The Canadian MEND Program[1]

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ABSTRACT

Sustainable development is a driving force in how the Canadian mining industry approaches its existing and future activities. Progress has been made to advance environmental performance and stewardship to provide benefits to civil society. Technologies are now in place to plan for, open, operate and decommission mine properties in an environmentally acceptable manner, both in the short and long term. Moreover, mining companies, governments and consultants have acquired greater capability to deal with environmental and societal issues such as water contamination from mine wastes, including acid generation.

Acidic drainage remains one of the most significant environmental liabilities facing the mining industry. The Mine Environment Neutral Drainage (MEND) program was the first international, multi-stakeholder initiative to develop scientifically-based technologies to reduce the effect of acidic drainage. The original program and its subsequent initiatives have contributed enormously to the understanding of acidic drainage and how to prevent it. MEND focused the acidic drainage effort and developed a toolbox of technologies that is available to all stakeholders.

MEND is also a partner in the Global Alliance, an international partnership among organizations involved in acidic drainage research. A major undertaking for this alliance is the production of a Global Acid Rock Drainage Guide (GARD Guide) that will be a "state" of the art" reference for the mining industry, regulators, non-government organizations and other stakeholders.

Through the efforts of MEND and other partnership programs, a significant advancement in environmental management has been achieved that has contributed to the long-term sustainability of the mining industry and the environment.

Additional Key Words: consortia, MEND, multi-stakeholder

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INTRODUCTION

Mining with environmental stewardship involves not only optimizing the technical performance of mining and extraction processes to maximize profitability of an operation, but also entails leaving a positive environmental and social legacy. Since the 1970s, there has been recognition of the need to minimize the negative imprint of mining on the natural environment. In the 1980s, a collective approach to problem solving emerged in Canada, with the formation of multi-stakeholder initiatives, or consortia, to address technical issues of national importance. These consortia are models of collaboration among industry, various levels of government, NGOs (non-governmental organizations) and First Nations (i.e. Aboriginal Canadians). The MEND framework was adopted by both Canadian and international programs, such as AETE (Aquatic Effects Technology Evaluation Program), TIME (Toxicological Investigations of Mining Effluents, ADTI (Acid Drainage Technology Initiative - USA). The National Orphaned and Abandoned Mines Initiative (NOAMI) adopted the framework to develop a policy based program for remediation of orphaned and abandoned mine sites in Canada.

Programs are frequently launched to focus research efforts on areas of concern, and also to obtain information for formulating sound policy. It is especially important for environmental issues to ensure that government policy is supported by sound science. The benefits of collaborative programs include the sharing of experiences, and the thorough evaluation of technologies and practices and their incremental improvement.

The Mine Environment Neutral Drainage (MEND) initiative was the first international multi-stakeholder program to develop scientifically-based technologies to reduce the effect of acidic drainage. Central to the success of MEND was the development of a multi-year research strategy based on feedback from an extensive network of Canadian experts.

MEND (1989 – 2009)

Acidic drainage has long been recognized as the largest environmental liability facing the Canadian mining industry. Since 1989, the MEND multi-stakeholder partnership has developed technologies to prevent and control acidic drainage. The initial MEND Program (1989-1997) contributed greatly to the understanding of acidic drainage. Tremendous technical progress was made in the areas of prediction and modelling, prevention and control, disposal technologies, lime treatment, passive treatment and monitoring. In 1998, a three-year program commenced to further verify MEND-developed technologies in the field and to build technology transfer capacity through workshops, reports, and a website. Linkages between Canadian and international industry and government programs were also strengthened. The main activity for 2001 was release of the six-volume MEND Manual, which addressed key acidic drainage issues (MEND 5.4.2). Information from more than 200 technical documents and workshop notes produced under MEND up to 2000 was summarized, or referenced in this manual.

In 2002, a renewed MEND initiative was created that focussed on Canadian national and/or regional information needs, with a strong emphasis on technology transfer. A multi-stakeholder Strategy Session held in 2002 developed a research framework based on four broad research themes; mine waste management practices, emerging challenges, prediction and post-closure management (MEND 8.2). Participants at the session recommended a number of research activities for a multi-year program to advance acidic drainage knowledge across these four fronts. Subsequently, the MEND Network was surveyed to help define research priorities. Top priorities

were identified as closure management, verification of technologies, metal leaching, passive treatment, early prediction and sludge management. Strong support was also given for research on cold temperature effects, paste backfill and monitoring methodologies. The need for guidance documents and technology transfer activities (e.g. workshops, updates on emerging technologies) was identified as a crosscutting issue within each of the themes. In contrast to the earlier MEND work related to control and limitation of liabilities, there was a shift to recognition of environmental and sustainable development issues.

