Management of Acid and Metalliferous Drainage in Tasmania

Good Practice Guidance

2020-2025

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Mineral Resources Tasmania
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Contents

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Disclaimer:

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1. Introduction

The Good Practice Guide (GPG) for Management of Acid and Metalliferous Drainage (AMD) has been developed to provide guidance on how AMD is best managed on sites within Tasmania. It is acknowledged that there are numerous guidelines with respect to AMD; in Australia, the detailed *Sustainable Mining Series* includes *Preventing Acid and Metalliferous Drainage* (DFAT, 2016c) and the International Network for Acid Prevention (INAP) has published the *Global Acid Rock Drainage (GARD) Guide* available online (INAP, 2009). Both of these resources are technical in nature and aimed at engineers and scientists.

The intent of the GPG is to abridge the current resources available for management of AMD within Tasmania and provide management solutions which are specific to the Tasmanian climate and geological setting. The GPG will not be an exclusive resource for management of AMD, but instead provide the resources for current and future operators to understand and implement leading practice techniques for management of AMD. The document will point readers in the direction of further resources where available and identify when further assistance might be required from a consulting firm.

There have been many advances in the past two decades in the ability to identify and predict AMD, however liabilities continue to occur within the industry (Lottermoser, 2012; Dold, 2017). Mining, despite investing heavily in waste characterisation research, tends to be a reactive industry which fixes issues once they arise (Lottermoser, 2012; Pepper et al., 2014). The emphasis of the GPG is to prevent AMD forming by managing Potentially Acid Forming (PAF) material in a manner which excludes oxygen as early as practical after blasting or crushing and minimises the water transport pathways. Excluding oxygen and minimising contact of acidic material with water prevents AMD becoming an issue.

Evidence shows that failing to predict and manage AMD for the worldwide industry costs an estimated $140 billion in the liability associated with current and future remediation. (Parbhakar-Fox and Lottermoser, 2015)

Most effective AMD management outcomes arise from early waste characterisation, specifically identifying PAF at the exploration and feasibility stages of an operation (Parbhakar-Fox and Lottermoser, 2015). Waste characterisation is a complex process, which should be undertaken by experienced and trained staff/consultants. Waste characterisation and prediction is generally specific to the site geology and conditions. There is a standard set of tools which can be utilised; but they need to be applied appropriately and effectively to achieve correct results (Parbhakar-Fox and Lottermoser, 2015).

Unplanned closure costs to remediate AMD have often been in the order of $50 to $100 million, sometimes more

(Parbhakar-Fox and Lottermoser, 2015).

The mining and quarrying industry have improved their management practices over time, however best practice management of AMD risks are not often universally understood or applied (DFAT, 2016c). There are examples of industry best practice in currently operating mines and quarries in Tasmania, however many of the older operations are dealing with an AMD legacy. Operators of these sites know that treatment of AMD is a financial, social and environmental burden that can last into perpetuity. The AMD legacy can last into 'perpetuity', preventing return of security deposits and causing a long-term liability for companies.

It is very difficult to regain management control over AMD once is being generated. The GPG provides monitoring and management techniques, which can prevent the need for active treatment of AMD throughout the mining and closure stages of the operation.

1.1. Structure of the Document

This document is divided into two parts; the first part provides:

- an overview of what AMD is;
- approaches for detection and testing of potentially acid forming rock;
- best practice management strategies; and
- knowledge base.

This part of the document provides a technical basis for AMD management and aims to highlight the significant cost savings which an operation can achieve, over the life of the project, by identifying the presence of PAF material and managing the risk of AMD throughout the operating life and into closure.

The Knowledge Base section covers topics which are needed throughout the AMD management cycle, and don't fit neatly into any specific category. This section covers modelling, risk assessment and regulatory requirements. Managers of sites with AMD should continually assess these topics throughout the mine life from exploration to closure.

Part 2 of the document is a series of technical fact sheets, which identify further resources that may be needed at each stage of an operation. The fact sheets provide useful technical guidance for qualified practitioners seeking further resources, or for less experienced operators, background knowledge when seeking expert help.

2. Understanding AMD

2.1. What is AMD?

AMD occurs when sulfide-bearing rocks are exposed to oxygen (the air). Most sulfides in Tasmania are present as pyrite (iron sulfide), and chalcopyrite (copper iron sulfide). Exposure to oxygen results in the oxidation of sulfur leading to the production of acid, which can leach metals and other elements from surrounding rock. Once started this process is difficult to stop. During most forms of mining and quarrying, rocks are routinely blasted or crushed, exposing large areas of fresh rock to oxygen and allowing oxidation to commence.

