Managing the waste rock storage design — can we build a waste rock dump that works?

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Abstract

For a waste rock dump to be managed both during operations and at closure, a thorough understanding of the composition of the waste is an important requirement. A comprehensive block model should be prepared, with an appropriate materials management and placement plan developed in conjunction with the mining schedule. However, a waste rock dump's success is hinged on such compositional elements being regularly updated through ongoing materials characterisation over the life-of-mine. Failure to undertake this may potentially result in inappropriate material placement and classification for environmental purposes, and unnecessary costs to the mine and surrounding environment. A revised cover system and landform design was undertaken for a base metal mine in northern Australia following reclassification of its waste. The original permitted landform design comprised an extensive protective cover system of non-acid forming waste rock (88% of overall waste), encapsulating the small potentially acid forming waste volume (12% of overall waste). Additional geochemical studies indicated that these ratios were incorrect and as such, the total volume of clean non-acid forming waste available for the facility was further decreased to a fraction of the initial value. A cover system incorporating both the barrier and moisture 'store-and-release' concepts was proposed to limit net percolation into the reactive potentially acid forming waste. In addition, a landform design and extensive surface water management plan was prepared to manage both the high intensity wet season rainfall received at site and the naturally erosive materials available for landform construction. This paper presents the issues encountered during the design stage, which included: a tropical climate; geochemically reactive waste materials; and a surface water management system design, which was to be maintenance free and similar to natural systems in the long term.

1   Introduction

The construction of waste rock dumps (WRDs) is a common requirement for most open pit mines across the globe. Historically, many of these WRDs are deemed to have failed through the use of inappropriate design or construction techniques, both being hinged on their appropriateness to the materials available and local conditions at the site. 'Failure' may be considered in terms of failure to understand the geochemistry of the mine waste leading to release of contaminants to the environment; failure to support vegetation or an eco-system, or geotechnical instability (Mitchell 2012). The timing of the failure may be during operations or many years following any rehabilitation and closure of such facilities, and subsequent costs to rectify any damage caused (socioeconomic or environmental) can vary by several orders of magnitude.

The mine site physiographic and climatic constraints must be carefully considered to ensure that the WRD can be constructed correctly. This is an approach that requires a conceptual design to be developed during initial mine feasibility and material characterisation studies. The conceptual model must then be revisited regularly, and refined as necessary, to ensure that the mining operations continue to manage the onsite materials and achieve any closure criteria that have been initially proposed or any necessary deviations are properly evaluated and documented. If this process is applied any alteration to the anticipated conditions, or misinterpreted geochemical data, can be managed as the mining life progresses, rather than at the end of operations when costs to rectify any issues will be far greater than what had been initialled estimated.

If a WRD 'works' it can be considered a success from its initiation through to a given time following closure. Where a site considers 'closure' from Day 1, the potential for success for it to work, is higher. For this to happen the site must consider the movement of any material to its final location (be it a WRD, tailings storage facility or heap leach pad) in relation to the site's closure plan. In an ideal scenario, appropriate material handling techniques, placement methods and construction protocols will have been developed prior to waste placement initiation, and these three items will have been appropriately designed and decided up in line with the waste materials' geochemical and geotechnical characteristics. In terms of appropriate handling and placement for the materials present, should techniques and planning initially proposed lead to WRD failure within a project this can be remedied. It will most likely require a change in WRD design and materials handling procedures employed, which must be achieved within operational cost constraints.

The development of a *conceptual closure plan* is paramount. The plan should be developed in line with data collected specifically from site and utilised to design an appropriate waste storage facility that is suited to its surroundings. For example, no waste storage facility should be designed and built independent of the site-wide closure plan; therefore, consideration should be given to the overall surface and groundwater management plans.

