Paste 2026 – AB Fourie, M Horta, M Oliveira & S Wilson (eds)

doi:10.36487/ACG_repo/2655_45

Deposition planning, spigoting, and pond management for the closure of a thickened tailings facility

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Abstract

One of the most critical phases in the lifecycle of a tailings storage facility is the transition to closure. Effective closure planning requires early integration of operational strategies with closure objectives, ensuring continuity between the end of deposition and the initiation of closure activities. In thickened tailings facilities, spigoting remains the primary method for tailings discharge. In this case, the spigoting strategy has been optimised to shape the final tailings surface in accordance with the approved closure design. This has significantly reduced the need for extensive earthworks during the closure phase, aligning deposition practices with long-term landform requirements. Additionally, a comprehensive review of existing instrumentation networks and their interaction with tailings distribution infrastructure has been essential. This integrated approach to deposition planning, spigoting management, and instrumentation control has proven fundamental for achieving a stable, compliant, and cost-effective closure.

Keywords: *tailings storage facility, thickened tailings, mine closure, co-disposal, surface water management, integrated closure planning*

1 Background and context

The long-term environmental stability and safe closure of tailings storage facilities (TSFs) represent one of the mining industry's most significant global challenges. Following high-profile failures such as the Mount Polley Mine, the Córrego de Feijão mine (Brumadinho) or Cadia, together with increased regulatory scrutiny, the focus has shifted from simply stabilising a facility post-operation to integrating closure planning throughout the entire lifecycle.

Thickened tailings facilities (TTFs), such as the Deposito de Pasta Seca (DPS) (shown in Figure 1) operated by Sandfire MATSA in Huelva, Spain, offer advantages over conventional slurry TSFs. These advantages are primarily related to improved water efficiency, reduced footprint, and enhanced geotechnical stability resulting from lower water content and faster consolidation. However, the final formation of the landform remains critical for long-term performance.

The Sandfire MATSA DPS, situated in a high-rainfall environment in southwestern Spain, operates under stringent Spanish and European Union environmental regulations, including the *EU Mining Waste Directive* (European Commission 2006) and its transposition into Spanish law through *Real Decreto 975/2009* (Gobierno de España 2009). This context elevates the importance of successful closure, particularly concerning surface water management and geotechnical integrity. The central message of this paper is that closure is not an end-of-life activity, but rather an integrated operational phase requiring proactive planning.

In addition, Sandfire MATSA has formally aligned the design, operation, and closure planning of the DPS with the *Global Industry Standard on Tailings Management* (GISTM) (International Council on Mining and Minerals, UN Environment Program & Principles for Responsible Investment 2020). The company has implemented the governance and accountability framework prescribed by GISTM, including the designation

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of an accountable executive, an engineer of record, and independent review functions. This organisational structure ensures clear ownership of tailings-related risks, robust technical oversight, and systematic decision-making throughout the facility lifecycle. Compliance with GISTM principles further reinforces the integration of safety, environmental protection, and social responsibility into both operational management and long-term closure objectives.

Figure 1 Deposito de Pasta Seca status before closure (source Google 2023)

1.1 The critical phase of transition to closure

The final years of active deposition are pivotal for the TSF's long-term performance. Deviations from the target final landform during operation translate directly into costly, time-consuming, and risk-prone earthworks during the closure phase. The primary challenges in this transition include:

1. achieving the required final surface topography to support sustainable drainage
2. minimising post-closure erosion potential and maintenance requirements
3. controlling costs and reducing the implementation schedule for closure construction.

1.2 Paper objective and scope

The objective of this paper is to detail the methodology and results of the integrated approach adopted at the Sandfire MATSA DPS. Specifically, it demonstrates how the optimisation of the spigoting strategy, coupled with a proactive review and management of the instrumentation network, successfully facilitated a stable, compliant, and cost-effective transition to closure. This paper examines deposition optimisation, instrumentation review, integration with the approved closure design, and the resulting benefits.

