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Hydraulic Dewatered Stacking — Developing Strategies for Brownfield Applications at Mogalakwena, South Africa

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Abstract

Anglo American has patented a new technology system for tailings deposition called Hydraulic Dewatered Stacking (HDS). The premise of HDS is to hydraulically co-dispose fines free sand with tailings to improve the overall drainage of the facility and deliver an unsaturated tailings facility. The objective of this novel approach is to improve water recovery, speed up reclamation, and enhance the safety of the storage facility (by reducing pore pressures and supernatant water). As part of the HDS technology development pathway, Anglo American is currently implementing two industrial-scale pilots to validate the science behind the HDS concept, improve the knowledge of the expected benefits, and generated learning and experience that will prove valuable in full-scale operation. The paper presents an HDS demonstration at the Mogalakwena mine in South Africa, referencing the successful greenfield trial at El Soldado, Chile and talks to the unique constraints at Mogalakwena where the sand availability is reduced.

The field trial at the Mogalakwena mine uniquely focuses on the application of HDS within a large-scale active tailings facility. The primary objective is to determine design criteria for a proposed full scale HDS implementation at Blinkwater 2, a tailings expansion project. A trial sand channel was constructed in 2022 and lessons learned were used to develop the trial which began in Q2 2023. Since the trial is constructed on top of an active tailings facility, the sand channels will be dewatered with excess water reporting to the central tailings pond. This will allow the surrounding tailings to drain and consolidate as though the sand channels were connected to a drainage network. The final design and initial results for the trial will be presented with preliminary field observations. Extensive instrumentation has been proposed within the footprint of the Mogalakwena trial area with additional instrumentation outside the footprint so that a comparison can be made between the augmented drainage from HDS and traditional slurry deposition that is ongoing adjacent to the trial area.

Keywords: Hydraulic Stack, Dewatered Tailings, Drainage, Cyclone, Consolidation, Unsaturated

Introduction

Major failures of tailings storage facilities continue to occur within the mining industry that have led to significant economic, environmental, and human losses. It is important to note that these failures are not restricted to regions with poor governance but continue to happen across all jurisdictions around the globe. Scrutiny is increasing within the mining industry and safe tailings management is becoming increasingly important to maintain social license to operate. There is clearly a need for continued innovation to improve practice across the globe leading to tailings safety, such as the HDS method described herein.

This paper describes the HDS method and highlights some of the recent field scale work undertaken/planned at the Mogalakwena platinum project in South Africa, on top of the current Blinkwater 1 (BW1) tailings facility.

Hydraulic Dewatered Stacking

The HDS method considers engineered co disposal of fines-free sand (i.e. free draining) and tailings placed in discrete features to promote internal drainage within the tailings facility. The goal is to have the fines free sand in connection with an internal drainage system that allows pore water to rapidly drain under gravity to a collection point, where it can be extracted from the TSF rather than remaining as a supernatant pond or porewater within the facility. The HDS method was developed from Anglo American's experience with Coarse Particle Recovery (CPR). A new approach to flotation that although widely used in some minerals, is now starting to gain traction in base metals hydrometallurgical circuits (Filmer and Alexander, 2016; Filmer and Alexander, 2017; Filmer and Newman, 2020). Through early rejection of barren sand, additional production capacity in the downstream process plant is made available, delivering value opportunities (Arburo et al. 2022). It should be noted that the HDS method is not restricted to projects that are producing CPR sand and can be applied to assets that operate with a medium to coarse grind (i.e. D80 of ~150µm). The main potential advantages of the HDS method are listed below:

- Improved drainage and consolidation of tailings; (quicker access to tailings beach, faster reclamation during closure phase).
- Improved safety of the TSF; reduced pore water within the tailings and external embankments (increased stability).
- Reduced potential for strength loss through higher consolidation and the delivery of unsaturated tailings facility (enhanced liquefaction resistance).
- Reduced risk of piping (due to lower hydraulic gradient within the dam).
- Improved water recovery (higher quantity, with likely lower suspended solids).
- Reduced cost relative to filtered dewatering technologies for similar project conditions.

