is applicable to most of the soil types likely to be encountered. One exception is very coarse grained soils consisting predominantly of cobbles and large boulders. In such cases, percentage estimates of boulder sizes, shapes and lithologies should accompany the USCS classification of the finer (i.e. gravel size and smaller) fraction of the soil.

Laboratory testing of index properties is conducted to confirm field estimates and refine preliminary classifications. Laboratory gradation analysis consists of sieve testing of coarse grained soils and hydrometer testing of fine grained soils. Combined sieve/hydrometer testing may be required for mixed grained soils. Atterberg Limits (e.g. plastic limit, liquid limit, etc.) and natural moisture content are used to assess the consistency of the soil. Specific laboratory tests are also available for measuring such parameters as dry unit weight, specific gravity, porosity, etc.

4.2.3 Hydraulic Conductivity

A knowledge of the hydraulic conductivities of the various soil units is necessary for seepage analysis, prediction of piezometric conditions within the foundation, assessment of the effectiveness of natural and constructed liners and design of underdrainage measures. For simple, low hazard dumps, or for preliminary studies, order of magnitude estimates of hydraulic conductivity based on empirical correlations with index properties (e.g. grain size) and soil descriptions, and percolation tests in hand-dug holes, may be sufficient. For more complex dumps, dumps in sensitive environments or on difficult foundations, or where specific measures for liners or seepage collection systems are required, more accurate measurements of hydraulic conductivity, based on specific field and laboratory testing, will be required.

In situ field measurement is usually the most reliable method for obtaining hydraulic conductivity data. In the field, materials can be tested in their natural state with minimal disturbance. Also, such factors as structure and fabric, which may have a significant influence on hydraulic conductivity, are difficult or impractical to simulate in the laboratory.

Double-ring infiltrometer testing would be conducted for detailed evaluation of the infiltration characteristics of the natural soils, and to confirm the assumed hydraulic conductivity of constructed liners. Falling head tests in piezometers or open boreholes would be conducted to assess in situ hydraulic conductivity of specific soil strata. Where significant aquifers occur, packer testing and/or pump testing would be required to determine aquifer parameters such as storativity and transmissivity.

Laboratory permeability testing would consist of constant or falling head permeameter tests on relatively undisturbed samples, such as thin walled piston or Shelby tube samples. Compaction permeameter testing of reconstituted samples would conducted to determine hydraulic conductivity parameters for underdrainage or liner design. Hydraulic conductivity measurements would also be obtained in conjunction with consolidation testing of fine grained soils as described below.

4.2.4 Consolidation

Where dumps founded on fine grained soils, an assessment of the consolidation characteristics of the underlying soils will be required. This information is necessary to be able to predict foundation settlements and the potential for generation and dissipation of excess pore pressures due to dump loading. Excess pore pressures in dump foundations can significantly reduce overall dump stability during construction; consequently, safe dump advancement rates may be limited by the rate at which excess pore pressures can be dissipated.

Consolidation settlement of foundation soils may also reduce infiltration and improve the shear strength characteristics of foundation materials. Conversely, consolidation of foundation soils will induce strain in the dump material, with a consequent change in shear strength and behaviour. If substantial settlements do occur, drainage blankets, finger drains, lined ditches, etc., may be disrupted, and this must be taken into consideration in the design of such measures.

Laboratory testing consists of one-dimensional consolidation testing on undisturbed samples. Alternatively, consolidation and hydraulic conductivity parameters may be obtained from the consolidation stages of certain types of triaxial and direct shear tests. Where excess pore pressure dissipation rates or settlement are critical to design, confirmation of parameters based on laboratory testing using field monitoring of test fills is recommended. Monitoring would likely consist of settlement plates and survey monuments to record displacements, and piezometers to monitor pore pressures.

4.2.5 Strength

The shear and compressive strength characteristics of the foundation materials are required for assessment of foundation stability and bearing capacity. For preliminary assessments, or where dumps are founded on competent soil strata (e.g. over consolidated, hard glacial till; dense sand and gravel; dense colluvium, etc.), conservative estimates of shear strength may be used, based on correlations with soil classifications and index properties (e.g. Terzaghi and Peck, 1967; Dept. of the Navy, 1971) and simple in situ strength index testing (e.g. pocket penetrometer, hand-held vane shear, etc.). In addition, natural slope or previous foundation failures should be back analyzed for effective strength parameters.

Where foundation conditions are complex, or foundation soils are fine grained, soft or susceptible to consolidation, pore pressure generation or other adverse effects, more detailed field and laboratory testing would be required. The number and type of tests to be conducted, and conditions of testing, depend on the complexity of site conditions, the nature of the soil to be tested and the loading conditions to which it will be subjected.

Where fine grained soils are present in the dump foundation, they will commonly be the weakest strata and merit the closest attention. Undisturbed samples (e.g. Shelby tube, piston samples, block samples) obtained from geotechnical boreholes or test pits would be subjected to unconfined compression, triaxial compression or direct shear. Test conditions (e.g. pore pressures, strain rate, loading rate, preconsolidation pressures, confining stress, etc.) would be controlled to simulate conditions both during dump construction (normally the worst case), and over the long term. Sufficient tests would be conducted to reliably establish the stress/strength characteristics of each unique soil strata.

Undisturbed samples of mixed grained or coarse grained soils are usually difficult or impractical to obtain. Softened glacial tills may present a particularly difficult sampling and testing problem, if they contain appreciable amounts of gravel, cobbles or boulders. If it is not possible to obtain reasonable undisturbed samples of such materials, pocket penetrometer or vane shear testing may provide the most reliable strength information. Laboratory strength testing of mixed or coarse grained soils is generally limited to triaxial or direct shear testing of reconstituted samples, which may not be very representative of in situ soil conditions. Test results are commonly interpreted as lower bound or conservative assessments of strength, and testing would normally only be conducted where preliminary assessments based on conservative strength assumptions indicate that the shear strengths of these materials is critical to design. One exception would be if unfavourably oriented discontinuities (e.g. bedding planes, slip planes, etc.) occurred within mixed grained soils and could be sampled intact. In such cases, direct shear testing along the discontinuity would be conducted.

In situ testing of complex, sensitive soil conditions would be carried out in conjunction with geotechnical drilling, and would normally consist of Standard Penetration or cone penetrometer testing. Empirical correlations are available which relate penetration resistance with shear strength and other parameters (e.g. CGS, 1985; Dept. of Navy, 1971; Peck et al, 1974). Penetration testing would also be used to correlate results of laboratory shear strength testing with in situ conditions.

4.2.6 Mineralogy and Soil Chemistry

The presence of swelling or low strength clay minerals can have a significant impact on the shear strength characteristics and behaviour of the soil. In addition, soil chemistry and clay mineralogy influence the ability of the foundation materials to neutralize leachate and adsorb contaminants released from the dump.

Although some basic soil chemistry parameters can be measured in the field, the bulk of testing is done in the laboratory. Mineralogical and contaminant testing, consisting of x-ray diffraction studies or other chemical or physical tests, would be conducted if problem clays or contaminants are anticipated, or in cases of very sensitive environments. Acid-base accounting of foundation soils would be conducted if a potential exists for acid generation in the waste materials.

4.2.7 In Situ Density

The in situ density of soils directly impacts shear strength, the potential for settlement of the foundation, and resistance to liquefaction during construction or in an earthquake. Empirical correlations between density, liquefaction potential and penetration indices (Standard Penetration, cone penetration, pressuremeter) are available (e.g. Seed and de Alba, 1986). As indicated above, penetration testing would normally be carried out in conjunction with geotechnical drilling. Where foundations consist of sandy or silty soils, such as on flood plains, in situ density testing is strongly recommended to assess the potential for liquefaction. In situ density of fine grained soils would also be determined in the laboratory in conjunction with other testing (e.g. consolidation, shear strength, etc.).

4.2.8 Compaction

Assessment of the compaction characteristic of the foundation soils would be required if foundation remedial or mitigative measures are contemplated, such as proof rolling or berm or liner construction. Field measurements are generally restricted to density measurements on test fills or proof rolled soils using nuclear densometers, sand cones or volumeters (Dept. of Navy, 1971). Laboratory compaction testing usually consists of Standard or Modified Proctor density testing (Lambe, 1951).

4.3 FOUNDATION BEDROCK

In addition to the basic geologic characteristics of the foundation bedrock, which would normally be evaluated during the field investigation phase (see Section 3.4), other properties of the bedrock which may be important in design are described in the following and are summarized in Table 4.2. Field and laboratory methods for characterizing important bedrock parameters are also given in Table 4.2. In the case of very weak, soil-like rocks, similar investigation and testing requirements as described above for foundation soils would be required. More detailed descriptions of the various bedrock properties are given in most introductory rock mechanics text books, such as Goodman (1980) Martin (1991), CGS (1985) and Hoek and Bray (1977) describe field data collection and sampling. Laboratory testing techniques and specifications are described by Martin (1991), Jaeger and Cook (1970) and ISRM.

4.3.1 Description

Descriptions of each of the major rock units identified during the field investigations should be prepared, and the rock classified according to lithology and origin. Basic descriptions and classifications are useful in assessing the general character of the bedrock. Preliminary, qualitative estimates of important parameters, such as compressive strength and durability, may be based on typical values for a particular rock type (e.g. Goodman, 1980; Hoek and Bray, 1977). In many cases, further testing of the bedrock may not be required.

Normally, an experienced geologist or geotechnical engineer would be able to describe the rock types in sufficient detail in the field using the unaided eye or a hand lens. However, in some cases (e.g. fine grained or clay-rich rocks), a more thorough investigation of the mineralogy or petrography of the rock, such as described below, may be required to adequately describe the rock.

4.3.2 Strength

The intact rock strength and the shear strength of discontinuities may have an influence on the stability or bearing capacity of the foundation. Preliminary estimates of compressive strength may be based on empirical

TABLE 4.2

MATERIAL PROPERTIES AND TESTING FOR FOUNDATION BEDROCK

MATERIAL PROPERTIES	APPLICATION	IN SITU / FIELD TESTING	LABORATORY TESTING	REFERENCES
DESCRIPTION –Lithology –Origin, name –Fabric, micro–structure	–Classification –Durability, weathering characteristics –Empirical correlations with intact strength –Strength anisotropy, weakness planes	–Field description (1) –Preliminary classification (2)	–Microscopic examination, thin sections (12) –Detailed classification (13)	–Martin (1991): 3,4,8,9,13–16, 19–21 –OSM (1989): 1,2,8,14–16,19,20 –CGS (1985): 1,2,3 –Barton & Kjaernsli (1981): 5 –Zavodni et al (1981): 10 –Freeze & Cherry (1979): 9–11,18 –Hurlbut & Klein (1977): 12,17 –Kerr (1977): 12 –Peck et al (1974): 1,2,8,9,11, 14–16,19
INTACT STRENGTH	–Foundation stability –Bearing capacity	–Field hardness (3) –Point load testing (4)	–Unconfined compression (14) –Triaxial (15)	
SHEAR STRENGTH OF DISCONTINUITIES	–Foundation stability	–Tilt tests (5) –Back analysis of natural failures (6)	–Direct shear (16)	
MINERALOGY AND PETROGRAPHY	–Presence of swelling or low friction clay minerals –Durability –Rock fabric, micro–structure –Rock classification	–Acid test for carbonates (7)	–X–Ray diffraction, scanning electron microscope (17) –Thin sections (12) –Geochemical analyses (18) –Atterberg limits on disaggregated rock (19)	
DURABILITY	–Potential for loss of strength, bearing capacity over the long–term –Trafficability –Potential for reduced hydraulic conductivity over the long–term	–Weathering of outcrops (8)	–Slake Durability (20) –Sulphate Soundness (21)	
HYDRAULIC CONDUCTIVITY	–Estimation of seepage, potential loss of leachate –Prediction of piezometric conditions for assessment of foundation stability	–Piezometer and borehole testing (9) –Infiltration testing (10) –Pump tests on aquifers (11)	–	

NOTE: Numbers in parentheses refer to the selected references listed on the far right which contain detailed descriptions and/or specifications for the various field and laboratory tests.

correlations as described above, or on simple field hardness tests such as described by Piteau (1970). Where more detailed information on rock strength is required, Point Load Index testing of typical core samples, from exploration drilling or hand specimens, would be conducted. Laboratory testing of intact strength of foundation bedrock would only be required where the foundation bedrock is very weak. Shear testing of discontinuities using field tilt testing, laboratory direct shear testing or back analysis of bedrock failures, would be conducted where failure along discontinuities in the foundation is possible.

4.3.3 Mineralogy and Petrography

The presence of swelling or low strength clay minerals, micro-cracking and other rock fabrics can have a significant influence on the durability and strength of foundation bedrock. A knowledge of the mineralogy and petrography of the rock may also assist in rock classification and description. Laboratory methods for studying clay mineralogy and petrography include x-ray diffraction, scanning electron microscope and thin sections (Kerr, 1977; Hurlbut and Klein, 1979). Atterberg Limit determinations on clay seams or disaggregated rock may also be helpful in identifying clay minerals.

4.3.4 Durability

Durability of the bedrock materials forming the dump foundation may influence long term foundation stability. Shear strength characteristics and bearing capacity of the bedrock may diminish with time if the bedrock degrades. Preliminary qualitative assessments of the susceptibility of bedrock to degradation should be based on observations of weathering of outcrops and swelling or degradation of exploration drill core. If preliminary assessments indicate the bedrock may be susceptible to weathering and degradation, Slake Durability and Sulphate Soundness testing should be conducted. Slake durability provides an indication of the susceptibility of the rock to mechanical breakdown, whereas sulphate soundness is a measure of the susceptibility of the rock to freeze-thaw degradation.

4.3.5 Hydraulic Conductivity

As indicated in Section 4.2.3 above, the hydraulic conductivity of the foundation affects seepage and piezometric conditions, and may determine the need for liners or underdrainage measures. Where preliminary field investigations indicate significant aquifers or potentially adverse groundwater conditions may exist in the foundation, hydraulic conductivity testing should be conducted. The only practical methods for assessing bedrock hydraulic conductivity involve in situ measurement techniques, such as infiltration, piezometer, borehole or pumping tests, as described in Section 3.6.

4.4 MINE ROCK

Important properties of mine rock which may influence stability and design are discussed by OSM (1989), Golder Associates (1987), Call (1981) and others, and are described below in Table 4.3. In contrast to foundation soils and overburden materials, relatively little work has been carried out to quantify the important physical characteristics of mine rock. This lack of information undoubtedly relates to the difficulty and expense of sampling and testing materials with diverse grain size (i.e. clay to boulders several metres in dimension) and physical properties.

The common practice in B.C. has been to select mine rock parameters for design using an observational approach based on existing dumps or precedence from dumps at other mines constructed with similar rock materials. Alternatively, several empirical approaches have been proposed (e.g. Barton and Kjaernsli (1981), Hoek (1983)); however, none has been rigorously tested or calibrated for mine rock materials common to B.C. Clearly, a more deterministic and reliable approach to quantifying critical mine rock parameters for design would be desirable, and merits research and development.

TABLE 4.3
MATERIAL PROPERTIES AND TESTING FOR MINE ROCK

MATERIAL PROPERTIES	APPLICATION	IN SITU / FIELD TESTING	LABORATORY TESTING	REFERENCES
DESCRIPTION -Lithologies -% Composition -Fabric, micro-structure -Particle shape, angularity	-Classification -Durability -Empirical correlations with intact and shear strength -Strength anisotropy	-Field description (1) -Preliminary classification (2) -Geotechnical Core Logging (3)	-Microscopic examination, thin sections (18) -Detailed classification (19)	-Martin (1991): 3,8,9,13,18, 19-27,29-31 -BCAMD Task Force (1990): 34-37 -OSM (1989): 1,2,4,11,16,17, 20-27,29,35
BULK GRADATION	-Empirical correlations with shear strength, hydraulic conductivity -Evaluation of potential segregation	-Visual estimation (4) -Field screening (5) -Segregation field trials (6)	-Sieve (20) -Hydrometer (21)	-West (1989): 32 -Golder Assoc. (1987): 4,5, 11,14
PLASTICITY OF FINES	-Classification -Empirical correlation with shear strength -Indication of clay mineralogy	-Toughness, dilatency, dry strength (7)	-Atterberg limits on fines or disaggregated rock (22)	-Nichols (1986): 6 -CGS (1985): 1,2,7,8,19,26,27 -Barton & Kjaernsli (1981): 10
INTACT STRENGTH	-Durability -Empirical correlation with shear strength	-Field hardness (8) -Point load testing (9)	-Unconfined compression (23) -Triaxial (24)	-Hurlbut & Klein (1977): 18,28 -Kerr (1977): 18
SHEAR STRENGTH	-Failure criteria -Embankment stability	-Field shear box/tilt test (10) -Documentation of repose angle slopes (natural and existing dumps) (11)	-Large scale direct shear or triaxial shear (25) -Small scale direct shear (26) -Small scale triaxial (27)	-MESA (1975): 7,14,20-24,26 -Peck et al (1974): 1,2,7,13,22 -Dept. of the Navy (1971): 2,7, 19-22
MINERALOGY AND PETROGRAPHY	-Presence of swelling or low friction clay minerals -Durability -Rock fabric, micro-structure -Rock classification	-Acid test for carbonates (12)	-X-Ray diffraction (28) -Thin sections (18) -Atterberg limits on fines or disaggregated rock (22)	
DURABILITY	-Potential for loss of shear strength over the long-term -Trafficability -Potential for reduced hydraulic conductivity over the long-term	-Weathering of outcrops, existing dumps (13)	-Slake durability (29) -L.A. Abrasion (30) -Sulphate Soundness (31) -Cherchar Test (32)	
HYDRAULIC CONDUCTIVITY	-Estimation of seepage rate, quantities -Prediction of piezometric conditions -Assessment of rock drain requirements	-Empirical correlations based on gradation (14)	-Compaction permeameter on fines (33)	
CONSOLIDATION AND SETTLEMENT	-Shear strength -Consolidation and settlement	-Unit weights estimated based on typical bulking factors, with some allowance for consolidation (15)	-	
GEOCHEMISTRY	-Environmental impact -Potential for heavy metals leaching, adsorption -Potential for ARD, neutralization	-Seep surveys (16) -Stream measurements of pH, conductivity, etc. (17)	-Column leaching (34) -Acid-base accounting (35) -Humidity cell (36) -Assays for specific potential contaminants (37)	

NOTE: Numbers in parentheses refer to the selected references listed on the far right which contain detailed descriptions and/or specifications for the various field and laboratory tests.

In the absence of a reliable method for evaluating critical dump material parameters prior to dump construction, conservative assumptions must be made. Assumptions which are critical to design must be verified during the early phases of dump construction. Suggested approaches for evaluating the key physical and geochemical properties are given in the following and summarized in Table 4.3. In many cases, characterization and laboratory testing techniques are similar to those given in Sections 4.2 and 4.3 above, and references given in those sections should be consulted for additional details on testing procedures and specifications.

4.4.1 Description

A basic description of mine rock materials should include a description of each major rock type, and an estimate of the percentage of the dump materials comprised by each type. In this regard, exploration drill cores, borehole geophysical logs, blasthole sampling, geologic mapping and other basic exploration techniques will provide useful information. Rock type descriptions should include factors such as lithology, fabric, particle angularity and shape. These factors have been demonstrated by Leps (1970) to have an impact on durability and strength of rock fill. In the case of potentially acid generating rocks, the type and percentage of sulphides and basic mineral (e.g. calcite) and their distribution in the host rock and on joints should be described.

In most cases, an experienced geologist or geotechnical engineer would be able to describe the rock types in sufficient detail in the field using the unaided eye or a hand lens. However, in some cases, a more thorough investigation of mineralogy or petrography of the rock may require microscopic examination or thin section studies. It is important to note that the composition of the mine rock may vary, depending on the phase of dump construction, the area being mined or other mine planning considerations. Hence, potential variations in the characteristics of the mine rock materials throughout the construction of the dump must be considered.

4.4.2 Bulk Gradation

The overall gradation of the mine rock has a direct impact on the shear strength and permeability characteristics of the dump. In general, coarser materials, with few fines, has higher strength and hydraulic conductivity than materials with appreciable fines. Where mine rock contains less than about 10% fines (i.e. fraction finer than No. 200 mesh), the most important factors controlling gradation are hardness and compressive strength of the rock fragments. Coarse dump materials generally derive their strength from interparticle contacts, and exhibit engineering properties similar to rockfill.

The gradation of mine rock depends on a wide variety of factors, including: lithology, durability, frequency and character of discontinuities, blasting and excavation technique, handling and transportation, placement methods, and other factors. Gradation may also change with time, due to mechanical or chemical breakdown (e.g. freeze-thaw, swelling of clay minerals, oxidation, etc.). In the absence of existing dumps, only qualitative assessments of gradation are practical, based on assessment of the parameters described above.

Even where established dumps composed of representative mine rock materials are present, measurement of dump material gradation is usually limited to field estimation of the percentage of cobbles and boulders, and maximum particle size, combined with laboratory gradation analysis of relatively small samples of the finer fraction. More rigorous methods of establishing the gradation of the coarser fraction, using specially constructed field screens, have been employed on rare occasions; however, such testing is expensive.

Where fine grained materials form a significant percentage of the dump materials (i.e. greater than about 10% passing No. 200 mesh), the characteristics of these finer materials may control or strongly influence overall dump material properties, such as shear strength, hydraulic conductivity, rate of oxidation and potential acid generation, etc.

Hence, it is important to establish the percentage of fines and gradation range of the finer fraction of the dump materials. In this regard, sampling and gradation testing of dump materials with a maximum particle size of about 15 cm is usually practical and should be conducted. Periodic sampling and testing throughout dump construction is recommended to verify assumed gradations and document changes due to variation in mining area, excavation techniques, etc.

One of the fundamental properties of mine rock materials is the tendency for the materials to naturally segregate when placed using end-dumping techniques. The result of natural segregation is to create a zone of coarse, durable rocks at the base of the dump or lift, which may provide an effective underdrainage layer for the dump. The amount of segregation which may be achieved depends on a wide range of factors, including lift height, durability, initial bulk gradation and placement technique. The effects of various construction methods on segregation are described by Nichols (1986), who also describes an approach for evaluating segregation. Nichols found that more segregation was achieved by end-dumping directly over the crest vs. dumping short and pushing material over the crest using a bulldozer. Also the higher the dump or lift, the greater the segregation. In most cases, however, rigorous testing to establish likely segregation is impractical, and evaluations are usually limited to qualitative assessments based on judgement. Such assessments must be verified by field examination of dumps during construction.

It is important to note that gradation of dump materials may change with time. Fine grained rocks may slake, and rocks may be crushed under high normal or shear stresses. Freeze-thaw action, oxidation, weathering or other chemical alteration may result in breakdown. In addition, in gap-graded materials, fines may wash down through pervious zones, changing the hydraulic conductivity of the dump materials. The potential for reductions in grain size of the dump material must be recognized and possible impacts addressed in the design.

4.4.3 Plasticity of Fines

If a substantial component of silt sized or finer material occurs within the mine rock, the Atterberg Limits (i.e. plastic limit, liquid limit) of this material should be determined in the laboratory. Plasticity of the fines may have an impact on the shear strength characteristics of the material, and may be indicative of the type of clay minerals contained within it. Atterberg Limits may also be conducted on mechanically disaggregated, fine-grained sedimentary rocks.

4.4.4 Intact Strength

Strength of the intact rock fragments influences the durability and shear strength of the dump materials. 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, and for preliminary investigations, intact strength may be estimated based on empirical correlations with rock type (e.g. Goodman, 1980), field hardness tests (e.g. 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. In such cases, more detailed evaluations of intact strength, consisting of laboratory unconfined compressive testing should be conducted.

4.4.5 Shear Strength

An understanding of the shear strength characteristics of the dump materials is fundamental to analysis and rational design. The effective shear strength of dump materials depends on a wide variety of inter-related parameters including: intact particle strength and strength anisotropy, particle angularity, gradation, basic surface roughness and frictional properties, lithologic composition, mineralogy, degree of saturation, and others. As well, shear strength may change with time due to such factors as consolidation; degradation due to freeze-thaw, swelling or slaking; oxidation; leaching or other chemical changes; strains induced by foundation or internal adjustments; or migration of fines.

It is generally accepted that shear strength is also a function of confining stress, and several shear stress models for rock fill materials have been proposed (e.g. Marshal, 1973; Barton and Kjaernsli, 1981; Hoek, 1983). Each of these methods predicts non-linear behaviour, with the effective friction angle decreasing with increasing normal stress. Marshal (1973) predicts shear strength based on Mohr-Coulomb theory directly from results of large scale triaxial testing. Barton and Kjaernsli (1981) predict shear resistance indirectly, based on basic interparticle friction, compressive strength and particle roughness. Hoek (1983) relates shear strength to compressive strength and empirical coefficients which vary depending on the rock type and rock mass quality.

The common practice in assessing the shear strength of dump materials for analysis and design has been to assume a linear Mohr-Coulomb type failure criteria, with no cohesion and a friction angle represented by the natural repose angle of the materials. Repose angles of mine dumps are easy to document in the field, and typically range from 35° to 40°. This relatively simplistic approach to evaluating shear strength is considered reasonable 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 (i.e. <10% passing No. 200 mesh), and dump materials are not subject to degradation.

For larger, more complex 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, a more comprehensive assessment of shear strength is recommended. In such cases, several approaches are available. An accepted approach would be to adopt very conservative shear strength assumptions; however, this may result in overly conservative and uneconomic dump designs.

Alternatively, empirical techniques such as proposed by Barton and Kjaernsli (1981) or Hoek (1983) could be employed. In this case, comparison of results with published data such as Marshal (1973) or Leps (1970) should be conducted to confirm the reasonableness of the results. Because of the lack of published data on shear strength testing of mine rock, and consequent lack of calibration of empirical failure criteria, reliance of empirical predictions of shear strength parameters alone is not recommended at this time. Empirical predictions should be supplemented by at least some testing, using one or more of the approaches described below.

As described above, development of a reliable empirical method for predicting shear strength of typical dump materials, or calibration of one or more of the existing empirical techniques, would be an important contribution and merits study. Large scale direct shear or triaxial testing of representative dump materials could be conducted; however, such tests are difficult and costly, and few if any local testing facilities are available.

More practically, direct shear or triaxial testing could be conducted on the fine fraction of the dump material. Maximum gradation for the sample would depend on the size of the test mould. Tests should be conducted at a variety of initial densities and normal or confining loads to simulate the range of stresses and densities likely to occur within the dump. Shear strain during testing should be sufficient to determine both peak and residual shear strengths. Testing should also be conducted on degraded materials, if degradation was considered likely. Testing results would be evaluated, and conservative strength parameters would be chosen for both short and long term stability considerations.

4.4.6 Mineralogy and Petrography

The presence of swelling or low strength clay minerals, micro-cracking and other rock fabrics can influence the durability and strength of the dump materials. A knowledge of the mineralogy and petrography of the rock may also assist in rock classification and description. Where preliminary descriptions indicate that expansive clay minerals or adverse micro-structures may be present, x-ray diffraction, scanning electron microscope and/or thin section examinations should be conducted. In addition, Atterberg Limit should be determined for disaggregated samples of fine grained sedimentary rocks or other rocks containing clay minerals, to assist in identifying the types of clay minerals which may be present.

4.4.7 Durability

Durability and the potential for physical or chemical degradation of mine rock influence the long term shear strength and hydraulic conductivity of the dump, as well as the short term trafficability and infiltration characteristics of the travelled dump surface. Slaking characteristics are very important for long term sulphide exposure and acid generation, as well as stability of the dump surface in terms of slumping and erosion. Also, weathering and mechanical breakdown of dump materials may be accelerated by stress conditions in large, high dumps, and should be taken into consideration.

Qualitative assessments of durability may be based on observed 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, and for rock materials proposed for rock drains, laboratory durability and physiochemical tests, such as Slake Durability, Los Angeles Abrasion, Sulphate Soundness, Cerchar Abrasion, freeze-thaw, swelling or others should be conducted.

4.4.8 Hydraulic Conductivity

Estimates of the hydraulic conductivity of dump materials may be required for seepage analysis and assessment of underdrainage requirements. They may also be required to be able to predict piezometric conditions within the dump which could lead to instability.

Due primarily to natural segregation of dump materials during construction, and variability of effective compaction throughout the dump, a wide range in hydraulic conductivity can be expected, depending on the location within the dump, and the direction of measurement. Hydraulic conductivity can also change with time due to migration of fines or slaking or weathering of dump materials. Hence, in situ or laboratory testing programs to accurately assess hydraulic conductivity are usually not worthwhile. Preliminary estimates of hydraulic conductivity have commonly been based on empirical correlations with gradation (e.g. 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.

4.4.9 Consolidation and Settlement

The relative amount of consolidation and settlement the dump undergoes during and following construction directly influences the density and shear strength characteristics of the dump materials. Depending on construction techniques, different areas within the dump may receive widely different compactive efforts. Settlement characteristics may vary, resulting in differential settlement with time and consequential cracking, which may lead to disruption of surface drainage, covers, etc., and highly localized infiltration and leaching of dumps.

Due to the coarse nature of most mine rock materials, laboratory compaction testing is difficult, and results are generally not representative. Hence, compaction and density/unit weight testing are usually not conducted. Preliminary estimates of dump material density and unit weight are commonly based on assumed bulking factors, with some allowances for consolidation and settlement. Typical bulking factors range from about 1.2 to 1.5, depending on material types, dump construction methods, etc.

4.4.10 Geochemistry

The geochemical properties of the mine rock may have a significant environmental impact. Groundwater and surface water passing through and over the mine rock may pick up contaminants, such as heavy metals. Oxidation of sulphide minerals within the mine rock may acidify groundwater, resulting in acid rock drainage (ARD). Alternatively, the mine rock may have a net neutralizing or buffering impact on surface water and groundwater.

Laboratory testing of mine rock chemistry is required as a condition of permitting. Testing which is commonly required includes Column Leaching and Acid-Base Accounting. In cases where preliminary testing indicates a potential for ARD, detailed testing, such as Humidity Cell tests, may be required. In addition, depending on the mineralogy of the orebody and host rocks, assaying or testing for specific potential contaminants may also be required. Detailed discussion of aspects regarding acid rock drainage prediction, testing, mitigation, etc. are given in the draft Acid Rock Drainage Technical Guide published by The B.C. Acid Mine Drainage Task Force (BCAMD Task Force, 1990).

4.5 OVERBURDEN

Overburden includes all surficial soils which must be removed in conjunction with mine development, and which are permanently incorporated into mine dumps, or which are used for mine dump reclamation or capping. Where significant volumes of overburden are incorporated within a mine dump, their influence on the stability and hydraulic conductivity must be assessed. Where they are used for capping and reclamation, overburden will affect the infiltration characteristics and may impact surface stability and erosion. Important material properties of overburden, their influence on design, and methods for obtaining them are described in the following and summarized in Table 4.4. Many of these properties and evaluation methods are similar to those for foundation soils or mine rock, and only brief descriptions are given below. More detailed descriptions and references are given under the appropriate subheads in Sections 4.2 and 4.4 above.

4.5.1 Description, Index Properties and Classification

As for foundation soils, basic descriptions, index properties and classifications are useful for separating soil samples into groups for testing, comparison and contrasting different soil units, and preparing preliminary estimates of soil properties based on empirical correlations. Descriptions and classifications should be prepared for all major overburden soil units and weathering horizons. Gradation analysis and Atterberg Limits should be conducted on representative samples. Natural moisture contents should be measured on sufficient samples to gain an appreciation for the distribution of moisture content throughout the deposit.