2 Sandfire MATSA Deposito de Pasta Seca and closure design requirements

2.1 Facility characteristics and operational overview

The Sandfire MATSA DPS is engineered to accommodate thickened tailings produced from the processing of polymetallic ore. The tailings material is characterised by a high solids content (65% typically), allowing for rapid consolidation and the formation of a steeper beach slope (up to 2% slope) compared to conventional slurries. Deposition occurs via a network of perimeter and infill pipelines using spigoting, where discharge ports are strategically opened and closed to distribute the tailings. This method provides an opportunity for precise control over the final topography. The facility's design is heavily influenced by the regional climate, which necessitates robust erosion control measures. The site has a Mediterranean climate with hot, dry summers and mild winters. Rainfall is moderate, concentrated mainly in autumn and winter rather than evenly distributed throughout the year. Summer temperatures frequently exceed 30°C, while winter averages are around 10–12°C.

2.2 Approved closure design and final landform

The approved closure design specifies a final landform that seamlessly integrates with the surrounding topography, primarily focused on establishing long-term geomorphic and hydrologic stability. Key features of the design include:

- Target slopes: final slopes are specified to be non-erosive (typically 22° or shallower) and compatible with the final cover system and revegetation.
- Drainage paths: a network of permanent channels and diversions must be established on the tailings surface to direct clean runoff away from the cover and prevent ponding or surface erosion.
- Cover system: the design requires a multi-layered cover system to limit infiltration and support a sustainable vegetative layer.

The core performance objective for closure is hydrological control which ensures that surface runoff is managed effectively to minimise erosion and prevent water infiltration that could destabilise the tailings mass or contaminate groundwater.

2.3 The gap: bridging operations and closure design

Historically, operations focused on maximising volume utilisation, often leaving an irregular final surface that required significant post-closure cut-and-fill earthworks (re-handling the tailings mass) to achieve the design topography. The gap addressed by this case study is 'how can daily operational decisions regarding tailings deposition eliminate the need for costly post-closure surface reshaping'? The solution lies in treating the spigoting system as a primary land-forming tool.

3 Optimisation of the tailings spigoting strategy

3.1 Spigoting as a land-forming tool

In TTFs, the spigot disposal plan controls the location, velocity, and duration of tailings discharge. By strategically managing these variables, operators can direct beach development using analysed topographic data and digital terrain models over the DPS. This approach is termed 'deposition for landform' (D4L). The goal of D4L is to use the final deposited tailings material to construct the approved final contours, allowing the tailings to desiccate. By considering seasonal variations and increasing the rotation of spigots, the process promotes the formation of desiccation cracks, which serve as proof of proper consolidation. It is shown in Figure 2 that the proposed spigots are installed prior to the closure stage.

