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Design and construction of a combination soil and water cover on a tailings storage facility in Tasmania

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ABSTRACT

The Main Creek Tailings Dam (MCTD), located at Grange Resources Pty Ltd's (Grange) Savage River Mine in north-west Tasmania has been in operation since 1985 and is transitioning from an operational TSF to closure. The MCTD is an upstream constructed facility with a maximum height of approximately 83 m. Tailings stored in the MCTD are potentially acid forming (PAF) and require careful management through operation and closure to minimise the risk of Acid and Metalliferous Drainage (AMD) forming in the TSF.

The site is situated on the west coast of Tasmania with rainfall significantly exceeding evaporation. Therefore, a water cover would typically be most suitable, however, due to the upstream constructed embankments a soil cover is required adjacent to embankments to meet long-term stability requirements.

During operations, three trial covers were constructed and instrumented to monitor the performance over several years. The information obtained was used to evaluate cover performance and calibrate numerical transient seepage models. The preferred cover based on the trial cover performance was a combination of clay and rock fill cover which maintained a high degree of saturation in the clay, minimising oxygen ingress to the underlying tailings, and reducing the likelihood of AMD formation.

The preferred clay and rock combination cover was assessed and optimised during the detailed design phase by undertaking 2-dimensional transient unsaturated seepage modelling in SVFlux, considering a conservative climate scenario.

Construction of the clay component of the combination cover has recently been completed. The construction process, challenges, and QA/QC is discussed in this paper.

Introduction

The Savage River open cut magnetite mine is situated on Tasmania's west coast, approximately 100 km south-west of the city of Burnie. The mine has been in operation since 1967 and is currently operated by Grange Resources Pty Ltd (Grange). The Main Creek Tailings Dam (MCTD) was the primary active tailings storage facility on the site until recently when the South Deposit Tailings Storage Facility (SDTSF) was commissioned downstream of the MCTD.

The MCTD comprises primarily of valley type storage with several embankments to impound the tailings. The main embankment utilises upstream construction methods and has a maximum height of 83 m. The tailings stored within the MCTD are potentially acid forming (PAF), therefore prevention of acid and metalliferous drainage (AMD) is a key consideration for the closure design.

The closure planning for the MCTD has evolved through the life of the facility involving concept closure planning, construction and monitoring of trial covers, detailed design, and construction which is currently underway.

The closure cover comprises a combination of soil and water cover to minimise oxygen ingress to tailings. Rainfall at the site significantly exceeds evaporation which maintains a water cover in perpetuity. A soil cover is provided adjacent to embankments to meet long-term stability requirements.

This paper presents the various components of planning undertaken to transition the MCTD from operations into closure.

MCTD History

MCTD is a zoned earth and rock fill embankment constructed (using conventional downstream construction methods) by previous mine operators between 1982 and 1985 using waste clay and rock fill materials from mine development operations. The main embankment was constructed to RL310 m, giving in a maximum height of approximately 60 m.

The main embankment crest was raised 5 m to RL315 m in 1994, as part of the closure works for mine abandonment by the previous operators.

The storage was then reopened, with the embankment raised by upstream construction methods to RL319 m in 2002, RL324.5 m in 2004, RL328.5 m in 2006, RL 333 m in 2012 and RL 336 in 2014/15. The closure raise to RL338 m was completed in 2019, which resulted in a total of 23 m height using upstream construction.

Throughout the life of the facility a number of embankments have been constructed to maintain impoundment, these embankments include the NW Pond Embankment, Spillway Embankment and the Saddle Dam. The Old Tailings Dam (OTD) is situated to the north of the MCTD, the Emergency Tailings Dam (ETD) is situated to the west of the MCTD. The general arrangement of the MCTD is presented in Figure 1.

