

WORKBOOK SERIES OF ADTI-MMS¹

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Abstract. Acid Drainage Technology Initiative—Metal Mining Sector (ADTI-MMS) is the United States' regional member of the Global Alliance sponsored by the International Network for Acid Prevention (INAP). The main focus currently of ADTI-MMS is to produce a series of workbooks detailing the management of acid rock and metals drainage in the United States. The Society of Mining, Metallurgy, and Exploration, Inc. (SME) publishes these workbooks following completion of consensus review in the workbook committees and by members of ADTI-MMS. Three volumes have been published to date and three additional volumes are in preparation. The purpose of these workbooks is not to duplicate efforts, such as the Global Acid Rock Drainage (GARD) guide produced by INAP, but to provide approaches and guidance on the design of programs to characterize, monitor, predict, model, and mitigate mining-influenced waters (MIW), including those found in pit lakes. These workbooks strive to provide awareness of the critical components and complexities involved in mitigating MIW. The holistic approach used accounts for all aspects of the mine-life cycle, from prospecting and exploration into mine planning and mining through reclamation and mine closure.

Additional Key Words: mining influenced waters, mine-life cycle

¹ Paper was presented at the 2010 National Meeting of the American Society of Mining and Reclamation, Pittsburgh, PA *Bridging Reclamation, Science and the Community* June 5 - 11, 2010. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

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Proceedings America Society of Mining and Reclamation, 2010 pp 598-610

DOI: 10.21000/JASMR10010598

<http://dx.doi.org/10.21000/JASMR10010598>

Introduction

Water quality impacts are a major environmental concern at many mines. Depending on the potential contaminants, their concentration, and their contact with living organisms, impacted water has the potential to harm plants, aquatic organisms, or other animals, including humans. Sources most likely to cause drainage-quality problems, if not properly managed, are base- and precious-metal deposits, uranium deposits, and high-sulfur coal deposits, although certainly not all deposits produce water-quality problems. Other types of deposits, such as industrial mineral deposits, can exhibit poor drainage quality if improperly managed. Research on water quality impacts at mine sites has been ongoing for several decades and tremendous progress has occurred over the last 10 years, especially through the efforts of organizations such as Acid Drainage Technology Initiative (ADTI, both Coal Mining Sector, CMS, and Metal Mining Sector, MMS), International Network for Acid Prevention (INAP), Mine Environment Neutral Drainage (MEND), International Mine Water Association (IMWA), Australian Centre for Minerals Extension and Research (ACMER), Partnership for Acid Drainage Remediation in Europe (PADRE), and others. However much of this research is scattered throughout the literature and, in some cases, it is difficult to obtain. Therefore, ADTI-MMS has summarized this research and philosophy on managing water quality at mine and mineral processing sites through a series of workbooks, Management Technologies for Metal Mining Influenced Water.

Problematic mine drainage is given many names including acid rock drainage (ARD), acid mine drainage (AMD) and mining-influenced waters (MIW; Schmiermund and Drozd, 1997), among other names. Generally speaking, the distinction between ARD and AMD depends upon whether drainage quality has been degraded by mining, as in the case of ARD and AMD, or the poor quality occurs naturally, as in the case of ARD, in the absence of anthropogenic disturbance. These two terms best describe acidic, high Fe, high sulfate waters from mines and natural sources where iron sulfides have weathered in the presence of oxygen and water to form acid/metal drainage. But not all adverse drainage from metal mines is acidic; some neutral pH waters can be detrimental to the environment if not properly managed. In the Introduction workbook, the definition of mining-influenced water (MIW) was expanded to include all waters affected by mining and metallurgical processing, which includes wastes from historic operations. This term resolves much of the confusion that exists from using AMD for cases where drainage

is from mines but is not acidic, and MIW is the preferred term used to refer to all mining-related waters because acidic, neutral, and alkaline waters can all transport metals and other contaminants that can impact the environment.

