BEST PRACTICE PRINCIPLES FOR MINE WASTE COVER SYSTEMS AND MINERAL MINE REHABILITATION IN QUEENSLAND

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ABSTRACT

Rehabilitating mine waste, whether held in tailings storage facilities, waste rock dumps or heap leach piles, remains a critical challenge for the mining industry globally. Effective management of mine wastes requires an understanding of how local climate affects weathering and leaching of waste material, to potentially impact the surrounding environment. Cover systems are an integral part of controlling this interaction and therefore a key component of effective mine rehabilitation planning.

Despite a wealth of published information about cover system design and the prevention of acid and/or metalliferous drainage (AMD) from mine waste, convincing examples that demonstrate cover system performance and good rehabilitation outcomes from metal mines in Queensland are scarce. On the contrary, there are numerous examples of AMD from covered and uncovered mine wastes in Queensland, many of which are now abandoned sites.

The Office of the Queensland Mine Rehabilitation Commissioner is undertaking research that will support the development of best practice advice regarding cover systems for mine wastes that have the potential to generate AMD in Queensland. The aims of the research program are to:

- *develop a risk-based framework to categorise mine waste structures in Queensland,*
- *outline clear design objectives for cover systems in each risk category,*
- *determine best practice cover system design principles to meet design objectives for mine waste with a high risk of AMD and*
- *provide guidance on the use of various cover system components (e.g., reduced permeability layers, capillary break layers, and thicker inert material layers) that is proportionate to risk.*

The work is intended to support stakeholders with guiding principles of best practice mine waste cover system design in Queensland. It will not supplant the need for site-specific cover system design but can be used to inform the transition to Progressive Rehabilitation and Closure plans for mineral mines in Queensland. Preliminary work towards achieving the first two aims is presented here.

Keywords: acid and metalliferous mine drainage, cover systems, progressive rehabilitation

1.0 INTRODUCTION

The Mineral and Energy Resources Financial Provisioning (MERFP) Act (2018) came into force on 1 April 2019. The objectives of the MERFP Act were twofold: (1) to manage the financial risk to the State if mineral and resource companies do not comply with their environmental management and rehabilitation obligations; and (2) to ensure that land disturbed by mining activities is rehabilitated to a safe, stable landform that does not cause environmental harm and is able to sustain an approved, post-mining land use.

The first objective of the MERFP Act was achieved by establishment of a financial provisioning scheme (FPS) in Queensland. FPS provides Government with access to funds to undertake rehabilitation works in circumstances where a resource company does not comply with their rehabilitation obligations. The amount of contribution or surety required, is determined with reference to the estimated rehabilitation cost (ERC) calculated by the Department of Environment and Science for each site. The second objective of the MERFP Act was achieved by establishing the requirement for mining companies to develop Progressive Rehabilitation and Closure (PRC) plans. PRC plans include time-based milestones, which are legally enforceable, for progressive rehabilitation of mined areas and the delivery of post-mining land uses. Existing site-specific environmental authority holders are required to submit PRC plans to DES by December 2024.

Subsequent to the MERFP Act, Queensland Parliament introduced legislation creating an independent Rehabilitation Commissioner for resource activities (Environmental Protection and other Amendments Act 2020). Among other things, the Queensland Mine Rehabilitation Commissioner is tasked with providing advice on complex mine rehabilitation matters and best practice mine rehabilitation in Queensland. One of the priorities for rehabilitation research in the Office of the Queensland Mine Rehabilitation Commissioner (OQMRC) focuses on best practice rehabilitation of mine waste structures that have the potential to cause acid and/or metalliferous drainage (AMD).

Ideally, best practice management of mine waste during mining operations, and improved construction methods for mine waste structures (INAP 2020), reduces the likelihood of AMD before final rehabilitation works commence. However, across Queensland many conventionally-constructed mine waste structures exist, for which rehabilitation will be underpinned by development of an engineered cover system. Cover systems are one tool for controlling the interaction between climate, mine waste and the receiving environment over the long-term. Their effectiveness in Queensland, design details and construction costs have become a hotly debated topic in light of the recent legislative reforms in Queensland relating to financial assurance and PRC plans. This paper outlines ongoing research in OQMRC, intended to support both regulatory and industry stakeholders with guiding principles of best practice mine waste cover system design and implementation in Queensland.

