A study on the possibilities, constraints, and motivation for transitioning a conventionally designed TSF into a full scale hydraulically dewatered stack (HDS) facility for fine residue disposal in South Africa.

N.W. Nxumalo, Jones & Wagener (Pty) Ltd, South Africa

P. Newman, Anglo American, UK

A. López, Anglo American, Chile

Abstract

Tailings dewatering, and optimized water recovery are desirable objectives for owners and operators of tailings storage facilities (TSFs) in the mining industry. A large international mining firm has undertaken several studies and field scale trials on the feasibility of hydraulically dewatered stacking (HDS) to improve water recovery from fine residue facilities. A concept study has been undertaken to transition a TSF designed to operate with conventional deposition and water recovery methods (ring feed pipe, spigots, penstock intake and outfall system) into an HDS facility. This paper discusses the possibilities, constraints and risks identified for full scale implementation of the HDS methodology on a TSF. Findings on the preliminary preferred configurations from a high-level water balance and conceptual 3D numerical modelling are also presented.

Introduction

Conventional methods of recovering water from a TSF comprise, (i) a gravity penstock intake and outfall pipe, (ii) a pumped decant system, and (iii) a network of basal drains. Gravity penstock and pumped decant systems drain supernatant water only. Basal drains collect water which infiltrates through the settled tailings and reports to the bottom of the facility. This water must infiltrate through the very fine and cohesive silty material through which water flow is impeded due to very low permeabilities. The process of draining water from the settled tailings occurs over extended durations and results in large volumes of water which are not recovered from the settled tailings. This water is undesirable, as it reduces the strength of the settled tailings material increasing risks to mining operations, the environment, and surrounding communities.

The HDS deposition methodology enables recovery of both supernatant and interstitial water. Successful implementation of HDS is a significant deviation to current water recovery strategies and will substantially increase water reuse quantities in mining operations.

CPR and HDS process and definition

Anglo American (AA) has successfully implemented Coarse Particle Recovery (CPR) at several of its assets. The technology generates a coarse reject material and creates a bulk concentrate for further processing (Filmer and Alexander, 2016; Filmer and Alexander, 2017, Filmer et. al., 2020). CPR uses a fluidised bed to enable valuable minerals, with as little as 1% mineral surface exposure, to be separated from gangue, a commercially valueless ore (Arburo et. al, 2022). This process increases ore recovery rates, improves plant energy efficiency rates and reduces water consumption by recovering minerals at a particle size 2-3 times coarser than conventional flotation processes (Arburo et. al, 2022). In the CPR process, underflow from the cyclones within the plant is recycled and reprocessed increasing product recovery while the overflow, a coarse graded reject sand referred to as CPR sand is pumped directly to the TSF.

The CPR sands are characterised by low fines content (less than 5% particles <75μm) (Newman et. al, 2022; Musso, et. al, 2023) resulting in relatively high permeability (Bustamante et. al., 2024). The CPR sands are co-disposed with conventional tailings to form preferential and connected three-dimensional (3D) drainage paths within the tailings. When engineered correctly, such a configuration has the potential to change dewatering of freshly deposited tailings slurry (abstracting pool water via infiltration into pre-configured berms vs, penstock recovery), increases consolidation and improves recovery of water from the insitu settled tailings, thereby leaving a waste residue that is desaturated.

HDS Trials and studies by Anglo American

Previous studies were undertaken by AA and WSP-Golder in Chile and by AA and SRK Consulting in South Africa. Both studies focused on (i) material characterisation through geotechnical testing programs in the laboratory, (ii) simulation of expected drainage behaviour in the laboratory and (iii) implementation of field scale trials to characterise drainage behaviour and verify laboratory test results.

El Soldado trial, Chile

Newman et al. (2022) highlighted that the El Soldado trial formed part of the laboratory test work carried out as part of the proof-of-concept study. The proof-of concept study was premised on the hypothesis that "*... placing interbedded layers of tailings with free draining sands (being a by-product produced by coarse particle recovery techniques from within the process flow sheet) will accelerate consolidation and increase the reduction in degree of saturation of the tailings mass. The purpose of this being to increase the tailings resistance to liquefaction*". The El Soldado study therefore considered two main objectives (i) laboratory characterisation of tailings and CPR sand samples and (ii) the design and implementation of a field scale trial.