Acid Drainage Technology Initiative—Metal Mining Sector (ADTI-MMS) is the metal mining group of ADTI, the United States' regional member of the Global Alliance sponsored by the International Network for Acid Prevention (INAP) (Hornberger et al., 2000; Williams, 2003; van Zyl et al., 2006; McLemore, 2008; Bucknam et al., 2009). The main focus currently of ADTI-MMS is to produce a series of workbooks that provides in-depth guidance about the management of acid rock and metals drainage in the United States. The general objective of these workbook volumes is to compile, analyze and summarize existing technical information and philosophy on environmental mine waste management. These workbooks will be useful to mine managers and planners (i.e., mining industry), consultants, regulators, researchers, undergraduate and graduate students, communities affected by mining activities, non-government organizations (NGOs), and the general public. The workbooks are not designed to be all-inclusive compendium of knowledge on acid drainage and other MIW and natural drainage, nor are they intended for policy or regulatory purposes. However, the workbooks do provide key information and enough technical detail to allow readers to make informed decisions on what technologies best apply to their needs. Furthermore, these workbooks are intended to supplement and enhance current literature, and differ from most studies, such as the Global Acid Rock Drainage Guide (GARD Guide) produced by INAP (Verburg et al., 2009; http://www.gardguide.com/index.php/Main_Page), by providing a philosophy and holistic approach for managing all types of MIW throughout the mine-life cycle. These workbooks strive to provide awareness of the critical components and complexities involved in mitigating MIW. The holistic approach used accounts for all aspects of the mine-life cycle in the U.S., from prospecting and exploration into mine planning and mining through reclamation and mine closure. This paper provides a summary of the ADTI-MMS workbook series, Management Technologies for Metal Mining Influenced Water, developed by the ADTI-MMS committees and published by the Society for Mining, Metallurgy, and Exploration, Inc. (SME).

ADTI-MMS

The mission of ADTI-MMS is to identify, evaluate, develop, and disseminate information about cost effective, environmentally sound methods and technologies to manage mine wastes and related metallurgical materials for abandoned, inactive, active, and future mining and associated operations and to promote understanding of these technologies. ADTI-MMS is not a policy or regulatory initiative; it is a technically focused consensus group of volunteer representatives from state and federal government, academia, the mining industry, consulting firms, and other interested parties who are involved in the environmentally sound management of metal-mine wastes and drainage quality issues. More specifically, the goals of the ADTI-MMS include:

- Finding ways to reduce the extent and severity of adverse impacts of drainage from mine wastes and mining related materials, such as mineral processing wastes
- Develop consensus on environmental mine waste management technologies for sampling and monitoring, drainage quality prediction, mitigation, and modeling
- Identify technological needs and work to address these needs
- Use sound scientific and technological fundamentals to interpret, assess, and summarize published literature and operational practices; communicate these findings to those responsible for environmental mine waste management.

Overall direction for the ADTI-MMS is provided by a Steering Committee that has representatives on the Operations Committee of ADTI. The Operations Committee also includes members from the Coal Mining Sector (ADTI-CMS). ADTI-MMS also includes the Western Universities Consortium, a cooperative venture of the University of Nevada, New Mexico Institute of Mining and Technology, University of Utah, University of Idaho and the University of Alaska, Fairbanks. The Consortium is dedicated to research, development, education and outreach related to reclamation and restoration of abandoned non-coal mines in the Western U.S. In addition to the Consortium universities, the University Network includes Northern Arizona University, University of California (Berkeley), the Colorado School of Mines, Desert Research Institute, University of Missouri (Rolla), Montana State University-Bozeman, Montana Tech of

the University of Montana, University of New Mexico, South Dakota School of Mines and Technology, and the State University of New York, College at Oneonta.

Scope of Volumes

Volume 1 of the series, Management Technologies for Metal Mining Influenced Water, is entitled **Basics of Metal Mining Influenced Water** (McLemore, 2008). This is the introduction volume of the series and covers the basics of what drainage is and the technologies applied to it. This introductory workbook begins by reminding us of the importance of mining to sustain our technological way of life, explains the mine-life cycle, and the different types of mining and processing operations. Mining is essential to maintain economic wealth because it is one of the ways wealth is created. Mining companies today realize that they must meet the mineral needs of our society while protecting health, safety and welfare of its workers, the surrounding community, and the environment. Planning a mine in today's regulatory environment requires a different philosophy in terms of designing a new or existing mine or expanding operations for ultimate closure. This philosophy is relatively new as the miners and regulators in the past rarely planned for mine closure. Complying with environmental regulations is the job of everyone at all stages of mining. Consequently, closure planning ideally should begin during the exploration and feasibility phases, and be augmented throughout development, mining and ore processing, and finally during closure and post-closure. These workbooks describe the technical aspects of sampling, monitoring, mitigating, and prediction programs in terms of the mine life cycle.

