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Transforming tailings storage: a comparative study of central thickened discharge versus conventional tailings storage facilities in Western Australia

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Abstract

This paper presents the findings of a high-level options study conducted for the development of a tailings storage facility (TSF) in a relatively arid region of Western Australia. The study evaluates various tailings management strategies and culminates in the selection and implementation of a central thickened discharge (CTD) scheme. The paper further explores the design rationale, operational performance to date, and long-term implications of the adopted CTD scheme.

The CTD scheme represents a strategic departure from the site's traditional upstream-raised TSFs, offering a range of technical, environmental, and operational advantages. Key benefits include a substantial reduction in liquefaction and geotechnical instability risks, simplified construction methodologies, improved tailings deposition and water recovery/management, and a lower overall environmental footprint.

Keywords: *tailings storage facility, central thickened discharge, upstream raise, thickening, tailings deposition*

1 Introduction

The critical importance of effective tailings management has been underscored by several catastrophic tailings dam failures worldwide in recent years. These failures have mainly occurred across homogenously constructed upstream or centreline-raised tailings dams and have been triggered by various mechanisms such as static liquefaction of tailings, sliding through weak foundation materials, and overtopping. A common contributing factor in many of these incidents has been the excessive storage of water within the tailings storage facility (TSF) and the presence of saturated tailings (Rana 2023).

In response, the mining industry is increasingly shifting away from conventional tailings management methods, which typically involve low solids concentrations and upstream/centreline-raised construction methods, toward thickened and dewatered tailings management schemes combined with properly designed and constructed retaining structures. These approaches, such as thickened (high-density, paste, etc.) or filtered tailings, aim to reduce the volume of water stored in TSFs, thereby enhancing geotechnical stability and reducing environmental risks (Furnell et al. 2022).

This paper presents the design considerations and implementation of a paste thickened discharge scheme for a TSF, based on a case study in Western Australia. The proposed scheme offers a viable alternative to traditional tailings management practice at the site by addressing key limitations, minimising the risk of TSF breaches and improving overall storage performance. The findings provide valuable insights into the evolving landscape of tailings management and its implications for sustainable mining operations.

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2 Project description

2.1 Site conditions

The project site is in an arid region of Western Australia, with monthly average temperatures ranging from 20–40°C. Annual evaporation is approximately 2.9 m (nearly 11 times greater than the mean annual rainfall of 265 mm), highlighting the dominance of evaporative processes.

The site is characterised by gently undulating terrain bounded by prominent rocky ridges, with an overall surface gradient of approximately 0.5%. Subsurface conditions consist of a near-surface layer of colluvial and alluvial soils, typically up to 3 m thick, overlying a lateritic caprock. Beneath the caprock lies a sequence of residual soils and weathered rock comprising variably cemented saprolitic silts and clays, as well as siltstone and sandstone. Groundwater levels are generally deep, occurring at depths greater than 20 m below ground surface.

There are a number of site constraints that influenced the design process including site and tenement boundaries, existing infrastructure, environmentally sensitive flora and fauna (such as threatened ecological communities and malleefowl mounds), heritage features (including gnamma holes, stone artefacts and artefact scatters), designated sterilisation areas, and local drainage characteristics.

2.2 Overview of tailings disposal facilities

The existing TSFs were originally developed using a conventional unthickened tailings disposal method, with containment provided by upstream-raised perimeter embankments constructed from locally sourced clayey soils. Over time, elevated porewater pressures (PWPs) developed within the deposited tailings (due to inadequate design provisions/contingencies), resulting in a high phreatic surface that often exceeded the elevation of the embankment raises. This condition led to seepage surfaces forming along the downstream slope, posing significant geotechnical risks, including potential instability and failure due to piping and liquefaction.

Figure 1a illustrates a typical embankment section, and Figure 1b a tailings discharge observed from a small hole formed during dynamic cone penetration (DCP) testing conducted as part of the geotechnical investigation for remedial design.