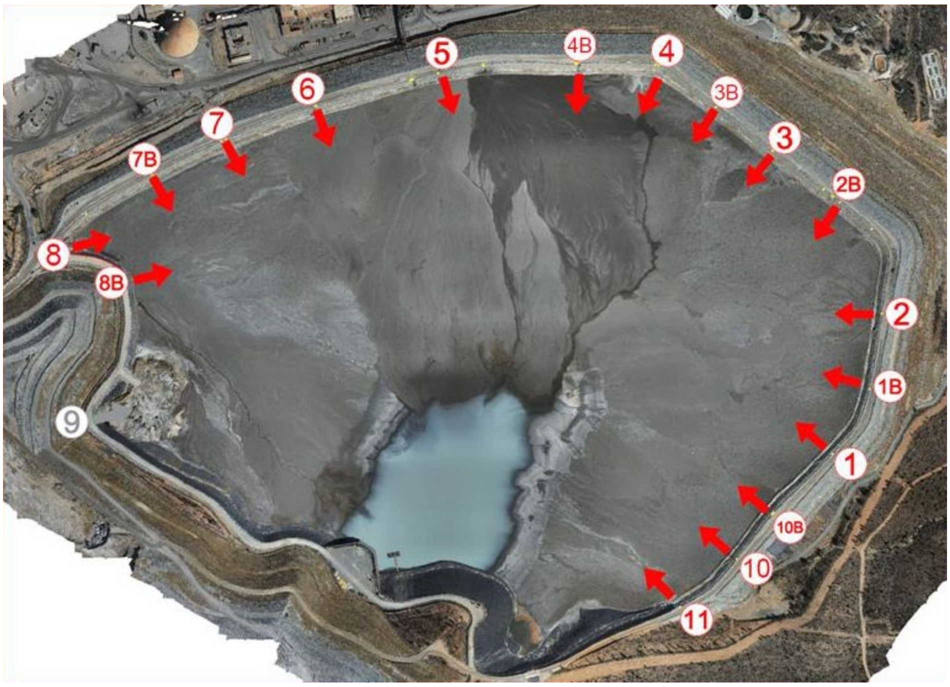


Figure 2 Spigoting installation for final landform

3.2 Model development and simulation

To implement D4L, the operational team utilised a combination of numerical modelling and high-frequency surveying data. On site the operational team is surveying the tailings beach (aerial and bathymetry) on a monthly basis, with a precision of 1 m. A 3D model is processed with Muk3D software (MineBridge Software Inc. 2023) and a monthly deposition plan is prepared. This allows us to check:

1. Model calibration: empirical data on thickened tailings rheology, beach slope angles, and consolidation rates were used to calibrate a deposition model.
2. Design integration: the model was fed the target final contour lines from the closure design.
3. Simulation: the model simulated various spigoting rotation schedules (which discharge points were active, for how long, and in what sequence) to predict the resulting final surface elevation.

This iterative simulation process was crucial for identifying zones requiring compensatory deposition (where the surface needed to be built up) versus zones where deposition needed to be terminated early to preserve planned drainage pathways. This allowed the final surface to be pre-shaped with a degree of precision not typically achieved in standard operations.

3.3 Implementation and results

Implementation involved adjusting the daily operational work instructions:

- Targeted perimeter build-up: deposition was prioritised at the perimeter crests to achieve the required elevation for the final cover tie-in, effectively reducing the need to truck in earthen materials for the final crest construction.
- Controlled drainage shaping: specific spigot sequences were used to create subtle high-points and low-points that aligned with the planned permanent drainage features.

The quantifiable benefit of this strategy showed that the optimised D4L strategy reduced the required volume of remedial cut-and-fill earthworks on the final tailings surface by approximately 65% compared to a non-optimised deposition scenario. This reduction is a direct measure of the cost-effectiveness and success of the integrated planning approach.

4 Instrumentation network review and integration

4.1 The role of instrumentation in tailings facilities closure

The existing geotechnical and hydrogeological instrumentation network is vital for monitoring the tailings facilities performance during operation and the immediate transition phase. Crucially, the final data sets from instruments like piezometers confirm that the phreatic surface (watertable within the tailings mass) has reached an acceptable level, which is a prerequisite for stable closure. Therefore, the network must be maintained and verified until the final performance baseline is confirmed.

Typical instrumentation:

- vibrating wire piezometers
- standpipe piezometers
- inclinometers
- settlement plates
- survey monuments
- surface water management
- drainage system monitoring.

4.2 Comprehensive review methodology

A comprehensive 2-stage review was essential to ensure the network was compatible with the planned closure construction:

- *Stage 1: condition verification*

All critical instruments (piezometers, inclinometers, and settlement monuments) were subjected to a functional check, including data reliability review and calibration against final survey coordinates. This ensured the integrity of the data used for the final geotechnical sign-off.

- *Stage 2: location compatibility and interference detection*

The location of every instrument was checked against the final closure design drawings (cover system, drainage channels, and access roads). This process identified potential interferences between instruments, foundation preparation, liner placement, and drainage construction.

4.3 Adjustment and decommissioning planning

Based on the review, precise actions were planned:

- Protection/relocation: a select number of vital piezometers needed for long-term monitoring (post-closure) were either protected with specialised casings or planned for relocation to positions outside the main construction envelope.
- Decommissioning planning: all other instruments that were no longer required were included in a detailed decommissioning plan. This critical step ensures that instruments (especially piezometers) are properly grouted and plugged to prevent them from becoming preferential vertical flow paths for contaminated water, which is a significant risk to long-term TSF integrity.
- Pipeline integrity: the final discharge pipelines and associated flow monitoring systems were reviewed, ensuring their final purge and dismantling would not disrupt the newly shaped tailings surface or contaminate final drainage routes.

