

HYDROGEOLOGICAL ASSESSMENT AND DEVELOPMENT OF AMD CONTROL TECHNOLOGY FOR MYRA FALLS WASTE ROCK

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ABSTRACT

The Myra Falls Minesite on Vancouver Island, British Columbia contains a relatively large waste rock pile built against a valley wall and having a lateral extent of 800 meters by 300 meters with a height of up to 40 meters. The waste rock dump has been generating acid for at least a decade. Acid-base accounting of 230 borehole samples has shown that the most active areas of oxidation occur within a 10 meter depth of exposed surfaces of the waste rock dump and in deeper zones where relatively high contents of sulfide minerals are located. Water moving through the waste rock dump originates from infiltration of precipitation and lateral groundwater discharge from the valley wall. During periods of significant rainfall, the shallow acid-generating zones are flushed with water and acidic water appears beneath the water table. During periods of negligible rainfall, neutral-pH water is present beneath the water table. However, general calculations suggest that a significant portion of the annual production of acidity is retained in the dump and therefore remains available for flushing. As a result, remediation and decommissioning planning must address the neutralization of this acidity or the control of infiltration and water-table variation.

Various approaches to preventing acid mine drainage were evaluated. The most promising approach was the development of a cementitious solidification mixture incorporating mine waste materials for use as a waste rock dump surface sealant and grouting matrix. Mine waste water sludge and mine tailings were used as principal components of the solidification mixtures. A field assessment program was also carried out to evaluate the application and durability of the test mixtures on waste rock test piles. The solidified materials prepared have achieved similar properties to construction concrete in terms of compression strengths, setting times, workability and durability as measured by freeze/thaw testing. In addition, the solidification mixtures can be prepared at costs less than costs associated with other surface sealants such as high density polyethylene.

INTRODUCTION

Waste rock dumps at Westmin Resources Ltd., Myra Falls mine site contain sulphide minerals and generate acidic drainage with elevated metal loadings, particularly zinc, copper and cadmium. A water collection and treatment system is presently in place to protect the downstream environment but the reclamation of these dumps and the eventual decommissioning of the mine will require control of the acid generation. An assessment of the technology available in 1987 for such a control system indicated that a cost-effective, long term solution to acid generation at this site was not available. In addition, hydrogeology and acid generation at the Myra Falls mine site was not well understood.

Therefore the objective of this research program was two-fold:

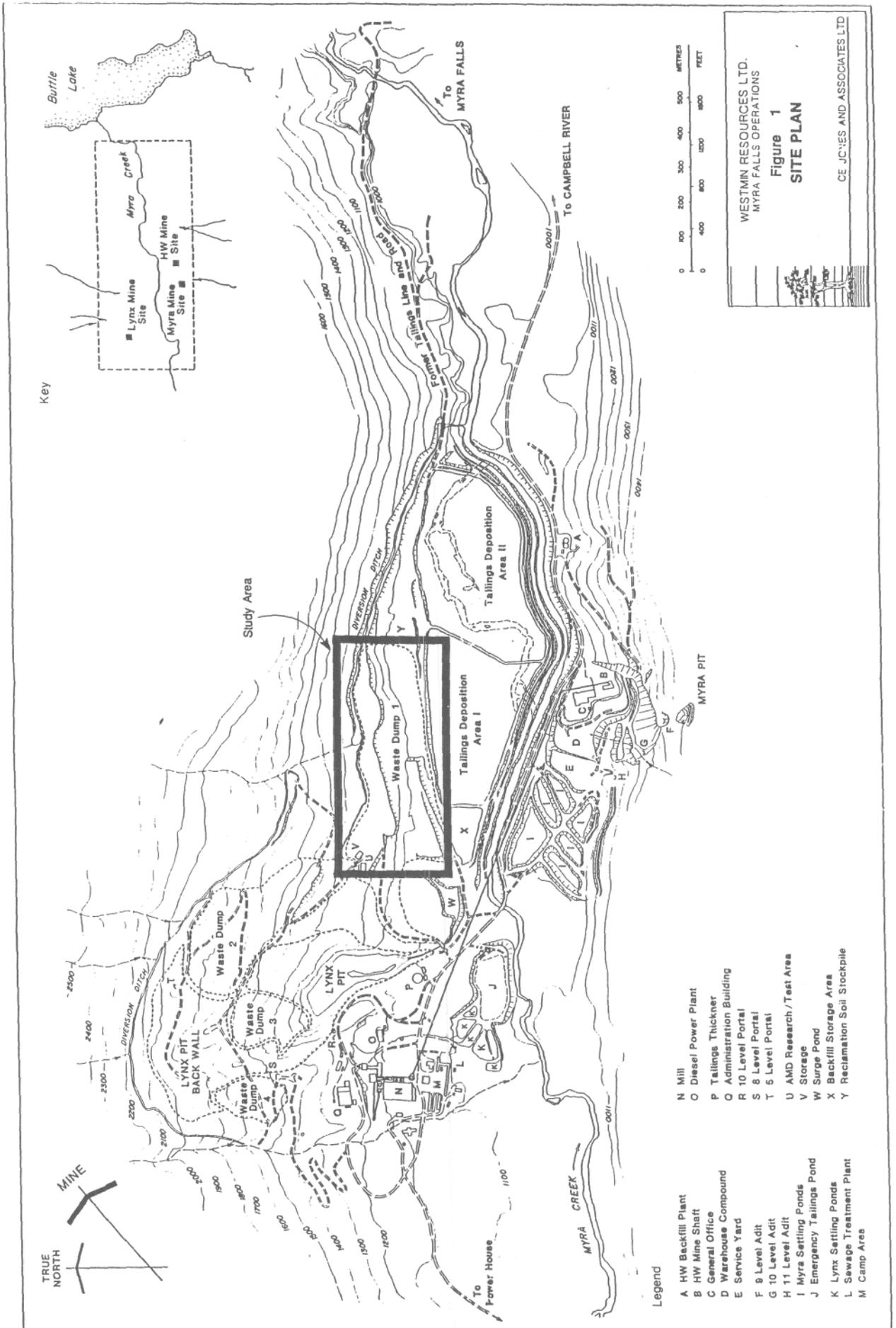
1. to characterise the acid drainage from the waste rock dumps, in particular to assess the hydrogeology of the main #1 dump (Site Plan, Figure 1)
2. to develop a cost-effective solution to control of acid generation in waste rock which would be compatible with final revegetation and decommissioning of the site.

The approach taken in this research program is illustrated in Figure 2. As evident from this flow chart the research program is not complete, however, major goals have been achieved in both the characterization of acid generation in the waste rock and in the development of a suitable control technology. This document provides a detailed assessment of the research efforts to date and describes the field scale testing which is proposed before the remediation strategy is finalized and waste dump treatment is begun.

PHYSICAL HYDROGEOLOGY

Recognizing the potential impacts of internal processes within the dump on acid-drainage control and reclamation planning, Northwest Geochem proposed an environmental assessment consisting of boreholes, monitor wells, acid-base accounting, water-quality analyses, and laboratory experiments. In order to define the physical hydrogeology of the area in and around the waste rock dump, the drilling/monitor-well program was conducted in 1988 consisting of 57 boreholes with an average depth of approximately 29 meters. The holes intended only for stratigraphic determinations were drilled with a tricone rotary bit and the holes for installation of monitor wells were drilled with an Odex hammer and casing. Up to 3 wells were placed in each of 22 selected boreholes for a total of 51 wells, using bentonite to isolate the monitored intervals in each borehole. Several of the well screens are located above the local water table to monitor significant increases in the elevation of the local water table and any perched water tables.

Interpretation of the borehole and groundwater data was aided by a conceptual model for water movement in and around the dump as shown in Figure 3. Water moving through the dump originates from two sources: infiltration of precipitation on the dump surfaces and lateral discharge of background groundwater from the adjacent valley wall. The background groundwater flows through the base of the dump and the underlying bedrock towards the Myra Creek floodplain. Infiltration from the dump surfaces moves generally downward towards the water table and mixes with the background groundwater. Volume rates of infiltration appear to be negligible during dry months and significant during wet months, based on water levels in monitor wells and variations in water chemistry. The combined water appears to leave the dump below the toe and enter the floodplain sediments. The water table has a relatively steep gradient of approximately 0.2 towards the valley floor to the south and east. Hydraulic conductivities of the bedrock based on 4 single-well tests ranged from 3.2×10^{-8} to 1.6×10^{-6} m/s (Knight and Piesold, 1989), which was consistent with earlier measurements in abandoned exploratory holes of 10^{-7} m/s for fractured bedrock (Simco Groundwater Research Ltd., 1983). The hydraulic conductivity of the waste rock appears to be greater than 10^{-4} m/s (Knight and Piesold), but this value likely applies only to the coarser



