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Tailings dam closure and declassification: closure optimisation with limited rehabilitation resources

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Abstract

Mine waste landforms will become part of the landscape in perpetuity. Detailed investigations and engineering design considering environmental factors are required before their implementation, and should be followed by monitoring and eventually relinquishment, if achievable. Some consequences of not undertaking the required investigations and design assessments before closure construction are that acceptable environmental and financial outcomes are not achieved and/or the end user or engineer of record (EOR) for a tailings storage facility (TSF) does not agree with, or accept responsibility for, the closure design or constructed closure landform.

The TSF owner's objective is to deliver optimised closure outcomes for their sites. The optimised closure outcome for a site may be one of the following or a combination: using the site for an alternative land use, ongoing management, relinquishment or divestment. Closure of this TSF aligned with their approach to risk management for TSFs and supported their aspiration to leave a sustainable and positive legacy.

The ~215 ha TSF site is located in the Pilbara region of Western Australia. Most of the tailings had been removed from the TSF for reprocessing. The TSF still required EOR oversight as safety risks (some credible failure modes) remained. These were associated with open water ponding and stormwater containment, including freeboard requirements, and the risk of embankment overtopping and embankment/dam breach which could release tailings. Originally there was a lack of tailings and borrow material characterisation and quantification. Investigations undertaken to support closure design included material sampling, geochemical and physical testing and characterisation, and quantification of tailings.

Initially the proposed end land use was focused on industrial use based on property zoning. A concept was developed that included multiple layers of cement-stabilised tailings with minimal growth media cover. The limited growth media thickness and lack of surface erosion modelling presented an unacceptable risk to the end user.

An optimised design, including surface erosion assessment, resulted in an increased growth media cover thickness using materials from within the TSF footprint, which reduced the cement stabilisation requirements and, therefore, closure construction cost. Construction drawings were produced for implementation.

The TSF has recently been closed and declassified as a dam as no credible failure modes remain.

Keywords: *closure, tailings, TSF, credible failure mode, consequences, risk, landform, characterisation, erosion, design, construction*

1 Introduction

The mining industry aims to close and integrate mine waste facilities into the surrounding landscape with minimal environmental impact. These waste landforms will, in general, remain in perpetuity (Chapman &

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Kemp 2019). Tailings storage facilities (TSFs) present challenges when it comes to their operation, closure and post-closure management. One of the critical issues is that achieving a state where the site requires no ongoing maintenance or long-term monitoring is typically not feasible (Bocking et al. 2009). This is primarily due to the persistent risks associated with inactive and closed TSFs, which include structural instability, potential for dam failure and environmental contamination.

Inactive and closed TSFs can pose significant contamination risks to the surrounding environment. Potential sources of contamination include heavy metals, sulphates and other toxic substances that can leach into groundwater and surface water systems. This contamination can have long-lasting impacts on ecosystems and human health, necessitating comprehensive monitoring and remediation strategies.

Declassifying a TSF as a dam is a complex process (Canadian Dam Association [CDA] 2019) that requires meticulous planning and rigorous assessment. The criteria for declassification often involve demonstrating that the TSF no longer poses a risk of catastrophic failure and that the stored tailings are stabilised to prevent environmental contamination. However, the residual risks associated with inactive TSFs, such as erosion, seepage, and acid and metalliferous drainage, pose ongoing challenges.

In summary, closing a TSF involves addressing multiple risks and ensuring long-term stability and environmental protection. The complexities involved in declassifying a TSF as a dam and managing the associated contamination potential underscore the need for innovative and robust closure planning and implementation strategies.

This paper presents the assessment and rehabilitation of an inactive TSF that required ongoing engineer of record oversight.

