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Summary

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Executive Summary

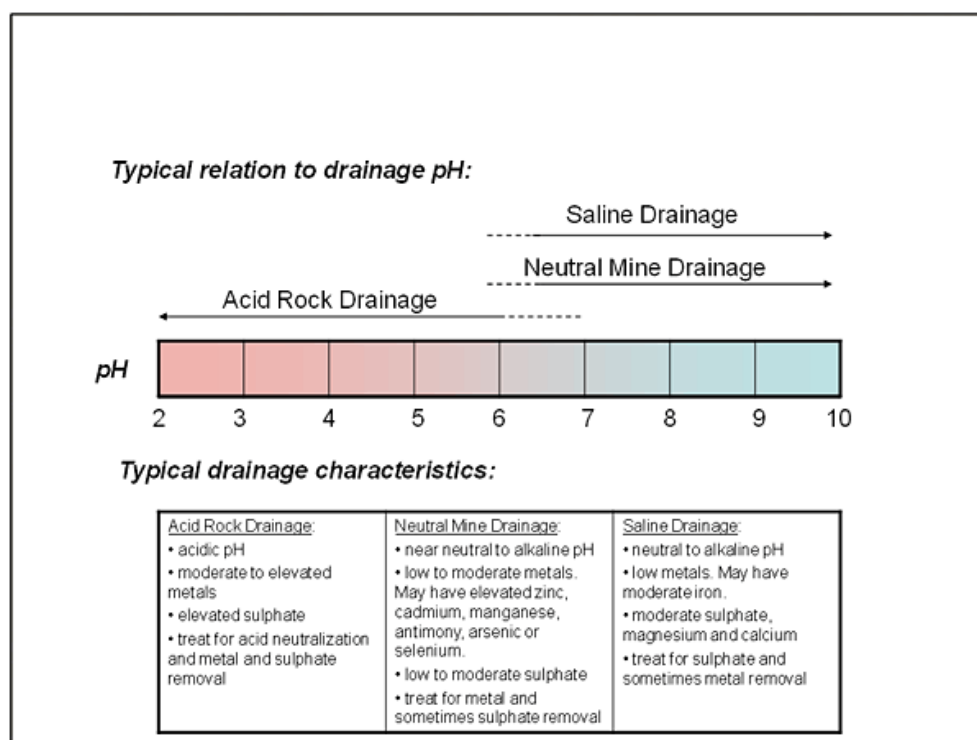
Introduction

The Global Acid Rock Drainage (GARD) Guide addresses the prediction, prevention, and management of drainage produced from sulfide mineral oxidation, often termed “acid rock drainage” (ARD), “acid mine drainage” or “acid and metalliferous drainage” (AMD), “mining influenced water” (MIW), “saline drainage” (SD), and “neutral mine drainage” (NMD).

This Executive Summary follows the general structure of the full GARD Guide, a state-of-practice summary of the best practices and technologies, developed under the auspices of the International Network for Acid Prevention (INAP) to assist ARD stakeholders, such as mine operators, regulators, communities, and consultants, with addressing issues related to sulfide mineral oxidation. Readers are encouraged to make use of the GARD Guide and its references for further detail on the subjects covered in this Executive Summary. The GARD Guide was prepared with the input and assistance of many individuals and organizations, and their contributions are gratefully acknowledged.

Acid rock drainage is formed by the natural oxidation of sulfide minerals when exposed to air and water. Activities that involve the excavation of rock with sulfide minerals, such as metal and coal mining, accelerate the process. The drainage produced from the oxidation process may be neutral to acidic, with or without dissolved heavy metals, but always contains sulfate. ARD results from a series of reactions and stages that typically proceed from near neutral to more acidic pH conditions. When sufficient base minerals are present to neutralize the ARD, neutral mine drainage or saline drainage may result from the oxidation process. NMD is characterized by elevated metals in solution at circumneutral pH, while SD contains high levels of sulfate at neutral pH without significant dissolved metal concentrations. Figure 1 presents the various types of drainage in a schematic manner.

Figure 1: Types of Drainage Produced by Sulphide Oxidation



Stopping ARD formation, once initiated, may be challenging because it is a process that, if unimpeded, will continue (and may accelerate) until one or more of the reactants (sulfide minerals, oxygen, water) is exhausted or excluded from reaction. The ARD formation process can continue to produce impacted drainage for decades or centuries after mining has ceased, such as illustrated by this portal dating from the Roman era in Spain (Figure 2).

Figure 2: Roman Portal with Acid Rock Drainage – Spain



The cost of ARD remediation at orphaned mines in North America alone has been estimated in the tens of billions of U.S. dollars. Individual mines can face post-closure liabilities of tens to hundreds of million dollars for ARD remediation and treatment if the sulfide oxidation process is not properly managed during the mine's life.

Proper mine characterization, drainage-quality prediction, and mine-waste management can prevent ARD formation in most cases, and minimize ARD formation in all cases. Prevention of ARD must commence at exploration and continue throughout the mine-life cycle. Ongoing ARD planning and management is critical to the successful prevention of ARD.

Many mines will not produce ARD because of the inherent geochemical characteristics of their mining wastes or very arid climatic conditions. In addition, mines that have implemented well founded prediction efforts and, where required, prevention measures and monitoring programs, should also be able to avoid significant ARD issues.

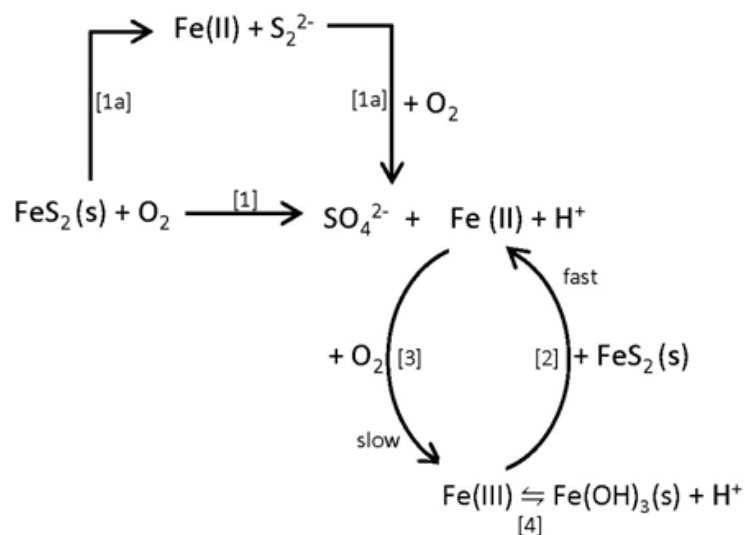
A comprehensive approach to ARD management reduces the environmental risks and subsequent costs for the mining industry and governments, reduces adverse environmental impacts, and promotes public support for mining. The extent and particular elements of the ARD management approach that should be implemented at a particular operation will vary based on many site-specific factors, not limited to the project's potential to generate ARD.

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Formation of Acid Rock Drainage

The process of sulfide oxidation and formation of ARD, NMD, and SD is very complex and involves a multitude of chemical and biological processes that can vary significantly depending on environmental, geological and climate conditions (Nordstrom and Alpers, 1999). Sulfide minerals in ore deposits are formed under reducing conditions in the absence of oxygen. When exposed to atmospheric oxygen or oxygenated waters due to mining, mineral processing, excavation, or other earthmoving processes, sulfide minerals can become unstable and oxidize. Figure 3 presents a simplified model describing the oxidation of pyrite, which is the sulfide mineral responsible for the large majority of ARD (Stumm and Morgan, 1981). The reactions shown are schematic and may not represent the exact mechanisms, but the illustration is a useful visual aid for understanding sulfide oxidation.

