10thICARDIMWA2015 | 10th International Conference on Acid Rock Drainage & IMWA Annual Conference

Managing the Waste Rock Storage Design, Can We Build a Waste Rock Dump that Works?

Rebecca Barritt and Peter Scott
O'Kane Consultants, Australia

ABSTRACT

For a waste rock dump to be managed both during operations and at closure, a thorough understanding of the rock material properties to be stored is compulsory. This is facilitated by the preparation of a comprehensive waste block model, 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 elements being regularly updated through ongoing materials characterization over the life of mine. Failure to undertake this may potentially result in inappropriate material placement, and unnecessary costs to the mine and surrounding environment.

This paper examines waste management process at different mine sites and compares the different approaches, and the opportunities and constraints that are placed on operation and closure of the facility by the management process adopted.

Keywords: characterization, planning, design

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 an 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.

It must be determined what is required of the site in order for a WRD to 'work'. This is an approach that requires a conceptual design to be developed and refined through initial mine feasibility and material characterization studies. The conceptual model must then revisited regularly, and refined as necessary, to ensure that the site is continuing to manage the onsite materials and achieve any closure criteria that have been initially determined. 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 and availability of personnel and equipment fewer.

If a WRD 'works' it can be considered a success from its initiation through to a given time following closure. 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. However this cannot be completed without a change in either the WRD design or materials handling processes employed.

At the start of a given project it is fundamental that the design is appropriate to the specific site considered. It is commonly seen that a design for Mine Site A is applied to Mine Site B because they have the same owners and it was previously considered to have 'worked' at A. However, little attention has been paid to the differences in equipment available, climate and terrain or more fundamentally differences in the waste rock materials.

Laboratory testing is often biased towards the ore being mined and the scenario is often that little information is obtained on the waste rock, or sampling and subsequent laboratory testing is sporadic and data gaps are common. Alternatively, enthusiasm is high during the initial stages of the venture, with full materials characterization completed and a thorough geological block model established, but as the project develops ongoing characterization through geotechnical and geochemical testing is absent. Here the mine site has failed to confirm that the anticipated conditions have been met, and as such there is potential that the initially appropriately designed facility cannot be constructed as conditions have changed.

This paper will discuss how the waste rock storage design can be developed from Day -1 of a venture and refined during the life of mine (LOM) to closure. The methodologies presented will be based on established experience in WRD design and construction, with relevant case study examples.

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 waste has been excavated and therefore the options for landform design are vast.

Any conceptual design where potentially geochemical problematic waste is considered should ensure that firstly sufficient volume of nonreactive waste is available at the appropriate time to construct the waste storage including for encapsulation or for use in a cover system. Secondly, that the nonreactive materials can be appropriately used within a design. For example, should a low permeability layer be constructed an understanding of the appropriate compaction required to achieve target values must be developed, or should erosive materials be known to the site it may be necessary to stabilize outer embankments with coarser grained rip-rap, recognizing this type of material does not readily support vegetation establishment.

Characterization and Availability of Materials

Understanding the materials present at the site is key for any mining project. The emphasis must be from the start on appropriately using the materials for the final WRD landform, in particular where reactive materials may be encountered and correctly placed within the facility.

During initial scoping studies exploration drilling often prevents sufficient sample size for most key geotechnical tests, for example particle size distributions (PSDs). In addition, the small sample collected may not be representative of the overall conditions, and flushing techniques can significantly alter the recovered material from its undisturbed, *in situ* position. Empirical equations can be used to further develop an understanding of the materials, however, these are often not referred to. Focus can be made on separating the anticipated stratigraphy into tens of individual units, some only 30 cm thick, whereas in terms of mining this becomes irrelevant as blasting or machine cutting may encounter several variations at once, and thus subsequent waste rock management and materials placement ignores initial characterization efforts.