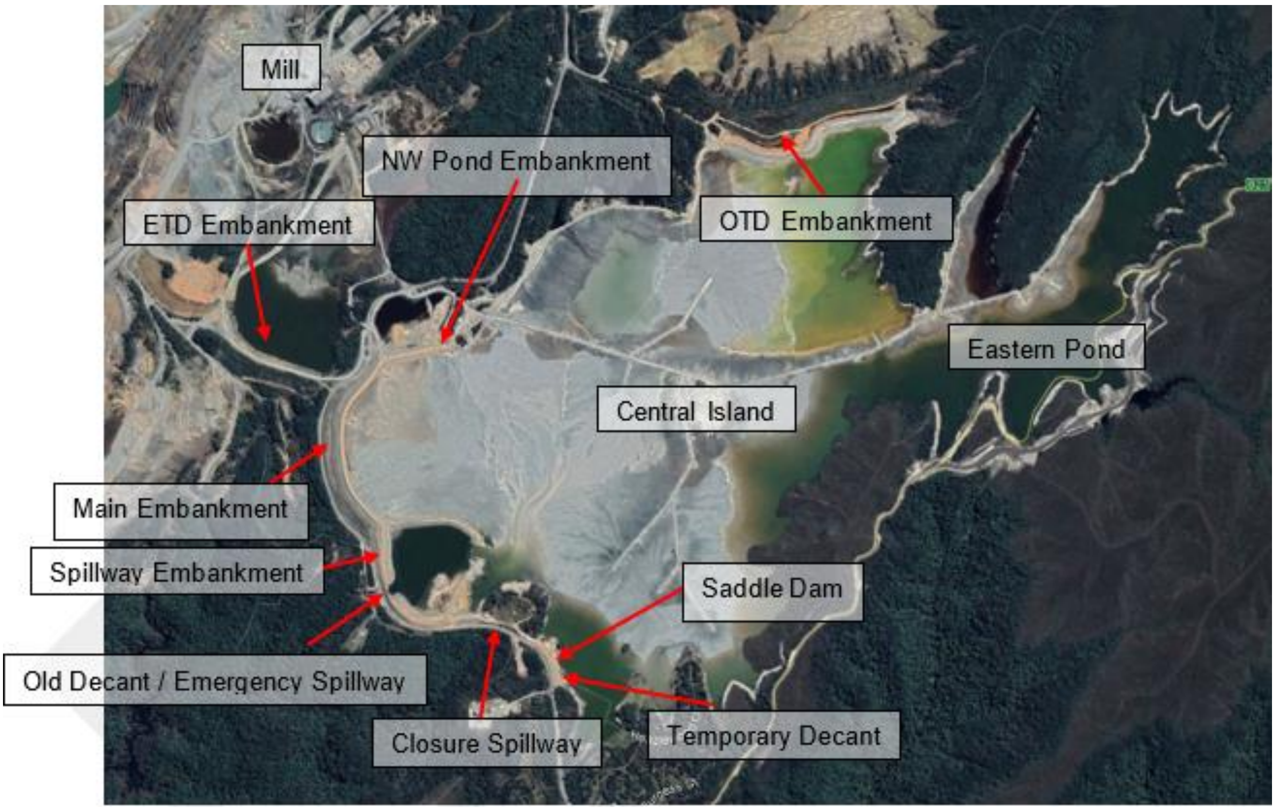

Figure 1 MCTD general arrangement.

Closure concept

The climate on the west coast of Tasmania is well known for high rainfall and low evaporation with an approximate 2:1 ratio, therefore the intent of the closure cover design is to use the wet climatic conditions to advantage to limit oxygen ingress to the stored tailings at closure to reduce the likelihood of the formation of AMD. The net positive rainfall environment enables a full water cover, however, a full water cover would result in water directly against upstream constructed embankments which are not designed to be water retaining.

Both soil and water cover types which limit oxygen ingress suit the climatic conditions when plotted on the GARD cover guide as shown in Figure 2. The closure concept involved a combination cover system comprising a ‘dry’ or ‘soil type’ cover 150 m wide adjacent to the upstream constructed embankments with a water cover of 1 m minimum depth elsewhere.