Figure 3: Model for the Oxidation of Pyrite (Stumm and Morgan, 1981).

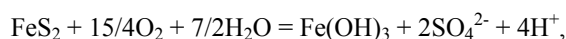


The chemical reaction representing pyrite oxidation (reaction [1]) requires three basic ingredients: pyrite, oxygen, and water. This reaction can occur both abiotically or biotically (i.e., mediated through microorganisms). In the latter case, bacteria such as *Acidithiobacillus ferrooxidans*, which derive their metabolic energy from oxidizing ferrous to ferric iron, can accelerate the oxidation reaction rate by many orders of magnitude relative to abiotic rates (Nordstrom, 2003). In addition to direct oxidation, pyrite can also be dissolved and then oxidized (reaction [1a]).

Under the majority of circumstances, atmospheric oxygen acts as the oxidant. However, aqueous ferric iron can oxidize pyrite as well according to reaction [2]. This reaction is considerably faster (2 to 3 orders of magnitude) than the reaction with oxygen, and generates substantially more acidity per mole of pyrite oxidized. However, this reaction is limited to conditions in which significant amounts of dissolved ferric iron occur (i.e., acidic conditions: pH 4.5 and lower). Oxidation of ferrous iron by

oxygen (reaction [3]) is required to generate and replenish ferric iron, and acidic conditions are required for the latter to remain in solution and participate in the ARD production process. As indicated by this reaction, oxygen is needed to generate ferric iron from ferrous iron. Also, the bacteria that may catalyze this reaction (primarily members of the *Acidithiobacillus* genus) demand oxygen for aerobic cellular respiration. Therefore, some nominal amount of oxygen is needed for this process to be effective even when catalyzed by bacteria, although the oxygen requirement is considerably less than for abiotic oxidation.

A process of environmental importance related to ARD generation pertains to the fate of ferrous iron resulting from reaction [1]. Ferrous iron can be removed from solution under slightly acidic to alkaline conditions through oxidation and subsequent hydrolysis and the formation of a relatively insoluble iron (hydr)oxide (reaction [4]). When reactions [1] and [4] are combined, as is generally the case when conditions are not acidic (i.e., pH > 4.5), oxidation of pyrite produces twice the amount of acidity relative to reaction [1] as follows:



which is the overall reaction most commonly used to describe pyrite oxidation.

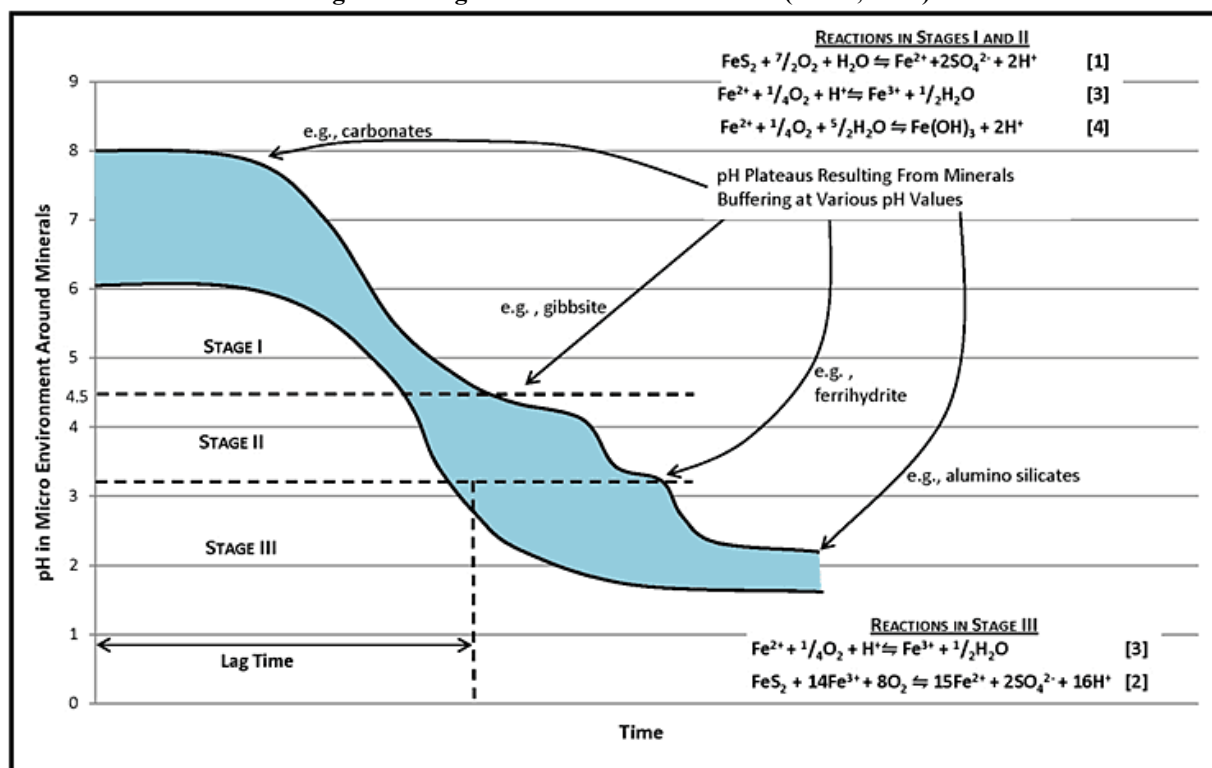
Although pyrite is by far the dominant sulfide responsible for the generation of acidity, different ore deposits contain different types of sulfide minerals. Not all of these sulfide minerals generate acidity when being oxidized. As a general rule, iron sulfides (pyrite, marcasite, pyrrhotite), sulfides with molar metal/sulfur ratios < 1, and sulfosalts (e.g., enargite) generate acid when they react with oxygen and water. Sulfides with metal/sulfur ratios = 1 (e.g., sphalerite, galena, chalcopyrite) tend not to produce acidity when oxygen is the oxidant. However, when aqueous ferric iron is the oxidant, all sulfides are capable of generating acidity. Therefore, the acid generation potential of an ore deposit or mine waste generally depends on the amount of iron sulfide present.

Neutralization reactions also play a key role in determining the compositional characteristics of drainage originating from sulfide oxidation. As for sulfide minerals, the reactivity, and accordingly the effectiveness with which neutralizing minerals are able to buffer any acid being generated, can vary widely. Most carbonate minerals are capable of dissolving rapidly, making them effective acid consumers. However, hydrolysis of dissolved Fe or Mn following dissolution of their respective carbonates and subsequent precipitation of a secondary mineral may generate acidity. Although generally more common than carbonate phases, aluminosilicate minerals tend to be less reactive, and their buffering may only succeed in stabilizing the pH when rather acidic conditions have been achieved. Calcium-magnesium silicates have been known to buffer mine effluents at neutral pH when sulfide oxidation rates were very low (Jambor, 2003).

The combination of acid generation and acid neutralization reactions typically leads to a step-wise development of ARD (Figure 4). Over time, pH decreases along a series of pH plateaus governed by the buffering of a range of mineral assemblages. The lag time to acid generation is a very important consideration in ARD prevention. It is far more effective (and generally far less costly in the long term) to control ARD generation during its early stages. The lag time also has significant ramifications for interpretation of test results. Because the first stage of ARD generation may last for a very long time, even for materials that will eventually be highly acid generating, it is critical to recognize the stage of oxidation when predicting ARD potential. The early results of geochemical testing, therefore, may not be representative of long-term environmental stability and associated discharge quality. However early test results provide valuable data to assess future conditions such as consumption rates of available neutralizing minerals.