Key

TRUE NORTH

Study Area

Legend

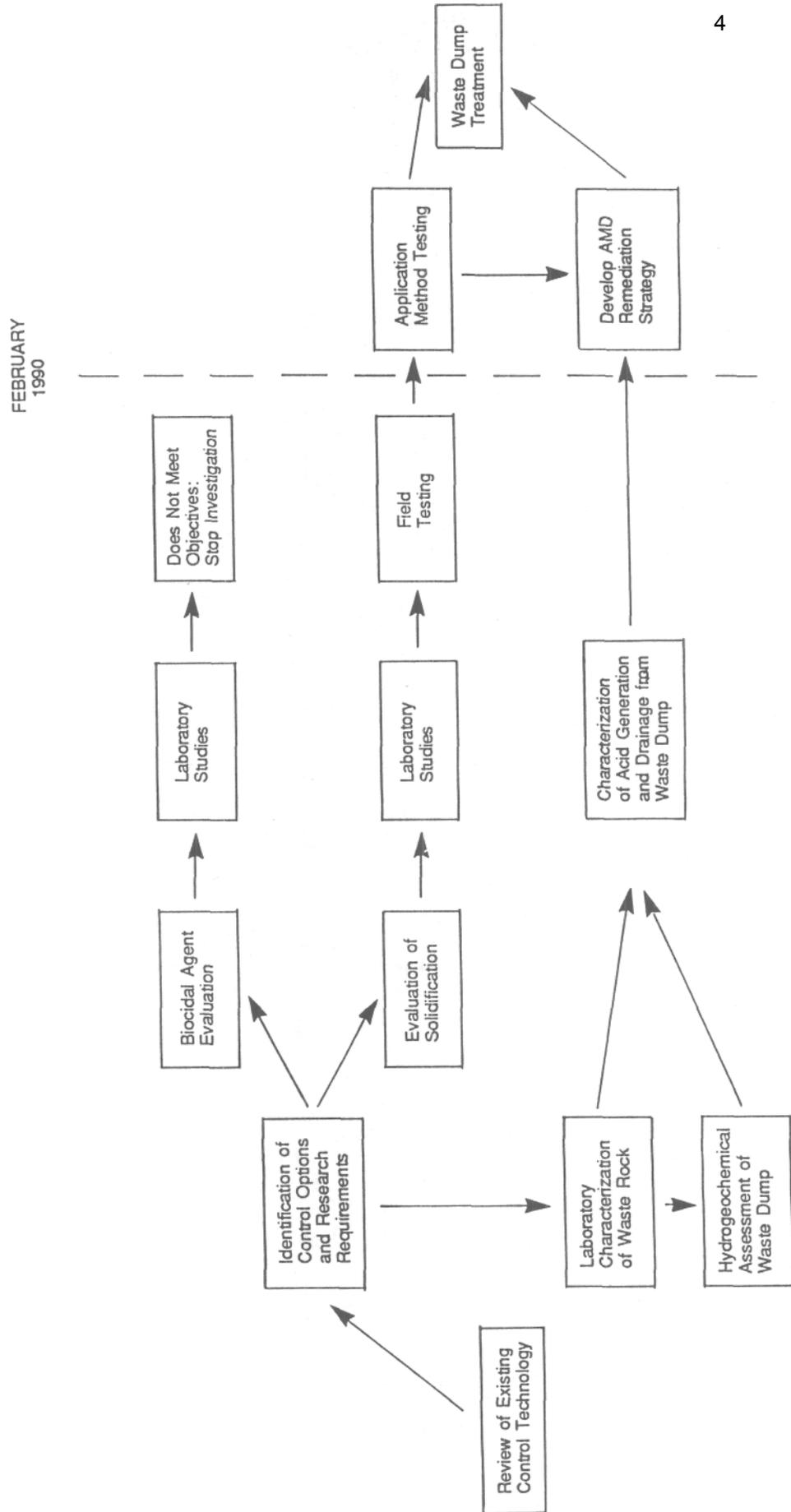
- A HW Backfill Plant
- B HW Mine Shaft
- C General Office
- D Warehouse Compound
- E Service Yard
- F 9 Level Adit
- G 10 Level Adit
- H 11 Level Adit
- I Myra Settling Ponds
- J Emergency Tailings Pond
- K Lynx Settling Ponds
- L Sewage Treatment Plant
- M Camp Area
- N Mill
- O Diesel Power Plant
- P Tailings Thickener
- Q Administration Building
- R 10 Level Portal
- S 8 Level Portal
- T 5 Level Portal
- U AMD Research/Test Area
- V Storage
- W Surge Pond
- X Backfill Storage Area
- Y Reclamation Soil Stockpile