2.0 METHODOLOGY

2.1 Mine waste structures and environmental factors

Under the current ERC framework, mine waste structures that have cover systems costings as part of rehabilitation include tailings storage facilities (TSFs), waste rock dumps (WRDs) and Heap Leach Piles (HLPs) (DES 2019). Mine waste can be deposited in other ways that do not necessarily fit simply into these broad groups (e.g., coal spoil piles, coarse rejects or scats, and co-disposal techniques). However, with the intent of targeting structures with the greatest risk of AMD, the current research focuses on mine waste stored in WRDs, TSFs and HLPs.

A risk categorisation framework was developed to support users in Queensland understand the risk of AMD from their TSF, WRD or HLP without any intervention or management. Geochemical risks were the focus; geotechnical risks from mine waste structures were not considered. Parameters considered in the development of the geochemical risk framework were climate, hydrogeology and waste material properties.

2.2 Cover system design objectives

After a risk categorisation framework was developed to support users identify the risk of AMD from their mine waste structure without any intervention, general and specific objectives of cover systems were outlined, to provide a shared understanding of design objectives for cover systems as correlating to risk level.

2.3 Cover system layering and best practice examples

Information about the purpose and function of various cover system layer components and a best practice example of cover system design over mine waste with a high risk of AMD in Queensland is being developed at present. The information is being drawn from international guidance on managing AMD (e.g., International Network for Acid Prevention, Mine Environment Neutral Drainage, The Global Acid Rock Drainage (GARD) guide www.gardguide.com) and will be ideally informed by data from cover system trials across Queensland.

3.0 RESULTS AND DISCUSSION

3.1 Development of a geochemical risk framework for TSFs, WRDs and HLPs in Queensland

Risk is a function of the likelihood of a harmful event occurring, and the consequence of that event. In the case of geochemical risks from mine waste structures, the consequence is an adverse impact to the receiving environment. Likelihood can be predicted by understanding the environmental factors that interact with mine waste structures to contribute to geochemically harmful events. These include climate, vegetation, material properties, hydrology, hydrogeology and topography. To simplify the risk assessment process and provide a common platform for evaluating geochemical risks from mine waste structures in Queensland, we developed a risk rating matrix based on climate, net percolation and material properties.

Users start by identifying which of the 4 major climate regions in Queensland mining areas best describes their site. From the Köppen-Geiger classification (Beck et al. 2018) these are:

- Savanna (Aw) – wet summers, dry winters, consistently high annual temperature,
- Hot Semi-Arid (BSh) – hot summers, cool to mild winters, low rainfall,
- Hot Desert (BWh) – hot summers, cool winters, intense sunshine, little to no rainfall,
- Humid Subtropical (Cfa) – hot and humid summers, cool to mild winters.

Climatic region is important because rainfall (both intensity and seasonality) and evaporation are key drivers of the processes that contribute to contaminant mobilisation. Rainfall is the catalyst for dissolution and transport of materials, chemicals and contaminants in a mine waste structure, while drier climate conditions and changing temperature conditions strongly influence oxygen ingress into mine waste and are a key contributor to sulphide oxidation and the generation of AMD from sulphidic mine wastes.

Secondly, amongst several approaches, users typically estimate net percolation for their mine waste structure using either on-ground measurements, or particle size distribution as a proxy where local data is unavailable. Net percolation is the proportion (%) of annual rainfall entering a mine waste structure that is not taken up by plants (i.e., transpiration), 'lost' to the atmosphere through evaporation, or does not run off the structure (see also section 4.3.3 4 of the GARD guide http://gardguide.com/index.php?title=Chapter_4#). Where site-specific data is available, net percolation can be calculated according to the following water balance equation (Bradley & Meiers 2014):

$$NP\ \% = (PPT + Ron - Roff - AET - \Delta S) / PPT$$

where PPT is annual precipitation
Ron is annual run on
Roff is annual run off
AET is annual evapotranspiration, and
ΔS is the water storage content of the unsaturated MWS material.

Where site-specific hydrological data is unavailable, users are directed to estimate net percolation based on surface infiltration capacity, as estimated from the particle size distribution within their mine waste structure.