4.5.2 Hydraulic Conductivity

Depending on the quantity and distribution of overburden materials within the dump, the hydraulic conductivity of the overburden may have an impact on seepage and development of piezometric pressures or perched water tables within the dump. However, due to the difficulty in assessing hydraulic conductivity of waste materials as described above, estimates of hydraulic conductivity based on empirical correlations with gradation are usually sufficient. If large quantities of overburden are to be incorporated within the dump, or used for capping or sealing of the dump, or lining the foundation, compaction permeameter testing is recommended.

TABLE 4.4

MATERIAL PROPERTIES AND TESTING FOR OVERBURDEN

MATERIAL PROPERTIES	APPLICATION	IN SITU / FIELD TESTING	LABORATORY TESTING	REFERENCES
DESCRIPTION -Colour -Odour -Texture -Fabric, structure	-Soils mapping, classification -Identification of problem soils -Weathering characteristics -Various empirical correlations -Grouping samples for testing	-Field description (1)	-Microscopic examination (14)	-BCAMD Task Force (1990): 25-27 -OSM (1989): 4,11,12,15-23,25-27 -Craig (1985): 1-5,15-23 -CGS (1985): 1-5 -USBM (1982): 15-23
INDEX PROPERTIES: -Gradation -Plasticity -Moisture content -Unit weight -Specific gravity	-Classification -Empirical correlations with hydraulic conductivity, strength, consolidation -Volume/weight relationships	-Visual estimation of gradation (2) -Estimation of plasticity via dilatancy, toughness, dry strength (3) -In situ density/moisture testing (4) -Preliminary classification (5)	-Sieve (15) -Hydrometer (16) -Atterberg Limits (17) -Various direct and indirect methods of measuring volume/ weight parameters (18) -Lab classification (19)	-Barton & Kjaernsli (1981): 9 -Zavodni et al (1981): 7 -Freeze & Cherry (1979): 20,26,27 -CANMET (1977): 6,8,18 -Hurlbut & Klein (1977): 14,24 -Kerr (1977): 14 -MESA (1975): 2,3,6,15-18,
HYDRAULIC CONDUCTIVITY	-Estimation of seepage rate, quantities -Prediction of piezometric conditions -Assessment of rock drain requirements -Potential for use as low hydraulic conductivity cap or liner	-Empirical correlation with gradation (6) -Infiltration testing on test fill (7)	-Compaction permeameter (20) -Triaxial testing (21)	20,22,23 -Peck et al (1974): 1-5, 15-23 -Dept. of the Navy (1971): 1-3,5, 15-23 -Terzaghi & Peck (1967): 1,2,5,15-23
STRENGTH	-Liner shear strength -Embankment stability	-Empirical correlations based on index properties (8) -In situ shear testing on test fill (9)	-Direct shear testing (22) -Triaxial testing (21)	-Lambe (1951): 15-23
DENSITY/ COMPACTION	-Shear strength -Consolidation and settlement -Design of liners, caps -Design of mitigative measures	-Unit weights estimated based on typical bulking factor with allowance for some consolidation (10) -Volumeter, sand cone , nuclear densometer on test fills (11)	-Standard, Modified Proctor (23)	
MINERALOGY / SOIL CHEMISTRY	-Presence of swelling or low friction clay minerals -Neutralization, adsorption potential -Documentation of existing contaminant levels -Reclamation studies	-Seep surveys (12) -Acid test for carbonates (13)	-X-ray diffraction (24) -Acid-base accounting (25) -Adsorption (26) -Other physical and chemical tests to detect specific contaminants (27)	

NOTE: Numbers in parentheses refer to the selected references listed on the far right which contain detailed descriptions and/or specifications for the various field and laboratory tests.

4.5.3 Strength

If overburden materials comprise a significant proportion of the dump, or they are placed in the dump in a manner which could create a zone of weakness, assessment of shear strength may be required. Where soils contain a high proportion of fines, especially clay minerals, they may exhibit cohesive strength, and undrained shear strength parameters may be appropriate for design. Granular soils tend to exhibit predominantly frictional strength. Preliminary estimates of shear strength may be based on empirical correlations with index properties as described above. More detailed and reliable estimates will require laboratory testing, consisting of direct shear or triaxial testing at various consolidation pressures and piezometric conditions.

4.5.4 Density

As for mine rock, the placed density of overburden materials has an impact on shear strength and settlement characteristics of the dump. However, due to the difficulty in evaluating placed density, and likely variability throughout the dump, detailed assessments of density and analysis of settlements are usually not conducted.

If overburden is to be used for liners or caps, compaction testing, consisting of Standard or Modified Proctor testing, would be required.

4.5.5 Mineralogy and Soil Chemistry

The mineralogy and chemical composition of overburden soils may be important in terms of environmental impact. The presence of certain clay minerals may fix some contaminants or slow their release. Overburden soils may also tend to buffer surface water and groundwater. A knowledge of the basic soil chemistry may also be required for reclamation studies.

If testing of other dump materials indicates a potential for release of contaminants or ARD, detailed testing of overburden soils may be required.

Testing could include x-ray diffraction, Acid-Base Accounting, adsorption testing, and assaying or other chemical tests for specific contaminants. Details regarding acid rock drainage, testing, etc. are given in BCAMD Task Force (1990).

4.6 WATER QUALITY

Documentation of surface water and groundwater quality is an essential component of any mine dump investigation and design program. Baseline water quality studies provide a means for predicting and monitoring environmental impacts.

Sampling and water quality analyses should be conducted for all major springs, perennial streams and some major ephemeral streams. Major creeks should be sampled at regular intervals along their length, in particular upstream and downstream of potential impact areas. Proposed sampling locations and frequency should be determined in consultation with appropriate government agencies. Guidelines for groundwater quality monitoring are given in Piteau Associates (1990).

Table 4.5 presents a list of parameters which MOE commonly requires to be measured for baseline water quality documentation. As a reference, recommended maximum concentrations for drinking water and for protection of freshwater aquatic life, published by the Canadian Council of Resource and Environment Ministers (CCREM, 1987), are also given in Table 4.5. Criteria also exist for other water uses, such as recreation, irrigation and livestock. Provincial Water Quality Criteria are given in Pommen (1989).

TABLE 4.5

BASELINE SURFACE WATER AND GROUNDWATER QUALITY TESTING [1]

PARAMETER [2]	UNITS [3] AND DETECTION LIMITS	WATER QUALITY GUIDELINES [4]	
		CCREM [5]	CDWS [6]
PHYSICAL			
Temperature (field)	1°C		
pH (field and lab)		6.5-9	
Conductance (field and lab)	1 mho/cm		
Total suspended solids	1 mg/l		
Total dissolved solids	1 mg/l		
Turbidity	0.1 NTU		
Total Hardness	1 mg/l		
Fibre content			
ANIONS			
Bicarbonate	1 mg/l		
Sulphate	1 mg/l		
Chloride	1 mg/l		
NUTRIENTS			
Nitrate	0.005 mg/l as N		
Nitrite	0.002 mg/l as N	0.06	
Ammonia	0.005 mg/l as N	1.37	
Total phosphorous	0.003 mg/l as P		
METALS			
Aluminum	0.01 mg/l	0.1	
Antimony	0.002 mg/l		
Arsenic	0.001 mg/l	0.05	0.05
Barium	0.1 mg/l		
Cadmium	0.0002 mg/l	0.0008	0.005
Cobalt	0.001 mg/l		
Chromium	0.001 mg/l	0.002	0.05
Copper	0.0005 mg/l	0.002	1
Iron	0.002 mg/l	0.3	0.3
Lead	0/001 mg/l	0.002	
Manganese	0/001 mg/l		0.05
Mercury (total only)	0.00005 mg/l		
Molybdenum	0.005 mg/l		
Nickel	0.002 mg/l	0.065	
Selenium	0.001 mg.l	0.001	
Silver	0.0002 mg/l	0.0001	0.05
Zinc	0.0005 mg/l	0.03	5

NOTES:

1. Unless otherwise noted, all testing should be conducted by a certified laboratory.
2. Unless otherwise noted, both total and dissolved metal concentrations should be measured.
3. All testing should be conducted using the most current and accurate techniques and up to date guidelines.
4. See Pommen (1989) for B.C. water quality criteria.
5. Recommended guidelines for the protection of freshwater aquatic life published by the Canadia Council of Resource and Environment Ministers (CCREM), 1987.
6. Canadian Drinking Water Standards (CDWS) (CCREM, 1987).

5. MINE DUMP CLASSIFICATION

This section describes the various types of mine dumps and factors which may influence their physical stability and performance. In addition, a scheme for classifying dumps according to their potential for instability, based on semi-quantitative ratings for various key parameters which may affect stability, is proposed. A discussion on risks associated with potential instability is also included.

No comprehensive classification or hazard assessment using this approach has been developed previously for mine dumps. Because it is a new concept, it is recognized that testing, verification and calibration are essential, before it can be finalized and adopted for widespread use. Discussion and comments on the proposed scheme are encouraged.

5.1 MINE DUMP DESCRIPTION

Basic descriptions of mine dumps should clearly convey general information concerning the type and overall configuration of the dump. This type of information facilitates communication between design professionals and regulators. In addition, basic descriptions often provide insight into likely overall dump behaviour, and focus attention on potential problem areas which may have to be addressed early in the investigation and design process.

Most existing waste dump classification schemes (e.g. OSM, 1989; MESA, 1987; USBM, 1982; Taylor and Greenwood, 1981; and Wahler, 1979) classify dumps into a few 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 Fig. 5.1. For more detailed descriptions, the above references should be consulted.

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

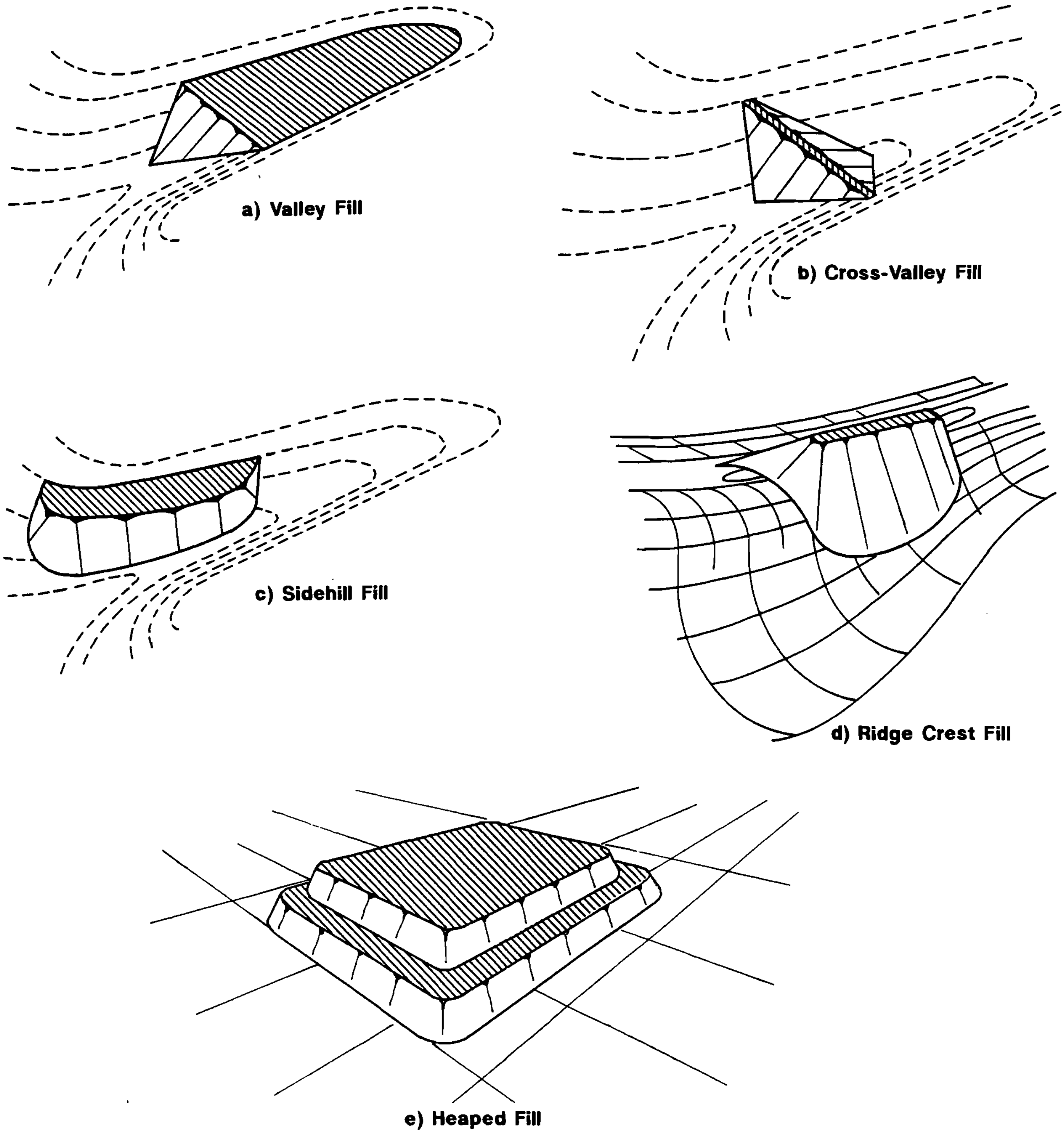


FIG. 5.1 BASIC MINE DUMP TYPES
(Modified after Wahler, 1979)

dump. Does the dump consist of a repose angle slope, or is the slope benched or regraded?

Basic descriptions should be concise, and are intended to complement, not replace semi-quantitative classification procedures, such as the one discussed below.

5.1.1 Valley Fills

As illustrated in Fig. 5.1a, 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.

In terms of British Columbia experience, 11 of 83 (i.e. 13%) dumps reported in the survey in Appendix A were classified, at least in part, as Valley fills.

5.1.2 Cross-Valley Fills

The Cross-Valley fill is a variation of the Valley fill. As illustrated in Fig. 5.1b, 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. diversions and/or culverts or flow-through rock drains).

Only two of the 83 dumps (i.e. 2%) reported in the survey in Appendix A were classified as Cross-Valley fills.

5.1.3 Sidehill Fills

Sidehill fills are constructed on sloping terrain and do not block any major drainage course, as illustrated in Fig. 5.1c. 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.

Sidehill fills represent the bulk of B.C. dumps, with 61 of 83 dumps (i.e. 73%) reported in the survey in Appendix A being classified, at least in part, as Sidehill fills.

5.1.4 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 5.1d illustrates the Ridge Crest fill type. None of the dumps reported in the survey in Appendix A were categorized as Ridge Crest fills.

5.1.5 Heaped Fills

Heaped fills, illustrated in Fig. 5.1e, 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. Heaped fills accounted for 7 of the 83 (i.e. 8%) dumps reported in the survey in Appendix A.

5.1.6 Other Fills

Other types of fills or special purpose fills, which cannot be described using one of the above types, or fills which incorporate more than one basic type (i.e. combination fills) may also be possible. In such cases, descriptions such as backfilled pit or in-pit fill, road fill or dual terms (e.g. Sidehill/Valley fill, Sidehill/Cross-Valley fill) may be most appropriate. Other fills accounted for 6 cases (i.e. 7%) of those dumps reported in the survey in Appendix A. Combination fills were reported in 10 cases (i.e. 12%).

5.2 FACTORS AFFECTING DUMP STABILITY

A variety of factors act in combination to control the stability of a mine dump. The main factors are discussed below.

5.2.1 Dump Configuration

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

a) Height: defined as the vertical distance from the dump crest to the ground surface at the dump toe. Dump heights typically range from about 20m to in excess of 400m.

b) Volume: usually expressed in terms of bank cubic metres (i.e. in-place volume prior to excavation). Small dumps are considered to contain less than about 1 million m^3, while large dumps have more than 50 million m^3. Medium sized dumps have volumes in the 1 to 50 million m^3 range. Based on these ranges, about 20%, 65% and 15% of the dumps reported in Appendix A would fall into the small, medium and large categories, respectively.

c) Slope Angle: the overall dump angle measured from the crest of the uppermost platform to the toe. The normal range of dump slopes is between 26°, which is a common angle adopted for reclamation, and 37°, the average repose angle of free-dumped cohesionless rockfill. Slopes steeper than 37° may also occur if the dump material contains appreciable fines or cohesive material, or consists of very large, angular boulders. Initially, steep slope angles in fine grained materials, or materials which slake or otherwise degrade, will reduce with time.

5.2.2 Foundation Slope and Degree of Confinement

Both the foundation slope and degree of confinement afforded by the shape of the foundation affect dump stability (Golder Associates, 1987; Tassie, 1987; Campbell, 1981; Blight, 1981). Steep foundation slopes and/or lack of confinement were considered contributory factors in several of the failures reported in Appendix A. The least desirable situation is where the slope angle increases towards the toe (i.e. a convex slope). If a slide occurs in this situation, it may gain considerable momentum as it translates downslope. The most favourable situations are a decreasing slope towards the toe (i.e. a concave slope), and three-dimensional confinement within a valley. Where the valley is sinuous, dump material may actually be restrained by the valley wall in the direction of movement. However, in the event of a flow slide developing, confinement in a valley may actually increase the flow distance.

5.2.3 Foundation Conditions

Foundation conditions are generally recognized as a key factor in overall dump stability (Golder Associates, 1987; Robertson, 1986; Nichols, 1981; Caldwell and Moss, 1981). Poor foundation conditions are cited as the most frequent cause of instability in those dumps reported in Appendix A. Foundation types may be considered to fall into three different 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 or strength reduction due to loading.

c) Intermediate: intermediate material which will consolidate and gain strength with time, but which may be subject to pore pressure generation and strength loss if loaded and sheared too rapidly.

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

5.2.4 Dump Material Properties

Properties of dump materials, such as gradation, shear strength, durability, etc. (see Section 4.4) are also recognized as key factors in overall dump stability (Singhal, 1988; Golder Associates, 1987; Tassie, 1987; Robertson, 1986; Caldwell and Moss, 1981; Blight, 1981). Several of the failures reported in Appendix A cite poor dump material quality as a factor contributing to instability. The most favourable dump materials will be those 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 favourable materials will be 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.

5.2.5 Method of Construction

Dump stability and the development of conditions which could lead to failure are also 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 a 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 selected is based on a combination of factors including: minimizing haulage distance, accessibility, available capacity and dump stability (which is usually critical during and shortly after construction). Stability can be enhanced by the judicious use of wrap-arounds, terracing, restricting lift heights to limit shear stresses on the foundations and the length of potential runout, dumping generally in the direction of valley contours, rather than downslope, and other techniques. Construction methods and techniques for improving dump stability are described in Section 7.3.

5.2.6 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; Whiting, 1981; 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). A critical condition may develop if a phreatic surface is generated within the waste, and if it intersects a slope which is at or near the repose angle of the waste material (Pernichele and Kahle, 1971). Water may enter a dump either by direct infiltration, by flowing on surface topography, 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 a 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 Appendix A. 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 (see Appendix A, END-1). 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.

5.2.7 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, 1979). High dumping rates have been considered a contributing factor in several of the dump failures reported in Appendix A.

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 filing or dump advancement is rapid, the dump material may not have an opportunity to consolidate and develop adequate shear strength to ensure stability.

5.2.8 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). The most significant impact on stability due to earthquakes appears to be potential liquefaction of susceptible foundation materials; however, saturated fine grained dump materials may also be subject to liquefaction. It is also conceivable that dynamic ground motions induced by nearby blasting associated with mining could affect dump stability. The work done by Stuckert et al (1989), however, suggests that blasting is unlikely to be a significant factor in dump stability, except possibly in the case of liquefaction.

Earthquake potential and expected ground velocity and accelerations for a given site may be predicted based on Seismic Risk Zones (Weichert and Rogers, 1987). Methods for assessing dynamic stability are discussed in Section 6.2.10 below.

5.3 CLASSIFICATION SCHEME

5.3.1 Dump Stability Rating

A semi-quantitative scheme for assessing the relative potential for dump stability, based on individual point ratings for each of the main factors affecting dump stability, is presented in Table 5.1. Each factor is given a point rating based on qualitative and/or quantitative descriptions accounting for the possible range of conditions. An overall Dump Stability Rating (DSR) is calculated as the sum of the individual ratings for each of the various factors. The maximum possible DSR is 1800.

It must be recognized that the behaviour of a mine dump, and the potential for instability, depends on a wide range of diverse and interrelated factors, as discussed above. Not all of these factors lend themselves to easy quantitative assessment. Consequently, any comprehensive stability rating scheme for mine dumps will be partially subjective. Similarly, no

TABLE 5.1

DUMP STABILITY RATING SCHEME

KEY FACTORS AFFECTING STABILITY	RANGE OF CONDITIONS OR DESCRIPTION		POINT RATING
DUMP CONFIGURATION		< 50m	0
		50m - 100m	50
DUMP HEIGHT		100m - 200m	100
		> 200m	200
DUMP VOLUME	Small	< 1 million BCM's	0
	Medium	1 - 50 million BCM's	50
	Large	> 50 million BCM's	100
DUMP SLOPE	Flat	< 26°	0
	Moderate	26° - 35°	50
	Steep	> 35°	100
FOUNDATION SLOPE	Flat	< 10°	0
	Moderate	10° - 25°	50
	Steep	25° - 32°	100
	Extreme	> 32°	200
DEGREE OF CONFINEMENT	Confined	-Concave slope in plan or section -Valley or Cross-Valley fill, toe butressed against opposite valley wall -Incised gullies which can be used to limit foundation slope during development	0
	Moderately Confined	-Natural benches or terraces on slope -Even slopes, limited natural topographic diversity -Heaped, Sidehill or broad Valley or Cross-Valley fills	50
	Unconfined	-Convex slope in plan or section -Sidehill or Ridge Crest fill with no toe confinement -No gullies or benches to assist development	100
FOUNDATION TYPE	Competent	-Foundation materials as strong or stronger than dump materials -Not subject to adverse pore pressures -No adverse geologic structure	0
	Intermediate	-Intermediate between competent and weak -Soils gain strength with consolidation -Adverse pore pressures dissipate if loading rate controlled	100
	Weak	-Limited bearing capacity, soft soils -Subject to adverse pore pressure generation upon loading -Adverse groundwater conditions, springs or seeps -Strength sensitive to shear strain, potentially liquefiable	200
DUMP MATERIAL QUALITY	High	-Strong, durable -Less than about 10% fines	0
	Moderate	-Moderately strong, variable durability -10 to 25% fines	100
	Poor	-Predominantly weak rocks of low durability -Greater than about 25% fines, overburden	200

Continued..

TABLE 5.1 (Continued)

DUMP STABILITY RATING SCHEME

KEY FACTORS AFFECTING STABILITY	RANGE OF CONDITIONS OR DESCRIPTION		POINT RATING
METHOD OF CONSTRUCTION	Favourable	-Thin lifts (<25m thick), wide platforms -Dumping along contours -Ascending construction -Wrap-arounds or terraces	0
	Mixed	-Moderately thick lifts (25m - 50m) -Mixed construction methods	100
	Unfavourable	-Thick lifts (> 50m), narrow platform (sliver fill) -Dumping down the fall line of the slope -Descending construction	200
PIEZOMETRIC AND CLIMATIC CONDITIONS	Favourable	-Low piezometric pressures, no seepage in foundation -Development of phreatic surface within dump unlikely -Limited precipitation -Minimal infiltration into dump -No snow or ice layers in dump or foundation	0
	Intermediate	-Moderate piezometric pressures, some seeps in foundation -Limited development of phreatic surface in dump possible -Moderate precipitation -High infiltration into dump -Discontinuous snow or ice lenses or layers in dump	100
	Unfavourable	-High piezometric pressures, springs in foundation -High precipitation -Significant potential for development of phreatic surface or perched water tables in dump -Continuous layers or lenses of snow or ice in dump or foundation	200
DUMPING RATE	Slow	-< 25 BCM's per lineal metre of crest per day -Crest advancement rate < 0.1m per day	0
	Moderate	-25 - 200 BCM's per lineal metre of crest per day -Crest advancement rate 0.1m - 1.0m per day	100
	High	-> 200 BCM's per lineal metre of crest per day -Crest advancement > 1.0m per day	200
SEISMICITY	Low	Seismic Risk Zones 0 and 1	0
	Moderate	Seismic Risk Zones 2 and 3	50
	High	Seismic Risk Zones 4 or higher	100

MAXIMUM POSSIBLE DUMP STABILITY RATING: 1800

rating scheme can hope to realistically evaluate all possible permutations. The rating scheme presented in Table 5.1 is intended to strike a reasonable balance between range of applicability and ease of use. As discussed above, this is a new concept, subject to testing, verification and calibration.

5.3.2 Dump Stability Class

To simplify the rating scheme for possible practical application (see Section 5.3.3 below), four categories or Dump Stability Classes have been defined, based on Dump Stability Ratings. Table 5.2 summarizes the four classes and ranges of DSR values for each class.

5.3.3 Application to the Design Process

One of the key questions which must be addressed by the mine dump designer at an early stage in the design process is: What level of effort should be applied, and resources dedicated to investigation and design? The same question must also be answered by regulators when adjudicating designs. A reasonable approach to this issue is to base the decision on the likelihood of the proposed dump experiencing significant instability or failure. In this regard, the dump classification scheme (i.e. Dump Stability Ratings and Classes) outlined above provides a convenient method for assessing the appropriate level of effort. Dump Stability Ratings and Classes also provide a convenient and rational way for comparing and evaluating alternative dump configurations and sites. Possible permitting requirements, the likely level of operational restrictions and monitoring requirements may also be reflected by the Dump Stability Rating/Class.

Recommended levels of effort for investigation and design, likely permitting requirements and assessment of the possible level of operational restrictions and monitoring are given for each Dump Stability Class on the right side of Table 5.2. In general, proposed dumps with a low rating (i.e. Class I) require relatively little effort in terms of investigation and design, whereas dumps with a high rating (i.e. Class IV)

TABLE 5.2

DUMP STABILITY CLASSES AND RECOMMENDED LEVEL OF EFFORT

DUMP STABILITY CLASS	FAILURE HAZARD	RECOMMENDED LEVEL OF EFFORT FOR INVESTIGATION, DESIGN AND CONSTRUCTION	RANGE OF DUMP RATING (DSR)
I	Negligible	-Basic site reconnaissance, baseline documentation -Minimal lab testing -Routine check of stability, possibly using charts -Minimal restrictions on construction -Visual monitoring only	< 300
II	Low	-Thorough site investigation -Test pits, sampling may be required -Limited lab index testing -Stability may or may not influence design -Basic stability analysis required -Limited restrictions on construction -Routine visual and instrument monitoring	300-600
III	Moderate	-Detailed, phased site investigation -Test pits required, drilling or other subsurface investigations may be required -Undisturbed samples may be required -Detailed lab testing, including index properties, shear strength and durability likely required -Stability influences and may control design -Detailed stability analysis, possibly including parametric studies, required -Stage II detailed design report may be required for approval/permitting -Moderate restrictions on construction (eg. limiting loading rate, lift thickness, material quality, etc.) -Detailed instrument monitoring to confirm design, document behaviour and establish loading limits	600-1200
IV	High	-Detailed, phased site investigation -Test pits, and possibly trenches, required -Drilling, and possible other subsurface investigations probably required -Undisturbed sampling probably required -Detailed lab testing, including index properties, shear strength and durability testing probably required -Stability considerations paramount. -Detailed stability analyses, probably including parametric studies and full evaluation of alternatives probably required -Stage II detailed design report probably required for approval/permitting -Severe restrictions on construction (eg. limiting loading rates, lift thickness, material quality, etc.) -Detailed instrument monitoring to confirm design, document behaviour and establish loading limits	> 1200

will require in-depth investigation, detailed assessment of design alternatives, etc. In terms of permitting, Stage II detailed design studies are more likely to be required in the case of Class III and Class IV dumps than for Classes I and II. Possible restrictions on dump operation and monitoring requirements also increase with increasing rating/class.

5.3.4 Examples

Two examples which illustrate the use of the classification system in establishing Dump Stability Ratings and Classes are given below, and summarized in Table 5.3. These examples represent situations at nearly opposite ends of the design spectrum.

Example 1: A 25m high single lift dump of primarily good quality, coarse rockfill will be supported on a 10° to 15° slope (10° at toe), underlain by a thin layer of dense colluvium over flat dipping, competent sedimentary bedrock. The dump will contain 3 million m^3 of material over a wide crest, resulting in an average placement of about 20 m^3/lineal m of crest per day. The dump is planned within a bowl shaped depression with a narrow outlet which offers a three-dimensional constraint against downslope movement. The dump will be formed at the repose angle, but eventually flattened to 26° in reclamation. The site is located in Seismic Risk Zone 1.

According to the Dump Stability Rating scheme in Table 5.1, the dump as planned scores a total of 250 points out of a maximum possible of 1800 points. The dump is ranked as Class I, and may be described as a relatively straightforward, with negligible risk of significant instability. This dump would likely require only a very modest investigation and design effort.

Example 2: A 250m high sidehill dump is planned to be supported on an even slope averaging 25° to 30°, with softened, saturated till in the lower portion, including the toe. The dump will be constructed in a

TABLE 5.3

EXAMPLES OF MINE DUMP CLASSIFICATION

FACTOR	EXAMPLE 1		EXAMPLE 2	
	DESCRIPTION	RATING	DESCRIPTION	RATING
Dump Height	25m	0	250m	200
Dump Volume	3 million BCM's	50	20 million BCM's	50
Dump Slope	37°	100	26°	50
Foundation Slope	10° - 15°	50	25° - 30°	100
Degree of Confinement	Confined within small depression with narrow outlet (Confined)	0	Even slope, Sidehill Fill (Moderately Confined)	50
Foundation Type	Dense colluvium over competent bedrock (Competent)	0	Softened till (Weak)	200
Dump Material Quality	Hard, durable, coarse rockfill (High Quality)	0	25% degradeable mud-stone (Poor Quality)	200
Method of Construction	Single 25m thick lift (Favourable-Mixed)	50	40m thick lifts with wrap-arounds (Mixed)	100
Piezometric & Climatic Conditions	Good segregation, no watercourses, seeps (Favourable)	0	Saturated toe, springs on slope (Unfavourable)	200
Dumping Rate	20 BCM's/m/day	0	120 BCM's/m/day	100
Seismicity	Zone 1	0	Zone 3	50
DUMP STABILITY RATING		250		1300
DUMP STABILITY CLASS		I		IV

series of 40m high lifts which are wrapped around in a descending sequence. Lifts are designed so that the overall slope will average 26°. The dump will contain 20 million m^3 of material consisting of a range of rock types, including up to 25% friable, weak, slaking mudstone, which has low hydraulic conductivity. Because of topographical constraints, it is necessary to place the waste at an average rate of about 120 m^3/lineal m of crest per day. Several springs emerge in the mid portion of the dump, coalescing into a small stream near the toe. The site is located in Seismic Risk Zone 3.

As summarized in Table 5.3, this dump scores a total of 1300 points, which ranks it as Class IV, which is in the highest category of failure hazard. Such a dump would likely require intensive site and laboratory investigations, combined with detailed analysis and design, with thorough consideration of alternative sites and dump configurations. Detailed (Stage II) reporting on critical aspects would be required.