In order to appropriately design and subsequently construct and close a WRD any materials characterization program should be completed with the geochemical and geotechnical test schedule focused on any potential issues that the anticipated waste materials may pose to the landform 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 PSD analysis, specific gravity and development of erosion parameters such as rill and inter-rill. If materials are to be excavated from the fresh and un-weathered portion of a given stratigraphy geochemical testing should be focused on understanding the potential for acidity, sulfate and/or metals leachate to be generated.

Laboratory testing does not necessarily need to be expensive and timely. There are many low cost but comprehensive tests or procedures than can save time and budgets. Many WRDs have been designed with a limited number of tests completed, but having still developed an extensive knowledge of the onsite materials. Field testing should also be completed to supplement any laboratory program, they provide great value and can assess any *in situ* conditions quickly and commonly at low costs. They may also present more accuracy when compared to laboratory tests that require the sample to be remolded, and thus representative of the *in situ* conditions. 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, of great importance if a cover system is required for WRD rehabilitation and subsequent closure, and for development of a revegetation plan. If on site clay materials are to be used as part of a low permeability sealing layer, or to limit atmospheric interactions with waste materials, it is prudent to compare laboratory hydraulic conductivity (K_{sat}) values with those that can actually be achieved on site with the equipment available. Often K_{sat} laboratory values are two orders of magnitude greater than can be achieved at site, if this is not addressed in terms of practicality and feasibility at an early stage then the project may be targeting an impossible design from the offset.

Once the materials available have been characterized it is paramount that their respective volumes and distribution within the material to be mined is determined. 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.

Conceptual Design Modelling and Updating a Design

Once a thorough understanding of the materials expected to be encountered at site, and respective volumes, is determined the data should be used to develop a conceptual landform design. The design should be aimed at the final landform at its completion and closure, however, it is also important to it to be developed in 'workable' stages throughout the LOM.

Where initial materials characterization testing has identified potentially problematic materials expected to be encountered during operations it is paramount that they are appropriately considered and thus managed within the landform design. At this point it may be necessary to conduct numerical or analytical modelling to gain a perspective on how the facility may perform over a given timeframe. The use of modelling is a common tool to support a given design, however, it is often used to create the design. For example if a project requires PAF or reactive waste materials to be encapsulated the volume of available benign materials must be determined before any modelling commences. Without a basic understanding of the site conditions modelling simulations may determine that a much greater thickness of benign materials are required than is available, identifying a design which will either never be constructed or will require a separate mineable source of benign materials to what can be provided by the ROM operations. Where climate data is required for use within a model it must be site specific and preferably cover the timeframe that is modelled (O'Kane and Barbour, 2006). Often less than five years of data are compiled and then re-used for years 6-10 and so forth, potentially omitting any above or below average data, of which is key to understanding any WRD's limits in potential performance. If an appropriate range of climate data is not available then assessments relating to the probability of exceedance must be made. It should be understood, however, that a model will never supply the final design and must only be used as a tool to help inform design decisions. There is a tendency to focus on model outputs and rely on values presented, without revisiting the conceptual design and questioning its feasibility, as previously mentioned.

Once a conceptual design has been approved by all relevant parties 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 it is something that must be regularly reviewed 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 or problems may lead to incorrect waste placement, potential delays during operations and additional unnecessary costs.

If initial material characterization was poorly completed and conditions are found to vary during operations, but the conceptual design has not been updated, the relevant regulatory body may require further evidence that a facility can be constructed at site and will meet any prescribed closure criteria. This may also cause delays to the mining schedule and require costly drilling and investigation programs. At this stage a portion of the WRD will have already been completed, reducing the number of options available to the site for design and ultimate successful completion of the project, or requiring such materials to be moved.