The acid and leached metals generated by the oxidation of sulfur can enter water bodies resulting in transport and offsite effects. This process is commonly referred to as Acid and Metalliferous Drainage or Acid Mine Drainage (AMD). The presence of elevated metals, acid, or other elements in waterways is often toxic for aquatic ecosystems and prevents its use for stock watering, recreational water use or potable water. The effects of AMD can remain present in the landscape for many hundreds of years and cause permanent and irreversible ecological damage.

PAF material is present in host geology predominantly throughout western and north western Tasmania, with isolated occurrences in the north and east of Tasmania.

2.2. Geology

The geology in Tasmania is remarkably diverse and mineral rich, despite its small size (Seymour DB. et al., 2007). There are rocks present from every period of the earth's history, with at least four major episodes of economic mineralisation. The mineralisation on the Western side of Tasmania has resulted in a high-density of mines in a small area south of the Pieman River and north of Macquarie Harbour. The richly mined mineral fields of the west coast mostly lie within the Mount Read Volcanics (MRV). The formation of the MRV was possibly the most important event in the Tasmanian geological context and formation occurred during the middle Cambrian time (Seymour DB. et al., 2007). The main mineralised belt of the MRV was deposited in a marine environment and contains sulfide mineralogy. Figure 1 shows areas of Tasmania which have been identified as predisposed to AMD occurrences based on the distribution of sulfides.

Mineralisation also occurs on the north-east of Tasmania, which boasts a history of predominantly gold and tin mining. The deposits on the east coast of Tasmania are largely cassiterite and wolframite-bearing vein deposits from the Late Devonian time (Seymour DB. et al., 2007). Fact sheet 3 describes the linkages between geology and AMD in more detail.

Figure 1 – Geology predisposed to AMD shown in brown.

2.3. Climate

Climate affects the way a mineral deposit reacts to the environment, but plays a secondary role to geology in the formation of AMD (Plumlee GS and Nash JT, 1995). Tasmania has a cool, temperate climate with four defined seasons. The western part of Tasmania receives prevailing westerly winds and high rainfall over the predominantly hilly and mountainous terrain, whilst the 'midlands' and eastern parts of Tasmania are generally flatter and have significantly less rainfall, with regular periods of drought. Conversely, there is a small pocket of mountains in Tasmania's north-east which receives moderate rainfall. Rainfall in the west of Tasmania is typically around 2200mm per annum, with the eastern part of Tasmania receiving an average of 620mm per annum (Bottrill, 2001). Snow is common during the winter in the west and south-west of Tasmania.

The high rainfall, particularly on the west coast of Tasmania provides both challenges and opportunities with regard to management of AMD. AMD dispersal relies on water to take contamination from its source, downstream into the environment, so there are specific challenges in areas prone to high rainfall, like the west coast of Tasmania. The high rainfall and moderate temperatures can also provide adequate saturation of tailings year round. This provides the opportunity for disposal of PAF material using a water cover with minimal risk of a reduction in water cover over the summer months.

2.4. How to identify AMD

AMD has no standard appearance, however there are some indicators which frequently accompany the development of AMD.

The most common presentation of AMD in Tasmania is orange/brown precipitation in the water, drains, or on the ground. Often when staining is present, pyrite and other sulfide minerals are visually identifiable on the surface of rocks in the disturbed area. Figure 2 shows a quarry with staining present within the drainage network (centre), on the floor (right) and around the edge of the settling pond (left). These indicators of AMD mean that oxidation has occurred and the site very likely requires management. Identifying the most effective and cost-effective approach may require assistance from an AMD specialist.

Figure 3 shows the iron hydroxide precipitate in the water discharge from an adit at an abandoned mine site near Cethana. This part of the streambed is thick with iron precipitates due to long-term inflows from the adit. This site has received complaints from the public due to the unusual colour of the water, highlighting how visually striking AMD can be, and how it can decrease the aesthetics of a waterway.

AMD can also present as sulfate or hydroxide compounds on tailings beaches and waste rock dumps. The sulfate appears like a white powder and tends to occur after a period of dry, it can be particularly common during late summer. Figure 4 shows sulfate on tailings at an abandoned site near Zeehan. It has a blue appearance due to copper content, however it can be white or stained depending on the mineralisation of the material which has formed the sulfate.

Figure 2 – AMD present in a quarry as orange/brown iron precipitate in drainage and iron staining on the quarry floor.

Figure 3 – Red iron hydroxide precipitate present from adit flows.

Figure 4 – Shows sulfate on the tailings at the Austral Smelter site near Zeehan.

Figure 5 – Poor revegetation success at South Mount Cameron, Endurance Mine site. Revegetation success on tailings has been limited and slow to take. The site has a history of legacy acid drainage issues.

Revegetation failure can also indicate the presence of AMD. Poor revegetation success can indicate many things, however AMD should be considered, particularly in areas where sulfides have been present. For example, the South Mount Cameron Endurance site has been revegetated for some years. Revegetation occurred on old tailings beaches where AMD is present, which resulted in limited revegetation success. Adjacent Blue Lake has an average pH of around 4, indicating ongoing acid loads through the tailings, explaining the poor revegetation success. Poor revegetation at Endurance is shown in Figure 5.