Figure 1
SITE PLAN

WESTMIN RESOURCES LTD.
 MYRA FALLS OPERATIONS

CE JONES AND ASSOCIATES LTD

Figure 2
Research Approach for AMD Control at
Westmin Resources Ltd., Myra Falls Operation



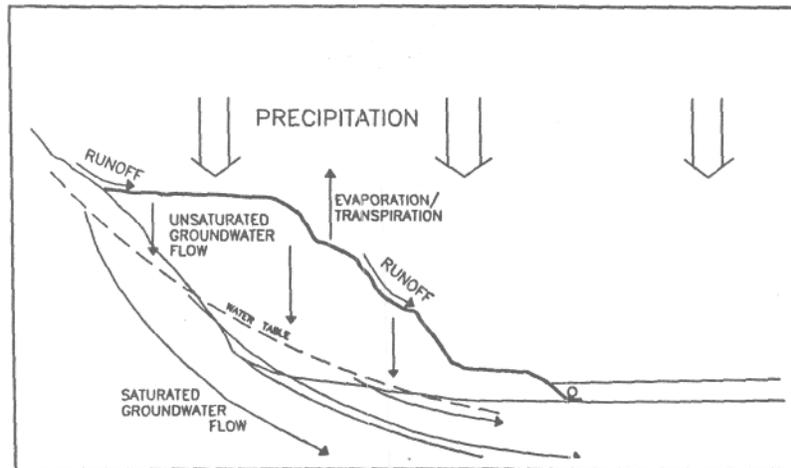


Figure 3. Conceptual model of water movement in and around the waste rock dump.

rock. The finer rock, particularly crushed rock near the base of the dump, probably has a much lower conductivity. Because of the similar hydraulic behavior of deeper waste rock and bedrock, these rock types probably have similar values of conductivity on the order of 10^* to $1Q^{-5}$ m/s.

CHEMICAL HYDROGEOLOGY

As part of the drilling program rock and sediment samples were collected from boreholes beginning at a depth of 15 feet and were submitted for acid-base accounting (ABA). Mean values of ABA parameters indicated that the waste rock has a significant capacity for generating acidity (MPA), which is not offset by the neutralization potential. As a result, the mean value for NNP is significantly negative and net acidity can be expected from the waste rock on average. ABA analyses of the organic material beneath the waste rock also had a negative mean value for NNP, suggesting that this material could also generate net acidity. However, the sulfur measured in the ABA analyses was probably organic sulfur, which may not be acid-generating or may be only slowly reactive as sometimes found in acidic peat bogs. ABA analyses of bedrock produced a positive value of NNP_1 indicating that this rock will not generate net acidity on average. However, the range of ABA values for bedrock are sufficiently variable so that net acid generation may occur in some areas. Mean values for paste pH were above neutral indicating that on average the samples were not actively generating net acidity prior to analyses, although a large proportion of some samples was likely from inside boulders where active acid generation would not occur. However, the minimum value of 4.00 for paste pH in waste rock demonstrates the occurrence of active acid generation in some samples.

