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A holistic approach to large-scale alternative dewatered tailings management: lessons from case studies

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Abstract

Large-scale alternative dewatered tailings applications are increasingly being considered in the mining industry in an era of water scarcity and focus on dam structural integrity. However, evaluating business cases for these applications is often ineffective when based on costs alone. Leveraging lessons from the authors' multi-disciplinary team approach over several years, this paper makes the case for a new, more holistic approach to create effective business cases for evaluating large-scale alternative dewatered tailings applications. Effective business cases not only consider costs but also key drivers including physical and chemical stability, land and water usage, potential environmental impacts, and other sustainability drivers considered over the life of mine, while meeting regulatory requirements.

This approach expands the battery limits traditionally used by siloed discipline engineers to examine a wider range of pathways through the tailings management system from dewatering plant to ultimate facility design. The key drivers and trade-offs that have the potential to significantly impact project economics are the focus.

To optimise a case and potentially be more cost competitive, the authors propose that the tailings dewatering technology selection follows the filtered tailings storage facility (TSF) design, rather than lead the design. Rather than starting upstream at the dewatering plant and targeting a tailings solids mass concentration, it is more productive to consider the final TSF landform (and geotechnical and chemical stability requirements) and work back upstream to optimise material handling to achieve this constraint. The achievable filtered tailings moisture content or thickened tailings rheology are then determined to meet these downstream requirements.

Often a hybrid system of filtered tailings with conventional wet slurry tailings provided the best technical and economic business case when considering proof of concept at scale of current filtration technologies. Benchmarking against large pilot-scale filtration studies and full-scale thin lift deposition operations was useful in identifying potential project risks and opportunities.

One of the key drivers used in the proposed holistic approach is the potential water savings. Water recovery from tailings can occur at the tailings dewatering plant and/or at the TSF itself. In all cases, the balance between water recovered from one area versus another must be optimised to minimise capex, opex and operational risks. It is recommended that stakeholders collaborate to evaluate the risks and opportunities in the project planning and design stages using a systems risk-based and multi-criteria decision analysis (MCDA) approach. Using this method, considering identified key drivers, enables the making and documentation of design decisions and the identification of potential opportunities.

Keywords: *large scale, filtered, stacked*

1 Introduction

Making a successful business case for the dewatering and subsequent transport and placement of fine-grained tailings at large scales (50 ktpd and above) includes considering the industry's push to explore alternative tailings approaches, in addition to cost optimisation. Key drivers other than costs may include minimising tailings physical stability risks and potential consequences (such as deformation, potential loss of life and environmental impacts), reducing seepage and potential groundwater impacts (by eliminating the reclaim water pond at the facility or maximising water recovery ahead of deposition), providing flexibility in land usage and reducing footprints, and maximising tailings storage facility (TSF) capacity over the life of mine.

Similar physical stability and seepage reduction can be achieved for various alternative dewatered tailings systems, even with broadly variable deposition approaches. The authors have found that the siloed selection of dewatering, material handling and deposition processes does not provide the most effective approach to building an optimum solution. Instead, the authors discuss several examples of key drivers and metrics that can be considered as part of a holistic approach to extrapolating both proven and emerging technologies to large-scale alternative dewatered tailings applications.

In the holistic approach, a multi-disciplinary team of tailings dewatering technologists, large-scale materials handling experts and non-conventional tailings facility design engineers (referred to here as the holistic team) were convened for the duration of each project to evaluate and de-select pathways through the tailings management system (Figure 1). At each step, and for each pathway, optimisations were sought based on trade-offs of key metrics, working backwards from TSF siting and design to cost-effective material transport, deposition and stacking plans. Desired dewatered tailing properties (whether based on rheology of high-density thickened tailings or filter cake moisture content) were thus defined.

For each project, several alternatives were considered, and then trade-offs on key cost and other drivers were used to narrow down the selection to preferred investment options. In some cases, this approach was used to show that a particular tailings management system (or ‘pathway’ in Figure 1) was not economically feasible at the scale of the project, or not technically feasible based on the current state of the technology required. For other projects of similar scale but with differing site constraints, a sufficient business case could be made to continue into proof of concept piloting.

Filtered tailings trade-offs centred on whether large-scale applications would be better served by a staged implementation to minimise risks and maximise opportunities. The staged implementation reduces project risks by allowing for an anticipated operational learning curve and taking advantage of any future technology improvements, rather than trying to address all the risks of a full-scale implementation too soon or through potentially incomplete pilot-scale field trials. Other examples of considered metrics/trade-offs include whether targeting higher filter cake moisture contents at the dewatering plant could be leveraged to optimise dewatering costs against the potential for evaporative drying at the TSF. A range of moisture content targets were explored, considering filtration efficiency as well as transport and material handling impacts of achieving lower versus higher cake moistures at the plant or in the TSF. For high-density thickened tailings alternatives, targeting slurry rheology (yield stress) rather than slurry solids mass concentration presented opportunities to evaluate both dewatering technology, water balance, transport efficiency and ultimate deposition opportunities, including beaching and enhanced evaporative drying.

Ultimately, the holistic approach allowed the team to better understand dewatering technology constraints and opportunities, material handling and stacking/deposition plan strategies to optimise both capex and opex, and the placement and handling that were key to meeting the stability requirements of the proposed landforms, discussed further in Section 2.2.