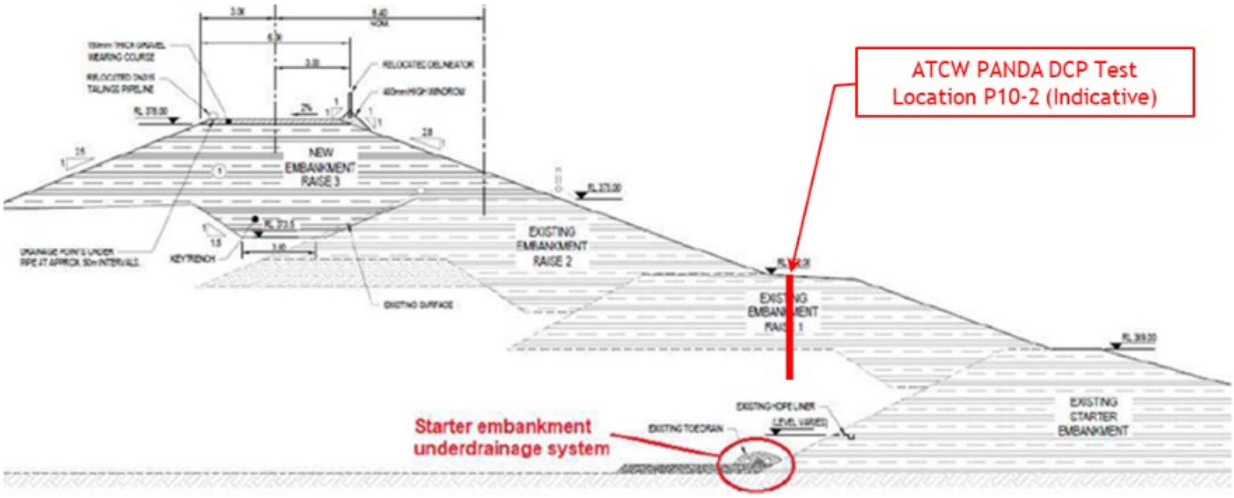
To mitigate the geotechnical instability risks, a comprehensive program of remedial works was undertaken, involving geotechnical and hydrological interventions aimed at reducing excess PWPs and improving overall TSF stability. In parallel, an options study was conducted to identify a suitable design for a new life-of-mine (LOM) TSF to support ongoing underground mining operations extracting copper, lead, zinc, and gold.

The options study considered a projected mine life of 11 years, with an estimated cumulative tailings production of approximately 8.5 Mt, averaging 0.8 Mtpa. Based on an anticipated dry density of over 1.65 t/m³, the total required storage volume is approximately 5.2 Mm³. The design process considered site-specific constraints, long-term geotechnical performance, and environmental sustainability to ensure safe and effective tailings containment throughout the operational life of the mine. The closure and rehabilitation were also one of the main considerations for the adopted disposal method.

2.3 Tailings characteristics

Ore processing at the site generates 4 distinct tailings streams:

- all-in copper tailings
- copper tailings cyclone overflow (with sand fraction removed)
- all-in zinc tailings
- zinc tailings cyclone overflow (with sand fraction removed).



(a)

(b)

Figure 1 (a) Embankment typical section; (b) Tailings discharge from dynamic cone penetration hole due to excess porewater pressure

The general characteristics of the tailings streams are summarised in Table 1, including key parameters such as solids concentration, particle size distribution (PSD), and geotechnical properties. The PSD curves for each stream are presented in Figure 2, providing insight into the relative fineness and classification of the materials.

The particle density for all tailings streams ranges between 3.1 and 3.2 t/m³, and the materials are classified as low-plasticity silt (overflow tailings) or sandy silt (all-in tailings) in accordance with Australian standard AS1726:2017 (Standards Australia 2017).

Table 1 Tailings basic characteristics

Parameter	Unit	Tailings 1 – copper all-in	Tailings 2 – copper overflow	Tailings 3 – zinc all-in	Tailings 4 – zinc overflow
Particle density	t/m^3	3.19	3.20	3.10	3.18
Liquid limit	%	21	36	22	38
Plastic limit	%	17	25	15	25
Plasticity index	%	4	12	7	12