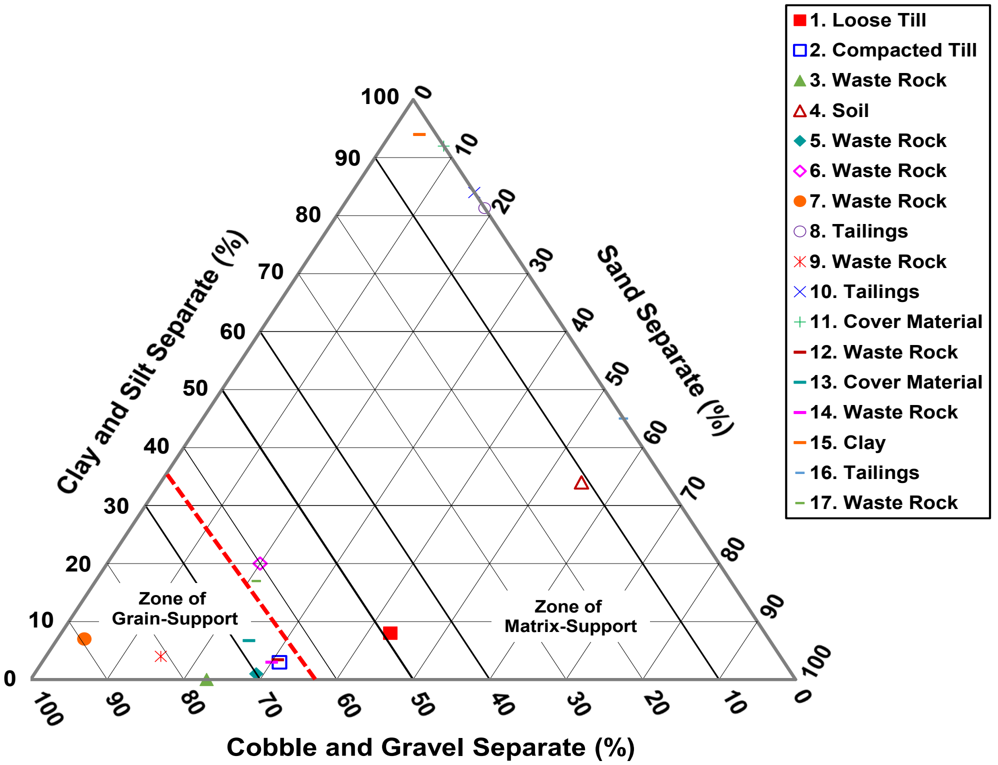

Fig. 1. Ternary plot to determine if a mine waste sample is grain-supported or matrix-supported, based on the proportion of clay and silt, cobble and gravel, and sand in the material. Adapted from INAP (2017).

Particle size distribution gives an indication of hydraulic conductivity and water retention properties of mine waste material (INAP 2017). As a general principle, finer-textured material will have lower net percolation (increased run-off, and also increased water retention at the surface providing increased opportunity for evapotranspiration). Users are directed to INAP (2017) to determine the particle size distribution of their mine waste as either grain-supported or matrix-supported (Figure 1 below). Grain-supported materials (i.e., a large proportion of gravel-sized clasts, such that individual clasts touch each other in the overall structure) are likely to have higher net percolation than matrix-supported materials (where clasts are separated by finer-grained material in the overall structure).

Finally, users determine the proportion of hazardous material in their mine waste structure, where hazardous material includes, potentially acid forming (PAF) material, non-acid forming (NAF) material with a propensity for metal mobilisation, and/or highly sodic material. Whether material is PAF or NAF can be calculated by acid base accounting through determination of:

- Maximum potential acidity (MPA in kgH_2SO_4), calculated from sulfur percentage (30.63 x S%), typically total sulfur;
- Acid neutralising capacity (ANC in kgH_2SO_4) measured in the laboratory;
- Net acid production potential (NAPP in kgH_2SO_4), calculated as MPA - ANC;
- Net acid generation (NAG) pH and acidity at pH 7 and pH 4.5 (in kgH_2SO_4) measured in the laboratory; and
- Paste pH/electrical conductivity (EC).

An ANC/MPA ratio of 2 is recommended to initially classify material, where:

- Non-Acid Forming (NAF) > 2.
- Potentially Acid Forming (PAF) ratio < 2.