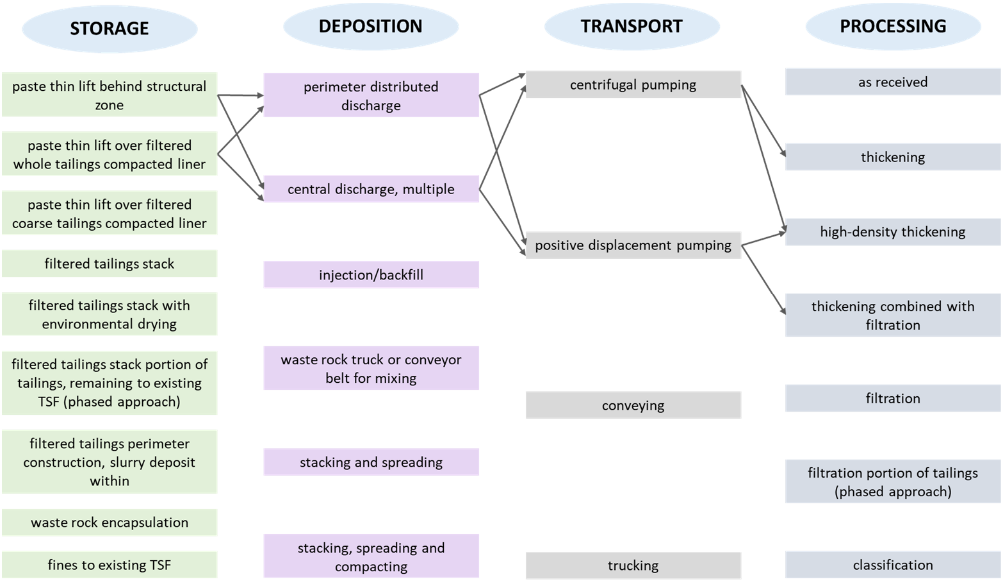


Figure 1 **Example of holistic approach to selecting pathways through the various processes of the tailings management system to develop options for evaluation**

2 Key drivers

Several key drivers exist for moving towards alternative dewatered tailings systems and should be considered upfront when evaluating tailings management options.

2.1 Water savings

The copper mining industry reports an average water consumption of between 0.5 and 0.7 m^3 per tonne of ore processed. This water is essentially lost to evaporation, seepage and in situ entrainment with the tailings solids in the storage facility. Major copper producer Chile is expecting that up to 71% of this water will come from desalination sources by 2033 (Comisión Chilena del Cobre 2022). According to a McKinsey report (Brychcy et al. 2020) desalinated water in regions such as northern Chile can cost up to 10-times more than aquifer-sourced water. The incentive to reduce water consumption is increasing as water costs and scarcity rises.

While there are many examples of filtered tailings applications, particularly in precious metals, at the time of writing this paper, the industry had yet to see a large-scale copper tailings filtration operation. To delay capital costs associated with filtered tailings systems, a phased approach may be taken where a fraction of tailings is filtered before moving to 100% filtration. Significant water savings can be achieved without the high upfront costs and operational risk of converting to a complete filtered tailings system.

A simplified example of the potential water savings associated with transitioning to filtered tailings is shown in Figure 2 for a typical conventional or cyclone sand dam copper TSF. This example assumes that all water removed from tailings at the filter plant is recovered and that any water remaining in the filtered tailings is not. Minor losses, such as filter plant water recovery inefficiencies, are not accounted for in this simplified graphic.

The x-axis shows the fraction of tailings by solids mass diverted to filtration, with the remaining tailings being deposited in a conventional manner at a water consumption rate of between 0.5 and 0.7 m^3/t. The y-axis shows the corresponding water consumption rate, indicating the potential water savings. The green area of the graph shows that water consumption can be reduced by 25 to 32% through filtering half of the tailings to a 20% filter cake moisture content (25% geotechnical moisture content). This range of reduction is increased further to between 32% and 37% for a 15% filter cake moisture content (17.6% geotechnical moisture content) shown in the blue area of Figure 2. This generic figure is a useful tool for upfront evaluation of water savings when considering alternative dewatered tailings pathways through the tailings management system.

One obvious benefit of improving water consumption is the ability to expand production with a fixed available water quantity. Several copper operations have limited water rights, and these rights will become more difficult to acquire as competition for water access increases.

Figure 3 shows an example from a US based copper project that is currently designed for 27 ktpd. To date, this project has only secured 1,062,000 m^3/year of water rights, which could have a severe impact on the tonnes of copper ore that can be processed. If more water is not made available, an operation with a conventional tailings system (water consumption of 0.5 m^3/t) would only be able to process around 6 ktpd. Implementing a filtered tailings system could potentially increase this rate to around 16 ktpd, however, this is still shy of the 27 ktpd target.

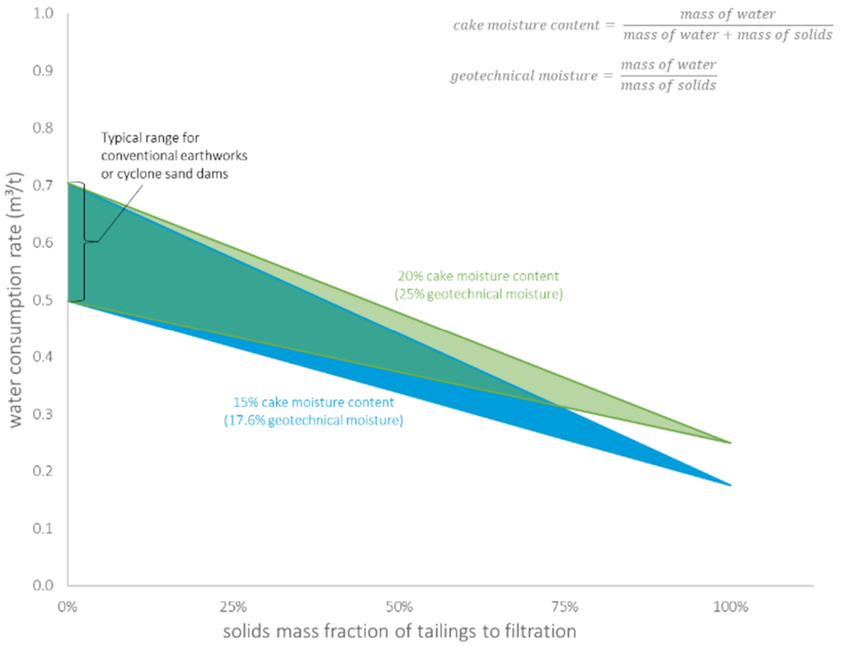


Figure 2 **Water consumption rate reduction with fraction of tailings to filtration**

