MEND MANUAL

VOLUME 6 – MONITORING

MEND 5.4.2f

Editors:
Gilles A. Tremblay
Charlene M. Hogan

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MONITORING

AUTHORS OF THE MEND MANUAL

This Manual was compiled on behalf, and under the direction of MEND and MEND 2000, by URS Norecol Dames & Moore, in association with SENES Consultants Limited, SRK Consulting, BC Research Inc., EVS Environment Consultants and O'Kane Consultants Inc. The different volumes and sections of the Manual were authored as follows:

Volume 1:	
	SENES Consultants Limited
Volume 2:	
Section 2.1 to 2.3	SENES Consultants Limited
Section 2.4	URS Norecol Dames & Moore
	EVS Environment Consultants
Section 2.5	SENES Consultants Limited
Section 2.6	BC Research Inc.
Volume 3:	
Section 3.1 to 3.3	URS Norecol Dames & Moore
	SRK Consulting
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Volume 4:	
Section 4.1	SENES Consultants Limited
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Section 5.1	SENES Consultants Limited
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VOLUME 6 – MONITORING

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While considerable progress has been made in tackling the problems of acidic drainage, major challenges remain. Comments on this document and other aspects of acidic drainage should be sent to:

Gilles Tremblay
Natural Resources Canada (CANMET)
555 Booth Street
Ottawa, Ontario
K1A 0G1

DISCLAIMER

The primary purpose in producing this manual is to provide a succinct summary of the extensive work completed by MEND and MEND 2000 on the processes of acid generation from sulphur-bearing minerals and sulphide wastes in a manageable single reference document. A secondary objective is to provide additional recommendations on the application of currently available technologies. The result is a detailed reference on sampling and analyses, prediction, prevention, control, treatment and monitoring of acidic drainage. The information provided is based on the opinions of the authors of the particular sections and should not be construed as endorsement in whole or in part by the various reviewers or by the partners in MEND (the Government of Canada, Provincial Governments, the Mining Association of Canada, contributing mining companies and participating non-governmental organizations).

The user of this guide should assume full responsibility for the design of facilities and for any action taken as a result of the information contained in this guide. The authors and Natural Resources Canada (through the Mine Environment Neutral Drainage (MEND) and MEND 2000 programs) make no warranty of any kind with respect to the content and accept no liability, either incidental, consequential, financial or otherwise arising from the use of this publication.

PREFACE

Acidic drainage[1] has been identified as the largest environmental liability facing the Canadian mining industry, and to a lesser extent, the public through abandoned mines. This liability is estimated to be between $2 billion and $5 billion Canadian, depending on the sophistication of treatment and control technology used. There are numerous examples throughout the world where elevated concentrations of metals in mine drainage have adverse effects on aquatic resources and prevent the reclamation of mined land. Metal leaching problems can occur over an entire range of pH conditions, but are commonly associated with acidic drainage. In North America acidic drainage has resulted in significant ecological damage and multimillion-dollar cleanup costs for industry and governments.

The Canadian Mine Environment Neutral Drainage (MEND) Program was formed in 1989, to develop scientifically-based technologies to reduce or eliminate the liability associated with acidic drainage. This nine-year volunteer program established Canada as the recognized leader in research and development on acidic drainage for metal mines. Through MEND, Canadian mining companies and federal and provincial governments have reduced the liability due to acidic drainage by an estimated $340 million. It is also acknowledged that the reduction in liability is significantly higher than this quoted value, with a minimum of $1 billion commonly accepted. This is an impressive return on an investment of $17.5 million over nine years. A three-year program, called MEND 2000, was initiated in 1998 to further confirm MEND-developed reclamation technologies in the field. The key to MEND 2000 was technology transfer – providing state-of-the-art information and technology developments to users and to ensure that the information is clearly understood, particularly for newly-developed technologies.

THE MEND MANUAL

More than 200 technology-based reports were generated from the MEND and MEND 2000 programs. These reports represent a comprehensive source of information, however, it is not practical for users to have on hand or assimilate all the detailed information. For this reason, a single source of information on acidic drainage and on the results of MEND research is needed which is complimentary to many detailed technical reports. The MEND Manual describes the MEND-developed technologies and their applicability in terms of cost, site suitability and environmental implications - **a "toolbox" of techniques and options**.

The objective of the manual was to summarize work completed by MEND in a format that would provide practitioners in Canadian industry and government with a manageable single reference document. The document is not a “How to” manual. It is a set of comprehensive working

[1] The terms “acidic drainage”, “Acid Mine Drainage” (AMD) and “Acid Rock Drainage” (ARD) are used interchangeably throughout the manual to describe effluent generated from the oxidation of sulphide minerals

references for the sampling and analyses, prediction, prevention, control, treatment and monitoring of acidic drainage. The document provides information on chemistry, engineering, economics, case studies and scientific data for mine and mill operators, engineering design and environmental staff, consulting engineers, universities and governments.

The MEND Manual consists of six volumes. The information found in each volume is as follows:

Volume 1: Condensed "stand-alone" summary of the Manual.

Volume 2: Sampling and Analyses
- Water and solids sampling
- Biological sampling
- Geophysics and remote sensing
- Chemical analyses for water and solids

Volume 3: Prediction
- Laboratory static and kinetic geochemical tests methods
- Field methods
- Modelling

Volume 4: Prevention and Control
- Water covers
  - Non-oxidized and oxidized waste materials
- Dry covers
  - Soil and organic covers
- Disposal technologies
- Saturation (elevated water table)
- Blending and layering
- Separation and segregation
- Backfilling (in-pit) and co-disposal
- Permafrost

Volume 5: Treatment
- Active treatment methods
  - Chemical treatment
  - Metal recovery/recycling
  - Treatment byproducts
- Passive treatment
  - Anoxic limestone drains

    - Aerobic wetland treatment systems
    - Passive anaerobic treatment systems
    - Biosorption treatment methods
    - Passive *in situ* treatment methods
- Hybrid active/passive treatment systems

Volume 6: Monitoring

- Monitoring objectives
- Monitoring program design and data management
- Recent developments affecting acidic drainage monitoring

BACKGROUND ACIDIC DRAINAGE FROM SULPHIDE MINERALS

Base metal, precious metal, uranium, diamond and coal mines often contain sulphide minerals, in the mined ore and the surrounding rock. When these sulphide minerals, particularly pyrite and pyrrhotite, are exposed to oxygen and water, they oxidize, and the drainage may become acidic unless sufficient acid-neutralizing minerals such as calcite are present.

The acidic water may contain elevated concentrations of metals and salts. These can include typical major rock constituents (Ca, Mg, K, Na, Al, Fe, Mn) as well as trace heavy elements such as Zn, Cu, Cd, Pb, Co, Ni, As, Sb and Se. Rainfall and snow-melt flush leachate from the waste sites. If acidic drainage is left uncollected and untreated, the drainage can contaminate local water courses and groundwater, affecting plants, wildlife, and fish.

Naturally occurring alkalinity, such as carbonate minerals and carbonate ions in solution may partially or completely neutralize acidity *in situ*. The resulting leachate is non-acidic with very low iron concentrations[1] but can contain elevated concentrations of sulphate, calcium and magnesium.

Neutralization by reactions with acid consuming minerals (carbonate minerals in particular) may result in low concentrations of dissolved metals due to the low solubility of metal carbonates, basic carbonates, hydroxides and oxyhydroxides at pH 6 to 7.

DURATION

The lag time for acid drainage to appear (if at all) is controlled by the concentration and reactivity of the iron sulphides, and the availability of carbonate minerals. Acid may be generated and released by high sulphur wastes having small amounts of carbonate minerals a few days after exposure. Low sulphur (< 2%) wastes with some carbonate may not release acid for years or decades.

[1] Under anoxic conditions Fe will remain in solution in its reduced state

Once acidic oxidation of iron sulphide minerals is initiated the rate tends to increase until a peak is reached. The general trend is for a long-term decrease in acidity release. As the readily available mineral-grains are consumed, the reactive surface shrinks and oxidation product coatings limit reactivity. The rate of decrease is determined by numerous factors but mainly the reactivity of the sulphide minerals, the size of particles, and the availability of reactants (i.e. oxygen and other oxidants). The decrease in oxidation rates may not be apparent in mine waste drainage because oxidation products are stored and released over a long period during flushing events at a rate controlled by the solubility of the oxidation products.

SEASONAL EFFECTS

Under all climatic regimes, release of acidity is controlled, to varying degrees by seasonal precipitation patterns (e.g. transport medium). Under uniform precipitation conditions, the acid load and concentrations leached from a reactive waste are constant. As precipitation patterns vary, the following is observed:

- During dry spells, base flow conditions develop. A small proportion of the reactive surfaces are leached which allows oxidation products to build up in unleached sections;
- As infiltration increases (either due to snow pack melting or increased rainfall), a greater degree of leaching may occur due to rinsing of greater reactive surface areas. The contaminant load and usually the concentration increases;
- As wet conditions persist, the load leached decreases due to removal of acid products and flows are diluted resulting in lower concentrations; and
- When dry conditions are re-established, loads may be similar or lower than wet conditions but concentrations may increase.

SOURCES

Acidic drainage may originate from a variety of natural and man-made sources. Potential natural sources can include:

- Talus;
- Runoff from rock faces; and
- Groundwater seeps.

Man-made sources can include:

- Mines and associated facilities;
- Road cuts and fill;

- Quarries; and
- Other construction fill.

Mines are the major source of acidic drainage primarily because sulphide minerals are concentrated in geological environments containing ore deposits. In addition, rock removal and processing occurs on a large scale, and the methods involved (from blasting to processing) result in particle size reduction thereby increasing the surface area available for reactions. Some significant natural and non-mining sources of acidic drainage have also been documented. For example, at the Halifax International Airport in Nova Scotia, remedial measures are necessary to treat acidic drainage from excavated slates.

At active mine sites (and many inactive mine sites), systems are operated to collect and treat effluents and seepage, and prevent downstream environmental impacts. In some instances, acid generation may persist for hundreds of years following mine closure. The operation of treatment plants for very long periods of time is clearly not desirable. In addition, conventional water treatment technologies produce sludges with low solids content. In some extreme cases, the volume of sludge produced from the acidic drainage effluent can exceed the volume of tailings and/or waste rock. Storage capacity could become an issue for decommissioned mine sites.

LIABILITY ASSOCIATED WITH ACIDIC DRAINAGE

CANADA

Estimates for Canada in 1986 showed that acid generating waste sites totaled over 12,000 hectares of tailings and 350 million tonnes of waste mine rock. These wastes were observed to have mainly accumulated in the previous fifty years of mining. This survey did not represent the entire Canadian inventory, since it did not include abandoned mine sites for which responsibility had reverted to the responsible government authority.

The Canadian mine waste inventory was updated by CANMET in 1994 by surveying mining companies and provincial databases (MEND 5.8e). The results of this survey are summarized in Table 1. A complete national database on mine wastes has never been completed, although several provinces and territories have made considerable progress in defining their own mine waste inventories.

Using a wide variety of nationwide sources, estimates were made of the amount of acid-producing mine wastes (Table 2). Estimates of acid-producing and potentially acid-producing wastes are less accurate than the mine wastes for the following reasons:

- Only a portion of tailings and waste rock piles may be potentially acid producing;
- Some, or all, of the wastes may be stored in a way to eliminate acid potential; and
- Acid production may appear decades after the waste was produced.

Table 1
Estimates of Mine Wastes in Canada

	Tailings (tonnes * 10^6)	**Waste Rock (tonnes * 10^6)**
Newfoundland and Labrador	600	600
Nova Scotia	20	50
New Brunswick	80	30
Québec	1,900	2,700
Ontario	1,700	130
Manitoba	200	100
Saskatchewan	400	50
British Columbia	1,700	2,600
Territories	200	30
Canada	6,800	6,290

Table 2
Canadian Acid-Generating Wastes

	Tailings (tonnes * 10^6)	**Waste Rock (tonnes * 10^6)**
Newfoundland and Labrador	30	-
Nova Scotia	10	40
New Brunswick	80	30
Québec	250	70
Ontario	1,000	80
Manitoba	200	70
Saskatchewan	70	20
British Columbia	200	420
Territories	60	20
Canada	1,900	750

A summary of the estimated existing liability associated with acid-producing mine wastes is shown in Table 3. The assumptions made to calculate the reclamation and maintenance costs for the various options are presented in MEND 5.8e.

Table 3
Liability for Acidic Drainage from Mine Wastes

Waste	Options	$Billions
Tailings	Collect, Treat	1.5
	Water Cover	1.5
	Dry Cover	3.2
Waste Rock	Collect, Treat	0.4
	Dry Cover	0.7
	Relocate to Pit	2.1

The liability was estimated to be between $1.9 billion and $5.3 billion, depending on the sophistication of treatment and control technology selected. The most economical strategy to meet environmental objectives may be to collect water and treat it for a very long time, but such practice raises concerns about treatment product disposal and sustainability of the process.

WORLDWIDE

In the United States approximately 20,000 kilometres of streams and rivers have been impacted by acidic drainage, 85-90% of which receive acidic drainage from abandoned mines (Skousen 1995). Although there are no published estimates of total U.S. liability related to acidic drainage, several global examples indicate the scope of the issue:

- Leadville, a Superfund site in Colorado, has an estimated liability of US$290 million due to the effects of acidic drainage over the 100-year life of the mine;
- The Summitville Mine, also in Colorado, has been declared a Superfund site by the U.S. Environmental Protection Agency (USEPA). The USEPA estimated total rehabilitation costs at approximately US$175 million;
- More than US$253 million dollars have been spent on Abandoned Mine Lands reclamation projects in Wyoming (Richmond 1995);
- At an operating mine in Utah, U.S. regulators estimate the liability to be US$500-US$1,200 million (Murray *et al*. 1995);
- The Mineral Policy Center in the US has estimated that there are 557,000 abandoned mines in 32 states, and that it will cost between US$32 - $72 billion to remediate them (Bryan 1998); and
- Liability estimates for Australia in 1997 and Sweden in 1994 were $900 million and $300 million respectively (Harries 1997; Gustafsson 1997).

Based on these data, as well as the number of new mining projects under development, and mine sites in regions not mentioned above (Europe, South America, Africa), the total worldwide liability is estimated to be around US$100 billion.

MINE ENVIRONMENT NEUTRAL DRAINAGE (MEND) PROGRAM

In the 1970s and early 1980s, the Canadian mining industry and the government of Canada conducted research into methods of establishing sustainable vegetative growth on tailings and waste rock. At that time, closure of mine sites involved recontouring and revegetation for stability and erosion control. It was believed, at the time, that this technology would also address acidic drainage and allow the sites to be abandoned without future liability. Very successful re-vegetation methods were developed, and many sites were revegetated. However, after several years, the quality of water drainage from vegetated sites had not significantly improved, and mine site operators were faced with the prospect of operating water treatment plants indefinitely.

In response, the Canadian mining industry initiated a task force in 1986 to research new methods to remediate acid generating mines sites. The task force consisted of a steering committee and a technical working group, with representation from the mining industry, Energy, Mines and Resources, Environment Canada, British Columbia, Manitoba, Ontario, Québec and New Brunswick. It was referred to as the RATS (Reactive Acid Tailings Stabilization) task force. Its recommendations were published in July 1988 (MEND 5.5.1), and were implemented by the Mine Environment Neutral Drainage (MEND) program. Provincial groups worked with MEND to coordinate research. Provincial initiatives included:

- British Columbia - British Columbia Acid Mine Drainage (BC AMD) Task Force,
- Ontario - MEND Ontario (MENDO); and
- Québec - Programme de Neutralisation des eaux de drainage dans l'environnement minier (NEDEM Québec).

The initial MEND research plan was based on a five-year budget of $12.5 million (MEND 5.5.1).

Three years into the program, the original "RATS" plan was revised and a "Revised Research Plan" was produced. This plan expanded MEND to a 9-year program and the partners agreed to an expanded budget of $18 million (MEND 5.7.1). Planned funding for MEND was divided equally between the three major partners; the mining industry, the federal government and five provincial governments. When MEND ended in December 1997, the two levels of government together with the Canadian mining industry had spent over $17 million within the MEND program to find ways to reduce the estimated liability (Table 4).

Table 4
Funding Contribution by MEND Partners

Partners	Spent ($M)	Funding (%)
Federal government	6.3	37
Mining industry	6.7	39
Provinces	4.1	24

ORGANIZATION OF THE MEND PROGRAM

Two important objectives for MEND Program were established:

- To provide a comprehensive, scientific, technical and economic basis for the mining industry and government agencies to predict with confidence the long-term management requirements for reactive tailings and waste rock; and
- To establish techniques that will enable the operation and closure of acid generating tailings and waste rock disposal areas in a predictable, affordable, timely and environmentally acceptable manner.

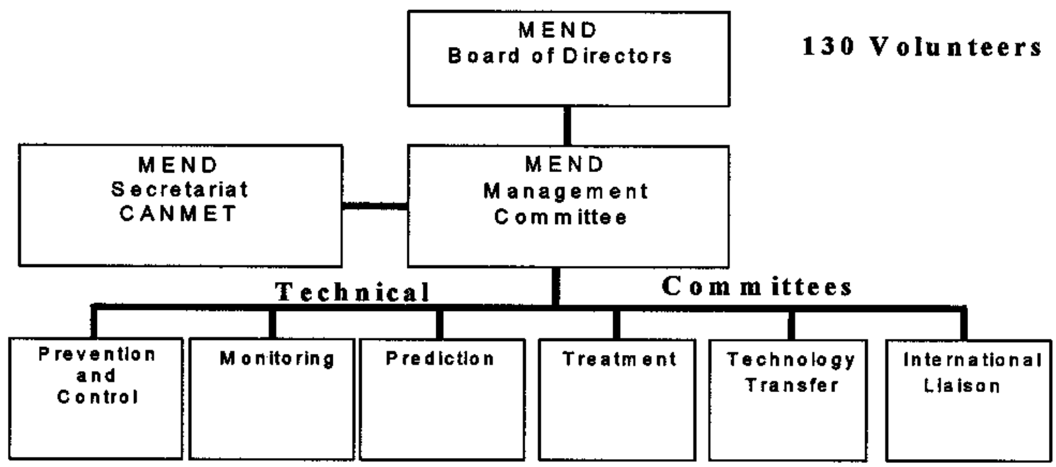
To ensure transparency of the program, it was also recommended that all research reports produced be made available to the partners and the public. Prior to their release the reports were critically reviewed and edited to enhance credibility and provide quality.

MEND adopted an organizational structure that included a Board of Directors, a Management Committee and several technical committees and a coordinating secretariat (Figure 1). The roles of these components were as follows:

- The Board of Directors provided vision and approval of yearly plans and budgets;
- The Management committee provided day-to-day management of the program; and
- The technical committees addressed technological issues and solutions.

The Secretariat ensured coordination of the elements within, and external to MEND. An important role of the Secretariat was to provide program and project management.

Figure 1: **MEND Organization**



MEND relied heavily on the 130 volunteer representatives of the different participating agencies: regulators, mining company managers and engineers, non-government organizations (NGOs) and government officials and scientists.

MAJOR ELEMENTS AND RESULTS OF THE CANADIAN RESEARCH

MEND organized its work into four technical areas: prediction, prevention and control, treatment and monitoring. The four technical committees were also involved in technology transfer and international activities.

Over 200 projects were completed. Some of the highlights of the MEND Program include:

Prediction and Modelling

- **Field studies of several waste rock piles provided important understanding for development of prediction techniques**. One of the most important observations was that waste rock piles accumulate extensive quantities of oxidation products and acidity that can be released to the environment in the future (MEND 1.14.3; MEND 1.41.4).