The data to be considered for derivation of a closure plan should comprise: geological block model; geochemical and geotechnical characteristics of the waste materials; local surface water hydrology and hydrogeology in addition to the hydrogeological regime of the larger catchment the mine site will feed into; ecology; heritage and cultural requirements; climate; natural topography and aesthetics. These items should also be assessed in terms of management both during operations and upon closure. Fundamentally, these items should be continually re-assessed throughout the life-of-mine (LOM). This practice allows the overall design to be updated and refined using relevant data therefore providing sufficient time for changes to the design to be initiated.

1.1   Conceptual design development

Standard practice allows a WRD to be designed at the start of a project, based on the initial geological block model. Once a site has an understanding of the materials anticipated to be recovered, and their respective volumes, a conceptual landform is proposed for regulatory and stakeholder review. The landform will normally have taken into account various initial laboratory test results, but essentially, at this stage of the project, any conceptual design can only be considered as good as the data that has been gathered for its development. At this stage no, or very little, waste has been excavated and, therefore, the options for landform design are vast.

Where potential geochemical, problematic waste may be encountered, the design should be appropriate to meeting the closure requirements of the site, i.e. containment of problematic waste, minimal discharge to the receiving environment, acceptable final waste landform design and construction, and meets approved closure criteria. For example, this may comprise encapsulating the problematic materials and thus sufficient volume of nonreactive waste must be made available at the appropriate time required. Additionally, materials intended to be used within a design must be appropriate to their function. This is of particular importance if a low permeability unit is required, or when considering the outer landform slopes and potential for erosion resistance.

A strong understanding of the materials available must be developed through laboratory testing and subsequent development of a supportive mining schedule (Barritt & Scott 2015). Without characterising the waste to be excavated and subsequently placed at the WRD, the landform is open to potential issues which may lead to its failure. Any materials characterisation program should be completed with the geochemical and geotechnical test schedule focused on potential issues that the anticipated waste materials may pose to the landform from meeting prescribed closure criteria (Jasper et al. 2006). For example, if it is known that all waste rock is expected to be benign and geochemically non-reactive, but there is potential for it to be geotechnically unstable and erosive, then laboratory testing should be focused towards analysis that will provide information regarding rock strength, particle size and erosion parameters. If materials are to be

excavated from the fresh and unweathered portion of a given stratigraphy, geochemical testing should be focused on understanding the potential for acidity, sulphate and/or metals leachate to be generated. Field testing should be completed to supplement any laboratory program, providing great value and assessment of in situ conditions quickly, and provide more reliable information that reflects actual field conditions. They may also be more reliable when compared to laboratory tests that require the sample to be remoulded. This is of particular relevance with permeability testing: multiple use of in situ testing across a range of locations, at site, allows for the heterogeneity of surface materials to be understood, which is of great importance if a cover system is required for WRD rehabilitation and subsequent closure, and for the development of a revegetation plan.

Once characterisation of materials expected to be encountered has been completed, the proposed mining schedule should be investigated in order for the landform's design to be further developed and a suitable construction plan proposed. If reactive waste requires encapsulation but the mining schedule has found that the nonreactive materials will all be recovered late in the operation then dump construction must be designed to minimise exposure of the reactive waste to uncontrolled oxidation. This practice will limit potential contamination during operations, in addition to reducing the requirement for material double handling. Understanding the total volume of materials required to be managed onsite allows for an appropriate conceptual landform design to be prepared. The marriage of material properties, respective available volumes and relative timing of materials extraction to the operation are key to appropriately designing a WRD.

The conceptual landform design should be developed in conjunction with other site disciplines prior to stakeholder and regulatory review. Ensuring that the WRD does not operate as a standalone feature is crucial to its, and other mine aspects, success. This is particularly relevant to the site-wide surface water management plan and strategy in addition to using data from the hydrogeological model. Design and refinement of the landform design should be an iterative process, likewise with the overall closure plan for the site.