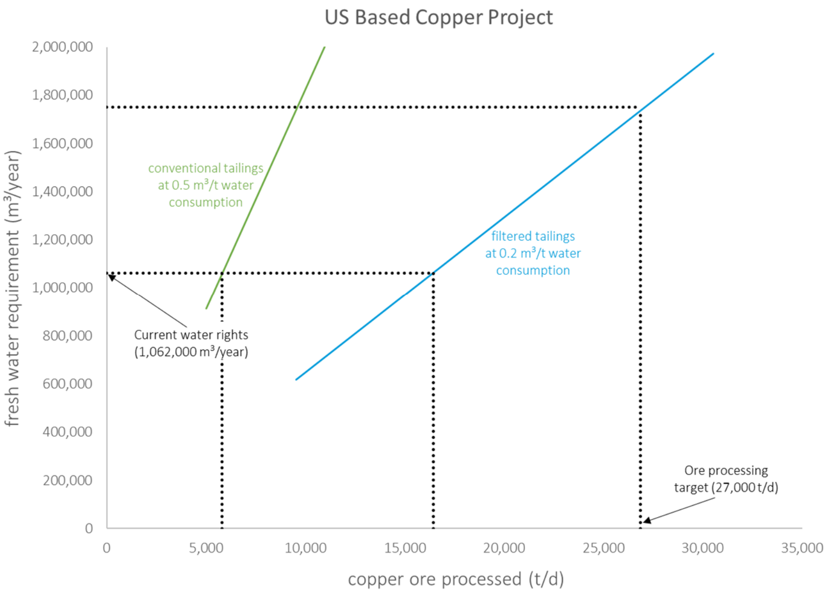


Figure 3 **Freshwater requirements for US based copper project**

2.2 Landform stability

Alternative dewatered tailings applications ranging from paste and high-density thickened, centrifuged, and filtered tailings have the potential to deliver a geotechnically stable landform. Key drivers and metrics around landform stability include:

- Enhanced physical stability: the ability of the stack to withstand excessive brittle/catastrophic failure versus acceptable deformations and/or differential settlements given variability of saturation (transient pore pressure development) within the stack (Norambuena Mardones et al. 2023) as well as foundation conditions and geologic-seismic hazards (loadings).
- Reduced chemical stability risks (including acid rock drainage potential) through both concurrent reclamation and infiltration minimisation, lower overall driving gradients and reduced seepage potential based on both less entrained water and lower overall permeability of the compacted or consolidated tailings.

Maximising water recovery combined with enhanced evaporative drying also contributes to strength gains, above and beyond the contribution from an increase in density via compaction or consolidation alone (Simms 2021). However, relying on evaporative drying alone can limit the safely achievable overall stacking height (Reid & Fourie 2023).

If the deposition plan does not involve borrow or waste rock embankments as structural containment, at least some percentage of the tailings will need to undergo mechanical dewatering (most likely by pressure filtration) to improve the strength of the structural zone of the facility and achieve the desired stability. For this structural zone, mechanical compaction to some degree of standard or modified Proctor specification will be required, and compaction at the requisite nominal earthwork lift thicknesses of 30 to 50 cm or less to achieve the specified density will drive the stacking plan, equipment selection and costs.

2.3 Other drivers and corporate commitments

A business case for alternative dewatered tailings does not only consider available technology and cost drivers. Other metrics that can be more difficult to conceptualise are needed, such as scalability of available technologies, transition risks (for brownfield operations), process complexity, industry benchmarking, ESG and other corporate commitments. As one operator put it:

> *'…the preferred investment alternative must be one that complies with delivering the most attractive option for the asset, in which risks are better controlled and that fully complies with standards of practice and corporate guidelines, standards and commitments. The focus should be on lowering the risk of the TSF profile by means of reducing the amount of water stored in the facility, and assessing non-conventional options aimed to enhance dam safety, reduce PAR (People at Risk) and the TSF's overall risk of failure.'*

For example, a key benefit of dewatered tailings is the reduction of potential impacts to groundwater because of less entrained water being sent to the facility and lower driving gradients at the facility (due to the lack of impounded water with the drying of tailings during placement and compaction, and the lower hydraulic conductivity of placed tailings). This leads to a transient drain-down rather than a steady state condition which can significantly reduce the potential for seepage even if the facility is unlined. Achieving these unsaturated conditions therefore has benefits beyond just physical stability.

In the alternatives de-selection process, the authors have found it advisable to first evaluate alternatives for pre-identified key drivers before considering costs. For example, reducing probable loss of life (PLL) also involves reducing people at risk (PAR), not only downstream of a facility but also on the working platforms of a filtered tailings stack. Physical stability of unsaturated or partially saturated tailings can mitigate the PLL if the facility is designed and constructed to manage anticipated deformations under static and seismic loadings, as opposed to having to consider 'dam' breach scenarios for saturated slurry tailings. However, over-simplifying PAR exposure can have consequences if, for example, mechanically compacted filtered tailings zones require a large mobile fleet, and the operational working deck has a significant number of people present during a shift. If these are not reasonably differentiated from downstream PAR (as the operating crew are compacting to achieve dilatant conditions and would likely observe any developing distress or deformation), then the increased number of people working in the immediate vicinity of the working deck might result in the TSF having a lower dam safety score overall. Consideration is being given to remote controlled fleets and/or stacking plans with heavier reliance on conveyors and stackers rather than conventional earthworks mobile fleets, in part, to reduce the number of people on the operating deck.