- **Geochemical and physical characteristics of a waste rock pile, from its origin in underground workings to its disassembly and placement underwater in a nearby lake was completed.** This study provided qualitative and quantitative information on mass transport and water infiltration within a waste rock pile. Geochemical processes were dependent on physical factors such as channeling or stratification within the dump (MEND 1.44.1).

- **Laboratory and field prediction tests for waste rock and tailings have been investigated and further developed**. These tests include static and kinetic tests, mineralogical evaluations and oxygen consumption methods.

- **An "Acid Rock Drainage Prediction Manual" for the application of chemical evaluation procedures for the prediction of acid generation from mining wastes was produced (MEND 1.16.1b)**.

- **Advances in the prediction of drainage quality for waste rock, tailings and open pit mines have been made**. A tailings model (RATAP) was distributed and a geochemical pit lake model was developed (MINEWALL). A critical review of geochemical processes and geochemical models adaptable for prediction of acidic drainage was completed (MEND 1.42.1).

- **Models that will predict the performance of dry and wet covers on tailings and waste rock piles are available (WATAIL, SOILCOVER).**

Prevention

- **Prevention has been determined to be the best strategy.** Once sulphide minerals start to react and produce contaminated runoff, the reaction is self-perpetuating. Also, at some mine sites, acidic drainage was observed many years after the waste pile had been established. With many old mine sites, there may be no “walk-away” solution;

- **In Canada, the use of water covers and underwater disposal are being confirmed as the preferred prevention technology for unoxidized sulphide-containing wastes.** A total of 25 reports and/or scientific papers have been prepared on subaqueous disposal (MEND 2.11). A generic design guide was developed (MEND 2.11.9). The guide outlines the factors involved in achieving physically stable tailings, and discusses the chemical parameters and constraints that need to be considered in the design of both impoundments, and operating and closure plans.

- **Underwater disposal of mine wastes (tailings and waste rock) in man-made lakes is presently an option favored by the mining industry to prevent the formation of acidic drainage.** At the Louvicourt Mine (Québec) fresh, sulphide-rich tailings have been deposited in a man-made impoundment since 1994. Laboratory and pilot-scale field tests to parallel the full-scale operation and evaluate closeout scenarios are ongoing (MEND 2.12.1).

- **The use of water covers to flood existing oxidized tailings can also be a cost effective, long lasting method for prevention of acid generation**. Both the Quirke (Elliot Lake, Ontario) and Solbec (Québec) tailings sites were subjects of MEND field and laboratory investigations (MEND 2.13.1 (Quirke); MEND 2.13.2 (Solbec)). These sites were decommissioned with water covers and are presently being monitored. Where mining wastes are significantly oxidized, laboratory results have shown that the addition of a thin sand or organic-rich layer over the sulphide-rich materials can prevent or retard diffusion of soluble oxidation products into the water column.

Control

- **Dry covers are an alternative where flooding is not possible or feasible**. MEND has extensively investigated multilayer earth covers for tailings and waste rock (e.g. Waite Amulet and Les Terrains Aurifères (tailings) and Heath Steele (waste rock): 3-layer systems). These type of covers use the capillary barrier concept and although they are effective, they are also costly to install in many areas of Canada.

- **Innovative "dry" cover research is indicating that a range of materials, including low cost waste materials from other industries (crude compost, lime stabilized sewage sludge, paper mill sludge) may provide excellent potential for generating oxygen-reducing surface barriers.** This technology would see the application of one waste to solve a problem of other wastes.

- **Non acid-generating tailings can be used as the fine layer in composite moisture-retaining surface barriers**. Laboratory studies have confirmed that sulphide-free fine tailings offers some promising characteristics as cover materials (MEND 2.22.2). Barrick's tailings site in Northwest Québec, Les Terrains Aurifères, is the first full-scale demonstration project of using tailings in a cover system (MEND 2.22.4). A second site, Québec crown-owned Lorraine, has also been rehabilitated using the same closure technique.

- **The first full-scale application in Canada of a geomembrane liner for close-out was completed in 1999 at Mine Poirier in Northwest Québec.** Performance monitoring of the close-out scenario to evaluate the liner is ongoing (Lewis and Gallinger 1999).

Disposal Technologies

- Several other disposal technologies that will reduce acid generation and have been investigated include:

- **Permafrost in northern environments.** Permafrost covers approximately 40% of Canada, and cold conditions inhibit oxidation. Predictive methods have been researched. Although acid generation is common in cold environments, it occurs when exposed sulphides are warmed to temperatures above freezing (MEND 1.61.1-3; MEND 1.62.2).

- **Blending and segregation (or layering).** Technology is defined as the mixing of at least two rock waste types with varying acid generation potential, neutralization potential and metal content to produce a pile that has seepage water quality acceptable for discharge without additional measures (MEND 2.37.1; MEND 2.37.3).

- **Elevated water table in tailings.** This technique offers a method of inhibiting the oxidation of sulphides through the effective saturation of pore spaces. It may be applied as one component of a multi-component reclamation strategy (MEND 2.17.1).

- **In-pit disposal following mining.** Mined-out pits can provide a geochemically stable environment for wastes and can be a focal point in mine rehabilitation. The addition of buffering material may be required (MEND 2.36.1).

- **Depyritized tailings as cover materials**. Laboratory and field tests are showing that depyritized tailings have excellent potential as covers. Economic analyses have indicated that hydraulic placement will be necessary to be cost effective (MEND 2.22.3).

Lime Treatment

- **Studies conducted to date support the view that sludges will remain stable if properly disposed**. Concerns had been raised with regard to the long-term chemical stability and the potential liability arising from dissolution of heavy metals contained in the sludge (MEND 3.42.2). Other findings include:
  - Optimum conditions will depend on site-specific factors e.g. pH, metal loading chemistry;
  - Modifications to the treatment process (e.g., lime slaking, pH adjustment, mixing, aeration, flocculent addition) can influence operating costs, sludge volumes, and metal release rates (Zinck and Aubé 1999);
  - The method of disposal of the sludge will affect its long-term stability. Aging can promote recrystallization which improves sludge stability;
  - Codisposal of sludges with other mining wastes requires further study; and

  - Leach test protocols need to be developed specifically for lime treatment sludges.

- **The status of chemical treatment and sludge management practices was summarized in a reference document (MEND 3.32.1)**.

Passive Treatment

- **In Canada, experience indicates that passive systems do have specific applications for acid mine drainage (AMD) treatment.** These applications range from complete systems for treating small seeps to secondary treatment systems such as effluent polishing ponds. Alone, they cannot be relied upon to consistently meet AMD discharge standards. Large-scale passive systems capable of handling the low winter temperatures, high metal loads, and fluctuations in flow rates associated with the spring freshet have yet to be implemented.

- **The status of passive systems for treatment of acidic drainage was summarized in a reference document (MEND 3.14.1)**.

Monitoring

- **Several guides are available to assist in the development of acidic drainage monitoring programs.** An important MEND deliverable is MEND 4.5.4, *Guideline Document for Monitoring Acid Mine Drainage.* This document is designed to serve as a single source introductory guide to a wide range of AMD monitoring concerns, while also providing users with information on literature sources for site-specific concerns and emerging monitoring techniques. Monitoring requirements are addressed for both source and receiving environments, with receiving environment concerns restricted to freshwater systems.

  Other guideline documents include a field sampling manual (MEND 4.1.1) that presents an approach to assist people in selecting the appropriate methodologies for the sampling of tailings solids, liquids and pore gas. A comprehensive list and description of sampling techniques, and a guide to waste rock sampling program design for the exploration, operation and closure phases of a mining project is produced in MEND 4.5.1-1. Available sampling techniques for waste rock is given in MEND 4.5.1-2.

At the conclusion of the MEND program, a "tool box" of technologies has been developed to assist the mining industry in addressing its various concerns related to acidic drainage, and in significantly reducing its estimated liability. A particularly important outcome has been the development of a common understanding among participants, inasmuch as it has allowed operators to take actions with greater confidence and to gain multi-stakeholder acceptance more rapidly.

NEW IDEAS

In 1992, a Task Force was formed to solicit and nurture innovative new ideas. An additional goal was to encourage researchers from outside the general area of mining environment to becoming involved in acid drainage research. The resulting technology would need to be reliable, inexpensive, permanent, and widely applicable. The innovator had to demonstrate the relevance of the idea at the concept level, which would then be the basis for proceeding to a more detailed development project.

A two-page proposal format was developed and distributed across Canada. New ideas were solicited in two rounds. A total of 135 proposals were received and 18 were funded. Up to $10,000 was provided for the review and the development of the concepts. Table 1.4-1 lists the new ideas projects funded by the Task Force.

Table 5
New Ideas Projects

New Idea #	Project Title
01	Status of AMD Research in the U.S.
02	Permafrost to Prevent AMD
03	Low Cost Wax Cover
04, 21	Chemically Modified Clay Cover
05	Ferric Phosphate Coating of Pyrrhotite
06	State of Art of Japanese Technology
07	Formation of Hardpan in Pyrrhotite Tailings
08	Passivation of Sulphide Minerals
09, 22	Selective Ion Exchange Resin
10	Chelating Ribbons
11	Comingled Waste Disposal
12	Chelating/Membrane Filtration
23	Sprayed Polyurethane Covers
24	Literature Review: Foam Flotation
25	Limestone Precipitation Layer in Coal Wastes
26	Ion Flotation for Zinc Recovery

The eighteen New Ideas projects cost about $230k. Although most of the new ideas were innovative and applicable and provided useful information, they did not achieve the objective of providing a solution to the problem of acidic drainage. However, at least three had potential applications (sprayed polyurethane, modified clay and permafrost) and three yielded useful state-of- art reviews (U.S. research, foam flotation and Japanese technology). Also, a large number of additional researchers were made aware of the acidic drainage problem, and some may in due course make useful contributions. Finally, the endeavour increased MEND's certainty that a magic answer was not overlooked.

TECHNOLOGY TRANSFER

Technology transfer activities were expanded in the later years of the program. The dissemination of information on developed technologies to the partners and the public was a major function of the program. A MEND 2000 Internet site (**http://mend2000.nrcan.gc.ca**) was established and is updated with current information on technology developments. The site provides report summaries, the MEND publication list, information on liabilities, case studies, and conference and workshop announcements. MEND and MEND 2000 hosted several workshops per year at various locations across Canada. Proceedings for the workshops on chemical treatment, economic evaluations, in-pit disposal, dry covers, monitoring, case studies of Canadian technologies, research work in Canada, and risk assessment and management are available from the MEND Secretariat.

MEND participated in the organization of several International Conferences on the Abatement of Acid Rock Drainage (ICARDs) held in 1991 (2^{nd} – Montreal), 1994 (3^{rd} - Pittsburgh) and 1997 (4^{th} -Vancouver).

Other technology transfer initiatives included:

- MEND videos are available in English, French, Spanish and Portuguese. They describe technological advances relating to the prediction, prevention and treatment of acidic drainage from mine sites;
- The MEND Manual that summarizes all of the MEND and MEND-associated work on acidic drainage from mine wastes;
- The Proceedings of the 4^{th} International Conference on Acid Rock Drainage are available on CD-ROM;
- About 200 reports completed during MEND and MEND 2000;
- MEND reports on CD-ROM. A project to have the key MEND reports available on CD-ROM will be completed in 2001; and
- National case studies on acidic drainage technologies.

THE MEND MODEL

MEND has been described as a model way for governments and industry to cooperate in technology development for advancing environmental management in the mining industry. Decisions are now being made based on findings from scientific research. Reasons for this include:

- The high return on the investment targeted and achieved, in terms of knowledge gained and environmental and technical awareness of the scope of the acidic drainage problem and credible scientific solutions;
- The partnership and improved mutual understanding developed between the two levels of government, the mining industry and NGOs in search of solutions to a major environmental problem;
- The secretariat group which coordinated activities, managed the accounting, reporting and technology transfer;
- The peer review process that was both formal and informal, and resulted in enhanced credibility of the information base; and
- The approach taken for transferring the knowledge gained during MEND.

In large part as a result of MEND, it was shown that new mines are able to acquire operating permits faster and more efficiently than before since there are now accepted acidic drainage prevention techniques. As an example, the Louvicourt mine in northwest Québec adopted MEND subaqueous tailings disposal technology and has been able to progress from the exploration phase to an operating mine within 5 years, with a reduced liability of approximately $10 million for the tailings impoundment. Similar benefits are reported for existing sites in the process of decommissioning. MEND has also fostered working relationships with environmental groups, ensuring that they are an integral part of the process.

MEND 2000

MEND concluded on December 31, 1997. However, the partners agreed that additional cooperative work was needed to further reduce the acidic drainage liability and to confirm field results of MEND-developed technologies. MEND 2000 was a three-year program that officially started in January 1998. The program was funded equally by the Mining Association of Canada (MAC) and Natural Resources Canada, a department of the Canadian government. The objectives of MEND 2000 were to:

- Transfer and disseminate the knowledge gained from MEND and other related acidic drainage projects;
- Verify and report the results of MEND developed technologies through long-term monitoring of large scale field tests;

- Maintain links between Canadian industry and government agencies for information exchange and consensus building; and
- Maintain linkages with a number of foreign government and industry driven programs (e.g. International Network on Acid Prevention (INAP), the Mitigation of the Environment Impact from Mining Waste (MiMi - Sweden), and the Acid Drainage Technology Initiative (ADTI - USA).

An important function of MEND is technology transfer. All research results must be effectively communicated to industry, government agencies and the public if the program is to continue to achieve the desired results.

CONCLUSION

The benefit of the MEND programs has come through the sharing of experiences, the thorough evaluation of technologies and their incremental improvement. Mining companies and consultants have acquired more capabilities to deal with water contamination from mine wastes, including acid generation. No dramatic technological breakthrough other than water covers has been achieved. Nonetheless, Canadian industry reports that a significant reduction in liability is predicted. An evaluation of MEND in 1996 concluded that the estimated liability had been reduced by $340 million, for five Canadian mine sites alone (MEND 5.9). It is also acknowledged that the reduction in liability is significantly higher than this quoted value, with a minimum of $1 billion commonly accepted. The same study concluded:

- There is a much greater common understanding of acidic drainage issues and solutions;
- The research has led to reduced environmental impact;
- There is increased diligence by regulators, industry and the public; and
- The work should continue with strong international connections.

As a result of MEND and associated research, technologies are in place to open, operate and decommission a mine property in an environmentally acceptable manner, both in the short and long term.

MEND is an example of a successful, multi-stakeholder program addressing a technical issue of national importance, and has been a model for cooperation between industry, environmental groups and various levels of government.

MEND AND RELEVANT PUBLICATIONS

MEND Reports are cited in Appendix C.

Bryan, V. 1998. Personal Communication.

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Lewis, B.A. and Gallinger, R.D. 1999. *Poirier Site Reclamation Program*. In: Sudbury '99 – Mining and the Environment II Conference Proceedings. Sudbury, Ontario. 13 to 17 September. Vol 2, pp. 439-448.

Murray, G.S.C., Ferguson, K.D. and Brehaut, C.H. 1995. *Financial and Long Term Liability Associated with AMD*. In: Proceedings of the 2nd Australian Acid Mine Drainage Workshop. Charters Towers, Queensland. 28 to 31 March. pp. 165-177.

Price, B. 1995. *Defining the AMD Problem: II. An Operator's Perspective*. In: Proceedings of the 2nd Australian Acid Mine Drainage Workshop. Charters Towers, Queensland. 28 to 31 March. pp. 17-19.

Richmond, T.C. 1995. *Abandoned Mine Land Reclamation Costs in Wyoming*. In: Sudbury '95 – Mining and the Environment Conference Proceedings. Sudbury, Ontario. 28 May to 1 June. Vol 3, pp. 1221-1230.

Skousen, J. 1995. *Prevention of Acid Mine Drainage*. In: Acid Mine Drainage Control and Treatment. (Eds. J.G. Skousen and P.F. Ziemkiewicz). West Virginia University and the National Mine Land Reclamation Center, Morgantown, West Virginia. pp. 13-14.

Zinck, J.M. and Aubé, B. 1999. *Optimization of Lime Treatment Processes*. In: Proceedings of the 31st Annual Meeting of the Canadian Mineral Processors. Ottawa, Ontario. 19 to 21 January. pp. 75-93.

FOREWORD

PREFACE

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6.0 MONITORING

In this Volume, monitoring refers to the strategic collection and assessment of data relevant to the prediction, prevention, control and treatment of acidic drainage.

Several guides are available to assist in the development of acidic drainage monitoring programs including reports completed under the auspices of MEND and the British Columbia Acid Mine Drainage Task Force (BC AMD Task Force). Strategies applicable to the monitoring of acidic drainage can also be applied to the monitoring of neutral pH/metal leaching contaminated drainage, and drainage from potentially acid generating materials.

The objective of this Volume is to familiarize readers with the work completed by MEND in the area of monitoring and by others in relevant areas. About $1.1 million was spent on twenty-five monitoring related projects under MEND.

6.1 INTRODUCTION

An effective monitoring program would be expected to allow a mine with the potential for ARD or metal leaching effects to mitigate adverse impacts to the receiving environment. In this respect, the key objectives common to ARD monitoring programs are to:

1. Assess the potential for acidic drainage;
2. Detect the onset of ARD (if any) at an early stage so mitigative actions can be taken;
3. Assess the performance of ARD prevention, control and treatment measures;
4. Establish and regularly update site-specific monitoring databases; and
5. Provide data required for management decision making.

MEND monitoring projects have included the preparation of manuals, reference materials, and reports on emerging monitoring technologies. A key MEND deliverable on acidic drainage monitoring is MEND 4.5.4, *Guideline Document for Monitoring Acid Mine Drainage*. The document is structured to serve as a guide for the design and implementation of monitoring programs from the perspective of the development of a new mine.

Information is also provided for operating and decommissioned mines with potential acidic drainage concerns. Documents available from MEND and the BC AMD Task Force are listed in Table 6.1-1.

Table 6.1-1
Projects Completed by MEND and the BC AMD Task Force

MEND Project	Title
1.16.2a	Interlaboratory Measurement Program for the Standard ARD Material NBM-1
1.16.2b	Additional Certified Reference Material for NNP
4.1.1	Field Sampling Manual for Reactive Sulphide Tailings
4.2.1	Review of Canadian and United States Legislation Relevant to Decommissioning Acid Mine Drainage Sites
4.3.1	RTS-1, RTS-2, RTS-3 and RTS-4: Sulphide Ore Mill Tailings Reference Materials
4.3.2	Processing and Homogeneity Testing of a Standard Reference Material
4.5.1-1	Review of Waste Rock Sampling Techniques
4.5.1-2	Handbook for Waste Rock Sampling Techniques
4.5.2**	Field Quality Assurance/Quality Control (QA/QC) Protocols for Monitoring and Predicting Impacts of Acid Rock Drainage
4.5.4	Guideline Document for Monitoring Acid Mine Drainage Appendix A – Technical Summary Notes
4.6.1	Applications of Geophysical Methods for Monitoring Acid Mine Drainage
4.6.2*	Continuous Monitoring of AMD – Literature Review
4.6.3	Application of Remote Sensing and Geophysics to the Detection and Monitoring of Acid Mine Drainage
4.6.4*	Piezocone Technology – Demonstration Project
4.6.5ac	A Survey of *In Situ* Oxygen Consumption Rates on Sulphide Tailings: Investigations on Exposed and Covered Tailings
4.6.5b	A Rapid Kinetic Technique for Measuring Reactivity of Sulphide Waste Rock: The Oxygen Consumption Method
4.7.1**	Monitoring Acid Mine Drainage
4.7.2**	Literature Review for Biological Monitoring of Heavy Metals in Aquatic Environments
4.7.3**	The Effect of Treated AMD on Stream Macroinvertebrates and Periphytic Algae: An *In Situ* Mesocosm Experiment
4.7.4**	Review of Sediment Monitoring Techniques
4.7.5**	BC Mine: Ion Speciation Model
4.7.6**	Use of Paleolimnological Techniques to Assess the Effects of Acid Rock Drainage
4.8.2	Evaluation of an Underwater Monitoring Probe for Locating and Estimating the Impact of Groundwater Discharges to Surface Waters Adjacent to Potential Sources of Acid Mine Drainage
MA-1	Environmental Monitoring of Uranium Mining Wastes Using Geophysical Techniques Phase 1 – A Comparison and Evaluation of Conductivity and Resistivity Methods to Monitor Acid Mine Drainage from Uranium Waste Rock Piles and Tailings Areas
W.011	Summary Notes MEND Monitoring Workshop. "Monitoring and Waste Management for Acid Mine Drainage". University of Saskatchewan, Saskatoon, Saskatchewan. 10 June 1996.