Following approval of a WRD's conceptual design it is crucial that it is referred to and updated throughout the LOM. A change within the industry must be made whereby the development of a conceptual design is not just for regulatory approval to commence the operation, but is installed in the mine plan before the commencement of mining and is regularly reviewed and updated through the mine life. Should a variation be found (material properties, recoverable volumes and scheduling for example), a change to the WRD design is paramount. Failure to address such ongoing variations may lead to incorrect waste placement, potential delays during operations and additional unnecessary costs, not to mention the potential that regulatory approval for the design might be revoked, jeopardising the overall mining venture.

2 Case study: Poly-Metallic Mine, Australia

2.1 Initial dump design

An initial WRD design was proposed at a mine site in Australia that would encapsulate potentially acid forming (PAF) material with non-acid forming (NAF) and acid consuming (AC) waste during its LOM. Laboratory testing was completed at the start of the project following a drilling program which identified that some 83% of NAF material was available for encapsulation of the 17% PAF waste. The site is located within a region that has a distinct 'wet' season where substantial rainfall volumes are anticipated each year, often in excess of 1,000 mm, but typically around 800 mm. As such the proposed design would limit the volume of water reaching the reactive PAF waste, and thereby reduce the potential for contaminated seepage from emanating at the landform's toe and further oxidation of the waste materials.

The design permitted some 18 m of NAF waste acting as a 'protective' unit over the PAF material, topped with a moisture 'store-and-release' cover system. The cover system comprised 0.7 m growth medium over a 0.6 m thick compactive clay layer (CCL) unit. The cover system's purpose was to further restrict the potential volume of water entering the landform, in addition to providing a medium to support vegetation growth and

establishment. The outer portion of the landform would be finished with a repeated 'bench and batter' design with an overall 1:4 (V:H) slope geometry. A suitable waste placement strategy was developed to meet this design, with several control measures included to limit the potential amount of surface water infiltration during construction. Additional surface water management structures were proposed for operations and progressive cover system construction and rehabilitation. The design was such that it:

- Provided sufficient storage capacity for both the reactive and non-reactive materials.

- Was suitable to the regional climate.

- Accommodated the geochemical nature of the anticipated waste materials.

- Considered the subsurface conditions.

2.2   Material classification

Further geochemical analysis of the PAF materials found that they were more reactive than initial laboratory testing had shown. In parallel, studies on the NAF/AC materials indicated that they had been inappropriately characterised as the combined NAF/AC waste volume was considered in effect as NAF and suitable to be placed in the out of pit overburden emplacement facility.

Initial investigations undertaken as part of the feasibility studies compiled a waste classification based on ~1,100 acid base accounting sets of data that identified potentially acid forming waste, non-acid forming waste and acid consuming waste. The studies indicated that there was a significant volume of NAF and AC waste that would adequately encapsulate and limit oxidation of PAF waste in an out of pit overburden emplacement facility. The studies estimated that the combined volume of NAF and AC waste comprised 83% of the total overburden mass proposed to be mined.

Subsequent investigations that reassessed previous data, 1,100 acid base accounting (ABA) analyses, combined with an additional set of data comprising ~2,700 ABA analyses identified that the waste classification compiled was initially too simplistic. What was actually present in the pit area as overburden, comprised the following:

- NAF materials that had very low sulphur and metals and generated neutral mine drainage with minimal sulphate and minimal metal concentration.

- AC waste that comprised significant concentration of sulphide sulphur, equally high concentration of carbonate minerals that generated metalliferous and sulphate seepage when exposed to oxidising conditions.

- PAF waste highly reactive that contains high concentrations of fine grained metal sulphides that, when exposed to air and water, oxidises rapidly and may spontaneously combust in the absence of excess neutralising minerals; this waste will generate low pH seepage with elevated sulphate and metal concentrations.

- PAF waste with moderate concentrations of sulphide sulphur in excess of carbonate minerals, generating high sulphate, metalliferous acidic seepage.

The volume of absolute 'NAF' waste was reduced to 59% of the overall total, with the PAF volume increased to 31%, leaving the remaining 10% as AC waste. As such, a modification to the initially proposed, and approved, landform design was required. However, further analysis (combined total of 3,800 ABA analyses) reduced the potential NAF volume further, in addition to identifying AC waste materials as saline and metal leaching (AC), thereby preventing their use within the 'protective' unit or cover system as originally intended from the mining schedule.

