Sustainable Closures for Tailings Landforms in the Torrid Zone

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ABSTRACT

Closing tailings storage facilities (TSF) to provide stable landforms in perpetuity is a critical goal of leading practice mine closure. The ability to put this theory into practice is often confounded by short term operational objectives, environmental challenges and cultural heritage constraints. A case study from the Tanami Desert in Northern Australia examines these constraints and offers guidance on sustainable designs for TSF closures throughout the Torrid (Tropical) Zones.

The TSF at the case site has an area of approximately 230ha, with a final height of 15 meters due to cultural heritage and visual amenity commitments. The facility is scheduled to close in 2029, allowing time to develop the desired final landform. The case site is located at 20°30'S and while the average annual rainfall is less than 412mm the site can experience intense monsoonal storms, with the probable maximum precipitation estimated at 390mm in a single 45 minute event.

Overall the closure strategy is to manage surface water using a water shedding final landform. By shedding surface water, water persistence and infiltration is limited. Therefore reducing the tailing phreatic surface (water table), and minimizing groundwater recharge. The technical challenge is to manage the potential peak surface water volumes over the large surface area in perpetuity. These large volumes prohibit water channels or other artificial flow concentration measures without significant cost and ongoing management. The options examined included multiple final landform profiles to shed surface water in an effective and manageable manner. The options analysis indicated the simplest solution was to manage the operational tailing disposal to create a final tailings beach that is in alignment with the designed final land form surface.

The solution is pragmatic, reduces re-handling and allows a final landform that balances the cultural heritage commitments and desired landform stability. This solution was only possible because of early closure planning and the commitment from the company to optimize operations for closure.

INTRODUCTION

Newmont Tanami Operations' Granites Processing Facility is located in the Tanami Desert in central Northern Territory, Australia. The site, herein referred to as Newmont Tanami Operations (NTO) has been operating since the 1980's and has utilized multiple tailings storage facilities (TSF), ranging from in-pit disposal to paddock facilities. The successful closure and rehabilitation of these tailings storage facilities is critical to the environmental performance of the facility and the ability to relinquish the lease at mine closure.

The Granites climate is classified as semi-arid, monsoonal and is challenging in terms of a TSF closure design. The site has a low average annual precipitation of 412mm per annum and an evaporation rate approximately seven times rainfall of ~2,788mm per annum. These conditions are ideal for sulphide salt formation (Jarosite, Melanterite and Gypsum). The majority of precipitation occurs during the (summer) months of November through to April and severe and high intensity rain storms are common.

The Granites operation has undergone expansion and extension of the mine life through successful exploration programs, which has led to the complete filling of the original TSFs. Subsequently an expansive paddock TSF has been constructed to accommodate the life of mine tailings. The tailings solids being deposited in this TSF are thickened pre-discharge and non-acid forming. These solids are discharged through a series of spigots at intervals around the perimeter of the embankment. This facility is complex, consisting of three internal cells with the southern embankments adjoining two ~50metre deep in-pit TSFs. The closure of this singular landform (including in-pit facilities) is the subject of this paper.

Previous TSFs have been closed or partially closed at the operation. The success of TSF closure is directly influenced by the management of conflicting requirements for cultural heritage, visual amenity, surface water, ground water and vegetation growth.

Closure Requirements

In addition to internal corporate requirements, three primary pieces of legislation regulate the operation, decommissioning and closure activities at NTO. This legislation includes the Northern Territory Mining Management Act 2015, the Work Health & Safety (National Uniform Legislation) Act 2011 and the Commonwealth Aboriginal Land Rights (NT) Act 1976). The closure objectives and completion criteria for TSFs have been assessed by NTO and the relevant aspects to the TSF landform have been summarized in Table 1.

Table 1 NTO Closure Aspects for Tailings Storage Facilities

Aspect	
1. Public Safety	5. Water Quality
2. Landform Stability	6. Post Closure Land Use
3. Geotechnical and Geochemical Stability	7. Community & Stakeholder Consultation & Visual Amenity
4. Establishment of Sustainable Ecosystems	

Project Climate

Annual rainfall is variable, a minimum of 153mm was recorded in 1992 and a maximum of 833mm was recorded in 2000. Intense rainfall events are also common, in January 2007, the 72-hour rainfall totaled 303mm, an event with an Annual Return Interval (ARI) of one in fifty years.