A common corollary of sulfide oxidation is metal leaching (ML), leading to the frequent use of the acronyms “ARD/ML” or “ML/ARD” to more accurately describe the nature of acidic mine discharges. Major and trace metals in ARD, NMD, and SD originate from the oxidizing sulfides and dissolving acid-consuming minerals. In the case of ARD, Fe and Al are usually the principal major dissolved metals, while trace metals such as Cu, Pb, Zn, Cd, Mn, Co, and Ni can also achieve elevated concentrations. In mine discharges with a more circumneutral character, trace metal concentrations tend to be lower due to formation of secondary mineral phases and increased sorption. However, certain parameters remain in solution as the pH increases, in particular the metalloids As, Se, and Sb as well as other trace metals (e.g., Cd, Cr, Mn, Mo, and Zn).

Figure 4: Stages in the Formation of ARD (INAP, 2009)

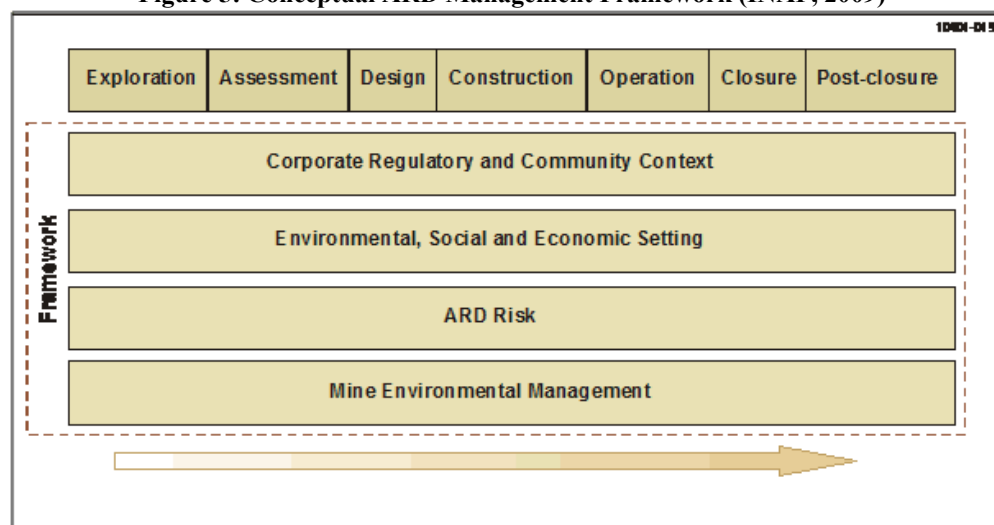


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Framework for Acid Rock Drainage Management

The issues and approaches 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 country context and are adapted to climate, topography, and other site conditions.

Therefore, despite the global similarities of ARD issues, there is no “one size fits all” approach to address ARD management. The setting of each mine is unique and requires a carefully considered assessment to find a management strategy within the broader corporate, regulatory and community framework that applies to the project in question. The site-specific setting comprises the social, economic and environmental situation within which the mine is located, whilst the framework comprises the applicable corporate, regulatory norms and standards and community specific requirements and expectations. This framework applies over the complete life cycle of the mine and is illustrated conceptually in Figure 5.

Figure 5: Conceptual ARD Management Framework (INAP, 2009)

All mining companies, regardless of size, need to comply with the national legislation and regulations pertaining to ARD of the countries within which they operate. It is considered good corporate practice to adhere to global ARD guidance as well, and in many cases such adherence is a condition of funding.

Many mining companies have established clear corporate guidelines that represent the company's view of the priorities to be addressed and their interpretation of generally accepted best practice related to ARD. Caution is needed to ensure all specifics of the country regulations are met, as corporate ARD guidelines cannot be a substitute for country regulations.

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, environmental and governance elements (sustainable development). ARD plays an important part in the mine's social license due to the fact that ARD tends to be one of the more visible environmental consequences of mining. The costs of closure and post-closure management of ARD are increasingly recognized as a fundamental component of all proposed and operating mining operations. Some form of financial assurance is now required in many jurisdictions.

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Characterization

The generation, release, transport and attenuation of ARD are intricate processes governed by a combination of physical, chemical and biological factors. Whether ARD becomes an 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 the following questions:

1. Is ARD likely to occur? What type of drainage is expected (ARD/NMD/SD)?
2. What are the sources of ARD? How much ARD will be generated and when?
3. What are the significant pathways that 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?

The geologic and mineralogic characteristics of the ore body and host rock are the principal controls on the type of drainage that will be generated as a result of mining. Subsequently, the site climatic and hydrologic/hydrogeologic characteristics define how mine drainage and its constituents are transported through the receiving environment to receptors. To evaluate these issues, expertise from multiple disciplines is required, including: geology, mineralogy, hydrology, hydrogeology, geochemistry, (micro)biology, meteorology, and engineering.

The geologic characteristics of mineral deposits exert important and predictable controls on the environmental signature of mineralized areas (Plumlee, 1999). Therefore, a preliminary assessment of the ARD potential should be made based on review of geologic data collected during exploration. Baseline characterization of metal concentrations in various environmental media

(i.e., water, soils, vegetation and biota) may also provide an indication of ARD potential and serves to document potentially naturally elevated metal concentrations. During mine development and operation, the initial assessment of ARD potential is refined through detailed characterization data on the environmental stability of the waste and ore materials. The magnitude and location of mine discharges to the environment also are identified during mine development. Meteorologic, hydrological and hydrogeological investigations are conducted to characterize the amount and direction of water movement within the mine watershed(s) to evaluate transport pathways for constituents of interest. Potential biological receptors within the watershed boundary are identified. As a consequence, over the mine life, the focus of the ARD characterization program evolves from establishing baseline conditions, to predicting drainage release and transport, to monitoring of the environmental conditions and impacts.

Despite inherent differences at mine sites (e.g., based on commodity type, climate, mine phase, regulatory framework), the general approach to site characterization is similar:

- Define the quantity and quality of drainage potentially generated by different sources
- Identify surface and groundwater pathways that transport drainage from sources to receptor
- Identify receptors that may be affected by exposure to drainage
- Define the risk of this exposure

Figures 6 and 7 present the chronology of an ARD characterization program and identify the data collection activities typically executed during each mine phase. The bulk of the characterization effort occurs prior to mining during the mine planning, assessment and design (sometimes collectively referred to as the development phase). In addition, potential environmental impacts are identified and appropriate prevention and mitigation measures, intended to minimize environmental impacts, are incorporated. During the commissioning/construction and operation phases, a transition from site characterization to monitoring occurs, which is continued throughout the decommissioning/closure and post-closure phases. Ongoing monitoring helps refine the understanding of the site, which allows for adjustment of remedial measures, in turn resulting in reduced closure costs and improved risk management.