The NAG pH test can be combined with NAPP values to classify material as NAF or PAF (as per Figure 2).

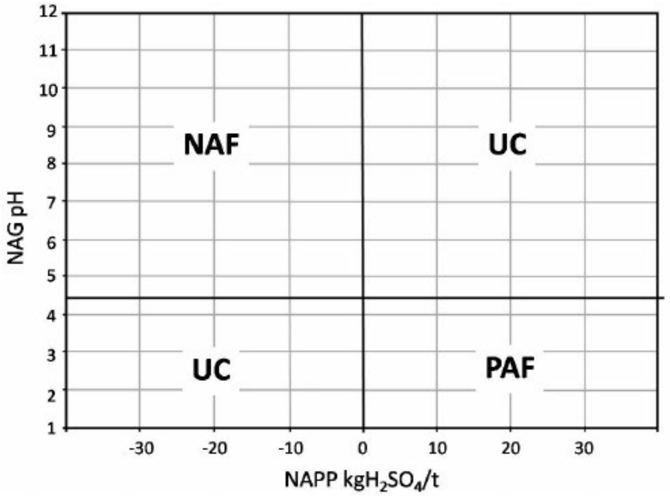

Fig. 2. Determination of NAF or PAF based on net acid generation (NAG pH) and net acid producing potential (NAPP kgH_2SO_4). Sourced from AMIRA (2002). NAF= non-acid forming; PAF= potentially-acid forming; UC = uncertain

For NAF or uncertain material (Figure 2), short term static leach tests such as Australian Standard Leaching Procedure (ASLP), shake flask extraction or USEPA LEAF [Table 5 in DMP (2016)] are necessary to provide an indication of the likelihood for contaminant mobilisation. For sodic spoils, kinetic columns are recommended to identify whether material may cause saline drainage (Edraki et al. 2019). Section 4.3.2 of the GARD guide is also recommended to assist users determine an appropriate sample size, sampling regime and testing methods for their material http://gardguide.com/index.php?title=Chapter_4#).

3.2 Geochemical risk rating for mine waste in Queensland

Users armed with the above information can assess the likelihood and consequence of environmental harm relating to geochemistry of their mine waste structures, using Table 1. This risk rating in Table 1 represents the risk of environmental harm, where no management or control measures are implemented during life of mine or rehabilitation.

Table 1. Geochemical risk rating for unrehabilitated mine waste structures in Queensland

Climate *Köppen-Geiger Classification*	**Hydrogeological** *Net Percolation (% of Annual rainfall)*	**Waste Material** *% Hazardous material (m^3 or t)*	**Risk Rating**
Tropical Savannah (Aw)	High >10%	High >30%	Very High
		Medium 5-30%	High
		Low <5%	Moderate
	Medium 5-10%	High >30%	High
		Medium 5-30%	Moderate
		Low <5%	Low
	Low <5%	High >30%	High
		Medium 5-30%	Moderate
		Low <5%	Low
Hot Semi-Arid (BSh)	High >25%	High >30%	Very High
		Medium 5-30%	High
		Low <5%	Moderate
	Medium 15-25%	High >30%	High
		Medium 5-30%	Moderate
		Low <5%	Low
	Low <10%	High >30%	Moderate
		Medium 5-30%	Low
		Low <5%	Very Low
Hot Desert (BWh)	High >25%	High >30%	High
		Medium 5-30%	Moderate
		Low <5%	Low
	Medium 10-20%	High >30%	High
		Medium 5-30%	Moderate
		Low <5%	Low
	Low <10%	High >30%	Moderate
		Medium 5-30%	Low
		Low <5%	Very Low
Humid Subtropical (Cfa)	High >10%	High >30%	High
		Medium 5-30%	Moderate
		Low <5%	Low
	Medium 5-10%	High >30%	High
		Medium 5-30%	Moderate
		Low <5%	Low
	Low <5%	High >30%	Moderate
		Medium 5-30%	Low
		Low <5%	Very Low

3.3 Design objectives for mine waste structures in Queensland

Currently in Queensland, risks relating to mine waste structures are evaluated as part of ERC calculations, and rehabilitation costs are linked to design features specified for cover systems over waste structures in each risk category (DES 2019). There has been contention around this approach with rehabilitation practitioners seeking flexibility to propose alternative cover system designs and the regulator requiring confidence that alternative designs will achieve rehabilitation objectives [e.g., Land Court file EPA032-20]. In the present work, we have identified an opportunity to link risk profiles for mine waste structures to design objectives for cover systems, rather than directly to explicit cover system design features in the first instance. Understanding the objectives for a well-functioning cover system, with respect to controlling the geochemical risks from mine waste structures identified previously (Table 1), is an ideal platform from which cover system features can be evaluated during rehabilitation planning.