Corporate commitments to reduce carbon emissions and reliance on diesel trucks is another key metric (if not constraint) with significant cost impacts for large-scale operations. The earthworks associated with filtered stacked tailings requires an increase in mobile fleets (trucks, dozers, graders etc.). Consideration can be given to all-electric fleets, but the source of electricity should be queried. Comprehensive trade-off studies should properly account for all sources of carbon emissions across the operation that may be impacted by conventional versus alternative dewatered tailings management (including dewatering processes, pumping of tailings and reclaim water, and desalinisation and pumping of make-up water supply if not locally sourced). It is not often that a complete accounting of carbon emissions across the operation is undertaken at the project planning phases.

In terms of corporate commitments, it is the authors' experience that owners willing and able to invest substantially in proving technologies and executing well-conceptualised experiments to test approaches at bench, pilot and field scale are those who are making the most progress towards envisioning the mine of the future.

3 Stacking plan considerations

3.1 General

Over the course of several projects the holistic team worked through an alternatives de-selection process rather than the more typical 'selection' process. De-selection involved brainstorming all possible approaches (Figure 1), but purposefully working backwards from considering the siting constraints of the space to be filled to exploring pathways through deposition/stacking plans, material handling and dewatering to evaluate the most technological and economical methods to filling it. This approach addresses questions such as how much tailings characteristics and operational variability can the design tolerate? How will the variability be managed over the life of the asset? Can optimisation, staging, or combinations of processes and stacking plans be used to maintain flexibility and robustness of large-scale alternative dewatered tailings systems?

Stacking plan metrics include haul distances and geometries, throughputs, required lift thicknesses and achievable in situ void ratios/densities (achieved through compaction, consolidation and/or evaporative drying).

Lessons learned by the authors on key drivers/metrics include:

- Lift thickness and density requirements (whether compacted or not, and if so to what degree) for structural and non-structural zones need to be considered in context of not only the geotechnical requirements, but also from material handling and stacking equipment constraints.
- For a given filtered tailings stack, the ability to manage static and seismic strain softening, liquefaction potential and associated deformations without catastrophic (brittle) collapse can be achieved both through filtration and other dewatering methods (centrifuge, high-density thickening) if combined with drying processes and/or mechanical compaction at the TSF. Similar ultimate stack performance can be achieved for each, if the degree of saturation of various lifts, rate of rise, transient pore pressure development and overall stack design height are part of the stacking plan development and consistently managed during operations.
- Stacking plans need to be optimised for different landform geometries (side hill fills, valley fills, ring-dykes, downstream versus upstream constructions) and structural and non-structural zones

need to be considered early in the project to determine equipment requirements, material take-offs and staging over the life of mine.

- Stacking plans must be appropriate for the scale of the project (with industry benchmarking taken into consideration).
- Stacking plans that incorporated fixed conveyance over long distances, portables and trucks over the shortest possible distances, or eliminated trucks from the system altogether made the best business cases.

Stacking plans that could also reduce the amount of water entrained at the facility were considered during optimisations. It was found that there is more than one pathway to achieve and maintain unsaturated conditions, and that both mechanically and hydraulically placed tailings allow for a reasonable balance of rate of rise and pore pressure dissipation versus opex and ultimate heights planned.

It has been postulated that transient pore pressure build-up begins to develop on compacted samples with a degree of saturation between 80 and 100% (Aghazamani 2022) or even lower at 60 to 70% saturation. However, practical experience on operating tailings stacks has demonstrated that the potential for pore pressure build-up can be successfully managed through the stacking/sequencing plan for the height of facility at the time of the transient conditions. Transiently elevated pore pressures within the stack should be anticipated and if monitored and managed appropriately, do not automatically lead to a de-stabilising condition. As with conventional facilities, both the rate of rise and the pore pressure development needs to be actively monitored and balanced with the compaction specifications to achieve the desired stack physical stability during each stage of growth.

3.2 Material transport and handling

Engaging the holistic team early to benchmark fit-for-purpose and hybrid material handling systems against similarly scaled projects (even if not strictly tailings projects, e.g. heap leach projects) led to appropriately scaled innovative approaches being considered. Key metrics for integrated material transport and handling include:

- Achievable filter cake moisture content
- Conveyability and material flow behaviour
- Material properties consistency/variability
- Transport distance
- Equipment availability and system redundancy
- Tailings tonnage/scale
- Deposition planning/stacking plan.

One example of a lesson learned through the holistic approach is that the optimum deposition lift for most portable stacking systems with radial stackers is 5 to 7 m. For larger advance or retreat stacking systems the optimum range is significantly higher at 15 to 30 m lifts. For structural zones, geotechnical engineers target 50 cm lifts or less, as sufficient compaction of material in lifts above this is not feasible (Norambuena Mardones et al. 2023). However, several benchmarked projects considered not only dewatering in a silo, but also material handling. Vendor quotes were sought long before an integrated stacking plan with required lift thicknesses was developed. The reverse was also observed, where several benchmarked projects considered piloting dewatering plants at scale without considering how material handling would impact the overall capex and opex of the full-scale project.