5.4 ASSESSMENT OF RISK

Risk may be defined as the product of hazard and exposure, where hazard may be measured in terms of the frequency or likelihood of occurrence and magnitude of an adverse event, and exposure may be measured in terms of proximity to the hazard, period of exposure and potential impact. For mine dumps, there are two primary sources of hazard: the physical stability of the dump (i.e. failure hazard) and the chemical stability (i.e. potential for acid rock drainage). As indicated earlier, the physical aspects of dump stability are the focus of this study. For a discussion on chemical stability and ARD, the reader is referred to BCAMD Task Force (1990).

Although the Dump Stability Rating scheme described above provides a means for assessing the relative likelihood (and possible magnitude) of instability, it provides no measure of the likely exposure. Hence, DSR values of themselves are not an all encompassing measure of risk. For a more complete treatment of risk, some means of quantifying exposure are needed. It is hoped that current research being conducted on runout characteristics of dump failures (see Section

1.2.3) will provide some insight on the exposure issue, and will ultimately permit a more systematic evaluation of risk.

In the meantime, the following general discussion on risk and methods of control and mitigation is included to provide the reader with some guidance and insight. For discussion purposes, possible risks have been divided into three general areas: safety of personnel and equipment; risk to facilities; and environmental risk.

5.4.1 Safety of Personnel and Equipment

The foremost stability related concern at any dumping operation is for the safety of its personnel and equipment. A primary objective in the design and sequencing of construction is to minimize the likelihood of a failure occurring with little or no warning. Although assurance of safety is largely an operational matter, sound designs will minimize the hazard, reduce the exposure, and hence, improve the risk.

Situations which are most prone to relatively sudden failures, and hence, are inherently hazardous, include:

- dumping downslope over steep terrain, particularly slopes over 25° to 30°;

- dumping materials with fine grained constituents which impart a cohesive component to strength, and which can induce construction slopes to be steeper than the normal repose angle;

- dumping over sensitive foundation materials which may undergo a large loss of strength if sheared or loaded too rapidly;

- placement of fine grained dump materials into a gully containing enough flow to cause a phreatic surface to form within the dump, which can cause toe spreading or failure;

- rapid filling at a rate which does not allow pore pressure dissipation and the full development of interparticle strength. If this situation occurs concurrently with slope oversteepening, a sudden failure may ensue.

- overfilling gullies such that the effects of confinement are lost;

- combination of two or more of the above factors.

5.4.2 Risk to Facilities

Mine and public facilities located around the periphery of a dump may be exposed to damage if a failure occurs. In this regard, as discussed above, an assessment of the potential size, shape and runout distance of a failure lobe is necessary to determine the likelihood of failure debris impacting a facility (e.g. load-out, plant site, settling pond, interceptor ditch, etc.).

Along with sound designs to minimize the risk of a major failure occurring, protective measures consist of monitoring, operational controls, providing adequate separation between the dump and the facility, and construction of deflection or impact berms.

5.4.3 Environmental Risk

In assessing the potential risk to the environment imposed by a particular dumping scheme, a range of scenarios for dump performance should be considered, including evaluation of impacts resulting from a probable worst case failure. The worst case failure involves assessment of the maximum potential runout distance and associated impacts on the terrain, water courses and facilities, if any, in the path of the slide.

If significant environmental impacts are perceived, based on a worst case scenario, more detailed studies to quantify the hazard, fully evaluate the potential environmental impacts, and develop effective operational controls, and monitoring and mitigative measures will be required. If environmental risks are deemed unacceptable, mitigative measures are impractical or too costly, or salient factors cannot be reliably assessed with current technology, it may be necessary to abandon the site in favour of a less environmentally risky alternative.

6. STABILITY ANALYSIS

6.1 FAILURE MODES

A knowledge of the basic modes of mine dump deformation and failure is fundamental for selecting the appropriate stability analysis technique, as well as for designing dump monitoring programs. Various failure modes which have been reported in the literature (e.g. Pernichele and Kahle, 1971; CANMET, 1977; Caldwell and Moss, 1981; Blight, 1981; and Campbell, 1981) are described in the following, and are illustrated in Tables 6.1 and 6.2. Failure modes involving only the dump (i.e. embankment) materials are described in Section 6.2 and summarized in Table 6.1. Failure modes involving, at least in part, failure of the foundation or base of the dump, are described in Section 6.3 and summarized in Table 6.2. Key factors contributing to the various types of instability, and recommended stability analysis techniques, are also summarized for each failure mode in Tables 6.1 and 6.2. Slope stability analysis methods are described in Section 6.4 below.

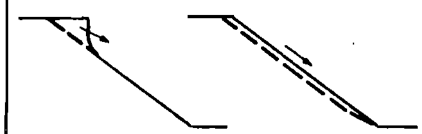
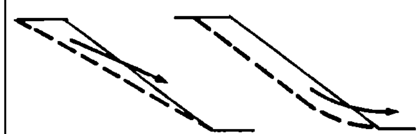
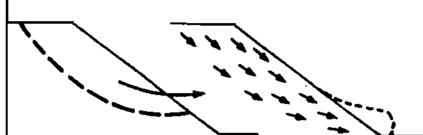
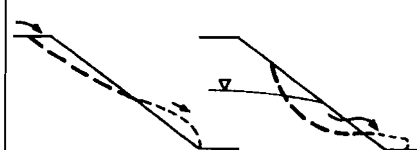
6.2 EMBANKMENT FAILURES

6.2.1 Edge Slumping

Edge slumping, also known as crest slumping or sliver failure, is probably the most frequently observed failure mode, and most of the larger mine dumps in British Columbia experience this type of instability during operation. Edge slumping involves sliding of a thin wedge of material, usually originating at or near the crest of the dump, parallel to the dump face. This type of failure generally results from oversteepening of the crest area of the dump. Oversteepening may be due to the presence of fines or cohesive waste materials. In such cases, failure commonly occurs when heavy precipitation relieves negative pore pressures in the fines, with resulting loss of apparent cohesion. Edge slumping may also occur where slaking dump materials create a low permeability layer on the dump face, permitting development of high pore pressures at a shallow depth

TABLE 6.1

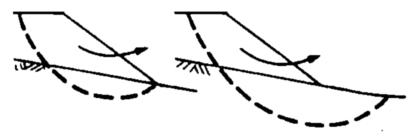
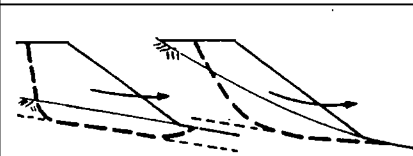
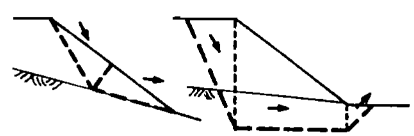
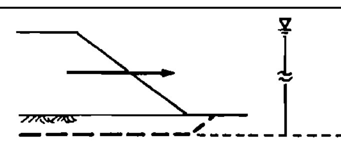
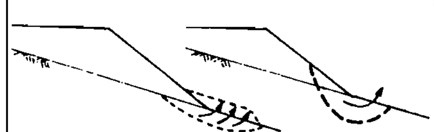
MODES OF MINE DUMP INSTABILITY - EMBANKMENT FAILURES

FAILURE MODE	DESCRIPTION	ILLUSTRATIONS	KEY FACTORS CONTRIBUTING TO INSTABILITY	STABILITY ANALYSIS [1] METHODS
EDGE SLUMPING (Crest slumping, surface or sliver failure)	Shallow failure involving downslope translation of material from the crest area, parallel to the dump face. Failure does not extend into the foundation.		-Oversteepening of the crest due to presence of fines or metastable steep repose angle of coarse rock blocks -Slaking materials which form low permeability layers parallel to dump face -Heavy precipitation -Rapid rates of crest advancement -Most likely to occur in dumps constructed by end-dumping in thick lifts, or by dozing materials over dump crest	-Infinite slope analysis
PLANE FAILURE (Bi-planar failure)	Sliding along a single plane of weakness within the embankment. May also involve shearing through the toe if the weakness plane does not daylight on the dump face. Similar to edge slumping, but failure surface is generally deeper within the mass and results in substantially more crest breakback.		-Creation of a weakness plane which daylights on, or parallels the dump face, possibly due to a zone of poor quality waste, overburden, or snow -High pore pressures within dump -Also see factors for edge slumping	-Plane failure analysis -Biplanar or slab analysis -Wedge analysis
ROTATIONAL FAILURE (Circular arc, creep)	Mass failure along a circular or curved failure surface within the dump material. Creep failures involve wide spread rotational slip characterized by bulging at the dump toe.		-Homogeneous dump consisting of weak, fine-grained materials -Excessive dump height in cohesive materials -High pore pressures within dump -Lack of lateral confinement or support (ie. 3-D effect)	-Slip circle -Methods of slices -Y=0 method
FLOW FAILURES (Debris flow, mud flow, flow slides)	Shallow failures involving slumping of saturated or partially saturated dump materials. Slumped material flows down the dump face in a semi-fluid state.		-Concentrated surface flows discharging over the dump crest -Heavy precipitation, high infiltration, and/or development of a perched water table resulting in saturation of near surface dump materials	-Infinite slope analysis with inclusion of seepage forces

NOTES: 1. See Section 6.4 and Table 6.3 for descriptions of stability analysis methods and references.

TABLE 6.2

MODES OF MINE DUMP INSTABILITY – FOUNDATION FAILURES

FAILURE MODE	DESCRIPTION	ILLUSTRATION	KEY FACTORS CONTRIBUTING TO INSTABILITY	STABILITY ANALYSIS[1] METHODS
ROTATIONAL FAILURE (circular arc)	Mass failure along a circular or curved failure surface which extends into the foundation soils.		–Weak foundation soils –High pore pressures in foundation soils	–Slip circle –Methods of slices –Y=0 method –Bearing capacity analysis
NON–CIRCULAR ROTATION (base spreading)	Similar to rotational failure except that part of the slip surface occurs along a weak basal plane.		–Occurrence of a weakness plane at the base of the dump, or in the foundation soils –High pore pressures in foundation soils –Steep foundation slopes –Adverse geologic structure	–Methods of slices generalized for non–circular failure geometries –Y=0 method
WEDGE FAILURE (multiple wedge, bi– planar, base spreading, 3-D extended wedge)	Embankment fails as series of interactive blocks or wedges separated by planar discontinuities. Part of the failure surface occurs along a weak basal plane.		–Occurrence of a weakness plane at the base of the dump, or in the foundation soils –High pore pressures in foundation soils –Steep foundation slopes –Adverse geologic structure –Overfilled gullies	–Wedge analysis –Methods of slices generalized for non–circular failure geometries –Y=0 method –3–D wedge analysis
BASE TRANSLATION (planar sliding)	Sliding of the bulk of the dump as a rigid block, along a weak basal plane		–Occurrence of a weakness plane at the base of the dump, or in the foundation soils, or a discontinuity in the bedrock –High pore pressures in foundation soils –Steep foundation slopes –Adverse geologic structure	–Plane failure analysis
LIQUEFACTION	Liquefaction of foundation soils or discrete soil stratum results in translation of the dump en–masse, or progressive failure.		–Occurrence of liquefaction susceptible soils or soil stratum in foundation –High natural, construction or earthquake induced pore pressures in foundation soils	–Empirical relationships between density, seismicity and liquefaction potential
TOE FAILURE (Toe spreading)	Localized slumping of the dump toe due to yielding or failure of foundation soils or loss of confinement. May result in progressive failure of the overall dump.		–Locally weak foundation soils –Locally steep foundation slopes –Locally high pore pressures in foundation soils	–Slip circle –Methods of slices –Stability charts –Bearing capacity charts

NOTES: 1. See Section 6.4 and Table 6.3 for descriptions of stability analysis methods and references.

beneath the face of the dump. Heavy precipitation may also trigger failure in this case. Oversteepening of the dump crest may also occur in coarse rockfill dumps. Interlock of rock blocks may result in overly steep repose angle slopes at low confining stress. Creep, dynamic disturbances or stress changes may result in failure of the interlock, and edge slumping may occur.

Edge slumping commonly results in loss of the dump crest area; however, the bulk of the dump and the dump foundation are not involved in the failure. Edge slumping is most likely to occur in dumps constructed by end-dumping in thick lifts, or where dump material contains abundant fines or is degradable. Also, construction using dozers to push dump materials over the crest, rather than dumping directly over the crest, and rapid rates of crest advancement, tend to promote oversteepening in the crest area. Infinite Slope Analysis is the most appropriate stability analysis method for this type of failure.

6.2.2 Plane Failure

Plane failure of the embankment involves sliding along a single plane of weakness within the embankment. If the weakness plane does not daylight on the dump face or at the toe, some shearing through dump material at the toe of the failure will be required. Weakness planes may be created during construction if poor quality or fine dump materials, such as overburden, are dumped over the dump crest and form zones or layers parallel to the dump face. Weakness planes may also form if material is dumped over thick accumulations of snow or ice on the dump face, or if a zone of susceptible dump materials slake or degrade due to exposure or shear strain within the dump. High pore pressures within the dump may also contribute to plane failure. In the case of a weakness plane parallel to the dump face, plane failure is similar to edge slumping, except that the failure surface is generally deeper within the dump mass and failure results in substantially more breakback. Specific analysis methods for simple plane failure (i.e. rigid block sliding on a plane) are available. Where failure involves shearing through the toe, more complex analysis methods (i.e. slab or bi-planar or wedge analysis) are required.

6.2.3 Rotational Failure

Rotational failure of the embankment involves mass failure of the dump along a circular or curvilinear failure surface formed within the embankment. Creep failure is a special case of rotational failure, involving widespread rotational shearing through the mass, without movement being focused along a single failure surface. Creep failure commonly manifests itself by long term, progressive bulging at the toe of the dump. Rotational failures are commonly associated with homogeneous embankments consisting of weak or fine grained dump materials. In cohesive dump materials (e.g. overburden dumps), they may be precipitated by constructing the dump or individual lifts too high or too steep. Rotational failures may also be triggered by high pore water pressures in the dump. A wide variety of proven methods are available for analyzing rotational failures, including simple Slip Circle Analysis and various Methods of Slices.

6.2.4 Flows

Flows consist of debris flows, mud flows and flow slides. These failures generally involve shallow slumping and subsequent fluidization of saturated or partially saturated dump materials at the dump crest or on the dump face. The volume and velocity of the flow may increase downslope as a result of erosion of the underlying material and increasing momentum. Flows may develop in response to saturation of the dump due to high precipitation and infiltration, development of perched water tables, and/or concentration of surface flows on the dump. In general, the potential for flow failures is higher for low density, loose fills composed of fine materials, and lower for very dense, consolidated fills with few fines. Infinite Slope Analysis with consideration of seepage forces is the conventional approach for assessment of flow failures.

6.3 BASE FAILURES

6.3.1 Rotational Failure

Rotational foundation failures are similar to rotational embankment failures except that the failure surface extends into the foundation soils. Rotational foundation failures may occur where foundation soils are weak, or high pore pressures exist within the foundation. As indicated above, a wide variety of proven methods are available for analyzing rotational failures, including simple Slip Circle Analysis and various Methods of Slices. Bearing capacity analysis may also be a convenient method for assessing the potential for rotational foundation failure.

6.3.2 Non-Circular Rotational Failure

Non-circular rotation, which is sometimes also referred to as a form of base or foundation spreading (Caldwell and Moss, 1981), is similar to rotational foundation failure, except that part of the failure surface occurs along a weakness plane. This plane may occur along the interface between the dump and the foundation (e.g. base failure), or within the foundation, and may or may not daylight on the slope. This type of failure may occur where the dump is founded on steep slopes with a thin soil veneer, where a discrete weakness plane occurs within the foundation soils, where foundation soils are weaker than the embankment waste, or where adverse geologic structures, such as weak bedding joints, occur in the bedrock underlying the dump. High pore pressures in the foundation may trigger non-circular failure. Non-circular rotational failure could also occur along weak zones within the embankment, although no failures of this type have been reported in the literature. Non-circular rotational failure is analyzed using various Methods of Slices for general failure surfaces.

6.3.3 Wedge Failure

Wedge failure involves mass failure of the embankment as a series of interactive blocks or wedges separated by planar discontinuities. Part of the failure usually involves sliding along a weakness plane similar to non-rotational failure, and this type of failure has also been classified by Caldwell and Moss (1981) as a form of base spreading. Wedge failure may occur in several different ways, depending on the number and configuration of blocks involved (e.g. double wedge, bi-planar, multiple wedge, etc). Conditions for the development of a wedge failure are similar to those required for non-rotational failure. Wedge failure may be analyzed using generalized Methods of Slices as well as specific wedge analysis techniques.

6.3.4 Base Translation

Base translation is analogous to plane failure and involves mass movement of the entire dump as a rigid block, sliding along a single weakness plane at the base of the dump, within the foundation soils or along a discontinuity in the bedrock. As with most other foundation failure modes, base translation may be exacerbated by high pore pressures in the foundation. Base translation is assessed using Plane Failure Analysis.

6.3.5 Liquefaction

If liquefaction of foundation soils or a discrete soil stratum in the foundation (or within the dump) occurs, the entire dump may be translated en masse, or progressive failure may occur. Liquefaction susceptible soils generally consist of loose silts and fine to medium sands, such as may occur in lacustrine and deltaic deposits; however, denser and coarser deposits may also be susceptible. Liquefaction occurs when effective stress on the soil becomes very low due to high pore pressures. High pore pressures may be induced by dynamic events such as earthquakes, or when foundation soils are loaded too rapidly for excess piezometric pressures to dissipate. Evaluation of liquefaction potential due to dynamically generated pore pressures (i.e. earthquake generated pore pressures) is usually based on empirical criteria which relate in situ density to liquefaction potential (e.g. Seed and De Alba, 1986). Liquefaction potential due to rapid dump loading may be based on assessment of pore pressure generation and dissipation rates based on laboratory testing and field monitoring of test fills, trial dumps, etc.

Liquefaction of saturated dump materials may also be possible; however, this type of failure is most commonly associated with embankments used to impound tailings or water, or where dumps are subjected to very high levels of saturation, as may be the case in some leaching operations. No cases of liquefaction of dump materials in non-impounding dumps or dumps not associated with leaching operations (neither of which are considered herein) were noted in the literature.

6.3.6 Toe Failure

Toe failure, also known as toe spreading, involves localized slumping of the dump toe due to yielding or failure of foundation soils or loss of confinement. Toe failure may occur where local foundation soils are weak, foundation slopes are locally steep, or where high pore pressures exist in the foundation. Where weak foundation soils are particularly susceptible to strain, toe failure may result in rapid progressive failure of the overall dump. Toe failure may be recognized by bulging of the toe and disruption of foundation soils downslope, beyond the toe. Similar methods to those used for assessing rotational failure are also applied in analyzing toe failure.

6.4 ANALYSIS METHODS

Various methods for analyzing the different modes of failure are briefly described in the following and summarized in Table 6.3, together with a discussion of their advantages and limitations. For more detailed information, and worked examples, the reader is referred to the references summarized on the right side of Table 6.3.

TABLE 6.3
DUMP STABILITY ANALYSIS METHODS

ANALYSIS METHOD	DESCRIPTION	ADVANTAGES	LIMITATIONS	REFERENCES
STABILITY CHARTS	Charted and tabulated solutions for many of the simple and more sophisticated methods described below.	-Quick, inexpensive and easy to use -May be used for design of small, simple or low hazard dumps -Useful for preliminary estimates of stability or sensitivity, or as check on validity of results from more rigorous methods	-Approximate solutions only -Cannot model complex failure surfaces -Not recommended as only analysis method for large, complex or hazardous dumps	Hoek and Bray (1977) Duncan et al (1987) Blight (1981) Vandre (1980) Brauns (1980) Morgenstern (1963)
INFINITE SLOPE (Limit Equilibrium)	Assumes failure surface is planar, shallow and parallel to slope face. FOS based on force equilibrium of a vertical slice of unit width, but moment equilibrium is also satisfied implicitly.	-Quick, inexpensive and easy to use -Ammenable to hand calculations -Can account for seepage forces -Chart solutions available	-Approximates near surface stability only -Generally intended for homogenous slopes only	Duncan et al (1987) OSM (1989) USBM (1982) Craig (1974)
PLANE FAILURE (Limit Equilibrium)	Assumes failure mass is a rigid block which slides on a planar surface which daylights on the slope. FOS based on force equilibrium, but moment equilibrium is also satisfied implicitly.	-Quick, inexpensive and easy to use -Can account for tension cracks and piezometric pressures -Ammenable to hand calculations or computer solutions	-Does not account for internal deformations commonly observed in conjunction with mass failure	Hoek and Bray (1977) OSM (1989) Hawley et al (1986)
WEDGE OR BLOCK eg. -Double Wedge -Bi-Planar Slab	Assumes failure mass is divided into two or more rigid, interactive blocks. Bocks comprising the upper portion are assumed to be in limit equilibrium. The block forming the toe supports the other blocks. Forces on the upper blocks are resolved using the equations of equilibrium, and a net driving force on the toe block is determined. FOS is based on stability of the toe block.	-Appears to model some types of dump behaviour well -Relatively simple, quick and easy -Ammenable to hand calculations as well as computer solutions -Useful for parametric studies -May be generalized for 3D analysis -Chart solutions available	-Moment equilibrium may not be satisfied -Must assume point of application of resultant force on toe block -FOS based on only a relatively small portion of the failure surface, not the overall failure surface as is the case with most other analysis methods; hence, must use caution when interpreting result or comparing with other methods	Campbell (1986) Goodman (1980) USBM (1982) Hawley et al (1986) CANMET (1977)
SLIP CIRCLE (Limit equilibrium) eg. -Swedish Circle (ie. ø=0 Method) -Friction Circle -Log Spiral	Failure plane assumed to be circular or log spiral, and failure mass acts as a rigid body which rotates about the centre of curvature. The Swedish Circle method assumes ø=0, and FOS is based on moment equilibrium. The Friction Circle method assumes all forces are concentrated at a single point on the failure circle, and FOS is based on all three equations of equilibrium. The Log Spiral method assumes c=0, and FOS is based on moment equilibrium. All three methods explicitly or implicitly satisfy all conditions of static equilibrium.	-Quick, inexpensive and easy to use -Amenable to hand calculations or computer solutions. -Friction Circle provides lower bound limit equilibrium assessment of FOS -Useful for preliminary estimates of stability, sensitivity -Normal stress distribution assumed for Log Spiral more reasonable than concentrated stress assumed for Friction Circle	-ø=0 assumption for Swedish Circle restricts applicability to total stress analyses of cohesive slopes or foundations -May be very conservative -Restricted to circular or log spiral failure surfaces and homogeneous slopes -Not recommended as only analysis method for large, complex or hazardous dumps	Craig (1973) Wright (1981) OSM (1989) USBM (1982)

TABLE 6.3 (Continued)
DUMP STABILITY ANALYSIS METHODS

ANALYSIS METHOD	DESCRIPTION	ADVANTAGES	LIMITATIONS	REFERENCES
METHODS OF SLICES (Limit Equilibrium)	Failure mass defined by general slip surface is divided into a finite number of slices. The equilibrium of each slice is considered individually, and FOS is based on the sum of the shear stresses and available shear strength on the base of each slice.	-Can simulate a wide variety of failure surface shapes, embankment shapes and and non-homogeneous slopes -Widely used and understood approach to engineering analysis of slopes -More rational assessment of normal stresses along failure surface than slip circle methods	-Require assumptions regarding forces acting within the mass -May be subject to numerical problems -Tedious or impractical for hand calculations	Craig (1974) USBM (1982) OSM (1989) CANMET (1977) Duncan et al (1987) Wright (1981)
Simplified Methods eg. -Ordinary Method of Slices (OMS) -Bishop's Simplified -Force Equilibrium	Simplified methods do not satisfy all conditions of static equilibrium. OMS neglects inter-slice forces, and a unique FOS is solved directly. Bishop's Simplified neglects inter-slice shear forces, Force Equilibrium methods neglect moments, and both require iteration to solve for FOS.	-May be used to explain internal deformations -Relatively quick and easy to use -Usually accurate to within +/- 10-15% of more rigorous methods, which may be all the accruacy that is required -Useful for preliminary estimates of stability, sensitivity -Useful as a check on more rigorous methods	-Do not satisfy all conditions of static equilibrium -OMS may be very conservative in cases of high pore pressures or flat slopes -Convergence problems with Bishop's Simplified for steep failure surfaces -OMS is suitable for total stress analysis only	Craig (1974) Duncan et al (1987) OSM (1989) Lowe and Karafiath (1960) CANMET (1977)
Rigorous Methods eg. -Janbu -Spencer -Morgenstern-Price -Sarma	Rigorous methods satisfy all conditions of static equilibrium. Variations between the different methods are generally related to assumptions regarding the treatment of inter-slice forces. All of these methods require iteration to solve for FOS. FOS calculated by the various methods are usually within 5% of one another.	-Satisfy all conditions of static equilibrium -More comprehensive, realistic model than simplified methods -Available computer solutions simplify application and permit detailed parametric studies	-More complex, costly and difficult to use than simplified methods -Require detailed understanding of analysis for proper interpretation of results -Except for Sarma, restricted to vertical slices	Janbu (1956) Spencer (1967) Morgenstern and Price (1965) Sarma (1973)
Y=0 METHOD	Method of Slices which analyzes the distribution of shear stresses along the selected failure plane to determine which portions of the failure surface are in a condition of limiting equilibrium. Can also be used to predict likely position of tension cracking in the dump.	-Quick, inexpensive and easy to use -Provides insight into the internal deformations of the dump -Allows evaluation of progressive failure -Well suited for probability of failure assessments. -Useful in design and interpretation of monitoring programs.	-Same limitations as for rigorous methods of slices	Robertson (1986) Caldwell and Moss (1981)

Continued...

TABLE 6.3 (Continued)
DUMP STABILITY ANALYSIS METHODS

ANALYSIS METHOD	DESCRIPTION	ADVANTAGES	LIMITATIONS	REFERENCES
NUMERICAL METHODS eg. –Finite Element –Finite Difference –Distinct Element –etc.	Analyzes the distribution of stresses and strains within the dump mass, or models piezometric conditions.	–May provide insight into internal stresses, deformations, and modes of failure –Recently developed techniques may be able to model discontinuous behaviour and large strains –Useful for piezometric modelling for input into other analysis techniques –Useful for predicting dump response during dynamic events	–Historically have been based on small strain theory and were not very compatible with large deformations commonly observed in dump failures –Not much recent application –Expensive	OSM (1989) Glass (1981) Freeze & Charry (1979)
LIQUEFACTION	Empirical, laboratory and field monitoring techniques to assess the potential for liquefaction of foundation materials due to seismic events or rapid crest advancement.	–Empirical techniques widely used and accepted method for evaluating liquefaction potential –Field testing and monitoring provide direct measure of stability	–Detailed field investigations required to evaluate potential –Laboratory testing may not be representative of insitu conditions and complexity –Field monitoring is difficult to maintain	Seed & DeAlba (1986)
DYNAMIC STABILITY Pseudo–Static	Analyzes effects of earthquakes on dump stability using limit equilibrium techniques incorporating a constant static horizontal force to simulate seismic accelerations.	–Simple, easy to use with many of the limit equilibrium techniques described above	–Does not model dynamic nature of earthquake events realistically –Usually very conservative –More complex stress–strain analyses required if pseudo–static approach indicates low FOS	Glass (1981) Makdisi & Seed (1978)
Stress–strain	Analyzes the dynamic response of embankments to dynamic accelerations. Internal deformations are then compared to stress–strain characteristics of dump material to assess stability.	–Model the dynamics of earthquakes more accurately than pseudo–static methods	–Wide range of assumptions required regarding acceleration, time–history of design earthquake, bulk dump response parameters, etc. –Complex and expensive	Glass (1981)

Continued...

Reliable assessments of foundation conditions and material properties are fundamental to developing an understanding of potential dump behaviour. Based on these assessments, and alternative possible dump configurations, a preliminary evaluation of potential modes of dump instability would be conducted. Those failure modes identified as being critical to dump stability would be subject to detailed analysis. Appropriate design criteria would then be developed based on analysis results, practical mining considerations, consequences of instability and other factors.

The key step in the analysis stage is the determination of the critical failure mode (or modes). In many cases, the critical failure mode(s) may be readily apparent, based on site configuration or material characteristics. However, where dump configurations or foundations are complex, preliminary analysis of a variety of failure modes may be necessary to determine which failure mode(s) controls. Stability charts and other rapid analysis techniques may be particularly useful for preliminary identification of key failure mechanisms.

Once the key mode of failure has been clearly established, detailed stability analysis would be carried out using a variety of analytical techniques, as described below and summarized in Table 6.3. In most cases, the various analytical techniques appropriate to a given mode of failure yield comparable results; hence, a variety of equally reliable approaches may be available. For more complex dumps, comparison of results obtained from different analytical techniques is recommended, as this approach may provide a more thorough understanding of dump behaviour, and more confidence in the analysis results.

Where foundation conditions and material properties are complex or poorly defined, it may be difficult to determine the critical failure mechanism with confidence. Likewise, some failure mechanisms are less well understood than others, and available analytical techniques may be very complex and cumbersome, or may not realistically model the actual failure mode (e.g. complex failures involving more than one mode of instability, three-dimensional effects, earthquake induced instability, etc.). In such cases, a conservative approach to design is necessary, and higher factors of safety, more conservative geometry and/or strength assumptions than might normally be adopted would be considered appropriate. In addition, sensitivity analysis or parametric studies of a variety of possible failure mechanisms often prove helpful in evaluating complex or poorly understood failure modes, foundation conditions or material characteristics.

6.4.1 Total Stress vs. Effective Stress

Slope stability analysis can be conducted in two basic ways: Total Stress Analysis or Effective Stress Analysis. These approaches differ in the way they deal with internal water forces, and in the way they measure shear strength. In the total stress approach, only external water forces (i.e. forces exerted by standing bodies of water, and not pore pressures within the dump mass) are considered explicitly. Analyses are conducted based on total unit weights and undrained shear strength parameters. Because a knowledge of internal pore water pressures is not required for the total stress approach, it is the only approach applicable in cases where pore pressures acting on the failure plane are unknown and cannot be reliably determined. It is also suitable for evaluating short term stability conditions, where there is insufficient time for induced pore pressures to dissipate.

Effective stress analyses require a knowledge of the distribution of pore water pressure along the failure surface, so that the effective stress (i.e. total stress - pore water pressure) may be calculated. Drained shear strength parameters are used. The effective stress approach is generally considered more versatile and more reliable than total stress, because any total stress condition can be modelled using effective stress, and effective stress simulates the physical behaviour more closely. The effective stress approach is particularly suitable in assessing long term stability, with steady state groundwater conditions.

Most of the analysis techniques described below can be formulated in terms of either total or effective stresses.

6.4.2 Stability Charts

Stability and bearing capacity charts and tables provide a rapid and inexpensive method for assessing embankment stability. For small, simple and low hazard dumps, stability chart solutions may be all that is required for design. They are also useful for preliminary estimates of stability or sensitivity, or to check the validity or reasonableness of results from more complex, rigorous analyses. Charted and tabulated solutions are available for many of the more sophisticated methods described below.

It is important to note that stability charts yield approximate solutions only, and cannot model complex failure modes. Consequently, where accuracy is important, such as for large or potentially hazardous dumps, or where complex failure modes occur, stability charts are not recommended as the only analysis method.

