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TECHNICAL COMMUNICATION

The Global Acid Rock Drainage Guide (GARD Guide)

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Abstract The International Network for Acid Prevention (INAP) has consolidated relevant information and produced a global acid rock drainage (ARD) guide (GARD Guide) that summarizes the best technical and management practices for industry and stakeholder use. The Guide provides a structured system to identify proven techniques for characterization, prediction, monitoring, treatment, prevention, and management of ARD. It will help industry to provide high levels of environmental protection, support government efforts in assessing and regulating mine reclamation, and enable the public to gain a higher degree of understanding of acid prevention plans and practices. This paper describes the organization and content of the internet-based GARD Guide. ARD management strategies are outlined to show GARD Guide principles in practice. Finally, the path forward for the GARD Guide is presented.

Keywords AMD · ARD · Assessment and management · Characterization · GARD Guide · Global Alliance · International Network for Acid Prevention · Mine waste · Mitigation · Monitoring · Oxidation · Prediction · Sulphide · Treatment

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Introduction

Research on the formation of acid rock drainage (ARD) and methods to minimize its impact has been going on for more than 50 years. Progress has accelerated over the last 20 years as interest in the topic has grown. Hence, there is considerable scientific and technical information available on ARD through organizations such as the International Network for Acid Prevention (INAP), Mine Environment Neutral Drainage (MEND), the International Mine Water Association (IMWA), the Acid Drainage Technology Initiative (ADTI), the Australian Centre for Minerals Extension and Research (ACMER), the South African Water Research Commission (WRC), and the Partnership for Acid Drainage Remediation in Europe (PADRE). However, this research is generally only available through disparate references and some of it is not easily accessible. Many examples and case studies of ARD prediction and mitigation have been completed in the last 20 years that strengthen the more fundamental ARD scientific research. Knowledge gained from both positive and negative field results contributes greatly to current and future ARD management plans. The transparency of these studies enhances the credibility of ARD investigations. Application of ongoing science and engineering research supports continual improvement in ARD management.

The Global Acid Rock Drainage Guide (INAP 2009) or GARD Guide aims to consolidate the best technical and

management practices into a guide with high industry and external stakeholder credibility. The Guide has been prepared as a road map through the process of evaluating, planning, designing, and managing ARD over the life cycle of mining. It provides a structured system to identify proven techniques for characterization, prediction, monitoring, treatment, prevention and management of ARD. It will help industry to provide high levels of environmental protection, support government efforts in assessing and regulating mine reclamation, and enable the public to gain a higher degree of understanding of acid prevention plans and practices.

At present, it provides a broad, but not highly detailed, understanding of ARD technologies and management. However, a comprehensive ARD management plan can be developed using the concepts and guidance in the GARD Guide supplemented by more specific references and technical and site-specific knowledge. The GARD Guide also provides numerous references to help interested readers find more detailed information on ARD technologies and management options.

The following are specific objectives of the GARD Guide:

1. Describe issues associated with sulphide mineral oxidation.
2. Expand best global ARD management practices.
3. Promote a risk-based reduction and control of ARD at the source.
4. Leverage the world's ARD expertise by sharing it with developing countries.
5. Achieve 'global best practice' in future mining projects.

The GARD Guide deals with the management of drainage produced from sulphide mineral oxidation, encompassing acid rock drainage (ARD), saline drainage (SD), acid mine drainage or acid and metalliferous drainage (AMD), and neutral mine drainage (NMD). The GARD Guide also addresses metal leaching caused by sulphide mineral oxidation. While focused on mining, the technology described is relevant to encounters and exposure of sulphide minerals due to other activities (e.g. rock cuts, excavations, tunnels). Some of the approaches in the GARD Guide are also relevant to issues arising from reactive non-sulphide minerals.

Development of the GARD Guide was sponsored by INAP with the support of the Global Alliance, and started in late 2006. The GARD Guide was created through the contributions of many individuals and organizations. A team led by Golder Associates prepared a draft of the Guide in 2008. INAP also received input from other contributors, peer reviewers, workshop participants, and interested stakeholders. INAP gratefully acknowledges all of this assistance.