A ‘Proof of Concept’ study was undertaken to assess the potential for CPR sand to provide effective drainage for tailings facilities and showed the HDS method. This study indicated that further evaluation was warranted to test the effectiveness of the HDS method. Laboratory testing and numerical assessment from the ‘Proof of Concept’ study are summarized in a last years TMW22 paper (Newman et al., 2022). The first large-scale trial is underway at El Soldado mine, Chile (Newman et al, 2022) and a second trial considers HDS within an active tailings facility at the Mogalakwena mine, South Africa; the subject of this paper. A preliminary sand placement trial was completed in 2022 at the BW1 facility and several lessons learned, which were applied to the El Soldado trial; for the 2023 full-scale demonstration, the experience from El Soldado (commissioned in Q3 2022) enabled a rapid commissioning and fast progress on sand channel construction at BW1. The design, instrumentation design and early stages of channel placement are described in this paper; building on, and contributing to, the rapidly growing experience of this new approach to tailings management.

Mogalakwena BW1 Trial

Trial Objectives

The Mogalakwena demonstration has two primary objectives; demonstrate the feasibility of HDS implementation in an operating TSF; and determine the ‘zone of influence’ from the drainage channels installed – a key aspect of the HDS technology The outcomes of the trial will be incorporated into the design of the Blinkwater 2 tailings facility as well as other platinum tailings operations.

Operational objectives:

- Can controlled placement of fines-free sand be achieved using the proposed deposition unit?
- Can the supply pipeline be effectively managed, so the deposition unit can reach all the trial area?
- Can deposition be completed with limited disruption to operations (i.e. can co-disposal of sand and thickened tailings be achieved)?
- How can fines-free sand be deposited at significant distances from the external embankment?
- Can the deposition unit safely traffic across the tailings surface?

Technical Objectives:

- Can the deposited sand effectively drain the surrounding tailings mass?
- Will this method deliver improved water return (rapid drainage with minimal suspended solids)?
- What level of accelerated consolidation and subsequent strength development will occur in zones where fines-free sand is co-disposed with thickened tailings?

- Will the deposited drainage channels be resistant to clogging?
- What spacing will adequately achieve the above objectives – i.e. what is the 'zone of influence'?

The zone of influence of a drainage channel within the tailings mass is a key design parameter when assessing implementation options, particularly in platinum where the sand available is likely to be limited.

BW1 Constraints

The HDS trial at the Mogalakwena mine has been designed based on a Hydrofloat™ plant upgrade that will produce a fines-free CPR sand as a reject. The current plant redesign indicates that the CPR sand will make up between 13% to 18% of the 1300 tph of material from the plant (approximate ratio of between 1:5 and 1:6 CPR sand to tailings). This is unlike CPR sand from copper tailings, where a ratio of up to 1:3 CPR sand to tailings could be available. The lack of sand availability is a key constraint when designing a trial to prove the HDS method for platinum tailings.

Process plant upgrades for the Mogalakwena site are underway at the time of writing and full-scale production of CPR sand is not yet available. Generating enough CPR sand for the proposed HDS trial was not possible in the short term; therefore, an imported sand will be used for first stages of the BW1 trial. The expected CPR sand is poorly graded fines free sand, while the imported sand is more well graded, with up to 15% fines (<75 μm). The properties of the tailings, anticipated CPR sand, and imported sand are described in the following sub-sections. The main design criteria are provided in Table 1.

Table 1: BW1 HDS Trial – Design Criteria

Parameter	Design Assumption
Maximum CPR sand production	100 tph
Maximum trial height above tailings surface	1.5 m *
Assumed ratio of CPR sand to tailings	13% - 18%
Assumed in-place density CPR sand (and imported sand)	1.54 t/m^3
Assumed in-place density tailings	1.54 t/m^3

*The maximum design height for the test area was specified for safety reasons since the foundation of the HDS is situated on low strength tailings

The assumed in place densities were obtained from previous studies that consider the load density curve for both tailings and CPR sand; however, there is flexibility within the design and the actual densities achieved are not likely to adversely affect the trial. Verification of the assumed densities will be undertaken once the field trial is underway.

There are some significant challenges with operating a trial on top of the existing facility. The safety of the tailings dam is of paramount importance, so the trial must account for these ongoing activities. Like many tailings facilities, the BW1 tailings surface continues to rise annually with continuous construction of embankment dams throughout the life of mine. Where a stand-alone cell would allow careful control of both tailings and CPR sand deposition, the design for the HDS trial at BW1 TSF must consider the continued rising of the tailings surface and need for ongoing operational management and construction throughout.