6.4.3 Infinite Slope Analysis

Infinite Slope Analysis is a limit equilibrium analysis which assumes a planar failure surface at a shallow depth, parallel to the slope face. The Factor of Safety (FOS) is based on force equilibrium of a unit width vertical slice of the failure mass. Moment equilibrium is implicitly satisfied. Infinite slope analysis is analytically simple, easy to use and amenable to hand calculations. Seepage forces can be accounted for, and chart solutions are available.

Infinite Slope Analysis approximates near surface stability only, and is strictly valid only where the thickness of the failure is negligible in comparison to the length of the failure plane. Application is normally restricted to homogeneous slopes.

6.4.4 Plane Failure Analysis

In plane failure analysis, the FOS is based on force equilibrium of the entire block, which is assumed to be rigid, and moment equilibrium is implicitly satisfied. The effects of various piezometric surfaces and tension cracks can also be simulated easily. The analysis is analytically simple, and amenable to hand calculation or computer solution.

As with other limit equilibrium analyses, this model assumes that the ratio of available shear strength to shear stress is the same everywhere along the failure surface. Furthermore, this model provides no explanation of internal deformations which are commonly observed in conjunction with overall failure.

6.4.5 Wedge Failure Analysis

For wedge failure analysis, the blocks comprising the upper portion of the failure mass are considered to be in a state of limiting equilibrium. The block forming the toe of the slope supports the upper blocks. The equations of equilibrium are used to resolve the net driving force imparted to the toe block by the upper active or sliding blocks. FOS is then based on the resistance of the toe block to sliding along its base. Some wedge analysis formulations consider both force and moment equilibrium, while others consider force equilibrium in one or two directions only.

Wedge failure appears to model some types of dump behaviour very well, especially the case where dumps are located on steep slopes with a veneer of relatively weak soils forming the foundation. The models are analytically relatively simple and amenable to hand calculations or computer methods. Chart solutions are available for some models, making parametric studies relatively easy. In addition, the analysis may be generalized to three dimensions (Golder Associates, 1987).

In common with methods of slices, wedge analyses require some assumptions regarding inter-block forces to render them statically determinant. Also, the FOS calculated by these methods is based on a relatively small portion of the failure surface, unlike most limit equilibrium methods, which base the FOS on the shearing resistance of the overall failure plane. Consequently, caution must be used when interpreting results or comparing them with results from other methods.

6.4.6 Slip Circle Analysis

Slip circle analyses assume the failure plane to be a circle or logarithmic spiral, and the failure mass to behave as a rigid body which rotates about the centre of curvature. The Swedish Circle Method, also referred to as the $\phi=0$ Method, assumes the shear strength to be due to cohesion alone. FOS is based only on moment equilibrium. The Friction Circle Method assumes all forces are concentrated at a single point on the failure surface. FOS is based on all three equations of equilibrium. The Log Spiral Method assumes no cohesion, and FOS is also based on moment equilibrium. All three of these methods explicitly or implicitly satisfy all conditions of static equilibrium.

Slip circle methods are analytically simple, are amenable to hand calculation or computer analysis and provide a useful tool for preliminary estimates of stability and sensitivity. The Friction Circle Method provides a lower bound, conservative assessment of FOS for limit equilibrium methods. The $\phi=0$ condition for the Swedish Circle Method restricts its use to total stress analysis of cohesive foundations or embankments. All three methods are limited to homogeneous slopes, and provide only approximate solutions. These methods should not be used as the only analysis technique for large, complex or potentially hazardous dumps.

6.4.7 Methods of Slices

General

Methods of slices are limit equilibrium techniques whereby the failure mass, defined by a general slip surface, is divided into a number of slices. The equilibrium of each slice is considered individually, and a FOS is generally based on the sum of the shear stresses and available shear strength on the base of each slice. Methods of slices can simulate a wide variety of failure surface shapes, embankment configurations and non-homogeneous slopes. They are a widely used, understood and accepted approach to engineering analysis of slopes. Methods of slices also provide a more rational assessment of the normal stresses along the failure surface than more simplistic methods, such as slip circle analysis, and provide some explanation of internal deformations within the failure mass.

Some assumptions regarding internal stress distributions are required to render the analyses statically determinant. These methods tend to be analytically complex, and hand calculations are usually tedious or impractical; however, a variety of easy to use computer programs are commercially available for many of the more common methods of slices. Problems with convergence of iterative solutions sometimes limit their usefulness. For purposes of discussion, methods of slices are divided into two basic groups: Simplified Methods and Rigorous Methods.

Simplified Methods

Simplified methods, such as the Ordinary Method of Slices (OMS), Bishop's Simplified Method, and various force equilibrium methods, do not satisfy all conditions of static equilibrium. OMS neglects inter-slice forces, which allows direct calculation of a unique FOS. Bishop's Simplified Method neglects inter-slice shear forces, and requires iteration to solve for FOS. Force equilibrium methods neglect moments, and also require iteration to reach a result.

In comparison to more rigorous methods, simplified methods are relatively quick and easy to use, and can be solved using hand calculations, though these tend to be tedious and not very efficient. Simplified methods are commonly accurate to within 10 to 15% of the more rigorous methods, which in many cases may be all the accuracy that is needed or significant. Simplified methods are also useful for preliminary assessments of stability and sensitivity, and as a check on the validity of results from more detailed calculations.

In some cases, such as with OMS when pore pressures are high or slopes are flat, results tend to be overly conservative. In addition, OMS is suitable only for total stress analysis. Also, convergence problems may be experienced with Bishop's Simplified Method where failure surfaces are very steep.

Rigorous Methods

Rigorous methods, such as those of Janbu, Spencer, Morgenstern-Price and Sarma, satisfy all conditions of static equilibrium. Variations between the methods are generally related to assumptions regarding the treatment of inter-slice forces. All of these methods require iteration to reach a solution, and values of FOS calculated by the various methods are usually within about 5% of one another.

Because they satisfy all conditions of static equilibrium, rigorous methods provide implicitly more realistic models of the physical mechanics of failure than simplified methods. Through informed selection of analysis parameters, a wide variety of internal stress conditions can be modelled. Although not practical for hand calculations, computer programs are available for detailed parametric studies.

Rigorous methods are more complex, costly and difficult to use than simplified methods. Selection of modelling parameters and interpretation of results require a detailed understanding of the analytical basis and assumptions each method employs. Except for Sarma, these methods are restricted to simulating the failure mass using vertical slices.

6.4.8 Y=0 Method

The Y=0 Method is a method of slices analysis technique which can be set up with the same inter-slice force assumptions made in Bishop's, Janbu's or Spencer's methods. It analyzes the distribution of shear stresses along the selected failure surface to determine which portion of the failure surface is in a condition of limiting equilibrium. It provides the same results as the other methods of slices, as well as an understanding of the inter-slice force distribution. The method thus provides some insight into the likely internal deformations of the failure mass, and the possible locations of tension cracks or failure scarps. This technique is relatively simple and useful in the design and interpretation of monitoring programs. Furthermore, the Y=0 Method is well suited for probability of failure assessments.

6.4.9 Numerical Methods

Little information is available in the literature regarding the recent application of numerical methods of analysis, such as Finite Element, Finite Difference, Distinct Element, and others, to the analysis and design of mine dumps. Historically, these methods have been based on small strain theory, which is generally not compatible with the large strains commonly observed during dump failure. In addition, such methods require a detailed knowledge of the stress-strain behaviour of the dump materials, which is generally not available. Finite element and finite difference techniques have also been successfully utilized to evaluate dynamic response of embankments to earthquakes (Glass, 1981).

Recent developments in numerical analysis have seen the formulation of codes which can simulate discontinuous behaviour and large strains, such as the Universal Distinct Element Code (UDEC). Based on these recent developments, it is possible that numerical analysis may become a useful tool for mine dump design in the future.

Another area where numerical methods might be applied indirectly to mine dumps is in predicting piezometric conditions. Numerical seepage analysis techniques are available using the finite element or finite difference approaches (Freeze and Cherry, 1979), and this technology has been used extensively in analysis of dams and tailings impoundments.

6.4.10 Liquefaction Analysis

As indicated in Section 6.3.5 above, analysis of liquefaction potential due to earthquakes is commonly carried out using empirical methods based on in situ density of liquefaction susceptible soils (e.g. Seed and De Alba, 1986). Assessment of liquefaction potential due to high pore pressures generated by rapid loading or crest advancement is usually based on laboratory determination of pore pressure generation and dissipation rates and field monitoring of test fills or trial dumps.

6.4.11 Dynamic Stability Analysis

Techniques for analyzing the stability of embankments subjected to dynamic loading (e.g. earthquake) can generally be divided into two types: pseudostatic techniques and stress-strain techniques. Pseudostatic analyses are usually conducted using conventional limit equilibrium analysis techniques, such as those described above, which have been modified to incorporate a constant horizontal destabilizing force to represent the effects of the earthquake. The magnitude of this force is usually determined on the basis of a seismic risk evaluation of the site (see Section 3), which provides expected earthquake magnitudes and ground accelerations (i.e. seismic coefficients) for specific return periods (e.g. 1:50 year event, 1:200 year event, etc.). Pseudostatic analysis techniques are described in some detail by Glass (1981) and Makdisi and Seed (1978).

Because earthquakes are dynamic events, with directions and magnitudes of ground accelerations varying throughout their duration, pseudostatic analyses do not provide a very good model of the physical conditions. Where pseudostatic assessments are based on anticipated peak ground accelerations, they tend to yield very conservative results.

Dynamic stability analyses based on stress-strain techniques generally provide a more realistic view of the impact of seismic events. However, these methods tend to be much more complex than simple pseudostatic approaches, and require a variety of assumptions regarding the acceleration time-history of the design earthquake event and a variety of parameters to model foundation and dump response. In general, dynamic techniques are designed to assess the amount of internal deformation which can be expected during an event. This deformation is then assessed in terms of the shear strength characteristics (i.e. peak and residual shear strength vs. shear strain and shear stress) to determine the likelihood of overall failure of the embankment. A good discussion of dynamic analysis techniques is given in Glass (1981).

The common practice for mine dumps in British Columbia has been to first evaluate static stability using limit equilibrium techniques as discussed above. This would be followed by pseudostatic analysis to gain an initial appreciation for the potential for instability due to seismic events. If the results of pseudostatic analysis indicate low factors of safety (i.e. less than about 0.9 to 1.0, depending on the assumed seismic coefficients), more complex (and costly) dynamic analyses will be required. No guidelines have previously been provided for selecting an appropriate seismic coefficient for pseudostatic analysis. The recommended approach is to conduct analyses for a variety of possible ground accelerations to assess the sensitivity of the design to earthquake events. To evaluate the need for further dynamic analyses, seismic coefficients based on current Canadian seismic risk zoning and peak acceleration predictions (i.e. 10% probability of exceedance in 50 years) outlined in Weichert and Rogers (1987) are considered appropriate.

6.5 INTERPRETATION OF STABILITY ANALYSIS RESULTS

Two basic approaches are available for assessing the results of stability analysis: deterministic approaches based on evaluation of the Factor of Safety, and probabilistic approaches based on assessing the Probability of Failure.

6.5.1 Factor of Safety

The classical approach to evaluating the stability of slopes is to calculate a Factor of Safety. For most limit equilibrium types of analysis, the FOS is commonly defined as the ratio of the available shear strength along the most critical failure surface, to the shear stress along that surface. Definitions of FOS may vary, depending on the analysis method (e.g. ratio of driving forces to resisting forces, ratio of overturning moments to restoring moments, etc.). However, provided they reflect the fundamental ratio of available shear strength to shear stress over the whole failure surface, FOS calculated from different methods can be compared.

In determining the appropriate factor of safety for a given design case, several factors must be taken into consideration, including:

- The degree of uncertainty in the shear strength parameters
- The variability of material composition (e.g. proportion of fines)
- The variability of foundation conditions and geometry
- Short term (i.e. during construction) vs. Long Term (i.e. final reclamation slopes)
- Consequences of failure
- The type of analysis technique utilized, its inherent conservatism and how well the method models the physical conditions
- The importance of field control during operation of the dump

Many of these factors are subjective, site specific or cannot be determined with confidence. Consequently, it is considered unduly restrictive to establish specific FOS criteria which must be met in all design cases. Selection of a reasonable design factor of safety should be based on sound engineering judgement, with careful consideration given to the ramifications if assumptions prove to be incorrect.

Guidelines for FOS reported in the literature (e.g. Duncan and Buchignani and DeWet, 1987; MESA, 1986; and USBM, 1982) range from FOS = 1.0 for transient conditions, such as earthquakes where the consequences of failure are low, to greater than 2.0 for dumps founded on problem soils or where consequences of failure are severe. In the case of stability of the dump face, where frictional materials are at their angle of repose, the FOS is usually considered to be 1.0 for shallow, near surface failures.

Suggested guidelines for minimum FOS design values for mine dumps in British Columbia are given in Table 6.4.

6.5.2 Probability of Failure

Probabilistic approaches are based on the premise that critical parameters in the stability analysis are subject to variability, and that variability can be modelled using statistical techniques. Uncertainty in the values of critical parameters can be translated into variations in the FOS, which can also be modelled statistically. The probability of the FOS being less than 1.0 is then a statistical measure of the likelihood of slope instability. Probabilistic analyses of slope stability are described by Bosscher et al (1988). Caldwell and Moss (1981) illustrate the application of Probability of Failure analysis to dump design using the Y=0 Method described above.

Probabilistic methods require an additional step in the stability assessment and design process. In most cases, sufficient information on the variability of key material properties is unavailable. As a result, probabilistic approaches to dump design have received little attention from industry to date, and no documented case histories were noted in the literature. However, statistical approaches such as probabilistic

TABLE 6.4

INTERIM GUIDELINES FOR MINIMUM DESIGN FACTOR OF SAFETY [1]

STABILITY CONDITION	SUGGESTED MINIMUM DESIGN VALUES FOR FACTOR OF SAFETY	
	CASE A	CASE B
STABILITY OF DUMP SURFACE		
-Short Term (during construction)	1.0	1.0
-Long Term (reclamation - abandonment)	1.2	1.1
OVERALL STABILITY (DEEP SEATED STABILITY)		
-Short Term (static)	1.3 - 1.5	1.1 - 1.3
-Long Term (static)	1.5	1.3
-Pseudo-Static (earthquake) [2]	1.1 - 1.3	1.0

CASE A:
- -Low level of confidence in critical analysis parameters
- -Possibly unconservative interpretation of conditions, assumptions
- -Severe consequences of failure
- -Simplified stability analysis method (charts, simplified method of slices)
- -Stability analysis method poorly simulates physical conditions
- -Poor understanding of potential failure mechanism(s)

CASE B:
- -High level of confidence in critical analysis parameters
- -Conservative interpretation of conditions, assumptions
- -Minimal consequences of failure
- -Rigorous stability analysis method
- -Stability analysis method simulates physical conditions well
- -High level of confidence in critical failure mechanism(s)

NOTES: 1. A range of suggested minimum design values are given to reflect different levels of confidence in understanding site conditions, material parameters, consequences of instability, and other factors.

2. Where pseudo-static analyses, based on peak ground accelerations which have a 10% probability of exceedance in 50 years, yield F.O.S. < 1.0, dynamic analysis of stress-strain response, and comparison of results with stress-strain characteristics of dump materials is recommended.

analysis are well suited to cost-benefit studies, and it is likely that more attention will be given to such approaches in the future.

6.6 SETTLEMENT

As a result of the material characteristics and the construction methods commonly in use, mine dumps are subject to substantially greater settlements than most other types of engineered embankments. The potential for disruption of drainage and crack formation due to differential settlement is large and must be taken into account when designing covers for dumps. For comparison, settlement of dams constructed using dumped rock fill (reported by Clements, 1984) is of the order of a few percent of the overall height. OSM (1989) suggests that for planning drainage measures, estimates of settlement based on 1% of the dump height are appropriate.

As a result of potential differential and total settlement of dumps and dump foundations, few structures which are sensitive to settlement are constructed on mine dumps. In cases where structures are to be located on waste, specific construction measures should be undertaken to limit potential settlements (e.g. compaction, controlled lift thickness, etc.), or construction of the structure might be delayed until settlements have ceased. In this regard, documentation of settlements is essential.

6.7 FAILURE RUNOUT

A comprehensive mine dump design must recognize that failures might occur, and provide for mitigative and/or protective measures to reduce the impact of failures to an acceptable level. As discussed in Section 5.4, assessment of risk and rational design of mitigative measures requires an understanding of the runout characteristics of potential failures. The only methods currently available for runout analysis involve empirical correlations (e.g. Golder Associates, 1987). However, as indicated in Section 1, research into runout prediction is currently being sponsored by EMRC. Results of that study will be incorporated into an updated version of these guidelines.

7. CONSTRUCTION

7.1 FOUNDATION PREPARATION

Depending on results of field investigations, materials testing and stability analyses, specific measures may have to be taken to improve marginal or poor foundations to ensure that in situ conditions meet or exceed analysis and design assumptions. Foundation preparation measures which may be required include clearing, stripping or removal of poor or weak soils, installation of specific underdrainage measures and preloading of the site. Each of these measures and their application are described in the following paragraphs.

In general, where foundation conditions are poor, soils are soft, very wet or weak, the recommended approach is to choose a more favourable site. Where other sites are not available or cannot be economically developed, measures to improve foundations conditions as described below may be the only practical alternative.

7.1.1 Clearing

Logging and/or clearing of the vegetative cover is not normally required. In many cases, the process of clearing or logging may disturb and weaken underlying soils; hence, clearing could have a negative impact on overall dump stability.

Where a site is forested, it may be a requirement to log merchantable timber. If so, logging of slopes should be performed in as short a time as possible in advance of dumping so as to minimize the exposure period of the devegetated ground. Clearing of the site would also be required if stripping of organic or weak overburden soils is required. On steep, heavily vegetated slopes, where vegetation could form a continuous weak mat or zone beneath the dump, partial clearing may also be required. Portions of the dump foundation which are planned to convey water should generally be cleared of vegetation and organic overburden to ensure adequate hydraulic performance.

7.1.2 Stripping

If thick (i.e. >1 to 2m) soft organic soils or muskeg deposits underlie a dump, particularly where foundation slopes are steep, it may be necessary to remove them. If stripping is required, special care must be taken to ensure that the excavated surface is sufficiently dense to support the dump load. Proof rolling of the excavated surface may be necessary to achieve this objective. Grading and drainage of the stripped surface may also be required to prevent accumulation of water and softening of foundation soils.

Where soft soil deposits are thin, or where it can be reliably demonstrated that the process of dump advancement will displace or sufficiently consolidate weak foundation soils, removal or other remedial measures (e.g. prelifts) may not be required. In such cases, field trials will be required to confirm the feasibility of leaving soft soils in place.

7.1.3 Underdrainage

In areas of groundwater discharge, saturated soils may be too soft to support a fill of significant height. In this situation, excavation of the soil may be ineffective, and even counterproductive, if equipment tracking over the wet areas remoulds and weakens the underlying soils. A better method of foundation preparation may be to construct finger drains of sand and gravel, typically in a herringbone pattern, to collect water from a wide area beneath the dump and direct it into a single collector ditch.

Underdrains may consist of either or both gravel filled trenches and gravel blankets. Where seepage rates are high, perforated steel pipes may be installed in trenches to increase the hydraulic capacity. A formal rock drain may be required at the base of a valley dump where significant flow occurs through the dump site. Design considerations for rock drains are discussed in Section 7.2.2.

In all cases where underdrainage measures are proposed, the short and long term benefits and performance must be evaluated at the outset and confirmed through monitoring.

7.1.4 Prelifts

Where soil conditions are too soft and wet to support equipment for stripping or excavating drainage trenches, an alternative means of foundation preparation and protection is to place a prelift of dump material to consolidate and/or span or contain weak soils. Prelifts typically range between 5 and 15m in thickness. The ability to construct a prelift requires that access be available into the area of concern, which is frequently in the toe region of the dump. Developing access into the toe area of many dumps is often difficult and costly; hence, prelifts tend not to be utilized extensively.

7.2 SURFACE WATER AND SNOW CONTROL

7.2.1 Diversions and Runoff Control

Mine dumps frequently cover a large surface area, and measures are required to control runoff water to prevent saturation of exposed slopes, prevent development of phreatic surfaces within the dump, protect against loss of fines from the dump material by piping, and minimize surface erosion or development of flow failures on dump surfaces.

Surface water from catchment areas outside the dump and runoff from direct precipitation on the dump surface should be collected and diverted around the dump, or conveyed through the dump in a properly engineered and constructed rock drain. Diversions are often feasible for Sidehill and Heaped dumps, but are usually difficult to incorporate into Valley or Cross-Valley fills, unless topography and stream gradients are such that the majority of stream flow can be intercepted upstream of the dump and channelized on the valley wall beside the dump. Sidehill diversions are generally not favoured because of the need for regular maintenance, which can make them unsuitable for continued use after dump completion.

In large dumps, where there is concern for toe stability if pore pressures are allowed to buildup within the fill, it is recommended that the dump surface be sloped away from the crest at a slight gradient (1 to 2%), to direct runoff into a ditch at the rear of the dump platform. To be effective, the ditch must discharge into another subcatchment out of the dump site catchment, or into a rock drain.

7.2.2 Flow-Through Rock Drains

Construction of flow-through rock drains for mine dumps provides dump designers with a viable, economic alternative to costly and often difficult to maintain surface water diversions. However, it is important to note that no long term experience with rock drains is currently available. Clearly, additional research, field trials and documentation of long term performance is essential.

The following discussion is not intended as a comprehensive treatment of rock drain design, and is provided as an overview of the important factors which must be considered in rock drain design. Because flow-through rock drain technology is relatively new, and the state-of-the-art is changing rapidly, rock drain designers are cautioned to refer to the most current literature.

In the past decade, the practice of conveying surface flows through mine dumps by means of rock drains has gained general acceptance for flows up to about 20 m^3/s. Applications to construct dumps with rock drains to convey larger flows, of 30 m^3/s or more, are currently being evaluated for several coal mines in British Columbia and Alberta.

In analyzing flows through a completed rock drain, three conditions are of primary interest and warrant detailed analysis. These are: the capacity of the inlet, flow conditions in the outlet, and contingency for overflow in the event that the extreme flood flow exceeds the capacity of the drain (Das et al, 1990).

Inlet Capacity

The capacity of the drain inlet to transmit water is controlled by the dump slope, valley side slopes, dump height, amount and nature of sediments accumulating upstream of the inlet, and potential obstructions, such as may be formed by debris from landslides and organic materials. In the long term, the possibility that stream alluvium, which would normally be transported downstream during the freshet and storm events, will completely fill the headpond above the dump should be examined, and the impact on long term performance of the dump evaluated.

Outlet Flow

The most vital component of a rock drain design is the drain outlet. The outlet should be capable of transmitting at least the 200 year flood flow without compromising the stability of the final dump slope. Where the consequences of instability of the dump are severe, the maximum probable flood may be an appropriate design level. Alternatively, appropriately designed overflow channels could be incorporated into the design.

Design aspects to be considered are the final geometry of the slope, the height of the seepage face predicted to occur on the slope during the flood event, seepage forces which could destabilize the slope, and scour forces at the outlet which could undermine the toe. In addition, environmental effects downstream of the dump, including potential scouring of downstream facilities such as bridges and piers, should be assessed. A procedure for calculating rock drain capacity, including outlet flow, is presented by Leps (1973) and applied to an actual rock drain by Claridge, et al (1986).

Overflow Channel

It may be desirable to provide an overflow channel in the event of extreme flood flows, future blockage of the inlet to the rock drain, or in anticipation of voids plugging with fines. The function of an overflow channel is twofold:

i) it will serve to channelize flow which is not absorbed into the inlet, in a location where it will then have the opportunity to seep downwards through the mine dump into the rock drain;

ii) the channel can be designed to function much as a spillway for a dam, to direct flows in a controlled manner such that the integrity of the downstream portion of the dump is not compromised during the flood event.

7.2.3 Snow Control

It has been observed at dumps in operation at coal mines in the Rocky Mountains that rotational or non-rotational type failures frequently occur during the late spring and summer. From back analysis of such failures, it has been concluded that residual snow and ice concentrations from the previous winter, in combination with relatively fine dump materials, may have been responsible for some of the failures. The snow and ice may melt rapidly and, if present in a continuous layer, could form a weak zone. Also, excess pore pressures may develop, which cannot readily be dissipated in the fine dump material.

To minimize the effect of snow on dump stability, the following general guidelines should be followed, where appropriate:

a) Dump materials should not be placed on dumping faces where the depth of snow is significant (i.e. >1m). The dump surface should be worked evenly so that there are no large depressions that may infill with snow.

b) Snow removed from the mine should not be disposed in an active dump. A separate dumping area should be provided where consequences of instability, avalanches, etc. are minimal. In this regard, it may be convenient to designate one dump as a snow-only dump during winter operations.

c) Snow should not be disposed in drainage courses or gullies which will be covered by dump materials.

d) Dump development should be planned such that winter dumping is on windward exposed faces, where accumulations of snow will be the least.

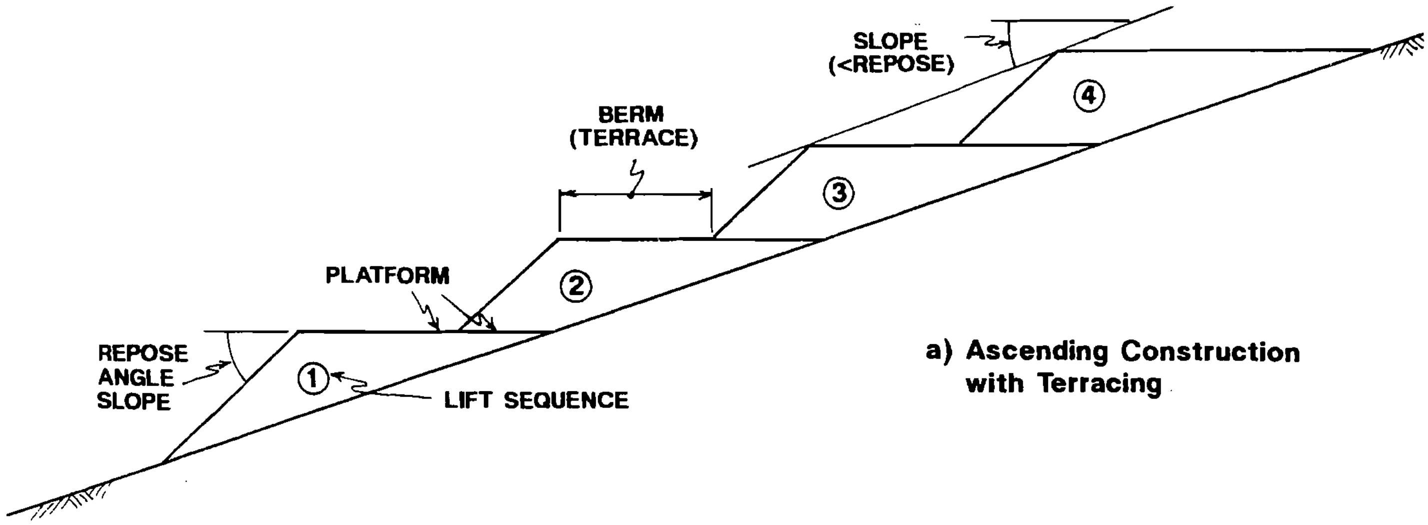
7.3 CONSTRUCTION METHODS

7.3.1 Platforms and Lifts

Many of the larger mine dumps have been developed in thick lifts via a series of platforms spaced at vertical intervals of 10m or more (see Fig. 7.1). Platform elevations are set to minimize the vertical haul required. Dump stability may be enhanced by controlling the width and length of the platforms and the vertical spacings between them. If space is available, wide platforms may permit berms to be maintained at the platform elevations, resulting in a benched slope with a relatively flat overall slope angle. Closely spaced platforms and thin lifts also reduce the amount of loading imposed in one increment. This can be an important factor where the dump is supported on saturated soils which generate pore pressure when loaded.

7.3.2 Ascending vs. Descending Construction

Ascending and descending construction methods are illustrated in Fig. 7.1. Ascending or upward construction is preferred, because each successive lift is supported on a previously constructed lift, the behaviour of which



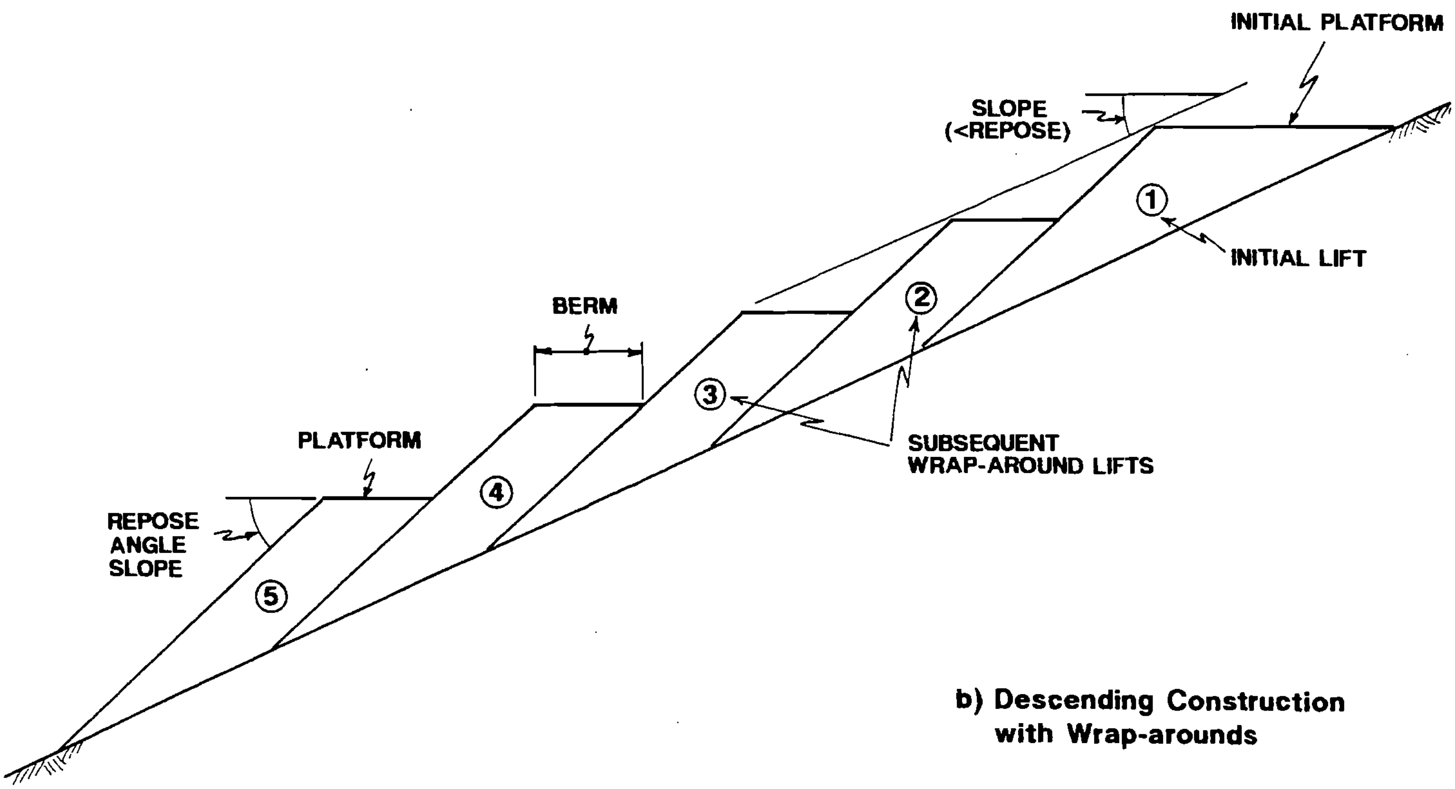


FIG. 7. 1 ASCENDING vs DESCENDING CONSTRUCTION

may be well documented and understood. Any failure surface will have to develop through the previously constructed lift, which also acts as a bu ttress for the toe and provides some confinement for foundation soils. Another advantage of ascending construction is that the toe is always supported on level ground (i.e. the previous platform).