Other common indicators of AMD can be:

- Dense covering of green algae with unusually clear water;
- Death of aquatic wildlife downstream when AMD is mixed with receiving water; and
- Pasture or vegetation dieback after a flood or uncontrolled release of water.

Usually the visual appearance of AMD means that PAF material has not been adequately managed, so visual presentation of AMD shows that management measures are not effective or being implemented correctly. Any visual evidence of AMD should be investigated immediately.

3. Acid and Metalliferous Drainage and the Mine Lifecycle

This GPG focuses heavily on planning, estimating, modelling and managing PAF material, rather than treating AMD at the end of the mine life. Treatment of AMD can cost millions of dollars and is often required for many years after mine closure has occurred. The more investment made into identification of potential AMD issues, and understanding the rate of acid and metal release and waste characterisation during the exploration and feasibility stages of new operations; the lower the overall AMD management costs will be over the life of the operation.

The fact sheet series describes current good practice when managing AMD throughout the life of an operation. This section defines which part of the mining life cycle each fact sheet best applies to, with a summary of its content.

3.1. Fact sheet 1: References and Glossary of Terms

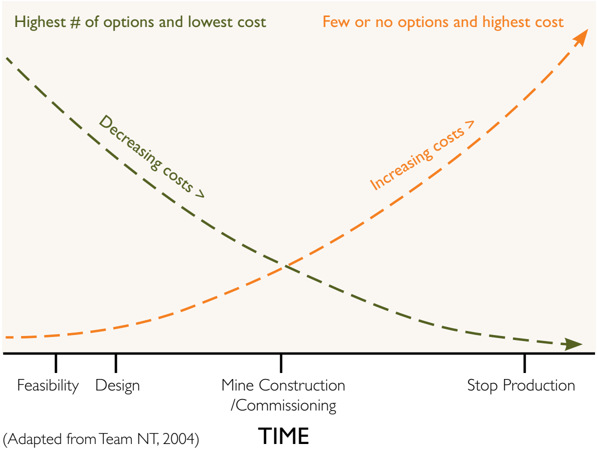
This fact sheet gives a list of references and a glossary of terms which can be used when assessing and managing AMD during all phases of an operation. The list of resources is not exhaustive, but covers the major publications in Australia and worldwide. It is worth noting that these documents cover management of AMD in all climate types, Tasmania's temperate climate does pose some challenges with respect to AMD management.

3.2. Fact sheet 2: Implications of not Managing AMD Correctly

This fact sheet discusses the implications of failing to manage AMD throughout the mining lifecycle.

AMD needs to be considered throughout the life cycle of a mine, and long-term management plans, including final closure, need to be developed from the initial states of mine planning. Ideally, the AMD management plan is initially developed during the planning stages of the project, and is continually updated throughout the mine life as more information becomes available. The plan should include all aspect of management – from the large-scale, big picture issues such as mine closure, to the day-to-day handling and management of materials.

Integrating mine closure into the early planning phases of a new mining project may sound counterintuitive, however how the site is developed and managed will determine what options are available for closure, and the likelihood of success. Closure options during the pre-mining phases might be very conceptual; development of closure landforms, mine and dump designs are all performed during this period of the mine life. History shows that a lack of AMD identification and management during the operating phase of a mine site can lead to failure during the closure and rehabilitation phases of an operation. Figure 6 indicates that as mine planning and operations continue over time, the options for closure diminish and the costs increase.



(Adapted from Team NT, 2004)

Figure 6 – Closure options and effectiveness with time (source: GARD Guide, Chapter 6).

3.3. Fact sheet 3: Identification and Characterisation of Materials

This fact sheet is designed to help explorers understand why identification and testing for AMD is important during all phases of exploration.

The initial scoping phase generally provides a data-set which determines if there is a marketable resource. This phase also aims to collect samples of waste rock for characterisation at broad spacing to produce a waste model, which can be refined as more data is collected. MRT has made a significant amount of data available to the public free of charge (Figure 11, in Fact Sheet 3). The purpose of collecting the data is to start development of a statistically valid spatial ore and waste model.

Industry best practice for AMD assessment has mostly been discrete sampling with the use of static lab tests to predict PAF material and likely AMD generation. There has been criticism of this method for many reasons (Parbhakar-Fox and Lottermoser, 2015), with the obvious one being that lab conditions do not simulate site conditions. Assessments of AMD risk are usually a site-specific calculation. Errors which affect AMD estimation and rate of pollution release can potentially make a project unviable. The project team, including geologists, mine planners, environmental scientists and AMD experts, need to ensure that an adequate geological and geochemical database is compiled to clarify baseline conditions and to estimate the risk of PAF (DFAT, 2016c). AMD management can add extra cost burdens to projects due to costs like alkalinity addition, unexpected closure requirements, additional trucking and dump construction costs and mine design compromises, just to name a few.