Mogalakwena trial, South Africa

A concept design for the BW2 TSF was undertaken by AA and Jones & Wagener (Pty) Ltd (J&W) in 2022, and a key finding of the study was that the options for implementing HDS on the BW2 TSF was dependant on the capabilities of the deposition equipment. This resulted in AA commissioning the Blinkwater 1 TSF trial (Murray et. al, 2023) and the primary objective was to assess the effectiveness of the sand placement unit. The focus of the field-scale trial was thus on advancing the knowledge base relating to operating a Self-Propelled Cyclone Unit (SPCU) and its performance in relation to (i) sand thickness required to form a stable working platform (ii) ease of preforming controlled deposition to form drainage channels, (iii) formation of blanket drains, and (iv) the potential erosion of CPR sand.

Contributions of present paper

The objectives and learnings of previous studies do not extend to the design of a full-scale facility for the HDS deposition method. The scope did not include assessment of appropriate spacing for CPR sand berms and the constraints which must be considered when the HDS method is implemented. This paper seeks to expand the knowledge base gained from previous studies and field scale trials. The focus and objectives include (i) documenting risks associated with design and full-scale implementation of the HDS methodology, (ii) identifying constraints associated with full-scale implementation of the HDS methodology, and (iii) evaluating water recovery performance of the platinum CPR sand berm configurations under high inflow rates.

Transitioning a conventional TSF design to HDS deposition

AA commissioned J&W to undertake the feasibility and detailed engineering for BW2 at the Mogalakwena Mine in Limpopo, South Africa. BW2 has a consequence classification of Extreme (ICMM, 2020) and is a waste rock impounded facility with a peak tailings throughput of 14.2 Mtpa, an annual rate of rise of 6.0 m and a total capacity of 114 Mt. The conventional design, referred to as the “base case”, comprises an embankment constructed in the downstream direction to a maximum height of 60 m, a Class C barrier, with an above and below liner drainage system as well as temporary and permanent penstocks. The penstock systems (temporary and permanent) are designed to accommodate the planned commissioning of the TSF in two phases.

Prior to commencement of the detailed engineering for the base case, AA commissioned the study to investigate transitioning BW2 from the conventional base case design into an HDS facility.

Three-dimensional numerical model

The influence of CPR sand berms on dewatering of tailings and the flow regime is omni-directional in nature and occurs in the 3D space. To understand the omni-directional flow properties and quantity of water reporting into the CPR sand columns, several 3D flow and seepage models were constructed in FEFLOW software.

FEFLOW uses finite element analysis to solve the groundwater flow equation for saturated and unsaturated conditions which are critical for accurate modelling of the movement of water through tailings. All materials in the present study were modelled as saturated. Furthermore, consolidation of the tailings during deposition and cycling were not modelled. As a result, variability in saturation levels and the effect on permeabilities are not built into the model resulting in conservative estimates of water reporting to the CPR sand berms. Permeabilities of the tailings slurry and CPR sand berm/outer embankment were specified as 0.0035 m/d and 1.7 m/d respectively. The vertical permeability to horizontal permeability ratio of all materials present was specified as 0.1.

The FEFLOW models were used to evaluate ideal spacing (40 m, 60 m, 80 m, and 100 m) for the proposed CPR sand berm columns, evaluate inclusion of horizontal sand layers connected to the vertical sand columns and to assess the impact of the hydraulic gradient on abstraction capacity of the drains. The models considered cyclic deposition through a series of paddocks.

This enabled simulation of the omni-directional flow regime and hydraulic interaction between the tailings and the CPR sand columns, both in the short term (i.e., during deposition), and in the long term (i.e., during consolidation) phases. Figure 1 illustrates a simplified TSF model with paddocks spaced at 40 m, 60 m, 80 m and 100 m.