* Open file report
** BC AMD Task Force

The projects listed in Table 6.1-1 are described below under the headings of manuals, reviews, emerging technologies and reference materials. A number of the reports are also discussed in Volume 2.0, which deals with sampling techniques and analysis.

6.1.1 MANUALS

MEND 4.1.1 Field Sampling Manual for Reactive Sulphide Tailings

This is a guide to sampling methodologies applicable to tailings impoundments and the collection of solid, liquid and pore-gas samples. Guidance and recommendations are given on the selection of methods, emphasizing minimal sample disturbance and contamination. The objectives, descriptions, advantages and disadvantages of the methodologies are described in the manual.

MEND 4.5.1-1 Review of Waste Rock Sampling Techniques

The report presents a literature review and discussion of waste rock sampling techniques. It also provides guidance as to the available techniques and suggested methodologies to apply during the various stages of mine development. An example of how data were collected and utilized to assess ARD potential at a site in Canada is included for demonstration purposes.

MEND 4.5.1-2 Handbook for Waste Rock Sampling Techniques

The handbook provides a concise summary of sampling techniques. It was a product of a comprehensive literature review, a detailed industrial survey and an expert workshop. The document is meant to be a guide only, and users are cautioned that sampling strategies for waste rock piles depend upon numerous site-specific factors. Mathematical formulations applied to determine the number of samples required from a waste rock pile should be used with caution. Each distinct zone of a waste rock pile should be assessed separately and sample composites should be avoided.

MEND 4.5.4 Guideline Document for Monitoring Acid Mine Drainage

This guideline document is designed to serve as a single source introductory guide to a wide range of AMD monitoring concerns, while also providing users with information on literature sources for site-specific concerns and emerging monitoring techniques. Monitoring requirements are addressed for both source and receiving environments, with receiving environment concerns restricted to freshwater systems. Appendix A − Technical Summary Notes of MEND 4.5.4 is a condensed version of the report.

6.1.2 REVIEWS

MEND 4.2.1 Review of Canadian and United States Legislation Relevant to Decommissioning Acid Mine Drainage Sites

Canadian and American legislation relevant to the decommissioning of AMD sites were reviewed (September 1993) and summarized. The report concluded that regulatory strategies specific to the decommissioning of AMD sites are in the development stage both in Canada and the United States.

MEND 4.5.2 Field Quality Assurance/Quality Control (QA/QC) Protocols for Monitoring and Predicting Impacts of Acid Rock Drainage

A literature review was completed on field sampling criteria with particular emphasis on quality assurance (QA) and quality control (QC) protocols. The focus was on components of programs for predicting or detecting acidic drainage and its environmental effects. The report reviews the elements of field QA/QC programs and recommends that more emphasis be placed on the implementation of QA/QC protocols.

MEND 4.6.2 Continuous Monitoring of AMD – Literature Review

This project identified and evaluated the capability of commercially available continuous monitoring technologies to address the requirements of AMD sites in Canada. It also reviewed the advantages and disadvantages of continuous monitoring versus manual monitoring. An international survey of commercially available monitoring equipment (i.e. for selected ions, redox potential, dissolved oxygen, pH, electrical conductance) applicable to AMD resulted in a list of about 50 manufacturers. The concept of detailed data collection over a finite period to assess trends and potential correlations is considered worthwhile in the development of a focused, long-term monitoring program.

MEND 4.6.3 Application of Remote Sensing and Geophysics to the Detection and Monitoring of Acid Mine Drainage

The study resulted in a compendium of information on remote monitoring technologies for AMD. Methods currently in use, organizations active in the field, suppliers of equipment and services, and lists of available products and equipment are given. Guides are presented in tabular format to address the applicability and effectiveness of various techniques to detect and monitor AMD. Each technique is also discussed separately. The final report, in handbook form, is the result of an in-depth literature search, an information survey of more than 900 organizations, the synthesis of catalogues from suppliers of equipment and services and numerous discussions with scientists working in the field.

MEND 4.7.1 Monitoring Acid Mine Drainage

The objective was to determine optimum water quality sampling frequencies and the most representative, measurable parameters (e.g. pH, conductivity) for AMD effluent by evaluating four of the most extensive water quality datasets associated with acid mine drainage in British Columbia. The report includes: potential failings with a monitoring program; recommended revisions to monitoring schedules based on information collected; and identification of baseline data requirements.

MEND 4.7.2 Literature Review for Biological Monitoring of Heavy Metals in Aquatic Environments

The project reviewed biological monitoring techniques for assessing the effects of metals in freshwater environments, specifically for the impacts of AMD. The study provides a conceptual framework for organization of the available indicators, and information was compiled for bioassessment techniques ranging from biochemical through to ecosystem level. The most cost-effective approach to assessing ecosystem health in waters affected by AMD was found to be a multi-disciplinary, "top-down" approach, designed to detect impacts before they become irreversible.

MEND 4.7.4 Review of Sediment Monitoring Techniques

This project reviewed available literature pertaining to sediment monitoring techniques and provided recommendations on the relevance and applicability of the techniques for measuring the impact of AMD. The review focused on the assessment of sediment quality through sediment chemistry, bioassay testing and benthic macroinvertebrate community structure. Analytical methods for sediment chemistry are reviewed and summarized.

MEND 4.7.6 Use of Paleolimnological Techniques to Assess the Effects of Acid Rock Drainage

The extent of an operation's environmental impact can only be determined with respect to original, baseline values. Because of costs associated with long-term studies, the use of paleolimnology was considered for describing past conditions including, for example, pre-mining conditions, at active or decommissioned sites. It was concluded that it should be possible to develop a calibration dataset, which relates species assemblages of the chosen taxon to levels of AMD-related parameters. However, no further commitment to develop an appropriate calibration dataset was undertaken.

6.1.3 EMERGING TECHNOLOGIES

MEND 4.6.1 Applications of Geophysical Methods for Monitoring Acid Mine Drainage

This investigation focused on electrical and electromagnetic geophysical applications since these methods have the potential to directly detect and map sulphides, areas of active chemical oxidation, and acidic seepage. The research was carried out at two sites in the Sudbury area and assessed electromagnetic methods (surface, airborne and borehole) and electrical methods (resistivity, induced polarization and self-polarization).

MEND 4.6.4 Piezocone Technology – Demonstration Project

In situ testing, using sophisticated yet robust penetration tools, offers an alternative to traditional methods and can be deployed at lower costs. Specifically, the use of the resistivity piezometer cone penetration test unit and specialized discrete water sampling techniques were evaluated for their ability to characterize sulphide tailings that have undergone oxidation. Two sites were tested in this demonstration project. Although more detailed geochemical evaluations are recommended for comparison to traditional techniques, the results of this study suggest that the resistivity piezometer cone is an effective tool for the economical characterization of sulphide-based tailings and surrounding native materials.

MEND 4.6.5ac A Survey of *In Situ* Oxygen Consumption Rates on Sulphide Tailings: Investigations on Exposed and Covered Tailings

The objective of this project was to demonstrate the use of a new oxygen flux measurement technique to determine the rate of oxygen uptake across the surface of tailings. The oxygen consumption method involves the direct measurement of the oxygen flux across the tailings-atmosphere interface. It provides a rapid and cost-effective assessment technique that can provide useful and critical data to evaluate the status of sulphide mineral oxidation and potential acid generation rates in tailings impoundments. This study was conducted to initiate a database of measurements at a variety of tailings impoundments. Sites were selected to represent different conditions such as sulphide minerals (pyrite and pyrrhotite), sulphide content, acidic versus neutral conditions, age since deposition, and sites with and without oxygen barrier covers over tailings.

MEND 4.6.5b A Rapid Kinetic Technique for Measuring Reactivity of Sulphide Waste Rock: The Oxygen Consumption Method

The oxygen consumption method that was initially developed as a tool to assess reactive tailings in the laboratory and field was adapted to measure reaction rates on waste rock samples in short-term experiments. The technique provides reaction rate data that can complement data from humidity cells. Many samples can be processed simultaneously and, therefore, a larger body of kinetic data can be developed for cost-effective statistical assessment and interpretation. This study presents the development of the technique, and its application to several types of waste rock from selected mines and exploration projects.

MEND 4.8.2 Evaluation of an Underwater Monitoring Probe for Locating and Estimating the Impact of Groundwater Discharges to Surface Waters Adjacent to Potential Sources of Acid Mine Drainage

Atomic Energy of Canada Limited developed a method for locating and measuring groundwater discharges allowing accurate and inexpensive environmental monitoring to be conducted at specific locations where environmental impact is occurring or is likely to occur. The method involves towing an electrical conductance, bottom-contacting probe over lake and river bottoms. The report summarizes two surveys completed in Northern Ontario where the probe was used to target possible seepage discharge areas. The areas were studied quantitatively to evaluate the utility of the probe and to provide site-specific information.

MA-1 Environmental Monitoring of Uranium Mining Wastes Using Geophysical Techniques Phase 1 – A Comparison and Evaluation of Conductivity and Resistivity Methods to Monitor Acid Mine Drainage from Uranium Waste Rock Piles and Tailings Areas

Protocols using geophysical methods of monitoring the migration of acidic leachate from uranium waste rock piles and tailings facilities need to be developed to monitor contaminants from uranium mine waste facilities. A first phase involving the testing of various off-the-shelf electromagnetic and resistivity equipment was completed over several site locations at the Cluff Lake Mine in Saskatchewan. The interpretation of sounding data was able to determine resistivities and thicknesses of layers in the subsurface that were meaningful with respect to the known logs from access monitoring wells. Positive results were obtained and a second phase was planned outside of MEND.

6.1.4 REFERENCE MATERIALS

MEND 1.16.2a Interlaboratory Measurement Program for the Standard ARD Material NBM-1

The overall project objective was to use the consensus approach in the determination of the net neutralization potential (NNP) and thereby standardize the material, NBM-1 for a static prediction test. In MEND 4.3.2, the material was processed and homogenized. In this project, fourteen laboratories were selected and requested to follow the standard acid base accounting method for the determination of the NNP. The material appears to be an acid consumer having an NNP of approximately 42 ± 9 tonnes $CaCO_3$/1000 tonnes. Due to bimodal distribution of the results, the mean of the NNP is assigned provisional status. This material, NBM-1, is commercially available through the Canadian Certified Reference Materials Program (CCRMP) at CANMET.

MEND 1.16.2b Additional Certified Reference Material for NNP

The objectives of this project are to prepare an additional reference material with a different NNP; and to attempt to elevate the status of the current reference material (NBM-1) from a provisional value for NNP to a certified value. Three hundred kilograms of material from Kudz Ze Kayah (Yukon) were prepared as a potential acid producer. The results will be available in 2001. The use of reference materials with well characterized values for NP and AP will add to current quality control measures of static prediction data obtained from laboratories.

MEND 4.3.1 RTS-1, RTS-2, RTS-3 and RTS-4: Sulphide Ore Mill Tailings Reference Materials

The key to reliable and reproducible analytical results is the availability of good, relevant standard reference materials. The CCRMP at CANMET has produced four mill tailings materials that have been certified and are now commercially available with supporting documentation.

MEND 4.3.2 Processing and Homogeneity Testing of a Standard Reference Material

ARD analytical methods are in the developmental stages and no reference material existed to enable laboratories to compare the accuracy and precision of their results. The objective was to use the consensus approach in the determination of the net neutralization potential and thereby standardize the material, NBM-1 for a static prediction test. In Phase I, the standard material was processed and the homogeneity assessed according to the protocols of CANMET's CCRMP. An interlaboratory test program was carried out under MEND 1.16.2a.

6.1.5 OTHERS

MEND 4.7.3 The Effect of Treated AMD on Stream Macroinvertebrates and Periphytic Algae: An *In Situ* Mesocosm Experiment

The three-year project at Equity Silver was aimed at evaluating a trough apparatus for measuring the environmental effects of treated acid mine drainage on aquatic invertebrates. The study was carried out to address allowable dilution rates of treated acid mine drainage that were discharged into a creek near the mine.

MEND 4.7.5 BC Mine: Ion Speciation Model

The project objective was to provide estimates of the most probable species of a given metal, and their redistribution when raw AMD is mixed with receiving waters. Ionic speciation must be considered in the development of monitoring criteria and monitoring programs that attempt to predict the environmental impact of metals introduced into the environment. Toxicity of dissolved metals is dependent on the physical/chemical parameters associated with specific species.

Workshop W.011 Monitoring and Waste Management for Acid Mine Drainage

MEND held a monitoring workshop at the University of Saskatchewan in Saskatoon in June 1996. The workshop notes included:

- A detailed review and discussion of MEND 4.5.4;
- A review of waste rock and tailings monitoring using geophysics at Cogema Limited's operations in Saskatchewan;
- The hydrogeologic characterization of a waste rock pile;
- The hydraulic characterization of waste rock: preferential flow paths;
- Field instrumentation to characterize surface flux boundary conditions at Rabbit Lake in Saskatchewan;
- An update on the waste management plan for Rabbit Lake; and
- Waste rock seepage predictions and field experience at Rabbit Lake.

6.2 ACIDIC DRAINAGE MONITORING

MEND projects provide diverse information regarding acidic drainage monitoring and sampling techniques and environmental monitoring programs in general. However, ARD monitoring represents only one component of an overall environmental monitoring program. Environmental monitoring programs vary from site to site as they are developed, taking into account the type and scope of operations, site-specific issues, and environmental protection requirements and objectives. In addition, monitoring requirements are likely to change over the life of a mine.

6.2.1 MONITORING OBJECTIVES

ARD monitoring programs need to have well defined objectives. An objective can be comprised of a question or policy. As an example, an objective of a monitoring program for a decommissioned site could ask and then answer the question, "How can we identify the changes that indicate that acid is being generated in a waste rock pile?" A correct response would include the identification of the potential and expected mechanism for ARD generation, the development of an appropriate monitoring program, a sampling and analysis program, and the review and assessment of the monitoring data. For the purposes of triggering a response on the part of the organization, there needs to be a meaningful monitoring result or action level.

ARD monitoring objectives are likely to vary over the life of a mine. For reference, the general objectives of monitoring during the baseline/exploration phase, the operational phase, and the decommissioning phase are outlined below.

1. Baseline/Exploration Phase Monitoring

The objectives of baseline monitoring are to:

- Determine whether there is a potential for acid generation for rock units likely to be exposed;
- If acid generation is possible/probable, use predictive model(s) to estimate the time frame over which acid generation may develop; and
- Provide data for prevention, minimization of treatment requirements in mine design and mine waste management planning.

Monitoring to determine acid generation potential includes the sampling of barren and mineralized rock, and soils for geochemical analyses. In this phase, attention is focussed on:

- Identifying and characterizing the geological units likely to be exposed;
- Determining testing requirements and monitoring parameters. This is best done sequentially by geologic unit;
- Determining how many samples of each geological unit are required for the characterization to be statistically sound. MEND 4.5.1-2 presents methods of calculating the sample population;
- Determining sample collection methodology. Samples can be collected in conjunction with exploration work;
- Acid base accounting testwork, mineralogical and kinetic tests as appropriate (Volume 3.0, Prediction, provides additional information); and
- Gathering other types of data required for predictive modelling, such as potential flow pathways between the mine components and the receiving environment.

The types of information that can be gathered in the baseline/exploration (pre-operational) phase are summarized in Table 6.2-1.

Table 6.2-1
Summary of Types of Information Generated from the Chemical and Physical Considerations for Tailings Pond Design and Planning

Consideration	Type of Information Acquired
Water balance, climate	• Minimum water depth • Pond volume • Pond residence time
Ore and waste rock mineralogy	• Mineral abundance (i.e., sulphides, carbonates, sulphates) • Presence of reactive minerals • Element abundance (i.e., % sulphur, metals) • Acid generating potential
Tailings solids	• Tailings throughput • Elemental abundance • Percent solids, grain size • Types and abundances of secondary minerals • Depositional strategies • Mass loading to pond
Tailings supernatant	• Flow rate • Concentrations of dissolved metals (i.e., Cu, Pb, Zn) • Concentrations of CN, CN-complexes, thiocyanate, thiosalts, sulphate, ammonia • pH • Depositional strategies • Mass loading to pond
Treatment methods/ by-products	• Treated effluent flow rates • Effluent composition (metals, pH, sulphate, cyanide, thiocyanate, chloride, etc.) • Hydroxide sludge composition (i.e., mineralogy, metal concentrations) • Sludge production • Depositional strategies • Mass loading to pond
Other inputs: mine/pit waters, waste rock seepages	• Flow rates • Concentrations of dissolved metals, sulphate, pH • Mass loading to pond
Stability testwork	• Kinetics of the subaerial oxidation of ore, waste rock and tailings • Oxidative and non-oxidative subaqueous reactivity (long and short term) • Hydroxide sludge stability (dissolution kinetics problematic elements) • Depositional strategies

Source: MEND 2.11.9, Table II-1

The Guide to the British Columbia Environmental Assessment Process (BCEAO, 1995) stresses that it is important to consult appropriate government agencies regarding the design and methods of baseline data collection. This aspect should also be taken into consideration in planning an ARD monitoring program. The ARD information base that is developed during the baseline/exploration phase will likely provide the basis for the assessment of ARD potential and ARD mitigation strategies addressed in the environmental assessment of the project.

2. Operational Phase Monitoring

The primary objective of operational phase monitoring is to provide an early warning of the onset of acid generation should it occur and the potential for impacts to the receiving environment. In this phase, attention is focussed on:

- Identifying the mine components to monitor. Components having the potential to generate acidic drainage include waste rock piles (also low grade ore stockpiles and possibly overburden stockpiles), tailings, and open pits and underground workings, and natural materials used for construction/mine closure purposes;
- Identifying the parameters that will be monitored;
- Identifying appropriate sampling sites. Basic considerations include monitoring close to the source and monitoring pathways to the receiving environment;
- Determining sampling frequency. Some fixed frequency monitoring can be established based on experience with the site; however, temporal variations associated with climate and local weather patterns can affect sampling frequency. For example, acid generation products accumulate under snow in winter and/or during summer dry periods - these products are flushed by snow melt and precipitation events; and
- Determining the sample collection and testing methodologies.