Trade-offs and a refined series of holistically optimised stacking plans demonstrated that:

- In many instances, it was impossible to completely remove trucks from the system.
- Those stacking plans that considered either reduced or removing trucks from the system showed the most promise in terms of economic feasibility.
- Intensive face-to-face workshopping of high-level stacking plans by the holistic team resulted in some innovative integrated approaches being considered. These included alternatives that allowed for more rapid stacking using currently available technologies while still achieving thinner lifts, and producing piles that could be more easily knocked down with dozers.
- Successfully operated stacks have also included training of earthworks/operation crews in more conventional earthworks construction and optimisation. This learning and optimisation curve around material handling and placement at variable tailings moisture contents has been the focus of interactions between design engineers, the engineer of record, the designated in-house responsible tailings facility engineer (RTFE), operation crews and contractors. When combined with instrumentation and monitoring it can also help re-define what is acceptable in terms of placement moisture specifications for the stack at the current growth stage as well as for the future, ultimate landform.

Several innovative integrated alternatives continue to be developed and are planned to be piloted at half-scale for proof of concept. A key lesson learned through this process is that innovation only truly comes from the hard-fought working through of project challenges.

3.3 Mechanical placement versus hydraulic deposition and enhanced evaporative drying

Dewatering tailings to some degree before deposition either by thickening, centrifuging, or filtration can mean gains of days, weeks or months compared to hindered settlement and consolidation of conventional slurry tailings.

Stacking plans for filtered tailings require consideration of mechanical placement and compaction of tailings in nominal earthwork lifts to achieve desired trafficability and strength in both structural and non-structural zones, albeit to potentially differing compaction specifications depending on desired performance of each zone.

High-density thickened tailings deposition offers potential benefits with regards to operating cost (over filtration and mechanical placement and compaction) and potential benefits in terms of water savings, footprint, seepage minimisation and decommissioning (over conventional slurry). It may be possible to gain much of the scale of benefits by thickening only to a consistency which allows the discharged slurry stream to flow into position without the need for mechanical assistance (McPhail 2008).

Alternative stacking and deposition plans, including consideration of thin lift hydraulic deposition with enhanced evaporative drying, show promise with respect to desiccation if achieved and maintained (local climate and operation allowing) and can lead to increased dilatancy and strength gains. Desiccation, if coupled with thin lift deposition (both with and without mud-farming), can also lead to substantial pre-consolidation pressures and strength gains that may not be overcome be subsequent lifts (Simms 2021), i.e. the tailings have the potential to achieve and maintain a dilative state, without mechanical compaction, depending on the overall proposed stacking plan, geometry and height of the tailings.

Evaporative drying coupled with continued self-weight consolidation have the potential to achieve a stable stacked landform. Unsaturated modelling may be used to predict the likelihood of success for project specific conditions. Figure 4 presents example simulations (Simms et al. 2007) for 0.2 and 0.5 m lifts underlain by either wet tailings (with pore pressure equivalent or higher than the freshly deposited lift) or dry tailings (with negative pore pressures resulting in additional dewatering by capillary adsorption up to the point that pore pressures in the previously deposited and freshly deposited lifts equilibrate). It is worth exploring whether the entire stack can achieve, and maintain, unsaturated conditions through hydraulic deposition and enhanced evaporative drying alone, particularly if it allows for a reduction in capex and opex.

Limitations to this approach include the potential for salt to form a crust and inhibit evaporation, requiring some form of mechanical working to break up the salt crust.

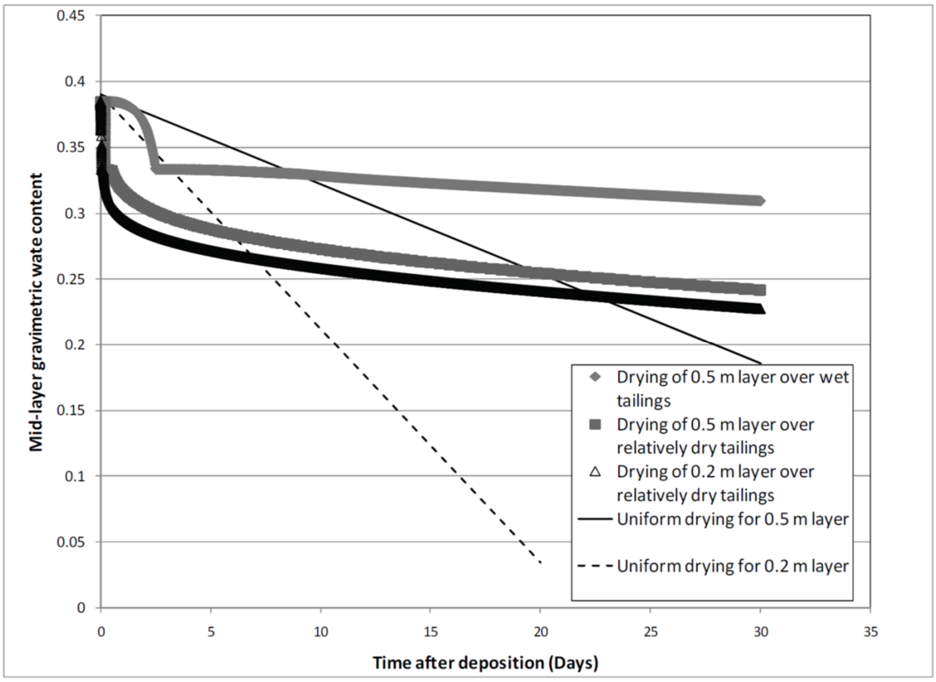


Figure 4 Simulation of drying for fresh layer deposited over 5 m of wet (gravimetric water content = 30%) or relatively dry (gravimetric water content = 20%) basal lift (Simms 2021)

Key risks include not maintaining consistent target slurry rheology during operations and loss of deposition control, including seepage and deposition plans/beaching not being realised as intended or modelled. Challenges include deposited layer thickness control, beaching distance and geometry (overall slopes achieved) and gaining operational experience in managing deposition. Based on several large-scale field trials and operations that the authors are aware of (Simms et al. 2007; McPhail 2008; Engels et al. 2018), the targeting of rheology, operation of thin lift deposition, and determination of cycle times is a steep learning curve and is heavily dependent on the operator's experience.