Whilst the initial landform design considered suitable material placement in line with the mining schedule, it did not contain sufficient control measures to limit oxidation of PAF materials once excavated. As such, large

tip heads were utilised (up to 15 m), which allowed the materials to segregate, promoting pathways for oxygen to enter the landform and further react with the materials present.

It was determined that the block model should be revisited and revised. Where data gaps existed, these should be infilled with further laboratory testing and a redesign of the overall landform be developed in order to appropriately manage the reactive materials present.

In order to ensure that a suitable landform could be constructed, with appropriate management of PAF and metalliferous NAF, a redesign of the cover system, internal landform configuration and outer profile was undertaken.

2.3   Block model and waste classification update

Reclassification of the waste rock suggested that it was necessary to manage the AC waste as well as the highly reactive PAF and low reactive PAF to minimise discharge of sulphate, metals and acidity. The block model indicated that the overburden mass comprised, as defined above, 15% NAF material, 35% PAF (25% highly reactive PAF and 10% low reactive PAF) and the remaining volume of overburden was acid consuming waste.

At this site, efforts had been made to quantify the materials in-pit for WRD construction; however, the reactivity of the PAF material had not be fully understood. In addition, the geochemical characterisation of the NAF waste had used the presence of sulphate and pH value as a discriminator for NAF versus PAF, whereas the presence of salts and heavy metals had been overlooked. Furthermore, when the materials balance was initially amended, the WRD construction techniques employed at site were not. As such the material placement measures promoted the materials' reactivity.

3   Internal landform design and dump construction

Based on the revised block model understanding and mining schedule for overburden for LOM, changes to the dump design and construction were required. The objectives of the changes include:

- Limiting exposure of PAF material during placement within the out-of-pit waste storage, i.e. reducing air entry to the placed reactive waste.

- Effective water management – encouraging runoff, limit ponding on dump lift surfaces to reduce net percolation and thereby reducing water entering the placed PAF waste pile.

- Using the acid consuming capacity of the AC waste to limit reactivity of the highly reactive waste leading to 'self-heating' (Beamish et al. 2005).

- Selective use of 'true' NAF on outer batters and surfaces as protective layers.

Dump design components include:

- Short tip heads (2 m) and paddock dumping for PAF waste to limit preferential pathways.

- All placed PAF within the dump must be covered with a low permeability layer so that no PAF waste is exposed in the wet season; no dumping of PAF waste to occur during the wet season.

- Use of starter bunds of, ideally, NAF but can also comprise AC material for each dump lift placed at the outer edge of the PAF cell paddock dumped and compacted to manage air entry (Figure 1).

- Interim covers of dump lift surface to PAF 'cell' to be compacted and sloped to limit air and water entry.

- Individual PAF cells.

- Outer batter of protecting NAF material.