In most open pit mines, the pit is initiated at a relatively high elevation and mining proceeds downwards. Consequently, economics dictate a level haul onto a series of platforms which are constructed at successively lower elevations (descending construction). In this case, foundation conditions and ground slopes in the toe region frequently control stability.

7.3.3 Material Distribution and Crest Advancement

In planning a dump, thought should be given to incorporating some redundancy into the number of dumping sectors which can be activated, as well as to maximizing the length of dump crest in each area. The benefits of doing this are twofold. First, if a failure occurs in one dump sector, or the rate of crest subsidence is excessive, operations in that part of the dump can be suspended until stable conditions resume. Second, by dumping over as long a crest length as possible, the rate of advance of the dump can be minimized. This will reduce the rate of loading on the foundations and the corresponding generation of pore pressures in the toe region. Also, a slow rate of filling allows more time for the dump materials to consolidate and gain frictional strength.

Because of the wide range of factors which influence stability (see Section 5), dumps tend to exhibit unique behaviour. Hence, it is difficult to determine limiting placement rate criteria at the design stage. Initial dumping rates and crest advancement should be conservative. Monitoring of dump behaviour is critical to be able to verify the appropriateness of dump advancement rates assumed for design, and to modify construction criteria as necessary.

7.3.4 Topographic Factors

Variations in ground slopes beneath advancing dumps frequently control dump stability during construction. Dump development should be planned to take maximum advantage of topographic diversity. Where dumps must be advanced over steeply sloping ground, several steps may be taken to minimize the risk of instability as follows:

- initiate a fill over steep slopes by dumping into a gully where slopes are lower, and three-dimensional confinement improves stability;

- design the toe of the lift to be supported on natural benches or the flattest available topography;

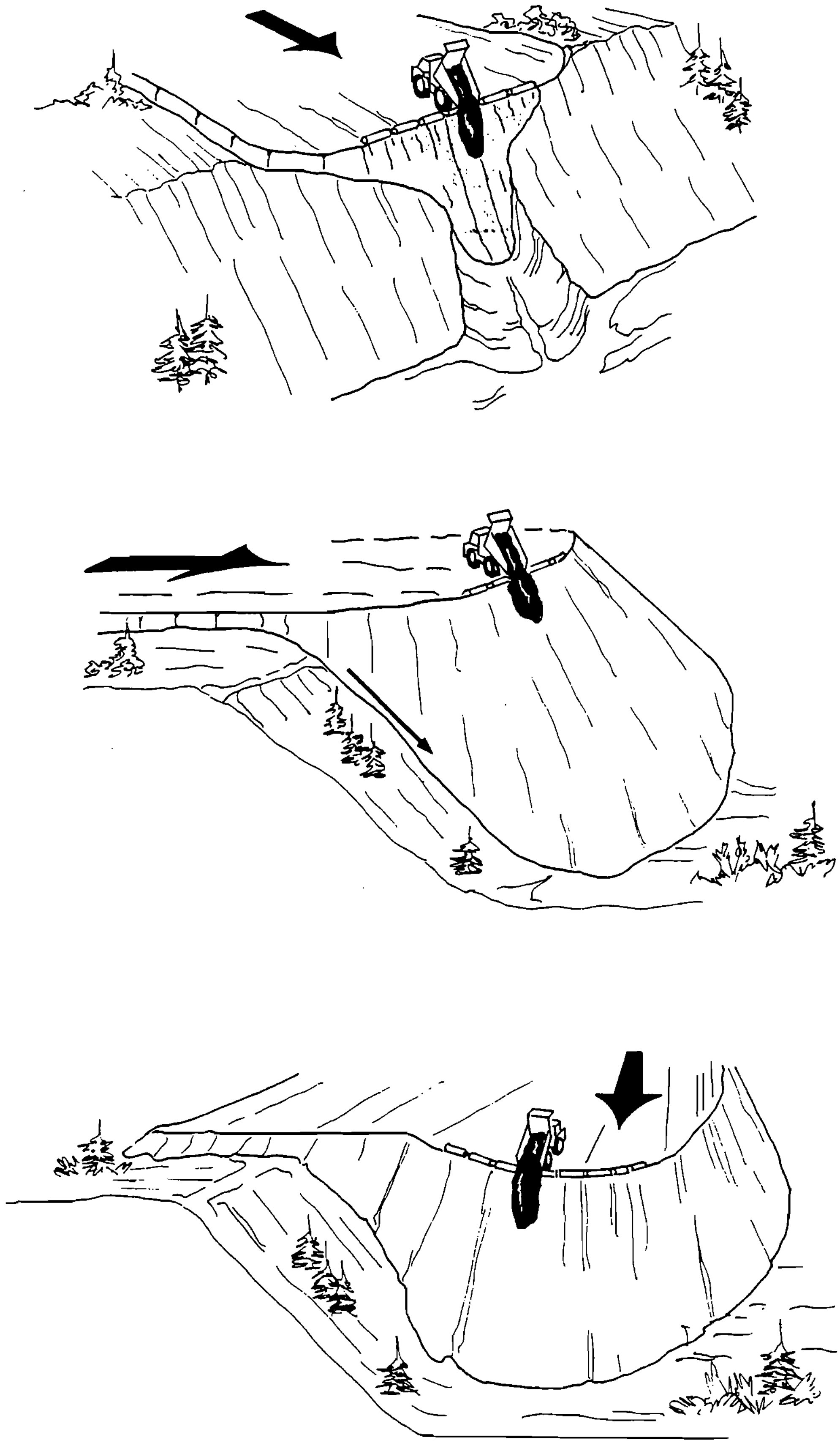
- after the initial fill has been keyed onto flatter topography, extend the dump in a direction parallel to the contours;

- individual gullies crossing a steep slope should be filled in by dumping along the gully axis. This approach will avoid having to cross steep gully side slopes, and will also tend to promote natural segregation of coarse rock in the bottom of the gully, improving underdrainage.

The recommended sequence for development of mine dumps over steep topography is illustrated in Fig. 7.2.

7.3.5 Terraces and Wrap-Arounds

Terraces and wrap-arounds provide a sound approach to mine dump design, and can simplify and expedite reclamation. Terraces are generally associated with ascending construction, and result when succeeding lifts do not extend to the crest of the previous platform, thus maintaining a berm. Berms may be left at all platform elevations or just selected ones. Figure 7.1a illustrates the concept of terracing.



i) Initiate dumping in area of flattest slopes, utilizing gullies to maximize confinement.

ii) Advance dump in a direction perpendicular to contours until dump is keyed onto flatter topography.

iii) Extend dump parallel to the contours.

FIG. 7.2 RECOMMENDED SEQUENCE FOR ADVANCEMENT OF DUMPS OVER STEEP TERRAIN

Wrap-arounds are generally associated with descending construction, and are configured to enclose and buttress the lifts which have previously been dumped at higher levels. Platforms or berms are typically located at vertical intervals of 20 to 40m, and may be graded downwards, in the direction of advance. The width of each platform or berm is determined on the basis of disposal capacity requirements, stability considerations and slope conditions at the toe of the slope (Section 7.3.4). Figure 7.1b illustrates the concept of wrap-arounds.

7.3.6 Buttresses and Impact Berms

In cases where potential hazards prohibit or restrict dump construction, it may be feasible to improve dump stability via the use of buttresses. Alternatively, establishment of hazard mitigation or protection works may render the site useable. Mitigative works usually consist of impact or deflection berms and debris basins or chutes. Design requires careful consideration of site specific conditions, as well as an assessment of the size and runout characteristics of potential failures. In some instances, the optimum solution might be to relocate facilities which may be endangered by possible instability.

In steeply sloping terrain, where the safety factor against a foundation failure is low, the potential for a long runout may be high. If potential damages associated with failure are unacceptable, one protective measure may be to construct a containment structure or buttress in the form of a ring at approximately the location of the ultimate toe of the dump. A buttress is considered to be an integral part of the dump toe. The design of the buttress is based on increasing the factor of safety to a specified design value, and is essentially a matter of configuring the toe zone to incorporate as much mass as possible to counterbalance the driving forces of the upper portion of the dump.

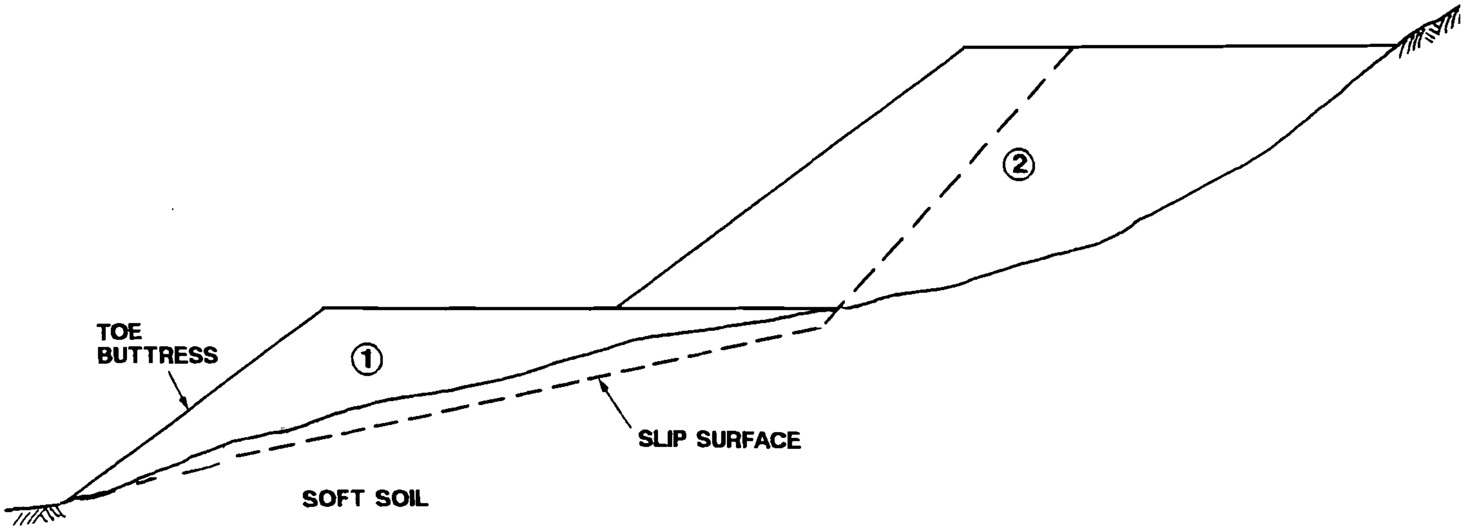
Impact berms are usually located downslope of the final toe on flatter topography, where they can best function to intercept both individual boulders and slides, and to protect facilities or a stream course below the dump. The design of impact berms is more complex than buttresses, as they must be of sufficient mass and height to prevent a failure runout of a specific size from crossing them. Impact berms may be very effective in mitigating runout problems associated with small slides and flows. However, constructing impact berms of sufficient mass and height to significantly mitigate major dump failures is usually impractical. Figure 7.3 illustrates typical configurations for a buttress and impact berms.

7.3.7 Control of Material Quality

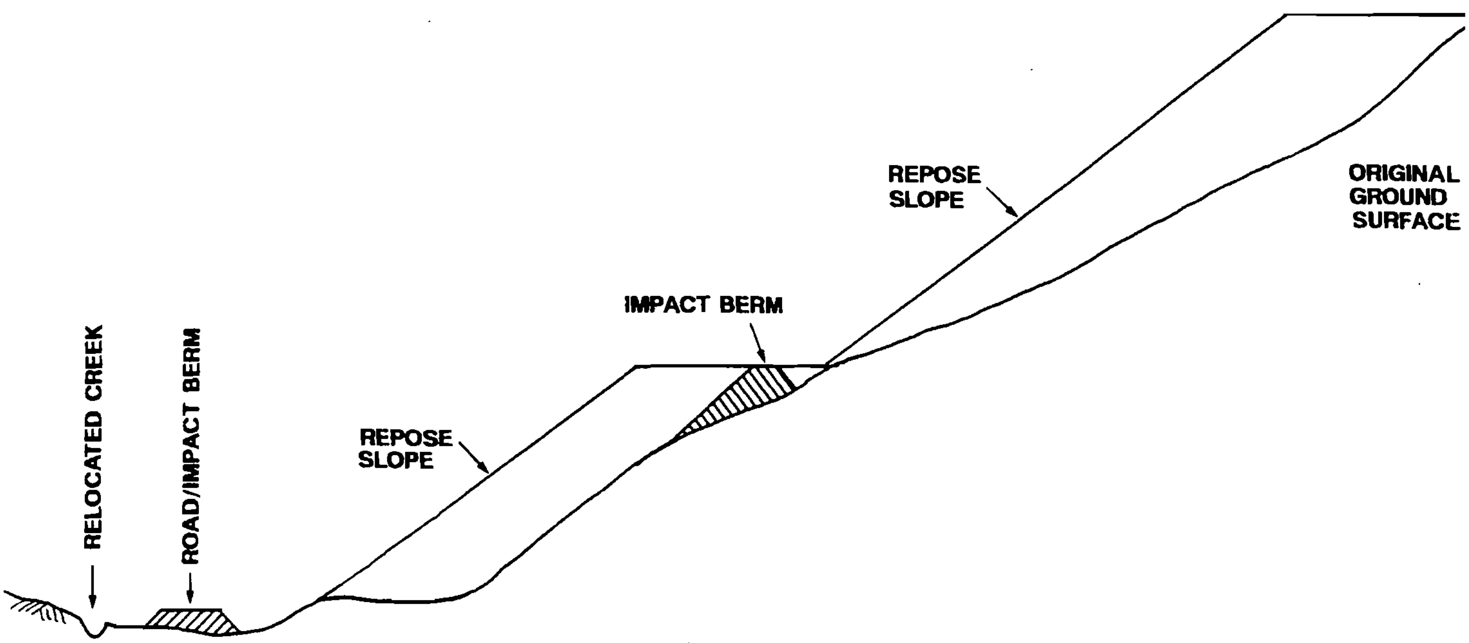
One of the most effective means of improving dump stability is to exercise control over the quality of material placed in critical parts of the dump. When dumping on steeply sloping terrain, only coarse, durable rockfill should be placed into gullies or defined water courses. It is also beneficial to place coarse rockfill directly onto steep slopes (i.e. slopes exceeding 25° to 30°) to improve the frictional contact between the fill and the foundation, to provide underdrainage and to mobilize as much strength as possible near the bottom of the dump.

Low quality, friable, fine grained materials should be placed in the upper portions of the dump, where the material is not exposed to significant runoff flows. Highly weathered, decomposed rock and soil should be spread in lifts on individual dump platforms, rather than down the dump face. If possible, soil and fine rockfill should be mixed with the coarser waste, or placed on the top of the final dump for use in reclamation. Fine dump materials should be placed in thin lifts and compacted with haul trucks to improve stability and strength. If placement of degradable rockfill materials onto an active dump is unavoidable, it should be dumped along with as much good quality coarse rock as possible.

Another approach to dealing with poor quality dump materials is to dispose of them in cells within the dump. Cells should be incorporated in the dump in an organized fashion such that they do not form a potential failure zone.



a) Toe Buttress



b) Impact Berm

FIG. 7.3 TOE BUTRESS AND IMPACT BERMS

7.3.8 Winter Construction

Where a dump has only marginal stability, and the risk of a failure with a long runout is not acceptable, particular attention should be given to the effect that incorporation of snow and ice into the dump mass may have on its stability. If a dump site is located in a leeward aspect which is prone to large snow accumulations, it may be best to suspend dumping in this area during winter. As a general guideline, dumping is not recommended when there is in excess of 1m of snow on the dump surface. This guideline may be relaxed if coarse, competent rockfill is dumped onto the snow, or if it can be demonstrated that the rock displaces the snow without incorporating snow and ice in distinct layers into the dump. Further discussion of snow control measures is provided in Section 7.2.3.

7.3.9 Restricted Operation

Dump performance should be monitored both visually and with instruments, in accordance with procedures outlined in the companion report on monitoring guidelines (Klohn Leonoff, 1991). Mine wide criteria should be developed on the basis of the performance history experienced for all dumps, and should be used to determine when restrictions need to be imposed on the dumping operation. Restrictions include suspension or a reduced rate of dumping and the use of select, coarse rock. Reduced dumping rates are usually imposed when dump deformation rates exceed a specified amount per hour, or per day.

7.3.10 Trial Dumping

At sites where dump stability is difficult to predict with confidence, the initial stages of dumping should proceed on a trial basis to permit verification of the design assumptions. For example, soft foundations may be susceptible to excess pore pressure generation, thus necessitating that the rate of dumping be restricted to a prescribed level. An allowable rate of dumping may be established based on a conservative interpretation of strength and consolidation data.

Pore pressure generation and dissipation rates are very difficult to predict accurately on the basis of laboratory testing alone. Hence, pore pressure sensors should be installed in the foundation of susceptible dumps to permit preparation of a pore pressure model which reflects actual measurements. To generate the data required to develop the model, the trial dump may be constructed in increments, allowing sufficient time between loading stages for pore pressure trends to be established.

7.4 DESIGNING FOR RECLAMATION

The Mines Act and Health, Safety and Reclamation Code (MEMPR, 1989) requires that dumps be reclaimed. The primary objectives of dump reclamation are to:

i) maintain long term stability;
ii) maintain long term erosion control;
iii) ensure that water released from the dump to the receiving environment is of an acceptable quality; and
iv) to ensure that land use and productivity objectives are achieved.

As indicated earlier, short term stability and design considerations may not be the same as long term, abandonment requirements. However, there may be distinct advantages to designing the dump with reclamation in mind from the outset. Such advantages could include lower overall reclamation costs, improved short term stability and fewer operational problems.

Long term erosion control is a function of the steepness of dump slopes, the durability of dump materials, and surface runoff collection. Regrading of angle of repose dump slopes and/or provision of berms and runoff collection ditches may be necessary to prevent erosion. Limiting the height of repose angle slopes and providing periodic berms simplifies implementation of erosion control measures.

Most dump materials tend to be reasonably well graded and self-filtering. Consequently, seepage flows released from dumps tend to be relatively free of suspended sediments. The main concerns with seepage water quality are heavy metal contamination or acid rock drainage. Special provisions for encapsulation of potential contaminants within other neutralizing materials or low permeability envelopes may be required. Alternatively, it may be more efficient to treat seepage flows to reduce effluent contaminants to acceptable levels, and rely on contaminant levels reducing naturally with time to acceptable levels. In any event, the long term impact of disposal of potentially reactive dump materials requires careful consideration and planning during the initial design phase. Details regarding evaluation and long term mitigation of potentially reactive dump materials are given in B.C. AMD Task Force (1990).

Land use and productivity objectives need to be clearly identified at the outset of the project, and realistic plans developed to achieve them. As for long term stability and erosion control, incorporation of land use planning with dump design may simplify and reduce the costs of achieving land use objectives.

For additional discussion regarding reclamation requirements, the reader is referred to MEMPR (1990).

7.5 UPDATING DESIGN BASED ON PERFORMANCE

As discussed in Section 2 above, mine dump design is an iterative process. Rational implementation requires that designs be initiated, monitored and revised based on the documented performance. This process is particularly important because of the wide range of unknowns the mine dump designer must deal with, and potential impacts if the design assumptions prove to be incorrect. Mine planners should make specific provisions for monitoring and evaluating dump performance, and for updating and revising dump plans on a regular basis.

8. ACKNOWLEDGEMENTS

Many individuals and organizations participated in this study, and their contributions are appreciated. In addition to the various mines responding to the mine dump questionnaire, who are listed in Appendix A, written contributions were received from: J.C. Errington, MEMPR; L. Bolt, USBM; J. Purkis, Minnova Inc.; D.S. Cavers, Hardy BBT Ltd.; D. Fawcett, Smoky River Coal Ltd.; and R. Jeria, Westar Mining. The authors also express their appreciation to Mr. R.W. McGinn and Mr. T. Vaughan-Thomas of MEMPR for their assistance with coordinating the study and for their guidance. Reviews and editorial comments provided by the B.C. Mine Development Steering Committee and technical reviewers are acknowledged with thanks.

9. ANNOTATED BIBLIOGRAPHY

American Society for Testing Materials (ASTM). Annual Book of ASTM Standards, Part 19.
Testing Specifications

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

Blight, G., 1981. "Failure Mode". Workshop on Design of Non-Impounding Mine Waste Dumps. SME. November.
Wedge Failure, Stability Analysis, Stability Charts

Bosscher, P.J., Edil, T.B. and Mickelson, D.M., 1988. "Evaluation of Risk of Slope Instability Along a Coastal Reach". Proc. 5th Intl. Symp. Landslides, Lausanne. Balkema.
Probabilistic Stability Analysis, Risk

Brams, J., 1980. "Safety Against Slip in Inclined Bases of Slope Toe." J. Geot. Eng. Div., ASCE, Vol. 106, No. GT10, October.
Stability Analysis, Stability Charts

British Columbia Acid Mine Drainage Task Force (BCAMD Task Force). 1990. Draft Acid Rock Drainage Technical Guide. Prepared by Steffen Robertson and Kirsten (B.C.) Inc. in association with Norelco Environmental Consultants and Gormely Process Engineering. May.
Acid Rock Drainage, Regulatory Guide

British Standards Institution (BSI), 1975. "British Standard 1377: Methods of Test for Soils for Civil Engineering Purposes". BSI, London.
Testing Specifications

Caldwell, J.A. and Moss, A.S.E., 1981. "Simplified Stability Analysis." Workshop on Design of Non-Impounding Mine Mine dumps. SME. November.
Failure Modes, Shear Strength, Stability Analysis, Stability Charts, Probabilistic Stability Analysis

Call, R.D., 1981. "Evaluation of Material Properties". Workshop on Design of Non-Impounding Mine Waste Dumps, SME, November.
Material Properties

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

Campbell, D.B., 1986. "Stability and Performance of Waste Dumps on Steeply Sloping Terrain". Intl. Symp. Geotech. Stab. Sfc. Min., Calgary, November.
Stability Analysis, Monitoring

Campbell, D.B. and Shaw, W.H. 1978. "Performance of a Waste Rock Dump on Moderately to Steeply Sloping Foundations". Intl. Symp. Stab. Coal Min., Vancouver, December.
Case History, Monitoring, Failure Runout

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

Canadian Council of Resource and Environment Ministers (CCREM), 1987. Canadian Water Quality Guidelines. Task Force on Water Quality Guidelines, March.
Water Quality

Canadian Geotechnical Society (CGS), 1985. Canadian Foundation Engineering Manual. 2nd Ed., Bitech Publishers, Vancouver.
Site Investigation, Foundations

Claridge, F.B., Nichols, R.S. and Stewart, A.F. 1986. "Mine Waste Dumps Constructed in Mountain Valleys". CIM Bull., August.
Construction Methods, Rock Drains, Material Properties, Design Considerations, Case Histories

Clements, R.P., 1984. "Post-Construction Deformations of Rockfill Dams". J. Geot. Eng. Div. ASCE, Vol. 110, No. 7, July.
Settlement

Compton, R.R., 1962. Manual of Field Geology. Wiley, NY.
Site Investigation, Geology

Craig, R.F., 1983. Soil Mechanics. 3rd Ed. Van Nostrand Reinhold, Berkshire.
General Reference on Soil Mechanics

Das, B.M., Claridge, F.B. and Garga, V.K., 1990. "The Use of Rock Drains in Surface Mine Waste Dumps." CIM Bulletin, Vol. 83, No. 942, October.
Rock Drains

Department of Energy, Mines and Resources Canada, 197?. Tentative Design Guide for Mine Waste Embankments in Canada. Technical Bull. TB 145, Mines Branch Mining Research Centre.
General Reference on Mine Dumps

Department of the Navy, 1971. Design Manual - Soil Mechanics, Foundations and Earth Structures (NAVFAC DM-7). Naval Facilities Engineering Command, Alexandria, VA.
Site Investigation and Testing, Material Properties

Duncan, J.M., Buchignani, A.L., and DeWet, M., 1985. An Engineering Manual For Slope Stability Studies. Virginia Polytechnic Institute and State University, March.
Stability Analysis, Factor of Safety

E.L.U.C. Secretariat, 1978. Terrain Classification System. Resource Analysis Branch, B.C. Ministry of Environment.
Terrain Classification

Environment Canada, 1983. Sampling for Water Quality. Water Quality Branch, Inland Waters Directorate, Ottawa.
Water Quality

Environment Canada, 1988. Handbook on Climate Data Sources of the Atmospheric Environment Service. Canadian Climate Program, April.
Climate

Everett, A.G., Anderson, J.J., Peckham, A.E. and MacMillion, L., 1974. "Engineering Stability in the Future Spoil and Waste Piles of the Western United States". Source publication unknown. Abstract.

Fisheries and Oceans Canada and B.C. Ministry of Environment & Parks, 1987. Stream Survey Field Guide. Fish Habitat Inventory and Information Program, June.
Fishery Resources

Freeze, R.A. and Cherry, J.A., 1979. Groundwater. Prentice Hall, New Jersey.
General Reference on Hydrogeology

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

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

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.
General Reference on Surface Coal Mine Dumps

Goodman, R.E., 1976. Methods of Geological Engineering. West, New York.
General Reference on Rock Mechanics, Field Investigation

Goodman, R.E., 1980. "Introduction to Rock Mechanics." Wiley.
General Reference on Rock Mechanics, Rock Properties, Stability Analysis

Hoek, E., 1983. "Strength of Jointed Rock Masses". Rankine Lecture, Inst. Min. Met., London. March.
Shear Strength

Hoek, E. and Bray, J.W., 1981. Rock Slope Engineering. 3rd Ed. Int. Min. Met., London.
General Reference on Rock Mechanics

Hurlbut, C.S. and Klein, C., 1977. Manual of Mineralogy. 19th Ed. After Dana, J.D., Wiley, NY.
General Reference on Mineralogy

International Society for Rock Mechanics (ISRM). Various suggested methods for testing of rock. Prepared by the Commission on Standardization of Laboratory and Field Tests.
Rock Mechanics Testing

Jager, J.C. and Cook, N.W.G., 1979. Fundamentals of Rock Mechanics. 3rd Ed., Chapman and Hall, London.
General Reference on Rock Mechanics

Janbu, N., Bjerrum, L. and Kjaernsli, B., 1956. "Soil Mechanics Applied to Some Engineering Problems." Norwegian Geot. Inst. Pub. No. 16.
Stability Analysis

Kerr, P.F., 1977. Optical Mineralogy. 4th Ed., McGraw-Hill, NY.
General Reference on Mineralogy

Keser, N., 1976. Interpretation of Landforms from Aerial Photographs. Research Division. B.C. Forest Service, Victoria.
Air Photo Interpretation

Lambe, T.W., 1951. Soil Testing for Engineers. Wiley, NY.
Laboratory Testing

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)

Leps, T.M., 1970. "Review of Shearing Strength of Rockfill". J. Soil Mech. Fndn. Div. ASCE. Vol. 96, No. SM4, July.
Shear Strength

Leps, T.M., 1973. "Flow Through Rockfill." Embankment Dam Engineering (Casagrande Volume), J. Wiley & Sons.
Rock Drains, Material Properties

Linsley, R.K. Kohler, M.A. and Paulhus, J.L.H., 1975. Hydrology for Engineers. 2nd Ed. McGraw-Hill.
General Reference on Hydrology

Lowe, J. and Karafiath, O., 1960. "Stability of Earth Dams Upon Drawdown." Proc. 1st Panamer. Conf. Soil Mech., Vol. 2. Mexico City.
Stability Analysis, Stability Charts

McDonald, J.D. and Errington, J.C., 1979. "Reclamation of Lands Disturbed by Coal Mining in British Columbia". Proc. 1st. Intl. Symp. Stab. Coal Min., Vancouver, 1978.
Reclamation

Makdisi, F.I. and Seed, H.B., 1978. "Simplified Procedure for Estimating Dam and Embankment Earthquake-Induced Deformations". J. Soil. Mech. and Fndn. Div., ASCE, Vol. 14, No. GT7, July.
Dynamic Stability

Mallett, C.W., Dunbavan, M., Seedsman, R.W. and Ross, D.J., 1983. Stability of Spoil Piles in Deep Surface Mines. Report for Australia National Energy Research, Development and Demonstration Council. Abstract.