4 Dewatering process design and efficiency

It has been the authors' experience that early, direct, and frequent communication between the dewatering plant designers and the filtered TSF engineers is a key component to the success of challenging large-scale projects. The risk of a siloed approach is that the owner may end up with a project that is not pursued because of high dewatering plant costs driven by the dewatering plant designer chasing a target moisture content at the plant imposed by the geotechnical engineer, without considering what is economically achievable based on current technology. As an example, it is important filter plant designers be given a 'range' of acceptable filtration performance given the actual requirements of the project, and target moisture content is not defined by the equipment supplier but by what is acceptable to achieve the required compaction at the operating deck. With this flexibility, the optimised (lowest capex and opex) dewatering plant and stacking plan can be devised at ever increasing tonnages.

4.1 Thickened tailings yield stress target

For high-density thickened, hydraulically placed, thin lift deposited tailings, there is a balance between having a low enough yield stress (higher water content) to economically transport and place the material per the stacking plan versus maximising water recovery (lower water content) ahead of deposition to minimise the water loss through purposeful evaporation. Coupled with this are practical limitations to what current thickening technologies can achieve at full-scale.

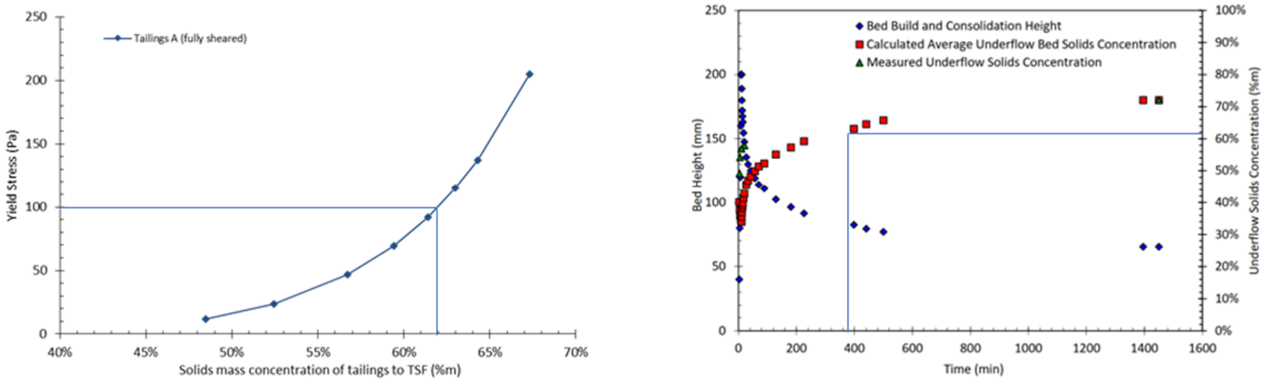
For a confidential large-scale application, the authors found it effective to approach the design by first completing trade-off studies across a range of slurry yield stresses with the following competing objectives:

- As high as possible for maximum water recovery at the plant and efficient evaporative drying in the field.
- Within achievable ranges based on available thickening/dewatering technologies and equipment constraints.
- Within desired ranges for economic pumping/transport.
- To achieve desired beaching behaviours within desired run-out distances.

Beaching analyses for a range of yield stresses, spigot arrangements and modelled deposition behaviours (based on established benchmarking) indicated that a yield stress between 55 and 65 Pa could produce the desired deposition for 2 and 3 km beach lengths and achieve an overall slope of 3%.

Subsequent slurry transport studies showed positive displacement pumps were required for these tailings from 40 up to 100 Pa yield stress, however, the pumping system could be designed to handle 60 to 80 Pa, and even up to 100 Pa if run with one less pump or slowing the pump speed down, at reduced costs.

Following these studies, the dewatering plant designer was presented with a target slurry yield stress range of 60 to 100 Pa, with 100 Pa offering the greatest water savings opportunity for the site. Bench scale thickening and 24-hour consolidation testing by both the authors and a major thickener supplier showed that these tailings were amenable to high-density and paste thickening, and that up to 100 Pa should be achievable in a paste thickener (Figures 5a and b).



(a) (b)

Figure 5 **(a) 100 Pa fully sheared tailings equivalent solids mass concentration; (b) Bench scale 24-hour consolidation testing to achieve equivalent solids mass concentration.**

Examples from industry have shown difficulties in achieving design thickener underflow concentrations and yield stresses close to 100 Pa in large paste thickeners (>30 m diameter) due to scale-up issues from laboratory testing and issues with thickener system design:

- Toromocho copper operation in Peru where 4 × 43 m diameter paste thickeners were installed to achieve up to 69% solids mass concentration for around 100 Pa underflow, but were not able to achieve this consistently (Johnson & Vizcarra 2020).
- Centinela copper mine in Chile installed 3 × 45 m paste thickeners to support their 3 × 60 m diameter high-density thickeners in achieving a combined yield stress range of 30 to 50 Pa (Vargas & Pulido 2022).
- Aktogay Copper in Kazakhstan have successfully installed 3 × 45 m diameter deep cone paste thickeners to achieve 68% solids mass concentration. The corresponding target yield stress has not been published at this time.