DURING OPERATIONS: CONTINUE PLANNING AND CHARACTERIZING

Appropriate waste rock handling during operations is very important. Through the development of a mining schedule the characteristics and volume of materials excavated at any time within the LOM will be known. As such temporary works can be established as required. There may be a restriction on material movement at certain times of the year, for example within tropical regions the assessment of particularly reactive materials should be made and interim procedures proposed to limit rainfall infiltration into exposed reactive waste material during the wet or monsoon season. Materials that are proposed to be used within the outer portions of a landform should be appropriately stockpiled for use at a later date. However, an appropriate material movement register should be established documenting the type of material hauled and the date it occurred. Should operations cease at some point in the future, or the mine changes owners, records would be in place regarding the composition of the stockpiled waste/overburden. This register documents the location of potential rehabilitation materials to be utilized as intended, as well as reactive materials requiring encapsulation and management. It is not uncommon to find during the advanced stage of mine operations that the best materials for closure and rehabilitation of the WRD have been 'lost' as the control on material movement has been poor.

The dumping technique used for material placement must be appropriate to the waste. For example, short tip heads or paddock dumping should be considered for highly reactive materials that have the capability to spontaneously combust. Material segregation has previously been identified as a significant factor in PAF risk management. If preferential pathways exist for oxygen and water to easily move through the WRD it can be expected that oxidation of reactive materials will be accelerated (Pearce, 2014). This has the potential to generate significant issues to the mine site, in terms of personnel safety (from the production of harmful, toxic gasses and spontaneous combustion) and to the environment.

Wherever possible it is advisable to compact each lift as the WRD is progressed. This will assist in managing surface runoff and reducing net percolation. Compaction can be enhanced with the use of finer grained materials such as clayey silts. This process reduces waste rock atmospheric interactions and thus may prevent the generation of acid and metalliferous drainage (AMD) or hazardous gas formation. Compaction can be achieved by use of dedicated equipment or by truck compaction during routine haulage and dumping procedure. When haul trucks are dumping waste at a facility it is advisable to regularly vary the route across the facility that is taken, thus allowing the compaction force to be spread over the materials, rather than concentrating all efforts along the same, repetitive pathway.

It is important that appropriate quality assurance and control (QA/QC) measures are established at the start of any WRD construction project. Over time regulatory requirements are commonly becoming more stringent, and rather than just presenting a landform design for both operations and closure of a facility, organizations are requesting that the methods proposed regarding how such facility will be constructed and how it can be completed are presented. Based on the material characteristics developed QA/QC methods will promote the suitability of a material to its design. There are a vast range of QA/QC actions applicable to many materials and conditions, but very important to site utilizing a compacted clay layer (CCL) is ensuring that the compaction effort for each lift is consistent with the desired optimum water content and density values (as determined through the materials characterization and conceptual design process).

As a mine is progressed it is paramount that ongoing materials characterization is completed to ensure that the facility constructed is as per the designated design, and if this is not possible then the design must be amended to ensure that the designated closure criteria are achieved. Material testing frequency should be conducted at a high level during the initial stages of the mine venture in order to fully understand the strata encountered, and ensure it is as expected. As knowledge of a material is gained, and its characteristics understood, the testing frequency can be decreased. However, the frequency should be increased as materials change composition. Results should feed directly into the materials placement plan and allow for the landform model and design to be updated. There are international standards that discuss the frequency that bulk testing should be completed, for example INAP (2009), these should be best practice and would require consultation and referrence within mining and waste management procedures, as applicable.

CASE STUDY

The following section of this paper discusses relevant case study examples where efforts were made either prior to the excavation of any waste materials, or during the LOM, to appropriately design and construct a WRD that works. In other words, meet the designated closure criteria for the project and achieve regulatory and stakeholder approval.

Poly-Metallic Mine#1 Australia

A WRD landform design was recently developed to include encapsulation of PAF materials. A well-developed geological block model was presented prior to initiation of the mining venture, with comprehensive, and reliable geotechnical and geochemical data. Previously the mine site had been focused on several lithological units, of varying thickness and description. However, in terms of the conceptual landform design only three material types needed classifying: metasediments (heavily weathered sediments and volcanoclastic), dolerite and un-weathered mineralized host rocks: termed mineralization. Geochemical testing had proven that materials within the weathered zone (upper 100 m deep) comprised entirely NAF waste. Below the zone of total oxidation some PAF material was identified within a transitional zone (active zone of weathering, some 15 m thick) and all fresh materials, unaltered by weathering processes, were PAF. Based on the understood mining schedule, and with reference to the mining equipment known to be utilized, a conceptual WRD design was prepared.