Since 2003, the MEND Steering Committee has developed an annual work plan to address these key research priorities. Many of these new projects re-examine issues and re-visit sites that were the subject of earlier MEND studies. Advances in technologies and knowledge make it timely to re-examine some of these issues. As well, several of the new projects verify the full-scale application of MEND supported technologies, and investigate their long-term performance. Over the last five years, there has been a shift in some priorities, with a greater interest in cold temperature effects and guidance documents.

A brief overview of the research themes and project descriptions is given below.

Mine Waste Management Practices

Research recommendations under this theme included sludge management, cold temperature effects, paste backfill and passive treatment.

Acidic drainage treatment and sludge management are two important facets of mine site environmental control practices. Sludge production is an increasing concern to the industry as the inventory of sludge continues to grow due to "perpetual pump and treat" operations. Research is needed to explore current sludge management practices, such as long-term sludge disposal options and sludge stability. In addition, opportunities for alternate uses of sludge need to be investigated, such as paste backfill, metal recovery from sludge via smelting, and reuse (e.g. in construction materials). Several projects were untaken in sludge treatment and disposal, stability and re-use.

MEND 3.42.3 *Review of Disposal, Reprocessing and Reuse Options for Acidic Drainage Treatment Sludge* provides a review of technologies related to the management of acidic drainage treatment sludges. The technology areas assessed included conventional disposal technologies such as pond disposal and co-disposal with tailings, and alternative disposal options such as underground sludge disposal. Options for metal recovery and novel sludge reuse technologies were reviewed and sludge stabilization and reclamation applications were documented.

Neutralization Sludge Characterization and Stability (in progress) investigated the geochemical stability of mine-site neutralization sludge disposed in pit lakes through detailed solid-phase characterization. The study highlighted the links between the acidic drainage chemistry and sludge metal-association for several sludge samples.

Currently, there is no single comprehensive treatment and sludge management information system for sites in Canada. Most sites employ some form of chemical treatment to address acidic drainage issues and the type of treatment varies from site to site. MEND 3.43.1 *Acidic Drainage Treatment Operations in Canada – An Interactive Database* (on-going) aims to collect, compile,

manage and interpret information available on acidic drainage treatment and sludge disposal. Information was collected from over 100 sites, using a detailed questionnaire, followed-up with interviews conducted with the site co-ordinators. A comprehensive database, containing an extensive number of parameters, was developed to store the information. This report offers many potential uses and information for treatment processes with respect to planning and guidance.

With the large number of mines opening in Northern Canada, the effect of cold temperature on various technologies is of increasing importance. Oxidation kinetics, permafrost and mine waste management, in cold weather conditions warranted further research. MEND 1.61.4 *Covers for Reactive Tailings Located in Permafrost Regions* gives a brief introduction to permafrost issues and then focuses on covers constructed over reactive tailings in Canadian permafrost regions. Case histories for Nanisivik, Raglan, Lupin and Rankin Inlet are examined, which represent sites with different tailings operations, cover design approaches and physical and climate conditions. MEND 1.61.6 *Cold Temperature Effects on Geochemical Weathering* examines geochemical processes expected to occur differently at low temperatures, or unique to low temperatures. A compilation of fourteen case studies, along with a literature survey, forms the basis of the findings. Progress was made on understanding several mechanisms; however, much of the data was limited and site specific. Main technology gaps were identified, along with opportunities to harness low temperature conditions to limit acidic drainage. MEND 1.61.5a *Northern Soil Covers – Phase I* (in final draft) reviews cold region phenomena that could impact on soil cover performance, including ground freezing, snow-distribution, limits to revegetation, and identifies research priorities to improve soil cover design and construction methods suitable for cold regions. The objective of MEND 1.61.5b *Northern Soil Covers - Phase II* (in progress) is to link the phenomena found in Phase I with actual northern sites where they occur.

Diavik Waste Rock Scale-Up Project is a multi-year collaborative project with the International Network for Acid Prevention (INAP) and several Canadian universities aimed at understanding the scale-up question in cold climates. It assesses the use of small-scale tests in predicting if, and when, low quality drainage may be released from a waste rock pile; and determines the smallest scale at which measurements can be made to provide information that can be used with confidence for predicting the behaviour of full-scale piles. This information will be valuable to mining companies developing management plans for sites. The project has provided useful information on the placement of monitoring instrumentation within a large-scale dump, scale differences in acidic drainage test work and the physical, hydraulic and geochemical properties of a large waste rock dump. The project was to be completed in 2010 but may be extended to allow the collection of more data.