Thickener technology is typically classified by the operating torque range of the rake mechanism, as summarised in Table 1. A key consideration when sizing the mechanism is that the thickener mud bed is unsheared and can have a significantly higher yield stress than the fully sheared thickener underflow after it has gone through the underflow pump. It is recommended that paste thickener technology (deep cone, high side walls and high mechanism torque rating) is selected for cases where the expected unsheared vane yield stress is approaching 100 Pa to allow for any unexpected spikes in rheology above 100 Pa. It should be noted that thickeners are sized based on vane yield stress measurements and that these values are different from Bingham yield stresses measured using rotational and tube viscometers.

Table 1 Thickener technology classification

Technology	k-factor	Maximum operating torque (Nm)	Typical maximum diameter available (m)
High-rate	50	10,530,000	120
High-density/compression	100	14,630,000	100
Paste	300	8,890,000	45 (largest installed)
		13,280,000	55 (largest designed and quoted)

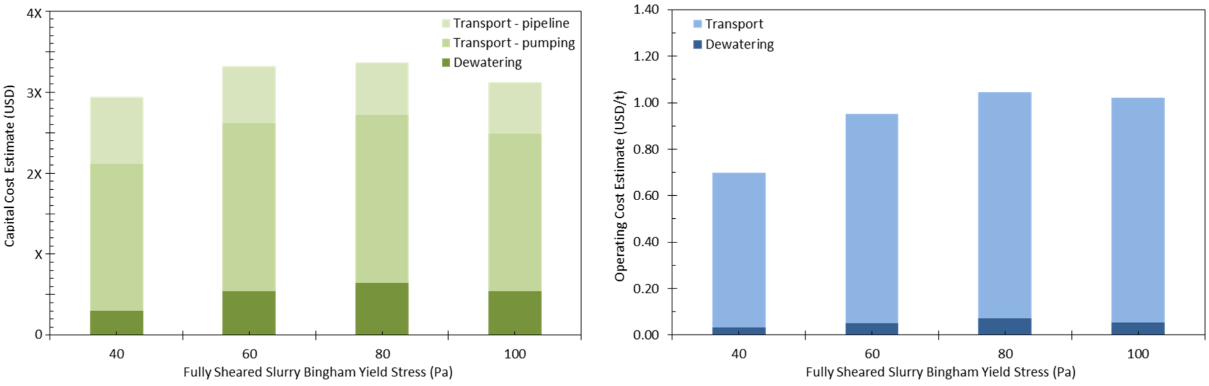
Unlike a conventional tailings system where the slurry yield stress is kept anywhere below a maximum yield stress and flow rate for transport, high-density thickened multi-spigot tailings systems require tight control of the slurry yield stress for deposition. This presents operational challenges as thickener performance can vary with short-term upset conditions, and longer-term changes in ore properties. In paste backfill plants, dialling in a tight tailings solids mass concentration is commonly achieved using partial stream filtration and water addition to make up specific recipes.

For the specific application presented in Figure 5, the paste thickener sizes are common between the 60 Pa case to the 100 Pa case at 45 m diameter and can be operated at different mud bed heights to vary the consolidation times required to achieve the target underflow solids mass concentrations. Lessons learned from industry benchmarking led to a recommendation that the tailings dewatering system be designed to achieve 80 Pa thickener underflow for trimming to 60 Pa to maintain tight control of the slurry yield stress for deposition. The paste thickener rake mechanism drive is designed for the 100 Pa Bingham yield stress case to allow for a robust tailings dewatering system that can produce higher yield stresses if any upside is achieved during operation.

Capital and operating costs developed (Figures 6a and b) indicated that designing for an operating window of 60 to 100 Pa final deposition was the optimum alternative:

- The slurry transport system can be designed to handle 60 to 100 Pa with minimal impact on costs.
- The paste thickeners can be sized to handle up to 100 Pa (fully sheared) with minimal impact on costs, and performance could be monitored upon start-up, and potentially pushed to higher thickener underflow densities if consistently achievable.
- The multi-spigot thin lift deposition plan could begin with 60 Pa and push up to 80 Pa or higher once operators have been through the learning curve and have a better feel for how the tailings flow at various conditions, subject to what is consistently achievable at the thickeners.

Starting the operation at 60 Pa is not ideal from a water consumption point of view, however, as Figure 7 shows, the higher cost of water consumed is balanced by the lower combined dewatering and transport costs. Pushing to higher yield stresses over time will improve the water consumption at site, allowing for potential expansion of production in the future.



(a) (b)

Figure 6 (a) Capital cost estimate by deposition yield stress; (b) Operating cost estimate by deposition yield stress

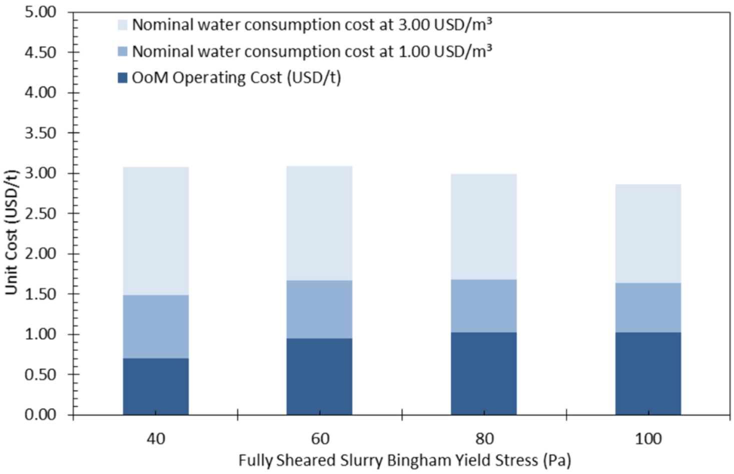


Figure 7 Impact of water consumption costs on unit operating costs

5 Making the business case

5.1 Alternatives de-selection

Alternatives de-selection can be made based on any number of pre-agreed upon evaluation factors, key drivers, and other metrics, including cost. Figure 8 provides an example of some evaluation factors that can be more difficult to conceptualise. Some of these can be evaluated through trade-off studies, while others through a series of risk, HAZOP, constructability and multi-criteria decision analyses (MCDA) workshops in which the holistic team, owner and other stakeholders participate.