Marshal, J.R., 1973. "Mechanical Properties of Rockfill". Embankment-Dam Engineering, Hirschfield and Poulos, eds. Wiley, NY.
Material Properties

Martin, D.C., 1991. Geotechnical Data Collection for Exploration Geologists. Geological Association of Canada. Short Course No. 10, 2nd Ed., February.
Field Investigations

Mine Development Assessment Act. 1990. Status of British Columbia, Chapter 59 (yet to be Proclaimed).
Regulatory

Mines Act. 1989. Statutes of British Columbia. Chapter 54. (Proclaimed July 15, 1990)
Regulatory

Mining Enforcement and Safety Administration (MESA), 1975. Engineering and Design Manual - Coal Refuse Disposal Facilities. Report prepared for U.S. Dept. Int. by D'Appolonia Consulting Engineers Inc.
General Reference on Coal Refuse Dumps

Ministry of Energy, Mines and Petroleum Resources (MEMPR), 1990a. Health, Safety and Reclamation Code for Mines in British Columbia. Incl. Mines Act, S.B.C. 1989, c.56. June.
Regulatory

Ministry of Energy Mines and Petroleum Resources (MEMPR), 1990b. "Bill 59: The Mine Development Assessment Act". Information Circular. July.
Regulatory

Ministry of Energy, Mines and Petroleum Resources (MEMPR), 1989. "Mine Development Review Process - An Introduction." Information circular. October.
Regulatory

Morgenstern, N.R. and Price, V.E., 1965. "The Analysis of the Stability of General Slip Surfaces." Geotechnique, Vol. 15, pp. 79-93.
Stability Analysis

Nasmith, H and Gerath, R.F., 1979. "Application of the E.L.U.C. Terrain Classifiation System to Engineering Projects". The B.C. Professional Engineer, August.
Terrain Classification

Nichols, R.S. 1981. "Waste Dump Stability at Fording Coal Limited in B.C.". Third Intl. Conf. Stab. Sfc. Min., Vancouver, June.
Case History, Design Considerations, Construction Methods, Material Characteristics, Site Selection, Monitoring

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

Nichols, R.S. and Rutledge, A.L., 1982. "Water Drainage Through Waste Dumps at Fording Coal Limited". CIM Bull. Vol. 75, No. 843, July.
Case History, Material Characteristics, Rock Drains, Segregation

Nguyen, V.U., Nemcik, J.A. and Chowdhury, R.N., 1984. "Some Practical Aspects of Spoil Pile Stability by the Two-Wedge Model". Min. Sci. Tech. Vol. 2, Elsevier.
Stability Analysis, Remedial Measures

Office of Surface Mining Reclamation and Enforcement (OSM), 1989. Engineering Design Manual for Disposal of Excess Spoil. Report (Contract No. J5110084) for U.S. Dept. Int. Prepared by CTL/Thompson Inc., 294 pp., November, 1982.
General Reference on Mine Dumps

Peck, R.B., Hanson, W.E. and Thornburn, T.H., 1974. Foundation Engineering. 2nd Ed., Wiley, NY.
General Reference on Soil Mechanics, Site Investigation

Pernichele, A.D. and Kahle, M.B., 1971. "Stability of Waste Dumps at Kennecott's Bingham Canyon Mine". SME Trans., Vol. 250, December.
Case History, Factors Affecting Stability, Failure Modes

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.
Field Measurement of Rock Strength

Piteau Assocaites, 1990. Groundwater Quality Monitoring Manual. B.C. Ministry of Environment, Environmental Protection Division, March.
Groundwater Monitoring

Pommen, L.W., 1989. "Approved and Working Criteria for Water Quality". B.C. Ministry of Environment. March.
Water Quality

Reeves, G.S. and Claridge, F.B. 1988. "Planning for Survival". Intl. Symp. Mine Planning Equip. Select., Calgary, November.
Rock Drains, Case History

Robertson, A. MacG., 198?. "Deformation and Monitoring of Waste Dump Slopes". Source publication unknown.
Failure Modes, Stability Analysis, Monitoring

Robertson, A. Mac G., 1986. "Mine Waste Disposal: An Update on Geotechnical and Geohydrogeological Aspects". Pro. 8th An. Symp Geot. Geohyd. Aspects Waste Mgmt., Fort Collins, February.
Failure Modes, Stability Analysis, Monitoring, Seepage

Robins J.D. 1978. "Constructing Spoil Storage Fills in the Steep Terrain Appalachian Coalfields. Intl. Symp. Stab. Coal Min., Vancouver, December.
U.S. Regulatory, Construction Methods

Sarma, S.K., 1979. "Stability Analysis of Embankments and Slopes." Geot. Eng. Div. ASCE, Vol. 105, GT12.
Stability Analysis

Saul, B.W., 1990. "Optimization of Waste Haulage with Linear Programming." Proc. 2nd. Intl. Symp. Mine Plan. Equip. Select., Calgary, November.
Economics, Planning

Seed, H.B. and de Alba, P., 1986. "Use of SPT and CPT Tests for Evaluating the Liquefaction Resistance of Sands". ASCE Spec. Publ. No. 6, June.
Liquefaction

Singhal, R.K., 1988. "Western Canada's Mountains Challenge Waste-Dump Planners". E&MJ, Vol. 189, No. 6, June.
Investigation, Construction Methods, Factors Affecting Stability, Failure Modes

Singhal, R.K. and Vladut, T., 1987. "Design of Soil Waste Dumps and Waste Disposal in Western Canadian Surface Mines". Pro. 9th An. Symp Geot. Geohyd. Aspects Waste Mgmt., Fort Collins, February. Abstract.

Society of Mining Engineers (SME), 1985. Design of Non-Impounding Mine Waste Dumps. Proceedings of workshop held in conjunction with Annual Fall Meeting of SME, ed. M.K. McCarter, November, 1981. 17 papers and workshop discussion.
General Reference on Mine Dumps

Spencer, E., 1967. "A Method of Analysis of the Stability of Embankments Assuming Parallel Inter-Slice Forces." Geotechnique, Vol. 17, pp. 11-26.
Stability Analysis

Stepanek, M. 1986. "Stability of Waste Embankments in a Northern Environment". Intl. Symp. Geotech. Stab. Sfc. Min., Calgary, November.
Permafrost

Stewart, A.F. and Martin, D.C. 1988. "Geotechnical and Hydrogeological Requirements for Development of Mining Projects in British Columbia". Mining Review, July/August.
Planning, Design Considerations

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

Symons, G. ed. 1987. Flow Through Rock Drains - Proceedings of the International Symposium. 15 papers on design and performance of rock drains with particular reference to mine waste dumps. Cranbrook, September.
Rock Drains, Laboratory Testing, Material Properties, Segregation

Tassie, W.P. 1987. "Waste Dump Management at Quintette Coal Limited". CIM Dist. 5 AGM, Ft. McMurray, Alta., September.
Case History, Factors Affecting Stability, Monitoring, Failure Rehabilitation

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

Terzaghi, K. and Peck, R.B., 1967. "Soil Mechanics in Engineering Practice." 2nd Ed. Wiley.
General Reference on Soil Mechanics, Soil Properties

Thompson R.W. and Ferguson, D.A. 1981. "The Impact of the Federal Surface Mining Control and Reclamation Act Upon Stability Designs for Surface Coal Mines". Proc. 3rd. Intl. Conf. Stab. Sfc. Min., Vancouver, June.
U.S. Regulatory, Reclamation

U.S. Bureau of Mines (USBM), 1982. Development of Systematic Waste Disposal Plans for Metal and Nonmetal Mines. Minerals research contract report (Contract No. J0208033) for U.S. Dept. Int. Prepared by Goodson and Associates, Inc., 614pp., June.
General Reference on Mine Dumps

Vandre, B.C., 1980. "Stability of Non-Impounding Mine Waste Embankments." USDA Forestry Service, Ogden, Utah. March.
Stability Analysis, Stability Charts

Vandre, B.C., 1986. "Waste Disposal Design Standards: Putting Square Pegs in Round Holes?" Pro. 8th An. Symp Geot. Geohyd. Aspects Waste Mgmt., Fort Collins, February.
U.S. Regulatory, Risk

Wagner, A.A., 1957. "The Use of the Unified Soil Classification System by the Bureau of Reclamation." Proc. 4th Intl. Conf. SMFE, London, Vol. 1. Butterworths.
Soil Classification

Wahler, W.A., 1979. "A Perspective - Mine Waste Disposal Structures - Mine Dumps, and Mill and Plant Impoundments". Proc. 6th Panamerican Conf. Soil Mech. Fndn. Eng., Vol. III., Lima.
Classification, Site Selection, Material Transportation

Weichert, D.H. and Rogers, G.C., 1987. "Seismic Risk in Western Canada." Symp. Earthquake Eng., Van. Geotech. Soc., Vancouver. May.
Seismic Zoning

Welsh, J.D., 1981. "Geotechnical Site Investigation". Workshop on Design of Non-Impounding Mine Waste Dumps. SME. November.
Site Investigation

West, G., 1989. "Rock Abrasiveness Testing for Tunneling". Technical Note, Int. J. Rock Mech. Min. Sci. & Geomech. Abstr., Vo. 26, No. 2. pp. 157-160.
Durability

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.
Site Investigation, Stability

BRITISH COLUMBIA WASTE DUMP SURVEY
APPENDIX A

SECTION I

GENERAL INFORMATION AND CHARACTERISITICS OF WASTE MATERIALS

STATUS- Status of the waste dump on the date of the survey questionnaire response.

DATE- Starting and finishing (anticipated if status is active) dates of utilization of the waste dump.

MATERIAL- Primary geologic materials of which the waste dump is composed and their approximate percentages.

UCS- Unconfined Compressive Strength of the waste materials. Qualitative descriptions were used where quantitative information was unavailable.

DURABILITY- LA=Los Angeles Abrasion test, SD = Slake Durability test. Qualitative descriptions were used where quantitative information was unavailable.

GRADATION- Percentages > 300 mm and < #200 sieve sizes. In some cases data for alternative sieve sizes have been provided.

WASTE DUMP NO.	NAME OF MINE	OPERATOR	LOCATION	TYPE OF MINE	WASTE DUMP NAME	STATUS	DATE Started Finished	MATERIAL TYPE	MATERIAL %	UCS (MPa)	DURABILITY	GRADATION %> 300mm	GRADATION %< #200
AFT-1	Afton	Afton Oper. Corporation	10km W. of Kamloops	Open Pit Base Metal	#1 Main	Finished	77 87 06	Diorite/Magnetite/Volc Tertiary Sed/Volc/OB	75 25	40-140 <10	15% V. Durable/ 85% V. Poor-Fair	<15	<1
AFT-2	Ajax		5km S. of Kamloops	Open Pit Base Metal	South	Active	90 06 96	Diorite	100	40-120	Variable	30	<1
BAL-1	Balmer	Westar Mining Ltd.	Sparwood	Open Pit Coal	Baldy North 6200/6170/ 5990	Active	89 03	Sandstone Mudstone Siltstone	65 25 10	100 30 55	High Low-Moderate Moderate	75 40 50	2 15 10
BAL-2					A29E North + South	Active	89 03 92 02	Sandstone Siltstone Mudstone	73 24 2				
BAL-3					Erickson	Active	81 06 94 04	Sandstone Siltstone Mudstone	48 33 19				
BAL-4					AS1-4500	Finished	89 06 90 08	Sandstone Siltstone Mudstone	60 26 14				
BAL-5					AS2-5167 to 4550	Projected	91 01 98 06						
BCC-1	Coal Mountain	Byron Creek Collieries	Corbin	Open Pit Coal	East	Active	88	Sandstone Siltstone Mudstone/shale	20-40 50 10-20	153-213 79-154 33-60	LA=25%/SD=99% LA=19%/SD=99% LA=15%/SD=98%	70 50 30	0 <5 10
BCC-2					West	Active							
BEA-1	Beaverdell	Teck Corporation	Beaverdell	Undrgrnd Silver	Lass 4	Active	40's	Granodiorite	100	High?	High?	5	5
BEL-1	Bell	Noranda Minerals Inc.	Granisle	Open Pit Base Metal	North Dump	Active	79	Waste rock Overburden	98 2	20-150			
BEL-2					South Dump	Currently Inactive	72 89	Waste rock Overburden	95 5				
BEL-3					No. 7 Dump	Active	79	Waste rock Overburden	85 15				
BEL-4					Overburden Dump	Currently Inactive	70 82	Waste rock Overburden	40 60				

WASTE DUMP NO.	NAME OF MINE	OPERATOR	LOCATION	TYPE OF MINE	WASTE DUMP NAME	STATUS	DATE Started Finished	MATERIAL TYPE	MATERIAL %	UCS (MPa)	DURABILITY	GRADATION %> 300mm	GRADATION %< #200
BUL-1	Bullmoose	Bullmoose Operating Corporation	Tumbler Ridge	Open Pit Coal	West	Active	83 95	Sandstone Mudstone	70 30	125 60	SD=97-98% SD=83-97%	50 10	2 2
BUL-2					Upper West	Active	89						
BUL-3					East	Finished	83 84						
BUL-4					North	Finished	83 89						
BUL-5					In-Pit	Active	83						
CAS-1	Cassiar	Princeton Mining Corporation	Cassiar	Open Pit Asbestos	Cirque	Finished		Argillite Serpentinite	60 40	50 35		50	10
CAS-2	McDame			Undrgrnd Asbestos	McDame	Active	89	Serpentinite Argillite	80 20	35 50	Durable Suscep to frz/thaw	20	10
END-1	Endako	Placer Dome	Endako	Open Pit Moly.	Burnsville	Active	mid 70's	Quartz Monzonite	100	110	High	30	2
END-2					New	Planned	91 94						
EQS-1	Equity Silver	Equity Silver Mines Ltd.	Houston	Open Pit Silver, copper, gold	Main	Finished	80 86	Tuffaceous Volcanics Gabbro/Monzonite Quartz Latite Dyke	90 10	50-112 90-115	Medium Low-Medium High		
EQS-2					Bessomer Ck	Active	86 91						
EQS-3					Southern Tail	Finished	84 90						
FOR-1	Fording	Fording Coal Ltd.	26 km N of Elkford	Open Pit Coal	Blaine	Finished	83 02 89 03	Sandstone Siltstone Mudstone	25 50 25	130 110 55	LA=29%/SD=99% LA=34%/SD=98%	70	1
FOR-2					Brownie	Active	83 02						
FOR-3					Clode	Active	90 02 93						
FOR-4					South Spoil Stage 1	Active	87 11						

WASTE DUMP NO.	NAME OF MINE	OPERATOR	LOCATION	TYPE OF MINE	WASTE DUMP NAME	STATUS	DATE Started Finished	MATERIAL TYPE	MATERIAL %	UCS (MPa)	DURABILITY	GRADATION %> 300mm	GRADATION %< #200
GBR-1	Golden	Golden Bear	80 km NW of	OpenPit/	Corsis Creek	Active	89 06	Colluvium/				0	25
	Bear	Operating	Telegraph	Undrgrnd			94	Landslide Debris	80		Moderate		
		Corporation	Creek	Gold				Limestone/Tuff	20	200/150	Moderate/Good		
GIB-1	Gibraltar	Gibraltar	McLeese	Open Pit	No. 1	Active	71	Overburden	31	Medium	Medium	55	1
		Mines Ltd.	Lake	Base Metal			93	Quartz Diorite	69				
GIB-2					No. 2	Active	71	Quartz Diorite	>95				
							2005						
GIB-3					No. 3	Active	76	Overburden	25				
							2000	Quartz Diorite	75				
GIB-4					No. 4	Active	72	Overburden	100				
GIB-5					No. 5	Active	73	Overburden	2				
								Quartz Diorite	98				
GIB-6					No. 6	Active	73	Overburden	64				
								Quartz Diorite	36				
GRH-1	Greenhills	Westar Mining	Elkford	Open Pit	East	Finished	82 09	Sandstone					
		Ltd.		Coal	2200		83 05	Siltstone			SD=96%		
								Shale/Mudstone			SD=85%		
GRH-2					2158-Hawk	Finished	83 01	Shale/Mudstone	~50				
					Pit		83 03	Siltstone	~45				
								Sandstone	5				
GRH-3					North	Active		Siltstone	70				
								Shale	20			30	5
								Sandstone	10			10	15-20
HVC-1	Valley	Highland	Highland	Open Pit	NW-Valley	Active	82	Granodiorite	40-50		High		
		Valley Copper	Valley	Base Metal	Bottom		2006	Sands and gravels	25-30		Low to moderate		
								Tills/silts/clays	30-40		Low to moderate		
HVC-2					Northeast	Active	82	Qtz Diorite-fresh	10-15	138	Moderate-High	15-20	10-15
								Qtz Diorite-altered	5-10	69	Moderate-High	15-20	10-15
								Ovrbrden (see HVC-1)	75-85		Low to moderate		
HVC-3					Sidehill	Active	82	Granodiorite	85-95	High	High		
							93	Overburden	5-15		Low to moderate		
HVC-4					Big Divide	Active	88	Granodiorite	40-50		High		
							2003	Ovrbrden (see HVC-1)	50-60				
HVC-5					Tailings Line	Active	86	Qtz Diorite	25-30		High		
					Causeway		98	Ovrbrden (see HVC-1)	70-75		Low to moderate		

WASTE DUMP NO.	NAME OF MINE	OPERATOR	LOCATION	TYPE OF MINE	WASTE DUMP NAME	STATUS	DATE Started Finished	MATERIAL		UCS (MPa)	DURABILITY	GRADATION	
								TYPE	%			%> 300mm	%< #200
HVC-6	Bethlehem	Highland	Highland	Open Pit	Bethlehem	Finished	60	Qtz Diorite	100	High	High		
		Valley Copper	Valley	Base Metal			80						
HVC-7	Highmont				Highmont	Dormant	80	Qtz Diorite	45-55	High	High		
							84	Qtz Porphyry+some OB	45-55				
HVC-8	Lornex #2				Lornex N.E.	Active	73	Qtz Diorite	85-90		High		
							2002	Overburden	10-15		Low		
HVC-9					N.W. 5065	Finished		Wet Overburden	100		Low		
HVC-10					N.W. 4920		73	Granodiorite	90-95		High		
							97	Overburden	5-10		Low		
ICM-1	Island	BHP-Utah	Port Hardy	Open Pit	South	Finished	86 05	Andesite		69-207	Moderate	20	2
	Copper	Mines Ltd.		Base Metal			87 05	Porphyry		>103	Moderate		
ICM-2					North	Finished	71 04	Pyrophyllite	63	<103	Low		
							85 08	Till	37				
ICM-3					West	Finished	86 03						
							86 09						
ICM-4					West In-pit	Active	89 10						
							92 09						
ICM-5					Beach	Active	71 08	Rock	85				
							95 12	Till	15				
LCR-1	Line Creek	Crowsnest	Sparwood	Open Pit	Mine Service	Finished	86	Sandstone	30-60	150		60	0
		Resources		Coal				Shale	25-50	25-50		40	5
		Ltd.			Area		88	Siltstone	40-60	100	SD=93-98%	25	10
LCR-2					West Line	Active	81 07	Overburden	<5				
					Creek		91						
LCR-3					Upper West	Active	87						
					Line Creek								
LCR-4					Line Creek	Active	90 09						
					Valley		92						
LCR-5					No Name	Finished	86						
					Creek		87						

WASTE DUMP NO.	NAME OF MINE	OPERATOR	LOCATION	TYPE OF MINE	WASTE DUMP NAME	STATUS	DATE Started Finished	MATERIAL		UCS (MPa)	DURABILITY	GRADATION	
								TYPE	%			%> 300mm	%< #200
MYR-1	Lynx/HW	Westmin Resources Ltd.	Myra Falls	Open Pit/ Undrgrnd Base Metal	No. 1	Active	66 98	Altered Rhyolite Andesite Massive Pyrite	50 50 <5	Low-med. High	Poor High	1	1
MYR-2					No. 2	Finished	67 72					10	10
NPL-1	Nickel Plate	Corona Corp.	Hedley	Open Pit Gold	North	Active	88 03	Skarn Andesite	70 30	69-413	High	75	5
PRE-1	Premier Gold	Westmin Mines Ltd.	Stewart	Open Pit Gold	650/585 South	Active	89 09 90 12	Andesite extrusive flows and tuffs Porphyritic andesite	50 50	22-38 69-94	Moderate Moderate	25> 1000mm	25< 20mm
PRE-2					685/665 Upper North	Finished	88 05 90 08						
PRE-3					615/535 Cooper Creek	Active	88						
PRE-4					585 Wilson Creek	Active	89 08						
QCL-1	Mesa	Quintette Coal Ltd.	Tumbler Ridge	Open Pit Coal	1570 Phase 2	Active	87 10 92 05	Sandstone/ Conglomerate Siltstone Mudstone/Carb. Mdst/ Coal	50 20 30	>103 83 7-34	High - V. High Medium - High V. Low - Low	75> 100mm 60> 100mm 40> 100mm	5 15 20
QCL-2					1506 Phase 1	Active	90 08 91 06						
QCL-3					1545 Mesa Early	Active	88 03						
QCL-4	Wolverine				1660 North	Active	82 91 01						
QCL-5					1595 South	Active	90 08 90 11						
QCL-6	Shikano				North	Active	86 11 2000						
QCL-7					Lower South	Currently Inactive	86 09						
QCL-8					770 Haul Road	Active	91 06						

WASTE DUMP NO.	NAME OF MINE	OPERATOR	LOCATION	TYPE OF MINE	WASTE DUMP NAME	STATUS	DATE Started Finished	MATERIAL TYPE	MATERIAL %	UCS (MPa)	DURABILITY	GRADATION %> 300mm	GRADATION %< #200
QSM-1	Quinsam	Brinco Coal	Campbell River	Open Pit Coal	No. 1	Finished	89 09 90 10	Siltstone/Sandstone Till	70-80 20-30		Poor-slakes easily	70 10	<2 <35
QSM-2					No. 2	Finished	89 08 90 07						
QSM-3					No. 3	Active	88 08 91 05						
SAM-1	Samatosum	Minnova Inc.	Barriere	Open Pit Silver	Main A and B	Active	89 03 92	Mafic Pyroclastics Sericite	63 25	30-70 12-16	LA=32%/SD=96% Poor	0	0
SIM-1	Similco Mines Ltd.	Princeton Mining Corporation	Princeton	Open Pit Base Metal	D2	Inactive	83 89	Andesite Diorite Felsite Dykes	65 25 10		High High		
SIM-2					D3	Finished	83 89						
SUL-1	Sullivan Mine	Cominco Ltd.	Kimberley	Open Pit/ U/G Base Metal	#1 Shaft	Active	46 92	Argillite Quartzite		175	High	Bulk < 150mm	
SUL-2					Open Pit	Finished	51 60						
SUL-3					3900	Finished	80's						

BRITISH COLUMBIA WASTE DUMP SURVEY
APPENDIX A

SECTION II

DUMP CONFIGURATION

<u>TYPE OF DUMP</u>-Describes i)the general classification category of non-impounding structures e.g. a)Valley Fill, b)Cross Valley, c)Sidehill, d)Ridge Crest and e)Heaped; and ii)the configuration of the overall slope e.g. benched, unbenched, resloped, etc.

<u>STAGE OR PHASE</u>-Indicates whether the following information is for the current,the ultimately proposed or already completed dump.

<u>VOLUME</u>- Volume of waste dump in Bank Cubic Meters (BCM's). Where dump masses were not provided by the mining company it was assumed that the volume units were in BCM. Where only the dump mass was provided, BCM's were calculated assuming a specific gravity of 2.6 for the waste. Where volumes were provided in bulk cubic meters, these were reduced to BCM's using a bulking factor of 1.25.

<u>OVERALL SLOPE</u>-See diagram (on following page).

<u>MAXIMUM HEIGHT</u>-See diagram.

<u>MAXIMUM THICKNESS</u>-See diagram.

<u>BERM WIDTH</u>- See diagram

<u>MAXIMUM WIDTH</u>-See diagram.

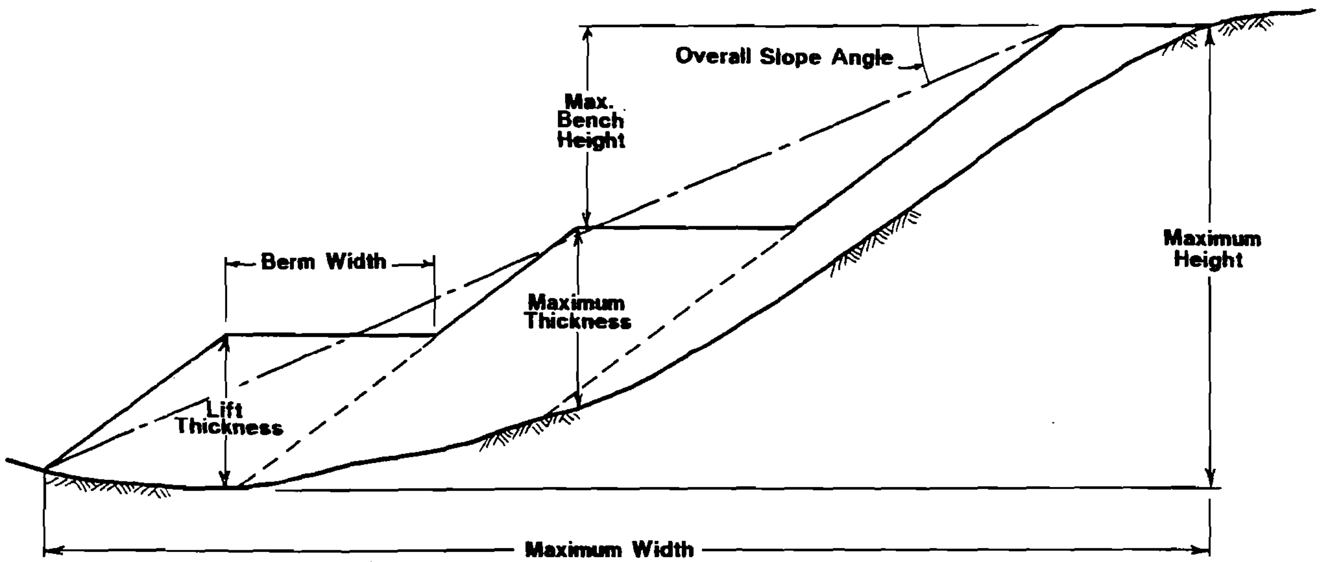
<u>LIFT THICKNESS</u>-Maximum thickness of lift placed during construction.

<u>MAXIMUM BENCH HEIGHT</u>-Maximum height between any two consecutive berms on the waste dump slope. In some instances the maxiumum bench height was determined by dividing the maximum height of the dump by the number of benches and therefore the value presented may be a lower bound. Queried where uncertain.

<u>NUMBER OF BENCHES</u>-Number of rises in the bench slope between the toe of the slope, and the dump platform. In some instances this value was interpreted from other information provided, and is queried where uncertain.

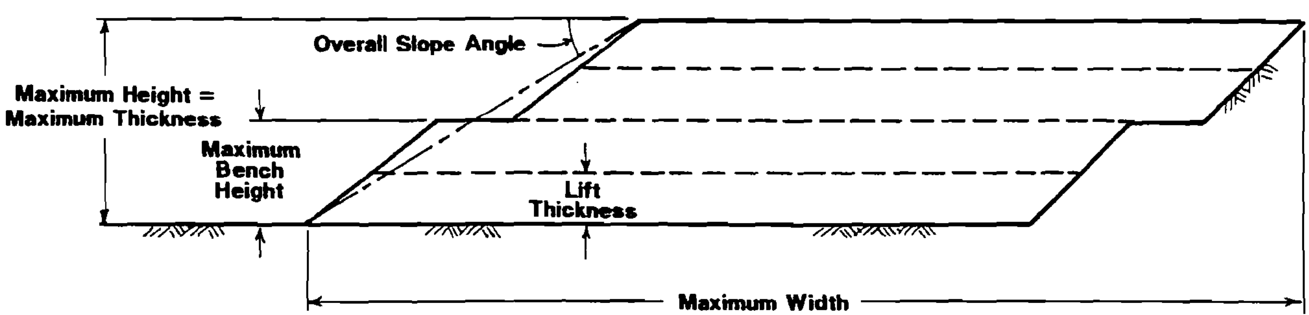
EXAMPLE 1

TYPE OF DUMP	METHOD OF CONSTRUCTION
Sidehill Fill Benched	Initial Repose Angle Lift with two lower wraparounds



EXAMPLE 2

TYPE OF DUMP	METHOD OF CONSTRUCTION
Open Pit Backfill Benched	Multiple Lift Repose Angle Benches



BRITISH COLUMBIA WASTE DUMP SURVEY

SECTION II

Dump Configuration

WASTE DUMP NO.	TYPE OF DUMP	STAGE OR PHASE	VOLUME (BCM's x10E6)	OVERALL SLOPE (°)	MAXIMUM HEIGHT (m)	MAXIMUM THICKNESS (m)	MAXIMUM WIDTH (m)	CREST LENGTH (m)	PLAN AREA (ha)	SHAPE IN PLAN	LIFT THICKNESS (m)	MAX BENCH HEIGHT (m)	NUMBER OF BENCHES	BERM WIDTH (m)
AFT-1	Valley Fill Benched	Ultimate	121	22	90	90	490	1370	100	Arcuate- Lobed	15	15	6	21
AFT-2	Sidehill Fill Benched	Ultimate	11.5	19-24.5	90	86	600	1700	47	Arcuate	3	15	6	20
BAL-1	Open Pit Backfill Ultimately Benched	Current Ultimate	5 28	37 15	 91	 100	 50	90 275	20	Linear	 100	 43	1 4	N/A 100
BAL-2	Sidehill Fill Ultimately Benched	Current Ultimate	28 41	37 20?	 312	 100	 122	 250	 100	 Convex	 100	 15?	South-5 North-10	 45?
BAL-3	Sidehill Fill Unbenched	Current Ultimate	140 210	37 37	274 244	 250	 610	 915	 1114	 Linear	 250	 244	 1	 N/A
BAL-4	Sidehill Fill Unbenched	Ultimate	1	37	46	37	122	244	11	Convex	37	46	1	N/A
BAL-5	Sidehill Fill Ultimately Benched	Ultimate	25	21	265	100	335	100	65	Convex	100	53+	5	
BCC-1	Valley Fill Benched	Current Ultimate	3	20 20?	75	75	600	<600	100	Linear	40 40	40+ 40+?	2 6	
BCC-2	Sidehill Fill Benched	Current Ultimate	 25	37 26	200 250		50 100	700 700		Linear	60-70 60-70	200? 60-70	1? 3-4	N/A
BEA-1	Sidehill Fill Unbenched	Current Ultimate	0.0085 0.014	45	46 52	21				Linear	21	46 52	1 1	N/A N/A
BEL-1	Sidehill Fill Benched	Current Ultimate	6.3 30.8	25 25	40 60	35 50	500 100	400 750	50 150	Convex	10-15 10-15	20? 30?	2? 2-3?	
BEL-2	Sidehill Fill Benched	Current Ultimate	2.8 4.4	20 20	30? 30?	50 50	600 600	550 550	30 40	Linear	25 25	30? 30?	2? 2?	
BEL-3	Sidehill/Valley Fill Benched	Current Ultimate	4.1 8.1	15 20	42? 45?	35 45	600 600	850 900	40 40	Linear	25 30	14? 15?	3? 3?	
BEL-4	Sidehill Fill Benched?	Current Ultimate	4 6.8	31 31	40 40	45 45	400 600	1050 1050	20 25	Convex	12 12	14? 14?	3? 3?	