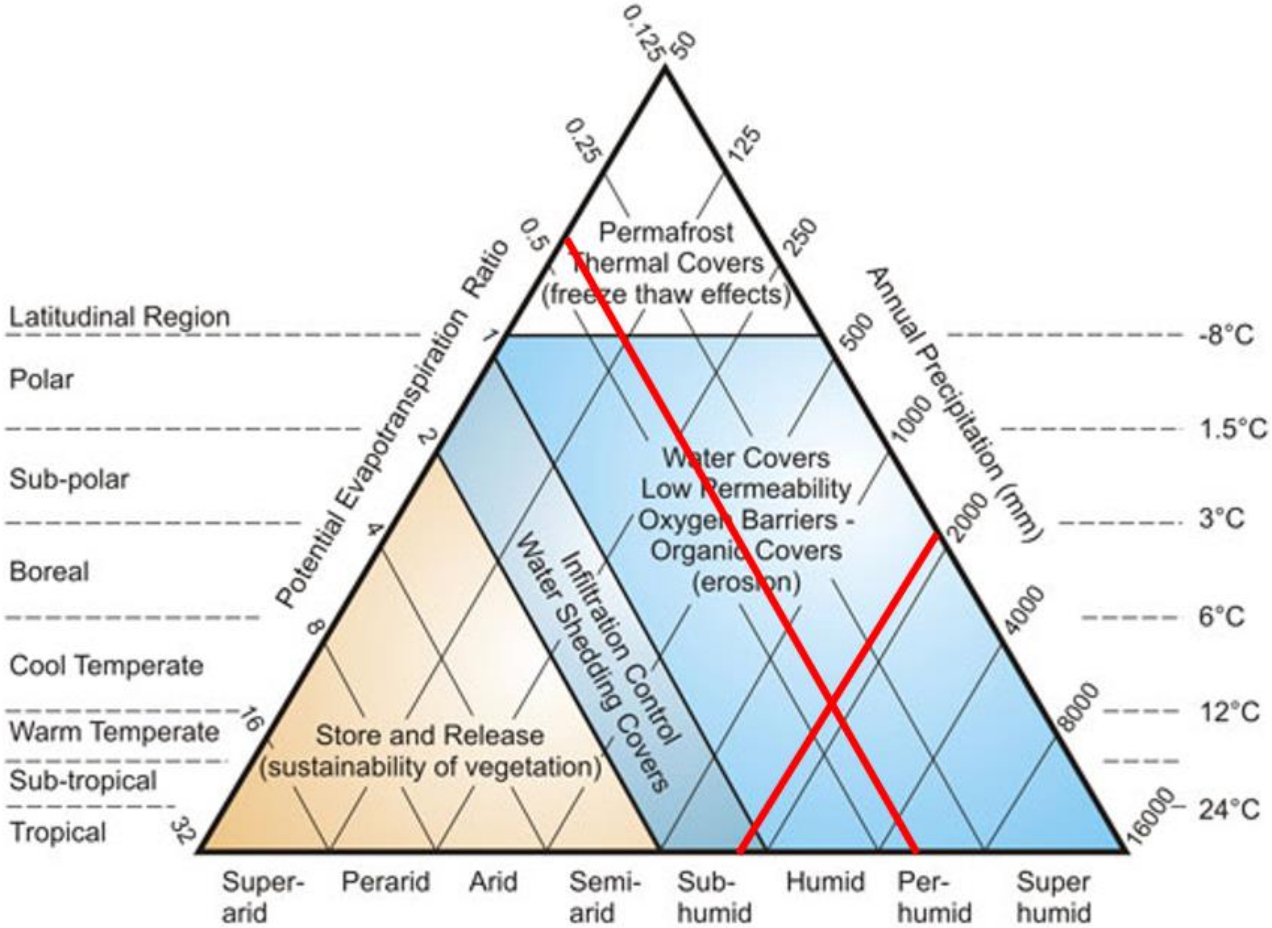

Figure 2 Climate and cover types (INAP, 2014).

During the various stages of raising MCTD the tailings management plan and conceptual closure plan were updated based on the expected life-of-mine. Premature closure plans were also developed at multiple raise heights such that MCTD could be closed successfully should an unplanned stoppage or closure occur.

Trial covers

The long-term performance of the closure cover is critical, therefore trials with field performance monitoring were undertaken comprising a section of water covered tailings and three trial soil covers approximately 40 m wide by 60 m long. The following trials were constructed on the NW Pond area:

1. Homogenous Clay Cover 2 m thick.
2. Geosynthetic Clay Liner (GCL) underlying a rock fill protection layer 1 m thick.
3. Clay 1 m thick underlying a 1 m thick rock fill protection layer.

The intent of all three covers was to maintain a high level (>80 per cent) saturation within the cover and therefore saturation was the key parameter being monitored. Instrumentation was installed in the underlying tailings and covers to monitor oxygen, soil matric suction, and volumetric water content. Standpipes with vibrating wire piezometers and a weather station were also installed.

Test pits were excavated into the trial covers and material samples were collected for laboratory testing including Soil Water Characteristic Curve and Permeability.

The collected data from all three covers was used to calibrate finite element models of the cover in the software package SVFlux. The performance from all three covers was acceptable, with >80 per cent saturation being met at all times, however, the close proximity to a pond (~60 m away) may have impacted saturation levels.

Other cover performance elements such as erosion due to rainfall run-off and wave erosion at the pond edge were assessed visually and found to be minimal on all trial covers. Erosion performance was also assessed based on the performance of the upstream batters of the MCTD embankments.

Cover design

Based on the results of the trial cover performance and model calibration, the larger MCTD main embankment was modelled at closure with SVFlux software to determine the optimal cover design for the MCTD. The climate model considered average conditions and also the driest 365-day period on record at Savage River to assess the extreme case where cover recharge is low resulting in worse case cover saturation. Four covers were modelled in 2D sections as follows:

1. 300 m wide – 1 m thick Clay Cover.
2. 150 m wide – 2 m thick Clay Cover.
3. 150 m wide – 1 m Clay underlying a 1 m Rock Cover.
4. 150 m wide – 1.7 m Clay underlying a 0.3 m Rock Cover.

The target saturation for the 1 m and 2 m thick covers was determined based on the chart shown in Figure 3 (Miller, 1998). A 1 m thick cover required a minimum saturation of 80 per cent and a 2 m thick cover required a minimum saturation of 70 per cent, which provides a reduction in Acid Sulphate Generation Rate (ASGR) of more than 95 per cent by limiting oxygen ingress to the underlying tailings.

