Closure Planning for a Tailings Storage Facility in Western Australia

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Abstract

A base metal mine in the Kimberly region in the north of Western Australia recently developed an in situ closure plan for a tailings storage facility (TSF). A key aspect of the closure plan is the design of a final landform and design of an enhanced moisture store and release cover system for the TSF. Cover design and closure criteria were developed by completing a set of studies that assessed the impacts on downstream receptors for various cover design alternatives. Key criteria for the design of the preferred cover system and final landform were the prediction of net percolation rates and long-term erosional stability, respectively.

The design phase used conservative estimates and tolerances, which were included in the soil-atmosphere and seepage modelling programs. For example, no vegetation was assumed for the cover surface in the soil-atmosphere model. Robust design measures were used during the assessment of the cover alternatives and final landforms including the choice of a 2 m thick cover profile even though modelling predicted no significant difference in net percolation between 1 m to 2 m thick covers using benign waste rock material.

The primary method of ensuring a conservative design is to construct a watershed-scale cover system field trial by closing and rehabilitating a large portion of the TSF (cell #1) while the remainder of the TSF is still operational (cell #2a and b). The preferred cover and landform design can then be assessed on a watershed-scale using a state-of-the-art monitoring system designed to measure key performance objectives. A watershed-scale field trial will enable characterisation of key physical, chemical and biological processes controlling performance as well as enable future calibration of a soil-atmosphere model to actual field responses. This will allow refinement of the closure plan to ensure that optimal performance for the remainder of the TSF is achieved post closure.

1 Introduction

Closure planning studies for mine waste storage facilities should include best industry practises and proven techniques while incorporating site-specific issues. The plan, which must be flexible to accommodate changes in methods and/or technology, is about optimising post-mining land capability, minimising the costs in achieving optimal land use, and limiting long-term maintenance liabilities. In addition, conservative parameters and allowances for design refinement should be incorporated where possible in order to optimise the long-term sustainability of the plan. Closure planning support studies should include as much site-specific characterisation of variables as possible; however, in order to ensure a waste storage facility closure plan achieves specified closure criteria and minimises risk, a conservative design process should be implemented to ensure greater certainty of complying with regulatory agency requirements (O’Kane and Wels 2003; INAC 2003; MEND 2004; MEND 2007).

Several studies were completed in support of developing a closure plan for a TSF which incorporated several measures that were considered to be reasonably conservative. This paper discusses some of the conservative measures incorporated during the design phase of the development of a cover system and final landform in addition to those anticipated to be used during implementation.

The mine is located in the East Kimberley Region of Western Australia (Figure 1). The mine is an underground mine with a nickel sulphide ore body and was commissioned in 2004 with an initial mine life of 4.5 years. The operations are now projected to continue for another 10 years. The climate is tropical semi-arid with hot summers and warm dry winters. Mean annual rainfall is approximately 636 mm over an
average of 60 days, although this varies considerably from year to year. Annual potential evaporation is approximately 2000 mm.

The main objectives of the closure plan for the TSF are to provide geotechnical and geomorphic stability, to blend visually to the surrounding natural landscape, and to provide optimal surface water management to minimise net percolation into the underlying tailings and prevent erosion.

Figure 1  Map showing the region where the mine is located.

2 Cover system and landform design process

Closure planning for mine waste facilities should be firmly based in developing a robust set of closure criteria. For example, impacts to downstream receptors should not exceed trigger values set out by regulatory agencies. The framework for closure planning presented in Figure 2 shows an iterative process that tests factors of the design against closure criteria. During each step of this process, conservative measures should be incorporated so that risk is minimised. This may include the selection of conservative parameters during numerical modelling procedures to ensure the predicted results are for the “worst-case scenario”. These conservative assumptions can then be “layered” throughout the design. For example, during the basic cover design phase, soil-atmosphere modelling may be completed to assess several cover system alternatives using a conservative estimate for the hydraulic conductivity of potential cover materials resulting in a conservative estimation of net percolation (i.e. higher than expected). If a bare surface (i.e. no vegetation) is also assumed for the various cover system alternatives during the soil-atmosphere modelling program, the estimated net percolation is also elevated. Thus the estimation of net percolation would be increased in a compound manner by the use of two or more conservative assumptions.

A conservative design process should also include field trials conducted prior to commencement of closure or, as in the case of this example, by conducting trials during progressive rehabilitation of the waste facility. Field trials allow performance of the design to be confirmed or refined based on field responses.
3 TSF cover and landform design overview

The landform design consists of constructing three catchments on the TSF once the facility has reached capacity. The three catchments will be created by placing tailings into two separate cells. The first cell (Cell #1) will form a single catchment, and the second cell (Cell #2) will be split into two sub-catchments (Cell #2a and #2b) at closure. Cell #1 will be covered and rehabilitated while tailings are placed into the second cell, thus allowing for progressive rehabilitation of the TSF during operations. The final landform design is shown in Figure 3.