WASTE DUMP NO.	TYPE OF DUMP	STAGE OR PHASE	VOLUME (BCM's x10E6)	OVERALL SLOPE (°)	MAXIMUM HEIGHT (m)	MAXIMUM THICKNESS (m)	MAXIMUM WIDTH (m)	CREST LENGTH (m)	PLAN AREA (ha)	SHAPE IN PLAN	LIFT THICKNESS (m)	MAX BENCH HEIGHT (m)	NUMBER OF BENCHES	BERM WIDTH (m)
BUL-1	Sidehill Fill	Current	20	28	230	110	400	200		Linear	50	50?	5?	30
	Benched	Ultimate	27	28	280	200	400	200	79		50	50?	6?	30
BUL-2	Sidehill Fill	Current	0.85	36	100	40	150	300		Linear	50	50?	2?	30
	Ultimately Benched	Ultimate	20	28	300	100	300	400	34		50	50?	6?	30
BUL-3	Sidehill Fill Benched	Ultimate	2	27	80	50	100	400	2.0	Linear	50	50?	2?	30
BUL-4	Sidehill Fill Unbenched?	Ultimate	7	36	50	50	200	700	2.1	Linear	50	50?	1?	N/A?
BUL-5	Sidehill Fill	Current	40	28	150	140	1000	1000	187	Linear	50	50?	3?	30
	Benched	Ultimate	125	28	350	140	1000	1000			50	50?	7?	30
CAS-1	Sidehill/Valley Fill Benched	Ultimate	30	15	360	40	350	350	50	Convex	4			
CAS-2	Sidehill Fill Unbenched	Current	55	38	30	20		300	2	Convex	20	30	1	N/A
END-1	Sidehill Fill Benched	Current		37	25?	25?	90	60	2.2	Linear	12	13?	2	
END-2		Ultimate	22	37	34	34	305	305	16	Linear	15	17?	2	
EQS-1	Sidehill Fill Benched	Ultimate	33	20	90	55	550	1000	52	Convex	10	10	9	10
EQS-2	Sidehill Fill Benched	Ultimate	6.3	20	40	40	300	1000	27	Convex	10	10	4	10
EQS-3	Open Pit Backfill Resloped	Ultimate	8	14	50	50?	300	1000	30	Convex	10	10	5	10
FOR-1	Sidehill Fill	Current	20	37	185	126	250	900	23		126	185	1	N/A
	Ultimately Benched	Ultimate	100	32	295	170	430	1600	131	Convex	170	295	1	N/A
FOR-2	Sidehill Fill	Current	80	37	360?	130	250	1400	13.3		130	360	1	N/A
	Ultimately Benched	Ultimate	463	32	240?	285	1600	2000	400	Linear	285	240	1	N/A
FOR-3	Sidehill Fill	Current	19.6	37	120	100	60	100	1.2		100	120	1	N/A
	Unbenched	Ultimate	18.6??	37	140	140	600	1440	9.6	Triangular	140	140	1	N/A
FOR-4	Sidehill Fill	Current	14.9	35	413	142	180	475	13.1		142	413	1	N/A
	Ultimately Benched	Ultimate	14.9	32	435	125	140?	450?	24	Convex/ Linear	125	435	1	N/A

WASTE DUMP NO.	TYPE OF DUMP	STAGE OR PHASE	VOLUME (BCM's x10E6)	OVERALL SLOPE (°)	MAXIMUM HEIGHT (m)	MAXIMUM THICKNESS (m)	MAXIMUM WIDTH (m)	CREST LENGTH (m)	PLAN AREA (ha)	SHAPE IN PLAN	LIFT THICKNESS (m)	MAX BENCH HEIGHT (m)	NUMBER OF BENCHES	BERM WIDTH (m)
GBR-1	Sidehill Fill Ultimately Benched	Current Ultimate	0.4 1.0	38 35	150 250	50 50	20 20	210 210	4.0 6.5	Linear	50 50	150 125+?	1 2?	N/A N/A
GIB-1	Sidehill Fill Benched	Current Ultimate	12 17	26? 17?	76 79	70 70	305 305	1524 1768	42 45	Arcuate	24	25 26	3 3	30 30
GIB-2	Heaped Fill Benched	Current Ultimate	0.7 0.9	17.5? 16?	32 43	24 31	213 244	732 793	7.8 8.4	Linear	11 11	11 11	3 4	30 30
GIB-3	Sidehill Fill Benched	Current Ultimate	22 23	6 6	73 73	72 72	488 488	2012 2012	28 28	Arcuate	12 12	12 12	6 6	120 120
GIB-4	Sidehill Fill Benched	Current Ultimate	31 53	14 15	131 171	70 104	1067 1067	1524 1829	111 130	Arcuate	15 15	26+? 34+?	5 5	120 120
GIB-5	Sidehill Fill Ultimately Buttressed	1st Lift Ultimate	19 24	37 30	110 110	87 87	457 457	610 1219	45 63	Arcuate	87 15	110 80?	1 3	N/A 60
GIB-6	Sidehill Fill Benched	Current Ultimate	7 31	30 30	70 107	31 46	244 610	1829 2256	34 98	Linear/ Arcuate	18 15	35+? 25+?	2 4	60 60
GRH-1	Sidehill Fill Benched	Ultimate	4	33	168	80	110	400	30	Linear		118?	3	
GRH-2	Sidehill Fill Unbenched	Ultimate	.7	38	160	35	450	300	27	Fan	35	160	1	N/A
GRH-3	Sidehill/Valley Fill Benched	Current Ultimate	60 100	26 26	363 400	100 100	500 500	200-400	50 85	Linear	200? 200?	325?	3	
HVC-1	Valley Fill Benched	Current Ultimate		37?	15 90	15 90	 ~1000			Linear	2.5 2.5	15 15+?	1 6?	N/A
HVC-2	Sidehill Fill Benched	Current		Varies	90	90	Varies	Varies			Varies		Varies	
HVC-3					10-25									
HVC-4					5-10									
HVC-5					~20									

WASTE DUMP NO.	TYPE OF DUMP	STAGE OR PHASE	VOLUME (BCM's x10E6)	OVERALL SLOPE (°)	MAXIMUM HEIGHT (m)	MAXIMUM THICKNESS (m)	MAXIMUM WIDTH (m)	CREST LENGTH (m)	PLAN AREA (ha)	SHAPE IN PLAN	LIFT THICKNESS (m)	MAX BENCH HEIGHT (m)	NUMBER OF BENCHES	BERM WIDTH (m)
HVC-6					100-200									
HVC-7					70									
HVC-8					90									
HVC-9					90									
HVC-10					120									
ICM-1	Sidehill Fill Unbenched	Ultimate	3.8	37	56	56	335	853	15	Rectangular	56	56	1	N/A
ICM-2	Sidehill Fill Benched Ultimately Resloped	Ultimate	38.9	30	47	47	610	4877	141	Linear	12	12	4	
ICM-3	Heaped Fill Unbenched/Resloped?	Ultimate	2.1	30	20	20	201	884	14.2	Oblong	20	20	1	N/A
ICM-4	Open Pit Backfill Benched	Ultimate	6.8	37	152	152	244	244	6.9	Inverted Cone	6	76+?	2?	30
ICM-5	Marine-Sidehill Fill Unbenched	Current Ultimate	242 282	35 35	91 91	70? 70?	1067 1097	4145 5029	247 328	Rectangular	70 70	91 91	1 1	N/A N/A
LCR-1	Sidehill Fill Unbenched	Ultimate	1	37	60	60	50-100	1000	10	Linear	30-60	30-60	1-2	
LCR-2	Sidehill/Valley Fill Ultimately Benched	Current Ultimate	90 100	37	240	160	400	2100	125 200		160	240 100	1 13?	N/A 50
LCR-3		Current Ultimate	5-10	37	150	80	40	150	2		80	150	1 5?	N/A 50
LCR-4		1st Lift Ultimate	1 50	37 28	175	155	35 250	250 500	2 95		155	175 50?	1 4?	N/A 50?
LCR-5	Sidehill/Cross Valley Benched?	Ultimate	10	26	100	60	30	200	15	Linear	<60			

WASTE DUMP NO.	TYPE OF DUMP	STAGE OR PHASE	VOLUME (BCM's x10E6)	OVERALL SLOPE (°)	MAXIMUM HEIGHT (m)	MAXIMUM THICKNESS (m)	MAXIMUM WIDTH (m)	CREST LENGTH (m)	PLAN AREA (ha)	SHAPE IN PLAN	LIFT THICKNESS (m)	MAX BENCH HEIGHT (m)	NUMBER OF BENCHES	BERM WIDTH (m)
MYR-1	Sidehill Fill Unbenched	Current Ultimate	.54 .85	43?	50	30	500	500		Linear	20	50	1	N/A
MYR-2	Sidehill Fill Benched?	Ultimate	.69	42?	180	30	300	130	5	Linear	20	90?	2+?	
NPL-1	Sidehill Fill Unbenched	Current	2.4	37	98	46	1200	1300	8.8	Triangular	30	98?	1?	
PRE-1	Sidehill Fill Unbenched	1st Lift Ultimate	1.5 1.8	37 37	30 65	30 65	40 40	200 300		Linear	30 30-65	30 65	1 1	N/A N/A
PRE-2	Sidehill Fill Benched	Ultimate	1.5	20-35	70	70	40	1000		Linear/ Arcuate	20-50	20-50	2-3	0-30
PRE-3	Sidehill Fill Unbenched	Current Ultimate	.31 1.9	37 37	100 130	50 130	50 50	400 400		Convex	30-100 30-130	100 130	1 1	N/A N/A
PRE-4	Sidehill Fill Unbenched	1st Lift Ultimate	.8 1.5	37 35	20 125	20 55	75 75	600 825	2.3 3.1	Concave	20 20-125	20 125	1 1	N/A N/A
QCL-1	Sidehill Fill Ultimately Benched	Current Ultimate	~10 ~22	37 <26	250 265	120 170	110 120	250 250	 90	Convex	30 30	250 100	1 5	N/A
QCL-2	Cross Valley Fill?/Road Unbenched	Current Ultimate		37 37	140 140	25 110	100 100	40 200	4 20	Linear	25 110	140 140	1 1	N/A N/A
QCL-3	Sidehill Fill Ultimately Benched	Current Ultimate	 5	37 <26	180 180	80 80	100 150	250 300	18 28	Convex	80 80	180 100	1 2	N/A 100
QCL-4	Sidehill/Valley Fill Ultimately Benched	Current Ultimate	15 23	37 <26	250 250	150 150	200 200	500 500	36 56	Convex	130 130	250 90	1 2	N/A 50
QCL-5	Road Ultimately Benched	Current Ultimate	.92 .98	37 <26	120 120	70 70	45 45	40 40	4.5 6.8	Linear	70 70	120 20	1 3	N/A 40
QCL-6	Sidehill Fill? Benched	Current Ultimate	30 80	26 26	106 260	60 190	60 190	500 300	16.5 16.5	Convex	20 20	22 22	3 10	
QCL-7	Heaped Fill Benched	Current Ultimate	3.7 	 14	 45	 40	 500	 1100	 330	Convex	 15	 22	 3	
QCL-8	Road Unbenched	Current Ultimate	.14 .26	37 37	40 40	30 30	40 40	40 1750	20 70	Linear		40 40	1 1	N/A N/A

BRITISH COLUMBIA WASTE DUMP SURVEY
APPENDIX A

SECTION III

FOUNDATION CONDITIONS AND DESIGN

PHYSIOGRAPHY-Description of foundation configuration and geometry in section and in plan. Perennial drainage is also noted.

SLOPE (ANGLE)-Angle of underlying foundation slope i) in the toe region of the dump, ii)the range of angles observed, and iii)the average slope beneath the dump. Negative angles indicate the foundation slopes in the opposite direction to the dump face.

FOUNDATION MATERIALS AND CONDITIONS-Description of geologic materials encountered or assumed/expected to be at the base of the waste dump. Seepages and springs are also noted.

SHEAR STRENGTH-Parameters used to define the strength of the foundation and waste materials for input to the stability analyses performed. ϕ = friction angle and Su= undrained strength.

FACTOR OF SAFETY-Calculated by the indicated analysis technique under either static or seismic conditions. N/D = analysis not done, N/S = analysis performed but results not specified.

WASTE DUMP NO.	TYPE OF DUMP	STAGE OR PHASE	VOLUME (BCM's x10E6)	OVERALL SLOPE (°)	MAXIMUM HEIGHT (m)	MAXIMUM THICKNESS (m)	MAXIMUM WIDTH (m)	CREST LENGTH (m)	PLAN AREA (ha)	SHAPE IN PLAN	LIFT THICKNESS (m)	MAX BENCH HEIGHT (m)	NUMBER OF BENCHES	BERM WIDTH (m)
QSM-1	Heaped Fill Ultimately Benched?	Current Ultimate	.4 .4	38 27	20 20	20 20	80 80	230 230	3 3	Convex	2 2	20	1	N/A
QSM-2	Heaped Fill Benched	Ultimate	1	27	30	30	100	200	5.3	Convex	2	2?	15?	
QSM-3	Sidehill Fill Ultimately Benched	Current Ultimate	1.5 2.3	38 27	20 20	20 20	120 120	550 550	9.1 9.1	Convex	2 2		1	N/A
SAM-1	Sidehill Fill Ultimately Benched	Current Ultimate	2.7 3.3	37 27	75 75	70 60	350 350	250 250	22 25	Convex	6 6	75? 15+?	1? 5?	N/A
SIM-1	Sidehill/Heaped Fill Benched	Current Ultimate	5	32 32	101 119	52 73	457	351	26	Convex	31 31	50? 40-50+?	2 3	15 (min) 15 (min)
SIM-2	Sidehill Fill Benched	Ultimate	15	27	181	70	518	1646	67	Linear	31	36+	5	15 (min)
SUL-1	Sidehill Fill Benched	1st Lift Ultimate	0.7 0.9	37 27 (resloped)	30 30	30 30	244 280	549 549	13 15	Concave	30 30	30 14+	1 2	N/A 8
SUL-2	Sidehill Fill Unbenched	Ultimate	0.9	35	40	40	213	914	11	Concave	40	40	1	N/A
SUL-3	Valley Fill	Ultimate							19.5	Linear				

WASTE DUMP NO.	SITE PHYSIOGRAPHY	SLOPE TOE (°)	SLOPE RANGE (°)	SLOPE AVG (°)	FOUNDATION INVESTIGATION	FOUNDATION MATERIALS AND CONDITIONS	DESIGNED BY	DESIGNED DATE	SHEAR STRENGTH WASTE ø (°)	SHEAR STRENGTH FOUNDATION ø (°)	STABILITY ANALYSIS METHOD	MIN. F.O.S. STATIC	MIN. F.O.S. SEISMIC
BUL-1	Moderately steep sidehill, concave in plan and section.		10 to 15		Test pits Drillholes	Blanket (>2m) colluvium/till overlies massive sandstone.	Klohn Leonoff	83 02	Ssd:42 Mud:3	O/B:36 B/R:42	Morgnstr Price	1.3	N/S
BUL-2	Moderately steep sidehill, convex in plan, concave in section.	15	15 to 45		Test pits Drillholes	Veneer (0.3m) glacial till overlies interbedded sandstone/mudstone.							
BUL-3	Moderate to steep sidehill, convex in section.	30 to 40	6 to 40		Test pits Drillholes	Veneer colluviun overlies bedrock. Toe underlain by glacial till.							
BUL-4	Moderately sloping sidehill, linear in plan and convex in section.	10 to 20	5 to 35		Test pits Trench Drillholes	Veneer colluvium overlies bedrock. LL 38% PL 63%							
BUL-5	Footwall of coal,concave in plan convex in section.			10 to 15	Test pits Drillholes	Sandstone. Thrust fault dips into slope. Plastic clay layer observed in one drillhole.							
CAS-1	Sidehill progressing downslope into a V-shaped valley.												
CAS-2	Moderately steep sidehill.				Seismic refraction	Glacial till.	In-house						
END-1	Relatively flat.				Exploration drilling	Swampy.							
END-2	Relatively flat.			2	Exploration drilling	Silty sand and gravel, trace clay.	In-house	90 10	36° c= 490kPa	30° c= 290kPa	Horiz. Transltn.	1.33	1.25
EQS-1	Gentle sidehill.	10	2 to 13	5	Drillholes	0 - 30m till.	Klohn Leonoff	84 02	37.5	25		1.3	1.1
EQS-2	Gentle sidehill, convex in plan.	2	0 to 5	3		5 - 30m till.							
EQS-3	Mined-out pit					Bedrock.							
FOR-1	Concave, U-shaped sidehills, linear in plan.	16	16 to 40	27	29 test pits 3 Becker	Veneer of colluvium overlies dense tills . Local weak zones of sat'd surficial clays. Occasionally disturbed. Low to medium plasticity fines.	Golder	82 02 82 10		27 (22-25)	Basal Sliding	~1.0	N/D
FOR-2	Mod. to steep concave sidehills, irreg./linear in plan.	10	10 to 60		33 test pits	Colluvial soils consisting of reworked Kootenay-Fernie Formation.	Golder	83 03	37	37-40	Double Wedge	1.53	N/D
FOR-3	Existing pit excavation.				Visual recon.	Mined out footwalls and highwalls.	Golder	90 01	37		Double Wedge	~1.0	N/D
FOR-4	Mod. steep sidehill, concave in plan and section. Expands into Kilmarnock valley floor.	23	31 to 33	28	8 test pits 5 Becker 18 Rotary	Veneer of colluvium along sideslope with till bench at toe and alluvium below till bench.	Golder	87 04	37	Colluv.=38 Till=32	Double Wedge		1.20

WASTE DUMP NO.	SITE PHYSIOGRAPHY	SLOPE TOE (°)	SLOPE RANGE (°)	SLOPE AVG (°)	FOUNDATION INVESTIGATION	FOUNDATION MATERIALS AND CONDITIONS	DESIGNED BY	DESIGNED DATE	SHEAR STRENGTH WASTE ø (°)	SHEAR STRENGTH FOUNDATION ø (°)	STABILITY ANALYSIS METHOD	MIN. F.O.S. STATIC	MIN. F.O.S. SEISMIC
AFT-1	Glaciated, rounded ridges and swales (NW-SE drumlins).			<5		Bedrock or veneer/blanket overconsol. dense glacial till overlies bedrock. Silt lenses associated with local glacial depressions.	In-house						
AFT-2	Moderate to flat sidehill, rounded ridge and swale, drumlinoid.	0	0 to 24	4	5 test pits	Veneer overconsol. dense glacial drift overlies bedrock. 3m loose-mod. dense outwash sand/silt/gravel with high water table underlies toe. Silty deposits assoc. with local glacial depressions underlie small portion of crest.	In-house (Rev. by Klohn Leonoff)	90 06	36	Till:36 Alluv:32 Silt:22	Bishop Simplifd.	1.85	1.4
BAL-1	Mined-out pit. Dump founded on benched hanging wall, with toe buttressed by opposite dipping footwall.	-10	-10 to 54			Sedimentary bedrock, bedding dips into the slope.	Golder	88 11	38	36	Double Wedge	2.3	N/D
BAL-2	Steep sidehill, irreg. in plan, concave in section.	0	0 to 47	25		Colluvium.		89 08	38	32	Double Wedge	1.0	N/D
BAL-3	Steep sidehill, irreg. in plan, concave in section. Crossed by Erickson Creek.	0	0 to 40	21	15 test pits	Gravelly sand with some silt (Colluvium) and coal bloom underlies slope. Sand and gravel outwash and fine sand and silt alluvium underly lower slopes/valley bottom.		81 08	37	33-39	Sarma	1.1	N/D
BAL-4	Relatively gentle slope.	11	11 to 18	15		Sandy silt (weathered till) overlying very dense well graded glacial till overlying Cretaceous sedimentary units dipping 35°-45°.		84 09	38	40	Bishop	1.25	N/D
BAL-5	Relatively gentle slope	10	10 to 23	14	4 test pits 13 drillholes			90 03	38	40	Bishop & Morg.-Price	1.1	N/D
BCC-1	V-shaped Corbin Ck valley. Irreg., concave slopes.				22 test pits 7 drillholes	Till, colluvium and alluvium.	Piteau	84 03	37	Till:35 Alluv:32	Janbu	1.17	
BCC-2	Moderately steep sidehill.	16	20 to 30	22		Till and alluvium, soft, saturated.	EBA	87/88					
BEA-1	Dry gully on sidehill.			25 to 30		Thin veneer soil overlies bedrock.	N/D						
BEL-1	Gentle sidehill, 50% of toe buttressed by opposite valley slope.	-4	-4 to 7	3		Till. 2 shallow sloughs in valley saddle.	N/D						
BEL-2	Gentle sidehill, 80% of dump on level terrain.	1	0 to -2	1		Till and lacustrine deposits.							
BEL-3	Predominantly mod. sloping sidehill, concave in section. Partly toed into rock ridge	6	0 to 15	10		Till.							
BEL-4	80% mod. to gently sloping sidehill. 20% flat, partly toed into rock ridge.	6	0 to 10	7		Till.							

WASTE DUMP NO.	SITE PHYSIOGRAPHY	SLOPE			FOUNDATION INVESTIGATION	FOUNDATION MATERIALS AND CONDITIONS	DESIGNED		SHEAR STRENGTH		STABILITY ANALYSIS METHOD	MIN. F.O.S. STATIC	MIN. F.O.S. SEISMIC
		TOE (°)	RANGE (°)	AVG (°)			BY	DATE	WASTE ø (°)	FOUNDATION ø (°)			
QSM-1	Level terrain with hardpan approx 10m thick.	0		0	4 drillholes 2 test pits	Dense, well cemented impervious clay till.							
QSM-2	Level terrain.	0		0	N/D	Hard, cemented till.							
QSM-3	Mod. steep sidehill steepened by subcrop mining of coal seam. Convex in plan and in section.	36	0 to 36	10	Drillholes Test pits								
SAM-1	Mod. steep sidehill, concave in plan, irregular in section. Intermittent springs.	22	10 to 25	15	9 test pits	Glacial till and colluvium <5m thick. Seepage points over full long section of dump.	Piteau						
SIM-1	Flat to mod. steep, convex in plan and in section.	10	5 to 10		9 test pits	Outwash material and glacial till, competent volcanic bedrock.	Golder		37	37	Janbu 2 Wedge Sarma		N/S
SIM-2	Mod. steep sidehill, irregular in plan, convex in section.	25	10 to 25	18	10 test pits	Silty sandy gravels with trace of clay. Compact to very dense.	Golder		37	37	Janbu 2 Wedge Sarma		N/S
SUL-1	Gently sloping sidehill, slightly convex in plan.	4	4 to 10	6	24 test pits	Clay, sand with frequent pebbles and cobbles. Argillite/quartzite bedrock. No seepage in test pits.							
SUL-2	Gently sloping sidehill, concave in plan, smooth in section.	3	0 to 5	3		Weathered argillite/quartzite bedrock with some shallow, isolated gravel and clay pockets.							
SUL-3	V-shaped Mark Creek Valley.												

WASTE DUMP NO.	SITE PHYSIOGRAPHY	SLOPE TOE (°)	SLOPE RANGE (°)	SLOPE AVG (°)	FOUNDATION INVESTIGATION	FOUNDATION MATERIALS AND CONDITIONS	DESIGNED BY	DESIGNED DATE	SHEAR STRENGTH WASTE ø (°)	SHEAR STRENGTH FOUNDATION ø (°)	STABILITY ANALYSIS METHOD	MIN. F.O.S. STATIC	MIN. F.O.S. SEISMIC
MYR-1	Mod. steep sidehill, irreg. in plan and section.	10	10 t0 35	30	N/D	Glacial till (assumed) and top soil.	N/D						
MYR-2	Mod. steep sidehill, irreg. in plan and section. Some seepage.				N/D	Glacial till and rock.	N/D						
NPL-1	Mod. steep sidehill bottoming into steep V-Shaped valley. Linear in plan, irreg. in section.	12	10 to 31	25		Colluvial deposits and minor glacial till, both with high percentage of rock fragments.	Hardy BB	86					
PRE-1	Mod. steep to steep sidehill, convex in plan, irreg. in section. Crossed by small V-shaped ck.	0	0 to 30	25	Recon. Test pits Exploration drillholes	Clayey glacial tills and gravels. No perched groundwater tables.	Piteau	88 04					
PRE-2	Gentle to steep sidehill, convex to concave in plan and irreg. in section.		0 to 30	20		Glacial tills/clays, some local pockets of organic soils, up to 2m thick. 25-30% bedrock.							
PRE-3	Mod. to v. steep sidehill, conc. in plan, uniform in section. Crossed by Cooper Creek.	0 to 15	0 to 35	25		Glacial tills/clay, gravel and bedrock (20%). Smooth bedrock surface underlies thin till layer.	In-House	88/89					
PRE-4	Steep sidehill, linear in plan and benched in section. Crossed by Wilson Creek.	10 to -10	-10 to 50	30		Predominantly bedrock (60%) and glacial till (40%).	Golder	89	Su= 1378 kPa.	Su= 50 kPa.	Janbu	1.0	N/D
QCL-1	Moderately steep sidehill, convex in plan, concave in section.	10	10 to 40		7 test pits 6 Berma probes	Thin veneer granular or organic soils overlies weathered bedrock.	Golder	88	37	33	2 Wedge Janbu simplifd.	~1.2	
QCL-2	Steep sidehill and V-shaped valley, concave in plan and in section.	19	0 to 42	20	Airphotos Recon.	Colluvium on upper reaches, veneer of organic soils in lower reaches.	Golder	90 07	37 in general	Variable	Generally design to F.O.S. of 1.2, modify as required during construction. Seismic F.O.S. not determined.		
QCL-3	Mod. steep sidehill, concave-convex in plan, concave in section.	10	10 to 45	27		Bedrock exposures. Blanket of well-graded colluvium.	Golder	88 09					
QCL-4	Irregular in plan, concave in section.	15	15 to 32	20		Colluvium.	Golder	81					
QCL-5	Recent landslide (>100 yrs old) on southernmost limit.	16	16 to 27	20		Colluvium.	Golder	90 07					
QCL-6	Gently sloped, rolling hillside. Convex to linear in plan, irregular in section.	15	0 to 15	4	As above a 5 Test pits	Peat and organic silty colluvium, glacial till, fluvial sand and gravel deposits. Bedrock.	Piteau	85 05	37	Su=100 kPa	Janbu	1.3	
QCL-7	Gently sloping floodplain, linear in section. Adjacent to Murray River.	3	2 to 3	3	Drillholes T.pits/seismic/Test fill	Fluvial sand and gravel overlies thick lacustrine clay-silt deposits with some thin sand layers. Colluvium on upper slopes. Water table ~3-10m below grnd surface.	Golder	90 01	37	S+G=30 Silt: Su= 60-250kPa	Sarma	1.3	
QCL-8	Mod. steep sidehill, irreg. in plan, concave-convex, irregular in section.	0 to 10	5 to 40	N/S	26 Drillhls. 18 Test pits	Silty, clayey and organic surficial sediments. Seepage in two locations.	Golder	90 07	Same as for QCL-2 thru 5.				

WASTE DUMP NO.	SITE PHYSIOGRAPHY	SLOPE TOE (°)	SLOPE RANGE (°)	SLOPE AVG (°)	FOUNDATION INVESTIGATION	FOUNDATION MATERIALS AND CONDITIONS	DESIGNED BY	DESIGNED DATE	SHEAR STRENGTH WASTE ø (°)	SHEAR STRENGTH FOUNDATION ø (°)	STABILITY ANALYSIS METHOD	MIN. F.O.S. STATIC	MIN. F.O.S. SEISMIC
HVC-6	Locally steep.		>25			Thin sand/gravel till with trace to some silt overlies bedrock.				30-39, c=0 for most dumps	Observe displacement of weak foundations and slumping of dump crests and redesign accordingly.		
HVC-7	Moderately steep.		10 to 20			Silty sand till overlies shallow bedrock.							
HVC-8	Relatively flat.		5 to 10			Sandy till (<10m) overlies bedrock. Local sand and gravel.							
HVC-9	Moderately steep.		<15	<15		Well graded till. Upper 1m weathered w. some seepage.							
HVC-10	Flat to moderately steep.												
ICM-1	Sidehill.	0	0 to 39	22		Located on existing tailings pond.	SRK						
ICM-2	Sidehill.			5	No testing		N/D						
ICM-3	Flat.	0	0	0	N/D	Andesite bedrock.	Site rev. by SRK						
ICM-4	Steep in-pit slopes. Round in plan, benched in section.	0		45		Bedrock.							
ICM-5	Mod. steep, submerged sidehill (located in Rupert Inlet).	3	3 to 9	6	Bathymetry Seismic Sampling	Approx. 15m of soft, fine grained soils overlying sand and gravel overlying glacial till and bedrock.	Golder/ Piteau	74/ 79	32 to 35	30 ru=.22	Bishop Simplifd.	1.0	
LCR-1		<5	<10		Test pits	Sand and gravel overlying clay/silt lenses.	Piteau	86 06	30 to 37	Gravel-35 Clay-Su= 100 kPa	Janbu & Morg.-Price	1.0	
LCR-2	U-shaped creek valley, concave in section.	10 to 30	0 to 40		Recon. Seismic	Thin veneer overburden overlies variably weathered sed. bedrock. <0.3m colluv. above el. 1600m. Well graded glacial outwash and lacustrine deposits below el. 1600m.	Golder Piteau	79 06 81 03	37	32		1.1	
LCR-3		30	20 to 30										
LCR-4		0 to 30	0 to 30		Test pits Drillholes	Sand and gravel, colluvium, till	Piteau	89 07					
LCR-5	U-shaped creek valley, concave in section.	10 to 30	0 to 40				Piteau	88 01					

WASTE DUMP NO.	SITE PHYSIOGRAPHY	SLOPE			FOUNDATION INVESTIGATION	FOUNDATION MATERIALS AND CONDITIONS	DESIGNED		SHEAR STRENGTH		STABILITY ANALYSIS METHOD	MIN. F.O.S. STATIC	MIN. F.O.S. SEISMIC
		TOE (°)	RANGE (°)	AVG (°)			BY	DATE	WASTE ø (°)	FOUNDATION ø (°)			
GBR-1	Mod. steep to steep sidehill, convex in section.	30	25 to 35	30	Grab sampling	Generally loose colluvium with 25% fines. Seepage in one isolated area. Entire foundation on old landslide debris.	Piteau	88 06	37	32-36	Janbu	1.05	N/D
GIB-1	Moderately sloping sidehill.	8	5 to 12	10	Diamond drilling Trenching Airphoto interp.	Compact basal glacial till- hard and durable with low permeability.	N/D						
GIB-2	Knoll, convex in plan, linear in section.	2	0 to 5	3									
GIB-3	Gentle sidehill, linear in plan, convex in section	1	1 to 4	3									
GIB-4	Moderately sloping sidehill, convex in plan and section.	3	3 to 19	9									
GIB-5	Moderately sloping sidehill, convex in plan, linear in section.	<6	6 to 13	11									
GIB-6	Flat to mod. steep sidehill, circular in plan, S-shaped in section.	3	0 to 23	7									
GRH-1	Smooth, regular in plan and in section.	16	15 to 20	17		Soil mantle of silty sand and angular gravel sized rock fragments.	Golder	81			Sarma	1.0	N/D
GRH-2	Steep sidehill with regular shape in plan and in section.			28		Granular colluvium, silty sand and angular gravel. Snow covered.	Golder	81			Sarma	1.1	N/D
GRH-3	Steep sided V-shaped Britch Creek Valley.	21	21 to 35	28	Grab sampling	Veneer of topsoil underlain by glacial till, some fluvial deposits.	Piteau	83 10	37	32	Janbu	1.2	N/D
HVC-1	U-shaped valley, linear in plan, concave in section.		<30	<10	11 test pits 7 test holes	Lacustrine silts, gravel over till and weak lake bottom silts with trace of clay.	Golder	87 11		30-39, c=0 for most dumps	Observe displacement of weak foundations and slumping of dump crests and redesign accordingly.		
HVC-2	Broad hillside with some eskers, parallel to Highmont valley. Convex in plan, locally convex and hummocky in section.	5 to 10		8	5 test pits	Sand and gravel eskers, silty tills (avg. thickness <10m) overlies bedrock.	Golder	84 11					
HVC-3	Relatively flat.		<10			Sand and gravel overlies sandy till and bedrock.	Golder	87 11					
HVC-4	Flat. Old lake bottom.		<5			Weak lacustrine silts and sand overlying till.	Golder	87 11					
HVC-5	Flat.		0			Peat, soft silt,granular esker ridges and drumlins.							

BRITISH COLUMBIA WASTE DUMP SURVEY
APPENDIX A

SECTION IV

DEVELOPMENT AND OPERATION

FOUNDATION PREPARATION-Any preparation work that was done to the foundation in advance of dumping, e.g. cleared and grubbed, low permeability lining placed, organics removed, etc.

DIVERSIONS/ROCK DRAINS-Major creek diversions and underdrains specifically designed/constructed for the dump. Anticipated reccurrent flow magnitude and frequency, if available.

METHOD OF DUMP CONSTRUCTION-Details on construction method, e.g. single or multiple lift, wrap arounds, construction sequence, etc.

DRAINAGE/SNOW CONTROL-Description of any methods used to facilitate water/snow removal and handling.