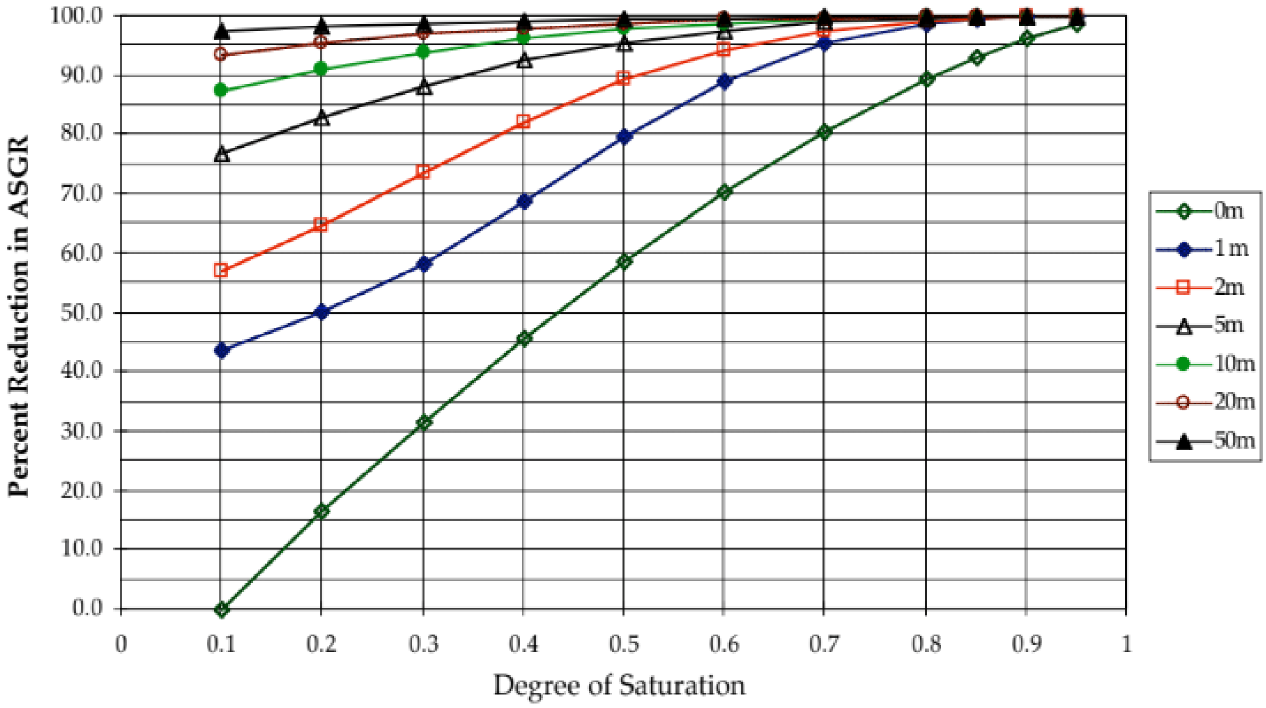

Figure 3 *Cover saturation versus reduction in ASGR (Miller, 1998).*

A typical cross-section from the 2D model is presented in Figure 4 which shows that the modelling takes into account seepage vertically and horizontally throughout the tailings and MCTD Embankment.