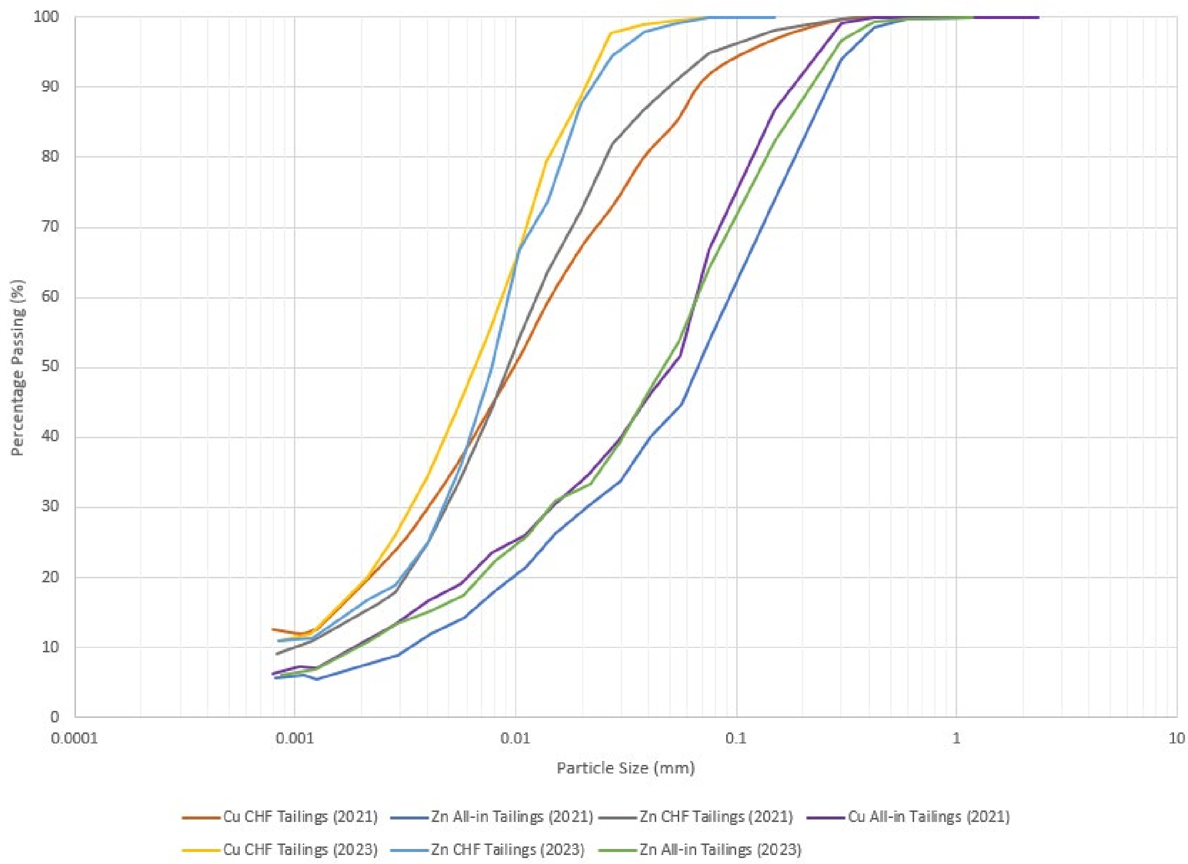


Figure 2 Tailings particle size distribution curves

3 Tailings storage facility options

3.1 General

Since the introduction of the thickened tailings disposal concept in Canada during the early 1970s by Eli Robinsky (1975), the advantages of CTD TSFs over conventional TSFs have become well established (Seddon & Williams 2010). These benefits typically include:

- reduced footprint and volume of retaining embankments
- enhanced water recovery and reduced reliance on decant ponds
- accelerated tailings de-saturation and improved geotechnical strength
- lower susceptibility to liquefaction
- potential improvements in overall cost efficiency including construction, operation and closure.

Given the specific geotechnical, environmental, and operational constraints of the site under study, a multi-location options assessment was undertaken for the proposed TSF. This paper presents the most technically viable and efficient storage option identified at each of the 3 candidate locations, culminating in a comparative evaluation. The concept models for these options are presented in Figure 3.

Figure 3a shows the conventional centreline-raised TSF. Two geometric variations of the CTD option were considered for the project: a full circular TSF and a semi-circular or sidehill TSF configuration, as illustrated in Figures 3b and 3c, respectively.