Figure 6: Overview of ARD Characterization Program by Mine Phase (INAP, 2009)

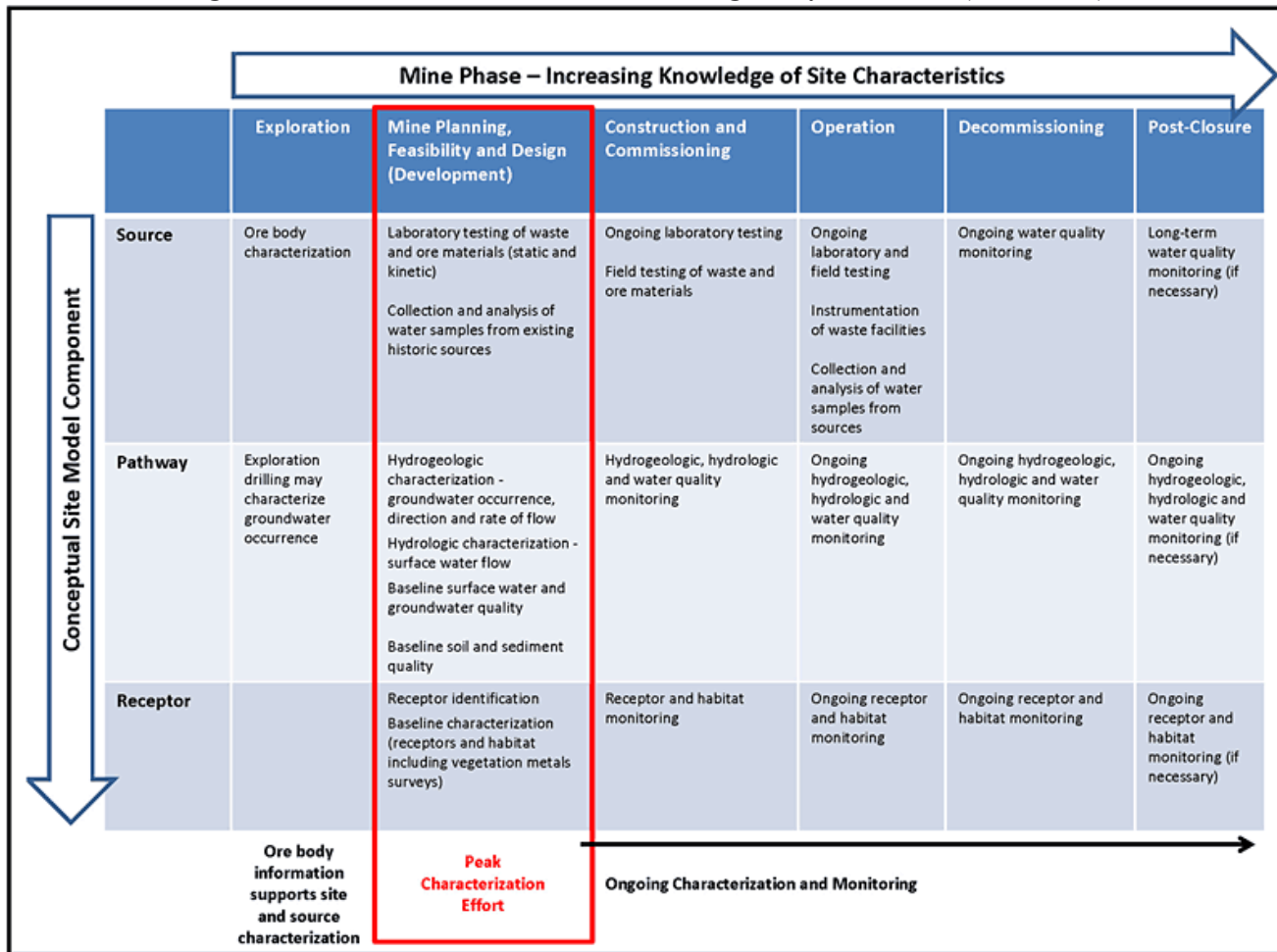


Figure 7: ARD Characterization Program for Individual Source Materials by Mine Phase (INAP, 2009)

Mine Phase – Increasing Knowledge of Source Material Characterization						
Waste or Facility Type – Potential ARD / NMD / SD Sources	Exploration	Mine Planning, (Pre-) Feasibility and Design	Construction and Commissioning	Operation	Decommissioning	Post-Closure (Care and Maintenance)
	Waste Rock Drill core descriptions and assay data (petrology and mineralogy) Block model (quantity of ore and waste)	Laboratory testing of drill core samples – sample selection targets waste ^(a)	Ongoing laboratory testing of drill core or development rock samples ^(a) Field leach testing (barrels, test pads)	Ongoing laboratory testing ^(a) Ongoing field leach testing Collection and analysis of runoff and seepage samples from waste rock facility	Collection and analysis of runoff and seepage samples from waste rock facility	Collection and analysis of runoff and seepage samples from waste rock facility (if necessary)
	Tailings Review of any historical data	Laboratory testing of pilot plant tailings ^(a) Analysis of pilot testing supernatant.	Ongoing laboratory testing of pilot plant tailings ^(a)	Ongoing laboratory testing of tailings discharge ^(a) Collection and analysis of supernatant and seepage samples from TSF	Collection and analysis of supernatant and seepage samples from TSF	Collection and analysis of supernatant and seepage samples from TSF (if necessary)
	Ore	Laboratory testing of drill core samples ^(a)		Ongoing laboratory testing ^(a)	If ore stockpiles exist, collection and analysis of runoff and seepage samples	
	Pit	Laboratory testing of drill core samples – sample selection targets pit walls ^(a)		Field scale leach testing (e.g., wall washing) Collection and analysis of water samples (i.e., runoff, sumps)	Collection and analysis of pit water and pit inflow(s) water samples	Collection and analysis of pit water samples (if necessary)
	Under-ground Workings	Laboratory testing of drill core samples – sample selection targets mine walls ^(a)		Collection and analysis of water samples (i.e., sumps, dewatering wells)	Collection and analysis of mine pool water samples	Collection and analysis of mine pool water samples (if necessary)

^a Typical laboratory testing components: particle size, whole rock analysis, mineralogy, ABA, static and kinetic leach testing.

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Prediction

One of the main objectives of site characterization is prediction of ARD potential and drainage chemistry. Because prediction is directly linked to mine planning, in particular with regard to water and mine waste management, the characterization effort needs to be phased in step with overall project planning. Early characterization tends to be generic and generally avoids presumptions about the future engineering/mine design, while later characterization and modeling must consider and be integrated with the specifics of engineering/mine design. Iteration may be required as evaluation of the ARD potential may result in the realization that a re-assessment of the overall mine plan is needed. Integration of the characterization and prediction effort into the mine operation is a key element for successful ARD management.

Accurate prediction of future mine discharges requires an understanding of the sampling, testing, and analytical procedures used, consideration of the future physical and geochemical conditions, and the identity, location and reactivity of the contributing minerals. All mine sites are unique for reasons related to geology, geochemistry, climate, commodity, processing method, regulations and stakeholders. Prediction programs therefore need to be tailored to the mine in question. Also, the objectives of a prediction program can be variable. For instance, they can include definition of water treatment requirements, selection of mitigation methods, assessment of water quality impact, or determination of reclamation bond amounts.

Predictions of drainage quality are made in a qualitative and quantitative sense. Qualitative predictions are focused on assessing whether acidic conditions might develop in mine wastes, with the corresponding release of metals and acidity to mine drainage. Where qualitative predictions indicate a high probability of ARD generation, attention turns to review of alternatives to prevent ARD and the prediction program is refocused to assist in the design and evaluation of these alternatives.