SPECIAL DEVELOPMENT REQUIREMENTS-Description of any special development requirements utilized in the dump construction, e.g. safety berms, toe dykes, slope flattening, deflection berms, etc.

DUMPING PROCEDURE/GUIDELINES-The predominant dumping method used in the construction of the dump. Brief description of guidelines on dumping method.

CONTROL OF WASTE QUALITY-Description of any special controls on waste quality, e.g. to assist reclamation or to provide coarse materials for rock drains, etc.

TRAINING OF OPERATIONS PERSONNEL-Brief description of any training programs to help personnel identify instabilities, potential problems, etc. during dump development.

WASTE DUMP NO.	FOUNDATION PREPARATION	DIVERSIONS/ ROCK DRAINS	METHOD OF DUMP CONSTRUCTION	DRAINAGE/ SNOW CONTROL	SPECIAL DEVELOPMENT REQUIREMENTS	DUMPING PROCEEDURE/ GUIDELINES	CONTROL OF WASTE QUALITY	CREST ADVANCE (m3/m/day)	TRAINING OF OPERATIONS PERSONNEL
AFT-1	Cleared and grubbed	Ephemeral drainage -control works not required	Single lift repose angle benches		None	Direct dumping over crest Dump short and doze Free dump on platform	No		
AFT-2	Cleared & grubbed, 1m compacted till liner to seal outwash deposits	Ephemeral drainage -control works not required	Multiple lift repose angle benches	Runoff collected and sedimented				106	
BAL-1	None	Pit flooded to 25m depth. -control works not required	Initial repose angle lift w. later multiple lower wrap-arounds	None	Safety berm near to to protect haul road	Direct dumping over crest	No	Avg. 204 Peak 270	No specific training program
BAL-2		None			None	Direct dumping over crest(75% Dump short and doze (25%)	No	Avg. 207 Peak 358	
BAL-3		Rock drain for Erickson Creek formed by natural segregation.	Single lift repose angle benches			Direct dumping over crest	Select. coarse rock placement for rock drain	Avg. 340 Peak 626	
BAL-4	Cleared and grubbed	Rock drain for Milligan Ck. formed by natural segregation. 1:200yr flow 0.2m³/s					No	Avg. 170 Peak 200	
BAL-5		None	Initial repose angle lift w. later multiple lower wrap-arounds					170	
BCC-1	Cleared, selective stripping	Rock drain constructed for Corbin Creek 200 yr design flow 8.8m³/s.	Multiple lift repose angle benches	Snow loaded out	Slope at toe flattened for stability	Variable	Coarsest, most durable waste in rock drain		Trained to recognize visual sign of instability
BCC-2	Pre-lift	Coarse rock underdrain	Initial repose angle lift w. later multiple lower wrap-arounds	Platform ditched No snow dumped over crest		Depends on available equipment	No		
BEA-1			Single lift repose angle? bench			Muck cars dump over crest Excess dozed over crest			
BEL-1	Logged	None	Initial repose angle lift w. later multiple lower wrap-arounds	No snow control Ditched to control infilt/seep	Sloughs backfilled. Flat, terraced slope for reclamation	Dump short and doze Occasionally dump directly over crest	Overburden placed on terraces to assist reclamation Selective placement to aid stability	Peak 150	Trained to recognize visual sign of instability
BEL-2	Logged	Minor seepage from tailings dam conveyed through dump toe.	Initial repose angle lift w. later multiple lower wrap-arounds	No sfc. drainage or snow control	First lift retained by haulroad			Peak 100	
BEL-3	Logged		Multiple lift repose angle benches		None			Peak 150	
BEL-4	Logged							Peak 100	

BRITISH COLUMBIA WASTE DUMP SURVEY
APPENDIX A

SECTION V

MONITORING AND STABILITY HISTORY

TYPE OF MONITORING-Method of dump monitoring, equipment spacing and personnel responsible for detecting instability or high groundwater pressures. MCM = mechanical crest monitors, Piezos = piezometers, etc.

FREQUENCY- Approximate frequency of readings for the various personnel and types of monitoring equipment.

ALLOWABLE MOVEMENT THRESHOLDS-Movement thresholds determining the course of action that must be taken to provide an acceptable level of safety for operations personnel.

MOVEMENT/FAILURE REPORTING-Chain of command involved in reporting signs of dump instability and failure.

SPECIAL INSPECTIONS/REVIEWS-Inspections/reviews by outside consultants or reports to Mines Inspection Branch, and special in-house reviews.

INCIDENCE OF INSTABILITY-Date and approximate size of the instability, and a brief description.

PERCEIVED CAUSE OF INSTABILITY-Perceived or possible cause of instability. N/A = not applicable (i.e. no failure).

RUNOUT- Approximate runout distance of failure from toe of original dump.

ADDITIONAL COMMENTS-Additional comments that clarify any of the previously given information.

WASTE DUMP NO.	FOUNDATION PREPARATION	DIVERSIONS/ ROCK DRAINS	METHOD OF DUMP CONSTRUCTION	DRAINAGE/ SNOW CONTROL	SPECIAL DEVELOPMENT REQUIREMENTS	DUMPING PROCEEDURE/ GUIDELINES	CONTROL OF WASTE QUALITY	CREST ADVANCE (m3/m/day)	TRAINING OF OPERATIONS PERSONNEL
QSM-1	Cleared and grubbed	None	Multiple lift re-contoured benches	Perimeter ditching	Catchment berms	Free dump in lifts on platform. Direct dumping half-way through dump life	Mix/blend to reduce acid generation	N/A	On-site
QSM-2	Cleared and grubbed down to glacial till	N/A	Multiple lift re-contoured benches			Free dump in lifts on platform, dumping and dozing over crest	Use waste to improve haul truck access		
QSM-3			Multiple lift re-contoured/resloped	As required		Extending length and height by dumping and dozing over crest			
SAM-1	Commercial logging		Initial repose angle lift w. later encompassing benches?	Perimeter ditching	None	Dump over crest then doze to required thickness once lift is completed	Yes, for AMD control		Exp. personnel
SIM-1	Trees removed	None required	Single lift with later bottom lift wrap arounds	None required	None required	Dump directly over crest	Yes		Informal training
SIM-2			Multiple lift w. bottom lift wrap around			Dump directly over crest			
SUL-1	Clearing, stripping and grading.	Ditching to collect runoff for treatment	Initial repose angle lift with later lower wrap-around	Grading & snow removal on haul roads as req'd	None	Dump short and doze	No potentially acid generating waste	1m/day	
SUL-2	Unknown		Single repose angle lift	Snowplow to active storage locations					
SUL-3									

WASTE DUMP NO.	TYPE OF MONITORING	FREQUENCY	ALLOWABLE MOVEMENT THRESHOLDS	MOVEMENT/ FAILURE REPORTING	SPECIAL INSPECTIONS/ REVIEWS	INCIDENCE OF INSTABILITY	PERCEIVED CAUSE OF INSTABILITY	RUN-OUT (m)	ADDITIONAL COMMENTS
AFT-1	Visual	Daily				None	N/A	N/A	Dumps constructed with flat slope for stability and to facilitate reclamation.
AFT-2									
BAL-1	MCM @ 30-75m Visual - Dumpman Visual - Foreman Visual - Geotech	Every 2 hrs Continuous Twice/shift Twice/week	>40-50mm/hr -read MCM's hourly >50-75mm/hr -stop dumping (under review)	Foremen report status each shift Failures: Dumpman- Foreman- Geot/A.Super- Manager- General Mgr.- Mines Insp.	Quarterly reviews by consultant. Annual report to Mines Insp.	Minor cracking and settlement.	High dump rate;fine waste	N/A	Standing water in pit resulted in some movement (bulging?) of toe. Some oversteepening of crest due to fine grained waste materal.
BAL-2						89 06 - 35,000 m³ 90 07 - 10,000 m³	High dump rate; fine,wet waste. Heavy precip; fine waste.	183 123	Very active dump. Wrap-arounds reducing effective height, hence, stability is expected to improve.
BAL-3						82 06 - 750,000 m³ -stopped short of creek		975	Stability expected to increase with time due to buttressing against opposite valley wall.
BAL-4						None	N/A	N/A	
BAL-5						None	N/A	N/A	
BCC-1	Visual MCM's	Ea. shift	Visual signs of instability - read MCM's daily.	Operator- Team Leader- Engineering- General Mgr.	Annual review by consultant.	90 07	Foundation failure on seam of saturated clay.	>100	
BCC-2	Visual-Operator MCM's Piezos @ toe	Continuous Weekly	>400mm/day - stop dump.		Annual rev. by consul.& report to Mines Insp.	90 05 - failure	High dump rate.	75	
BEA-1	Visual	Daily		Observer- Foreman- General Mgr.		None	N/A	N/A	
BEL-1	Visual-Operator Visual-Supervisors Visual-Engineer	Continuous Twice/shift Weekly	Visual sign of minor instability reported and remedial action taken as necessary.	Observer- Operations Supervisor		None	N/A	N/A	Moderate dump height, terraced configuration contribute to stability.
BEL-2									Limited dump height, buttressing by haulroad and tailings dam, flat terraced slope contrib. to stability.
BEL-3									Selective placement of O/B and buttressing with waste rock, toe into rock ridge contrib. to stability.
BEL-4									Localized slumping in O/B waste. Overall moderate slopes contrib. to stability.

WASTE DUMP NO.	TYPE OF MONITORING	FREQUENCY	ALLOWABLE MOVEMENT THRESHOLDS	MOVEMENT/ FAILURE REPORTING	SPECIAL INSPECTIONS/ REVIEWS	INCIDENCE OF INSTABILITY	PERCEIVED CAUSE OF INSTABILITY	RUN-OUT (m)	ADDITIONAL COMMENTS
BUL-1	Visual Prisms @ 50m Piezos in found'n	Daily		Engineer- Chief Eng.- Mine Mgr.	Annual review by consultant	None	N/A	N/A	Weekly reports on results of visual monitoring of waste dumps.
BUL-2	Visual Prisms ea. lift	Daily Not yet installed							
BUL-3	Visual 2 prisms	Monthly Once/year			Annual inspection by Engineer				
BUL-4	Visual Prisms MCM's	Weekly Once/year Weekly							
BUL-5	Visual Prisms Piezos in found'n	Daily Not yet installed			Annual review by consultant				
CAS-1	Visual - Picket lines Survey	Monthly Yearly	Noticeable subsidence	Surveyors- Chief Eng.- Mine Mgr.		None	N/A	N/A	Subsidence, but no catastrophic failures.
CAS-2	Visual	Daily							Used for development waste only, <35,000 m^3/yr.
END-1	Visual	3x/shift	Major cracking	Pit Shifter- Mine Super.- Engineering		Minor crest subsidence	Snow melt/dumping into water/diffrntial settlement		
END-2									
EQS-1	Visual Prisms @ 50m Int.	Each shift Quarterly				None since mid 1982	Prior to 1982 high dumping rates resulted in generation of high pore pressures in underlying till.	N/A	10m wide berms and 20° overall slopes implemented in 1982 has substantially improved stability and reduced settlements.
EQS-2	Visual Survey	Each shift Annually							
EQS-3									
FOR-1	MCM's @ 50-100 Visual	Every 4 hrs Ltd.	<1.2m/day-DOC (Dump Over Crest) >1.2m/day-stop	Dumpman- Foreman- Supervisor- Control Foreman- Mine Super./ Engineering- Gen. Mgr.	None	Several	Foundation failures, high pore pressures.	140	
FOR-2		Every 2 hrs	<1.2m/day-DOC >1.2m/d-dump short >2.0m/day-stop			88 09-8,000,000m^3 Multiple small failures	Foundation failure, high pore pressure.	500	
FOR-3		Every 2 hrs	<600 mm/day-DOC >600 mm/day-stop			None	N/A	N/A	
FOR-4		2 to 4 hrs	<1.0m/day-DOC >1.0m/d-dump short >1.2m/day-stop			89 11 - 2,500,000m^3	Failure within colluvium beneath toe wedge.	1200	

WASTE DUMP NO.	TYPE OF MONITORING	FREQUENCY	ALLOWABLE MOVEMENT THRESHOLDS	MOVEMENT/ FAILURE REPORTING	SPECIAL INSPECTIONS/ REVIEWS	INCIDENCE OF INSTABILITY	PERCEIVED CAUSE OF INSTABILITY	RUN-OUT (m)	ADDITIONAL COMMENTS
GBR-1	MCM's @ 50-100 Visual Prisms	2-4 x daily		Pit Super.- Engineering- Manager		Numerous between 20-80,000m³	Oversteepened crest, high pore pressures in fndn. Reactivation of landslide.	400	Failure mvt. rates gen. 2-3 m/min. Small dump built with small equip. High fines content.
GIB-1	MCM's Visual	Daily	Settled area flagged off until movement ceases	Pit General Foreman & Pit Super. Incidents entered in Mine Log Book		None	N/A	N/A	Ongoing settlements are normal. Rate or amount of settlement is a function of height.
GIB-2									
GIB-3									
GIB-4									
GIB-5									
GIB-6									
GRH-1	MCM's @ 100m Visual	Every 2 hrs Every 2 hrs	>50mm/hour- increase frequency of MCM readings. Rates increasing logarithmically & >1m/day- stop dump.	Spotter- Pit Control Foreman	Quarterly & annual review on all dumps by consultant.	83 05	High pore pres. in dump and foundation. Circular failure.	280	
GRH-2						83 03	Wet waste, no toe support, poss. snow on fndn. Comb. circular and basal failure.	700	Sturzstrom type slide failure.
GRH-3						89 11-300,000 to 500,000 BCM	Foundation failure-circular type.	1000	Numerous small sliver failures have also occurred.
HVC-1	Visual	Each shift	Operations Supervisors		Consultants contacted as required.	None currently.			On active dumps O/B is placed on outside faces wherever possible to suit reclam'n requirements.
HVC-2						Minor instability/ cracking 30-45m from crest.	High dumping rate, weak waste.		Control of pore pressure in waste and foundation through selective dumping & cntrl of dump advance rate are key factors in stability.
HVC-3									Inc. any lifts to the north, west of Valley Pit btwn 1270-1360 elev
HVC-4						Slumping, foundation spreading.	Weak foundation, saturated overburden.		Includes any lifts btwn S. end of 24 Mile Lake and HH dam.
HVC-5									Displacement of weak fndn soils permitted additional lift.

WASTE DUMP NO.	TYPE OF MONITORING	FREQUENCY	ALLOWABLE MOVEMENT THRESHOLDS	MOVEMENT/ FAILURE REPORTING	SPECIAL INSPECTIONS/ REVIEWS	INCIDENCE OF INSTABILITY	PERCEIVED CAUSE OF INSTABILITY	RUN-OUT (m)	ADDITIONAL COMMENTS
HVC-6						None	N/A	N/A	Last inspected in 1985.
HVC-7						No signs of major instability	N/A	N/A	Overburden capping for reclamation is planned.
HVC-8			Operations Supervisors		Consultants contacted as required.	None	N/A	N/A	Last inspected 87 09.
HVC-9 HVC-10						Small scale during early stages.	Saturated O/B		Later stages stable
ICM-1	None								
ICM-2						Minor settlements at crest.	Dumping over previously dumped, unconsolidated till	15	
ICM-3						None	N/A	N/A	
ICM-4						None	N/A	N/A	
ICM-5	Survey (levelling)	Daily	<90mm/day-open >90mm/day-closed	Surveyor-Gen. Foreman-Engineering		Several crest & infinite slope /toe failures since 1974	Dump advanced too fast for pore press. to dissipate in underlying clay	46	
LCR-1	Toe stakes		<600mm/day-safe >600mm/day-caution -read MCM's hourly >700mm/day-stop	General Foreman-Engineering		88 06	Failure along clay lense.		
LCR-2	1-2 MCM's/dump Visual	4-6 hrs. Continuous				82 07 - 1966 platform 84 05 - 1894 dump 89 05 - 1762 platform	Steep fdn, high precip? Base not toed-in. High fines content.	500	
LCR-3						2182 Platform 2158 Platform			Immediately upstream of LCR-2.
LCR-4	MCM Toe stakes/Piezos Visual	4-6 hrs. Continuous				None	N/A	N/A	
LCR-5	Visual	Continuous							

WASTE DUMP NO.	FOUNDATION PREPARATION	DIVERSIONS/ ROCK DRAINS	METHOD OF DUMP CONSTRUCTION	DRAINAGE/ SNOW CONTROL	SPECIAL DEVELOPMENT REQUIREMENTS	DUMPING PROCEEDURE/ GUIDELINES	CONTROL OF WASTE QUALITY	CREST ADVANCE (m3/m/day)	TRAINING OF OPERATIONS PERSONNEL
BUL-1	Not cleared	Rock drain for Y Creek formed by select dumping of coarse waste rock. 200 yr design flow 25m³/s.	Multiple lift repose angle benches	Dump platforms sloped for drainage Snow removed	None	Dump directly over crest and free dump in lifts on platform	Coarse rock for rock drain	47	Training program & manual
BUL-2								Avg. 100	
BUL-3	Large trees removed	None							
BUL-4	Cleared	None							
BUL-5	Overburden stripped.	Rock drain for Y Creek Runoff collected and diverted away from final slopes				Dump directly over crest	Coarse rock for rock drain	33	
CAS-1	Cleared	None	Multiple lift repose angle benches	None	None	Placement in lifts on dump platform			Yes
CAS-2	None	Culverts as required	Single lift repose angle bench		Deflection barriers	Dump short and doze		<1m/day	
END-1	Logged	None	Multiple lift repose angle benches	Dump platform sloped at 3% away from crest.		Dump directly over crest	No		Basic orientation
END-2									
EQS-1	Cleared	None	Single lift repose angle benches	Dump platforms sloped away from crest. Perimeter ditching. Designated snow dump.		Dump short and doze Dump directly over crest			Training & testing of operators
EQS-2	None	Bessemer Creek diverted							
EQS-3	N/A	None							
FOR-1	Some clearing and grubbing prior to placing toe dyke	N/A	Initial repose angle lift with later lower wrap around	Platform graded. No snow put over crest	Toe dyke constructed	Direct dumping over crest. Extensive guidelines developed	P. qual. rock not used drg. road constr'n.	Peak 55.6	Yes, drg production
FOR-2	None	None designed-natural Brownie Crk Avg=4.1m³/s Peak (200 yr)=11.3m³/s	Initial repose angle lift with later lower wrap around		Water clarification via collection pond	Direct dumping over crest Dump short and push	Not selective	Avg 21.4 Peak 34.3	
FOR-3	None Mined out pit	Formed through end dumping	Single lift repose angle bench		None	Direct dumping over crest	P. qual. rock not placed in spoil	Avg. 270 Peak 370	
FOR-4	None	None	Single lift repose angle bench buttressed	None	North and south toe dykes	Dependent on crest rates	Select for access road & rockdrains	Avg. 53.7 Peak 94.7	

WASTE DUMP NO.	FOUNDATION PREPARATION	DIVERSIONS/ ROCK DRAINS	METHOD OF DUMP CONSTRUCTION	DRAINAGE/ SNOW CONTROL	SPECIAL DEVELOPMENT REQUIREMENTS	DUMPING PROCEEDURE/ GUIDELINES	CONTROL OF WASTE QUALITY	CREST ADVANCE (m3/m/day)	TRAINING OF OPERATIONS PERSONNEL
GBR-1	Exploration roads act as shear keys	Ephem. streams w. springs 0.2 to 0.4 m^3/s. Rock drain formed by natural seg'n.	Initial repose angle lift with later lower wrap arounds	No winter operation	5m deflection berm at toe. Creek training	Initially dozed. Presently dump short and push due to previous instability		57	Yes, crack recognition
GIB-1	Clear cut logged	Creek diversion.	Single lift repose angle benches	Prevailing winds prevent snow accumulations on dump areas Runoff collection ditches at toe		Direct dumping over crest	Selective placement for reclamation & stability. Overburden contained by waste rock within dump lifts.		Geotech. engineer trains operations personnel
GIB-2									
GIB-3									
GIB-4		Ephemeral creek diversion.	Multiple lift repose angle benches						
GIB-5			Initial repose angle lift w. later benched toe buttress						
GIB-6		Top end of gulleys or small valleys will be filled.	Multiple lift repose angle benches						
GRH-1	None	None	Multiple lift repose angle benches	Ditching of dump platforms	None	Direct dumping over crest, dump lifts on platform	Avoid conc'n of HW and FW rock.		Yes. MCM reading.
GRH-2	None	None	Single lift repose angle bench		None	Direct dumping over crest	Maintain coars rock w/o coal fines over drainage areas.	2-3m/day	
GRH-3	None	Britch Crk Peak (10 yr) =1.5 m^3/sec.	Multiple lift repose angle benches		Advance to full limit to maintain toe in valley bottom.	Direct dumping over crest, dump lifts on platform.		1 m/day	
HVC-1	Clearing	Diversions presently, rock drains in future.	Multiple lift repose angle benches	Future ditching and diversion	Ring dykes enclose soft displaced silts on lake bottom.	Dump short and doze/direct dump on platform (alternate)	Selective placement		
HVC-2		Creek diversions and rock drains. Highmont Stream avg.=2-3000 USGPM peak= 4-5000 USGPM		Ditching		Dump short and doze Dump directly over crest Placement in lifts			
HVC-3				Future ditching		Dump short and doze/direct dump on platform (alternate)			
HVC-4	Coarse rock placed in first lift				Ring dykes enclose soft displaced silts on lake bottom.				
HVC-5	Drain any lakes-no rocks			Impermeable bottom lift					

WASTE DUMP NO.	FOUNDATION PREPARATION	DIVERSIONS/ ROCK DRAINS	METHOD OF DUMP CONSTRUCTION	DRAINAGE/ SNOW CONTROL	SPECIAL DEVELOPMENT REQUIREMENTS	DUMPING PROCEEDURE/ GUIDELINES	CONTROL OF WASTE QUALITY	CREST ADVANCE (m^3/m/day)	TRAINING OF OPERATIONS PERSONNEL
HVC-6									
HVC-7									
HVC-8	Clearing		Multiple lift repose angle benches			Dump short and doze/direct dump on platform (alternate)	Selective placement		
HVC-9									
HVC-10			Multiple lift repose angle benches			Dump short and doze/direct dump on platform (alternate)	Selective placement		
ICM-1	None	None	Single lift repose angle bench	None	None	Dump short and doze		0.6 m/ day	Training Manual
ICM-2	Logged	Creeks diverted.	Multiple lift re-contoured benches						
ICM-3		None	Single lift re-contoured benches					1.8 m/ day	
ICM-4	None		Multiple lift repose angle? benches		Safety berms above haulroads				
ICM-5			Single lift repose angle bench		None			15 m/ year	
LCR-1		None	Single/multiple lift repose angle extension of river terrace	None	Roll out berm to protect creek				Training Manual
LCR-2	Some clearing.	Rock drain for West Line Creek. 200 yr. mean flow = 7 m^3/sec.	Initial repose angle lift w. later multiple lower wrap-arounds			Dump directly over crest Dump short and doze	No poor quality waste rock		
LCR-3									
LCR-4	Valley floor already cleared for settling ponds	Rock drain for Line Creek 200 yr. mean flow = 38 m^3/s.			Contingency for sedimentation pond	Initially dump across creek, then along creek axis	Good quality rock for rock drain		
LCR-5	Some clearing	Rock drain for No Name Creek.	Single lift road fill construct. both from above and below		Sedimentation pond		Good quality rock for underdrainage		

WASTE DUMP NO.	FOUNDATION PREPARATION	DIVERSIONS/ ROCK DRAINS	METHOD OF DUMP CONSTRUCTION	DRAINAGE/ SNOW CONTROL	SPECIAL DEVELOPMENT REQUIREMENTS	DUMPING PROCEEDURE/ GUIDELINES	CONTROL OF WASTE QUALITY	CREST ADVANCE (m3/m/day)	TRAINING OF OPERATIONS PERSONNEL
MYR-1	Clearing	Drainage diverted around dump. Some seepage, quantities unknown.	Single lift repose angle bench	None	None	Dump short and doze	No	3	No
MYR-2		Diversion around perimeter of open pit and dumps (1983).	Multiple lift? repose angle benches			Direct dumping over crest		N/A	
NPL-1	Minor grubbing and clearing	Small diversion ditch for spring runoff.	Initial repose angle lift ult. encompassed by higher lift	Reg. grading as required		Direct dumping over crest Till dumped short and dozed	Yes. Fines used for reclamation		No
PRE-1	None	Rock drain for tributary of Wilson Ck. formed by limit. dumping of crs. waste rock.	Initial repose angle lift ult. encompassed by higher lift	Minor snow incorp. during current phase.		Direct dumping over crest Dump short and doze	No potentially acid generating waste dumped in vicinity of rock drains. Some selective placement of crs waste rock for rock drains	5m/ day	Dumps monitored by exper. personnel. No specific training program for other operations personnel.
PRE-2	Pre-stripping	Rock drain for Cooper Ck. formed by some selective placement of coarse waste rock and natural segregation.	Single lift repose angle bench	Future plans to train water into rock drain	Impact berm to prevent small slumps from reaching creek	Direct dumping over crest Dump short and doze Place lift on platform		1-10m/ day	
PRE-3	None		Initial repose angle lift w/ up to 4 higher encompassing lifts	Water trained towards rock drain	Haulroad cut into side of dump to access lower lifts	Direct dumping over crest Dump short and doze		1-5m/ day	
PRE-4		Rock drain for Wilson Ck. formed by limited dumping of crs. waste rock	Initial repose angle lift ult. encompassed by higher lift		None	Direct dumping over crest Dump short and doze		1-5m/ day	
QCL-1	None	Rock drain for small perennial creek formed by natural segregation of dumped waste material.	Multiple repose angle lifts with wrap arounds	Snow removal for all QCL dumps.		Direct dumping over crest		200-300 (design)	Training program for dump monitors
QCL-2			Repose angle bench	Ditching on platform.		Dump short and doze initially on steep terrain then dump over crest			
QCL-3		None	Repose angle bench with later lower wrap around	Ditching to specific points at crest.		Direct dumping over crest			
QCL-4	Stripping of mat'l from wetland area	Ditching of water to dump sides. Diversion to northern limit of crest.	Repose angle bench with later lower wrap around						
QCL-5			Multiple lift road fill construction		Waste rock buttress at toe				
QCL-6	Organics > 150mm thick removed	Rock drains formed during dumping into creek valleys.	Multiple lift repose angle benches	Ditching into natural drainage at toe.			Yes, due to low height (lack of natural seg'n)		
QCL-7			Staged multiple lift repose angle benches		Ring dyke for each lift				
QCL-8	Grubbing and clearing	French drains in each drainage.	Single lift road fill construction	Ditching into sedimentation ponds.					

WASTE DUMP NO.	TYPE OF MONITORING	FREQUENCY	ALLOWABLE MOVEMENT THRESHOLDS	MOVEMENT/ FAILURE REPORTING	SPECIAL INSPECTIONS/ REVIEWS	INCIDENCE OF INSTABILITY	PERCEIVED CAUSE OF INSTABILITY	RUN-OUT (m)	ADDITIONAL COMMENTS
MYR-1	Piezo for AMD					None	N/A	N/A	Dump orig. used from 1966-70, reactivated in 1980. Resloped in 1975 to 30 deg.
MYR-2	None								Main sidehill dump. Add'l smaller dumps of similar config.
NPL-1	Visual	Twice/shift	Crack-stop, monitor visually Stabilizes-proceed	Dumpman-Foreman-Mine Super.-Mgr.	Quarterly rev. by consultants	None	N/A	N/A	
PRE-1	Visual MCM's- 1-2/dump @ 50m intervals if	3-4x/day 3-4x/day (when in		Dumpman-Mine Shifter-Mine Super-		None	N/A	N/A	Frequent checks by supervisors during dumping. Several small dump failures with little warning.
PRE-2	operational limit-ations permit	service)		Manager. Incidents recorded in		One small failure on upper lift.	Not properly toed in. Rotational failure through foundation.		
PRE-3				daily log book		Three small sloughs during early development. One snow dump failure.	Weak fdn. High p. pressure Smooth underlying bedrock	50 to 100	Some large settlements w/o failure on north end.
PRE-4						None	N/A	N/A	
QCL-1	MCM's @ 40-80m	Inactive : twice/shift Active:	>3cm/hr-monitor hourly >5cm/hr	-notify foreman -shut down &	Consultant and /or in-house reports on un-	Several failures up to 100,000 BCM's. Ongoin high crest mvmnts.	Steep foundation; fine, wet waste; high dumping rate	200	Dumping rate linked to recorded movement rates. Several large failures
QCL-2	Visual-Geotech	ea. 3 hrs 3x/week	>20cm/hr <3cm/hr for 12 hrs & <1.2m/24 hrs	notify GE -clear area -re-open dump	usual occur-rences	None	N/A		(>1x10E6 m³) in Mesa dumps were sustained in 1985-86.
QCL-3						Ongoing crest mvmnts.	Lack of lateral support, dump height, water at toe due to adjacent failure.		
QCL-4	As for QCL-1	As for QCL-1	As for QCL-1			83 05 - 100,00m³ 87 07 - 5,600,000m³	Strain induced high pore press. in toe of dump.	350 2000	
QCL-5						None	N/A	N/A	
QCL-6	None at present.								Plans for monitoring incl. survey dump toe and inclinometers.
QCL-7	Piezometers		>10 kPa/24 hrs-closed based on review by GE			Small 90 03 90 05 - >1,000,000m³	Foundation liquefaction, weak/sensitive foundation	1000	Both failures occurred v. rapidly. Large failure temporarily blocked Murray River.
QCL-8	Visual/Prisms 5 Piezos	Weekly 2x/week	>4 kPa-notify GE >10 kPa-shut down			90 04 - single small failure (<40000 BCM)	Weak and saturated foundation.	50	

WASTE DUMP NO.	TYPE OF MONITORING	FREQUENCY	ALLOWABLE MOVEMENT THRESHOLDS	MOVEMENT/ FAILURE REPORTING	SPECIAL INSPECTIONS/ REVIEWS	INCIDENCE OF INSTABILITY	PERCEIVED CAUSE OF INSTABILITY	RUN-OUT (m)	ADDITIONAL COMMENTS
QSM-1	Visual	Daily		Movements reported to Mgr.		None	N/A	N/A	
QSM-2						Some exterior slumping of wet clay/till material.	High moisture content of dump material.	10	
QSM-3								30	
SAM-1	Visual	Daily			None	None	N/A	N/A	Dump is planned and operated to ensure potential acid gen. rock is enclosed by buffered rocks.
SIM-1	Visual	>2x daily	Any visible movement-stop & review	Foreman-Gen. Foreman-Gen. Super.-Engineering-Safety	None	None	N/A	N/A	Very stable dump. One incidence of minor settlement. Final design pending exploration program.
SIM-2						Settlement.	Heavy rain and runoff.	N/A	Very stable dump. Remedial diversion measures succesful in stopping settlement.
SUL-1	Visual	Every shift	Any visible movement - stop & review	Shift Boss-Foreman-Engineering		None	N/A	N/A	Good drainage of fill material. Current intermediate lift contributes to stability.
SUL-2									Dump has been abandoned for ~25 yrs. Very limited dumping has occurred since that time.
SUL-3									Dump active from turn of century until early 1980's. Occasional use presently.

Queen's Printer for British Columbia©
Victoria, 1992
MR 2287