2 Site tailings storage facility assessment failure modes

An engineering assessment of water storage facilities that included an inactive site TSF was undertaken and catastrophic failure modes were identified. The ~215 ha TSF site is located in the Pilbara region of Western Australia. Most of the tailings had been removed from the TSF for reprocessing. The following summarises the failure modes identified in a failure modes, effects and criticality analysis conducted for the site TSF:

- slumping or sloughing of the embankment — involves the significant movement of material within the embankment
- erosion of the embankment/crest — a risk of erosion affecting the embankment or crest
- embankment slope failure/slumping/cracking — potential instability leading to embankment failure
- sudden water release from the spillway — occurs when obstructions dislodge or erode, causing rapid water release
- spillway flows below design levels — a risk when the spillway invert level is reduced to be below the intended design level
- lack of a protective windrow/barrier — inadequate protective measures in certain areas
- ongoing erosion and seepage through side walls — erosion and seepage along the side walls
- lack of a protective barrier (fence) and access control (gates) — an absence of preventative safety measures to block access to ponded water that could lead to drowning incidents.

3 Risk factors

Despite the TSF being inactive with tailings partially removed, or maybe because of this, several key risks that required ongoing inspections and oversight (Australian National Committee on Large Dams [ANCOLD] 2012) remained. These included the presence of remaining tailings within the TSF footprint that presented an ongoing risk, particularly in terms of stability and environmental impact. Open water ponding within the TSF and the need to manage stormwater introduced significant safety risks, including drowning, and embankment overtopping. Overtopping could lead to the potential for embankment or dam breaches, which could lead to tailings release. Water management infrastructure had already been removed, which exacerbated the risk of overtopping.

Incomplete characterisation of the tailings and borrow materials hampered the ability to plan and implement closure and rehabilitation under known or predicted environmental conditions, posing a risk to the stability and success of the closure strategy. Additionally, an insufficient understanding of the quantities of remaining tailings and available rehabilitation materials complicated planning efforts and the implementation of effective closure measures.

A study including data collection, assessments and detailed design was completed to address these risks, leading to the construction of the rehabilitation landform and subsequent declassification of the facility as a dam. An additional risk mitigation factor was appointing the designer to provide site supervision support.

4 Study approach

The effectiveness of site rehabilitation is influenced by various factors including climate, hydrology, material properties (geology and geochemistry), hydrogeology, construction techniques and topography/geometry (Kemp & Olds 2017).

For this project, the correct studies and investigations were initially identified. However, due to budget limitations, not all of them could be completed during the initial phase of work. Unfortunately, this resulted in unaddressed gaps, leading to the next site owner refusing to take over the site, based on the exclusions associated with the initial assessment. Subsequently, a second phase of work was undertaken to address these gaps. An optimised design was achieved that resulted in an improved environmental outcome while also reducing construction costs: a rarity in such cases.

The assessment and detailed design approach included:

1. Initial phase

- materials characterisation and quantification
- improved integrated 3D landform
- materials movement, placement and usage optimisation
- tailings removal to full depth and relocation to encapsulation area
- isolation of tailings within available void space/outside of potential flood zones

2. Second phase

- maximisation of cover depth over tailings material
- reduced/removed reliance on tailings stabilisation
- generated cover material from within the footprint
- erosion assessment with a focus on event-based impacts
- improved surface treatment based on erosion assessment.

5 Key aspects

In the study and design several key aspects were investigated. These included material sampling and testing, focusing on the internal footprint (both tailings and the natural ground) and borrowed materials from an external stockpile. Additionally, physical and geochemical characterisation of the materials was conducted. The remaining tailings was quantified from test pits and in situ material was assessed for its potential as a rehabilitation resource. Stormwater and storm surge assessments, 3D landform geometry, volumetric assessment, erosion assessment and hydrogeology were also considered. Notably, the material characterisation revealed that all materials were geochemically acceptable. However, the tailings lacked erosion resistance while sand and topsoil were less prone to erosion.

5.1 Erosion assessment

The erosion assessment calculated the estimated erosion across the landform surface in response to discrete storm events. To achieve this, the bed shear stress was calculated using a 2D hydraulic model, simulating direct rainfall across the entire landform. The methodology outlined by the United States Bureau of Reclamation (USBR 2019) was employed to estimate scour and erosion potential. This method correlates the modelled bed shear stress with an estimated erosion rate. Finally, we interpolated the erosion rate over the 2D flood model simulation time to estimate potential erosion depths following the storm event.