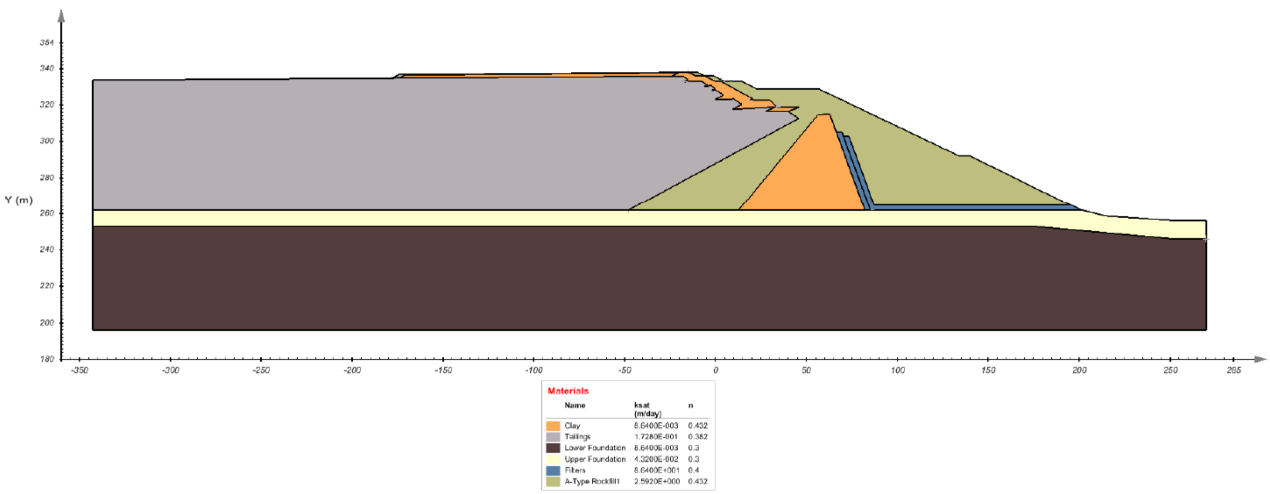

Figure 4 *Cover model typical cross-section.*

Climate data set

The climate data is a key input to the SVFlux model as rainfall infiltration and evaporation have a significant impact on the cover saturation.

Daily rainfall data has been recorded by the Bureau of Meteorology (BOM) from February 1966 to 2018 at the Savage River Mine. The daily data was reviewed to determine the driest 365-day period on record. The driest period recorded was 25/08/1966 to 25/08/1967, with a total rainfall of 1242.5 mm. The average annual rainfall is 1952.7 mm.

Rainfall data from the driest 365-day period is presented in Figure 5. The time period starts from August 25, 1966.

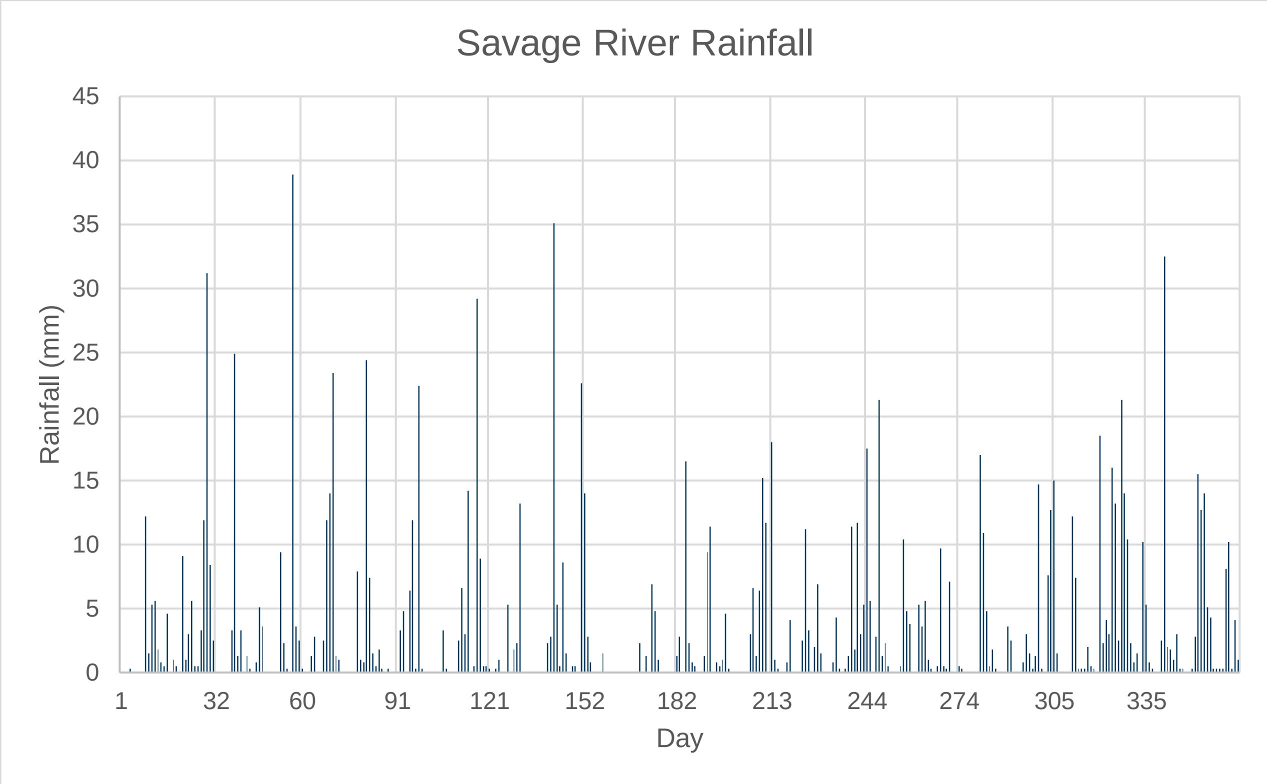

Figure 5 ***Savage River rainfall.***

Temperature data is also recorded at the Savage River Mine by BOM, data for the driest 365-day period has been collated and is presented in Figure 6. Temperature data is required to calculate Actual Evaporation in SVFlux using the Modified Wilson Empirical Equation in SVFlux.