5 Alignment of operational infrastructure with closure construction

5.1 Transitioning discharge systems

The physical infrastructure – specifically the main discharge pipelines and pumping stations – must be systematically closed out. The strategy at Sandfire MATSA involved a staged final purge process using water and air to remove all remaining thickened tailings. The piping was then dismantled and recycled offsite. The key challenge was performing this clean-out without damaging the newly established final surface contours created by the D4L strategy. This required a highly localised and controlled operation.

5.2 Use of final infrastructure for closure works

To maximise efficiency, existing operational infrastructure was converted into permanent closure features:

- Access roads: primary operational access roads, built for heavy haulage, were assessed for their suitability as permanent inspection roads and maintenance routes for the closed TSF, reducing the need for new road construction.
- Discharge corridors: areas previously dedicated to pipeline corridors were often designed to align with final drainage channels, providing a pre-established, gently sloped route for surface runoff.

5.3 Financial and schedule impact

The integrated approach directly impacted the closure project's financial and scheduling performance:

- Cost savings: the 65% reduction in earthworks volume translated into substantial savings in equipment rental, fuel consumption, and labour hours.
- Schedule compression: by pre-shaping the surface during the operational phase, the closure construction phase (surface preparation and cover placement) could commence immediately upon cessation of deposition, significantly shortening the overall project timeline and reducing the financial liability period for the operator.

The ability to move directly from deposition to cover placement without an extensive intermediate earthworks phase proved to be the single greatest schedule efficiency achieved.

6 Reclaim pond management and progressive reduction of the supernatant pond

The management of the reclaim pond is a critical component in the operational and closure performance of the Sandfire MATSA DPS. Although tailings technology inherently reduces the volume of supernatant water compared to conventional slurry systems, maintaining a controlled reclaim pond is essential for water recovery, operational flexibility, and ensuring the safe transition toward closure.

During the operational phase, the reclaim pond has been maintained at a minimum practical volume to balance water recovery needs and geotechnical stability. The use of barge-mounted pumps and floating intake systems allows continuous decanting while adapting to seasonal fluctuations in water balance. Regular topographic and bathymetric surveys have been conducted to monitor the pond area and elevation, ensuring that its extent remains within the operational envelope defined by design criteria.

A progressive reduction strategy has been implemented to minimise the size of the reclaim pond as deposition advances. This strategy involves controlled spigot rotation, elevation management, and deposition sequencing to promote uniform beach development and reduce localised ponding. The objective is to encourage tailings consolidation and achieve a gently sloping surface that naturally directs runoff toward designated reclaim zones or perimeter drainage structures.

As closure approaches, the remaining pond volume is systematically reduced through water recovery to the process plant, combined with natural evaporation and infiltration control. The final stages of reclamation will ensure that all supernatant water is removed or integrated into the closure drainage system, leaving a stable, unsaturated surface. This progressive approach significantly reduces closure risks, avoids abrupt dewatering operations, and supports the formation of the final self-draining landform required for long-term surface water management.

7 Plan review

7.1 Key success factors

The successful transition to closure at the Sandfire MATSA DPS was founded on 3 non-negotiable pillars:

1. Early integration: defining the closure design as an operational target from the outset, moving beyond siloed planning.
2. Technological application: utilising numerical modelling and high-precision surveying to execute the D4L strategy, proving that precise final surface shaping.
3. Proactive management: treating the instrumentation network as a critical asset for both operational and final performance sign-off, ensuring its verification and compliant decommissioning.