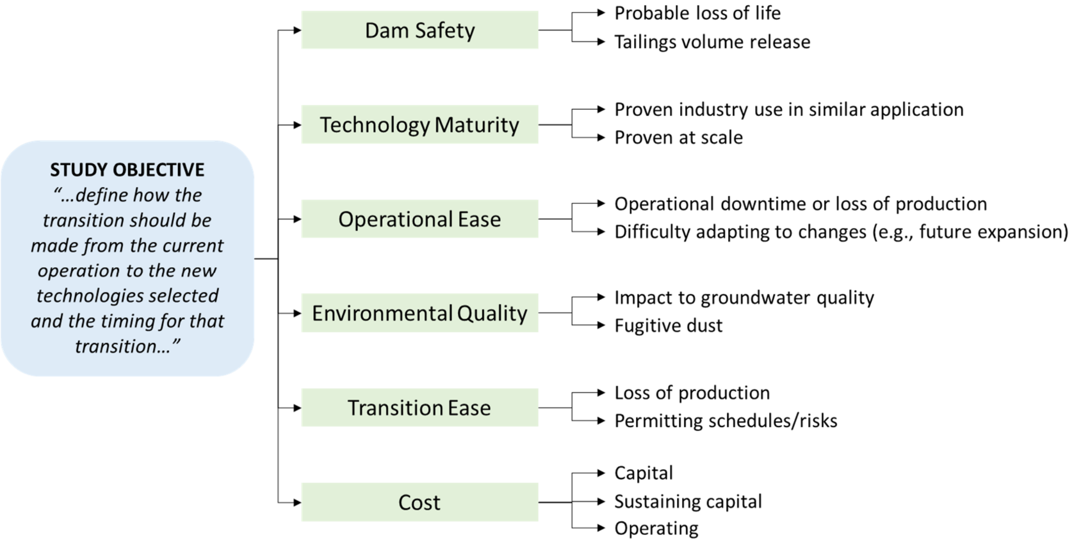


Figure 8 Example of project evaluation factors

Utilising an MCDA approach at the end of the trade-offs and workshops proved to be an effective way to compare alternatives and support (in a transparent, repeatable, and defensible way) both alternative de-selection and documentation of the basis for preferred investment option recommendations.

5.2 Net present value

While assessed separately from the other MCDA criteria, making the business case did also necessarily consider cost. Interesting findings from a recent evaluation using the holistic approach included:

- Dewatering capex and opex needs to be considered, regardless of whether at the plant or TSF, and high-level order-of-magnitude trade-offs on dewatering efficiencies can be used to not only optimise costs but to illustrate that dewatering opex must happen somewhere and may not be that different between alternatives.
- Net present values (NPVs) of a number of pathways through the tailings management system (Figure 1) can be considered in high-level trade-offs long before detailed designs are generated. Recent studies (Table 2) show that while the CAPEX and OPEX of various options combining trucking, fixed and portable conveying can vary widely, the NPVs may be relatively similar. For the example case presented in Table 2, there was no clear preferred alternative based on cost alone, and other key drivers such as risk of groundwater impact and site/foundation conditions may eventually prove to be the deciding factors in the ultimate selection of the preferred investment option.

Table 2 25 ktpd order-of-magnitude cost comparisons, structural zone only, 50-year life of mine. Total tailings production of 100 ktpd

Technology	Trucking only	Fixed conveyance + trucking	Fixed + portable conveyance + minimal trucking
Mobile fleet capex	USD -140 M	USD -100 M	USD -70 M
Conveyance capex	0	USD -80 M	USD -160 M
Average unit opex (USD/t)	USD -2.53	USD -2.56	USD -2.10
Total material handling and placement NPV (capex + opex) @8% annual discount rate	USD -360M	USD -350M	USD -354M

6 Conclusion

By applying a holistic approach to large-scale alternative dewatered tailings management studies, the following lessons were observed by the authors:

- For some recent studies, the order-of-magnitude NPVs of several pathways through alternative dewatered tailings systems are generally similar, however, the cost distribution varies, i.e. the costs are either incurred in capex or in SUSSEX/opex.
- The consideration of water consumption costs in the overall opex can make alternative dewatered tailings more economically attractive for sites that experience high costs for fresh or desalinated water.
- If sufficient dewatering and strength gain for the proposed landform height and geometries can be obtained for a large portion of the facility, it may be technically feasible (and generally more economical) to consider in situ dewatering by thin lift deposition and enhanced evaporative drying.
- If the fundamental principles of soil mechanics are considered and observed, similar physical stability can be achieved for the various landforms, even with broadly variable stacking plan approaches. The constraints on both cases are rate of rise, management of transient pore pressures, achieving required densities/void ratios and ultimate planned stacking heights.
- For large-scale pressure filtered options, removing or reducing the use of trucks from the material handling and placement system and replacing with conveying and stacking equipment can reduce both opex and PAR.

The authors' direct experience on project teams and independent technical/tailings review board participation has highlighted that hard-earned gains and technology leaps are not achievable until a functional deposition scheme is developed, and a holistic team of design engineers, the engineer of record, the RTFEs and onsite engineering and operations coordinate in making the operational reality match the desired plan. While good quality engineering and piloting can contribute to both project optimisation and de-risking, the 18 to 24 month commissioning and start-up period should be considered part of the plan to account for initially higher operational risks and costs to manage them, until operators have completed the necessary learning curve.

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