In portions of the dump there appears to be a shallow acidic zone and a deeper neutral zone, separated by an "acid front". Where the thickness of the dump is minimal and acid generation is significant, the acid front has already passed through the full thickness of waste rock and reached the water table. Due to the complexity of water movement and the preferential movement through channels in waste rock dumps (Northwest Geochem, 1990), the acid front is not thought to be a flat, continuous surface, but simply a conceptualization to aid in understanding and discussing acid drainage in the dump. The seasonal appearance of acidic water below the water table during wet seasons suggests that the shallow acidic zone is occasionally flushed, at least in portions of the dump.

In addition to the shallow acid zone, other geochemical features were detected within the dump. Zones of net acid generation at depth ("hot spots") occur within pH-neutral zones of boreholes. There are several potential causes for any particular hot spot such as anomalously more reactive sulfide minerals or little initial neutralization potential. Like the shallow acid zone, these zones supply acidity to water moving through them. Other features found within the dump include low-sulfur zones in which little acid generation can occur and anomalously high NP zones which can retard the migration of the acidity for long periods of time.

Because there is little neutralization capacity in the rock, most of the neutralization observed in the dump is apparently derived from alkalinity in the background groundwater laterally discharging from the adjacent valley wall. When the acid zones are flushed by precipitation events, the acidic water flows downward to the water table and mixes with the neutral-pH groundwater. If acidity is less than approximately 100 mg/L, then pH will remain near neutral values due to the alkalinity, whereas, during wet months, the alkalinity is overwhelmed and acidic pH is found below the water table. Based on a generally defined flowpath through the western portion of the dump to the floodplain, pH consistently remains near neutral in the upgradient portion of the flow system near the valley wall, but fluctuates significantly near the toe. This is attributed to the progressive addition of acid water along the length of the flowpath.

The leaching of metals further degrades water quality in the dump. However, significantly elevated aqueous concentrations of metals are noted even in neutral-pH water. This may be a consequence of enhanced leaching or solubility by aqueous complexation, but further work is required to confirm this and to design controls for metal leaching.

Despite the flushing of acid zones, especially during wet months, general calculations suggest that most of the annual production of acidity is retained in the dump, and this acidity likely remains available for flushing. As a result, remediation and decommissioning planning must address either the neutralization of this acidity or the control of infiltration and water-table variation. Further work is planned to delineate in more detail the physical and chemical hydrogeology of the waste rock dump to develop reliable remediation and decommissioning plans.

CONTROL TECHNOLOGY

Present technology does not provide a long-term solution to acid generation which would be suitable for use at the Westmin Resources Myra Creek site. Several approaches which offer some potential for control of acid generation include: application of alternative bactericides; and, restriction of oxygen and water movement through waste rock by use of surface covers.

Although the use of cationic surfactants as an AMD control measure was evaluated, the results indicated that the transient nature of the bactericide together with the shallow depth of penetration rendered the use of surfactants ineffective as a long-term solution to acid generation in waste rock. The more promising approach of development of a surface cover was pursued using mine waste products such as wastewater sludges and tailings could be integrated into a concrete-like geopolymer material. The resultant product could be used as

a surface sealant and a grouting material for the control of AMD from the Myra Falls waste rock dump. In addition, the approach if successful would enable the use of a wastewater sludge which otherwise would be subject to storage and disposal requirements of the B.C. Special Waste Regulation.

The use of the solidified material as a surface sealant and/or a grouting material for the control of AMD generation would require that the material:

- is easily applied (i.e., good flow characteristics during application and an initial setting time greater than 2 hours but less than 12 hours);
- is durable (i.e., not subject to freeze-thaw effects and has reasonable strength to support a load and enable subsequent reclamation activities);
- is chemical resistant and cannot be readily affect by contact with oxidized rock and/or waters with low pHs;
- has low permeability to air and water;
- is economical compared to other sealing methodologies, and,
- is compatible with land reclamation efforts which will be initiated on the waste rock pile.

Figure 4 shows the overall approach which was used.