Landform Design

The combined landform covers 230ha, with the majority being the paddock TSF (Figure 1). The landform has been constructed on natural ground which slopes at approximately one percent towards the north-west. The southern embankment is partially formed from the northern embankment of two in-pit TSFs.

Once filled to capacity each of the 3 cells will have the same reduced level (RL) of 397m Australian Height Datum (AHD), and the depth of tailings will vary between 10 to 15m. The initial construction design graded the final tailings beach surface of each cell at 1.2% towards the central decant towers, as a water holding facility. A plan view of the original designed landform tailings beach is included as Figure 1.

Figure 1 The TSF landform construction design contours

Current TSF Operations

The TSF is currently in 3 separate stages of operation, the two smaller in-pit TSFs to the south of the landform are filled to capacity and awaiting closure. Cells 1 and 2 of the main paddock TSF (the east and west cells in the center of figure 1) starter embankments were constructed in 2013 and are currently being used to deposit tailings. Cell 3, the northernmost cell of the landform in figure 1, has yet to be constructed, although the design is finalized and approved. Each cell is designed to be raised on a cyclic basis to achieve the design density of the contained tailings.

Tailings are discharged into the landform via ring mains around the perimeter embankments of each cell. Tailings are typically discharged through 3 or 4 operating spigots at any given time.

Tailings are pumped to the TSF as wet thickened tailings with an average solids content of 61%. Deposited tailings have an in-situ density of 1.49t/m^3 and a dry density of 1.62t/m^3. (ATC-Williams, 2013)

METHODOLOGY

To achieve the closure requirements and objectives (Table 1) the landform must be less than 15m in height (Table 1 – Aspect 1 and 7), water shedding (Table 1 – Aspect 2, 3, 4, 5 and 6). In order to create a water shedding landform, the following considerations were required. The landform must withstand intense rainfall and a probable maximum precipitation (PMP) event. To ensure the cover system does not transmit water into the tailings or the groundwater system during a PMP event, modeling of the cover saturation was undertaken. To ensure the facility is geotechnically stable, static modeling of embankment angles was conducted. Finally, to ensure the cover system was cost effective, re-contouring of the tailings beach was considered in conjunction with the dam engineers and operational staff using a modified options analysis.

RESULTS AND DISCUSSION

Probable maximum precipitation

For the closure design the probable maximum precipitation (PMP) was estimated using methods outlined by the Bureau of Meteorology (BOM). The long duration PMP analysis focused on cyclonic or low pressure system storms. The rainfall intensity applied to the closure design was a critical duration PMP event of 45 minutes occurring as part of a longer duration rainfall event which results in complete saturation of the cover system. A rainfall intensity of 521mm/hr was applied, resulting in a total rainfall of 370mm during the critical event. A PMP event is generally considered to have an ARI in excess of 1 in 10,000 years and is considered appropriate for closure design.

To evaluate the total surface flow from the final surface the total Probable Maximum Flood (PMF) volumes were calculated, using the 45 minute PMP event, catchment area and coefficient of discharge calculations. For the calculation of the PMF, the surfaces were assumed to be saturated. This is considered the worst case scenario for maximum surface water run-off. The PMF value for the final landform is 330,000m^3/hr.

Cover System

To evaluate the cover options, numerical modelling was used to estimate the water fluxes for two cover options. Broadly, the cover system satisfied four criteria:

- Provision of a growth media to sustain a resilient vegetation community
- Effective management of surface water run-off, to limit the risk of water infiltration into the tailings and groundwater and minimize the likelihood of sustained saturation of vegetation

- Erosion resistance during intense rainfall and wind events
- Prevention of the migration and infiltration of salts to the root zone or groundwater

The first cover design to be evaluated was a 2m oxide cover, paddock dumped and contoured to a water shedding gradient (Figure 2(a)). Modelling showed the saturation profile increased during the annual rainfall cycle. While this cover satisfactorily managed the risk of salt intrusion it has the potential to contaminate groundwater, due to the overall saturation of the cover profile increasing during the annual rainfall cycle.

The second cover design was a modified store and release design (Figure 2(b)). This design was comprised of coarse oxide rock placed directly upon the tailing surface, followed by a low permeability layer (1 x 10^{-8} m/s), upon which a layer of non-compacted fine oxide waste was placed. The saturation profile seen in the upper layer of fine oxide waste shows the same wetting pattern described for the 2m oxide cover (above). However, the saturation profile below the compacted layer remained constant during the 365 day rainfall cycle, indicating a strong capillary barrier. The computed flux at the base of the fine oxide waste rock cover (immediately above the compacted zone) was less 2 mm/yr.