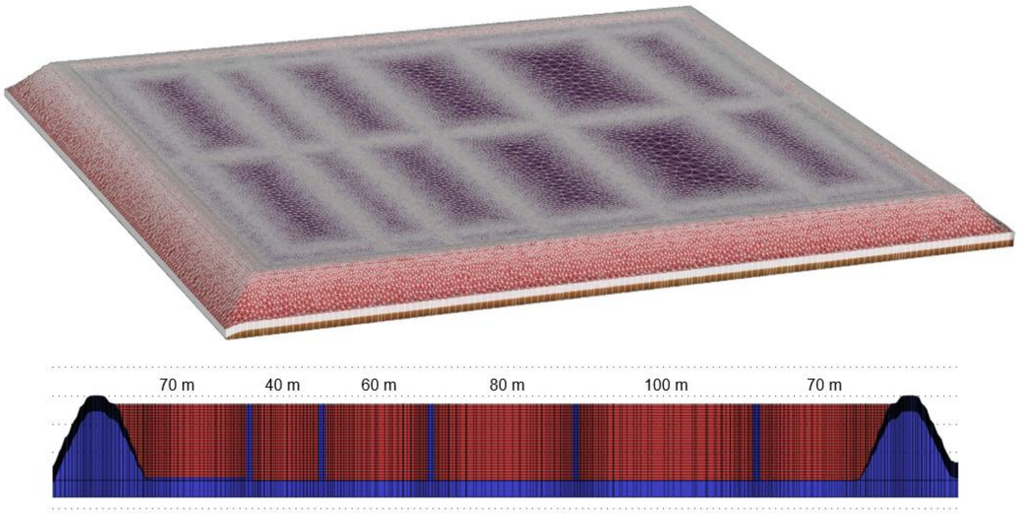


Figure 1: Simplified FEFLOW model with paddock spacings of 40m to 100m.

Cases evaluated included CPR sand configuration for (i) tailings only (base case), (ii) tailings with vertical sand drains only and (iii) tailings with vertical sand drains and horizontal sand layers. Figure 2 presents schematic cross sections of vertical sand columns only and columns with horizontal sand layers.

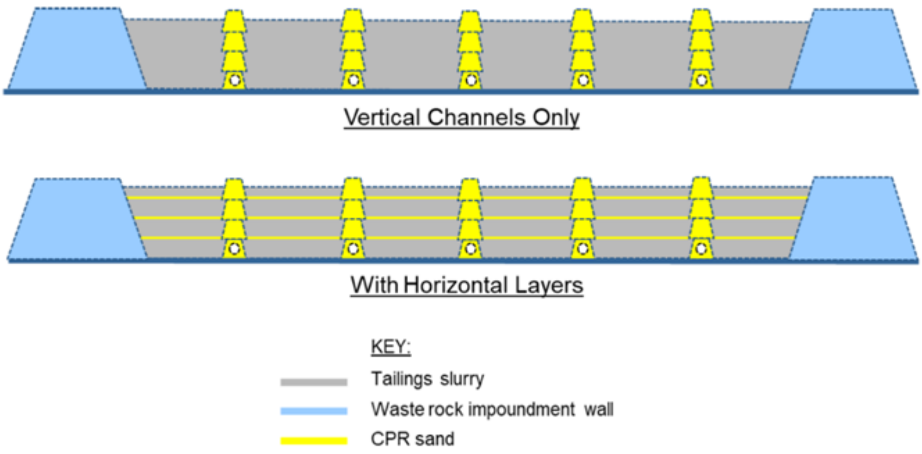


Figure 2: CPR sand configuration with horizontal and without horizontal layers.

Typical results are presented in Figure 3 and demonstrate the influence of the of horizontal sand layers and CPR sand column spacing. The phreatic surface for Case 1 is located on the surface indicating a pool and for Case 2 and Case 3, the phreatic surface varied depending on the sand column spacing.

Inclusion of horizontal sand drainage layers is ideal and improves recovery of water. The phreatic surface in Case 3 is lower compared to that of Case 1 and Case 2 as more water is intercepted and conveyed out of the facility. However, such a geometry increases the required volume of CPR sand, which is limited, and was regarded as a prohibitive constrain to implementing the horizontal drains.