The design was developed based on the PAF waste reactivity and its relative timing in relation to the NAF materials required to encapsulate it and limit the ingress of atmospheric oxygen and incident water.

PAF encapsulation was to be achieved throughout the LOM, even though it would not be encountered until several months into the project. Fortunately, due to the proposed open-pit design PAF waste would be encountered concurrently with NAF materials. The initial design promoted moisture storage within the NAF waste following rainfall events, and its subsequent release to the atmosphere via evapotranspiration during dry periods, limiting rainfall infiltration to the underlying PAF. This moisture 'store-and-release' concept was deemed best suited to the arid to semi-arid climate that the mine site experiences. A second PAF waste management strategy was proposed that included a basal NAF layer to lift the PAF waste from the natural ground surface, thus eliminating the potential for lateral flow through the PAF waste and providing storage for seepage water from the overlying PAF waste (and potential adsorption of AMD products) if the upper NAF material are overwhelmed and seepage into the PAF waste occurs. Furthermore, additional geotechnical stability was provided.

The preferred final design comprised horizontal PAF and NAF layering of specified thicknesses (Figure 1). This option was chosen to be the most appropriate for several reasons, including concurrent placement of NAF and PAF waste at the facility thus preventing double handling or significant temporary works; allowing 'buffer' zones to exist should net percolation occur in extreme rainfall events; and reduction in the potential for differential settlement.

The outer WRD was designed based on the geotechnical properties of the available NAF materials and suitablity to the climate experienced. Perimeter embankments would be of sufficient width that PAF waste was not positioned beneath a sloping section and that PAF waste would not daylight the facility. In addition perimeter embankments utilized appropriate geometries whereby minimal surface erosion would occur and geometries appropriate to the materials and climate at the facility. NAF waste within the outer profile would be homogeneous, thus preventing the development of material segregation and preferential flow path establishment. Appropriate QA/QC measures were proposed in order to achieve the designated facility, in conjunction with an ongoing geotechnical and geochemical laboratory testing program. Finally, a surface water management plan was proposed that allowed individual catchment areas to be developed and minimize the potential for failure of the facility.

The success of this project came from 1) the initial extensive characterization of the materials present and their relative timing and 2) the use of ongoing materials sampling, laboratory testing and characterization to ensure that the facility constructed would perform as per the design.