The GARD Guide approach proceeds from site characterization to preparation, and ultimately implementation of an ARD management plan (Fig. 1). It includes a loop for verification and calibration of predictions and assessments as part of evaluating the performance of the management plan. ARD management is applied at all phases of a mine, from exploration to post closure, as part of an environmental management system (EMS), which includes a continuous improvement process. This approach to ARD management also provides the framework for the various technical chapters in the GARD Guide, and is discussed in the next section of the paper.

An ARD management plan is based on technical understanding and knowledge, but is defined within corporate policies, government regulations, and community expectations. The plan is based on site characterization and ARD prediction science and incorporates engineering measures aimed at ARD prevention and control. Water treatment may be included as a contingency, or as a necessity for existing mines, in the plan.

Implementation of an ARD management plan requires the use of management systems and communication between stakeholders. A plan's performance is monitored through a range of mine operating and environmental metrics, including the evaluation of mine water quality. The overall performance of ARD management is evaluated against site-specific environmental requirements and the criteria established by corporate policies, government standards, and community expectations. Accordingly, the ARD management process is a continuous loop.

The level of assessment and planning for each phase of mining varies based on the information available, the extent of rock excavation, and the potential environmental impact. For example, relatively little disturbance and excavation of rock potentially containing sulphide minerals usually occurs during exploration. However, ARD management plans are required for exploration drilling, bulk samples, and test pits/underground workings. A poorly planned exploration drilling program could cause long-term ARD problems through disturbance of natural ground water conditions and provision of new vertical flow paths. In addition, site characterization, including ore and waste characterization and ARD prediction, must begin at the start of mineral exploration.

With its potentially wide-ranging and multigenerational consequences, ARD is an important 'sustainable development' or 'sustainability' issue. Environmental impacts of ARD can be serious and enduring. Depending on where a mine operates, ARD can also impact the well-being of people surrounding the mine, now and in the future. Poor management of ARD not only can harm the environment, but also the mining industry's reputation and communities' acceptance of individual mining operations. Applying the concept of