The paddocks with 40 m spacing had lower phreatic surfaces and it was concluded that depending on availability of CPR sand berm spacing ranging between 40 m to 60 m is ideal.

Furthermore, abstraction of pool water via CPR sand berms depends on the hydraulic gradient and it was found that in the early stages of deposition the hydraulic gradient is not adequate for recovery of pool water and results in low outflow rate of the system. This results in larger supernatant water pools with risk of overflow between paddocks. Inclusion of a penstock intake and outfall pipe must therefore be implemented to provide decant capacity in the initial stages of an HDS facility and for stormwater management.

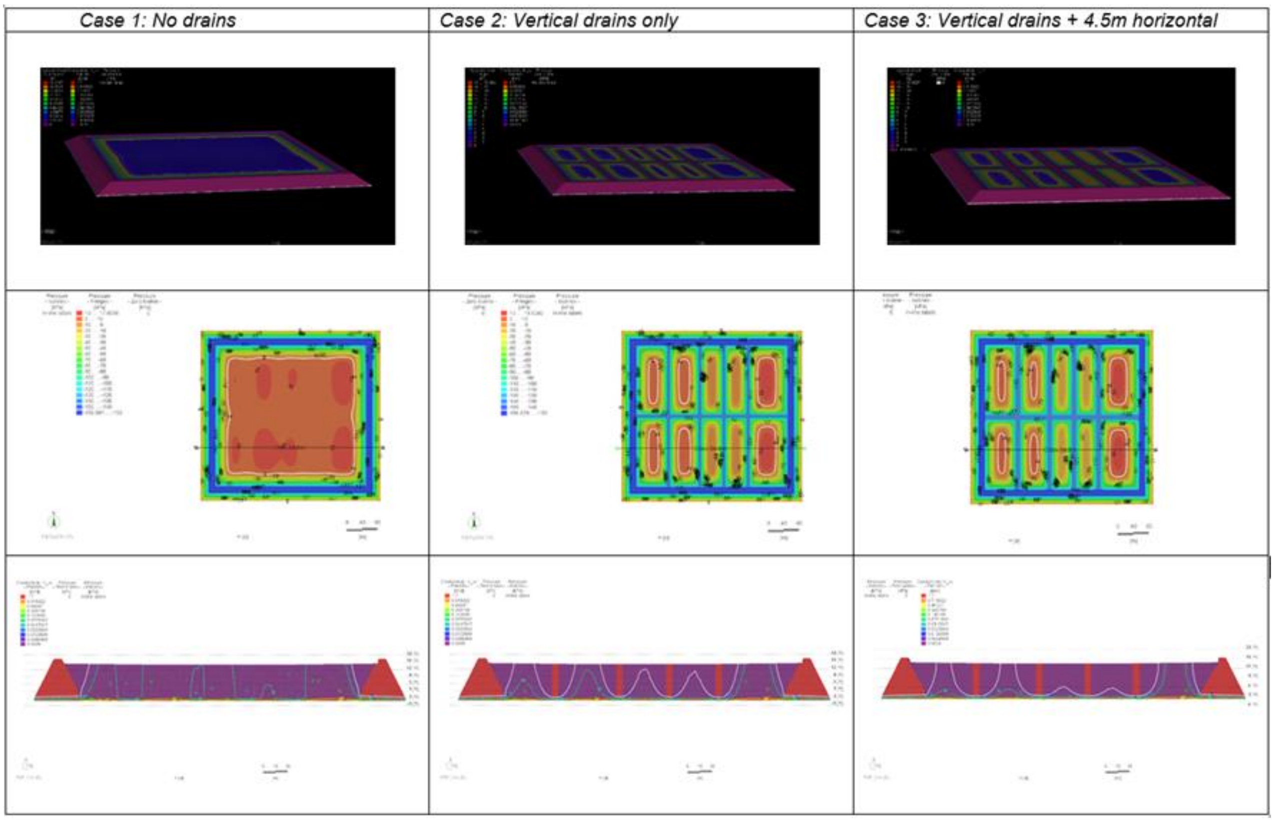


Figure 3: FEFLOW geometry and model results

High level water balance

Several options were identified for the CPR sand configuration and with iterative workshops and ratings, two options were selected, for which water balances were developed in order to undertake a comparative evaluation and selection of the preferred go-forward solution. The water balance was carried out at a monthly timestep, using stochastically generated rainfall data for the LoM duration (2028 to 2038), and is not intended as a detailed/final water balance. Figure 4 illustrates the schematic inputs, storage and output components considered in the water balance.