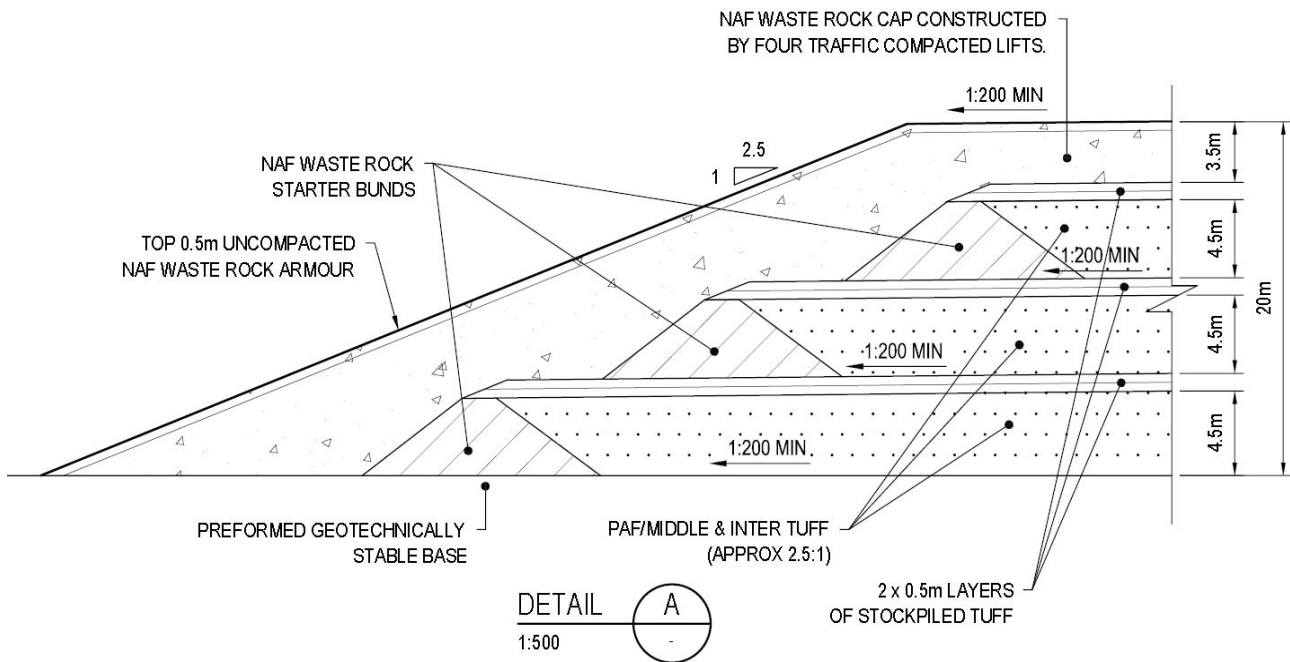- Concave outer batter profile designed to reduce erosion.

NAF WASTE ROCK CAP CONSTRUCTED
BY FOUR TRAFFIC COMPACTED LIFTS.

1:200 MIN

2.5
1

NAF WASTE ROCK
STARTER BUNDS

TOP 0.5m UNCOMPACTED
NAF WASTE ROCK ARMOUR

1:200 MIN

1:200 MIN

1:200 MIN.

PREFORMED GEOTECHNICALLY
STABLE BASE

PAF/MIDDLE & INTER TUFF
(APPROX 2.5:1)

2 x 0.5m LAYERS
OF STOCKPILED TUFF

3.5m
4.5m
20m
4.5m
4.5m

DETAIL   A
1:500   -

Figure 1   Waste dump construction option

4   Cover system design

A cover system that utilises both the 'moisture store-and-release' and 'barrier' concepts was identified as most suited to the climate experienced at site. However, based on information gained from other activities onsite, it was believed that the current design, in particular the growth medium thickness, was not adequate for the site's closure requirements. Numerical modelling was undertaken to assist with optimising the cover system design using characteristics of materials collected during a previous site visit. These comprised NAF waste rock, topsoil, clay and alluvium materials. Several cover system arrangements were considered, all with a compacted clay layer (CCL) beneath a 'growth medium'. The presence of an underlying lower hydraulic conductivity (K_{sat}) CCL beneath the growth medium aids in minimising net percolation (NP) to the underlying waste whereby the growth medium meets the cover objectives for the majority of the time but the additional lower K_{sat} layer is designed to limit NP when overlying storage capacity is exceeded. For relatively flatter surfaces, the presence of the CCL would enhance water holding capacity in the overlying growth medium such that evapotranspiration would subsequently remove the water. For reasonably sloped surfaces, water would be diverted laterally, as interflow, within the growth medium and 'overtop' of the CCL.