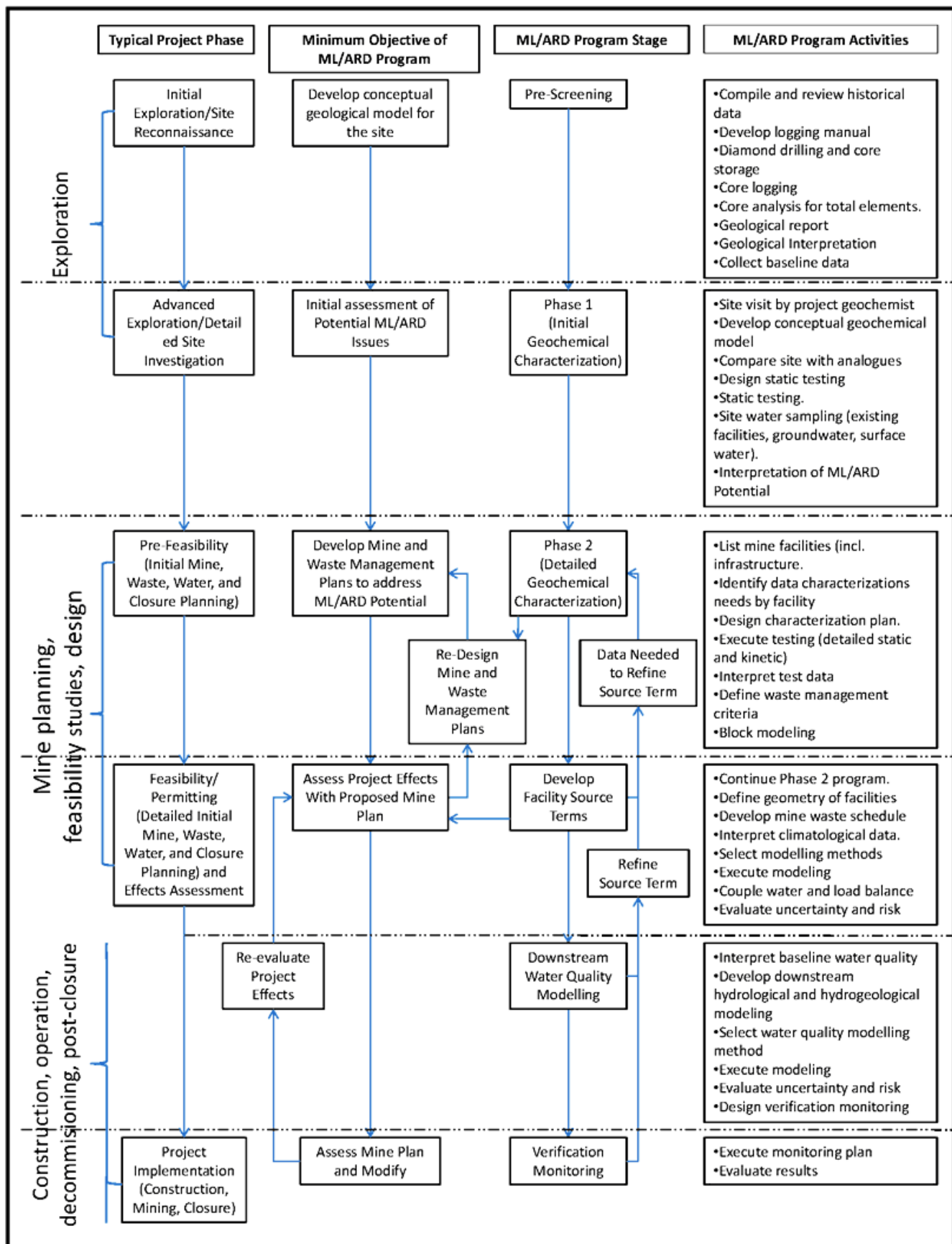
Significant advances in the understanding of ARD have been made over the last several decades, with parallel advances in mine water quality prediction and use of prevention techniques. However, quantitative mine water quality prediction can be challenging due to the wide array of the reactions involved 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.

Prediction of mine water quality generally is based on one of more of the following:

- Test leachability of waste materials in the laboratory
- Test leachability of waste materials under field conditions
- Geological, hydrological, chemical and mineralogical characterization of waste materials
- Geochemical and other modeling

Analog operating or historic sites are also valuable in ARD prediction, especially those that have been thoroughly characterized and monitored. The development of geo-environmental models is one of the more prominent examples of the “analog” methodology. Geo-environmental models, which are constructs that interpret the environmental characteristics of an ore deposit in a geologic context, provide a very useful way to interpret and summarize the environmental signatures of mining and mineral deposits in a systematic geologic context, and can be applied to anticipate potential environmental problems at future mines, operating mines and orphan sites (Plumlee et al., 1999). A generic overall approach for ARD prediction is illustrated in Figure 8.

Figure 8: Generic Overview of ARD Prediction Approach (INAP, 2009)



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Prevention and Mitigation

The fundamental principle of ARD prevention is to apply a planning and design process to prevent, inhibit, retard or stop the hydrological, chemical, physical, or microbiological processes that result in the impacts to water resources. Prevention should occur at, or as close to, the point where the deterioration in water quality originates (i.e. source reduction), or through implementation of measures to prevent or retard the transport of the ARD to the water resource (i.e. recycling, treatment and/or secure disposal). This principle is universally applicable, but methods of implementation are site specific.

Prevention is a proactive strategy that obviates the need for the reactive approach to mitigation. For an existing case of ARD that is adversely impacting the environment, mitigation will usually be the initial course of action. Despite this initial action, subsequent preventive measures are often considered with the objective of reducing future contaminant loadings, and thus reducing the ongoing need for mitigation controls. Integration of the prevention and mitigation effort into the mine operation is a key element for successful ARD management.

Prior to identification of evaluation of prevention and mitigation measures, the strategic objectives must be identified. That process should consider assessment of the following:

- Quantifiable risks to ecological systems, human health, and other receptors
- Site specific discharge water quality criteria
- Capital, operating and maintenance costs of mitigation or preventative measures
- Logistics of long-term operations and maintenance
- Required longevity and anticipated failure modes

Typical objectives for ARD control are to satisfy environmental criteria using the most cost-effective technique. Technology selection should consider predictions for discharge water chemistry, advantages and disadvantages of treatment options, risk to receptors, and the regulatory context related to mine discharges.

A risk-based planning and design approach forms the basis for prevention and mitigation. This approach is applied throughout the mine life cycle, but primarily in the assessment and design phases. 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, cost). Mitigation measures implemented as part of an effective control strategy should require minimal active intervention and management.

Prevention is the key to avoid costly mitigation. The primary objective is to apply methods that minimize sulfide reaction rates, metal leaching and the subsequent migration of weathering products that result from sulfide oxidation. Such methods involve:

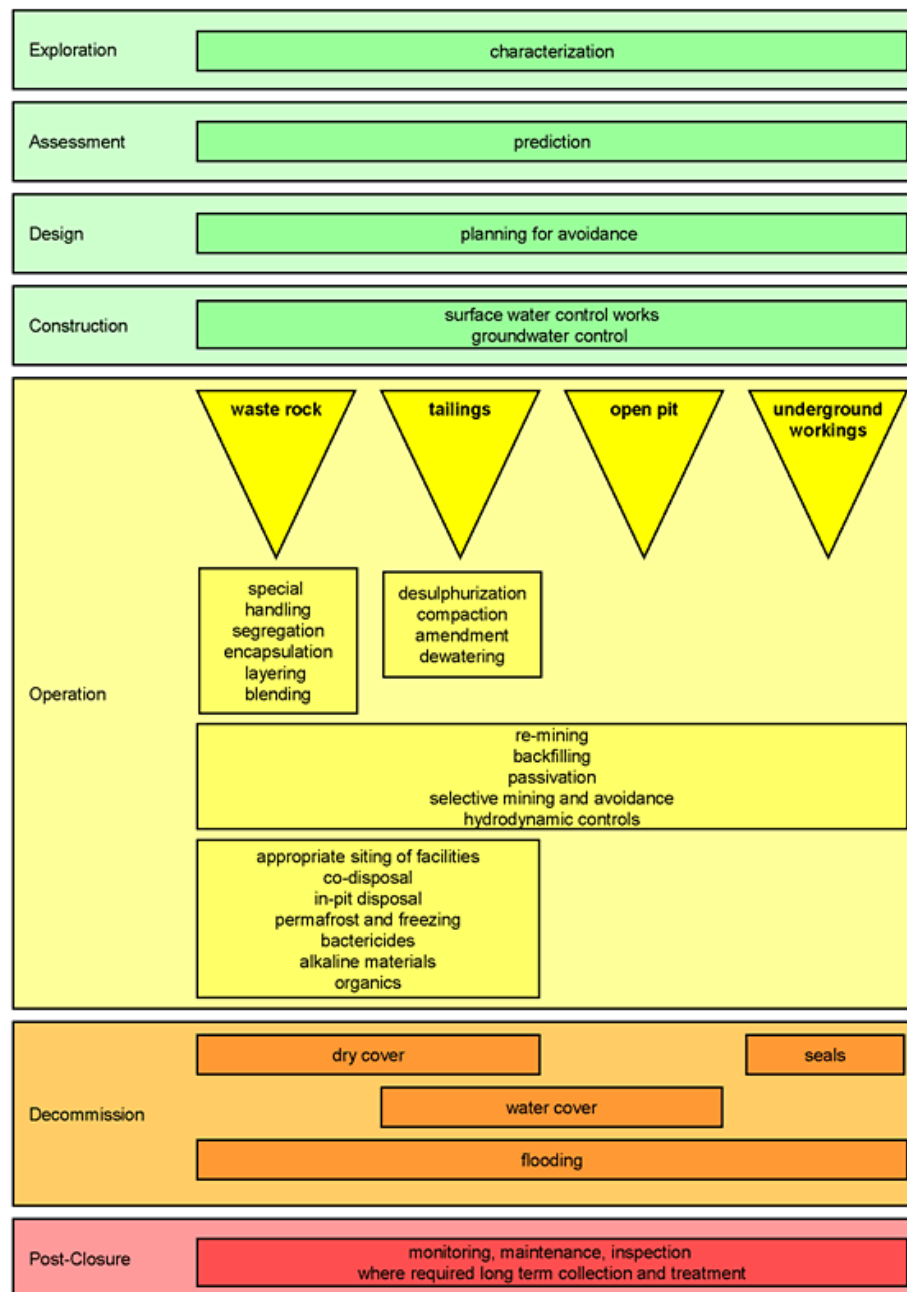
- Minimizing oxygen supply
- Minimizing water infiltration and leaching
- Minimizing, removing or isolating sulfide minerals
- Controlling pore water solution pH
- Controlling bacteria and biogeochemical processes

Factors influencing selection of the above methods include:

- Geochemistry of source materials and the potential of source materials to produce ARD
- Type and physical characteristics of the source, including water flow and oxygen transport
- Mine-development stage (more options are available at early stages)
- Phase of oxidation (more options are available at early stages when pH is still near neutral and oxidation products have not significantly accumulated)
- Time period for which the control measure is required to be effective
- Site conditions (i.e., location, topography and available mining voids, climate, geology, hydrology and hydrogeology, availability of materials and vegetation)
- Water quality criteria for discharge
- Risk acceptance by company and other stakeholders

More than one, or a combination of measures, may be required to achieve the desired objective. Figure 9 provides a generic overview of the most common ARD prevention and mitigation measures available during the various stages of the mine-life cycle.

Figure 9: Generic Overview of ARD Prevention and Mitigation Measures (INAP, 2009)



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Acid Rock Drainage Treatment

Sustainable mining requires the mitigation, management and control of mining impacts on the environment. The impacts of mining 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, operational use (dust suppression, mine cooling, irrigation of rehabilitated land), etc. Mine drainage treatment, in this case, is aimed at modifying the water quality so that it is fit for the intended use on or off the mine site.

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. Mine drainage may act as the transport medium for a range of pollutants, which may impact on-site and off-site water resources. Water treatment would remove the pollutants contained in mine drainage to prevent or mitigate environmental impacts.

In the large majority of jurisdictions, any discharge of mine drainage to a public stream or aquifer must be approved by the relevant regulatory authorities, while regulatory requirements stipulate a certain mine water discharge quality or associated discharge pollutant loads. Although discharge quality standards may not be available for many developing mining countries, internationally acceptable environmental quality standards generally still apply as stipulated by project financiers and company corporate policies. The approach to selection of a mine drainage treatment method is premised on a thorough understanding of the integrated mine water system and circuits and the specific objective(s) to be achieved. The approach adopted for mine drainage treatment will be influenced by a number of considerations.

Prior to selecting the treatment process, a clear statement and understanding of the objectives of treatment should be prepared. Mine drainage treatment must always be evaluated and implemented within the context of the integrated mine water system. Treatment will have an impact on the flow and quality profile in the water system; hence, a treatment system is selected based on mine water flow, water quality, cost and ultimate water use(s).

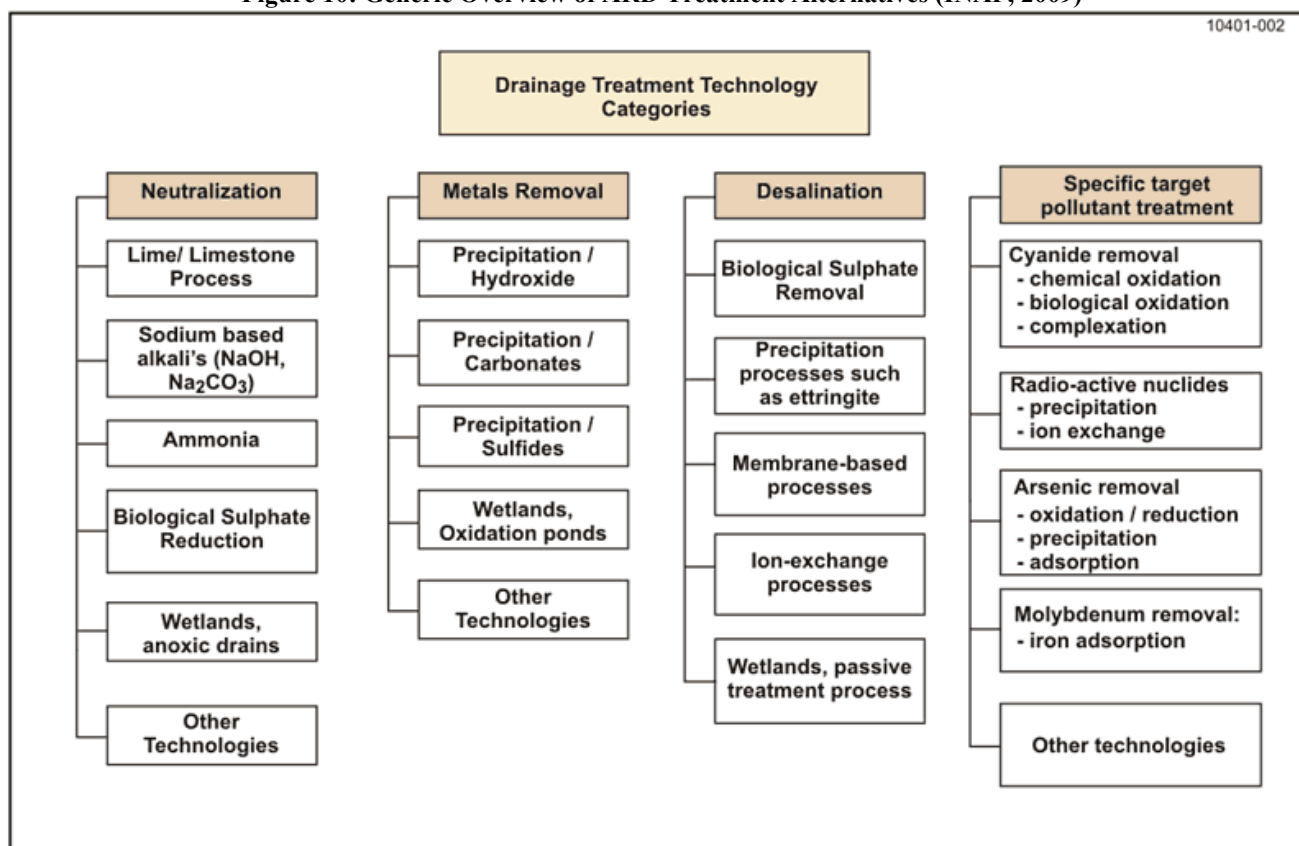
Characterization of the mine drainage in terms of flow and chemical characteristics should include due consideration of temporal and seasonal changes. Flow data are especially important as this information is required to properly size any treatment system. Of particular importance are extreme precipitation and snow melt events that require adequate sizing of collection ponds and related piping and ditches. The key chemical properties of mine drainage relate to acidity/alkalinity, sulfate content, salinity, metal content, and the presence of specific compounds associated with specific mining operations, such as cyanide, ammonia, nitrate, arsenic, selenium, molybdenum and radionuclides. There are also a number of mine drainage constituents (for example, hardness, sulfate, silica) which may not be of regulatory or environmental concern in all jurisdictions, but that could affect the selection of the preferred water treatment technology. Handling and disposal of treatment plant waste and residues such as sludges and brines and their chemical characteristics must also factor in any treatment decisions.