3. Decommissioning Phase Monitoring

Mine closure plans include measures to prevent and control acid generation and when required, to treat acidic drainage. The objective of decommissioning phase monitoring is to verify the performance of the measures taken and proactively provide an early warning of the onset of acid generation, should it have the potential to occur. For mines that were decommissioned prior to regulatory requirements for closure planning, the objective of monitoring is often to assess risks to the environment from acidic drainage and/or to monitor the effectiveness of seepage collection and remediation measures. In decommissioning phase monitoring programs, attention is focussed on:

- Monitoring the mine components of concern identified in the closure plan;

- Determining the parameters and media that will be monitored. A tiered sampling approach may be used; and
- Identifying appropriate sampling sites including surface water quality monitoring stations. The sampling locations, parameters and frequency should be tailored to suit decommissioning and post-closure sampling monitoring objectives. Sampling frequency may be higher in the first few years following the completion of decommissioning works and decrease if data confirm the performance of remediation measures.

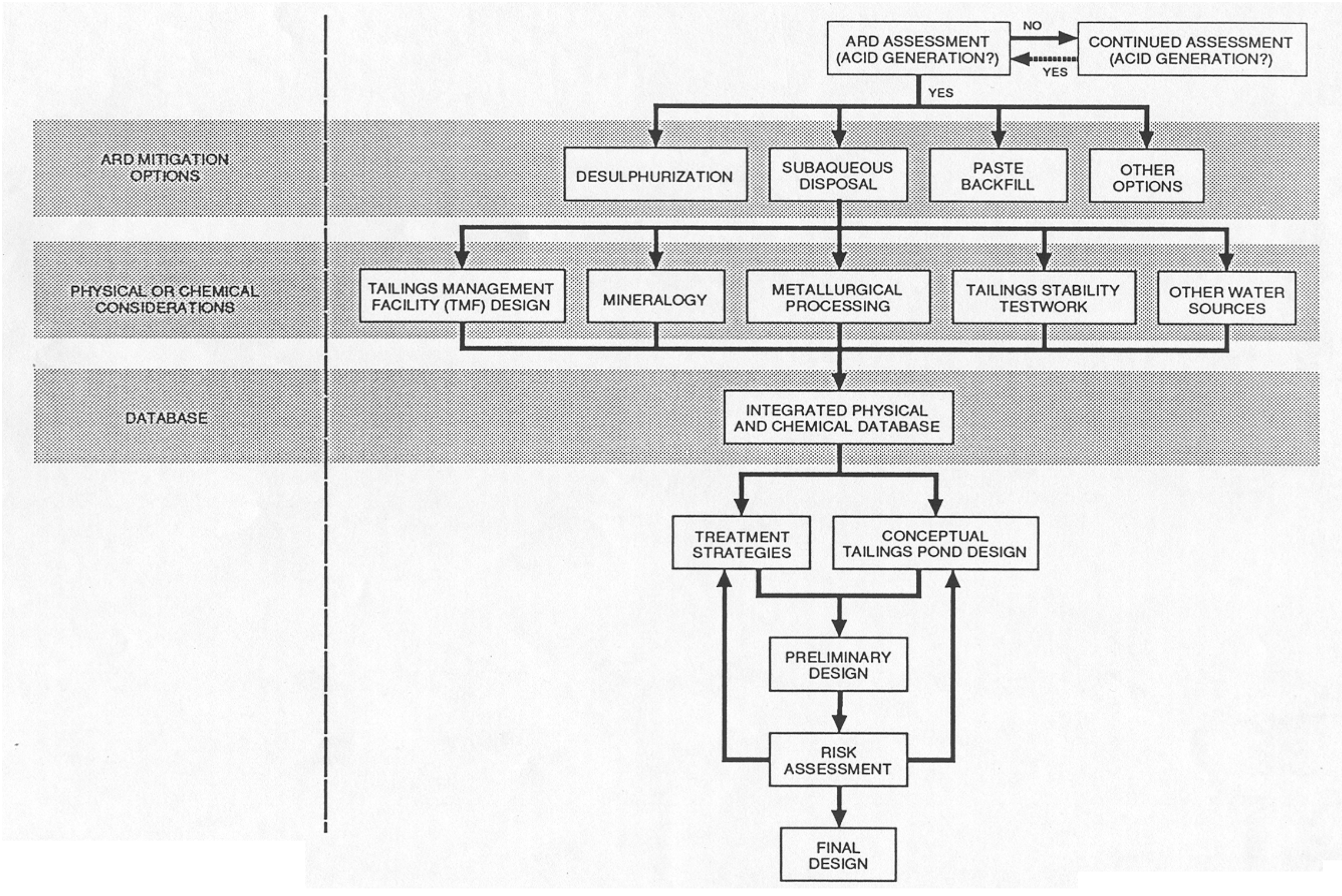
6.2.2 USE OF MONITORING DATA TO DEMONSTRATE EFFECTIVENESS

In terms of environmental protection and the minimization of liability and risk, ARD prevention is preferable. However, this is not always possible and other methods often need to be used to mitigate effects. All ARD mitigation strategies rely on the use of monitoring data to demonstrate their effectiveness. ARD prevention, control, and treatment strategies and related monitoring requirements[1] are summarized below.

1. Underwater storage of reactive waste. A generalized procedure for developing the design basis for a subaqueous tailings management system is shown in Figure 6.2-1. The procedure involves the investigation of ARD mitigation options following the comprehensive assessment of ARD potential. The selection and design basis of the preferred waste management strategy, subaqueous disposal into a constructed pond in this case, would be supported by an integrated database.
2. Chemical treatment. Collection and treatment of contaminated drainage can be an effective and reliable means of protecting the receiving environment. The performance of a treatment facility is assessed using influent and effluent quality data. For the chemical treatment of ARD, the monitoring of influent, effluent and receiving environments is required (often through regulatory mechanisms) to determine contaminant sources, final discharge quality and loadings, effectiveness of dilution zones, availability of dilution capacity and proximity and sensitivity of downstream resources. Environmental risk can be reduced through on-going vigilance, the use of a monitoring program, appropriate designs, risk management, and contingency planning.
3. Passive treatment. Opportunities for the passive primary or secondary treatment of ARD are limited in Canada due to climatic conditions, however passive treatment may be possible at some sites. Passive systems typically require regular monitoring and regeneration.
4. Blending of waste materials. The aim of blending potentially acid-generating wastes (usually waste rock) with materials containing excess neutralization potential is to

[1] Listing adapted from BCMEM (1998)

Figure 6.2-1 **Generalized Procedure for Establishing the Design Basis for the Subaqueous Disposal of Sulphide Tailings**



Source: MEND 2.1.1.9, Figure III-1

produce a composite waste material that will not produce acidic drainage. The performance of blending techniques depends on complex geochemical and hydrological processes and monitoring plays a key role in determining the effectiveness in mitigating ARD. Elevated concentrations of metals (e.g. zinc) at neutral pH are possible and can be identified through monitoring.

5. Placing covers over tailings and waste rock. Engineered covers are used to reduce oxygen transport to reactive wastes. They can also reduce water infiltration and thereby limit the volume of ARD. Their performance can be predicted through the use of geochemical models, however, their actual performance can only be assessed through monitoring.

Site hydrology, site water control, geotechnical conditions, and receiving environment conditions are significant factors to be considered in assessing the degree of impact of ARD and the effectiveness of mitigation strategies. Hydrological information needs typically include:

- Site water balance with water quality and flow rate information;
- Estimate of volume and composition of stored drainage;
- Water table elevations and hydraulic gradients;
- Probable maximum floods for various return periods;
- Hydrological properties of the underlying materials; and
- Climate and meteorological data.

6.2.3 MONITORING PROGRAMS

An ARD monitoring program should:

- Present the ARD prediction data and prevention and control strategies;
- Present the monitoring objectives and the monitoring strategy;
- Describe sampling and analyses protocols and QA/QC measures;
- Identify the persons responsible for monitoring; and
- Describe database management, and reporting and response requirements.

The cost of monitoring can be excessive if not managed. Experience suggests that instead of trying to monitor everything, it is best to focus on the site-specific information needs of the monitoring program.

An ARD monitoring program needs to be developed that takes both the mine and the mine waste management system into consideration. An excellent reference document in this regard is *A*

Guide to the Management of Tailings Facilities issued by the Mining Association of Canada (MAC) (1998). MAC published the guide to assist its member companies in assuring that they manage their tailings management facilities responsibly and safely, and in demonstrating these aspects to both regulatory authorities and the public. The guide stresses that tailings management facilities are site-specific, with each site having its unique setting both physically and environmentally. It is a generic guide that can be adapted to develop a customized tailings management system. The guide is available from MAC in English, French or Spanish, and in paper and electronic formats. It provides a series of informative management action checklists that apply to:

- The site selection and design of tailings facilities;
- The construction of tailings facilities;
- The operation of tailings facilities; and
- The decommissioning and closure of tailings facilities.

The checklists indicate management actions for the following areas: policy and commitment, planning, plan implementation, checking and corrective action, and management review for corrective action. Management actions corresponding to each of the four areas are well defined, and associated technical considerations are indicated where appropriate for environmental baseline, tailings characteristics, tailings facilities studies and plans, dam and appurtenant structures design, and control and monitoring considerations.

Environmental baseline considerations (MAC 1998) include:

- The identification of existing resources and land uses within tailings facilities and the greater potential impact area (i.e. address historic, present and future land and water uses, land tenure);
- Socio-economic data relevant to a tailings facility; and
- Physical and biological scientific data (Table 6.2-2).

Control and monitoring considerations (MAC 1998) include:

Quality Assurance/Quality Control;

Construction control;

Tailings dust control;

Tailings dam inspections;

Dam stability monitoring program plans; and

- Water quality plans that address hydrology, water control, perimeter dam seepage, and tailings deposition plans.

The management action items identified in the MAC (1998) guide can be applied to:

- Develop operating procedures and manuals; Identify gaps within established programs and procedures;
- Identify and address training requirements;
- Communications with stakeholders;
- Permitting of tailings facilities; and
- Environmental compliance and due diligence.

Effective ARD monitoring programs address the level of uncertainty in environmental monitoring data, and include a Quality Assurance component that is likely to produce a set of known and defensible quality data, and a Quality Control component that requires compliance with Quality Assurance measures, and provides the commitment to address data quality deficiencies. Poor quality environmental data provides a poor basis for decision-making.

An organization can manage the environmental aspects of its activities more effectively using an environmental management system (EMS). An effective EMS addresses all environmental activities within an organization, and is part of the overall management system including the organizational structure, planning activities, responsibilities, procedures, processes, and commitment to provide resources for the development, implementation, and review of its environmental protection policy. The ISO 14001 International Standard *Environmental Management Systems – Specification With Guidance For Use* (ISO 1996) should be reviewed by readers interested in this aspect.

In addition, an ARD monitoring program should demonstrate[1]:

- Technical understanding. The document needs to demonstrate there is an appropriate level of technical understanding of the ARD potential and control measures;
- Effectiveness. The program needs to address site-specific conditions and data needs;
- Contingency aspects. There needs to be a commitment to undertake mitigative actions should there be unacceptable levels of risk to the receiving environment (e.g. due to uncertainty in ARD prediction or a failure of primary ARD control measures);

[1] Listing based on and modified from text in BC Ministry of Energy and Mines (1998).

Table 6.2-2
Baseline Environmental Data Requirements Relevant to Tailings Facilities

Physical Data	
Climate	• Temperature • Wind • Precipitation and runoff • Evaporation • Return period floods • Air quality
Water	• Hydrology • Watershed delineation and flow patterns • Stream flow • Lake bathymetry • Hydrogeology (groundwater) characteristics • Surface water and sediment quality
Land forms	• Muskeg, peat or talus slopes
Geology and geochemistry	• Surficial deposits (type, location, density, permeability) • Stratigraphy • Geomorphology • Mineral and petroleum resources • Background elemental content
Topography	• Regional and detailed topographic maps • Stereo aerial photography • Satellite imagery
Soils	• Soils sampling and characterization
Natural hazards	• Landslides • Avalanches • Seismic events • Flood potential • Frost action
Biological Data	
Ecosystem	• Identity ecosystem
Terrestrial survey	• Flora • Natural pastures • Fauna • Endangered and threatened species • Migratory species
Aquatic survey	• Benthos • Macroinvertebrates • Fish • Aquatic plants

Source: Adapted from the Technical Considerations Section of MAC (1998)

- The potential (if any) for a significant delay in the onset of acidic drainage, as well as possible differences in laboratory test materials and data, and actual conditions need to be addressed;
- Multi-disciplinary input. ARD monitoring programs require input from a number of disciplinary areas including geology, hydrology, hydrogeology, environmental geochemistry, metallurgy, mining engineering, and geotechnical engineering. This needs to be reflected in the program; and
- Periodic auditing and management review. ARD monitoring requirements change over the life of a mine. As such, monitoring plans need to be reviewed from time to time to ensure that they continue to provide the necessary data.

Base Method

The base method for the development of an ARD monitoring program involves the following steps.

1. Initial characterization (Baseline). Collect available information and identify information gaps and areas of potential concern. Initially characterize the potential for acidic drainage from mine waste and workings.

2. Establish monitoring needs. Identify additional information requirements.

3. Develop monitoring objective(s). Formulate the question(s) to be answered by the monitoring program. Determine what level of results require action and identify the action that should be taken.

4. Develop the study framework. Develop a methodology to meet the ARD monitoring objectives. Specify the QA/QC program and define the data quality objectives - these along with the monitoring objectives determine the remaining components of the monitoring program framework. Develop standard procedures that specify the sampling protocols, required information content of field notes and other types of documentation (e.g. sample transmittal/ chain-of-custody forms). Determine the number of quality control samples (e.g. field blanks, duplicate samples/measurements); and allocate a percentage (generally at least 10% of samples) for quality control purposes.

5. Identify monitoring components. These include mine components (i.e. waste rock piles, tailings management facilities, mine workings) and supporting information (e.g. meteorological and hydrological data). The study methodology will depend upon the type of media being monitored.

6. Identify monitoring parameters. Parameters can be tiered with core parameters monitored regularly. The monitoring of secondary parameters can be triggered by a meaningful result. As an example, for the monitoring of seepage from a waste rock pile, the core parameters could be limited to sulphate, conductivity and pH. Predefined changes in one or more of the parameters would trigger the additional monitoring of metals concentrations.

7. Select monitoring locations. The selection of sampling stations needs to take into account possible acidic drainage transport pathways.

8. Sampling. Sampling frequency is determined largely by temporal variation in the parameters monitored. Collecting single samples at an arbitrary, fixed frequency may not meet monitoring objectives. Alternative sampling strategies are discussed in MEND 4.7.1.

   The number of samples is determined by spatial and/or temporal variability of the sample source, the degree of difference to be detected, and the power of the analysis to detect a difference. The appropriate numbers of samples are critical to the efficiency of a monitoring program. However, collecting too many samples wastes resources while too few samples results in objectives not being met.

   The selection of sampling techniques depends upon the medium being monitored (e.g. waste rock, tailings, groundwater), the physical characteristics of the monitoring site (as this affects accessibility), the parameters being measured, the number of samples required, and the cost-effectiveness.

9. Review the sampling strategy. A cost-benefit analysis of sampling options can be completed during the program development process. This can be a formal mathematical analysis or a qualitative analysis of the data's worth. Once a program is implemented, results should be periodically reviewed with respect to the monitoring objectives and data quality objectives.

10. Optimization. Ensure that the program includes the number of samples required, and meets the monitoring and data quality objectives.

11. Review the adequacy of the monitoring objectives. Objectives should be reviewed and revised as appropriate at regular intervals or where there are changes in mine waste characteristics, and conditions.

From a practical point of view, reviewers should also assess whether or not the effort being expended is appropriate for the value of the information obtained. The results of the reviews should be communicated to specified persons within the organization.

ARD Monitoring at Historic Sites

Volume 6 is largely targeted towards ARD monitoring for new mines commencing with exploration. Some readers may need to address ARD from mine wastes which were produced and disposed prior to the development of ARD prevention, control and treatment techniques. The application of these techniques to historic mine waste sites can be very challenging. The primary monitoring objective at a historic site can be to assess the degree of impact on the receiving environment, and to develop the database required for the assessment of closure options and the selection of the preferred closure option. Monitoring programs for historic projects tend to be well defined and focussed on the key site-specific technical aspects relevant to closure planning. The need for an adequate level of scientific and defensible data is also a priority at historic sites.

6.2.4 DATA MANAGEMENT

For ARD monitoring data management, each mine usually develops a system suited to its management plan. The following basic considerations apply to data management at all mines.

- Data needs to be verified. Data verification includes reviewing laboratory reports and questioning apparent anomalies, and checking for data entry errors.
- Data should be organized in a manner that facilitates analysis and review.
- Data should be indexed for easy access. Computer files can be given appropriately named directories and sub-directories. Hard copies of data, field notes and reports need to be filed in an orderly manner.
- A data management system should be used. To avoid the loss of the database, a copy of the database should be kept in a separate location.

6.2.5 DISCUSSION OF MEND MANUALS

Table 6.2-3 lists four MEND projects that provide a range of information with regards to ARD monitoring.

Table 6.2-3
MEND Manuals – ARD Monitoring

MEND Project	Title
4.1.1	Field Sampling Manual for Reactive Sulphide Tailings.
4.5.1-1	Review of Waste Rock Sampling Techniques.
4.5.1-2	Handbook for Waste Rock Sampling Techniques.
4.5.4	Guideline Document for Monitoring Acid Mine Drainage; Appendix A – Technical Summary Notes.

MEND 4.1.1 Field Sampling Manual for Reactive Sulphide Tailings

MEND 4.1.1 describes methodologies available for the sampling of tailings solids, liquid and pore gas phases within tailings and near tailings management areas. For the collection of solid-phase tailings samples, the document describes methods based on the use of heavy-powered equipment including drill rigs, light-powered equipment including samplers used in conjunction with drill rigs, and hand-operated equipment. Liquid-phase sampling includes the collection of samples during drilling, the physical separation of water from solid-phase samples, sampling from a drilled well, sampling from installations established independent of drilling, and the collection of groundwater samples using a pump or bailer. Pore gas sampling methods are grouped on the basis of sampling during drilling, the use of sampling ports established after drilling, the installation and use of sampling ports independent of drilling, and the use of a syringe type sampler or on-site auto-analyzer. The sampling methods are described and indexed based upon factors including field conditions, the required degree of isolation between the sample and the atmosphere, and the expected degree of sample disturbance.