BW1 Tailings

There are several sources of data on the platinum tailings generated at the Mogalakwena Concentrator. A summary of the main materials properties considered relevant for the HDS trial are presented in Table 2.

Table 2: Mogalakwena Tailings Geotechnical Summary (adapted from Newman et al, 2022)

Parameter	Estimated Value
Specific Gravity	3.00
Atterberg Limits	Non-plastic
Settled Density	1.35 t/m3
Density at 50kPa	1.54 t/m3
Permeability (vertical)	1.0 x 10-7 m/s (values measured ranging from 1 x 10 8 m/s to 7 x 10-6 m/s)

Laboratory testing data show that the platinum tailings are a fine-grained non-plastic material with an average P80 of approximately 75 µm. Particle size distribution testing is presented in Figure 1.

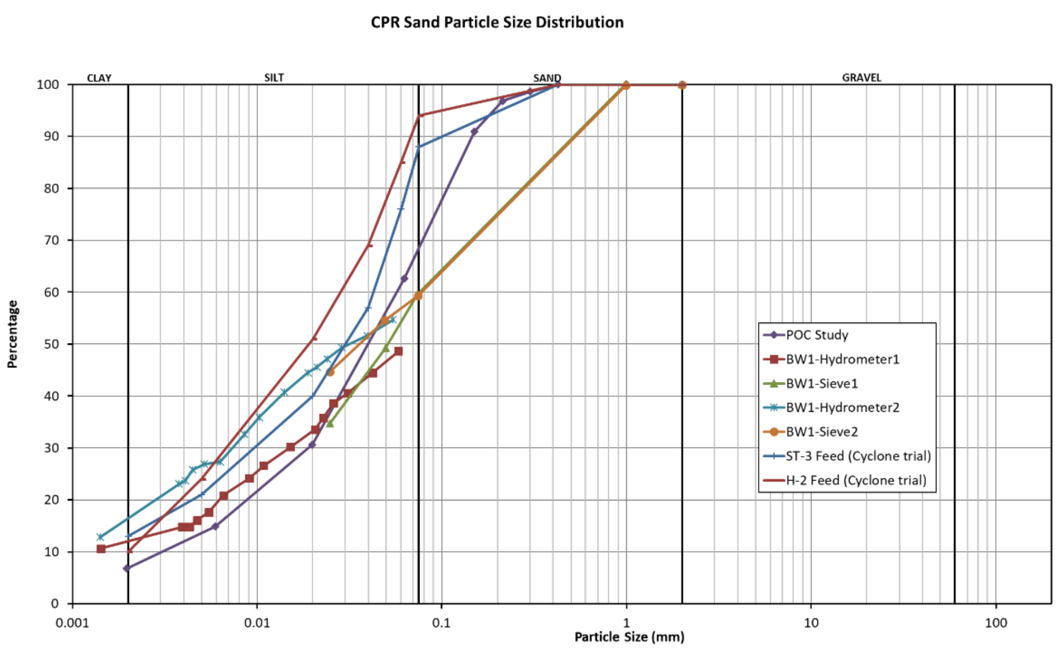

Figure 1: Particle Size Distribution for BW1 Tailings taken from Processing Plant

Imported Sand

Since producing significant quantities of CPR sand was not possible in the time frame for the trial, an imported sand has been used for the first half of the trial. CPR sand is quite unique in its particle size distribution and hence difficult to source from nature. Placement of the sand for the BW1 trial will use a cyclone system that will remove the fines fraction, providing some latitude on the design specification allowed when sourcing a suitable sand.

Figure 2 shows a preliminary estimate for particle size distributions (PSD) for the imported sand before and after the cyclone splits. The range of imported sand PSD are highlighted in blue while the overflow and underflow are labelled directly in the figure. As shown, the predicted underflow of the SPCU has similar fines content as the anticipated CPR sand from the processing plant. The removal of fines by cyclone should allow the imported sand to be free draining and act as a good substitute for the CPR sand in the upcoming trial. Observations from the sand placement trial indicate the imported sand is well draining.