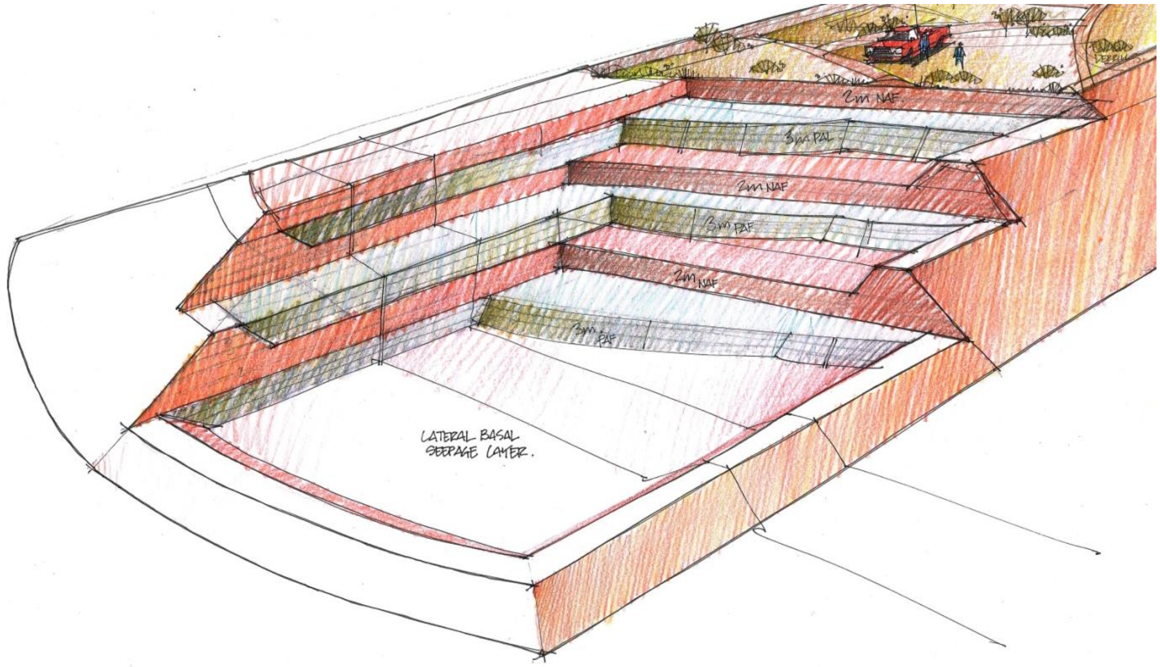

Figure 1 Schematic cross-section through the proposed WRD facility

Poly-Metallic Mine#2 Australia

A design was proposed for a large WRD that utilized NAF waste to encapsulate PAF material. The original geological block model was supported with geochemical data for a substantial (>15 m) unit of NAF waste, overlain by a CCL and finally growth medium. A second CCL was also proposed for between the PAF and NAF materials. As the project progressed it was determined that the waste materials had been incorrectly characterized. As such the design was amended with the NAF unit thickness decreasing. Further studies illustrated that portions of the NAF material were saline and metal leaching, and therefore could not be utilized as previously intended on the facility's outer embankment or plateau, in line with the regulatory requirements of the facility. As such the volume of 'clean' NAF was significantly reduced further and both the landform and cover system design required alteration to minimize any deleterious impact of the mine waste on the receiving environment in the short-term, and to facilitate recovery of the environment disturbed by mining over the long-term. A further complication was that the PAF waste had not been properly analyzed and it has been found to be highly reactive and capable of spontaneous combustion.

With 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 characterization of the NAF waste had used the presence of sulfates and pH value as a discriminator for NAF vs. 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.

CONCLUSION

It is of utmost importance that all materials expected to be excavated are appropriately characterized and their available volume determined. With a thorough understanding of the waste rock both prior to initiation of a venture and confirmed or otherwise during operations, in addition to the climate and environment of a site efforts can be made in developing a conceptual landform design that will meet regulatory closure criteria and satisfy stakeholders. Failure to provide appropriate materials handling and construction techniques to a facility presents huge potential for WRD failure at some point during the LOM, thus leading to environmental issues and large costs in rectifying any damage made during operations.

REFERENCES

INAP. (2009) Global Acid Rock Drainage Guide (GARD Guide). Document prepared by Golder Associates on behalf of the International Network on Acid Prevention (INAP).

Jasper, D. A., Braimbridge, M. F., Lacy, H. W. B. and Russell, M (2006) Integrating waste characterization into landform design for low-risk and low-cost mine closure. Proceedings of the First International Seminar on Mine Closure, Brisbane, Australia.

Mitchell, I. C. (2012) Robust mine closure development and maintenance. Proceedings of the Seventh International Conference on Mine Closure, Perth, Australia.

O'Kane, M. and Barbour, S. L. (2006) Choosing representative climate years for predicting long-term performance of mine waste cover systems. Proceedings of the 6th International Conference on Acid Rock Drainage (ICARD).

Pearce, S. (2014) Beyond the PAF cell. Proceedings of the eighth Australian workshop on Acid and Metalliferous Drainage.