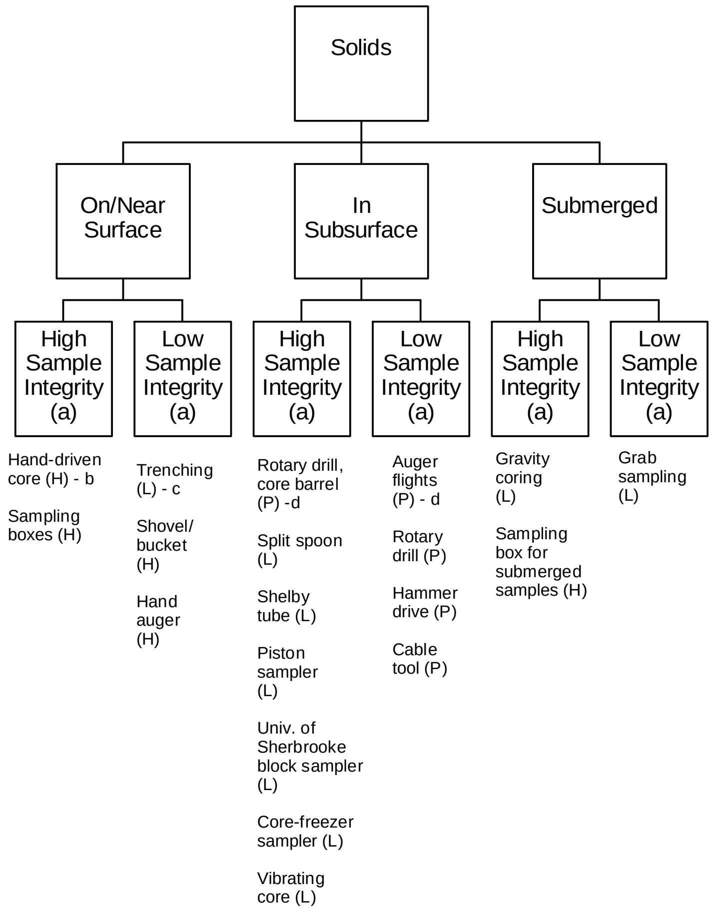
The selection of methods for the collection of tailings solids, liquid, and pore gas samples is dependent on factors such as site-specific conditions and equipment availability, and as such precludes the use of a rigid prescriptive guide for tailings sampling methodologies. Indexes and a flowchart which can assist in sampling method selection are provided in MEND 4.1.1. The flowchart is reproduced in Figures 6.2-2a and b.

MEND 4.5.1-1 Review of Waste Rock Sampling Techniques

MEND 4.5.1-1 reviews techniques for the sampling of waste rock piles, and the basis of sample program design including a statistical sampling approach. The report provides guidance as to:

- The characterization of waste rock using element content, mineralogy, mineral forms, static and dynamic test data, and an assessment of waste rock physical stability through hardness and weathering testing;
- The sampling and chemical analyses of surface water, groundwater and pore fluid, and appropriate container types and sample preservation methods;
- Oxygen and carbon dioxide gas sampling;
- Waste rock grain size, permeability, moisture, flow monitoring, infiltration modelling, biological monitoring, rock temperature monitoring and thermal analysis, and geophysical monitoring; and
- Meteorological data requirements including ambient temperature and net precipitation.

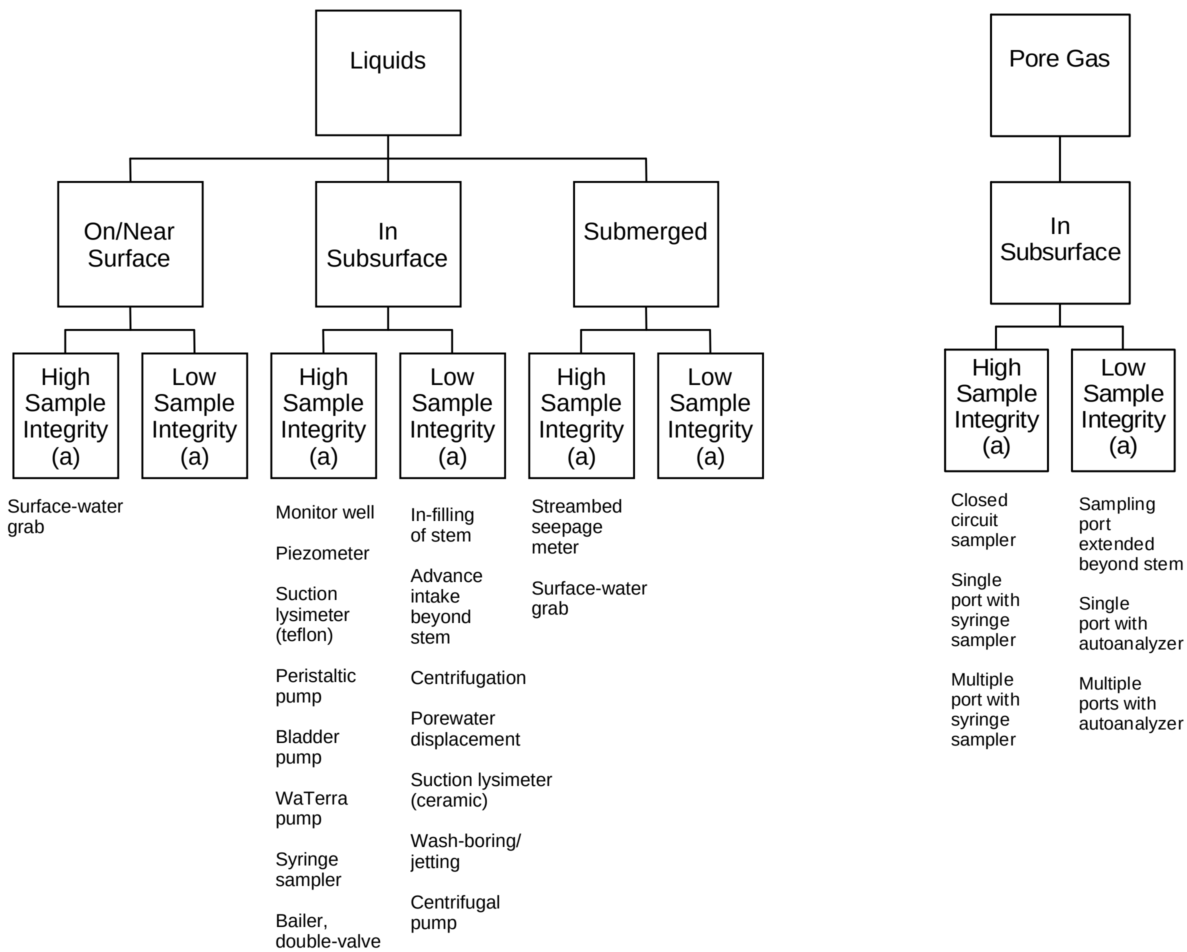
Figure 6.2-2a **Flowchart for Sampling Methods – Solids**



a This rating is qualitative in nature and will vary with equipment, site conditions and operator
b H - Handheld sampler
c L - Light powered
d P - Heavy powered

Source: MEND 4.1.1, Index 2-6

Figure 6.2-2b **Flowchart for Sampling Methods – Liquids and Pore Gas**



Source: MEND 4.1.1, Index 2-6

MEND 4.5.1-1 identifies waste rock sampling and data requirements for the baseline/exploration, operational, and decommissioning phases. An overview of waste rock sampling in each of the three phases is provided below.

1. Waste rock sampling during the baseline/exploration phase

During the baseline/exploration phase, data are collected to determine the economic viability of a project. With regard to acidic drainage, ultimate areas of interest relate to the projected costs for mine waste management and mine closure, and the protection of the receiving environment. The basis for the mine waste rock management plan is developed in this phase. The amount of data required depends on local conditions and the level of detail of the study which can vary from a preliminary mine project evaluation to a bankable feasibility study.

Mine waste rock production can be estimated based on the geology and mine plans. Barren and mineralized zones are characterized through ABA testing, and if appropriate, through additional testing. MEND 4.5.1-1 discusses the use of a staged evaluation in this regard. Rock testing and analyses include:

- Mineral form investigation;
- Static and kinetic testing;
- Physical stability and weathering testing to assess crumbling rates and the effect of sulphide exposure over time;
- Determination of the grain size distribution of the small rock particles (e.g. <10 cm in size) and the correlation of sulphide content and grain sizes to assess whether sulphides are likely to concentrate in fines - the latter applies to bulk samples but not crushed core samples; and
- Borrow material characterization. This includes testing to determine the net acid consuming or production potential of borrow materials proposed to be used in construction or closure works.

Supplementary baseline data requirements include climate and meteorology, hydrology, hydrogeology, water quality, and ecological studies. These data assist in identifying the potential for adverse impacts to the receiving environment.

The required level of investigation is site-specific and depends on the type and scope of the envisaged operation and the stage of the project (e.g. at the conceptual or detailed engineering stage). Providing there are sufficient data, the ARD database can be input into mathematical models to predict the effect of waste rock management options on the sulphide oxidation process and ARD generation and drainage quality. Predictive modelling results can provide an additional basis for the selection of a preferred waste management strategy.

2. Waste Rock Sampling During the Operational Phase

Waste rock sampling requirements during the operational phase are analogous to the baseline/ exploration phase. ARD monitoring data collected during the operational phase are added to the database. The ARD database should be linked to the overall environmental monitoring database. Sources of data that can be useful in identifying changes in conditions related to ARD are:

- Seepage, groundwater, surface water, and mine drainage quality monitoring;
- Continued characterization of waste rock and geological formations;
- Water balance assessments of waste rock piles, taking into account meteorological data, and water infiltration and flow data;
- *In situ* measurements (i.e. temperature, pore water, oxygen); and
- Biological effects monitoring of the receiving environment.

3. Waste Rock Sampling During the Decommissioning Phase

Waste rock sampling requirements during the decommissioning phase are similar to the operational stage. A state-of–the-art monitoring program for the South dump at La Mine Doyon located in the Abitibi region of Québec is described in MEND 4.5.1-1. The South waste rock dump has been generating acidic drainage since 1985, two years after the dump was started. The strong acidic drainage is collected and treated with lime. The monitoring program included chemical characterization, ARD assessment, physical stability testing, water monitoring, gas sampling, permeability testing, rock particle size analyses, rock pile porosity determination, water content, flow monitoring, infiltration monitoring, biological monitoring, thermal analyses, drilling and backhoe trenching, and microgravity geophysical surveying.

The South dump at La Mine Doyon was the subject of extensive investigations and studies carried out under MEND, primarily by Université Laval between 1991 and 1994. The results of these studies were issued in a series of ten reports (MEND 1.14.2x). The site investigations included tasks such as drilling and sampling of the rock dump materials; piezometer, lysimeter and thermocouple installations; sampling of acidic drainage, groundwater and pore water; collection of gas samples within the dump; collection of microbiological specimens; measurement of surface temperatures and temperature profiles in the dump; and collection of climatic and hydrologic data. The laboratory and analytical studies included the characterization of the physico-chemical and mechanical properties of the different types of waste rock; water chemistry analyses including rapid chemical techniques to monitor acidic mine drainage; hydrology and water budget studies; geotechnical and hydrological studies including evaluation of dry barriers; extensive studies of mineralogy and geochemical processes; microbiological enumeration and diversity studies; and predictive modelling of acidic drainage processes including heat transfer analysis. An important objective of the studies was to measure physical and chemical properties of an actual waste dump and to identify key processes contributing to the ARD generation.

MEND arranged for a peer review of the studies carried out at the south dump by a designated group of experts (Peer Review Team). The peer review was carried out under five separate technical components identified as (i) hydrology, (ii) geotechnology and hydrogeology, (iii) geochemistry and mineralogy, (iv) microbiology and (v) predictive modelling. The Peer Review Team made a technical and scientific review of the ten reports, with particular reference to providing a critique of strong and weak points, identifying new information and understanding developed from the studies and suggesting areas for future work. The overall conclusion of the peer review was that the study provided a new understanding of some specific technical issues and represents a thorough and exceptionally well documented case study (MEND 1.14.3e-f).

Another example of a waste rock sampling program is described in the Whistle Mine waste rock study (MEND 1.41.4). The field investigation involved waste rock sampling, five boreholes and three test pits. Monitoring wells, gas sampling ports and thermistors were installed in the boreholes, and lysimeters were installed in the test pits. Water quality data were obtained for seepage, wells and lysimeters. Oxygen, carbon dioxide and temperature measurements were made. Waste rock sample analyses included element analysis, static tests, kinetic tests, wash tests and bacterial analysis. Readers interested in the monitoring of waste rock dumps may also review the monitoring program applied at the Equity Silver Mine, near Houston, B.C. Useful references for Equity Silver include Wilson (1995) and Aziz and Ferguson (1997).

MEND 4.5.1-2 summarizes waste rock sampling techniques. Each waste rock sampling category (i.e. chemical characterization, water monitoring, gas sampling) is discussed under the following headings; possible methods, objectives, background, rating, limitations and advantages, recommended procedures, requirements, cost, and references. MEND 4.5.1-2 also indicates how the techniques can be applied to obtain information required for decision-making for the management, maintenance, monitoring and closure of ARD sites, and for predictive modelling - this information is summarized in Table 6.2-4. It is suggested that interested readers refer to both MEND Project 4.5.1-1 *Review of Waste Rock Sampling Techniques* and MEND 4.5.1-2 *Handbook for Waste Rock Sampling Techniques*.

MEND 4.5.4 Guideline Document for Monitoring Acid Mine Drainage

MEND 4.5.4 is a single source introductory guide to ARD monitoring. It reviews the basic principles of monitoring programs with an emphasis on monitoring theory concepts. It also reviews sampling techniques and provides background information to assist readers in understanding monitoring objectives. It is demonstrated that it is not logistically feasible or cost effective for an organization to sample all possible physical and biological components and their parameters. Effective monitoring programs can be developed using a tiered approach based on the concept of initially using a set of simple tests, with the tests increasing in complexity and cost when initial results identify the need for additional information. When ARD or its effects are identified through Tier I tests, more complex tests (Tier II) should be used for confirmation purposes and to assess the source and the spatial distribution of the data. Tier III tests are used to identify the casual mechanisms of effects. MEND 4.5.4 addresses basic statistical concepts that should be taken into consideration when developing a monitoring program. The concepts are: sample variation (spatial, temporal, and instantaneous); sample replication and the use of power analysis; frequency distribution and implications on program design on data analyses; data stratification; autocorrelation or serial dependence; general QA/QC principles and protocols; data management and tiering thresholds; and monitoring program and audits. A comprehensive listing of papers and texts is included in the bibliography of MEND 4.5.4 to assist readers interested in learning more in a specific area.

MEND 4.5.4 also reviews routine source monitoring during the baseline/exploration, operational and decommissioning phases. Compliance monitoring which is required by regulatory authorities, provides data that is used to demonstrate compliance with regulatory (and corporate) environmental protection requirements and objectives. Compliance monitoring components include: physical components (surface and groundwater quality, hydrology, and sediment quality in receiving waters); biological components (fish, benthic macroinvertebrates, macrophytes, and plankton); and interactive components (habitat classification, and effluent testing). Secondary diagnostic monitoring is carried out proactively at the initiative of mine proponents. As an example, secondary diagnostic monitoring can focus on drainage from a potential acidic drainage source with the objective of identifying the occurrence of acid generation. Investigative monitoring addresses site-specific issues. It can be focussed on a specific mine site component, an aspect of the receiving environment, or both. Tables 6.2-5, 6.2-6 and 6.2-7 respectively indicate monitoring options for waste rock, tailings, and mine workings.

The abiotic and biotic components of receiving environment monitoring are reviewed in MEND 4.5.4. Abiotic monitoring includes hydrology, water quality and sediments. Biotic components selected on the basis of being of key importance to most, but not all, mining operations are identified in the document. The primary (Tier I) biotic components are benthic macroinvertebrate communities and a range of fish indices (population, health and bioaccumulation). Other biological monitoring options are discussed or referenced. A number of possible ARD pathways from a waste rock pile to the receiving environment, and a possible monitoring strategy is shown conceptively in Figure 6.2-3.

Table 6.2-4
Application of Monitoring Data

Category	Required for Cost Estimates for Decision Making	Required for Modelling/Prediction/ Validation	Approximate Cost for Recommended Techniques (1995$)
Statistical sampling program	Yes	Yes	
Element content	Yes	Yes	$25 - $75/sample for ICP
Mineralogy	Yes	Yes	$100 - $200/sample for petrographic analysis
Mineral forms	Yes	Yes	Part of above
Static tests	Yes	Yes	$75/sample
Dynamic tests	Yes, depending on static	Yes	$1,000 - $5,000/test
Hardness and weathering	No	Yes	$200 - $300/sample
Water monitoring	No	Yes	Labour, site-specific
Pore water	Yes	Yes	Site- and option-specific
Seepage	Yes	Yes	Site- and option-specific
Groundwater	Site-specific	Site-specific	Site- and option-specific
Surface water	Yes	Yes	Site- and option-specific
Water quality – field analysis	Yes	Yes	Variable but inexpensive
Water quality – lab analysis	Yes	Yes	$100 - $200/sample
Gas sampling	No	Yes	~$100/m installation, ~$1,000-$3,500 for gas meter, plus sampling labour
Temperature profile in waste rock	No	Yes	$500-$20,000/hole for instrumentation, plus measurement labour
Water permeability	No	No	~$100/m for installation of piezometer, plus testing
Air permeability	No	Yes, if convection controls	Requires gas sampling ports, as above, plus measurement labour
Oxygen diffusion	No	Yes, if diffusion controls	Lab program ~$5,000
Particle size	Yes	Yes	$60 - $100/test for sieve analysis, up to $1,000/test incl. coarse fraction
Porosity	Yes	Yes	$100 - $200/test
Water content	Yes	Yes	~$20/sample
Flow monitoring	Yes	Yes	$200 - $2,000 per location plus measurement labour; >$1,500/ electronic recording flow meter
Infiltration monitoring	No	Yes	~$1,000 per barrel lysimeter, ~$2,000 HELP model
Biological monitoring	No	No	Refer to Volume 2.4
Meteorology	No	Yes	$5,000 - $10,000/station
Thermal analysis	No	No	Relatively expensive
Drilling	Site-dependent	Site-dependent	Variable, $50 - $100/metre
EM surveys	No	No	Area dependent

Source: MEND 4.5.1-2, Table 4

Table 6.2-5
A General Classification(1) of Monitoring Options for Waste Rock

Monitoring Category	Baseline/Exploration Phase	Operational Phase	Decommissioning Phase
Rock Characterization			
Chemical characterization			
Element content	P	I	I[2]
Mineralogy/mineral forms	P	I	I[2]
AMD assessment tests			
Static tests	P	I	I[2]
Dynamic tests	P	I	I[2]
Physical stability			
Hardness	SD	I	I[2]
Weathering	SD	I	I[2]
Particle size distribution	SD	I	I[2]
Water			
Water quality	P	P	P
Monitoring locations			
Surface flow on pile	N/A	I	I
Pore fluid in pile	N/A	I	I
Seepage to surface of pile	N/A	I	I
Groundwater	P	SD/I	I
Toe discharge / Collection ditch	N/A	P	P
Inflow to treatment facility	N/A	P	P
Natural receiving waters	P	P	P
Flow monitoring (each station)	P	P	P
Other Categories			
Structural stability	P	P	P
Gas composition	N/A	I	I
Internal temperature profile	N/A	I	I
Permeability			
Water permeability	N/A	I	I
Air permeability	N/A	I	I
Oxygen diffusion (covers)	N/A	N/A	SD/I
Porosity	N/A	I	I
Water content	N/A	I	I
Infiltration	N/A	I	I
Meteorology	SD	SD	SD
Geophysical techniques	N/A	SD/I	SD/I
Bacterial monitoring	N/A	I	I

Notes:

(1) Classifications will vary in priority on a site-specific basis. Multiple classifications are in order of most common priority.

(2) Additional predictive AMD assessment should be completed prior to decommissioning. These procedures would then be considered.