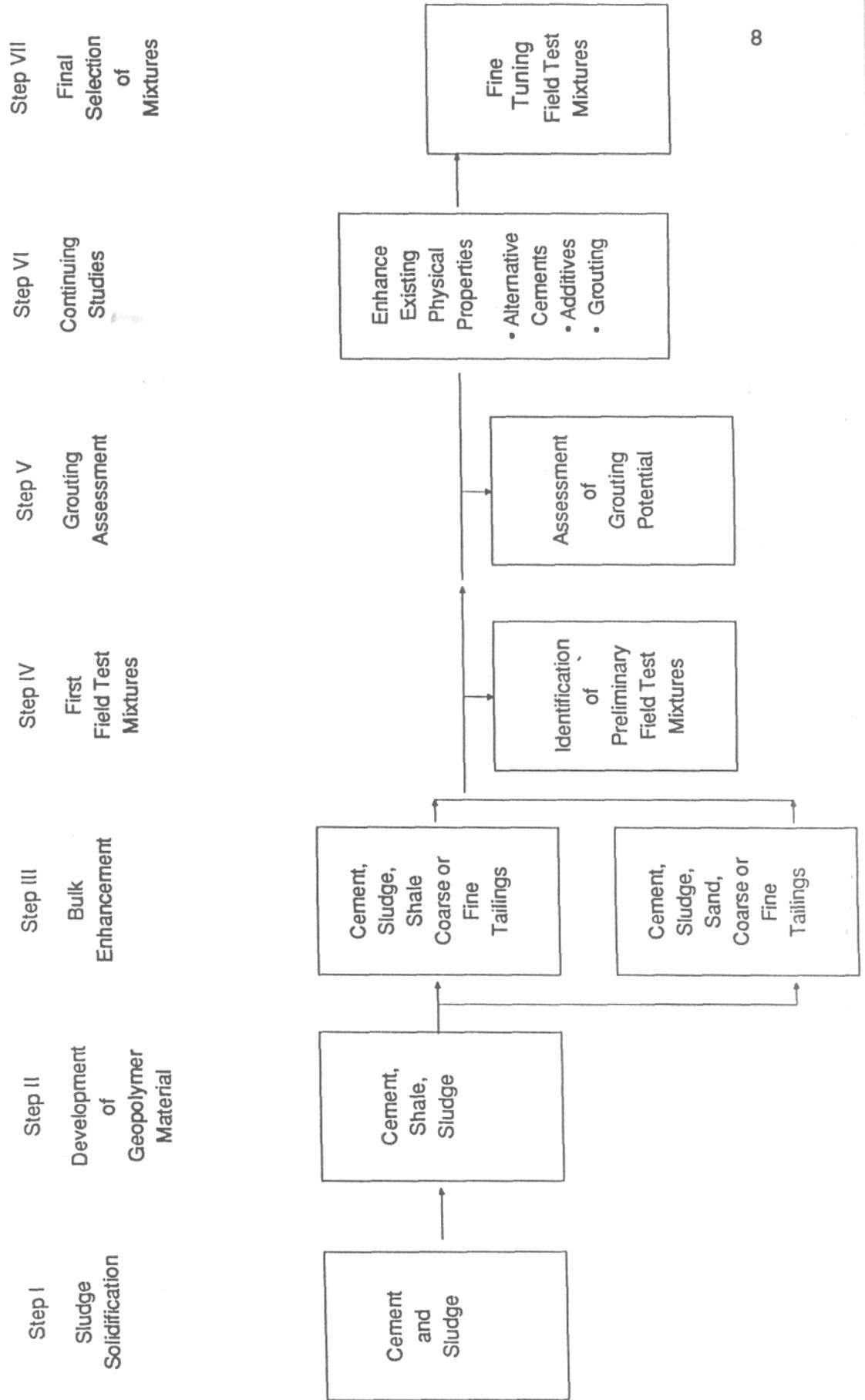
LABORATORY STUDIES

Mixing and test procedures were carried out by use of a combination of procedures developed by the Environment Canada Wastewater Technology Centre for waste solidification and by ASTM for concrete testing. There was a bias towards the ASTM procedures because the intended use would be more like that of a concrete material rather than a waste material which would be buried in a landfill without exposure to the open environment.