During the 2022 sand placement trial, the cyclone underflow stacked well, delivering a steep-sided (1:2 side slopes) drainage channel; this provided the confidence that the sand, although not ideal, would provide a suitable proxy for CPR sands allowing the trial to commence prior to full commissioning of the CPR plant.

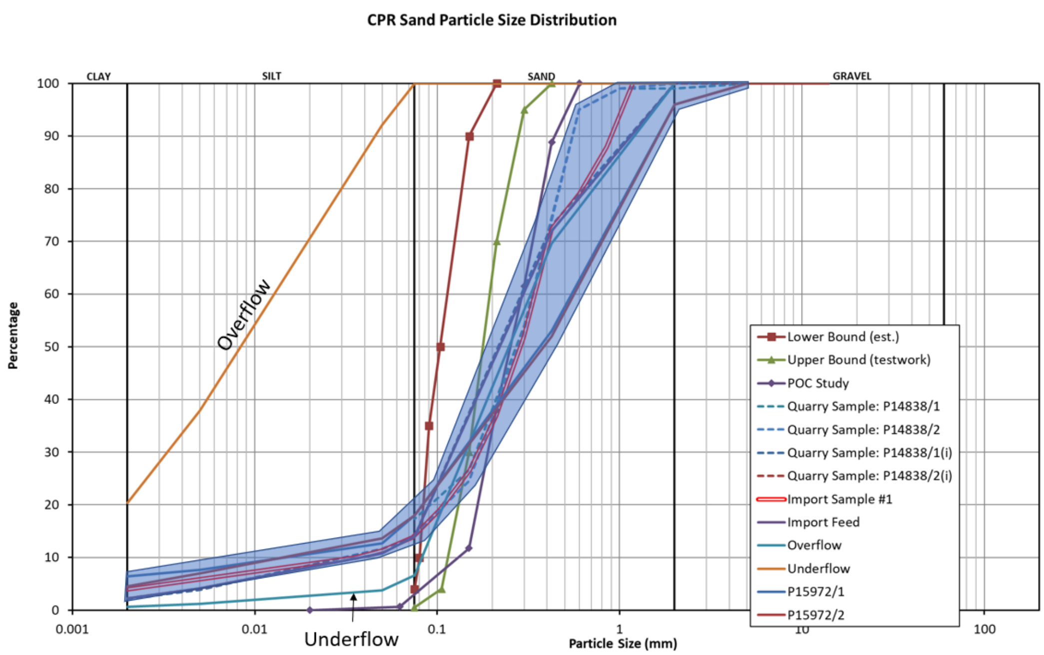

Figure 2: CPR Sand and Imported Sand Particle Size Distribution

Trial Geometry

In assessing the trial design and layout, the proposed implementation geometry has been considered. Several geometries were reviewed at the conceptual level when the Mogalakwena trial was first proposed. The final design assumes vertically continuous drainage channels due to the limited CPR sand availability. Based on outcomes of the sand placement trial undertaken in 2022, the drainage channels would be raised every 1.5 m, have a 3 m crest width, and 1:2 V:H side slopes. The minimum distance calculated between drainage channels was 40 m centre to centre to maintain a 1:5 sand to tailings ratio.

Hence the trial design used 40 m offset as the minimum distance between drainage channels but also includes 50 m and 60 m offsets as two alternatives that may represent a more realistic and robust implementation route for the BW2 tailings facility. In these scenarios, it may be possible that some of the tailings will remain saturated for longer at the centre-point of the two drainage channels and the primary object of the trial is to understand performance with increasing offset distance between drainage features. The plan view of the proposed geometry is presented in Figure 3.

Figure 3: Proposed Construction Geometry

Deposition Method

Due to the predicted material balance available at the Mogalakwena mine, it was agreed that there is insufficient sand available for construction of horizontal blanket drains, so the deposition focuses on construction of vertically continuous drainage channels. Since the Mogalakwena trial specifically investigates the HDS method at brownfield sites, the deposition unit must walk onto the tailings facility as it deposits sand. The deposition units are remote-controlled vehicles to minimize the risk to personnel. The delivery system includes several lengths of high-pressure mining hoses to allow deposition units to move a fixed distance without needing to extend the fixed pipes.