The key aims of mine material characterisation are to determine (DFAT, 2016c):

- the potential extent or magnitude of AMD generation;
- the potential rate and timing of AMD generation; and
- the likely contaminants of concern in leachate produced from the oxidation and transport of sulfidic materials.

> *"AMD risk assessments rely on too few predictive static and kinetic tests, with the inherent geological variability hardly considered, and statistically sound AMD block models are hardly ever prepared"*
>
> (Lottermoser, 2012)

Data capture in this phase of exploration and scoping should aim to identify waste domains and provide qualitative assessment of AMD potential from predisposed geology and geological core logging. Early indicators of AMD potential can be provided by measurements of total sulfur and total carbon content (DFAT, 2016c), these early indicator tests need to be used in consultation with a consultant familiar with AMD prediction and in areas where any non-carbonate carbon is unlikely to occur. Screening can be conducted with the use of a handheld XRF analyser or laboratory analysis of core samples.

3.4. Fact sheet 4: AMD Prediction Methods

This fact sheet is aimed at sites which have discovered economic mineralisation and are planning to develop a project.

Management decisions regarding material classification and waste dumping over the life of the project can be refined as detail is added to ore and waste models to ensure best practice management of AMD. Figure 12 (in Fact Sheet 3) shows how a block model might grow in density and accuracy as a project progresses.

Estimates and modelling (application of the test work) need to be done by skilled and experienced practitioners and are site-specific. No single AMD characterisation test is sufficient to fully assess the AMD risk across the range of material types typically present at mine sites, with multiple test methods required. Scaling up of test work, such as static and kinetic tests, has inherent challenges, which are best undertaken by skilled and experienced practitioners (DFAT, 2016c).

> *"There are no simple methods for extrapolating laboratory test results to large-scale mine site waste containment facilities to predict the concentrations of solutes that will be produced" (Pearce et al. 2015).* (DFAT, 2016c).

While water quality sampling of waterways on the prospective mine site is not routinely conducted during exploration, a baseline sampling regime is essential before earthworks occur. Baseline sampling aims to identify the conditions present in the receiving environment before mining commences, which might be considerably different from the default trigger values provided in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZGFMWQ, 2018). Remediating to baseline conditions can be far more cost-effective and realistic than trying to remediate to a guideline (Plumlee GS and Nash JT, 1995). Regardless of pH, if sulfate and/or metals are present in the waterway this can also be a sign that AMD is present on the site.

3.5. Fact sheet 5: Monitoring Requirements

Fact sheet 5 covers topics which are pertinent to management of AMD on a site which is operating.

Successful implementation of the AMD management plan requires commitment by mine management and staff and positive collaboration across all relevant sections of the business unit. Operational aspects of the AMD management plan, such as waste segregation and water management, should be communicated to mine management to ensure that it is understood by those who are driving the plan (i.e. mine supervisor).

Operators need to be aware of the basic principles of the AMD process, and in turn that waste segregation is a significant part of the process to prevent oxidation and a major component of maintaining compliance with the plan (Dowd, 2005). Management must also commit to ongoing waste characterisation as the mine develops, updating the waste model over the life of the mine. Failure to make continual improvements to the waste model can lead to incorrect waste placement and can result in unnecessary costs to the mine and environment (Barritt et al., 2016).

Avoidance of AMD in the mine design is ideal. Without exposure to oxygen, PAF materials can't form AMD, and therefore if possible, mine designs should avoid areas of high sulfides. Methods of appropriate waste dump design are discussed in more detail in the Fact Sheet 6, however during feasibility studies, the method of waste dump construction needs to be identified and costed, therefore AMD management over the life of the site needs to be considered.

Managing water within a site that has sulfide-bearing materials can be one of the biggest reasons for success (or failure) when managing AMD on a site. The primary objective with water management is to allow the least amount of water to become contaminated. This means keeping water from flowing into operational areas, waste rock dumps, stockpiles and tailings dams where possible by the use of diversion drains and ensuring that clean and contaminated water remain separate on site. Tasmania faces water management challenges, particularly on the heavily mineralised West Coast, which is well known for its high rainfall. Large amounts of water falling quickly onto a site can provide challenges for water management. Minimising the volume of AMD created can also minimise costs if water treatment becomes the only management option.

3.6. Fact sheet 6: Prevention of AMD During Operations

Fact sheet 6 covers handling of PAF materials during operations. Figure 7 shows how AMD might be generated during open cut, traditional drill, blast, load and haul cycles. The fact sheet covers both tailings and waste rock as these streams of PAF are managed in separate ways. Tailings represent waste which has been through the process plant (mill) and waste rock is part of the in-pit segregation process. Waste rock is generally classified as PAF or NAF, based on the waste segregation plan (an aspect of the AMD Management Plan).