The influence of paste backfill on operational and long-term mine and ground water quality was identified as a priority and MEND completed a summary of current practices in the industry. MEND 10.2 *Paste Backfill Geochemistry - Environmental Effects of Leaching and Weathering* provides a brief summary pertaining to the geochemical characterization of both cemented and uncemented paste backfill, and methods used to predict environmental impacts to surface and ground water quality associated with the application of paste backfill in underground mines. Little information is available on the influence of paste backfill on water quality, as most of the research has focused on the economics and the structural characteristics of paste in terms of meeting the required backfill strength.

Emerging Challenges

At the 2002 Strategy Session, issues around metal mobility were considered "emerging challenges", including; metal leaching in neutral or non-acid conditions; mobility of arsenic, selenium, antimony, molybdenum, nickel, tellurium and thallium; and cost-effective treatment of hard-to-treat elements.

MEND 10.1 *Water Quality Issues in Neutral pH Drainage: Examples and Emerging Priorities for the Mining Industry in Canada* reviewed selected Canadian mining operations to determine priority chemical elements of interest associated with leaching under non-acidic conditions. Molybdenum (Mo) and selenium (Se) were identified as emerging concerns at several mining operations across Canada and recommendations were made for further investigations on their environmental impact. The follow-up report, MEND 10.1.1 *A Review of Environmental Management Criteria for Selenium and Molybdenum,* addressed the gaps for aquatic and terrestrial toxicity issues related to Se and Mo on downstream environmental receptors. The report examined general characteristics of Se and Mo, including typical source profiles, environmental fate and transport, key toxicity effect, select strategies for remediation of soil with plants, and reported thresholds for animals of interest.

Other treatment options for mining effluents, upstream of the lime treatment process or in combination with lime treatment, need to be investigated. Processes such as membrane separation or ion-exchange may be applied to selectively remove metals or other contaminants (i.e. sulphate). Some options may not be cost-effective today, but may be so in the future.

An overview of membrane separation technologies was provided in MEND 3.15.1 *Application of Membrane Separation Technology to Mitigation of Mine Effluent and Acidic Drainage*. Processes such as reverse osmosis and nanofiltration have been applied for treatment of acidic drainage and the removal of metal species and contaminants from mining and industrial effluents. Case studies utilizing membrane separation processes in mining operations were presented, with an emphasis on the cost impacts and improvements on environmental performance.

The mining industry faces challenges for mitigation of historic acid generating tailings. An innovative strategy is explored in the *Evaluation of the Benefits of Encapsulation of Acid-generating Tailings by Acid-consuming Tailings – A Laboratory Study* (in progress). The study is examining the encapsulation of acid-generating tailings between two acid-consuming layers; a strategy that may have wider potential application to the mining industry.

Prediction and Post-Closure Management

The MEND Strategy Session endorsed documenting case studies as a vehicle for technology transfer and a means of comparing predicted and actual field performance. Verification of MEND-developed technologies by long-term monitoring will expand the knowledge base and possibly extend application. Case studies also demonstrate practical experiences with different aspects of metal leaching/acid rock drainage (ML/ARD) mitigation and assessment practices at well-characterized sites. Several MEND projects that look at the field performance and sustainability of various aspects of the prediction and mitigation of drainage chemistry are currently underway or recently completed.

MEND 5.10 (English/French) *List of Potential Information Requirements in ML/ARD Assessments and Mitigation Work* listed potential information requirements and factors to consider for ML/ARD work, and serves as a general guide for the mining industry, consultants, regulators, educators and students, and the public interested or involved in mining issues.

MEND 9.1 *Case Studies of Metal Leaching/Acid Rock Drainage Assessment and Mitigation in British Columbia* illustrated site-specific application of ML/ARD mitigation and assessment at three mine sites in British Columbia with significant ML/ARD concerns: Johnny Mountain Mine, Snip Mine and the Sulphurets project. Site specific issues and key design and performance parameters were outlined, along with constraints, information gaps, errors and their management implications.

MEND 1.70.1 *Investigation of Predictions for Acidic Drainage at the Vangorda Plateau, Faro Mine Complex – Faro, YT* compared pre-development acidic mine drainage modeling predictions, post-operational modeling predictions and actual monitoring data at the Vangorda Plateau. The results of the comparison provide insight into the effectiveness of prediction methodologies and guidance for general application of these methodologies to future mine planning.