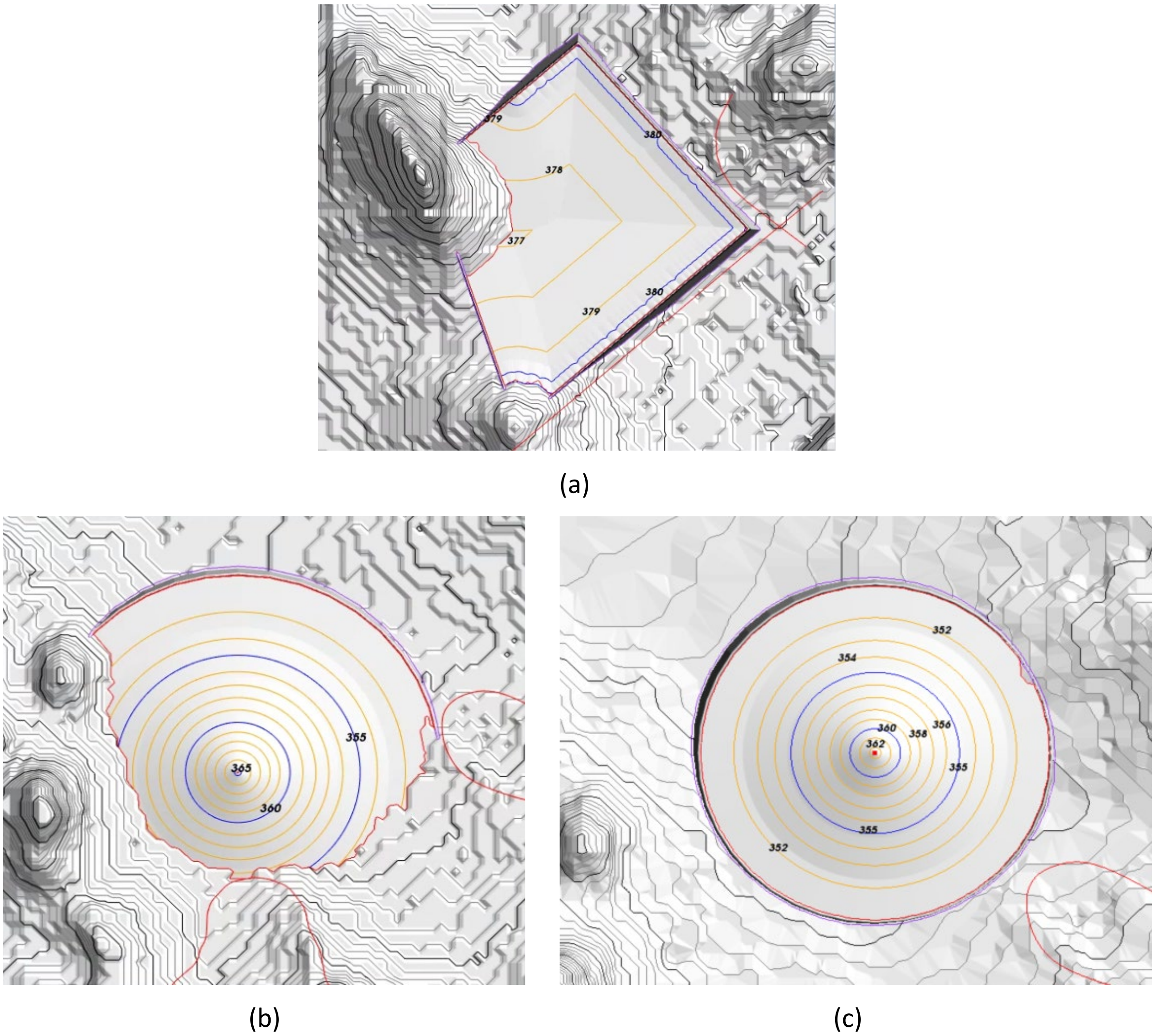


Figure 3 Concept models: (a) Option 1 – conventional tailings storage facility; (b) Option 2 – central thickened discharge tailings storage facility; (c) Option 3 – sidehill central thickened discharge

The main criteria considered in the assessment of TSF options included:

- technical, environmental and operational risks
- local topography
- distance to existing mining and processing infrastructure
- elevation variation between process plant and proposed point(s) of deposition
- failure impact (i.e. vicinity of camps/villages)
- rehabilitation requirements (i.e. estimated tailings beach area)
- ratio of tailings volume to embankment volume
- maximum embankment height
- water recovery
- client's preferred storage locations and deposition methodology (i.e. conventional or thickened).