A key challenge with hydraulic deposition of sand is the velocity needed to keep the sand suspended and prevent choking within the delivery pipes. This results in a high pressure, high velocity system which makes it difficult to place the sand at low energy and achieve discrete, steep sided drainage channels required by the trial design. There is a need to transition from a high energy system to low energy system at deposition to prevent the deposited material from washing sand away resulting in shallow side slopes.

A Self-Propelled Cyclone Unit (SPCU) was commissioned for the deposition at the BW1 trial. The SPCU uses horizontally oriented cyclones to actively dewater the sand as it comes out of the deposition unit (achieving a solids concentration of approximately 60-80% depending on feed solid content). The solids content in the feed has been trialled between 30-50% solids (m_{solid}/m_{total}), with some benefits observed at the higher range of solids concentrations. Up to five cyclones can operate at a time to increase production rate. Sand slurry is pumped through HDPE pipelines before entering a flexible high pressure mining hose that leads to the SPCU. Prior to entering the SPCU, the hose splits into smaller diameter hose that feed each individual cyclone through a specially designed splitter with individual valve control for each feed.

Figure 4: Self Propelled Cyclone Unit Operating at BW1

The cyclone overflows are captured in a single outlet pipe exiting the side of the SPCU (the green pipe in background of Figure 4, indicated by arrow). The cyclones primarily separate water and fines into the overflow to produce higher solids concentration in the underflow. The application of using cyclones for CPR sand is slightly different than traditional cyclone applications where the objective is to split the feed into coarse and fine fractions. Instead, cyclones are used as a method of transitioning from a high energy system to a low energy system to produce a high solids underflow without losing significant quantities of material (i.e. separation of sand and water). For the BW1 trial, the cyclones also serve to separate the fines from the imported sand to allow effective drainage to take place within the deposited sand.

The imported sand has a high enough fines content such that a modest portion of material reports to the overflow and this has the potential to contaminate the trial and deliver optimistic results. The current trial design includes a pumped diversion to remove the overflow to an area outside the trial to ensure that meaningful conclusions can be drawn. Removal of the overflow would not typically be required for the HDS method where CPR sand is available (i.e. El Soldado trial, where overflow is deposited within the trial area). Since the primary purpose of the drainage channels is to provide drainage to the tailings, the exact shape of the berm should not significantly affect the desired outcome. If the drainage features maintain vertical connectivity, small scale changes in shape due to deposition and erosion should not adversely affect the performance.

The side slopes generated during the sand placement trial indicate that relatively steep slopes can be achieved using hydraulic deposition; however, some of the material was deposited when the cyclones were "roping". Experience from the El Soldado trial suggests that the best performance is achieved when the underflow density is maximized, but without roping, which results in an undulating profile that is difficult for the SPCU to travel over. Several adaptations are being considered to maintain cyclone "flaring" while maximizing the underflow density.

Deposition will be completed in stages to allow the tailings to rise around the drainage channels over time in accordance with the tailings operational design. As the tailings surface rises toward the top of the sand channels, additional sand will be deposited directly overlying the previous drainage channels. Each channel will be raised in several campaigns with the crest elevation increasing by approximately 1.2 m each raise. Surveys will be undertaken throughout the drainage channel construction to ensure that the approximate geometry achieved. Each drainage channel will maintain vertical continuity throughout as shown in Figure 5.

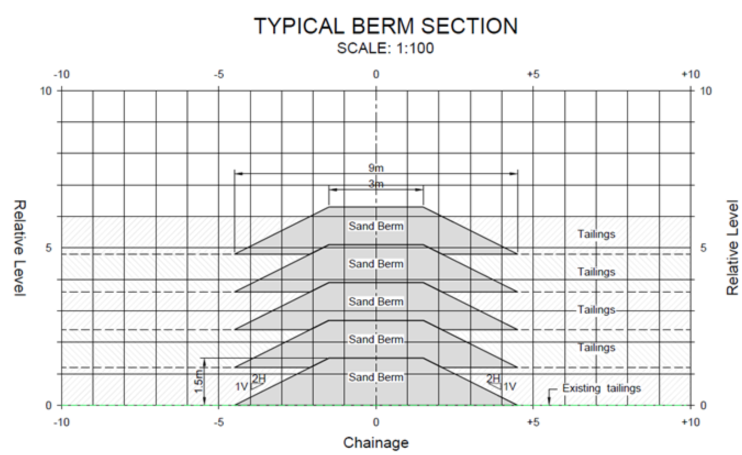

Figure 5: Typical Cross Section through a Drainage Channel (Staged Raises throughout Trial)