A mine-drainage treatment facility must have the flexibility to deal with increasing/decreasing water flows, changing water qualities and regulatory requirements over the life of mine. This may dictate phased implementation and modular design and construction. Additionally, the post-closure phase may place specific constraints on the continued operation and maintenance of a treatment facility.

Practical considerations related to mine-site features that will influence the construction, operation and maintenance of a mine-drainage-treatment facility are as follows:

- Mine layout and topography
- Space
- Climate
- Sources of mine drainage feeding the treatment facility
- Location of treated water users

A generic range of ARD treatment alternatives is presented in Figure 10.

Figure 10: Generic Overview of ARD Treatment Alternatives (INAP, 2009)

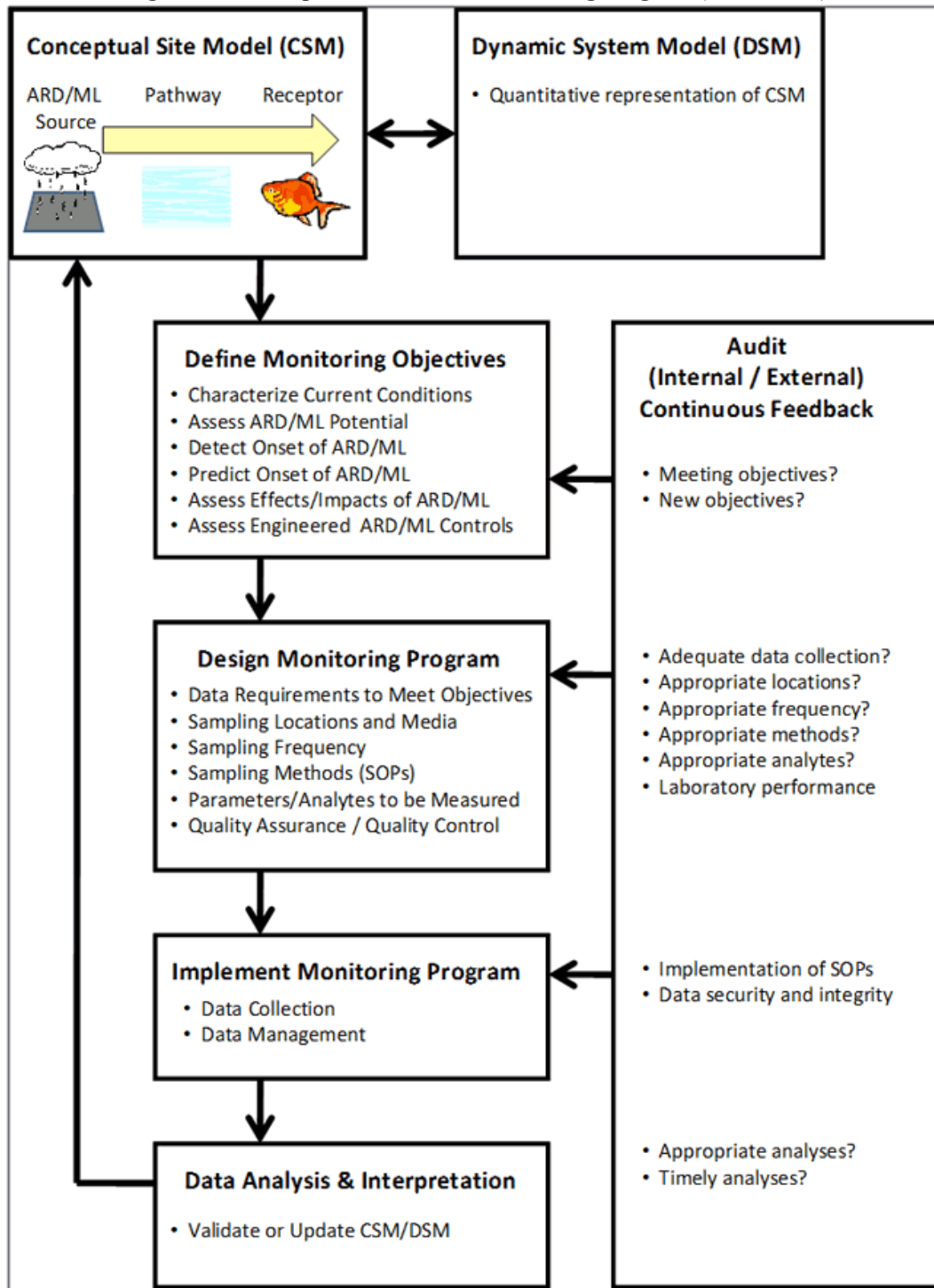
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Acid Rock Drainage Monitoring

Monitoring is the process of routinely, systematically and purposefully gathering information for use in management-decision making. Mine-site monitoring aims to identify and characterize any environmental changes from mining activities to assess conditions on the site and possible impacts to receptors. Monitoring consists of both observation (e.g., recording information about the environment) and investigation (e.g., studies such as toxicity tests where environmental conditions are controlled). Monitoring is critical in decision making related to ARD management, for instance through assessing the effectiveness of mitigation measures and subsequent implementation of adjustments to mitigation measures as required.

Development of an ARD monitoring program starts with review of the mine plan, the geographical location and the geological setting. The mine plan provides information on the location and magnitude of surface and subsurface disturbances, ore processing and milling procedures, waste disposal areas, effluent discharge locations, groundwater withdrawals and surface water diversions. This information is used to identify potential sources of ARD, potential pathways for release of ARD to the receiving environment, and receptors that may be impacted by these releases and potential mitigation that may be required. Because the spatial extent of a monitoring program must include all these components, a watershed approach to ARD monitoring (including groundwater) is often required. Monitoring occurs at all stages of project development, from pre-operational through post closure. However, over the life of a mine, the objectives, components and intensity of the monitoring activities will change. The development and components of a generic ARD monitoring program are presented in Figure 11.