P = Primary; SD = Secondary Diagnostic; I = Investigative; N/A = Not Applicable

Source: MEND 4.5.4, Table III: 2.2-1

Table 6.2-6
A General Classification[1] of Monitoring Options for Tailings

Monitoring Category	Pre-Operational Phase (Pilot Plant)	Operational Phase	Decommissioning Phase
Tailings Solids			
Chemical Characterization			
Element Content	P	SD	I[2]
Mineralogy/Mineral Forms	P	I	I[2]
AMD Assessment Tests			
Static Tests	P	I	I[2]
Dynamic Tests	P	I	I[2]
Particle Size Distribution	P	I	I[2]
Compaction	N/A	P/SD	P/SD
Water Quality			
Water Quality	N/A	P	P
Water Monitoring Locations			
Pore Water in TMF	N/A	SD/SI	SD/SI
Embankment Seepage	N/A	P	P
Groundwater	N/A	SD/P	P/SD
Surface Water in TMF[3]	N/A	P	P
Side and Bottom Drains	N/A	SD	SD
Release to Surface Water	N/A	P	P
Inflow to Treatment	N/A	P	P
Flow Monitoring (Each Station)	N/A	P	P
Colonization of Flooded Tailings	N/A	N/A	P
Plankton Colonization of Flooded TMF	N/A	N/A	SD/P
Other Categories			
Structural Stability	N/A	P	P
Gas Composition	N/A	I	SI
Internal Temperature Profile	N/A	I	SI
Permeability			
Water Permeability	N/A	I	SI
Air Permeability	N/A	I	SI
Oxygen Diffusion (Covers)	N/A	I	SI
Porosity (of deposited tailings)	N/A	I	SI
Infiltration	N/A	SD	SD
Meteorology	SD	P	SD
Geophysical Techniques	N/A	SD/I	SD/I

Notes:
(1) Classifications will vary in priority on a site-specific basis. Multiple classifications are in order of most common priority.
(2) Additional predictive AMD assessment should be completed prior to decommissioning. These procedures would then be considered investigative components for long-term monitoring.
(3) Surface water in a Tailings Management Facility (TMF) concerns ponding in sub-aerial deposition and large volumes in subaqueous deposition or flooded TMFs.

P = Primary
SD = Secondary Diagnostic
I = Investigative
N/A = Not Applicable

Source: MEND 4.5.4, Table III: 2.3-1

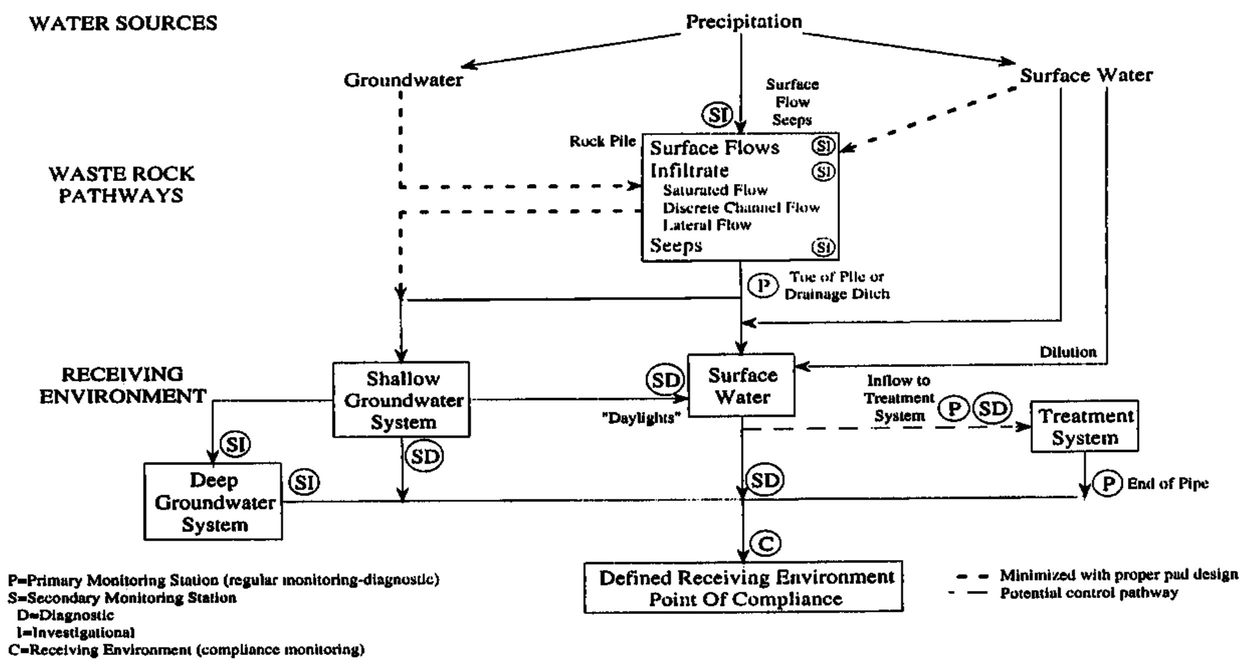
Table 6.2-7
A General Classification(1) of Monitoring Options for Mine Workings

Monitoring Category	Baseline/Exploration Phase	Operational Phase	Decommissioning Phase
Mine Rock			
Chemical characterization			
Element content	P	I	I(2)
Mineralogy/mineral forms	P	I	I(2)
AMD assessment tests			
Static tests	P	I/SD	I(2)
Dynamic tests	P	I/SD	I(2)
Physical stability			
Hardness	SD	I	I(2)
Weathering	SD	I	I(2)
Water			
Water quality	P	P	P
Water monitoring locations			
Outflows to surface	P	P	P
Flooded mineworks	N/A	N/A	P/SD
Groundwater	P	SD/P	P/SD
Pit or underground sumps	N/A	P/SD	N/A
Inflow to treatment facilities	N/A	P/SD	P/SD
Flow monitoring (each station)	P	P	P
Other Categories			
Structural stability	P	P	P
Water permeability		I	I
Meteorology	SD	P	P
Geophysical techniques	I	I/SD	SD/I

Notes:
(1) Classifications will vary in priority on a site-specific basis. Multiple classifications are in order of most common priority.
(2) Additional predictive AMD assessment should be completed prior to decommissioning.
P = Primary
SD = Secondary Diagnostic
I = Investigative
N/A = Not Applicable

Source: Adapted from MEND 4.5.4, Table III: 2.4-1

Figure 6.2-3 **Possible AMD Pathways and Monitoring Strategies for a Waste Rock Pile**



Source: MEND 4.5.4, Figure III: 2.2-2

6.2.6 MEND AND RELEVANT PUBLICATIONS

MEND 2.11.9 — 1998. Design Guide for the Subaqueous Disposal of Reactive Tailings in Constructed Impoundments. March.

MEND 4.1.1 — 1989. Field Sampling Manual for Reactive Sulphide Tailings. November.

MEND 4.5.1-1 — 1994. Review of Waste Rock Sampling Techniques. June.

MEND 4.5.1-2 — 1994. Handbook for Waste Rock Sampling Techniques. June.

MEND 4.5.4 — 1997. Guideline Document for Monitoring Acid Mine Drainage. Appendix A – Technical Summary Note. October.

MEND 4.7.1 — 1990. Monitoring Acid Mine Drainage. (BC AMD Task Force Document No. 4-10). August.

MEND 1.14.3-e — 1996. Peer Review of MEND Studies Conducted from 1990 to 1994 on Acidic Drainage at Mine Doyon South Waste Rock Dump. November.

MEND 1.14.3-f — 1996. Revue technique des étude réalisées par NEDEM de 1990 à 1994 sur le drainage minier acide de la halde sud de la mine Doyon. novembre.

MEND 1.41.4 — 1997. Whistle Mine Waste Rock Study (2 Volumes). December.

Aziz, M.L. and Ferguson, K.D. 1997. *Equity Silver Mine – Integrated Case Study*. In: Proceedings of Fourth International Conference on Acid Rock Drainage. Vancouver, British Columbia. 31 May to 6 June, Vol 1, pp. 183-195.

BCMEM – British Columbia Ministry of Energy and Mines. 1998. Guidelines for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia.

BCEAO – British Columbia Environmental Assessment Office. 1995. Guide to the British Columbia Environmental Assessment Process. July.

MAC – The Mining Association of Canada. 1998. A Guide to the Management of Tailings Facilities. September.

ISO – International Organization for Standardization. 1996. ISO 14001, Environmental Management Systems – Specification with Guidance for Use. First Edition. 1 September.

Wilson, G.W. 1995. *Assessment of Protective Covers and Dump Behaviour.* In: Proceedings of the 2nd Australian Acid Mine Drainage Workshop. Charters Towers, Queensland, Australia. 28 to 31 March, pp. 147-164.

6.3 RECENT DEVELOPMENTS AFFECTING ARD MONITORING

This section provides an overview of recent regulatory developments that are likely to affect acidic drainage monitoring in the future. Readers involved in acidic drainage monitoring are encouraged to keep up to date with developments in these areas.

6.3.1 OVERVIEW OF RECENT DEVELOPMENTS

The state of scientific knowledge regarding the potential effects of contaminants including acidic drainage on the receiving aquatic environment is increasing. Regulatory controls put in place for the protection of fish, fish habitat, and fishery resources have recently come under review with regards to their adequacy. An environmental effects monitoring (EEM) program has been established for the pulp and paper sector under the Fisheries Act and an EEM program for the metal mining sector is under development. MEND did not fund EEM research.

Recent developments relevant to environmental monitoring for mining projects are summarized below based on reviews completed by Garisto *et al.* (1998, 2000) and information from Campbell (1999).

1. <u>The EEM program for the pulp and paper sector</u>.

The first and second phases of the pulp and paper EEM program provided considerable information about the design of EEM programs and the need for, and collection of, scientifically defensible data. The EEM program was developed to assess the adequacy of effluent regulations on a site-specific basis. Adequacy was assessed based on the magnitude and extent of site-related effects on fish, fish habitat and the use of fisheries resources. It is expected that this knowledge will be applied to develop an EEM program for the mining sector.

2. <u>The Metal Mining Liquid Effluent Regulations (MMLER)</u>.

The MMLER were promulgated in 1977 under the Fisheries Act. The regulations control the maximum concentrations in mine effluents for As, Pb, Cu, Zn, Ni, Ra-226, total suspended solids, and define a lower pH limit. The regulations did not apply to gold mines where gold is recovered by cyanidation and gold production accounts for more 50% of the value of the mine's output.

In 1992, an Environment Canada sponsored workshop resulted in the key recommendations that:

- Prior to amendments to the MMLER, the effectiveness of the regulations should be evaluated through an aquatic effects assessment; and
- The assessment should be comprehensive, and review chronic, acute, and cumulative effects with multi-stakeholder participation.

The above recommendations led to two parallel initiatives – specifically the Assessment of Aquatic Effects of Mining in Canada (AQUAMIN) program and the Aquatic Effects Technology Evaluation (AETE) program. The AQUAMIN and AETE Secretariats were located at Environment Canada and CANMET respectively.

AQUAMIN's objective was to examine the effectiveness of the MMLER. AQUAMIN (1996a) indicates that this was accomplished through an assessment of existing information on the effects of metal mining on aquatic ecosystems in Canada. The study focussed on the effects of mine effluents on freshwater environments with two exceptions. AQUAMIN (1996a) recommended that:

- A cooperative national environmental protection framework be implemented. The framework should include three components: the MMLER, site specific requirements, and environmental effects monitoring;
- The revised MMLER, referred to hereafter as the MMER (Metal Mining Effluent Regulations), apply to all metal mines including gold mines but excluding placer operations;
- As, Cu, CN, Pb, Ni, Ra-226, a lower pH limit, total suspended solids, and zinc be regulated in the MMER;
- The MMER are expected to include a requirement that metal mine operators conduct and report periodic testing of effluent for acute lethality;
- In establishing sampling and reporting requirements in the MMER, efforts be made to simplify and streamline requirements to increase compatibility or eliminate duplication, identify data gaps, and ensure that compliance data are forwarded to regulatory agencies of the appropriate jurisdictions in an acceptable format, to reduce compliance costs;
- The MMER are expected to include a requirement that mine operators develop, conduct, and report on a site specific EEM program that:
  a) Monitors key components of aquatic ecosystems (e.g. water, sediments, fish, and benthic invertebrates); and
  b) Uses tools that are appropriate to site conditions. Methodologies, sampling frequency, and other details should be determined at the local level.

AQUAMIN (1996a) indicated that the main conclusion from its review of aquatic effects was that a variety of conditions (e.g. nature of mining operations and receiving environment) influenced the magnitude and extent of effects observed. For example, older mine sites and/or those with acidic drainage typically had more pronounced effects than newer sites. In addition, AQUAMIN identified sites where receiving environment conditions had improved over time as a consequence of improvements in effluent quality and wastewater management.

The AETE Program was carried out from 1994-1998 as a cooperative program between the mining industry, several federal government departments and a number of provincial governments. The mandate of AETE was to evaluate the environmental monitoring technologies that could be used to assess the impacts of mine effluent on the aquatic environment, and to provide guidance and recommend specific methods, or groups of methods, that would lead to accurate characterization of environmental impacts in the receiving waters in a cost-effective manner. Decisions resulting from this program are applicable to future EEM, baseline studies, and various risk assessments to be undertaken by the mining industry and regulatory agencies with respect to the impact of mine effluents on aquatic ecosystems.

The AETE program has generated over 25 scientific reports in the areas of toxicity testing, biological monitoring, as well as waste and sediment monitoring. A listing of these reports is included at the end of this section. The program highlights are summarized in AETE 4.1.4 titled *AETE Synthesis Report of Selected Technologies for Cost-Effective Environmental Monitoring of Mine Effluent Impacts in Canada.*

Possible EEM for Mining

Legislated EEM is not currently applicable to mines in Canada. However, a legislated EEM program for the mining sector is expected - the schedule for its implementation has yet to be determined. Environment Canada led a multistakeholder process to amend the MMLER effluent limits, and design an EEM program for mining. A key objective of an EEM program for mining could be to achieve nation-wide consistency in the approach to data collection, analysis and interpretation. Site specific concerns could be addressed through the use of a set of sampling variables, possibly tiered, with core elements and additional, site-specific elements. The costs of an EEM program would depend upon the program eventually specified for mining and site specific factors that control the time and effort required to complete the field program.

6.3.2 MEND AND RELEVANT PUBLICATIONS

The following references include those cited above as well as selected supplementary references for AQUAMIN and AETE.

References:

AETE 4.1.4 1999. AETE Program Synthesis Report of Selected Technologies for Cost-Effective Environmental Monitoring of Mine Effluent Impacts in Canada. March.

AQUAMIN 1996a. Assessment of the Aquatic Effects of Mining in Canada. Final Report. Prepared by AQUAMIN Working Groups 7 and 8. April.

Campbell, D. 1999. Natural Resources Canada. Personal Communication. February.

Garisto, N.C., Himbeault, K., Rosaasen, A., Campbell, D. and Orava, D. 1998. *Environmental Monitoring at Mine Sites – Future Directions.* In: Proceedings of the Centennial Annual Conference of the Canadian Institute of Mining, Metallurgy and Petroleum. Montréal, Québec. 3 to 7 May. Paper WEAM44.7.

Garisto, N.C., Himbeault, K., Rosaasen, A., Campbell, D. and Orava, D.A. 2000. *Environmental Monitoring at Mine Sites – Future Directions.* CIM Bulletin, Vol 93, N^o^ 1038, pp. 62-66.

Additional AQUAMIN References:

AQUAMIN 1996b. Assessment of the Aquatic Effects of Mining in Canada. Supporting Document I. Prepared by AQUAMIN Working Group 2, AQUAMIN Secretariat. March

AQUAMIN 1996c. Assessment of the Aquatic Effects of Mining in Canada. Supporting Document II: Regional Syntheses. Prepared by the AQUAMIN Working Groups 3, 4, 5 and 6, AQUAMIN Secretariat.

Additional AETE References:

Toxicity Testing

AETE 1.1.4 1996. Comparison of Results from Alternative Acute Toxicity Tests with Rainbow Trout for Selected Mine Effluents. April.

AETE 1.2.1 1997. Review of Methods for Sublethal Aquatic Toxicity Tests Relevant to the Canadian Metal-Mining Industry. April.

AETE 1.2.2 1997. Laboratory Screening of Sublethal Toxicity Tests for Selected Mine Effluents. January.

AETE 1.2.4 1997. Toxicity Assessment of Highly Mineralized Waters from Potential Mine Sites. July.

AETE 1.2.5 1998. Evaluation of Toxicity Reduction Evaluation (TRE) and Toxicity Identification Evaluation (TIE) Application to the Canadian Mining Industry. November.

AETE 4.1.2a 1997. Toxicity Assessment of Mining Effluents Using Up-Stream or Reference Site Waters and Test Organism Acclimation Techniques. July.

Biological Monitoring

AETE 2.1.1 1995. Review of Artificial Substrates for Benthos Sample Collection. June.

AETE 2.1.2 1997. Optimization of Field and Laboratory Methods for Benthic Invertebrate Biomonitoring. January.

AETE 2.1.3 1997. Technical Evaluation of Methods for Benthic Invertebrate Data Analysis and Interpretation. June.

AETE 2.1.3a 1999. Review of Potentially Applicable Approaches to Benthic Invertebrate Data Analysis and Interpretation. March

AETE 2.1.4 1999. Quality Assurance Program for Assessing Mine-Related Effects Using Benthic Invertebrate Communities. February.

AETE 2.1.5 1999. Technical Evaluation of Determining Mining Related Impacts Utilizing Benthic Macroinvertebrate Population Level Fitness Parameters. February.

AETE 2.2.1 1997. Technical Evaluation of Metallothionien as a Biomarker for the Mining Industry. February.

AETE 2.2.2 1997. Technical Evaluation of Histopathology as an Environmental Monitoring Tool for the Mining Industry in Canada. June.

AETE 2.2.3 1999. Technical Evaluation of Fish Methods in Environmental Monitoring for the Mining Industry in Canada. February.

AETE 2.3.1 1997. Technical Evaluation of Molluscs as a Biomonitoring Tool for the Canadian Mining Industry. March.

AETE 2.3.2 1997. Technical Evaluation of Monitoring Methods Using Macrophytes, Phytoplankton and Periphyton to Assess the Impacts of Mine Effluents on the Aquatic Environment. November.

Water and Sediment Monitoring

AETE 3.1.1 1999. Technical Evaluation on Sample Collection, Handling, Analysis and Interpretation for Trace Level Contamination in Water. January.

AETE 3.1.2 1997. Technical Evaluation on Water Quality and Biological Effects. May.

AETE 3.1.3 1998. Cost-Effective Protocols for the Collection, Filtration and Preservation of Surface Waters for Detection of Metals and Metalloids at ppb (µg/L) and ppt (ng/L) levels. Phase I: Evaluation of Bottle Type, Bottle Cleaning, Filter and Preservation Technique. April.

AETE 3.2.1 1995. Literature Review on the Techniques of Sonar Profiling and Grid Sampling, Using a Grab Sampler for the Identification and Mapping of Lake Sediment Facies for Environmental Effects Monitoring. August.

AETE 3.2.2a 1998. Assessing Aquatic Ecosystems using Pore Waters and Sediment Chemistry. December.

Integrated Studies

AETE 4.1.1 1996. 1995 Field Evaluation of Aquatic Effects Monitoring Methods - Pilot Study. September.

AETE 4.1.2 1996. 1996 Field Evaluation of Aquatic Effects Monitoring Methods (preliminary studies at candidates mine sites). December.

AETE 4.1.2a 1997. Toxicity Assessment of Mining Effluents Using Upstream or Reference Site Waters and Test Organism Acclimation Techniques. July.

AETE 4.1.3 1999. 1997 Field Evaluation of Aquatic Effects Monitoring Methods. March.

AETE 4.1.4 1999. AETE Program Synthesis Report of Selected Technologies for Cost-Effective Environmental Monitoring of Mine Effluent Impacts in Canada. March.