In our assessment, considering a one in 10,000 annual exceedance probability (AEP) with climate change, we observed even bed shear and erosion across the landform. Erosion over backfilled tailings was minimal. However, minor attention may be needed where the rehabilitation landform meets the natural topography. On average, erosion rates were mostly below 2 t/ha/yr (equivalent to less than 0.2 mm/yr). Some localised areas experienced higher rates (6–8 t/ha/yr), where the design required additional erosion protection measures. Care and maintenance at edges and slope transitions are also advisable.

6 Design summary

The primary objectives of the landform design were to encapsulate tailings and to tie the reshaped TSF landform in with the natural topography while minimising the need for net import of fill material beyond the TSF boundaries. To achieve this, the existing tailings was relocated to available void spaces within the TSF footprint, away from erosion risk areas. Additional void space was allocated to account for unidentified tailings material.

The facility geometry was designed to shed water, integrating with the existing topography (by matching very flat natural topography slopes) without exceeding erosion targets for the one in 10,000 AEP event with climate change accounted for. No engineered structures or rock-lined features were required due to the flat nature of the landform, and smooth transitions between the rehabilitated surface and the surrounding natural topography. Following tailings relocation, a minimum 500 mm cover of fill and topsoil was placed over the tailings. Beyond the relocated tailings area, the TSF footprint has undergone cut-and-fill operations to achieve an approximate zero net materials balance across the landform surface. Subsequently the top surface was seeded, then cleared and grubbed vegetation was beneficially used by spreading it in higher erosion risk areas, despite erosion targets being met.

The landform design ensured a balance between cut and fill without the need for net material import as there was very limited external borrow material available. Also, existing vegetation in the surrounding area and some within the TSF footprint was retained.

7 Declassification

Material sampling and testing were conducted, revealing that none of the tested samples (including tailings) exhibited enrichment of elements with environmental significance. Given the generally low erosion resistance of the tailings, its encapsulation or relocation below ground was necessary. The rehabilitation efforts involved moving the remaining tailings within the TSF to a storage area below natural ground level yet still within the TSF footprint. This material was then covered with a suitable site-specific cover system utilising embankment, topsoil stockpiles and natural materials within the TSF disturbance area as no/limited borrow material was available. In this instance there were no realistic environmental risks associated with the tailings material remaining after encapsulation. This is often not the case due to, among other factors, mine waste geochemistry.

To achieve a final free-draining landform covering the entire TSF footprint, all embankments were removed and integrated with the natural ground. This design ensures that excessive ponding of stormwater does not occur on the rehabilitated, nearly flat landform. Regular onsite visual inspections, along with drone surveys, confirmed the successful encapsulation of tailings within the below-ground storage area. Furthermore, the final landform construction aligned with the free-draining landform objective.

As a result of these measures:

- no retaining embankment remains and therefore there are no remaining geotechnical failure modes
- no embankments remain that can slump or erode
- no embankments remain that can pond water which could be suddenly released or pose a drowning risk.

Considering the above and recognising the absence of geotechnical failure modes, it was proposed that the site TSF should no longer be classified as a dam.

8 Conclusion

Mine waste facilities will remain in perpetuity. Therefore, closure and rehabilitation planning should be based on detailed assessment, appropriate data and integrated engineering design considering potential environmental impact. The integrated approach must consider site-specific climate, materials (physical and geochemistry), hydrology, hydrogeology, construction methods and landscape topography. This should be considered sooner rather than later to negate the need for redesign to meet end user or responsible person requirements.

To declassify a TSF as a dam, credible failure should be removed and confirmed to be non-credible in the long-term.

Meeting declassification requirements (removing credible failure modes) does not always address environmental risks associated with mine waste and therefore a truly integrated approach is required.

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