Several closure planning support studies were completed as part of the cover system and final landform design for the TSF, including a detailed material sample and testing program, soil-atmosphere modelling, seepage analysis, and landform evolution modelling. Details of the closure planning support studies can be found in Bonstrom et al. (2009). Based on site characterisation and soil-atmosphere numerical modelling, the rehabilitation cover will be constructed of available waste rock material. Waste rock material will be obtained from the adjacent northern waste rock dump (NWRD) facility. The adjacent eastern face of the NWRD was designed on the basis of landform stability as well as accommodating the required waste rock volumes for the TSF final landform design. The catchments will incorporate central, rock-armoured drainage channels that will direct surface water from the TSF to spillways for eventual release into the downstream Fletcher Creek system. The waste rock slope design also incorporates a toe drain to divert runoff from the NWRD away from the TSF.
4 Conservative design of the closure plan

The following sections describe how conservative estimations were incorporated into each aspect of the cover design.

4.1 Cover system and landform design

The cover design process consisted of material characterisation and soil-atmosphere modelling. Site specific variables were measured where possible and when assumptions were required, conservative estimates were used.

The material characterisation program included the collection of a large number of samples (>40) of potential cover material in order to define the range of textural gradation and hydraulic functions. This allowed for extensive sensitivity analysis to be completed during the soil-atmosphere modelling program to determine a range of net percolation rates for the proposed cover design. The range in net percolation rates were then used in seepage analyses that also use conservative methods and properties. Therefore, the predictions to the receiving environment, while based on measured variables where possible, are based on conservative parameters.

4.1.1 Cover profile thickness

The thickness of the waste rock material for the cover profile design was investigated in a preliminary modelling program. The program found little difference in cover performance with the waste rock thickness ranging from 1 m to 2 m. Consequently, a conservative approach was taken and the design process of the TSF cover and eastern face of the adjacent NWRD landform proceeded using a minimum 2 m thick waste rock layer. Therefore, the detailed modelling program used a 2 m waste rock layer within the various cover system alternatives. The 2 m waste rock layer provides a conservative approach by providing a buffer for variations in the higher hydraulic conductivity of the cover materials, decreased actual storage capacity of the cover system, and higher actual precipitation totals and rates compared to those used during the soil-
atmosphere modelling program. In addition, a 2 m thick cover profile provides additional protection from tailings exposure due to erosion compared to the 1 m thick profile.

4.1.2 Vegetation

A key conservative estimation used during the preliminary soil-atmosphere modelling program (to evaluate cover thickness) was a cover scenario with no vegetation cover. This was selected because drought, wildfire, or grazing has the potential to damage or destroy a vegetative stand. It is a conservative assumption because the presence of vegetation and resultant transpiration will increase surface evapotranspiration from the cover system, ultimately improving its performance. Vegetation will also improve the cover system in terms of aesthetics and erosion resistance.

A set of vegetation characteristics was developed for use in a secondary modelling program (sensitivity modelling) to compare the influence of vegetation on cover system performance to the bare surface scenario. Vegetation characteristics such as rooting depth and surface coverage have not been investigated for the site. The leaf area index (LAI) assumed for the simulations was 1.5, which equates to a surface coverage of approximately 65%. There was no rainfall canopy interception assumed for the modelling program. The rooting depth was 0.4 metre below the cover surface and the growing season was assumed to be from October 1st to May 31st.

A 100-year simulation was completed implementing a vegetative cover at the soil surface of a 2 m cover profile. The key vegetation parameters used were a leaf area index of 1.5 (surface coverage of 65%), a constant rooting depth of 0.4 m, and a growing season extending from October 1st to May 31st. The average annual net percolation for the 100-year simulation was 39 mm or 6.2% of average annual rainfall. Compared to the 53 mm annual net percolation for the base case, vegetation decreased the average net percolation by 26%.

Figure 4 shows the probability of the net percolation exceeding a given value for both the base case (i.e. bare surface) and the vegetation simulation. The improvement in performance shown in the difference in average net percolation is fairly consistent over the full range of net percolation. This is shown in the similarity of the shape of the curves from low through to high net percolation values. The probability of annual net percolation exceeding 25 mm is 44% for the base case and 38% with vegetation. A similar disparity between the curves occurs at 100 mm (22% and 18%) and 200 mm (8% and 3%).