While a detailed cost–benefit analysis is beyond the scope of this paper, the focus remains on assessing the feasibility and advantages of implementing a CTD versus conventional unthickened upstream-raised TSFs (i.e. like existing site TSF). The following sections provide a summary of the evaluated design options, highlighting their respective merits, limitations, and indicative cost estimates.

For closure and rehabilitation across all options, the entire tailings surface was assumed to be capped with a minimum 2 m thick layer of non-acid-forming (NAF) waste rock or clayey fill materials sourced from foundation stripping, followed by a 0.3 m topsoil layer applied once the selected TSF option reaches the end of its operational life. The downstream slope of tailings retaining embankments was likewise assumed to be constructed at a slope of 3H:1V and armoured with a 1 m-thick layer of NAF waste rock to provide long-term erosion resistance.

3.2 Option 1: conventional centreline-raised paddock tailings storage facility

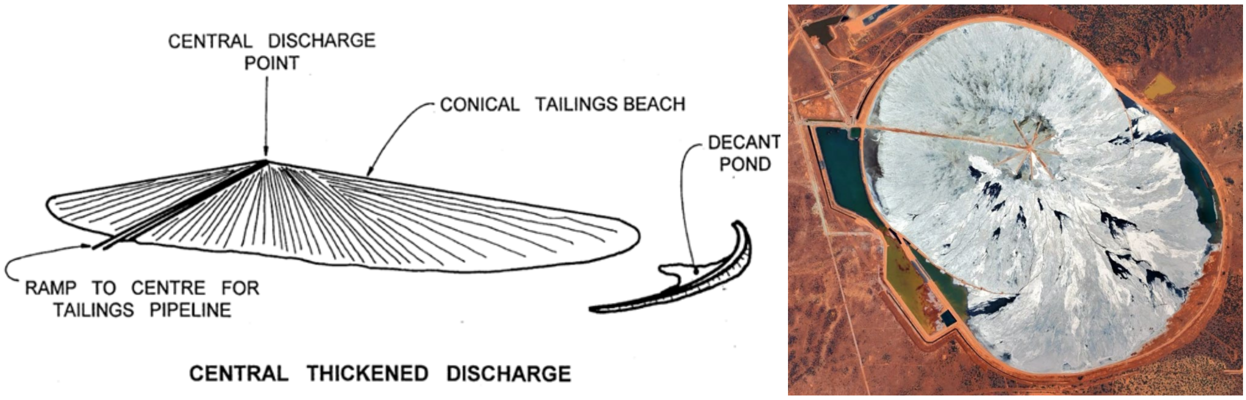
A conventional TSF was proposed adjacent to the process plant at the studied mine site. The facility adopted a paddock style configuration enclosed on 3 sides by perimeter embankments to provide containment. Due to site-specific constraints, including environmentally and culturally sensitive areas, the maximum achievable tailings beach surface area was limited to approximately 82 hectares for the most efficient location option. It should be noted that the most efficient location varies between the different tailings storage options.

Given concerns regarding the potential liquefaction susceptibility of the tailings, a centreline embankment construction method was proposed. The initial (starter) embankment was designed with a height of 10 m and a crest width of 7 m. Based on an anticipated tailings beach slope ranging from 0.5–1.5%, the final embankment height at the end of mine life was estimated to be approximately 13 m.

The ratio of tailings storage volume (5.2 Mm^3) to embankment construction volume (0.85 m^3) was approximately 6, which represented a generally acceptable storage efficiency for a conventional TSF. Tailings discharge was planned from the perimeter embankment toward the hillside, where a decant pond was expected to form, as illustrated in Figure 3a.

3.3 Option 2: central thickened discharge tailings storage facility, circular configuration

A typical CTD configuration comprises a central ramp or discharge point located within a circular perimeter embankment. Tailings are deposited from this central location, forming a conical beach that radiates outward toward the embankment. A small decant pond typically develops adjacent to the perimeter embankment, allowing for water recovery and management. Figure 4 presents a schematic of a standard CTD arrangement, alongside the layout of the Sunrise Dam TSF project in Australia, which exemplifies this approach.