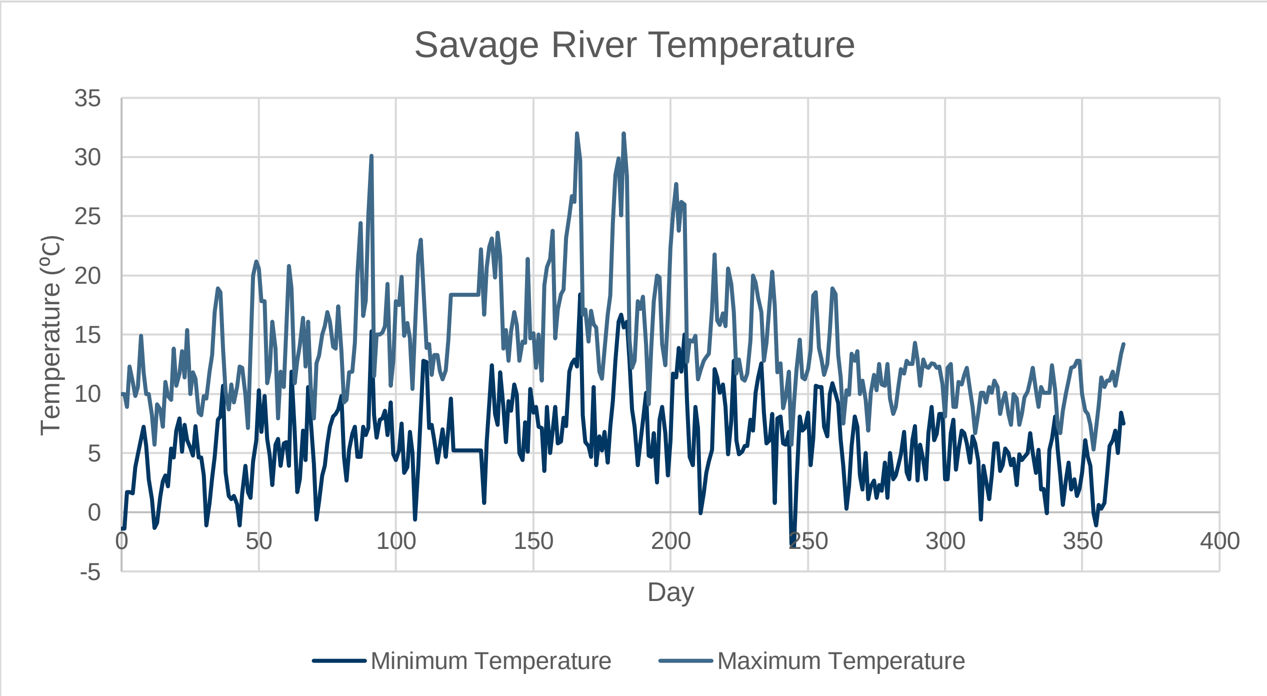

Figure 6 ***Savage River temperature.***

Potential Evaporation is used to calculate actual evaporation in SVFlux using the Modified Wilson Empirical Equation. Average Daily Evaporation for each month is recorded by the BOM. The data is presented in Figure 7. The data is used to calculate the actual evaporation in SVFlux.

