Waste landform cover system and geometrical design

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An integrated waste placement and landform optimisation approach

Abstract

A foremost challenge in mine waste storage management is effective design of stable waste landforms that provide geochemical and geotechnical stability that resist long-term erosion and degradation of cover systems. Surface instability can expose reactive waste, lead to acid metalliferous drainage (AMD) and increased sedimentation of downstream waters, and cause poor revegetation or related environmental impacts.

The landform surfaces are the interface between the mine landform and the surrounding environment and therefore affect long-term environmental impact. This article examines practical design guidance from early concept development through to the quantitative assessments required for detailed design. This extends to discussion on overall geometry of landforms, veneer stability, cover system design and the selection of cover system materials. These factors should be considered together and integrated with internal waste landform design to provide confidence in design and improve closure outcomes.

Embankment stability is affected by geometry, including slope lengths, gradients and catchments. Longer, shallower slopes have larger catchments and potentially more runoff, whilst shorter steeper slopes have less catchment but (owing to the steep grade) require less energy to mobilise waste.

A balance needs to be reached for best performance, which is unique for the specific material types and hydrological setting.

Introduction

Most mines across the world face long-term environmental issues leading to costly contamination treatment(s) due to the inherent mineralised nature of the waste produced at mine sites. There is a very high expectation for managing chemically reactive mine waste typically associated with sulfide oxidation and the release of acid metalliferous and/or saline drainage (Barritt and Scott, 2015). Significant emphasis is placed on controlling AMD release in mine waste management and mine closure plans using suitable cover systems. Cover systems have in the past been designed and retrofitted at the end of the life of the waste rock facility, with the expectation that the cover system would save the day when waste rock characteristics have changed during the life of the mine. Commonly the cost benefit analysis does not allow for placing waste under stringent engineering and geochemical specifications, and is usually seen to be too time consuming and costly (at the time). Cover system designers often fail to account for the geometrical design of the waste landform, specifically the outer embankments, where the greatest risk of erosion failure exists.

Poor waste rock landform, including cover system design and construction, often lead to AMD release to groundwater and surface water. Poor geometric design often leads to AMD and sediment release to surface water and eventually exposure of potentially acid forming (PAF) waste to the atmosphere. Quality control during construction is often overlooked.
An integrated cover system and landform geometrical design must be combined with waste characterisation and selective placement design to manage reactive waste, minimise the potential for AMD generation and release, and create a geotechnical and erosionally stable waste landform.

**Integrated waste landform design approach**

The performance of a landform will be influenced by climate, site hydrology, materials properties (geology and geochemistry) and topography/geometry. Understanding the final mine waste landform is best done by developing the conceptual model of the current conditions and known parameters. The model is progressively reviewed as more data are accumulated and understanding is more informed.

The Global Cover System Design Technical Guidance Document provides a ‘filter framework philosophy used to rapidly refine cover system alternatives through a set of site specific filters, to more efficiently determine cover systems for further evaluation’ (O’Kane and Baisley, 2014). This approach and guidance document informs the integrated design of waste landforms.

Design of an integrated waste landform should include an understanding of the site groundwater, landform foundation conditions, base and liner requirements, waste geochemistry, internal waste placement method, gas management, cover system design and geometric design including erosion assessments and surface water management. Alternative integrated designs should undergo regular risk-based assessment through the mine life. The failure modes and effect analysis (FMEA) risk assessment methodology is a top-down/expert-system approach to risk identification and quantification, and includes identification and prioritisation of mitigation measures. It is a very suitable risk assessment tool for mine waste landforms as it focusses much more on individual components of a system than standard environmental risk assessments.

Uncontrolled gas flows from the waste landform containing reactive sulfidic waste is a commonly overlooked risk. Geochemical reactions can deplete oxygen from air and cause unsafe conditions in the vicinity of waste facilities. Waste placement, cover system and liner design must consider the risks associated with gas flow and oxygen depletion.

Meteoric water percolates through a cover system and reports to the underlying waste through which it seeps to the base of the waste landform. If AMD is expected it should be collected and treated before entering the natural environment through groundwater or surface water.

The detailed design documentation must include construction methods of placement and compaction of materials as well as classification and specification of construction materials.

**Cover system selection and design assessment**

Cover systems on mine waste landforms are unsaturated systems that are exposed to the atmosphere, and limit water and gas flux into reactive mine waste. Cover systems must be geotechnically and erosionally stable to provide overall stability to the landform.

The performance of a cover system and its capability to limit AMD is dependent on the climate, landform hydrology, materials properties and vegetation, and the design should be based on site-specific parameters. Cover systems are designed to manage net percolation and oxygen/gas flux of waste storage facilities that varies between the plateau and upper and lower slopes of the facility. These variances should be considered when modelling and designing a cover system.

Net percolation into waste is controlled by diverting incidental meteoric water by a sufficiently low permeable layer to express as surface runoff or interflow away from reactive waste or through a store-and-release system where infiltrating water is stored within the rooting zone and is then released via evapotranspiration. All cover system types inherently contain these attributes under certain conditions (O’Kane and Baisley, 2014).

The continuum depicted in Figures 1 and 2 shows arid on the left, temperate in the centre and tropical on the far right (O’Kane and Baisley, 2014).
Gas flux, and related AMD, can also be controlled by an engineered cover system that limits the oxidation of reactive waste. Diffusion and advective gas fluxes have to be managed by the cover system. Diffusion can be managed through the selection of finer-textured cover system materials or by increasing the water content in the cover system materials to reduce the air-filled porosity. A potential issue is maintaining the near-saturated conditions throughout the year in varying seasonal climates. Engineering design is required to balance plant water requirements and maintain cover system saturation. Diffusion flux can also be controlled by altering the path length or concentration differences (O’Kane and Baisley, 2014).