(a) (b)

Figure 4 (a) Typical central thickened discharge arrangement; (b) Sunrise Dam gold mine, central thickened discharge tailings storage facility, Western Australia (Google Earth image, March 2024)

For the studied project, a CTD TSF design has been selected for implementation at a relatively open and flat site, with an approximate radius of 600 m, corresponding to a surface area of about 110 ha. Tailings are proposed to be thickened to achieve an average solids concentration of approximately 65% (by weight) and discharged via a central distribution system located on a ramp within the facility.

The thickener was strategically located on a nearby hillside adjacent to the TSF, taking advantage of the higher elevation to minimise tailings pumping costs. This also allowed for the continued use of existing infrastructure for transporting unthickened tailings to the thickening facility, thereby optimising both operational efficiency and capital investment.

The resulting tailings beach is expected to form a conical profile, with predicted slopes ranging from 3.0–1.7%, based on an empirical beach slope prediction model by Pirouz et al. (2014). Considering the final tailings beach elevation and the required freeboard, the volume of the perimeter embankment is estimated at 270,000 m^3. This results in a storage efficiency ratio of approximately 19, representing a substantial improvement over the conventional TSF option.

The conceptual design model for option 2 is presented in Figure3b.

3.4 Option 3: central thickened discharge tailings storage facility, sidehill configuration

Option 3 is similar to option 2 as it also comprises a CTD scheme, but integrated with a sidehill TSF configuration, strategically located along an existing drainage corridor. This layout leverages both the natural topography and the benefits of increased tailings solids concentration and steeper beach slopes to enhance containment efficiency.

Like option 2, tailings are discharged from a central ramp, forming a beach with predicted slopes ranging from 2.6–1.5%, based on adopting the beach slope prediction model by Pirouz et al. (2014). A relatively small operational decant pond is expected to form against the downstream perimeter embankment. The final tailings surface area is estimated at approximately 120 ha.

The embankment design follows the principles of the CTD configuration with a projected final embankment volume of 190,000 m^3. This results in a storage efficiency ratio of approximately 27, representing a notable improvement over both the conventional and fully circular CTD options.

The conceptual design model for option 3 is presented in Figure 3c.

3.5 High-level cost estimate

A high-level cost estimate was developed for the preferred LOM TSF options at each proposed location. The estimate encompasses key components including civil earthworks, procurement of major mechanical equipment (e.g. thickeners, pump stations, and pipelines), tailings dewatering infrastructure and installation costs, and closure and rehabilitation.

Table 2 presents a summary of the estimated capital expenditure (capex), operating expenditure (opex), and total cost for each option. While the conventional TSF requires more extensive civil works, the capex for the thickened tailings options is higher due to the additional costs associated with tailings thickening systems and delivery infrastructure. Similarly, the opex for thickened tailings options is elevated, primarily due to ongoing flocculant consumption and the maintenance requirements of thickening and pumping operations.

Table 2 High-level cost estimate

Options	Start-up cost (M AUD)	Capex (M AUD)	Opex (M AUD/year)	Total cost (M AUD)
Option 1: conventional tailings storage facility	12.98	58.90	0.05	59.45
Option 2 – central thickened discharge tailings storage facility	15.20	61.94	0.65	69.11
Option 3 – central thickened discharge with sidehill tailings storage facility	15.10	62.73	0.65	69.89

Although thickened tailings disposal options were found to be 16–18% more costly than the conventional TSF, option 3 (the sidehill TSF with a CTD scheme) was selected due to its superior storage efficiency and risk mitigation benefits. The decision also considered site-specific constraints, limited water availability, and the potential for water recovery through the thickening process, making it the most viable long-term solution for the project.

The site's climatic conditions, combined with the large and exposed tailings surface and high solids concentration of the deposited material, are expected to accelerate tailings de-saturation. This will enhance beach formation, promote consolidation, and support effective decant pond management following rainfall events and future closure and rehabilitation once the TSF reaches the end of its operational life.

Overall, the CTD option provides substantial closure and rehabilitation benefits by creating a more stable, water-shedding landform that reduces re-shaping, fill requirements, water management challenges, and closure timelines. It also enhances long-term geotechnical performance and environmental outcomes.