BW1 Monitoring and Observations

The main technical metrics for determining a successful trial are the desaturation of tailings, reduction of pore pressures, and increased consolidation settlement from the depressurization of tailings. The monitoring system proposed for the BW1 HDS trial focuses these metrics by measuring vertical deformation, pore pressures, saturation, and soil suction. The main elements of the monitoring system include:

- Survey Monuments

- Magnetic Settlement System
- Vibrating Wire Piezometers and Standpipe piezometers
- Water Content Probes
- Tensiometers
- Dewatering wells to discharge water to the tailings pond

Dewatering wells will be installed within each drainage channel to simulate an active dewatering system that allows desaturation to occur. The aim of a full scale HDS project is to eliminate surface water from tailings facilities by allowing rapid percolation of surface water into the drainage channels rather than forming a supernatant pond. The water will then be drained (or pumped) to a purpose-built water pond with evaporation protection measures in place. The dewatering wells will be installed within the drainage channels to simulate the central drainage that would be designed in a full scale HDS project and prevent pockets of saturated sand forming within the tailings mass. The general arrangement for the proposed monitoring system is shown in Figure 6.

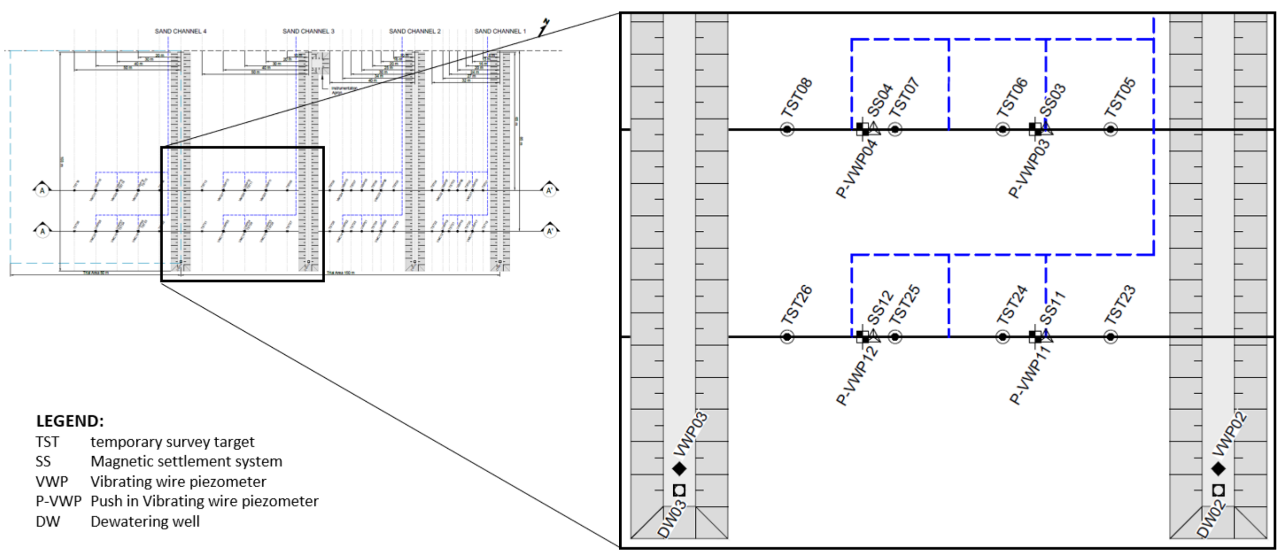

Figure 6: Conceptual Layout for Initial Monitoring Instrumentation at BW1 Trial

BW1 Trial Outlook

The BW1 trial is underway at the time of writing this paper. Observations and data collected from the trial will continue through to 2024, with first round of monitoring data expected to be collected in August 2023. The El Soldado trial was commissioned in Q3 2022, and the experience gained from that trial has informed decisions of the design of the BW1 trial, from both operational and design perspectives.