7.2 Broader applicability and limitations

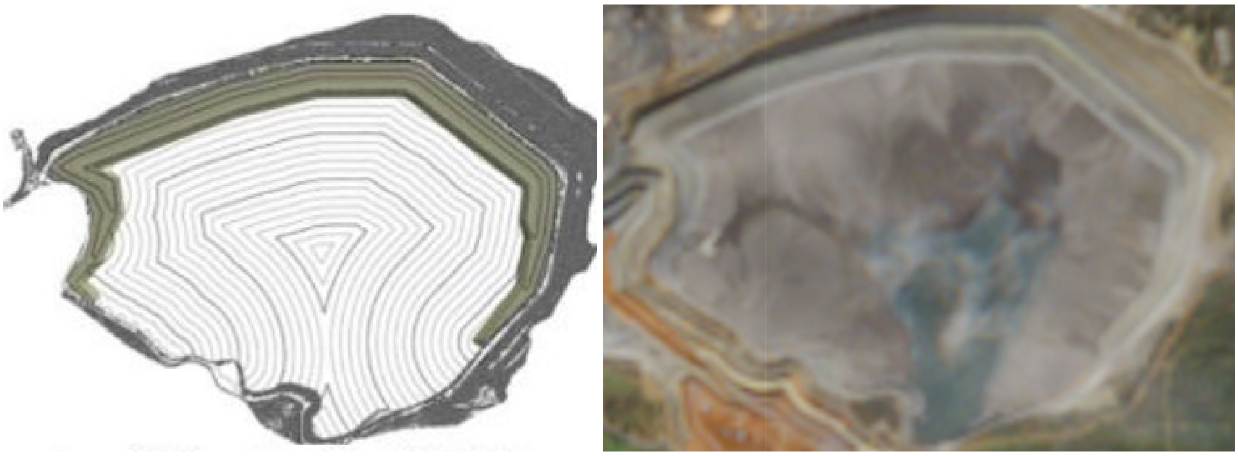
This integrated model holds high applicability for other thickened tailings facilities (TTFs) globally, especially where high consolidation rates allow for greater control over the deposited shape. However, this approach has limitations:

- Rheology dependence: its success relies heavily on the consistency and predictability of the tailings rheology. As the tailings operation for the closure will be limited (2 years maximum), there will be the chance to review and address in case before the final doming of the facility.
- Surveying investment: the D4L strategy requires a greater initial investment in high-frequency, high-precision surveying and modelling during the final years of operation.

7.3 Lessons learned and future research

The primary lesson learned is the necessity of cross-functional communication between the operations, technical services, and closure/environmental departments. The operational spigoting schedule must be directly driven by the closure department’s final landform requirements.

During the last quarter of 2025 and the beginning of 2026, the first stage of the closure plan was executed. Figure 3 illustrates the completed configuration of this stage, alongside a satellite image acquired on 23 January 2026. The results were excellent, confirming that the initial hypotheses for the construction were successfully met.



(a) (b)

Figure 3 (a) Closure project Stage 1 plan; (b) Copernicus Satellite image 23 January 2026

Future research should focus on the long-term performance monitoring of the pre-shaped surface, specifically comparing the erosion performance of these in situ formed channels versus traditional constructed drainage channels using earthmoving equipment.

8 Conclusion

The Sandfire MATSA DPS case study conclusively demonstrates that TSF closure can and should be achieved as a deliberate extension of the operational phase. The key to this success was the strategic shift from a volume-focused deposition schedule to a landform-focused (D4L) spigoting strategy.

The optimised deposition approach successfully pre-shaped the final tailings surface, resulting in an estimated 65% reduction in costly post-closure earthworks. This was coupled with a proactive review and compliant decommissioning plan for the existing instrumentation, ensuring data integrity and preventing future geotechnical risks.

This integrated approach – combining optimised deposition planning, spigoting management, and instrumentation control – is fundamental for achieving a stable, compliant, and demonstrably cost-effective TSF closure.

Acknowledgement

The authors would like to express their gratitude to Sandfire MATSA and all its departments – including operations, water management, geotechnical, processing, and environment – for their continued collaboration and commitment to responsible tailings management. Their proactive engagement, data sharing, and dedication to integrating closure objectives into daily operations have been fundamental to the success of this project.

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