4 Design provisions

4.1 General

Figure 5 presents the final design layout for the selected tailings management scheme. The key design considerations comprised geotechnical stability, operational efficiency, environmental constraints, and long-term performance.

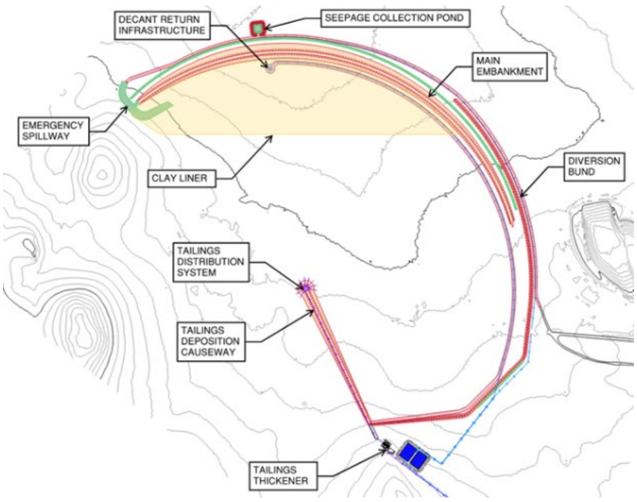


Figure 5 General tailings storage facility design layout

4.2 Tailings thickening, deposition and tailings storage facility embankment staging

Defining the appropriate thickener type is critical in thickened tailings disposal as underflow rheology and solids concentration directly influence tailings deposition behaviour and water management. To achieve target solids concentrations ranging from 59–73% across various tailings streams, 3 thickener technologies were evaluated:

- high-rate thickener (HRT)
- high-density/high-compression thickener (HDT/HCT)
- deep cone/paste thickener (PT).

Laboratory bench-scale testing confirmed that both HDT and PT technologies could achieve the required solids concentrations, with PT identified as the most suitable due to its consistent ability to produce the highest solids concentration and its cost being only 20–30% higher than HDT.

To maximise the benefits of the larger tailings surface area, tailings are discharged through a centrally located distribution system positioned over the deposition ramp. Figure 6 shows the paste thickener, tailings deposition ramp and distribution system at the end of construction.

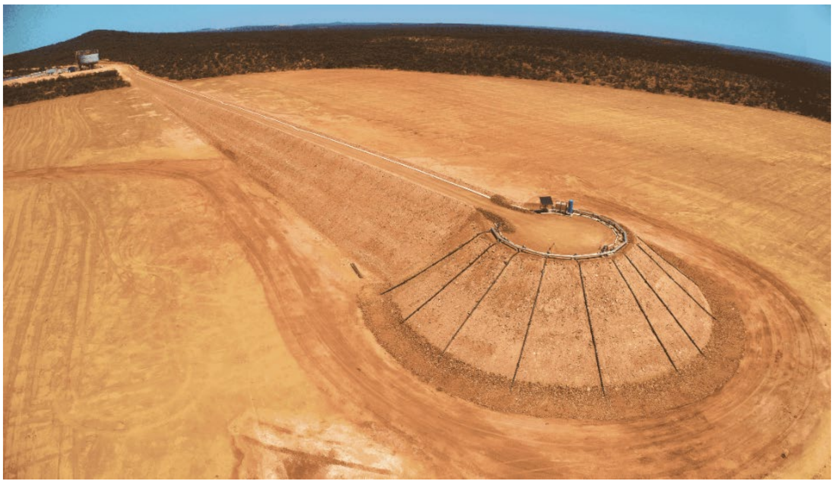


Figure 6 Paste thickener, tailings deposition ramp and distribution system

Tailings beach slope is a key factor in design of CTD TSFs as it influences capacity, embankment sizing, and tailings behaviour. It mainly depends on the tailings solids concentration/rheology and flow rates (i.e. number of achievable independent flow channels). The model proposed by Pirouz et al. (2014) was adopted to predict the beach slopes. Due to variability in tailings properties and deposition channels, 2 conservative beach profiles were adopted for design, with predicted slopes summarised in Table 3.

Table 3 Predicted tailings beach slopes (Pirouz et al. 2014)

No. of achievable flow channels	Predicted beach slope (%)			
	Upper	Middle	Lower	Run-out
1	1.8	1.4	1.0	0.5
2	4.0	3.0	2.3	0.5

A two-stage retaining embankment was proposed based on predicted beach profiles:

- Stage 1: 7 m high, provides storage for 3 years (flatter beach) or full LOM (steeper beach).
- LOM embankment: 10 m high (3 m raise), only required if the flatter beach profile develops.