Tests conducted on solidified Westmin mixtures were selected on the basis of EPA (1986) specifications for stabilized/solidified waste as listed below:

<u>EPA Specification</u>	<u>Test Conducted</u>
<i>Chemical Characteristics</i>	
• leachability of waste components to contacting water	→ leachate test
• reactivity of solidified waste	→ net neutralization potential
<i>Physical Characteristics</i>	
• strength or bearing capacity	→ compressive strength.
• permeability	→ water permeability
• durability under conditions of surface exposure	→ freeze/thaw testing, field weathering of test piles

Figure 4
APPROACH USED FOR SOLIDIFICATION STUDIES



Preliminary studies suggested that cement and coarse tailings should be the principal constituents of the mixtures, and that the solidified mixture could also incorporate the wastewater sludge without detriment to physical and chemical properties. Solidified mixtures were developed to evaluate the influence of material properties, mix proportions and the addition of various admixtures (air entrainment agents and strengthening agents) and supplementary cementing materials (fly ash, lime, wastewater sludge, soluble silicates) on physical and chemical properties of cured cementitious mixtures.

Variables which influence the cementitious mixtures were similar to those for a concrete mix:

- the water to cement ratio
- the texture and grading of the aggregate (e.g., tailings and/or sand)
- the percentage of aggregate used
- air content
- the use of supplementary cementing materials
- the use of admixtures

The test program was therefore designed to evaluate the effects of these variables. The program was initiated with the use of simple solidification mixtures composed of cement and tailings to define the role of physical factors such as water and air content and texture and grading. The program was then expanded to assess the addition of supplementary cementing materials and admixtures.

OPTIMIZATION OF CEMENTITIOUS MIXTURES - LABORATORY RESULTS

The results of the laboratory study indicated that the solidified materials prepared have similar properties to that of construction concrete in terms of compression strengths, setting times, workability and durability as measured by freeze/thaw testing. The water to cement ratio, cement, sludge, tailings and aggregate content of the mixtures were optimized by varying the proportion of these materials and evaluating the solidified material by standard concrete testing methods as discussed earlier.

The strength, durability and impermeability of a cementitious mixture depends to a large extent on the ratio of water to cement. Compressive strength is inversely related to the water-cement ratio. Increasing the cement content also results in solid mixtures with high compressive strength. Consequently, mixtures were prepared and tested which contained up to 25 percent cement with water to cement ratio's ranging from 0.35 to 1.2. Optimum water to cement ratio's, based on compressive strength and workability, were in the range 0.4 to 0.65 while cement contents of 20% and greater performing well.

Mine tailings were initially used as the only aggregate source in the mixtures and although their use did not show detrimental effects, the addition of sand as an additional aggregate source improved the workability and strength characteristics of the mixture and shortened the setting time. The use of different aggregates is important to obtain a range of particle sizes. A unimodal aggregate size will result in a larger percentage of voids which will require a large amount of cement paste to fill. Mixtures containing tailings and sand achieve a wider particle

size distribution and the effect was seen in higher compressive strengths of these mixtures.

Supplementary cementing materials are often used in conjunction with cement to enhance the properties of solidified materials through hydration and pozzolanic reactions. A series of test mixtures using fly ash, wastewater sludge, lime and soluble silicates were formulated to evaluate their effect on the properties of cementitious mixtures. The use of wastewater sludge in the mixtures was limited by the high water content in this material (95%). Although the sludge was dewatered to the greatest extent possible the residual water content increased the setting time to an impractical level. Sludge contents of less than 10%, however, were not found to adversely effect the mixtures.

The effectiveness of air entrainment and strengthening additives was evaluated for improvement of physical properties of the cementitious mixtures. Although the compressive strength can be increased over 200% with the addition of certain strengthening agents, a large increase in the overall material cost would also be realized.

Good durability was shown for mixtures with the addition of both air-entrainment and strengthening admixtures. Mixtures containing both admixtures attained fully 97% of their 28-day compressive strength within the first 7 days of curing. The results indicate that the use of air-entraining and strengthening additives improves the strength and setting time characteristics of the cementitious mixtures. Freeze-thaw test suggest that inclusion of strengthening agents improves the durability of the cementitious mixtures. Durability tests (laboratory freeze-thaw tests and field studies) are ongoing and conclusions on durability could not be reached within the one year study period.