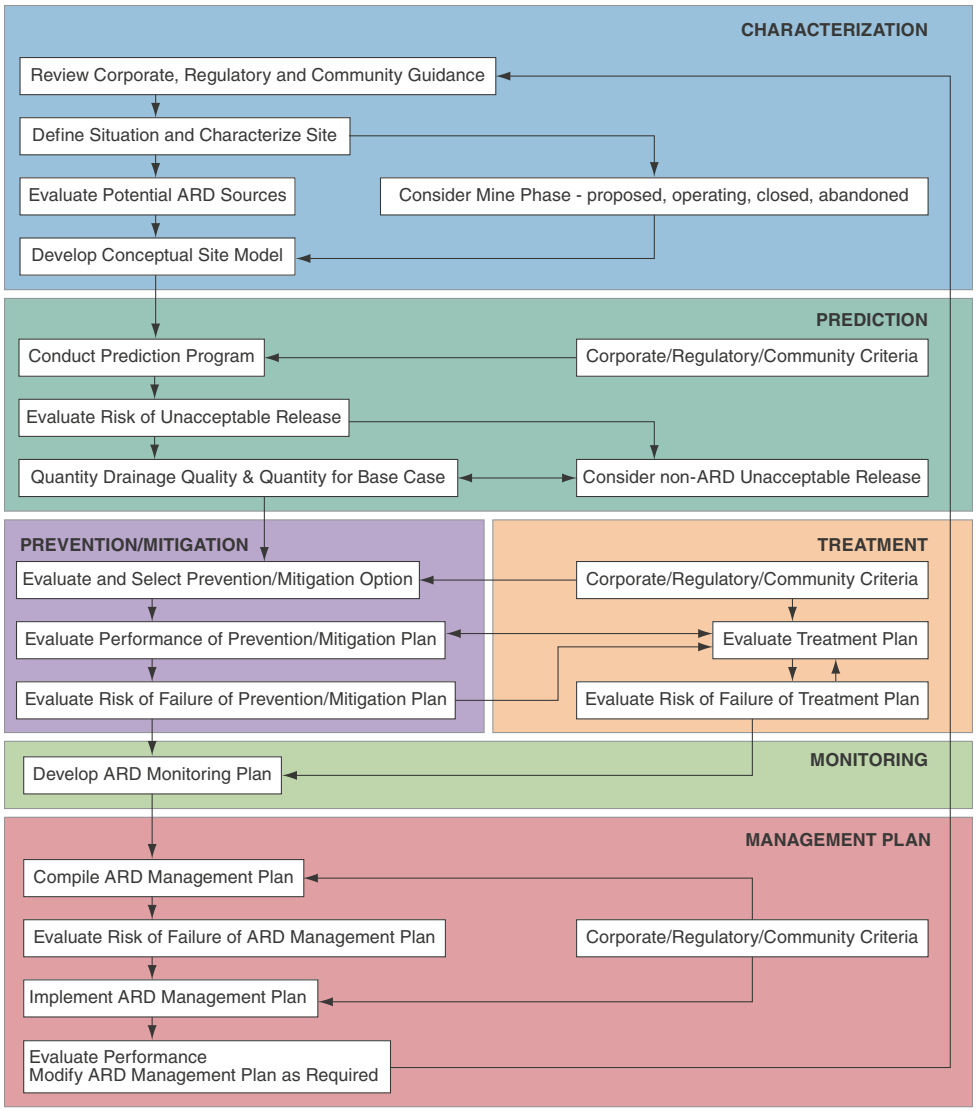

Fig. 1 An overall ARD management flow chart

sustainable development, on the other hand, offers an opportunity to involve multiple stakeholders in ARD management, improve risk management, and optimize the economic and social benefits of a mining operation.

In practice, sustainable development requires an integrated, balanced, and responsible approach that accounts for short-term and long-term environmental, social, economic, and governance considerations. These considerations were used as guiding principles throughout the Guide. The Guide is neither a stand alone document nor a substitute for specialist involvement; expert support from multiple disciplines is required for proper ARD management.

GARD Guide Content

The GARD Guide has 11 chapters. The chapters are presented in an organized fashion, addressing all aspects related to ARD management while building on each other. Considerations related to sustainable development are woven throughout the guide. The framework for the technical chapters in the guide is shown in Fig. 1. The technical elements are linked, leading to the development of an ARD management plan. Successful integration and implementation of ARD management within an overall mine development plan is a key objective of the GARD Guide. The contents of each chapter are summarized below.

Chapter 1—Introduction

The Introduction sets the stage for the GARD Guide by explaining its objectives, introduces the GARD Guide terminology and definitions, and provides general background. The chapter establishes that a comprehensive approach to ARD management reduces environmental risks and subsequent costs for the mining industry and governments,

reduces adverse environmental impacts, and promotes public support for mining. An ARD management plan is site-specific and must address many factors, not just a project's ARD potential.

Chapter 2—ARD Process

Chapter 2 summarizes the process of sulphide oxidation and formation of ARD. This process is very complex and involves a multitude of chemical and biological aspects that can vary significantly depending on environmental, geological, and climatic conditions. Since neutralization as well plays a key role in determining ARD composition, these reactions are also addressed in this chapter, as is metal leaching, which can occur under acidic, neutral, or alkaline conditions.