APPENDIX A – MEND CONTRACTORS

MEND CONTRACTORS

PREDICTION/PRÉVISION

1.11.1 Critical Literature Review of Acid Drainage from Waste Rock, April 1991.
Contractors: Northwest Geochem, Vancouver, BC
Morwijk Enterprises Ltd, Vancouver BC

1.12.1b DBARD for Paradox: Developments in DBARD, the Database for Acid Rock Drainage, March 1996.
Contractor: University of British Columbia, Vancouver BC

1.14.2b Sampling and Monitoring Data from the Mine Doyon South Waste Rock Dump (1990 to 1995), March 1994 (revised September 1997).
Contractor: Laval University, Sainte-Foy QC

1.14.2c Heat Transfer during Acid Mine Drainage Production in a Waste Rock Dump, La Mine Doyon (Québec), March 1994 (revised August 1997).
Contractor: Laval University, Sainte-Foy QC

1.14.2d Water Budget for the Waste Rock Dump at La Mine Doyon (Québec) March 1994 (revised August 1997).
Contractor: Laval University, Sainte-Foy QC

1.14.2e Diversité microbiologique dans la production de drainage minier acide à la halde sud de la Mine Doyon, March 1994 (revised August 1997).
Contractor: Laval University, Sainte-Foy QC

1.14.3E Peer Review of MEND Studies Conducted from 1990 to 1994 on Acid Mine Drainage at Mine Doyon South Waste Rock Dump, November 1996.
1.14.3F Revue technique des étude réalisées par NEDEM de 1990 à 1994 sur le drainage minier acide de la halde sud de la mine Doyon, novembre 1996.
Contractors: Geocon, SNC-Lavalin Environment Inc., Montréal QC
Unité de recherche et de service en technologie minérale, Rouyn-Noranda QC
Noranda Technology Centre, Pointe-Claire QC
SENES Consultants Limited, Richmond Hill ON

1.15.2a MINEWALL 2.0 Users Manual, September 1995.
1.15.2b MINEWALL 2.0 - Literature Review and Conceptual Models, September 1995.
1.15.2c Application of MINEWALL 2.0 to three Minesites, September 1995.
Contractor: Morwijk Enterprises Ltd., Vancouver BC

1.16.1a Investigation of Prediction Techniques for Acid Mine Drainage, November 1989.
Contractor: Coastech Research Inc., North Vancouver, BC

1.16.1b Acid Rock Drainage Prediction Manual, March 1991.
Contractor: Coastech Research Inc., North Vancouver, BC

1.16.1c New Methods for Determination of Key Mineral Species in Acid Generation Prediction by Acid-Base Accounting, April 1991.
Contractor: Norecol Environmental Consultants Ltd., Vancouver BC

1.16.3 Determination of Neutralization Potential for Acid Rock Drainage Prediction, July 1996.
Contractor: *University of British Columbia, Vancouver BC*

1.16.4 Evaluation of Static and Kinetic Prediction Test Data and Comparison with Field Monitoring Data, December 1995.
Contractor: *University of British Columbia, Vancouver BC*

1.16.5 Interprétation minéralogique d'essais statiques et cinétiques
Contractor: *COREM, Sainte-Foy PQ*

1.17.1 Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec 1985 Program, July 1986; Phase 2 - 1986 Program, July 1987; Phase 3 - 1987 Program, Volume I Report, May 1988; Phase 3 - 1987 Program, Volume II - Appendices, March 1988; Phase 3 - 1987 Program, Supplementary Report, March 1989; Generation and Evolution of Acidic Pore Waters at the Waite Amulet Tailings - Final Report", April 1990.
Contractors: *Noranda Technology Centre, Pointe-Claire QC*
Natural Resources Canada, Elliot Lake ON
University of Waterloo, Waterloo ON

1.19.1 Long Term Acid Generation Studies: Cinola Project British Columbia, March 1994.
Contractor: *Norecol, Dames and Moore, Vancouver BC*

1.19.2 Scaling Analysis of Acid Rock Drainage, December 1995.
Contractor: *Synergetic Technology, Calgary AB*

1.21.1a Critical Review of the Reactive Acid Tailings Assessment Program (RATAP.BMT2), April 1990.
Contractors: *SENES Consultants Limited, Richmond Hill ON*
Beak Consultants Limited, Brampton ON

1.21.1b Workshop on Modelling of Reactive Tailings Sponsored by the MEND Prediction Committee, Final Report, August 1990.
Contractor: *Kilborn Engineering (BC) Ltd., Vancouver BC*

1.21.2 Laboratory Studies of Pyrrhotite Oxidation, March 1998.
Contractor: *University of Waterloo, Waterloo ON*

1.22.1a Field Procedures Manual: Gas Transfer Measurements, Waste Rock Piles, Heath Steele Mines, New Brunswick, March 1994.
Contractors: *Nolan, Davis and Associates (N.B.) Limited, Fredericton NB*
Australian Nuclear Science and Technology Organization (ANSTO), Australia

1.22.1b Assessment of Gas Transfer-ANSTO Model at Heath Steele Mines, July 1997.
Contractors: *ADI Nolan Davis Inc., Fredericton NB*
Australian Nuclear Science and Technology Organization (ANSTO), Australia

1.25.1 Soilcover Users Manual Version 2.0, December 1996.
Contractor: *University of Saskatchewan, Saskatoon SK*

1.27.1a Guide for Predicting Water Chemistry from Waste Rock Piles, July 1996.
Contractor: *Norecol, Dames & Moore, Vancouver BC*

1.32.1 Prediction and Prevention of Acid Rock Drainage from a Geological and Mineralogical Perspective, October 1993.
Contractor: *National Hydrology Research Institute (Environment Canada), Saskatoon SK*

1.41.4 Whistle Mine Waste Rock Study, December 1997.
Contractors: *Golder Associates, Sudbury ON*
SENES Consultants Limited, Richmond Hill ON

1.42.1 Critical Review of Geochemical Processes and Geochemical Models Adaptable for Prediction of Acidic Drainage from Waste Rock, April 1995.
Contractors: *Noranda Technology Centre, Pointe-Claire QC*
Alberta Research Council, Edmonton AB
University of Western Ontario, London ON

1.44.1 History of Eskay Creek Mine's Waste-Rock Dump from Placement to Disassembly, May 1997.
Contractor: *Minesite Drainage Assessment Group, Vancouver BC*

1.51.1 Quantitative Analysis of Chemical and Biological Kinetics for the Acid Mine Drainage Problem, June 1994.
Contractor: *Synergetic Technology, Calgary AB*

1.51.2 Nonlinear Modelling of Chemical Kinetics for the Acid Mine Drainage Problem and Related Physical Topics, October 1993.
Contractor: *University of Alberta, Edmonton AB*

1.61.1 Roles of Ice, in the Water Cover Option, and Permafrost in Controlling Acid Generation from Sulphide Tailings, November 1996 (revised October 1997).
Contractor: *Natural Resources Canada, Ottawa ON*

1.61.2 Acid Mine Drainage in Permafrost Regions: Issues, Control Strategies and Research Requirements, July 1996.
Contractors: *AGRA Earth & Environmental Limited, Calgary AB*
Morwijk Enterprises Ltd., Vancouver BC

1.61.3 Column Leaching Characteristics of Cullaton Lake B and Shear (S) - Zones Tailings Phase 2: Cold Temperature Leaching, June 1997.
Contractors: *Natural Resources Canada, Elliot Lake ON*
Laurentian University, Sudbury ON

1.62.2 Acid Mine Drainage Behaviour in Low Temperature Regimes-Thermal Properties of Tailings, July 1998.
Contractor: *Norwest Mine Services Ltd., Vancouver BC*

PREVENTION AND CONTROL/PRÉVENTION ET CONTRÔLE

2.11.1a Subaqueous Disposal of Reactive Mine Wastes: An Overview, June 1989.
Contractor: *Rescan Environmental Services Ltd., Vancouver BC*

2.11.1a A Preliminary Assessment of Subaqueous Tailings Disposal in Benson Lake, British Columbia, March 1990.
Contractor: *Rescan Environmental Services Ltd., Vancouver BC*

2.11.1a A Preliminary Assessment of Subaqueous Tailings Disposal in Anderson Lake, Manitoba, March 1990.
Contractor: *Rescan Environmental Services Ltd., Vancouver BC*

2.11.1a A Preliminary Assessment of Subaqueous Tailings Disposal in Mandy Lake, Manitoba, March 1990.
Contractor: *Rescan Environmental Services Ltd., Vancouver BC*

2.11.1b Geochemical Assessment of Subaqueous Tailings Disposal in Buttle Lake, British Columbia, March 1990.
Contractor: *Rescan Environmental Services Ltd., Vancouver BC*

2.11.1b Geochemical Assessment of Subaqueous Tailings Disposal in Anderson Lake, Snow Lake Area, Manitoba, September 1990.
Contractor: *Rescan Environmental Services Ltd., Vancouver BC*

2.11.1b Geochemical Assessment of Subaqueous Tailings Disposal in Mandy Lake, Flin Flon Area, Manitoba, September 1990.
Contractor: *Rescan Environmental Services Ltd., Vancouver BC*

2.11.1c A Preliminary Biological and Geological Assessment of Subaqueous Tailings Disposal in Benson Lake, British Columbia, March 1991.
Contractor: *Rescan Environmental Services Ltd., Vancouver BC*

2.11.1c Chemical Diagenesis of Submerged Mine Tailings in Benson Lake and Natural Sediments in Keogh Lake, Vancouver Island, British Columbia, June 1992.
Contractor: *Rescan Environmental Services Ltd., Vancouver BC*

2.11.1d A Critical Review of MEND Studies Conducted to 1991 on Subaqueous Disposal of Tailings, July 1992.
Contractor: *The Rawson Academy of Aquatic Science, Ottawa ON*

2.11.1e Review of MEND Studies on the Subaqueous Disposal of Tailings (1993-95), May 1996.
Contractor: *P.G. Sly, Picton ON*

2.11.2a Literature Review Report: Possible Means of Evaluating the Biological Effects of Subaqueous Disposal of Mine Tailings, March 1993.
Contractor: *INRS-Eau, Sainte-Foy QC*

2.11.3abc Geochemical Assessment of Subaqueous Tailings Disposal in Anderson Lake, Manitoba. 1993-1995 Study Program, August 1996.
Contractors: *Rescan Environmental Services Ltd., Vancouver BC*
Analytical Service Laboratories Limited, Vancouver BC
University of British Columbia, Vancouver BC

2.11.4a Geochemical Assessment of Subaqueous Tailings Disposal in Buttle Lake, British Columbia. 1993 Study Program. May 1995.
Contractors: *Rescan Environmental Services Ltd., Vancouver BC*
Analytical Service Laboratories Limited, Vancouver BC
University of British Columbia, Vancouver BC

2.11.5ab Shallow Water Covers - Equity Silver Base Information on Physical Variables, May 1996.
Contractor: *Hay & Company Consultants Inc., Vancouver BC*

2.11.5c Geochemical Assessment of the Equity Silver Tailings Pond, August 1996.
Contractor: *Rescan Environmental Services Ltd., Vancouver BC*

2.11.9 Design Guide for the Subaqueous Disposal of Reactive Tailings in Constructed Impoundments, March 1998.
Contractors: *Lorax Environmental Services Ltd., Vancouver BC*
University of British Columbia, Vancouver BC
Hay & Company Consultants Inc., Vancouver BC
Bruce Geotechnical Services, Vancouver BC
Mehling Environmental Services, Vancouver BC

2.12.1a Evaluation of Man-Made Subaqueous Disposal Option as a Method of Controlling Oxidation of Sulphide Minerals – Synopsis Report
Contractor: *SENES Consultants, Richmond Hill ON*
University of British Columbia, Vancouver BC

2.12.1b Evaluation of Man-Made Subaqueous Disposal Option as a Method of Controlling Oxidation of Sulphide Minerals – Background and General Description
Contractor: *Golder Asssociés Ltée, Pointe-Claire PQ*

2.12.1c Subaqueous Disposal of Reactive Mine Tailings – Louvicourt Mine Test Cells – Geochemical Sampling and Analysis – Final Report
Contractor: *INRS – Eau, Sainte-Foy PQ*

2.12.1d Reactivity Assessment and Subaqueous Oxidation Rate Modelling for Louvicourt Tailings
Contractor: *Noranda Technology Centre, Pointe-Claire QC*

2.12.1e Evaluation of Man-Made Subaqueous Disposal Option as a Method of Controlling Oxidation of Sulphide Minerals: Column Studies – Final Report
Contractor: *Natural Resources Canada, Ottawa ON*

2.13.1a Wet Barriers on Pyritic Uranium Tailings - Part I and II - Laboratory Lysimeter Studies of Oxidation and Limestone Neutralization Characteristics of Uranium Tailings and Waste Rock, January 1998
Contractor: *Natural Resources Canada, Elliot Lake ON*

2.13.1b Wet Barriers on Pyritic Uranium Tailings - Part III - Laboratory Diffusion Lysimeter Studies of Uranium Tailings Deposited under a Shallow Water Cover, January 1998
Contractor: *Natural Resources Canada, Elliot Lake ON*

2.13.2a Expérimentation de l'inondation du parc à résidus miniers – Solbec-Cupra (Phase IV). Rapport sommaire, Décembre 1993.
Contractor: *Roche Ltée, Groupe-conseil, Sainte-Foy QC*

2.13.2b Flooding of a Mine Tailings Site – Solbec-Cupra. Suspension of Solids: Impact and Prevention, March 1994.
Contractor: *McGill University, Montréal QC*

2.13.2c Inondation artificielle du parc à résidus miniers Solbec-Cupra: Études microbiologique et chimique - Rapport final, Mars 1994.
Contractor: *Laval University, Sainte-Foy QC*

2.13.2d Suivi environnemental du pars à résidus minier Solbec - 1994-1997
Contractors: *Les Consultants S.M. inc., Sherbrooke PQ*
University of Western Ontario, London ON

2.15.1a Flooding of Pre-Oxidized Mine Tailings: Mattabi Case Study, June 2000.
Contractor: *Noranda Technology Centre, Pointe-Claire QC*

2.15.1b Laboratory Studies of Shallow Water Cover on Reactive Tailings and Waste Rock: Part 1- Oxidation and Leaching Characteristics
Contractor: *Natural Resources Canada, Ottawa ON*

Laboratory Studies of Shallow Water Cover on Reactive Tailings and Waste Rock: Part 2 - Roles of Oxygen Limiting Barriers and Water Flows
Contractor: *Natural Resources Canada, Ottawa ON*

Laboratory Studies of Shallow Water Cover on Reactive Tailings and Waste Rock: Part 3 - Mobility of Mine Tailings under Wave Action
Contractors: *National Research Council, Ottawa ON*
Natural Resources Canada, Ottawa ON

2.15.3 Laboratory Study of Particle Resuspension, Oxidation and Metal Release in Flooded Mine Tailings, November 1998.
Contractor: *University of Western Ontario, London ON*

2.17.1 Review of use of an Elevated Water Table as a Method to Control and Reduce Acidic Drainage from Tailings, March 1996.
Contractor: *SENES Consultants Limited, Richmond Hill ON*

2.18.1 Review of Water Cover Sites and Research Projects, September 1997.
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APPENDIX C – MEND REPORTS

PREDICTION/PRÉVISION

1.11.1 Critical Literature Review of Acid Drainage from Waste Rock, April 1991. $25

1.12.1b DBARD for Paradox: Developments in DBARD, the Database for Acid Rock Drainage, (6 diskettes included) March 1996. $25

1.14.2b Sampling and Monitoring Data from the Mine Doyon South Waste Rock Dump (1990 to 1995)(diskette included), March 1994 (revised September 1997). $35

1.14.2c Heat Transfer during Acid Mine Drainage Production in a Waste Rock Dump, La Mine Doyon (Quebec), March 1994 (revised August 1997). $15

1.14.2d Water Budget for the Waste Rock Dump at La Mine Doyon, (Quebec), March 1994 (revised August 1997). $20

1.14.2e Diversité microbiologique dans la production de drainage minier acide à la halde sud de la Mine Doyon, March 1994 (revised August 1997). $25

1.14.3E Peer Review of MEND Studies Conducted from 1990 to 1994 on Acid Mine Drainage at Mine Doyon South Waste Rock Dump, November 1996. $35

1.14.3F Revue technique des étude réalisées par NEDEM de 1990 à 1994 sur le drainage minier acide de la halde sud de la mine Doyon, novembre 1996. $35

1.15.2a MINEWALL 2.0 Users Manual (diskette included), September 1995. $30

1.15.2b MINEWALL 2.0 - Literature Review and Conceptual Models, September 1995. $25

1.15.2c Application of MINEWALL 2.0 to Three Minesites, September 1995. $25

1.16.1a Investigation of Prediction Techniques for Acid Mine Drainage, November 1989. $25

1.16.1b Acid Rock Drainage Prediction Manual, March 1991. $40

1.16.1c New Methods for Determination of Key Mineral Species in Acid Generation Prediction by Acid-Base Accounting, April 1991. $25

1.16.2a Interlaboratory Measurement Program for the Standard ARD Material NBM-1, July 1994 (Report only). Reference material ($95 CDN for 100g) available from the Canadian Certified Reference Material Program - tel: 613-995-4738 fax: 613-943-0573 (Copy of the report also comes with purchase of reference materials).