Chemical stability of the cementitious mixtures is a measure of the environmental suitability of the material. Because the test mixtures contained mine tailings as a major ingredient, the reactivity of the hardened mixture as determined by acid neutralization potential was measured. The results show that all test mixtures have NNP's greater than +20 tonne CaCO_3 / 1000 tonnes solid. Therefore, the cement content used in the mixtures more than adequately neutralizes the potential acidity of the mine tailings.

The leaching data for the test mixtures suggest that mixtures can be prepared to meet the Federal and Provincial discharge limitations and the B.C. Special Waste Regulation leaching criteria. Levels of aluminum occasionally exceed the B.C. Effluent criteria for Special Waste Facilities, however the criteria are not considered of direct relevance to the intended application.

The material costs of solidified mixtures which would effectively serve the purpose as durable surface sealants are in the order of \$4.10 to \$6.20 per square meter which is less than material costs for optimal surface sealants such as high density polyethylene. Installed till covers, of which at least one meter depth is required, cost in the order of \$14.25 per square meter (Mount Washington experience 1989, personal communication M. Galbraith). Therefore, the solidified tailings mixture approach may offer a competitive, cost-effective control for sealing of the waste rock dumps.

FIELD STUDIES

Six test piles of waste rock were placed on individual high density polyethylene membranes. The size of each test pile was approximately 5mx5mx2m (height). The test piles were prepared during the fall of 1987 and runoff waters from each were collected at intervals for analyses. Measurements of pH and runoff volume were continuous and recorded on a remote recording device.

Three solidification test mixtures were applied to individual test piles during the fall of 1988, and another three applied during summer of 1989. Five cubic yards of each selected test mixture were prepared by means of either mixing the ingredients at a concrete ready mix facility in Campbell River with delivery to the site by cement truck, or by loading the cement mixer truck with ingredients at the mine site.

Despite the favorable performance of the mixtures on a laboratory scale the 1989 field scale trials were not entirely successful. Within a five hour period all mixtures on the piles developed fine cracks. Subsequent efforts to duplicate this cracking in laboratory tests were unsuccessful. Although the exact cause of the cracking observed has not been determined, possible causes include: excessive heat of hydration, inadequate particle size distribution, or addition of coarser aggregate such as gravel.

Following placement of the solidified mixtures on the waste rock piles, monitoring of runoff waters was representative of leachates from the cementitious covers. The pH values ranged from 6.5 to 10.3. Assuming that a waste rock pile is successfully treated with such covers, the runoff waters would approximate the post-cover water quality observed in Table 6.2. If soil is placed on the cover as part of a reclamation program then a less alkaline pH could be expected. Metal releases are minimal with aluminum concentrations from 2.5 to 10 times lower than the B.C. Special Waste criteria level of 0.2 ppm and copper concentrations from 40 to 200 times lower than the WMB discharge limit of 0.2 ppm.

To this date, the chemical integrity of the solidified mixtures covering the test piles appears satisfactory.

GROUTING TRIAL

There are zones of net acid generation at depth in the Westmin waste rock dump based on acid-base accounting analyses, sometimes informally referred to as "hot spots" of acid generation. Application of grout to these zones could effectively control the acid generation process by sealing the "hot spot" so that neither oxygen nor water can reach the acid generating rock. Use of a cement containing grouting material to seal voids at depth in the Westmin waste rock dump would also provide a measure of alkalinity to neutralize potential acidity.

A grouting material composed of cement, mine tailings and sand at different water to cement ratios was used to demonstrate the capability to seal cobble to boulder sized void spaces. A water to cement ratio of 0.53 was found to satisfy all the requirements for a desirable grouting

material to fill large void spaces. To date the grout materials have performed well in the rock enclosures (i.e., cracking has not been observed, shrinkage appears to be minimal). Freeze/thaw testing of the grout mixture has successfully completed 25 cycles.

FUTURE STUDIES

Shotcreting is the preferred means for surface application of the cementitious mixtures because it can be applied in difficult places and over large areas. In the past five years, research in cement technology has focused on the development of a high flexural-tensile strength and low drying shrinkage for shotcreted materials. Flexural strength is a measure of the solid material's ability to withstand local settlement and reduces the incidence of cracking. These are important properties for the long-term use of the material as a surface sealant and will be the focal point for future studies.

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