Chapter 3—Corporate, Regulatory and Community Aspects

In this chapter, corporate, regulatory, and community aspects related to ARD are identified and summarized. Several examples are provided of corporate guidelines pertaining to ARD management and governmental regulations. The issues relating to ARD prevention and management are the same around the world. However, the specific techniques used for ARD prediction, interpretation of ARD test results, and ARD management may differ depending on the local, regional, or national context. Variations related to climate, topography, and other site conditions also modify the management approach. Furthermore, mining companies operate within the constraints of a 'social license' that, ideally, is based on a broad consensus with all stakeholders. This consensus tends to cover a broad range of social, economic, and environmental elements as well as governance requirements. ARD plays an important part in the mine's social license due to the fact that ARD can be one of the more visible and long-lasting environmental consequences of mining.

Chapter 4—Characterization

Environmental concern depends largely on the characteristics of the sources, pathways, and receptors involved. Characterization of these aspects is therefore crucial to the prediction, prevention and management of ARD. Environmental characterization programs are designed to collect sufficient data to answer a number of questions, including:

1. Is ARD likely to occur? What type of drainage is expected?
2. What are the sources of ARD? How much ARD will be generated and when?
3. What significant pathways transport contaminants to the receiving environment?
4. What are the anticipated environmental impacts of ARD release to the environment?
5. What can be done to prevent or mitigate/manage ARD?

Chapter 4 addresses these questions by presenting an ARD characterization program that identifies and describes the data collection activities required during each mine phase. These activities are defined for each source, pathway, and receptor, and for individual material types and mine facilities.

Chapter 5—Prediction

One of the main objectives of site characterization is prediction of ARD potential and drainage chemistry. Prediction is directly linked to water and mine waste management aspects of mine planning. Therefore, the prediction effort needs to be phased in step with overall project planning, and the mine plan should reflect elements to prevent ARD formation.

Significant advances in the understanding of ARD have been made over the last few decades, with parallel advances in mine-water quality prediction and use of prevention techniques. Quantitative mine-water quality prediction can be challenging due to the wide array of the reactions involved and potentially very long time periods over which these reactions take place. Despite these uncertainties, quantitative predictions that have been developed using realistic assumptions (while recognizing associated limitations) have proven to be of significant value for identification of ARD management options and assessment of potential environmental impacts. Chapter 5 includes guidance on generic, comprehensive approaches for ARD prediction, as well as more detail regarding individual geochemical testing methods and modelling techniques appropriate for both coal and hard rock mines.

Chapter 6—Prevention and Mitigation

ARD prevention applies a planning and design process to prevent, inhibit, or retard the hydrological, chemical, physical, or microbiological processes that produce ARD. Prevention should occur at the source. Measures to prevent or retard the rate of generation or the transport of the ARD to the water resource (i.e. recycling, treatment, and/or secure disposal) can be effective at mitigating ARD. These principles are universally applicable, but methods of implementation are site specific.

The GARD Guide advocates a risk-based approach to planning and design as the basis for prevention and mitigation.

This approach must be applied throughout the mine-life cycle. The risk-based process aims to quantify the long-term impacts of alternatives and to use this knowledge to select the option that has the most desirable combination of attributes (e.g. protectiveness, regulatory acceptance, community approval, and cost). Mitigation measures implemented as part of an effective control strategy should require minimal active intervention and management. More than one, or a combination of measures, may be required to achieve the desired objective. Chapter 6 includes an overview of the most common ARD prevention and mitigation measures available during the various stages of the mine-life cycle.

Chapter 7—Treatment

Sustainable mining requires the mitigation, management, and control of mining impacts on the environment. Such impacts on water resources can be long term and persist in the post-closure situation. Mine drainage treatment may be a component of overall mine water management to support a mining operation over its entire life.

The objectives of mine drainage treatment are varied. Recovery and re-use of mine water within the mining operations may be desirable or required for processing of ores and minerals, conveyance of materials, or other operational uses (e.g. dust suppression, cooling, or irrigation of rehabilitated land). Another objective of mine water treatment is the protection of human and ecological health in cases where people or ecological receptors may come in contact with the impacted mine water through indirect or direct use. In Chapter 7, an overview of treatment alternatives is presented, including a presentation of information requirements and the benefits and disadvantages of individual treatment techniques, including passive treatment technology.