MEND 2.12.2 *Assessing the Long-Term Performance of a Shallow Water Cover to Limit Oxidation of Reactive Tailings at Louvicourt Mine* investigated the long-term performance of the shallow water cover in large test cells by comparing data from the 1996 and 2005 sampling campaigns. This study was initiated nine years after the tailings were submerged, and integrates geochemical, mineralogical and biological data to provide an overall assessment of the long-term performance. The impact of periphyton layers, which developed in the interim, on the performance of shallow-water covers was investigated. Results indicated that development of the overlying biofilm was beneficial in preventing metal release to the overlying water column. Further studies at other Canadian sites with a biofilm are to be investigated under the 2009 work plan.

Case Study Review of In-Pit Disposal of Tailings and Waste Rock (in progress) is an update of MEND 2.36.1 *Review of In-pit Disposal Practices for the Prevention of Acid Drainage – Case Studies* (1995). This review will examine the disposal of tailings, waste rock and water treatment sludges in mined-out open pits for a diversity of metal mines. A number of in-pit disposal sites with adequate information on operational, chemical and cost aspects, were identified. Relevant aspects of each case will be detailed, including lessons learned and regulatory aspects.

Case Studies at Canadian Mine Sites

MEND Case Study Assessments assessed and verified the effectiveness of acidic drainage pollution prevention and control techniques at several sites. Prediction methods, prevention and control techniques, monitoring programs, and closure planning were evaluated. In Phase I of the project, three closed sites were assessed: Dona Lake, Mandy Lake and Heath Steele. Phase II included further field studies at Heath Steele, where a water cover was used as closure technology for the tailings impoundment.

BHP Rehabilitation Case Studies (in progress) investigated two sites, Mine Poirier (Joutel, Quebec) and East Kemptville Mine (East Kemptville, Nova Scotia). The long-term performance of the geomembrane liner installed at Poirier in 2000 was investigated. The liner has been

successful at reducing water infiltration into the tailings pile and limiting oxidation of the tailings, thereby reducing the release of acidic drainage and metals to the environment. Two rehabilitation strategies were implemented on the East Kemptville Mine site. Oxidation of the fine tailings was reduced by an elevated water table, and acidic drainage water produced by the coarse tailings and the mine waste rocks was neutralized through a lime treatment plant. Water handling strategies were also introduced to improve process efficiency.

A CD-ROM will be produced in 2009 containing both the *Case Study Assessments* and the *BHP Rehabilitation Case Studies.*

Guidance Documents

MEND 5.4.2 *MEND Manual.* More than 200 technology-based reports were generated by MEND from 1988 to 2000. 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 comprehensive single reference document. The document is not a "How to" manual. It is a complete set of working references for the sampling and analysis, prediction, prevention, control, treatment and monitoring of acidic drainage.

Accurate and timely prediction of metal leaching and acid rock drainage are keys to preventing potential environmental impacts from ML/ARD and minimizing the high costs of mitigation. Prediction of the future characteristics of drainage chemistry is required for all phases of a mine life. Prediction is technically very demanding and prediction methods and results are easily misinterpreted. As a result, specialized geochemical consultants are required to do much of the work. MEND and various jurisdictions have sponsored a project to update and expand the *Draft Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia* (Price, 1997), making it applicable on a national scale. This report, *Prediction of Drainage Chemistry from Sulphidic Geological Materials* (in final review) will be both a "tool-kit" and a critical review of current best-testing procedures.

The manual, MEND 2.21.4 *Design, Construction, and Monitoring of Covers Systems for Waste Rock and Tailings* incorporates and integrates the best available technology for the design and construction of cover systems over mine wastes. The report contains a summary document and four supporting technical volumes: theory and background; site characterization and numerical analyses of cover performance; field performance monitoring; sustainable performance of cover systems; and case studies. It is intended for use by mining personnel and stakeholders interested in cover systems. MEND 2.21.5 *Manual for Macro-Scale Cover Design and Performance Monitoring* introduces design and monitoring guidelines for mine waste soil cover systems on a macro-scale or watershed scale, and discusses challenges that arise due to increased size and complexity as compared to evaluating cover systems on a micro-scale. Macro-scale cover system evolution follows many of the same guidelines and is governed by the same processes as landform evolution. Challenges and lessons learned in tracking cover system evolution and long-term field performance are illustrated. A number of methods and associated instrumentation for macro-scale monitoring are detailed in the manual and appendix.