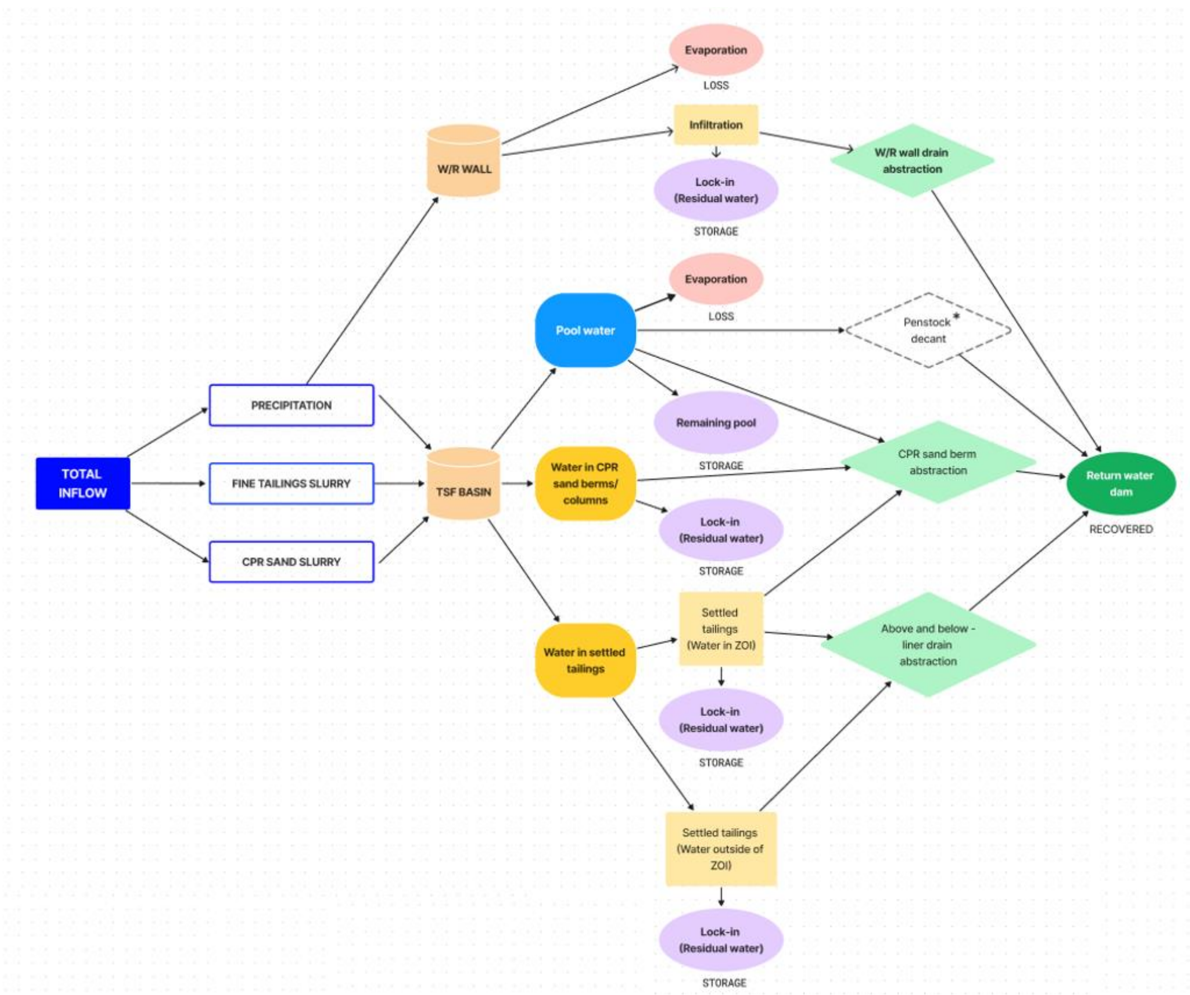


Figure 4: Water balance schematic diagram.