The Basics of Metal Mining Influenced Water volume also contains the initial version of the overall **Glossary** for the workbook. This **Glossary** presently incorporates pertinent terms from the volumes. As the remaining volumes are finalized, an on-line version of the **Glossary** will be updated with terms that are added to the volumes already incorporated in the **Glossary**. The updated **Glossary** will be maintained on the ADTI-MMS website at <http://ese.mines.edu/adti/index.html> so that those who purchase subsequent volumes can access as complete a version of the **Glossary** as possible.

Volume 2 is entitled **Mitigation of Metal Mining Influenced Water** (Gusek and Figueroa, 2009) and describes various techniques for preventing, controlling, and treating adverse impacts on water quality associated with metal mining wastes and associated metallurgical materials.

This volume embraces two, sometimes overlapping, approaches to resolving environmental problems associated with MIW; prevention and treatment, and includes a set of case studies, including design details associated with failures, to avoid repeating inadequate and inappropriate methods at other sites. Using the information provided in Volume 1, **Basics of Metal Mining Influenced Water**, as a foundation, Volume 2 focused on MIW prevention measures that disrupt the geochemical relationship termed the “*acid rock drainage tetrahedron*” that involves pyrite, water, air, and bacteria and how they naturally interact to produce acidic MIW. There is no single magic bullet to completely prevent acidic MIW formation; even a barrage of preventive bullets may only slow pyrite oxidation to manageable levels. This is the point that engineers and designers need to begin considering treatment technology options which fall into three main categories: active, passive, and semi-passive.

The mitigation volume reflects the state of the practice in MIW problem solving as of the first few years of the new millennium. Regardless, the first step in the mitigation process now and in the future will involve gaining a better understanding of the physical environment (Chapter 2) in the mine vicinity and how it can influence MIW situations. Chapter 3, Planning and Design Considerations, provides both real and hypothetical case histories and examples of what works and what does not in mitigating MIW before a future mine even opens. Source and Migration Control (Chapter 4) focuses on the proven technologies that have been used to mitigate MIW in a wide range of metal mining and ore processing situations including capping and covering of tailings and waste rock, surface water diversion, underground and pit backfilling, and acid rock drainage tetrahedron-disrupting amendments. Individually or in combination, these techniques comprise the “armory” of MIW prevention technologies that should be deployed as the first line of defense. Chapter 5, the longest of the volume, introduces the array of technologies available to treat residual MIW after all the practical source and migration controls have been implemented at a given site. Selection of a given technology will depend mostly on the MIW chemistry and treatment flow rate, which in combination influence the size and cost of the treatment system. The methods for mitigating MIW will continue to evolve as mining companies, regulators, researchers, and engineers publicize their successes and failures at conferences, forums, and in the technical literature. Ultimately, this volume will enable the user to objectively select the best, technologically proven, most economical method(s)

suited to a particular situation. It also will aid in determining research needs and cost effectiveness for various options.

Volume 3 is entitled **Mine Pit Lakes: Characteristics, Predictive Modeling, and Sustainability** (Castendyk and Eary, 2009) and provides a summary of the methods available for classification, prediction, sampling and monitoring, and remediation of pit lakes. The overall objective of the volume is to provide basic information on how to manage future or existing pit lakes. It is intended that the volume be used as a guide for:

- Identifying what information should be collected prior to development of an open pit that may result in a pit lake
- Predictive modeling of both the hydrological aspects and the geochemical aspects of pit lakes
- Identifying various methods currently available for management, remediation, or backfilling of pit lakes.

Part one is the introduction and describes the nature, formation, and distribution of pit lakes and the regulatory issues of pit lakes in the United States. The characteristics and classifications of pit lakes and regional climate are discussed in part two, whereas conceptual models are described in part three. Sampling and monitoring guidelines are found in part four. Detailed descriptions of predictive models of pit lakes are found in part five. Remediation methods are described in part six and post-mining issues and considerations are discussed in part seven. The conclusion to this volume, part eight, summarizes the state of the art of pit lake research, primarily in the areas of current accomplishments, data gaps, recommendations and remediation strategies.