The modelled performance of the modified store and release cover system was considered superior in achieving the closure outcomes, as such this system was recommended. This cover system will be applied to the final TSF beach design then overlain with topsoil stripped and stockpile prior to the construction of the TSF.

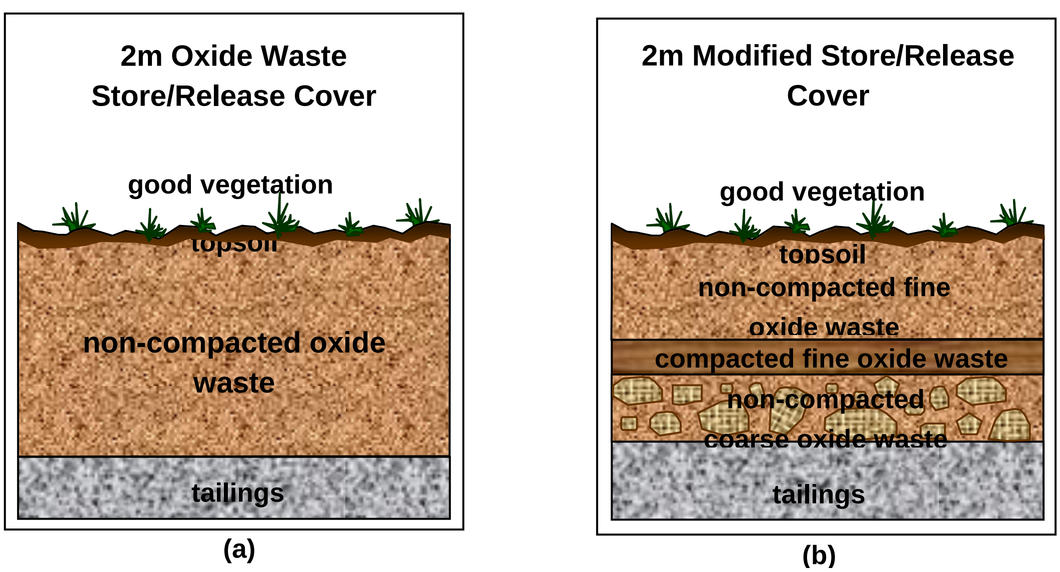

Figure 2 Cross section of two analyzed cover designs

Harmonizing Operation and Closure

Considering closure planning and design work early in the facility life cycle and has allowed TSF operation to be tailored to achieve best practicable closure outcomes. The ability to design and implement a closure concept prior to the end of facility life affords the integration of operations with closure. A strategy that can reduce both operational and closure costs, while increasing the potential of successful relinquishment.

As with all facilities there are constraints to the magnitude of possible options. These constraints include design depositional capacity, free-board for rainfall, approved factors of safety, limitations of the embankment design, physical tailings properties, and the availability of inert waste material for the cover.

The operational embankment design and construction is an upstream raise. As such, the phreatic surface within the deposited tailings places limitations on the location of the supernatant pond during operation of the TSF. Direct input from the design engineers and site operators has allowed modification of the operational practices.

Modification of Operational Tailings Beach

The tailings beach gradient is the result of tailings volume, spigot placement, tailings density, and operational control of the supernatant pond. All TSF operational landform options were designed to contain equal operational supernatant pond volumes, freeboard/flood storage capacity and maximum tailings height.

Through consultation with the design engineers and operational staff three options for the tailings beach were presented to create a water shedding design.

- The original design
- Alter supernatant pond location to within 30m of embankment
- Supernatant pond to embankment

The original design required closure re-handling of tailings and the utilization of large volumes of material to create a water shedding final surface (Figure 1).

A concave tailing beach slope was chosen for options two and three, to achieve a water shedding closure design of the tailings beach and closure cover. The gradient of the outer tailings beach is 0.5% (1 in 200), and the area immediately around the supernatant pond is 1% (1 in 100) to 2% (1 in 50) (Figure 3 and Figure 4). When combined with the 2m modified store and release cover system, this design allowed a final land form surface that will shed water as sheet flow during a PMP (extreme) event and will allow evaporative water loss after non-PMP (non-extreme) events.