A 'barrier' cover system generally consists of a layer of material with a relatively low k_{sat} and an overlying thicker layer of non-compacted borrow or barren waste material. The barrier may consist of a compacted layer of finer-grained material (e.g. clay or silt) or a geomembrane such as a high-density polyethylene (HDPE) liner or a geosynthetic clay liner (GCL). Figure 2 shows a cover system with a CCL as the barrier layer. The author's definition is that a 'barrier layer' should only be referred to as such if the k_{sat} of the barrier layer is 10^{-7} cm/s, or lower (noting that HDPE liners, GCLs etc. typically have specifications for k_{sat} one to several orders of magnitude lower than 10^{-7} cm/s). Lab-derived material characteristic data from site found that the k_{sat} of clay available for construction is typically in the range of 10^{-8} cm/s. Field-derived k_{sat} values would be expected to be slightly higher. The overlying layer not only supports vegetation, but also minimises risk of adversely impacting on the integrity of the barrier layer from potential damage due to various processes (e.g. wet/dry cycling).

Figure 2   Conceptual cover system design options

Rainfall can be stored within the cover system (primarily within the topsoil and growth medium) and gradually released back to the atmosphere through evaporation and transpiration. During periods of high (and more intense) rainfall the cover system primarily functions to limit NP through 'water shedding', as interflow and runoff, and therefore sheds excess water from the facility. During drier periods and/or periods of less intense rainfall, the cover system primarily functions to limit NP through 'moisture store-and-release'. Hence, the cover system functions, as a result of the presence of the barrier layer and the growth medium, along a continuum of performance where at times the primary cover system water balance component is evapotranspiration, and at other times it is surface runoff and interflow. Through this functionality, there will be an overall reduction in the potential volume of water to the underlying PAF material (i.e. a reduced potential for NP), which will result in an overall reduction in the potential for seepage (basal and toe) from the facility.

Various cover system design configurations, developed on the basis of the multi-functionality discussed above, were evaluated for their suitability at the site using the GeoStudio suite of finite element modelling software VADOSE/W. Cover options were evaluated for both the plateau and the WRD slope sections of the facility as different regimes exist between the two profiles. Initial short-term modelling scenarios were undertaken to assess the cover systems' performance over a 30-year period using a site-specific climate database. From this, the most promising cover system options were modelled over a 100-year period, again using a site specific climate database. The key objective for the numerical modelling was management of oxygen ingress, coupled with evaluating the saturation conditions of the CCL, in particular ensuring that it did not undergo desiccation through wet/dry cycles. Should this occur, the CCL's hydraulic properties would change, potentially resulting in higher permeability and reduced moisture retention, and therefore higher oxygen ingress rates in addition to higher NP. In addition, the diffusion of oxygen through the CCL can be minimised if the degree of saturation remains greater than 85% year-round (Nicholson et al. 1989; Mbonimpa et al. 2003). The modelling found that during the high rainfall wet season, infiltrating water will pond above the CCL and be stored within the growth medium materials. The stored water was either removed through

actual evapotranspiration (AET) or moves through the clay as Net Percolation and reports to the underlying waste.

The primary objective of the cover system is managing oxygen ingress rates. The numerical modelling conducted indicates two key aspects that positively illustrate this objective can be achieved. Firstly, the degree of saturation of the CCL was maintained at greater than 85% for greater than 99% of the times for the long-term (100 yr) climate database modelled. In other words, for the conditions modelled (a 0.6 m CCL, a 1.2 m coarser textured GM layer (5×10^{-4} cm/s), a 0.3 m finer-textured GM layer (5×10^{-5} cm/s, and a 0.1 m topsoil layer), there is a very high probability that oxygen diffusion across the cover system will be very low. The numerical model predicts that for this cover system, the average annual oxygen ingress for the 100-year climate database modelled is 1 mol/m²/yr.

The second positive aspect is that the modelling illustrates that a very large majority of moisture cycling occurs within the layers overlying the CCL; hence, there is minimal risk that the CCL will undergo wet-dry cycling, and therefore minimal risk that the hydraulic material properties of the CCL will change substantially. We recognise that a common perception is that the hydraulic characteristics of CCLs will change. However, this modelling illustrates what has been well-established in these situations; namely, that an insufficient thickness in the overlying GM layer is the primary cause for changes with and in-service CCL. For this project, we believe the risk of this occurring is minimal because of the robust thickness, and hence moisture holding capacity, of the overlying GM layers.