1.16.3 Determination of Neutralization Potential for Acid Rock Drainage Prediction, July 1996. $40

1.16.4 Evaluation of Static and Kinetic Prediction Test Data and Comparison with Field Monitoring Data, December 1995. $25

1.17.1a Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec 1985 Program, July 1986. $25

1.17.1b Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, Phase 2 - 1986 Program, July 1987. $25

1.17.1cV.1 Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, Phase 3 - 1987 Program, Volume I Report, May 1988. $25

1.17.1cV.2 Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, Phase 3 - 1987 Program, Volume II - Appendices, March 1988. $25

1.17.1c Sup Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, Phase 3 - 1987 Program, Supplementary Report, March 1989. $25

1.17.1d Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, "Generation and Evolution of Acidic Pore Waters at the Waite Amulet Tailings - Final Report", April 1990. $60

1.19.1 Long Term Acid Generation Studies: Cinola Project British Columbia (includes diskette), March 1994. $35

1.19.2 Scaling Analysis of Acid Rock Drainage, December 1995. $25

1.21.1a Critical Review of the Reactive Acid Tailings Assessment Program (RATAP.BMT2), April 1990. $30

1.21.1b Workshop on Modelling of Reactive Tailings Sponsored by the MEND Prediction Committee, Final Report, August 1990. $40

1.21.2 Laboratory Studies of Pyrrhotite Oxidation, March 1998. $35

1.22.1a Field Procedures Manual: Gas Transfer Measurements Waste Rock Piles Heath Steele Mines New Brunswick, March 1994. $30

1.22.1b Assessment of Gas Transfer-Ansto Model at Heath Steele Mines, July 1997. $40

1.25.1 Soilcover Users Manual Version 2.0 (includes diskettes), December 1996. $40 (Version 1.0 also available). Version 4.0 (Windows) is available from: Greg Newman, Geo-Analysis 2000 Ltd., 202 Kerr Rd., Saskatoon, Canada, S7N 3L9, E-Mail: GEO2000@the.link.ca

1.27.1a Guide for Predicting Water Chemistry from Waste Rock Piles, July 1996. $35

1.32.1 Prediction and Prevention of Acid Rock Drainage from a Geological and Mineralogical Perspective, October 1993. $35

1.41.4 Whistle Mine Waste Rock Study (2 volumes), December 1997. $50

1.42.1 Critical Review of Geochemical Processes and Geochemical Models Adaptable for Prediction of Acidic Drainage from Waste Rock, April 1995. $30

1.44.1 History of Eskay Creek Mine's Waste-Rock Dump from Placement to Disassembly, May 1997. $40

1.51.1 Quantitative Analysis of Chemical and Biological Kinetics for the Acid Mine Drainage Problem, June 1994. $30

1.51.2 Nonlinear Modelling of Chemical Kinetics for the Acid Mine Drainage Problem and Related Physical Topics, October 1993. $25

1.61.1 Roles of Ice, in the Water Cover Option, and Permafrost in Controlling Acid Generation from Sulphide Tailings, November 1996 (revised October 1997). $20

1.61.2 Acid Mine Drainage in Permafrost Regions: Issues, Control Strategies and Research Requirements, July 1996. $25

1.61.3 Column Leaching Characteristics of Cullaton Lake B and Shear (S) - Zones Tailings Phase 2: Cold Temperature Leaching, (diskette included) June 1997. $35

1.62.2 Acid Mine Drainage Behaviour in Low Temperature Regimes-Thermal Properties of Tailings, July 1998. $30

Associate Projects/Projets associés

PA-1 Hydrogeology of Waste Rock Dumps, July 1995. $20

PA-2 Metal Transport and Immobilization at Mine Tailings Impoundments, March 1997. $30

PREVENTION AND CONTROL/PRÉVENTION ET CONTRÔLE

2.11.1a Subaqueous Disposal of Reactive Mine Wastes: An Overview, June 1989. $25

2.11.1a Ben A Preliminary Assessment of Subaqueous Tailings Disposal in Benson Lake, British Columbia, March 1990. $25

2.11.1a And A Preliminary Assessment of Subaqueous Tailings Disposal in Anderson Lake, Manitoba, March 1990. $25

2.11.1a Man A Preliminary Assessment of Subaqueous Tailings Disposal in Mandy Lake, Manitoba, March 1990. $25

2.11.1b Geochemical Assessment of Subaqueous Tailings Disposal in Buttle Lake, British Columbia, March 1990. $25

2.11.1b And Geochemical Assessment of Subaqueous Tailings Disposal in Anderson Lake, Snow Lake Area, Manitoba, September 1990. $25

2.11.1b Man Geochemical Assessment of Subaqueous Tailings Disposal in Mandy Lake, Flin Flon Area, Manitoba, September 1990. $25

2.11.1c A Preliminary Biological and Geological Assessment of Subaqueous Tailings Disposal in Benson Lake, British Columbia, March 1991. $25

2.11.1c Keo Chemical Diagenesis of Submerged Mine Tailings in Benson Lake and Natural Sediments in Keogh Lake, Vancouver Island, British Columbia, June 1992. $25

2.11.1d A Critical Review of MEND Studies Conducted to 1991 on Subaqueous Disposal of Tailings, July 1992. $25

2.11.1e Review of MEND Studies on the Subaqueous Disposal of Tailings (1993-95), May 1996. $25

2.11.2a Literature Review Report: Possible Means of Evaluating the Biological Effects of Sub-Aqueous Disposal of Mine Tailings, March 1993. $25

2.11.3abc Geochemical Assessment of Subaqueous Tailings Disposal in Anderson Lake, Manitoba. 1993-1995 Study Program, August 1996. $50

2.11.4a Geochemical Assessment of Subaqueous Tailings Disposal in Buttle Lake, British Columbia. 1993 Study Program. May 1995. $40

2.11.5ab Shallow Water Covers - Equity Silver Base Information Physical Variables (diskette included) , May 1996. $35

2.11.5c Geochemical Assessment of the Equity Silver Tailings Pond, August 1996. $35

2.11.9 Design Guide for the Subaqueous Disposal of Reactive Tailings in Constructed Impoundments, March 1998. $50

2.12.1c Subaqueous Disposal of Reactive Mine Tailings Louvicourt Mine Test Cells Geochemical Sampling and Analysis, February 2001. $40.

2.12.1d Reactivity Assessment and Subaqueous Oxidation Rate Modelling for Louvicourt Tailings, March 2001. $40

2.12.1e Evaluation of Man-Made Subaqueous Disposal Option as a Method of Controlling Oxidation of Sulfide Minerals: Column Studies (CD included), March 2001. $40

2.13.2a Expérimentation de l'inondation du parc des résidus miniers - Solbec Cupra (Phase IV). Rapport Sommaire, Décembre 1993. $35

2.13.2b Flooding of a Mine Tailings Site - Solbec Cupra. Suspension of Solids: Impact and Prevention, March 1994. $25

2.13.2c Inondation artificielle du parc de résidus miniers Solbec Cupra: Études microbiologique et chimique - Rapport final, Mars 1994. $35

2.15.1a Flooding of Pre-Oxidized Mine Tailings: Mattabi Case Study, June 2000. $35

2.15.3 Laboratory Study of Particle Resuspension, Oxidation and Metal Release in Flooded Mine Tailings, November 1998. $35

2.17.1 Review of Use of an Elevated Water Table as a Method to Control and Reduce Acidic Drainage from Tailings, March 1996. $35

2.18.1 Review of Water Cover Sites and Research Projects, September 1997. $30

2.20.1 Evaluation of Alternate Dry Covers for the Inhibition of Acid Mine Drainage from Tailings, March 1994. $30

2.21.1 Development of Laboratory Methodologies for Evaluating the Effectiveness of Reactive Tailings Covers (diskette included), March 1992. $40

2.21.2 Field Evaluation of the Effectiveness of Engineered Soil Covers for Reactive Tailings: Volume 1- Laboratory and Field Tests & Volume 2 - University Contracts, October 1993. $60 (both reports)

2.21.3 Review of Soil Cover Technologies for Acid Mine Drainage - A Peer Review of the Waite Amulet and Heath Steele Soil Covers, July 1997. $40

2.22.2a Évaluation en laboratoire de barrières sèches construites à partir de résidus miniers, mars 1996. $30

2.22.2b Études de laboratoire sur l'efficacité de recouvrement construites à partir de résidus miniers, avril 1999. $30

2.22.2c Études sur les barrières sèches construites à partir de résidus miniers, Phase II - Essais en place (inclus disquettes) novembre 1999. $40

2.22.4aE Construction and Instrumentation of a Multi-Layer Cover Les Terrains Aurifères, February 1999. $40

2.22.4aF Construction et instrumentation d'une couverture multicouche au site Les Terrains Aurifères Québec, Canada, février 1999. $40

2.22.4bE Field Performance of the Les Terrains Aurifères Composite Dry Covers, March 2000. $40

2.22.4bF Suivi du Comportement du Recouvrement Multicouche Les Terrains Aurifères, mars 2000. $40

2.23.2ab Hydrologic and Hydrogeologic Evaluation of the Thickened Tailings Disposal System at Kidd Creek Division, Falconbridge Limited, October 1993. $35

2.23.2c The Verification of Modelled Pore Water Movement Within Thickened Tailings Using Tracers at the Falconbridge Limited Kidd Metallurgical Division Timmins, Ontario. May 2000. $35

2.23.2d A Geochemical, Hydrogeological and Hydrological Study of the Tailings Impoundment at the Falconbridge Limited, Kidd Creek Division Metallurgical Site, Timmins, Ontario, October 1995. $35

2.23.3 Investigation of the Porous Envelope Effect at the Fault Lake Tailings Site, May 1995. $40

2.24.1 Manual of Methods Used in the Revegetation of Reactive Sulphide Tailings Basins, November 1989. $20

2.25.1a Reclamation of Sulphide Tailings Using Municipal Solid Waste Compost: Literature Review and Recommendations, July 1992. $25

2.25.1b Reclamation of Sulphide Tailings Using Municipal Solid Waste Compost: Laboratory Studies, June 1995. $35

2.25.3 Evaluation of the Use of Covers for Reducing Acid Generation from Strathcona Tailings, September 1997. $40

2.31.1a Heath Steele Waste Rock Study, Phases I to III, March 1992. $40

2.31.1b Engineering Design and Construction Phase IV - Composite Soil Cover Acid Waste Rock Study Heath Steele Mines, November 1994. $30

2.31.1bMon Monitoring Report Phase IV - Composite Soil Cover Acid Waste Rock Study Heath Steele Mines, March 1996. $35

2.31.1c Monitoring Program 1995-96 Phase V - Composite Soil Cover on Waste Rock Pile 7/12 at Heath Steele, New Brunswick, February 1998. $25

2.32.3a Injection de résidus miniers dans des stériles miniers comme moyen de réduction des effluents acides, janvier 1994. $20

2.34.1 Evaluation of Field-scale Application of a Shotcrete Cover on Acid Generating Rock, September 1996. $30

2.35.2a Evaluation of Techniques for Preventing Acidic Rock Drainage: First Milestone Research Report, October 1993. $35

2.35.2b Evaluation of Techniques for Preventing Acidic Rock Drainage: Final Report, January 1997. $40

2.36.1 Review of In-Pit Disposal Practices for the Prevention of Acid Drainage - Case Studies, September 1995. $40

2.36.2a Hydrogeochemistry of Oxidised Waste Rock from Stratmat Site, N.B., March 1999. $40

2.36.2b Hydrology and Solute Transport of Oxidised Waste Rock From Stratmat Site, N.B. March 1999. $40

2.36.3 Assessing the Subaqueous Stability of Oxidized Waste Rock, April 1999. $40

2.37.1 Blending and Layering Waste Rock to Delay, Mitigate or Prevent Acid Rock Drainage and Metal Leaching: A Case Study Review, April 1998. $40

2.37.2 Methods for Delaying the Onset of Acidic Drainage – A Case Study Review. Final Report, March 2001. $25

2.37.3 Control of Acidic Drainage in Layered Waste Rock: Laboratory Studies and Field Monitoring, September 1997. $40

2.44.1 Microbial Plugging of Uranium Mine Tailings to Prevent Acid Mine Drainage - Final Report, December 1992. $25

2.45.1a Separation of Sulphides from Mill Tailings - Phase I, June 1994. $30.

2.45.2 Separation of Sulphides from Mill Tailings - Field, September 1997. $30.

Associate Projects/Projets associés

APC -1 Subaqueous Deposition of Tailings in the Strathcona Tailings Treatment System, September 1996. $40

TREATMENT/TRAITEMENT

3.11.1 Treatment of Acidic Seepages Using Wetland Ecology and Microbiology: Overall Program Assessment, July 1993. $35

3.12.1a Assessment of Existing Natural Wetlands Affected by low pH, Metal Contaminated Seepages (Acid Mine Drainage), May 1990. $25

3.12.2 Panel Wetlands - A Case History of Partially Submerged Pyritic Uranium Tailings Under Water, February 1993. $35

3.14.1 Review of Passive Systems for Treatment of Acid Mine Drainage, May 1996 (revised 1999). $30

3.21.1a Study on Metals Recovery/Recycling from Acid Mine Drainage, July 1991. $25

3.21.1b Metals Removal from Acid Mine Drainage by Ion Exchange, June 1995. $35

3.21.2a Metals Removal from Acidic Drainage - Chemical Method, March 1996. $20

3.22.1 Canada-Wide Survey of Acid Mine Drainage Characteristics, December 1994, (includes diskette). $40

3.32.1 Acid Mine Drainage - Status of Chemical Treatment and Sludge Management Practices, June 1994. $30

3.42.2a Characterization and Stability of Acid Mine Drainage Treatment Sludges, May 1997. $40

3.42.2b The Effect of Process Parameters and Aging on Lime Sludge Density and Stability, February 1999. $40

MONITORING/SURVEILLANCE

4.1.1 Field Sampling Manual for Reactive Sulphide Tailings, November 1989. $15

4.2.1 Review of Canadian and United States Legislation Relevant to Decommissioning Acid Mine Drainage Sites, September 1993. $25

4.3.1 RTS-1, RTS-2, RTS-3 and RTS-4: Sulphide Ore Tailings Certified Reference Materials, April 1990. Report only. Reference materials ($75.00 each) available from the Canadian Certified Reference Material Program - tel: 613-995-4738 fax: 613-943-0573 (Free copy of the report comes with purchase of reference materials)

4.5.1-1 Review of Waste Rock Sampling Techniques, June 1994. $25

4.5.1-2 Handbook for Waste Rock Sampling Techniques, June 1994. $20

4.5.4 Guideline Document for Monitoring Acid Mine Drainage, October 1997. $40

4.5.4 App Appendix A - Technical Summary Note: Guideline Document for Monitoring Acid Mine Drainage, October 1997. $20 (both for $50).

4.6.1 Applications of Geophysical Methods for Monitoring Acid Mine Drainage, December 1994. $50

4.6.3 Application of Remote Sensing and Geophysics to the Detection and Monitoring of Acid Mine Drainage, September 1994. $30

4.6.5ac A Survey of *In Situ* Oxygen Consumption Rates on Sulphide Tailings: Investigations on Exposed and Covered Tailings, November 1997. $35

4.6.5b A Rapid Kinetic Technique for Measuring Reactivity of Sulphide Waste Rock: The Oxygen Consumption Method, December 1997. $35

4.8.2 Evaluation of an Underwater Monitoring Probe for Locating and Estimating the Impact of Groundwater Discharges to Surface Waters Adjacent to Potential Sources of Acid Mine Drainage, March 1994. $30

Associate Projects/Projets associés

MA-1 Environmental Monitoring of Uranium Mining Wastes Using Geophysical Techniques Phase 1 - A Comparison and Evaluation of Conductivity and Resistivity Methods to Monitor Acid Mine Drainage from Uranium Waste Rock Piles and Tailings Areas, February 1996. $50

TECHNOLOGY TRANSFER/TRANSFERT DE LA TECHNOLOGIE

5.4.2a MEND Manual. Volume 1 – Summary. March 2001. $25

5.4.2b MEND Manual. Volume 2 – Sampling and Analysis. January 2001. $25

5.4.2c MEND Manual. Volume 3 – Prediction. December 2000. $25

5.4.2d MEND Manual. Volume 4 – Prevention and Control. March 2001. $25

5.4.2e MEND Manual. Volume 5 – Treatment. December 2000. $25

5.4.2f MEND Manual. Volume 6 – Monitoring. December 2000. $25

Individual volumes of the MEND Manual are $25.00 each or $100.00 for the complete set of six volumes.

5.4.2CD CD ROM: MEND Manual, July 2001. $100

5.5.1 Reactive Acid Tailings Stabilization (RATS) Research Plan, July 1988. $15

5.6.1 Proceedings - Second International Conference on the Abatement of Acidic Drainage, Montréal, September 16, 17 and 18, 1991 (4 Volumes). $150

5.7.1 1992 Revised Research Plan/Plan de recherche revisé 1992, August 1992. Complimentary

5.8 E Report of Results of a Workshop on Mine Reclamation. Toronto, Ontario, March 10-11, 1994. $20

5.8 F Résultats de l'atelier sur la réhabilitation des sites miniers. Toronto, Ontario, les 10 et 11 mars, 1994. $20

5.8.1 Economic Evaluation of Acid Mine Drainage Technologies (includes diskette), January 1995. $20

5.9 Evaluation Study of the Mine Environmental Neutral Drainage Program (MEND), October 1996. $25

AR -95 1995 Annual Report, June 1996. Complimentary (1991 to 1994 annual reports available on request)

NEW IDEAS/NOUVELLES IDÉES

6.1 Preventing AMD by Disposing of Reactive Tailings in Permafrost, December 1993. $25

6.2 Polymer-Modified Clay as Impermeable Barriers for Acid Mining Tailings, April 1994. $25

6.3 A Critique of Japanese Acid Mine Drainage Technology. April 1994. $35

INTERNATIONAL/E

7.1 Proceedings of the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh 1994. $15

7.2 Proceedings of the Fourth International Conference on Acid Rock Drainage, ICARD, Vancouver 1997. $150

7.2b CD ROM: Proceedings of the Fourth International Conference on Acid Rock Drainage, ICARD, Vancouver 1997. (Includes Plenary Session) $75

MEND WORKSHOP NOTES/NOTES DES ATELIERS $10.00 ea.

W.001 Traitement chimique du drainage minier acide, Val d'Or, septembre 1994

W.002 Chemical Treatment of Acid Mine Drainage, Val d'Or, September 1994

W.003 Economic Evaluation of AMD, Sudbury, November 1994

W.004 Évaluation économique des techniques de traitement du drainage minier acide (DMA), Sudbury, novembre 1994

W.005 Economic Evaluation, "Implications of Long-Term Treatment" and Chemical Treatment of AMD", Vancouver, February 1995

W.006 Acid Mine Drainage Control in the Coal and Metal Mining Industries, Sydney, June 1995

W.007 In-Pit Disposal Practices for AMD Control/Lime Treatment of Acid Mine Drainage, Sudbury, October 1995

W.008 Selection and Interpretation of Chemical Prediction Methods and Mathematical Prediction Methods, Pointe-Claire, December 1995

W.009 Acid Mine Drainage Technology Transfer Workshop, Winnipeg, March 1996

W.010 Dry Covers Technologies Workshop, Sudbury, April 1996

W.011 Monitoring and Waste Management for Acid Mine Drainage, Saskatoon, June 1996

W.012 Water Covers to Prevent Acid Mine Drainage Workshop, Vancouver, September 1996

W.013 The Prediction of Acid Rock Drainage Workshop, Vancouver, November 1996.

W.014 Managing Mine Wastes in Permafrost Zone, Edmonton, May 1997.

W.015 Prevention Technologies for Acid Mine Drainage, Fredericton, November 1997

W.016 Acidic Drainage Workshops, Fredericton, Moncton , March 1998

MEND 2000 WORKSHOP NOTES/NOTES DES ATELIERS NEDEM 2000

BC.01 5th Annual BC MEM - MEND 2000 Metal Leaching /ARD Workshop. *Risk Assessment and Management*. Vancouver, December 1998. $50

BC.02 6th Annual BC MEM - MEND 2000 Metal Leaching/ARD Workshop. *Case Studies, Research Studies and Effects of Mining on Natural Water Bodies* Vancouver, December 1999. $50

BC.03 7th Annual BC MEM – MEND 2000 Metal Leaching/ARD Workshop. *Dry Covers, Predicting Solubility Constraints, Research and New Developments*. Vancouver, November 2000. Available from BC MEM. $80.

ME.01 Assessment and Management of Risks Associated with Metal Leaching and Acid Rock Drainage at Mine Sites. Sudbury, September 1999. $25

ME.02 Case Studies on Wet and Dry Covers for Tailings and Waste Rock. Sudbury, September 1999. $25

ICARD WORKSHOP NOTES/NOTES DES ATELIERS DE LA CONFÉRENCE (VANCOUVER, MAY/JUNE 1997) $25.00 ea.

IW.01 Water Covers and Underwater Disposal.

IW.02 Chemical Prediction Techniques for Acid Rock Drainage.

IW.03 Predictive Models for Acid Rock Drainage.

IW.04 Dry Covers for Mine Tailings and Waste Rock.

IW.05 Treatment of Acid Mine Drainage.

IW.06 Bonding and Security.

IW.07 Waste Rock and Tailings Disposal Technologies.

The Acid Mine Drainage Prevention/Treatment in Coal Mining Workshop notes are not available through MEND. Please contact Kelly Wolfe to purchase the document entitled: Acid Mine Drainage Control & Treatment, 2nd edition at: National Mine Land Reclamation Center, West Virginia University, Box 6064, Morgantown WV, 26506-6064 USA.