The comparative water recovery results are presented below in Table 1. For Option 1, 70% of the total inflow water volume is recovered. Option 2 recovers 82% of the total inflow water volume.

The makeup of the recovered water volume in Option 1 is (i) 19 588 m³/d (53%) from pool abstraction, (ii) 2 703 m³/d (7%) from the settled tailings, (iii) 1 238 m³/d (3%) through the above and below liner drains, and (iv) 2 577 m³/d (7 %) through the waste rock (W/R) wall drains. The makeup of the recovered water volume in Option 2 is (i) 20 991 m³/d (56%) from pool abstraction, (ii) 6 311 m³/d (17%) from the settled tailings, (iii) 697 m³/d (2%) through the above and below liner drains, and (iv) 2 577 m³/d (7%) through the W/R wall drains. The recovery via pool abstraction and from settled tailings is substantially higher in Option 2 compared to those achieved in Option 1.

These recoveries were also compared to the water balance undertaken for the base case. The comparison confirms that while both Option 1 and Option 2 will improve water recovery compared to the base case configuration, Option 2 is significantly better than Option 1.

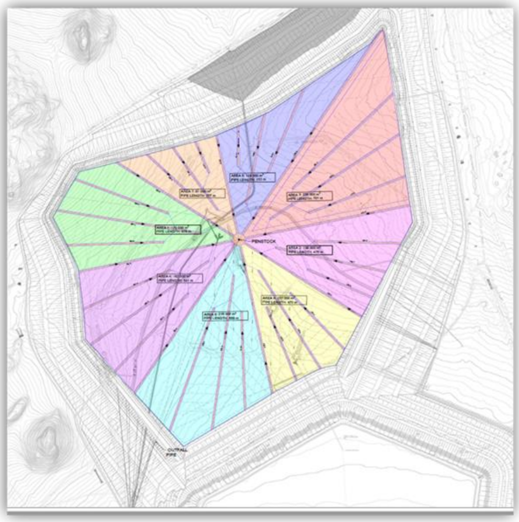
Table 1: Comparative water recovery results.

Scenario	Total water stored	Total water loss (evaporation)	Total water recovered	Recovery rate (m^3/t)
Option 1	24%	6%	70%	0.87
Option 2	16%	2%	82%	0.96
Base case	29%	11%	60%	0.57

Options identification and go-forward solution

Option 1 (Figure 5) comprises 8 compartments divided by CPR sand berms which intersect at the centroid of the TSF. A single penstock intake is located at this centroid position and all CPR sand berms are constructed radially from the outer embankment towards this centroid. Each compartment has additional inter-compartment CPR sand berms which are constructed to leave a minimum gap of ± 60 m to enable operational and storm water to flow unimpeded towards the centroid position where the pool will form. Potential erosion of the CPR sand berms during deposition is a risk due to narrowing of the flow paths and a second drawback is that the CPR sand berms are concentrated on the outer footprint of the basin away from the pool area where saturation, and hence potential for abstracting interstitial water, is expected to be highest. Set-up and mobilising of SPCUs to construct CPR sand berms is expected to require more effort during deposition since the berms are constructed from the outer basin perimeter and equipment must be moved continuously, over long distances, around the entire TSF perimeter to keep ahead of deposition.

Option 2 (Figure 6) comprises two penstock intakes located along a north-to-west divider road which will be constructed from waste rock material. The divider road will be raised continuously with deposition lifts as the facility rises. The basin footprint is divided into 6 compartments by CPR sand berms which intersect at the 2 penstock intake positions and extend to the outer perimeter of the basin. Each compartment contains CPR sand berms which do not extend to the perimeter and are constructed outwards from the divider road and penstock intake structure locations. The geometry is such that all CPR sand berms are not constructed from the outer perimeter of the basin and construction and set-up are therefore expected to be less onerous. This configuration is advantageous as CPR sand berms are concentrated centrally within the basin footprint and therefore expected to be more efficient with higher water recovery from both the pool and interstitial water.