Chapter 8—Monitoring

Monitoring is the process of routinely, systematically, and purposefully gathering information for use in making management-decisions. Mine-site monitoring aims to identify and characterize any environmental changes due to mining activities on the site and associated possible impacts to receptors. It is critical in ARD management decisions and in assessing the effectiveness of mitigation measures and subsequent. Chapter 8 presents and discusses the development and components of an ARD monitoring program, including the definition of monitoring objectives, the design and implementation of a monitoring program, the evaluation of results, and the use of feedback systems to ensure that the monitoring program meets its intended objective.

Chapter 9—Management and Performance Assessment

Chapter 9 focuses on ARD management and performance assessment, and their various aspects commonly included in an ARD management plan. The need for a formal ARD management plan is usually triggered by the results of an ARD characterization and prediction program or the results of site monitoring. The ARD management plan identifies the materials and mine wastes that require special management. Risk assessment and management are included in the plan to refine strategies and implementation steps. To be effective, the ARD management plan must be fully integrated with the mine plan. Operational controls such as standard operating procedures, key performance indicators, and quality assurance/quality control programs are established to guide its implementation. The ARD management plan identifies roles, responsibilities and accountabilities for mine operating staff. Data management, analysis and reporting schemes are included to track progress of the plan. Throughout the GARD Guide, it is stressed that the development, assessment, and continuous improvement of an ARD management plan must continue over the entire life of a mine.

Chapter 10—Communication and Consultation

Knowledge of ARD generation and mitigation has increased significantly during the last few decades. However, in order for this knowledge to be valuable, it needs to be translated into a form that is readily accessible and understood. Consultation should facilitate this process. The prediction of future drainage quality and the effectiveness of mitigation plans, their degree of certainty, and contingency measures to address that uncertainty need to be clear and understandable. An open dialogue on what is known, and what can be predicted with varying levels of confidence, helps to build understanding and trust, and ultimately results in a better ARD management plan.

Communicating and consulting with stakeholders about ARD issues is essential to the company's social license to operate. Due to the generally highly visible nature of ARD, special measures and skilled people are needed to communicate effectively, and the involvement of representatives from all relevant technical disciplines in a mining company may be required. Chapter 10 provides guidelines, "how to" information, and "dos and don'ts" regarding effective communication of ARD-related issues.

Chapter 11—ARD Management in the Future

This chapter briefly examines the current state and the future of ARD research and management. It begins with a discussion of the relevance and application of sustainable

development to ARD management. Current and future ARD management is viewed and managed through a sustainable development framework based on corporate objectives. The chapter briefly examines the state of research and possible future developments in ARD science and engineering. It also reviews the roles and responsibilities of the various stakeholders in advancing ARD science and management.

The Path Forward

The primary drivers for prevention of ARD are the mining companies. They need to do the planning, make the commitments, and earn their social license to operate through demonstration of their commitment to excellence. Other stakeholders include government agencies, communities affected by mining, non-governmental organizations (NGOs), and the public at large. They, in large degree, are the beneficiaries of the mining industry's good performance but can, in turn, enhance and expand this performance. You, the users of the GARD Guide, will ultimately determine its success—not only by effective application of its technical and management tools, but also by articulating your commitment to the successful prevention and management of ARD to your neighbours and the public.

The Guide has been established using a Wiki format, and will evolve as interested individuals provide relevant information and links to strengthen it. Your contributions to the GARD Guide will increase its value and raise best practice for ARD management around the world. We invite you to join us in this effort. If you see sections that could be improved or if you feel that important information should be added, please contact the corresponding author of this paper and provide him with the relevant text and/or figures or a link to where such information resides. Periodically, the GARD Guide staff will review and edit the suggestions provided, and then add material to the guide as appropriate. This should ensure that the Guide stays up to date, and improve the quality and relevance of the information in the Guide.

Reference

International Network for Acid Prevention (INAP) (2009) The Global Acid Rock Drainage Guide. http://www.gardguide.com is the web address