An ancillary result of the cover system as modelled is that there is also a high probability of predicted NP being very low (in the range of 1–2%).

The cover system configuration on the embankment was found to require a thicker growth medium thickness to achieve similar results. This is principally due to more water being removed due to runoff, thereby resulting in more demand for moisture from the CCL; the thicker GM layer minimised this risk. Predicted NP reporting to the PAF waste within the embankment sections was also modelled to have a high probability of being in the very low range.

5   Landform design

In order for the primary objectives of the landform to be met it is crucial that its design was appropriate for both the materials available and the climate. Previous studies undertaken had found that there was a tendency for the materials within the vicinity to be erosive and dispersive. Should these types of materials be utilised it is anticipated that erosion rates during the intense wet season would be unmanageable and over time the encapsulated metalliferous NAF and PAF waste may become exposed through surface rill and gullying. However, a balance may be required between the volume of material required and its required performance. Various slope profiles for the final landform outer slope such as shown in Figure 3 were evaluated in terms of their erosive potential, constructability, and suitability considering the materials available.
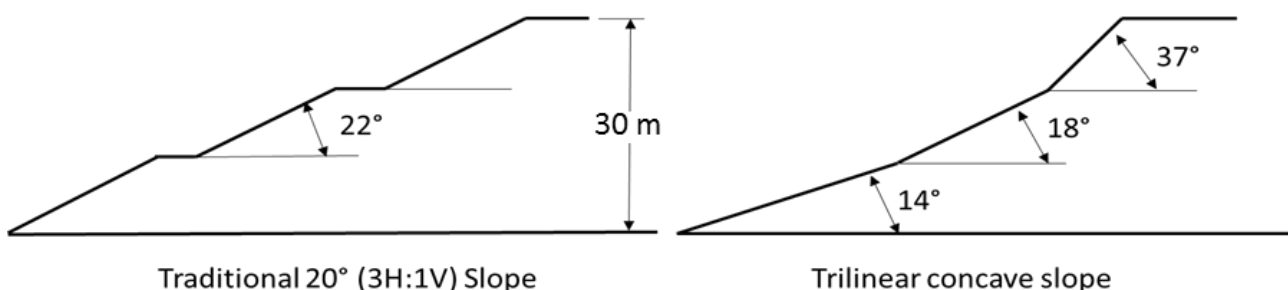

Figure 3   Schematic showing traditional and concave slope designs for reclaimed waste rock stockpiles

Based on the material properties developed for the cover system design, initial slope profiles were prepared in order to assess the stability of the available materials over varying slope gradients and lengths. All profiles

were initially simulated using the computer based Water Erosion Prediction Program (WEPP). WEPP incorporates the fundamentals of soil hydrologic erosion such as water infiltration, runoff, soil detachment mechanisms, soil water percolation, sediment transport, sediment deposition, evapotranspiration, and plant growth (Flanagan & Livingston 1995). It explicitly considers rill and interrill erosion and is therefore considered a reliable program to consider potential slope lengths and gradients. WEPP is capable of estimating net soil loss for an entire hillslope, or for each point on a slope profile on a daily, monthly, or average annual basis. However, it does not consider the potential effects of erosion and deposition on landform development, nor does it deal specifically with gully development. WEPP was selected for the assessment as it allows for rapid evaluation of different embankment profiles without knowing the exact details of the plateau catchment and its influence on the outer embankments (i.e. overtopping).

The 100-year climate database was used within the model, thereby addressing peak storm intensity which is key to ensuring the water shedding component of the cover system is sufficient. Due to time constraints, samples were not taken from site for additional laboratory testing (such as interrill erodibility or infiltration rates). As a result, known material properties were compared with an extensive in-house database.