A key challenge with the start of the BW1 trial was getting the cyclones running at the desired production rate while achieving high underflow density to form sufficiently steep slopes. The current drainage channel construction for the ongoing BW1 trial is significantly flatter than design, with slopes of approximately 1:4 V:H. This is thought to have resulted from cyclone spigots that are too large and a lower solids content in the SPCU feed. Additional adaptation to the SPCU is underway to ensure that the cyclones can evenly deposit high density sand with adequate side slopes. Drainage channels from the sand placement trial and the current BW1 HDS trial are presented in Figure 7. An SPCU is currently used for sand deposition in ongoing trials; however, alternative deposition strategies can be considered, and development of such strategies are being considered.

Figure 7: Sand placement trial from 2022 (left) and Current BW1 HDS trial (right)

The zone of influence is critical for implementation of the HDS method for tailings projects where there is low availability of sand coming from the plant. The learnings from the BW1 trial will be directly used to develop BW2, the design of which is currently underway. The proposed arrangement for BW2 consists of a central sand causeway with sand channels extending like spokes toward the external embankments to enhance tailings drainage. Two central decant towers are proposed to ensure that water will be removed, eliminating the formation of a supernatant pond. The conceptual design for BW2 is presented in Figure 8.

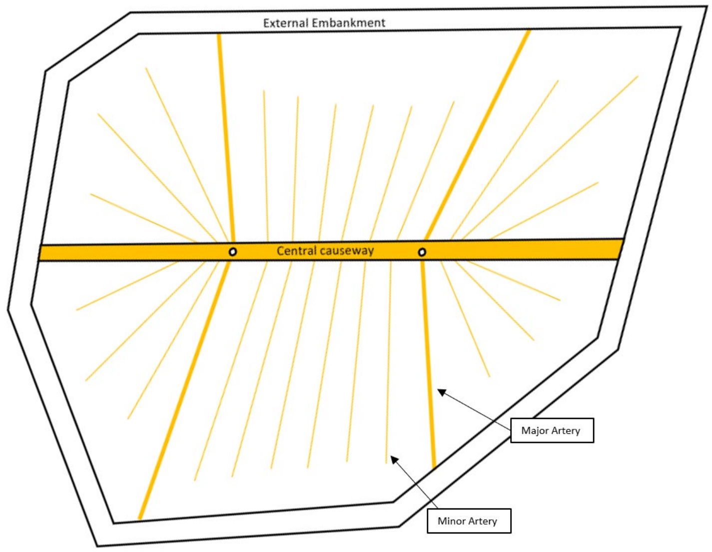

Figure8: Conceptual Design of HDS at BW2

As shown in Figure 8, there is clear benefit to understanding the zone of influence for each drainage channel. If the influence of the drainage channels proves limited, an augmented drainage system could be considered by installing horizontal drains and this adaptation is currently being considered for BW1.

One limiting factor for the trial success is that the tailings could have the potential for significant soil suction, which could delay dewatering of the tailings until a build up of pressure head can force the pore water from the tailings mass. This may result in delayed onset of consolidation and must be considered when the initial results data becomes available from the trial. Data from the El Soldado trial showed delayed response in dewatering when depositing tailings, so a delay is anticipated at the BW1 site.

Conclusion

Hydraulic Dewatered Stacking at Mogalakwena is an innovative new tailings strategy that uses the by-product of the updated processing technique, Coarse Particle Recovery, to form drainage channels within the tailings mass. The aim of this novel tailings deposition method is to create a free draining tailings facility that benefits from rapid consolidation and dewatering adjacent to the perimeter embankments.

While there are some projects for which this new strategy may not be suitable (i.e. sites that have problems with metal leaching and acid rock drainage; or sites with a very fine grind and no CPR plant), there is significant potential within the mining industry to leverage this strategy of enhanced in situ dewatering of tailings to improve TSF safety, water recovery, consolidation, and rapid rehabilitation. The HDS method aims to deliver many of the advantages of filtered tailings at a fraction of the cost.

The BW1 HDS trial will provide valuable insights into the feasibility of scaling the HDS method for platinum projects. The learnings will directly feed into future operations at the Mogalakwena mine site.

Acknowledgements

This paper describes the HDS trial at Mogalakwena and has incorporated lessons learned from another operational trial at El Soldado. A second paper at this conference describes this other trial – and it is recommended that readers review both papers which have been written in such a way to complement each other.

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