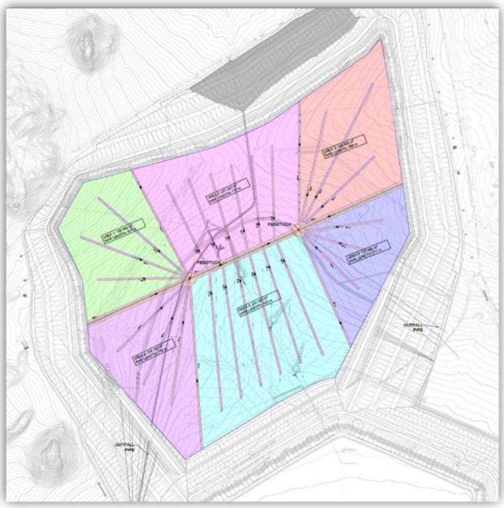


Figure 5: Option 1 configuration **Figure 6: Option 2 configuration**

A workshop was held during which advantages and disadvantages associated with each option were evaluated. Option 2 scored the highest with a weighted score of 115 compared to Option 1 which scored 77. Option 2 achieved the higher score due to (i) advantageous berm location to optimise wicking and abstraction, (ii) easier operation with all berms constructed from the central divider road instead of along the TSF perimeter, (iii) higher operational safety and (iv) the higher water recovery.

Infrastructure requirements

Compared to the base case, HDS is expected to increase costs substantially. In order to transition BW2 to an HDS facility an additional pipeline and pump station are required. Furthermore, since the base case engineering had been completed to feasibility level, there were modifications to the penstock, drainage system and phase 1 containment infrastructure which were required. Although the HDS solution delivers significant additional water, mitigates against the most likely failure mechanism (seepage driven) and enables a far lower closure cost, the business case for HDS is not yet positive.

Closure

The base case closure profile for BW2 comprises constructing a convex surface with waste rock on top of the TSF basin to allow surface runoff to drain towards the side slopes. The convex topography will have a final slope of 1:200 with the highest point being above the proposed base case penstock location. The constructability of the waste rock dome shape at end of life is improved significantly due to the "drier" tailings and additional access provided by the divider road. The CPR sand berms (with associated collector pipes) and divider road must therefore not be demolished at closure. A major risk associated with the base case closure solution is the potential ponding of water above the tailings level inside the waste rock dome after sealing the penstock. The ponded water due to infiltration will collect on top of the tailings and eventually infiltrate the tailings, feeding the phreatic surface within the TSF, thus delaying its desired drawdown. Mitigation considered in the base case scenario, comprised either a capping layer (barrier system with a liner) which must be placed over the dome to prevent infiltration, or the penstock should not be sealed, allowing ponded water to drain through it. The latter has safety risks related to an accessible penstock post closure due to the potential access by unauthorised persons. The HDS system provides an advantageous alternative solution which is operable as a safe passive drainage system. This will reduce the risk of ponding above the tailings level inside the waste rock body thereby allowing both penstocks to be sealed and negating the need for a capping layer.

Conclusion

The HDS deposition methodology is a significant deviation to current water recovery strategies and enables recovery of both supernatant and interstitial water. The CPR sand berms significantly improve the recovery, by shortening the drainage paths for seepage water and creating preferential drainage paths through which water including the interstitial water (which is not accessible in conventional deposition methods) is recovered. This leads to a TSF that is comparatively drier than a conventionally facility. This paper documents salient considerations for the design and for transitioning a conventionally designed facility into an HDS facility. Availability of CPR sand is a prohibitive constraint when considering the use of the more effective horizontal sand layer configuration. It was concluded that typical spacing of 40 m to 60 m is ideal for CPR sand berm configuration at BW2. Furthermore, implementation of HDS and recovery of pool water does not immediately replace the use of tradition penstock or pump recovery systems. Outflow through the CPR sand berms is driven by the hydraulic gradient which is not adequate in the early stages of development, and this motivates for inclusion of a secondary penstock or pump outflow system.

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