Volume 4 is entitled **Geochemical Modeling for Mine Site Characterization and Remediation** and is scheduled for completion in 2010. The modeling volume will describe models available to address questions associated with impacts of metal mine wastes on water quality. The models available will be identified and their strengths, weakness, and appropriate application will be discussed. Publications describing applications of the models will be cited to provide additional insight.

Volume 5, **Techniques for Predicting Metal Mining Influenced Water**, also is scheduled for completion in 2010. The objective of the prediction volume is to describe tools available for effective and accurate prediction of mine and metallurgical processing wastes and related drainage quality. This volume will provide an assessment of strengths and weaknesses of the various static and kinetic protocols and present ideas on how to develop a logical prediction framework. Detailed description of protocols will be provided in the appendices. It is recognized that not a single tool, or set of these tools, will be optimal for prediction at all operations. This workbook is intended to be a technical document and is aimed at an audience with some understanding of metal mine waste composition, analysis, and dissolution. Such understanding will guide the selection of tools for a specific operation or purpose. References will be cited to provide additional background to assist in the selection process.

The final volume of ADTI-MMS' Management Technologies for Metal Mining Influenced Water workbook series is **Sampling and Monitoring for the Mine Life Cycle**. This is volume six and also is scheduled for completion in 2010. The sampling and monitoring volume will provide a summary of various methods of sampling and monitoring for MIW, as well as an assessment and the applicability of the numerous methods. This volume will enable the user to select the best, technologically proven, most economical method suited to a particular situation, especially with regards to mine closure. The volume will provide design details associated with failures, to avoid repeating previous applications of inadequate and inappropriate methods. It also will aid in determining research needs and cost effectiveness for various options. Sidebars throughout the document provide more detailed descriptions of important concepts and examples. A number of appendices are included to supplement the document. An annotated bibliography covers details and examples of sampling and monitoring programs. Some features of mine water quality problems occur often enough that case study examples are almost too numerous to review individually and will be synthesized to illustrate unsuccessful and successful sampling and monitoring programs. Field measurements, collection methods, and analytical techniques and procedures that apply to a sampling and monitoring program, are included, along with a summary of the principles, limitations, and uses of the various techniques. This workbook will aid in determining research needs and cost effectiveness for various options

related to sampling and monitoring. Hopefully, this workbook also will help planners to readily assess the relevant literature.

Holistic Philosophy

The holistic philosophy used in these workbooks maintains that sampling, monitoring, prediction, and mitigation programs should be designed to take into account all aspects of the mine-life cycle, from prospecting and exploration into mine planning and mining through reclamation and mine closure. This philosophy is relatively new in today's mining operations, as the mining companies and mine regulators in the past rarely planned for mine closure. One of the principles of sustainable development in mining today is that every mining or processing operation has a beginning and an end (Fig. 1; McLemore, 2008). The mine-life cycle can be divided into five stages: exploration, development, operations, closure, and post-closure. Figure 1 briefly describes the mine- life cycle.