Figure 11: Development of an ARD Monitoring Program (INAP, 2009)



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Acid Rock Drainage Management and Performance Assessment

The management of ARD and the assessment of its performance are usually described within the site environmental management plan or in a site-specific ARD management plan. The ARD management plan represents the integration of the concepts and technologies described earlier in this chapter. It also references the engineering design processes and operational management systems employed by mining companies.

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 development, assessment and continuous improvement of an ARD management plan is a continuum throughout the life of a mine. The development, implementation and assessment of the ARD management plan will typically follow the sequence of steps illustrated in Figure 12.

As shown in this figure, the development of an ARD management plan starts with establishment of clear goals and objectives. These might include the prevention of ARD or achieving compliance with specific water quality criteria. This includes consideration of the biophysical setting, regulatory and legal registry, community and corporate requirements and financial considerations. Characterization and prediction programs identify the potential magnitude of the ARD issue and provide the basis for the selection and design of appropriate ARD prevention and mitigation technologies. The design process includes an iterative series of steps in which ARD control technologies are assessed and then combined into a robust system of management and controls (i.e., the ARD management plan) for the specific site. The initial mine design may be used to develop the ARD management plan needed for an environmental assessment (EA). The final design is usually developed in parallel with project permitting.

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 (SOPs), key performance indicators (KPIs) and quality assurance/quality control (QA/QC) 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.

In the next step, monitoring is conducted to compare field performance against the design goals and objectives of the management plan. Assumptions made in the characterization and prediction programs and design of the prevention/mitigation measures are tested and revised or validated. “Learnings” from monitoring and assessment are evaluated and incorporated into the plan as part of continuous improvement. Accountability for implementing the management plan is checked to ensure that those responsible are meeting the requirements stipulated in the plan. Internal and external reviews or audits should be conducted to gauge performance of personnel, management systems, and technical components to provide additional perspectives on the implementation of the ARD management plan. Review by site and corporate management of the entire plan is necessary to ensure the plan continues to adhere to site and corporate policies. Additional risk assessment and management may be conducted at this stage to assess the effects of changing conditions or plan deviations. Finally, results are assessed against the goals. If the objectives are met, performance assessment and monitoring continues throughout the mine life with periodic re-checks against the goals. If the objectives are not met, then re-design and re-evaluation of the management plan and performance assessment and monitoring systems for ARD prevention/mitigation are required. This additional effort might also require further characterization and ARD prediction.

The process described in Figure 12 results in continuous improvement of the ARD management plan and its implementation, and accommodates possible modifications in the mine plan. If the initial ARD management plan is robust, it can be more readily adapted to mine plan changes.

Implementing the ARD management plan relies on a hierarchy of management tools. Corporate policies help define corporate or site standards which lead to SOPs and KPIs that are specific to the site and guide operators in implementing the ARD management plan. Where corporate policies or standards do not exist, projects and operations should rely on industry best practice.

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Acid Rock Drainage Communication and Consultation

The level of knowledge of ARD generation and mitigation has increased dramatically over the last few decades within the mining industry, academia and regulatory agencies. However, in order for this knowledge to be meaningful to the wide range of stakeholders generally involved with a mining project, it needs to be translated into a format that can be readily understood. This consultation should convey the predictions of future drainage quality and the effectiveness of mitigation plans, their degree of certainty and contingency measures to address that uncertainty. An open dialogue on what is known, and what can be predicted with varying levels of confidence, helps 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.

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Summary

Acid rock drainage is one of the most serious environmental issues facing the mining industry. A thorough evaluation of ARD potential should be conducted prior to mining and continued through the life of mine. Consistent with sustainability principles, strategies for dealing with ARD should focus on prevention or minimization rather than control or treatment. These strategies are formulated within an ARD management plan, to be developed in the early phases of the project, together with monitoring requirements to assess their performance. The integration of the ARD management plan with the mine operation plan is critical to the success of ARD prevention. Leading practices for ARD management continue to evolve, but tend to be site specific and require specialist expertise.

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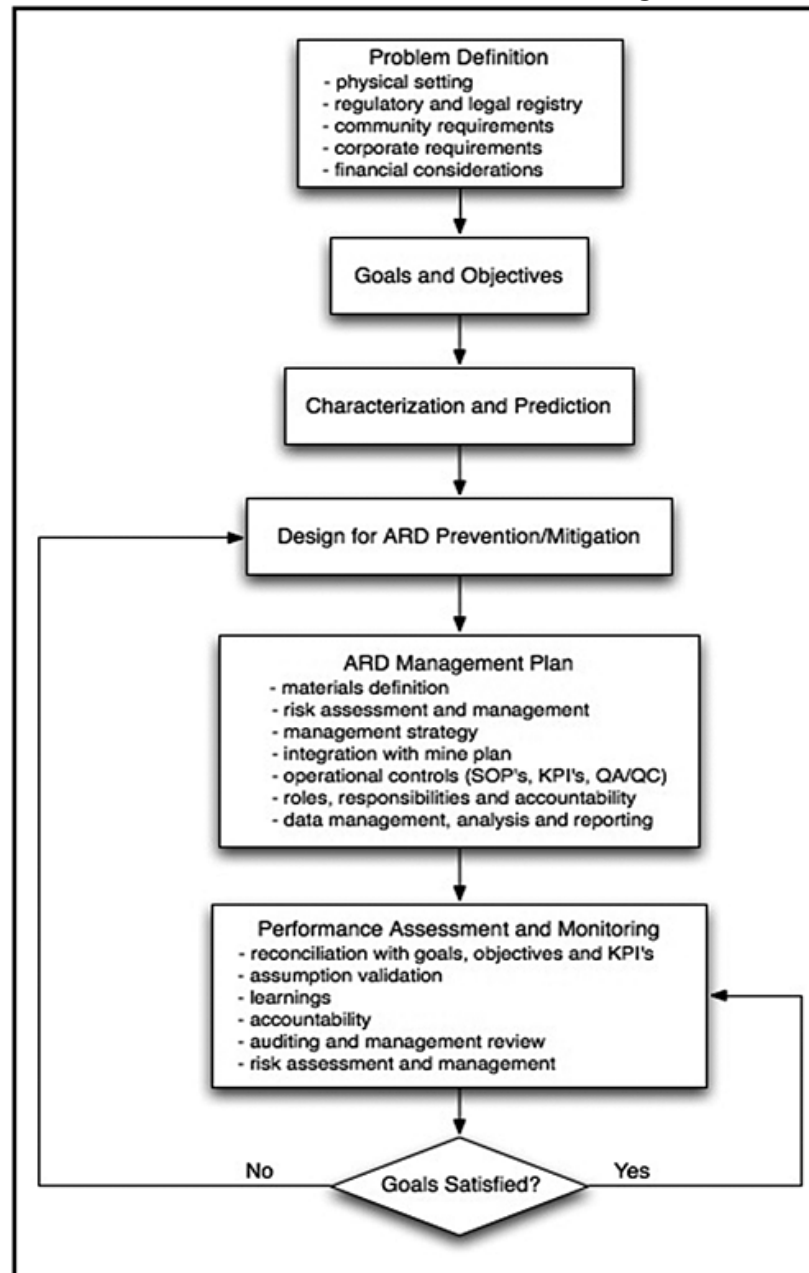
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Figure 12: Flow Chart for ARD Performance Assessment and Management Review (INAP, 2009)



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