MEND 2.11.2b *Literature Review Report: Possible Means of Evaluating the Biological Effects of Sub-Aqueous Disposal of Mine Tailings* is an update of MEND 2.11.2a (1993) and reviews the development and application of tools to predict the effects of metals in sediment,

water and food. Several of the tools discussed in 1993 have been validated, and in some cases adopted by regulatory agencies. These include the acid volatile sulphide – simultaneous extracted metals (AVS – SEM) approach to predict the absence of toxicity in anoxic sediments, the biotic ligand model (BLM) to predict waterborne metal toxicity and the dynamic multipathway bioaccumulation model (DYMBAM) that predicts metal bioaccumulation in aquatic organisms.

Technology Transfer

An integral part of MEND is technology transfer - the distribution of information on developed technologies to the partners and the public. Information is transferred through a number of routes. The MEND web site at **http://mend.nrcan.gc.ca** (currently under construction) is regularly updated with report summaries, a publication list, case studies, newsletters, workshop and conference announcements and links to other relevant initiatives. Workshops are an effective vehicle to transfer information, and MEND hosts one or two workshops each year. The BC-MEND Annual ARD/ML Workshop selects one research theme each year - one that reflects current practices, new research technologies and developments and is relevant to the times. Participants have a strong interest in field-test results and case studies, so these are always included in the sessions. Themes in recent years were performance of dry covers (2004), prediction of drainage chemistry (2005) and open pits and underground workings (2006), collection and treatment of mine drainage (2007), and most recently, management of tailings and tailings impoundments (2008). Workshops in other parts of Canada focus on issues of regional concern, such as sludge management, tailings disposal, neutral pH drainage, site remediation and case studies on mitigation technologies.

MEND technical reports are available from the MEND Secretariat in paper and/or CD ROM versions. Over 160 of the 200 MEND technical documents (covering 1988-2000) are available on three CD-ROMs. In addition, the workshop proceedings are available in CD-ROM.

GLOBAL ALLIANCE

The International Network for Acid Prevention (INAP) was formed in 1998 by a number of international mining companies dedicated to reducing the liabilities associated with sulphide-bearing mine materials. In 2002, INAP formally proposed the concept of an international model of interaction among the various organizations involved in acidic drainage research. The alliance brings numerous benefits to the partners, including additional resources, minimization of research duplication, worldwide links and enhanced technology transfer capabilities. Present partners are INAP, MEND, Acid Drainage Technology Initiative (ADTI-US), Australian Centre for Minerals Extension and Research (ACMER-Australia), Partnership for Acid Drainage Remediation in Europe (PADRE-Europe) and the Water Research Commission (WRC- South Africa). The alliance is currently searching for partners in South America and Asia.

An immediate benefit to the alliance is a greater understanding of the activities of each organization and possible joint support of projects that are of mutual interest. For example, INAP's Diavik Waste Rock Scale-Up project receives support by the MEND program.

A major undertaking for INAP and the Global Alliance is the production of a Global Acid Rock Drainage Guide (GARD Guide) that will be a "state of the art" reference for the mining industry, regulators, NGO's and other stakeholders. Current best practice in the management of contaminants produced by sulphide mineral oxidation will be consolidated to produce a guide

that will be up to date and global in scope. The Guide will address the production of contaminants from sulphide mineral oxidation that can result in ARD, neutral mine drainage and saline mine drainage. It will apply to the entire mining industry and all commodities produced by mining including base metals, coal, iron ore, gold, diamonds and uranium, and will cover all phases of an operation from initial discovery through to post-closure.

Golder Associates, Inc. was contracted to develop the GARD Guide, and assembled an international team of experts to compile this multi-chaptered document. After extensive internal and external peer review, the "Wiki" GARD Guide will be officially launched at the 8th ICARD, June 2009. The "Wiki" GARD Guide will be publicly accessible from the INAP web site (www.inap.com.au), and will be updated regularly. Secretariat services for the GARD Guide are provided by the MEND Office.

CONCLUSIONS

MEND continues to be a model of collaboration among industry, different levels of government and NGOs. The MEND program has provided a focus to develop solutions for environmental problems that face the mining industry across Canada and internationally. Through the 20 years of the MEND program, a significant reduction in environmental liability has been achieved. MEND is now recognized world-wide for its contribution to the long-term sustainability of the industry and the environment.

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