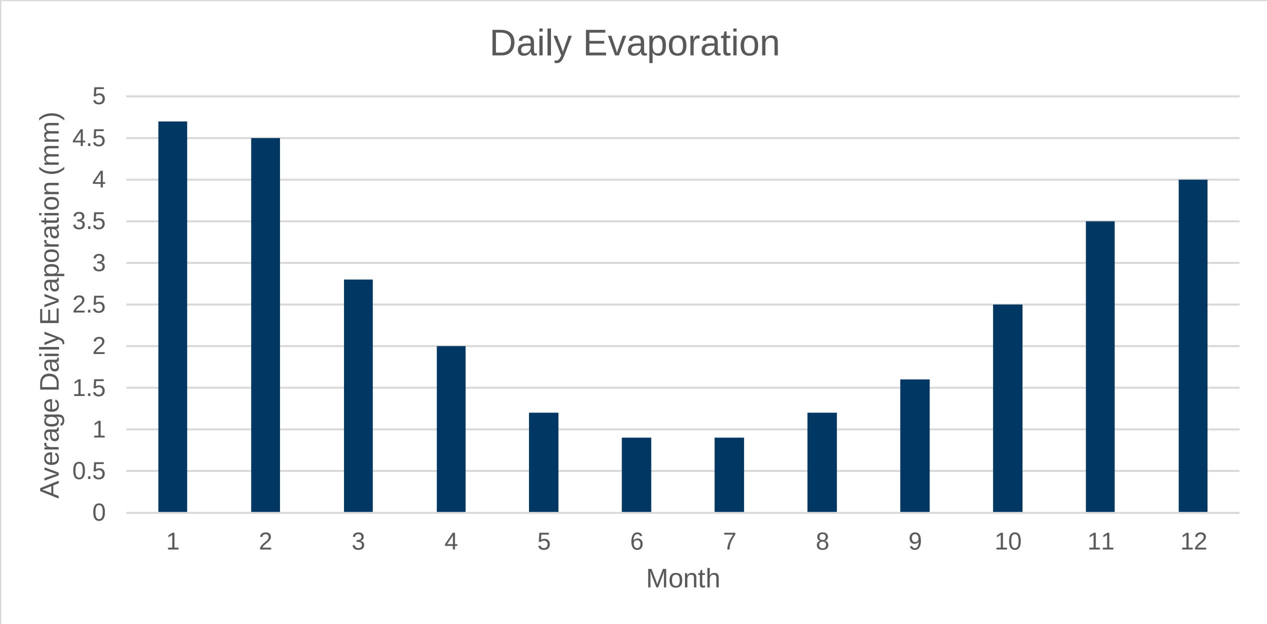

Figure 7 *Savage River daily evaporation.*

Material parameters and calibration

The unsaturated material parameters (SWCC and unsaturated permeability curves) were initially adopted from the SVFlux modelling of the NW Pond Cover Modelling. The material parameters for the foundation and filter materials have been adopted from previous design phases, saturated parameters have been assumed only. The permeabilities are presented in Table 1.

Table 1 *Material permeability.*

Material	Permeability, K (m/s)	Anisotropic Ratio
Lower Foundation	1×10^{-7} m/s	1
Upper Foundation	5×10^{-7} m/s	1
Filters	1×10^{-3} m/s	1
Tailings	2×10^{-6} m/s	10
Embankment rock fill	3×10^{-5} m/s	1
Embankment clay	1×10^{-7} m/s	1
Cover rock fill	3×10^{-5} m/s	1
Cover clay	1×10^{-7} m/s	1

An initial model set-up with the material parameters indicated a low phreatic surface through the embankment. The phreatic surface was lower than the phreatic surface indicated by the installed vibrating wire piezometers. To model a phreatic surface that represented actual conditions the permeability of both the rock fill and tailings were adjusted. The adjusted permeabilities are presented in Table 2.

Table 2 *Calibrated Parameters.*

Material	Permeability (m/s)	Anisotropic Ratio
Tailings	2×10^{-6} m/s	10
Rock fill	3×10^{-5} m/s	1

The current pond is approximately 300 m from the embankment, with a level of RL331.2 m. At closure, the pond will be 150 m from the main embankment, with a level of RL336 m. Therefore the final phreatic surface is expected to be higher than currently indicated by the piezometers. The calibration considered a phreatic level slightly above the current phreatic surface.

The tailings are expected to have a higher permeability horizontally and as such an anisotropic ratio Kh:Kz of 10 has been applied. The permeability of the tailings is significantly higher than that adopted for the NW Pond assessment. The tailings at the main embankment are typically coarse due to being spigotted and have a higher permeability due to the increased sand content. Previous falling head tests undertaken in the tailings beach near the embankment crest showed permeability ranging from 2×10^{-6} to 1×10^{-5} m/s.

Results

The 300 m wide cover enabled the pond to remain further from the main embankment, lowering the phreatic surface within the tailings and embankment and improving stability outcomes, however, the minimum target saturation levels of 80 per cent were not achieved for this case.

A series of 150 m wide covers with a total thickness of 2 m were also modelled as the thicker cover requires a slightly lower saturation level of 70 per cent to achieve a similar reduction in oxygen transfer rate (Miller, 1998). The combination clay and rock cover's both met the target saturation levels throughout the 365 day model period. The final design was selected as the 1 m Clay and 1 m Rock cover due to limited clay availability on-site. The rock cover allows for collecting recharge and limiting evaporation to keep the underlying clay cover at a satisfactory saturation level and provides erosion protection and a growth medium. A summary of the results is presented in Table 3.

Table 3 Cover modelling results.

Cover	Clay saturation			
	Target	Minimum	Maximum	Average
1 m Clay Cover	80%	65.0%	74.3%	69.4%
2 m Clay Cover	70%	69.8%	75.8%	72.9%
1 m Clay + 1 m Rock	70%	71.3%	74.0%	73.0%
1.7 m Clay + 0.3 m Rock Cover	70%	70.6%	76.3%	73.3%

The stability of the MCTD embankments and the selected closure cover was assessed and achieved acceptable factors of safety under ANCOLD guidelines (ANCOLD, 2019).