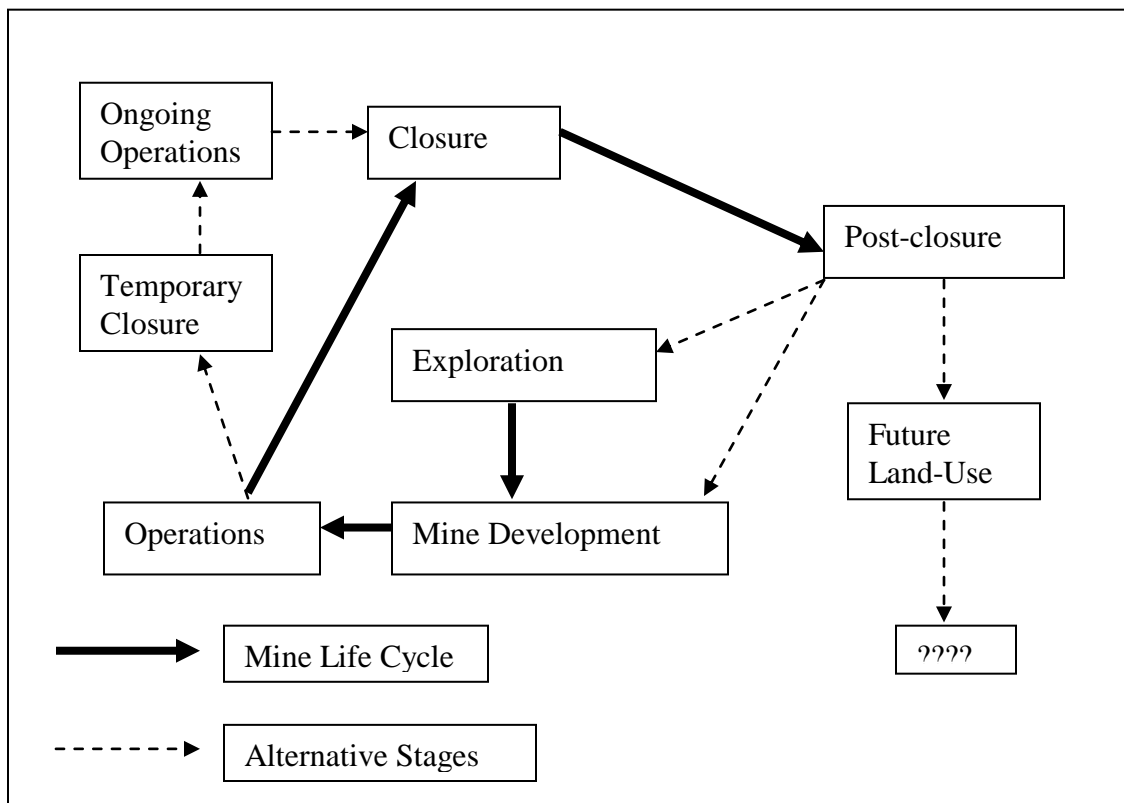


Figure 1. Mine Life Cycle Stages (Dirk van Zyl, written communication, March 27, 2002; McLemore, 2008).

ADTI-MMS Production and Review Process

ADTI-MMS uses consensus to promote scientifically sound mineral development that minimizes adverse impacts on water and maximizes beneficial post-mining land uses. Each volume of the workbook is written by a group of volunteers from among ADTI-MMS members, solicited, and managed by one to three volume editors in a technical committee. Upon completion of receipt and revision of all sections of a volume, the entire volume undergoes a consensus review by that volume's technical committee and requires 60% approval by committee members to advance to the next stage.

Upon acceptance by that group of a given volume's content, the volume goes before the ADTI-MMS membership for a consensus review and balloting process. Again, 60% approval by the membership is required. The volume editor(s) make technical and style changes brought up by the review and then resubmit the volume for a second review and ballot, if necessary. This process can require multiple stages of review and balloting to incorporate all comments and changes and reach final acceptance by the membership. Once a volume has achieved final acceptance by the membership, it is ready for submission to SME for their final formatting, editorial, and review process prior to publication. The publication schedule for each volume at that point is under control by SME.

Conclusion/Path Forward

ADTI-MMS has compiled a series of workbooks, published by SME that details the management of MIW in the United States. The objective of these workbook volumes is to compile, analyze and summarize existing technical information and philosophy on environmental mine and processing waste management. These workbooks target a diverse audience interested in mine waste management, such as mine managers and planners (i.e., mining industry), consultants, regulators, researchers, undergraduate and graduate students, communities affected by mining activities, non-government organizations (NGOs), and the general public. Members of ADTI-MMS are willing to provide workshops at national and local levels to disseminate and update the information provided in these workbooks. Subsequent updates of these workbooks will be posted on the ADTI-MMS web site (<http://ese.mines.edu/adti/index.html>).

Acknowledgements

These workbooks are a volunteer project of the Acid Drainage Technology Initiative–Metal Mining Sector (ADTI—MMS). The work was directed by the ADTI-MMS Steering Committee, representing each of the technical and support committees as well as industry, federal, state, academic and non-governmental organization representatives. The workbook contributors belong to varied professions and are linked by their common interest in metal mining and the water quality challenges it generates. Contributors include regulators from state and federal agencies, state and federal geological survey geologists, academicians, consulting engineers and scientists, and professionals from the metal mining industry.

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