The improvement in performance is due to the vegetation’s ability to “pull” moisture from lower in the cover system profile as compared to evaporation alone, which leads to increased evapotranspiration rates. The increase in evaporative front depth produces lower in situ water contents and increased storage capacity compared to the no vegetation condition. When vegetation was simulated, a greater percentage of negligible net percolation years (arbitrarily assumed as 5 mm for comparative purposes) were predicted. For example, the probability of net percolation exceeding 5 mm/yr was 52% with vegetation and 74% without vegetation. In addition, the lower in situ water contents and increased storage capacity reduced net percolation during the high rainfall years. The probability of net percolation exceeding 200 mm/yr was 8% without vegetation and 3% with vegetation, which represents a substantial difference in risk. Therefore, basing the cover system design on the bare cover surface modelling predictions adds a buffer to the actual long-term net percolation rate.
4.1.3 Landform design

The final landform design for the TSF incorporated a drainage scenario consisting of three sub-catchments with runoff discharge via external spillways. In addition, run-on will be prevented by the inclusion of a drain at the foot of the NWRD.

The final landform, which includes the TSF surface and adjacent NWRD slope, was assessed for landform stability. Landform evolution modelling, using the numerical software package Siberia, was completed for a 1,000 year period for bare surface conditions (i.e. no vegetation). This analysis illustrates that the preferred moisture store-and-release cover system and NWRD slope will be stable for at least 200 years. In addition, the landform stability analysis indicated that the drainage channel at the base of the NWRD slope would prevent run-on to the rehabilitated cover surface over the same time frame.

4.2 Implementation phase

The key advantage of progressive rehabilitation of the TSF will be the ability to monitor the performance of the cover design by implementing a watershed-scale performance monitoring system during rehabilitation of Cell #1. This allows for verification of the design with long-term field response measurements.

4.2.1 Watershed-scale field trial

The next step in the design of the closure plan for the TSF is to construct a watershed-scale field trial on Cell #1. The purpose of the Cell #1 field trial will be to demonstrate performance of the cover system and refine the cover system and final landform design, if required, based on field measured responses. The field trial is intended to gain an understanding of key processes influencing performance by conducting micro-scale and macro-scale measurements. The field trial is designed to capture the inherent spatial and temporal variability of water dynamics within the cover on a watershed-scale (i.e. macro-scale). By monitoring over a large
(watershed-scale) area rather than a single point, a more representative determination of performance can be measured. This will in turn lead to a more robust full-scale design and greater stakeholder confidence.

The watershed-scale trial will enable the characterisation of conditions, processes, and interactions within a watershed. Linking components of the watershed together is a key feature of the watershed-scale trial. Key processes and mechanism controlling performance can be understood before final closure of the TSF. These processes include: i) physical processes including measurements of runoff/erosion, in situ moisture conditions within the cover profile and underlying tailings material, tailings settlement and consolidation, tailings draindown, and climatic conditions, ii) chemical processes including soil dispersion, salinisation, and tailings porewater concentrations, and iii) biological processes such as root penetration, bioturbation, and vegetation establishment.

Monitoring these key processes will also provide further understanding of the:

- Geochemistry, geotechnical behaviour and hydrological characteristics of the tailings;
- Hydrogeological characteristics underlying the TSF; and,
- Surface hydrology of the TSF in addition to downstream hydrology.

Of key importance will be the development of a field response database to calibrate the preliminary soil-atmosphere model. The model calibration in essence is revisiting the cover system design soil-atmosphere modelling using hydraulic material properties derived from field data. Long-term predictive modelling would be completed using a climate database to determine if the cover system meets closure criteria. This allows the cover system design to be optimised for the remainder of the Cell #1 and Cell #2 once it reaches capacity. The model predictions will allow for continual improvements to impact assessment, management, and mitigation measures. In addition, final closure plan design criteria would be refined.

A watershed field trial allows issues relating to the cover system construction and implementation to be identified and addressed prior to full scale closure of the TSF.

5.0 Summary

The development of an in situ closure plan for the tailings storage facility at a base metal mine in Western Australia incorporated several conservative measures during the design phase. Additional conservative measures will be implemented during the progressive rehabilitation of the facility. Several examples of the conservative measures used in the design of the cover system and final landform include:

- Increasing the final cover profile thickness from 1 m to 2 m to provide additional buffering of net percolation through the profile in case material properties and/or climactic forcing was under estimated. In addition, the increased thicknesses provides additional protection from tailings exposure in the event of landform erosion,

- Net percolation rates predicted using bare surface (i.e. no vegetation) cover during soil-atmosphere modelling program was used to assess several cover design alternatives against closure criteria. Vegetation improves the performance by removing water from lower depths within the cover profile due to rooting characteristic.

- A watershed-scale field trial will be constructed during the closure of Cell #1 while Cell #2 is operational. This will allow physical, biological and chemical processes influencing the performance of the cover system and landform to be measured and tested against closure criteria. Adjustments to the final cover system and final landform design can be implemented to Cell #1 and Cell #2 based on field response.

References