Construction

Construction of the closure cover commenced in December 2020 with the placement of the clay layer. The construction methodology was unproven to this point. Before construction, it was not certain how placing clay over the beached tailings would perform due to the variable nature of the tailings beach and variation of bearing capacity. However, prior experience on-site with constructing access roads over the tailings had shown it was feasible. A safe work method was developed and to limit the risk of bearing failure and the potential to bog machines in the tailings. The method comprised a 1 m thick clay layer which was placed and compacted in a single lift. The design and specification called for multiple clay layers of 300 mm thickness. Placing a single 1 m thick layer is unconventional, therefore field and laboratory testing was undertaken at various depths to ensure the clay cover particle size distribution, density, and permeability specifications were achieved.

In summary, the lab testing showed that minor segregation occurred with the material being marginally coarser at the bottom of the layer, however, this achieved the required permeability. The placement methodology was effective throughout the whole clay placement with only minor bearing failures observed in extremely weak or wet areas of the tailings beach. Grange plan to complete the overlying rock layer once materials become available from the mine. Photos of the construction are presented in Figure 8 and Figure 9. Instrumentation will be installed similar to that used in the trial cover systems to monitor closure performance, particularly the soil cover and tailings saturation levels in addition to reviewing for any increase in pore pressures in the embankment when the pond is allowed to rise to meet the soil cover.

Figure 8 Clay cover placement.

Figure 9 Clay cover placement.

Tailings management

In the years preceding closure, tailings management required careful consideration to ensure that settled density was maximised, while storage capacity was fully utilised and the closure objectives could be met. The key closure objectives to be considered through tailings management were ensuring the large tailings beach maintained during operations was maintained at least 1 m below the future closure pond level to ensure that a minimum 1 m water cover would be established at closure. Tailings deposition modelling was utilised to plan deposition through to closure, allowing Grange to forecast available storage volumes and inform appropriate discharge locations to maximise the storage potential of MCTD whilst transitioning to a new facility.

Associated infrastructure

Before closure, several key pieces of infrastructure associated with the MCTD were required to be designed and constructed before transitioning to closure. Two of the key infrastructure items are detailed in the following subsections.

Closure spillway

The MCTD is designed to meet the Australian National Committee on Large Dams (ANCOLD) Guidelines on Tailings Dams. The guidelines recommend that for closure all TSFs can safely pass a Probable Maximum Flood (PMF) event. A new spillway was designed comprising a low flow channel in the centre of a larger 60 m wide open channel spillway. The mine access road crosses the spillway, therefore the low flow channel was included to pass regular flows up to a 1:140 Annual Recurrence Interval event through a single concrete culvert below the mine access road. The larger 60 m open channel was designed to pass a peak flow rate of 100.32 m^3/s in the PMF event. The spillway features a concrete nib wall at the inlet to maintain a consistent pond level. The spillway is lined with rip-rap with a minimum D50 of 100 mm, with shotcrete applied to the spillway excavation prior to rip-rap placement to prevent erosion of the *in situ* material.

OTD seepage collection bund and pipeline

The Old Tailings Dam (OTD) is a legacy TSF located upstream of the MCTD. The OTD is the major source of AMD due to its large surface area of exposed PAF tailings. Seepage from the toe of OTD embankment flowed into the MCTD, which was neutralised by the alkalinity in Grange's tailings slurry during MCTD operations. However, for closure the continual seepage of AMD into the MCTD pond would have turned the pond acidic, leading to AMD formation in MCTD also.

To capture the AMD seepage, the OTD seepage collection bund and transfer pipeline was designed and constructed. The scheme comprised the following:

A 6 m high earth fill embankment collection bund at the base of the OTD to collect seeps from the OTD at the interface with the OTD embankment and MCTD Tailings.

Surface water diversion drains on the OTD embankment to reduce clean water inflows into the collection bund.

An intake structure at the OTD seepage collection pond to allow precipitation to settle before entering the transfer pipeline.

A gravity polyethylene DN280 mm PN10 transfer pipeline from the OTD intake to the SDTSF Storage with allowance for pressure pigging of the pipeline to enable precipitation cleanout if required.

The items above were constructed in stages from 2014 to 2018 and the scheme is now transferring AMD seepage from the OTD to the SDTSF where it is neutralised through the higher pH active tailings deposition.

Conclusion

Planning for the closure of MCTD began in approximately 2010, approximately ten years before commencing construction of the closure cover. The planning process undertaken allowed key infrastructure needs to be designed and constructed in a staged manner in the lead-up to the cessation of tailings deposition and transition to closure.

As the knowledge base for closure has continually improved over time, the closure design was also progressively refined. Maintaining premature concept closure plans at various stages ensured the MCTD was operated in a state which could successfully enter a care and maintenance phase or early closure if required. The staged closure planning development approach and closure cover construction have thus far proved to be successful in that the cover has been able to be constructed in accordance with the design specification. At the time of writing, the post closure performance monitoring was being developed to validate the closure design.

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