Tailings present a specific risk as an AMD source as they are generally finely ground, presenting a large surface area for oxidation. The manner in which a tailings dam is constructed presents a closure risk, which will not be discussed in this document, and a closure challenge to prevent AMD, which is discussed in this document. The Leading Practice Series has published *Tailings Management* (DFAT, 2016d), which is a good resource when considering the type of tailings dam which will be used and the consequences of those choices. In Tasmania, tailings disposal should be subaqueous (underwater), which minimises the chance of AMD being an issue because the water cover limits the ingress of oxygen, hence limits the oxidation of the fine-grained particles.

There are many ways in which oxygen may be excluded from tailings to prevent oxidation of sulfides. INAP has presented a technical guidance on tailings dam cover systems (O'Kane and Baisley, 2014). The guidance suggests that an appropriate cover needs to consider many environmental factors, but planning should start during exploration. Figure 8 shows how resources should be allocated to cover system design and

Figure 7 – the drill, blast, load and haul of PAF can cause AMD, particularly with large end dumps.

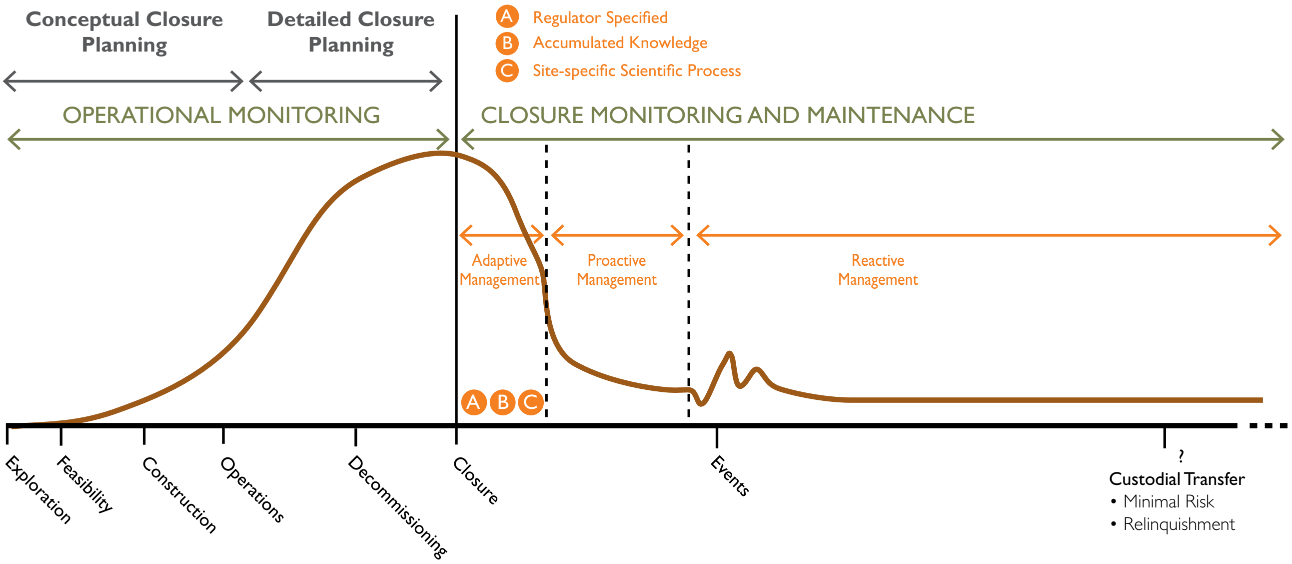


Figure 8 – Allocation of resources to closure in the context of a cover system. Source: (O'Kane and Baisley, 2014).

monitoring during the life cycle of an operation, it is interesting to note that it should be started before construction of the site commences.

Waste rock dumps pose one of the greatest risks for AMD generation on a site. If waste rock dumps are not designed and constructed correctly, oxygen ingress allows the formation of AMD, which is washed away and transported around the site by water flowing in and around the dump. Waste rock dumps should be designed after there is a sound understanding of the quantities and characteristics of waste that need to be managed over the life of the operation. There are a number of ways to minimise the risk of AMD within waste rock dumps, all of these solutions aim to exclude oxygen and water making contact with the sulfidic waste.

> *Mine waste is not all acidic, responsible mine operators have conducted test work to identify alkaline, neutral, potentially acidic and acidic waste during exploration and feasibility, populating and updating the waste model as the operation grows*
>
> (Barritt et al., 2016).

The current best practice for PAF is subaqueous disposal in a pit lake, or by placing the waste back underground before the operation is flooded. Subaqueous disposal provides a secure and long-term environment where the waste can no longer oxidise and it is unlikely that it will cause any environmental legacy.