Option two is a design compromise, where the supernatant pond location and tailing beach was altered to reduce tailings re-handling (Figure 3).

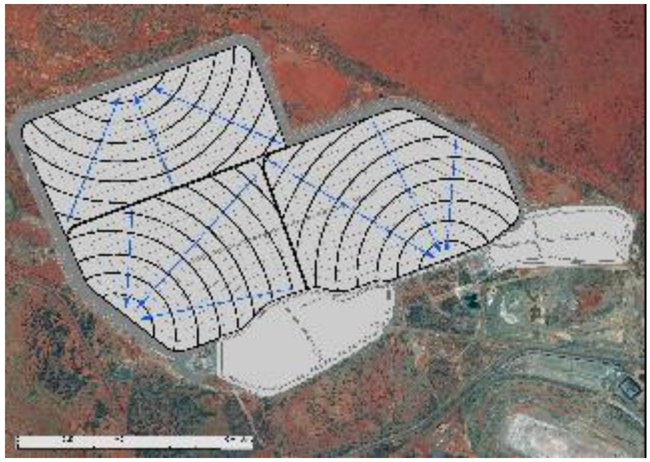

Figure 3 Modified final tailings deposition profile (heavy lines) to achieve desirable closure surface

When option 2 was compared to the initial design surface in Figure 1 (and Figure 3 – thin lines), the notable differences include the reduced tailing beach gradient, and the altered location of the supernatant/decant ponds closer to the embankment. These alterations minimized the re-handling volume required at closure for construction of drainage structures.

Option three is the ideal option, and is similar to option two, with the exception that both the supernatant pond and the tailing beach are altered to reflect the exact design of the final cover (Figure 4 and Figure 5).

Figure 4 Ideal tailings beach surface contours, matching the contours of the final landform

Options Analysis of Operational Tailings Beach

The three options were analyzed in terms of closure risk, cost, loss of tailings volume, re-handling volumes, construction complexity, and closure performance (Table 2).

Table 2 Options analysis

Options	Closure Risk	Cost	Loss of tailing volume (m^3)	Closure re-handle (m^3)	Cost of re-handle ($A)	Construction Complexity	Overall Rating
1. Existing operational plan (Figure 1)	High Risk: Unplanned closure results in a water retaining surface, tailings at closure, potential for groundwater interactions	Maximum tailings re-handle Maximum cover volumes	0†	200-250,000	>$1.5 million	Significant: re-handle leads to increased dust generation and potential failure to achieve satisfactory closure surface profile	Poor: due to high cost and complexity of closure surface creation, environmental risk of tailings dust generation and dispersion
2. Deposit tailings to final closure surface (Figure 3)	Low risk: due to operational construction of desired water shedding landform	Lower closure cost: minimal tailings re-handle, minimum cover volumes	(-)600-650,000	0	0	Reduced complexity of cover system Increased operation complexity to achieve landform	Poor: due to operational risk of saturating embankment during tailings deposition, ideal closure concept
3. Deposit tailings with extent of supernatant pond a minimum of 30m* from embankment (Figure 4)	Medium risk: limited exposure of tailings to re-handle, unplanned closure presents water management risk	Moderate cost due to re-handle of reduced volume of tailings	(-)150-175,000	30-40,000	~$250,000	Increased operational complexity to achieve landform and maintain supernatant pond location Reduced closure construction complexity	Best: compromise of operational and closure risk to achieve desired outcome **Chosen Outcome**

*30m distance resulting from phreatic surface gradient generated through tailings limited at toe drain on upstream starter embankment toe.

† Base case for tailings storage volume

CONCLUSION

The requirement to create a safe stable TSF landform at closure is an indisputable requirement of any operation. To successfully rehabilitate the Granites Processing Facility and achieve lease relinquishment, the associated TSFs must meet or exceed all closure criteria.

To best achieve the closure outcome Newmont Tanami Operations have taken advantage of implementing a specific closure design during the TSF planning and construction phase. The operational management of these facilities has then be tailored to achieve the closest practicable TSF beach surface for this landform.

To achieve a successful TSF closure at the Granites mine site Newmont Tanami Operations are currently applying option 3 from table 2, as a pilot trial on a smaller In-pit TSF to test assumptions of the methodology, prior to broader application. The management of the tailings deposition to achieve a closure orientated final landform provides a lower closure cost, reduced rehabilitation timeframe and higher probability of successful lease relinquishment.

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