Due to known erosion and water management issues, 'traditional batter-and-berm' profiles were not considered. Contemporary landform design philosophy advocates that the development of a sustainable landscape for mine closure incorporates waste landforms that replicate nature (Ayres et al. 2006). The replication of mature and relatively stable natural systems reduces the rate and risk of accelerated erosion. Most slopes in nature are characterised by a variety of shapes including convex and concave forms, whereas linear (or benched) landforms are considered to represent immature topography and are poised to evolve to lower energy states by shallow slope failures or accelerated erosion. Batter-and-berm configurations almost always fail in the long term. The sediment build-up over time can cause overtopping and scouring of embankments, which leads to accelerated erosion and embankment gullying. Sites adopting this landform design methodology are potentially committing to many years of maintenance and repair and, potentially, future legacy issues involving sediment and/or acid and metalliferous drainage release to the surrounding environment and non-conformance with closure objectives.

Modelling determined that the most promising, and therefore preferred profile in terms of erosion and therefore greatest potential long-term stability, comprised a concave arrangement (as shown in Figure 3). This profile arrangement allows erosion to the surface to be uniform along the length of the section, therefore minimising the potential for rill and gully formation. The landform evolution model SIBERIA was used to analyse the proposed 'preferred' profile. SIBERIA is a physically based three-dimensional model used for simulating evolution of landforms over geomorphic timescales (Hancock et al. 2000, 2008; Willgoose et al. 1991a, 1991b, 1991c). The profile was modelled for both 100 and 1,000-years and it was found that the extent of erosion, and gully formation, would be approximately 0.6 m and 3.7 m respectively. These values represent an unvegetated profile, and are therefore considered as being conservative. The proposed landform design is such that surface erosion is limited to the upper portion of the cover system and the underlying reactive waste materials will not become exposed.

6   Conclusion

For a WRD to be managed both during operations and at closure, a thorough understanding of its waste is a fundamental requirement. It is fundamental to the long-term geochemical and physical stability of a waste dump storage facility that a full understanding of the characteristics (chemical and physical) and distribution of the waste types is required before turning one sod of soil or moving one kilogram of rock from the proposed pit area. Comprehensive understanding of the waste's geochemical (and physical) reactivity both short-term and long-term is required at the commencement of mining and must be reviewed regularly throughout the mine life. In this case study, while a reasonable number (1,100) of samples were tested, it was assumed that because the acid consuming material generated near neutral to alkaline pH, it would be suitable as a construction material for outer surfaces of the waste storage facility.

Failure to undertake a correct assessment of the mine waste for acid forming, metal leaching and sulphate generating capacity may potentially may potentially result in inappropriate material placement, and unnecessary costs to the mine and surrounding environment. A revised cover system and landform design was undertaken for a base metal mine in northern Australia following reclassification of its waste. The original permitted landform comprised an extensive protective cover system of non-acid forming waste rock (88% of overall waste), encapsulating the small potentially acid forming waste volume (12% of overall waste). Additional geochemical studies indicated that these ratios were incorrect and as such, the total volume of clean non-acid forming waste available for the facility was further decreased to a fraction of the initial value, i.e. 15% of total waste mass.

For a final landform profile and a cover system to be effective in reducing air entry, net percolation and erosion the dump must be built correctly from the start of operations. Materials must be classified correctly and defined in the block model for the LOM resource. The material must be placed correctly in the dump to a designated design. Air entry to reactive waste must be limited through use of shallow tip heads and paddock dumping to reduce preferential pathways. Ponding of rainwater must be limited and net percolation reduced using interim compacted covers over the reactive waste. Starter bunds constructed of compacted NAF/AC material are needed to be installed to limit air entry to reactive PAF Cell.

A cover system incorporating both the barrier and 'moisture store-and-release' concepts was proposed to limit net percolation into the reactive potentially acid forming waste.

In addition, a landform design and extensive surface water management plan was prepared to manage both the high intensity wet season rainfall received at site and the naturally erosive materials available for landform construction.

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