On some sites, particularly those with a long mine life, the subaqueous disposal of waste is not easily achievable, or practical, within the time frame required to prevent the onset of oxidation. Long-term management of acidic water is environmentally challenging and may make subaqueous disposal challenging on some sites.

3.7. Fact sheet 7: Treatment of AMD

This fact sheet covers active and passive treatment systems. Treatment systems are used to remove metals from the water and raise pH to improve water quality when AMD leaves the site. Using a treatment system should be a last resort for AMD management. Active treatment systems involve the addition of a reagent, generally via a treatment plant, and the active input of labour and resources. Passive treatments do not require active input of reagents and labour, these are most commonly used on closure and rehabilitation sites.

3.8. Fact sheet 8: Planning for Closure

This fact sheet covers planning for closure, including landform design, stakeholder consultation, and planning for relinquishment.

A 'design for closure' approach should be applied to all parts of the mining cycle from Feasibility and Operations, through to Closure. Closure plans should be developed as part of mine planning and progressively implemented. Ideally, mines have a planned closure at the end of their life, however "research shows that almost 70% of the mines that have closed over the past 25 years in Australia have had unexpected and unplanned closures (Laurence, 2002)" (DFAT, 2016d). Unplanned closure means the risks are increased for both the environment, due to physical and contamination risks, and the community as the landform left may not provide a final landform which can be used and community resources (i.e. water) may be contaminated (McCullough, 2016).

Closure risk is reduced by progressive rehabilitation. Progressive rehabilitation is particularly important when managing AMD; it can include tasks such as installation of PAF covers (i.e. clay capping), subaqueous disposal of PAF material, or other activities which exclude oxygen from PAF material. Progressive rehabilitation improves rehabilitation outcomes and can lower closure costs.

Initial estimates for closure of Woodcutters mine (NT) was AUD $500K, to date Newmont have spent AUD $35M on closure. The major failings during planning and operations are; failure to classify waste, progressive rehabilitation was not undertaken, waste segregation was incorrect causing rehandle of waste and stakeholders are resentful of the way that rehabilitation has been handled and the time it's taken to occur. (Dowd, 2005)

Clear closure objectives lead to better management outcomes; well defined objectives also provide a clear indication of the intended outcome for stakeholder groups and the government (DFAT, 2016a). It is important to produce a final landform that fits with the surrounding environment and meets the expectations of the land users.

Traditional landowners need to be consulted throughout the mining program (McCullough, 2016). Closure in regional centres can mean that a town is left without a major industry. The company and Government need to work together to ensure that the workforce can be redeployed or reskilled.

"Mining engineers, mine geologists and consultants generally have the most influence in mine planning and design. They need to understand and take into account mine closure issues and integrate economic, environmental and social elements into the company's decision-making." (DFAT, 2016a).

The closure plan should not be housed within the environment department of an operation. All technical staff need to understand the plan and their role in its implementation. Leaving implementation until the end of the mine life is a common mistake. This approach fails to recognise that closure planning is a process, not an event (McCullough, 2016).

4. Knowledge Base

The prediction and management of AMD needs to be based on an accurate and sound understanding of the system. This includes monitoring, modelling, and predicting impacts such that appropriate management and mitigation strategies can be developed. A thorough understanding of the legal requirements related to AMD is also required. These topics are briefly described in this section and covered in more detail in Fact Sheets 3, 4, 5 and 8.

4.1. Modelling

Modelling assists with the decision making processes by simulating the current environment. For example a model, can assist with decisions about the project cost projections, environmental conditions and landscapes (to name a few examples). The more detailed and accurate the input information is, the less risk associated with the modelling results upon which to base decisions. Table 1 shows the most common models used when planning, operating and closing a mining operation.

A model is only as good as the information used in its generation. For the model to remain relevant throughout the life of the operation, continuous monitoring of waste rock and water quality is required. Models need to be continually updated with the data, with the information feeding back into the mine planning and closure planning cycles.

Model	**Purpose**
Hydrological	A hydrological model will start with baseline water monitoring of surface and groundwater flow and water quality during the early planning stages of a project. This information serves to inform the approvals process and commence development of a site-wide water balance. Over the life of the project, the water balance will be refined with new data, mining method, landform development and evolution of the site. It is fundamental to understand the water transport pathways, water quality, quantity and movement throughout the site as water is the transport medium for AMD.
Geological	Geological mapping from the outset of the project informs the local and regional geological setting of the proposal. It is important, particularly where AMD is likely to be present, that ore and waste are mapped geologically and geological/geochemical modelling commences as early as possible. The model houses the geological, chemical, characterisation and material properties that will be used to forecast the ore reserve, project costs, mine design and waste management techniques. A well-developed and accurate model will allow decisions about the project to be made with a higher degree of certainty.
Landform	Modelling the final landform assists with closure planning, stakeholder consultation and cost assessment. The final landform will also inform the hydrological model, assist with estimation of any effects of AMD and to allow for progressive rehabilitation.