In addition to climate, erosion on cover systems is generally affected by material texture, slope length, slope angle and vegetation cover. All of these aspects should be considered simultaneously as an integrated process when assessing the potential for erosion on a waste landform, and management should aim to achieve consistent erosion across the entire landform (Kemp et al, 2014a; O’Kane and Baisley, 2014).

Cover systems can be divided into the following six categories (MEND, 2012; INAP, 2015):

- erosion-protection
- store-and-release
- enhanced store-and-release
- barrier-type
- saturated soil
- rock cover.

Taking all these aspects into consideration and looking at characteristics of cover system assessment and engineering design that can be manipulated, it is clear that the climate is the one component that cannot be changed or manipulated. Therefore, the site climate/hydrological setting represents the first filter that can greatly reduce the number of potential cover systems applicable for a site (O’Kane and Baisley, 2014). The next filter is material, followed by other site-specific considerations such as topography and surface water management.

**Geometric design assessment**
Waste landforms are often designed and constructed with uniform and 'generally acceptable' geotechnically stable slopes. Slopes are often steep and include highly engineered (sized) drainage structures along contours, with vegetation establishment following these same lines. This does not always result in erosionally stable slopes that meet closure objectives of minimum erosion, long-term sustainability and reduced long-term monitoring and maintenance liabilities. These designs are often developed without having site-specific, field-measured material properties. Laboratory testing and modelling should only be used to enhance judgement.

Natural slopes usually consist of a variety of shapes and sizes, including concave slopes at the base. Drainage systems are not linear and vegetation adjusts and develops based on hillside hydrology.

The preferred reclaimed slope design is a concave or complex (convex-concave) profile. The use of terraces or contour banks should be avoided. The landform slope curvature can be obtained using a series of linear slopes or slope facets (Figure 3).

Failures of mine waste landforms are usually associated with gully erosion and re-establishment of surface water drainage courses (McKenna and Dawson, 1997). Additionally, linear or convex slopes will become concave, steep slopes will flatten and straight flat drainage courses will meander due to sedimentation. The sedimentation from erodible materials on slopes could result in blockages of surface water drains, leading to bench overtopping and erosion gullies down embankments.

Slumping and differential settlement could also influence surface water flow, leading to increased gully formation and material losses.

Water management will include a combination of water shedding, infiltration and store-and-release that should be assessed based on climate and internal waste characteristics.

Vertical drains down embankments should be avoided if possible. Also, internal drainage to relieve pore water pressure build-up that can cause veneer slip failure must be included in the design.

The plateau surface should be designed to suit cover and drainage objectives including vegetation re-establishment and habitat structure. When it is required to drain plateau runoff to natural ground it should preferably be done using wide shallow swales or drainage via haul routes with shallower slopes and already traffic-compacted areas.

Surface water should be kept away from the embankment – overtopping can lead to excessive gully erosion. Outer embankments should be designed based on an assessment of the material characteristics using 2D and 3D modelling tools. Figure 4 depicts a site-specific 3D model that was developed to integrate the rehabilitation of three waste rock dumps and to design a surface water management plan.
Where available, cover system materials are fine grained or dispersive and armouring should be added to dissipate energy and provide erosion control. Well-graded materials have a much better chance to be stable long term.

**Field performance monitoring**

Currently monitoring is set at three to five or maybe ten years after closure. Due to the variability in material used for rehabilitation, the unpredictability of the climate – including climate change – and time for revegetation to establish it is unrealistic to set a fixed timeframe for monitoring. It is critical to evaluate the performance of a waste landform with respect to net percolation, gas flux and erosion. Mine closure plans include closure objectives and performance criteria. Monitoring systems tested during operations and implemented at closure should be developed around those objectives and criteria. The monitoring period should continue until sufficient data have been collected to verify performance or show that predictive modelling results can be met.

Cover system performance monitoring and internal waste facility monitoring should be integrated and include measuring temperature, water content, pore water pressure, CO2 and oxygen. The monitoring should not only be done for compliance but more importantly for performance validation. The length of time that performance monitoring is required can be shortened when predictive modelling (for cover systems and for erosion) can be validated through applying monitoring data to the model.

Monitoring must assess erosion including measuring runoff volumes. The monitoring system can be used to evaluate erosion potential and can be compared to the predictive erosion model.

**Conclusion**

It is very important to understand (initially at concept level) and integrate all aspects related to managing mine waste facilities for closure.

The mining industry should be applauded where it has implemented integrated waste management and/or where it is now part of mining and closure planning.

An integrated approach has to be followed from waste rock characterisation, detailed placement design and potential acid load calculations to cover system materials characterisation and modelling that inform the detailed design. Cover systems are most effective when developed in unison with the geometric design, water management design and internal waste rock facility construction. Predictive modelling using
site-specific climatic and material characteristics should be used to advance concepts to detailed assessment to inform detailed design. However, the modelling has to be done correctly and interpreted to inform design.

Risks associated with each closure measure need to be understood, assessed using FMEA methodology and addressed in the detailed engineering design. High-level environmental risk assessments do not always address key landform engineering risks.

During construction there has to be sufficient quality assurance and control to verify that the waste rock facility has been constructed as per the design: that is for the base, the internal waste placement and the cover system.

References


MEND, 2012, Cold regions cover system design technical guidance document, MEND Report 1.61.5c, July 2012.