The retaining embankment is homogeneous and formed by compacted low-permeability clayey fill materials.

4.3 Water management

The tailings thickening process significantly reduces water content before deposition, resulting in a low-moisture tailings stack. Given the arid climate and high evaporation rates, minimal decant water is expected for recovery from the TSF. Any supernatant water will be removed and reused via pumping.

The decant pond will shift with tailings discharge but is expected to form at the lowest area next to the embankment due to natural topography. An emergency spillway near the left abutment has been included to safely pass the probable maximum flood.

Rapid de-saturation of thickened tailings is expected to limit seepage into the foundation and groundwater. A 0.3 m clay liner with a 0.5 m sacrificial cover and an underdrain at the embankment toe was proposed to control and minimise potential seepage, particularly beneath the decant pond. The seepage intercepted by the tailings underdrain reports to a fully lined seepage collection pond at the embankment downstream toe area. Transient seepage modelling across TSF life stages confirmed that seepage will be confined to the pond area, with the majority of the tailings stack remaining unsaturated.

5 Tailings storage facility performance to date

Construction of TSF Stage 1 was completed in January 2025, with tailings deposition commencing in February. However, deposition activities remained intermittent until April 2025. At the time that this paper was prepared, the TSF had been in full operation for approximately 8 months (Figure 7). A conical tailings beach has formed around the deposition ramp, with observed beach slopes of 4.0, 2.5, 1.6 and 1.0% across the upper to lower quartiles, aligning well with those predicted for the dual-stream scenario (Table 2). This suggests the Stage 1 embankment has sufficient capacity to store the LOM tailings, although the deposition ramp will need to be raised by 4–6 m in approximately 2 years.

Routine surveys and deposition data indicate an in situ tailings dry density of ~1.70 t/m³, which is higher than the design value of 1.65 t/m³. As per the design intent, the tailings bleed has been minimal with only a small pond occasionally formed near the embankment, primarily from rainfall runoff.

Figure 7 Aerial image of the tailings storage facility (end December 2025)

6 Conclusion

This paper outlines the design of a CTD TSF supported by a high-level options study and optimised design for the preferred scheme. The CTD TSF offers key benefits including improved water recovery, reduced embankment height, steeper beach slopes, and enhanced tailings de-saturation, and is particularly suited to arid climates. These features minimise decant pond formation and seepage risks. The CTD scheme also improves embankment stability by reducing saturation and seepage. Thickened tailings and minimal decant pond volume lower the risk of failure, including overtopping. In a potential breach scenario, limited tailings mobility is expected due to high solids concentration and de-saturation of tailings, resulting in reduced downstream impact.

Although the CTD-based TSF requires a larger surface footprint than conventional storage options, it provides significant advantages for closure and rehabilitation by promoting a more stable, water-shedding final landform and reducing the need for extensive re-profiling and borrow material. This approach also improves long-term water management by minimising persistent ponding and enabling more passive, low-maintenance drainage conditions, thereby reducing long-term closure liabilities. In addition, the desaturated, denser, and more stable tailings support earlier access for cover placement and enhances overall geotechnical performance during closure. Collectively, these factors contribute to a more efficient, cost-effective and sustainable closure outcome, aligning with increasingly stringent regulatory expectations for long-term stability and environmental performance.

The performance of the TSF to date shows that the adopted CTD scheme has achieved the design intent, with a minimal pond formed and steeper-than-expected tailings beach slopes developed, potentially due to the higher tailings solids concentration and lower production rates than those adopted in the design for various tailings streams. This has increased the tailings storage capacity to the LOM requirement without the need to raise the perimeter embankment, but it would require the deposition ramp to be raised sooner than that envisaged in the design.

While further technical and operational considerations (e.g. thickener performance, and closure) remain, this case study highlights the potential of central thickened tailings disposal as a viable alternative to conventional TSFs, especially in favourable climatic and topographic settings. Though not always the most cost-effective, the approach offers advantages in risk mitigation, regulatory compliance, water efficiency, and long-term TSF management.

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