Table 1 – shows the most common models used to assist with prediction of AMD during the life of an operation.

Figure 9 shows a road map to deciding if AMD is likely to be an issue on site. A vital feature of this decision tree is a valid waste model.

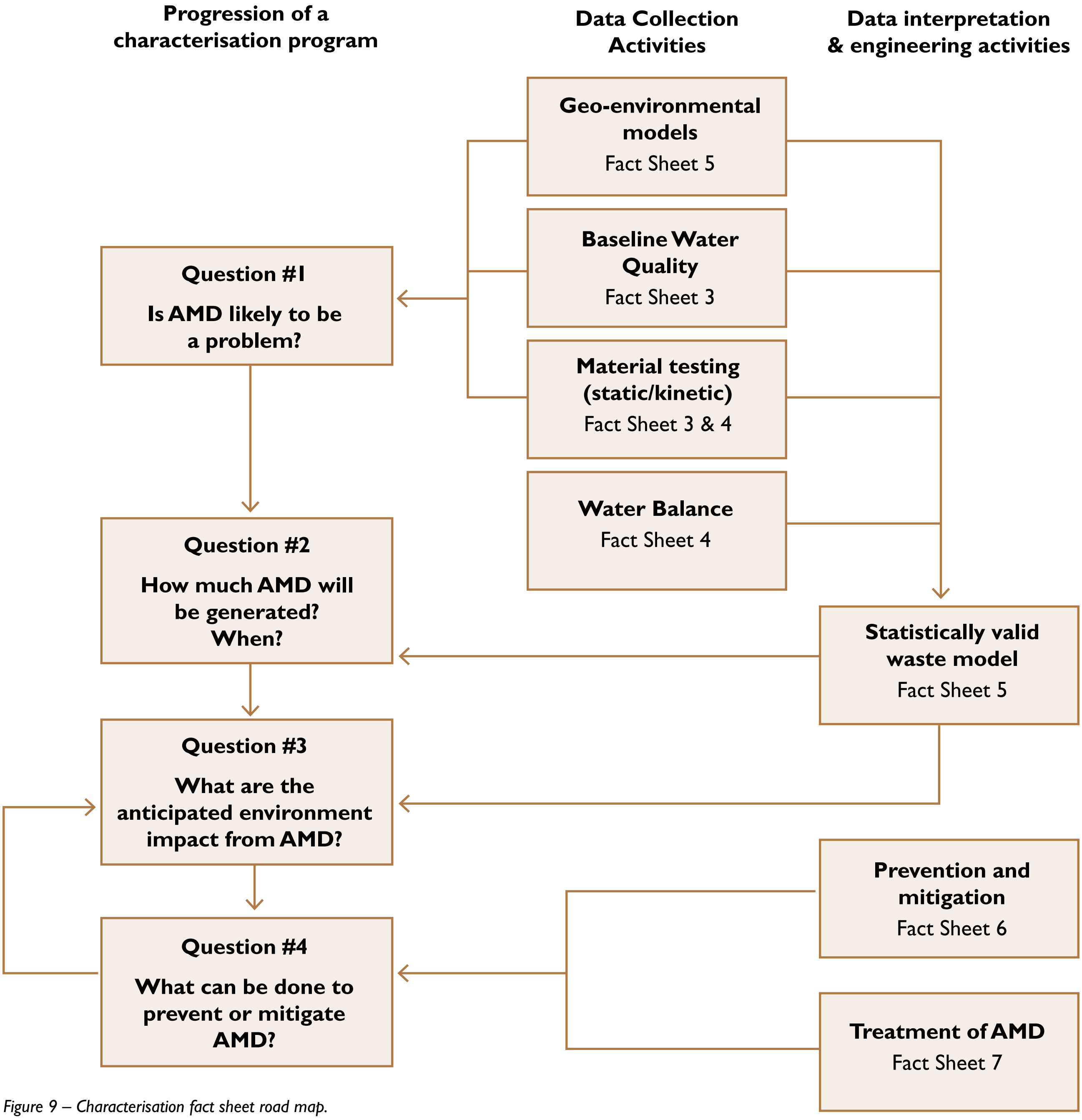


Figure 9 – Characterisation fact sheet road map.

4.2. Risk assessment

Using contemporary hierarchy of risk reduction (Figure 10), an elimination of the problem (i.e. prevention of oxidation) is the best way to reduce the risk of AMD formation. The early detection of PAF material allows for effective treatment and management of AMD, preventing an end of mine life AMD issue, which is often too large to rehabilitate. AMD risk management should be reviewed during the life of the operation as sampling information becomes more detailed. GPG provides guidance on test work which fits into the life of mine cycle with the aim of keeping the cost and effort involved in the analysis commensurate with each stage of the mine life.