In Queensland, rehabilitation objectives are to return land to a safe, stable, non-polluting condition that supports a post-mining land use (PMLU) (EP Act S111A). Cover system design objectives fit within this overarching framework and need to correspond with the level of geochemical risk the mine waste structure presents (Table 2). Linking the rehabilitation objectives for a cover system with its relative geochemical risk provides a way to demonstrate cover systems are designed proportionate to risk.

Table 2. Draft cover system design objectives as related to risk ratings for mine waste structures in Queensland

Rehabilitation objective being addressed by a cover system	Low Risk Rating mine waste structure	Medium Risk Rating mine waste structure	High or Very High Risk Rating mine waste structure
Safe		Minimise penetration of root mass into underlying waste	Prevent penetration of root mass into underlying waste
Stable	Limit erosion	Prevent erosion	Prevent erosion
Non-polluting	Reduce net percolation in wet season	Prevent net percolation in the wet season Limit oxygen contact with waste	Prevent net percolation in the wet season Prevent oxygen contact with waste Prevent capillary rise of contaminants to the surface in dry season
Supports a PMLU (e.g., grazing)	Safe access, where slopes allow for access; 3P (perennial, productive, palatable) grasses supported; Weeds controlled		
Supports a PMLU (e.g., native ecosystem)	A mixed community of grass, shrub and tree species supported; Weeds controlled		

3.4 Cover system layering and best practice examples

A cover system is made from multiple components that form an interconnected network to produce a more complex whole. This typically includes multiple layers of natural materials and/or synthetic materials of varying thickness, strength, permeability and structure, to meet design objectives. The most common cover system in Queensland's climate conditions is a store-and-release cover system (Williams 2013). Store-and-release covers are designed to hold water in a layer of benign material during the wet season, preventing deep drainage and reaction with the underlying mine waste, and allowing for subsequent evapotranspiration during the dry season.

The ability of store-and-release cover system to function correctly and meet design objectives is contingent on several factors that include:

- Incorporation of site-specific climatic data into the design
- Selection and availability of appropriate materials for the design
- Management and placement of the materials during construction
- Establishment of sustainable vegetation that is part of the modelled water balance

In its simplest form, the base method of design for a store-and-release cover system can be a layer of soil above a layer of inert material in the MWS. This design may be appropriate for an MWS with a low or very low risk rating. However, to function effectively for higher risk rating structures, the store-and-release system will need to be designed with additional components. The most common of these include:

- Additional layers designed for textural discontinuity
- Reduced permeability layers designed to retard NP
- Capillary break layers designed to maintain higher water content in the upper layer
- Thicker inert material layers to increase water holding capacity

Information about the purpose and function of various cover system layer components, and a best practice example of cover system design over mine waste with a high risk of AMD in Queensland, is being developed at present, to support mine rehabilitation planning in Queensland.

4.0 CONCLUSIONS

Rehabilitation of mine waste structures including waste rock dumps, tailings storage facilities and heap leach piles remains a challenge for the mining industry. Mitigating and managing geochemical risks from mine waste structures over the long term is a key part of rehabilitation planning. In Queensland, rehabilitation objectives are to return disturbed land to a safe, stable and non-polluting landform that supports a PMLU. Cover systems are one tool for facilitating these rehabilitation objectives for mine waste structures. However, there remains contention about what constitutes best practice cover design and implementation in Queensland. In the present work we have developed a framework that will support both industry and regulatory stakeholders considering geochemical risks from mine waste structures in Queensland. A thorough understanding of risk is the platform for understanding the necessary design objectives for cover systems to mitigate those risks over the long term. Future work will focus on providing guidance about the purpose and function of various cover system components (e.g., capillary break layers, low permeability layers etc) to support users to achieve design (and therefore rehabilitation) objectives for mine waste structures in Queensland.

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