Risks can include environmental, human health, financial, regulatory and reputational risks. History and experience in the mining industry show that AMD can be a large priority for risk management (DFAT, 2016c). Adequate risk management throughout all mining phases provides a basis for decision making, forms priorities for management and provides a process for transparency (INAP, 2009). Risk assessment should be site-specific and consider the downstream uses of water leaving the site.

An environmental or AMD risk assessment can use a risk = probability × consequence matrix. The GARD Guide (INAP, 2009) provides a useful step by step risk management protocol in section "3.6 Risk Considerations". Section 5 of the *Leading Practice Handbook: Preventing Acid and Metalliferous Drainage* has a framework for assessing the risk posed by AMD.

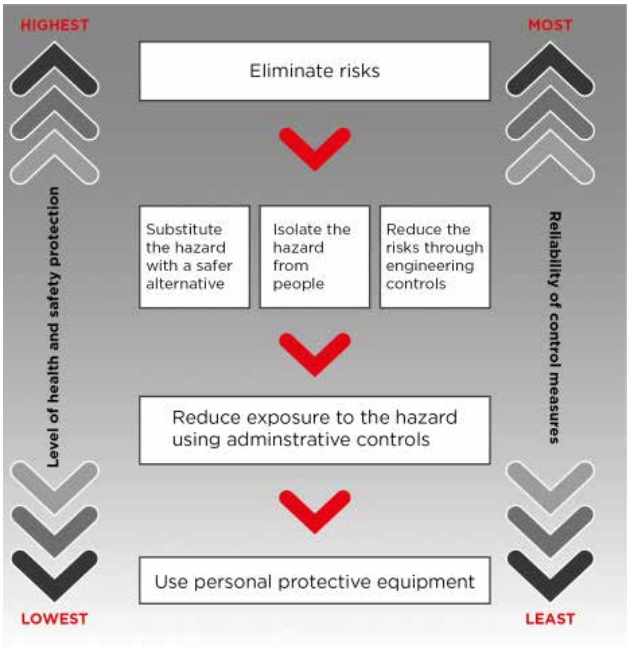


Figure 10 – Traditional hierarchy of risk controls often employed by safety departments. This can be applied to environmental management and AMD risk management. Source: (Australia, 2019).

Rio Tinto implemented a process to screen for AMD and geochemical risks for their operations in the Pilbara Region (Green and Borden, 2011). The risk assessment framework includes four stages:

Stage 1: preliminary AMD hazard score conducted during the exploration phase;

Stage 2: technical AMD and geochemical risk assessment report conducted during the exploration and feasibility stages;

Stage 3: detailed AMD hazard score, which quantifies the AMD risk on the specific site;

Stage 4: AMD risk assessment of management strategies.

The AMD and geochemical risk assessment used by Rio Tinto aims to proactively manage one of the biggest risks to an operation. The systems aims to attain progressively more information as the project progresses to develop a robust AMD Management Plan (Green and Borden, 2011).

Corporate governance law requires Australian companies to manage significant risks posed by the company's operations. Compliance with government regulations and permit conditions does not necessarily guarantee that AMD is being managed in the most practical, robust and cost-effective way (DFAT, 2016c).

4.3. Regulatory framework

All mine operators have legal responsibilities, which start before operations commence. Licencing is required in Tasmania to undertake exploration under the *Mineral Resources Development Act 1995* (MRDA). Approvals for exploration are sought from MRT and works can proceed once an exploration licence is granted by the Minister for Resources and approval from MRT is given.

For most major metalliferous projects and larger quarries, the activity will be referred to the Environment Protection Authority (EPA) for assessment. The EPA will assess the project under the *Environmental Management and Pollution Control Act 1994* (EMPCA) and determine which class of assessment the project will fall into, which affects the level of detail the development application requires. The EPA will provide the proponent with project-specific guidelines. When a mining lease and development application are submitted simultaneously, MRT will use the development application and subsequent documents to determine a recommendation to approve, or otherwise, a mining lease.

Most operations within Tasmania which have AMD present, will be regulated by the EPA. Part of the process for gaining approval will be providing a level of detail on waste characterisation, waste management planning, waste segregation planning, waste dumping and mine design, and a closure plan. EPA staff will assess the risk to the environment and impose conditions upon the operation to ensure it is capable of being managed in an environmentally acceptable manner.

MRT has in place a security deposit system to ensure that all rehabilitation and aftercare costs are borne by the organisation undertaking the project. MRT expects that mining and exploration in Tasmania are carried out sustainably (MRT, 2013). The purpose of taking a security deposit is to ensure that funds are available to remediate any environmental and safety legacy at the end of the operational life of a mine. The Tasmanian security deposit system takes into account both the cost of closure and the post-closure liabilities such as water treatment and monitoring.

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