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GLOBAL TAILINGS INITIATIVE

Transforming the Flowsheet for Tailings



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EXECUTIVE SUMMARY

The mining industry generates roughly 13 billion tonnes of tailings each year (ICMM, 2025). The majority of that is stored in facilities that are, by volume, approximately half water. Over the past decade, more than 20 tailings dam failures across four continents have killed more than 400 people, released more than 25 million cubic metres of tailings and water, and caused severe environmental harm. The failure rate remains unacceptably high. This white paper, prepared under CEEC's Global Tailings Initiative, asks why incremental improvements to containment practice have not significantly moved the curve, and what must change upstream of the dam to achieve better outcomes.

The white paper's central hypothesis is that the industry should move away from considering tailings as a single stream and should instead match dewatering technology to much narrower particle size ranges. Permeability scales with the square of particle size, so a whole-of-stream design is dictated by the finest 20% to 40% of the feed even when the remainder could be dewatered with simpler and lower-cost equipment. Splitting the stream ahead of dewatering and choosing equipment that suits each fraction is the single largest lever available for reducing the capital cost, the operating cost, and the stored-water risk of a tailings facility. To take but one example: for a 100 kt/d operation, a circuit comprised of hydrocycloning, horizontal belt filter pressing, and centrifuging has the potential to reach the same tailings moisture as whole-of-stream pressure filtration at roughly half the capital and operating costs.

Three findings support this hypothesis and frame the rest of the document:

1. The dominant driver of dewatering difficulty is the minus 20 µm fraction, not the bulk particle size distribution (PSD)—a point that is neither well understood nor leveraged by the industry.
2. Clays cannot be treated as "small particles"; their surface charge, water chemistry interactions (conductivity, sodium adsorption ratio, pH), and dispersive state determine whether any given dewatering equipment can work at all.
3. Once these two variables are understood, the feasible solution space is much wider than contemporary industry's predominantly binary choice between conventional wet storage and wholesale pressure filtration. Sand separation, codisposal, layered horizontal belt filter precoating, centrifuges, and hydraulic dewatered stacking are all viable intermediate pathways worthy of consideration.

Moving away from a single tailings stream is somewhat challenged due to the lack of:

- a common classification framework so that metallurgical and geotechnical engineers describe the same material in the same terms, and
- a silo-busting, cross-disciplinary collaboration between process, geotechnical, and mine planning teams. These disciplines often make decisions with different success metrics and rarely see each other's constraints.

Without greater cross-disciplinary integration, rethinking tailings management may optimise for one discipline at the expense of another, and the overall optimum solution may not be realised in practice.

The white paper closes with a call to action for the industry to use CEEC's community of practice to seed research, peer-review emerging solutions, and share case studies (in particular, operating data from the handful of sites already running split-stream dewatering at scale). Solving tailings at a positive internal rate of return (IRR) is achievable with today's equipment and the right approach.

Key message

The central insight of this white paper is that tailings management can be materially improved by moving away from treating tailings as a single stream and instead matching dewatering technologies to specific

particle size ranges. By separating the stream before dewatering, particularly by addressing the minus 20 µm fraction and clay behaviour, operators can reduce stored water risk, capital and operating costs, and reliance on either conventional wet storage or whole-of-stream pressure filtration. Achieving this requires a common classification framework and stronger collaboration between process, geotechnical, and mine planning disciplines so that tailings solutions are optimised across the full system, not within individual technical silos.

1. INTRODUCTION

1.1 Background to CEEC

CEEC International: Coalition for Minerals Efficiency (CEEC) is an industry body dedicated to accelerating the adoption of eco-efficient minerals and metals production practices. CEEC works to celebrate, collaborate, and communicate advances in mineral processing efficiency, with a focus on cross-sector collaboration spanning comminution, process innovation, sustainability, and operations strategy.

In recognition of the critical and growing challenge of tailings management, CEEC established the Global Tailings Initiative (GTI) to help the industry build towards responsible, low-impact tailings practices through collaborative activities. The GTI's initial focus is on ore and water characteristics and upstream processing choices that affect tailings properties, with broader focus areas including water recovery, dewatering technologies, storage optimisation, and emerging tailings innovation.

1.2 Purpose of this Document

This white paper serves multiple purposes within CEEC's GTI:

- Provide context to the current tailings management paradigm and the drivers for change.
- Present a vision of what is possible for global tailings management when upstream processing is designed with downstream storage in mind.
- Articulate and support a technical hypothesis for PSD-based tailings optimisation, grounded in first principles and industrial evidence.
- Define the landscape of solutions from simple to complex, with associated cost implications.
- Highlight knowledge gaps that require further investigation.
- Make a call to action for industry participants to engage in collaborative research, peer review, and knowledge sharing.

The document draws primarily on material presented at the CEEC tailings workshop in Adelaide in 2026, supplemented by published literature and the authors' collective project experience spanning multiple commodities, scales, and geographies.

1.3 Why we are Here

The impetus for this initiative comes from converging pressures. Demand for commodities continues to increase while ore grades decline. Brownfield development is the primary source of new forecast production, and many existing operations face genuine threats of shutdown due to insufficient tailings storage capacity. Permitting timelines for new tailings storage facilities or dam raises now extend to five to ten years in many jurisdictions. Upstream construction methods are increasingly prohibited by regulation or corporate policy.

Industry response has been fragmented. Some companies have adopted "all-or-nothing" approaches, typically wholesale pressure filtration, that impose a 10% to 25% margin reduction (or more) on already marginal low-grade projects, raising cut-off grades and reducing minable reserves.

Others have persisted with conventional wet tailings disposal, accepting the escalating regulatory, social, and financial risks. Technical missteps, particularly the initial underwhelming performance of paste thickeners at scale versus initial promises, have discouraged the industry from pursuing intermediate solutions that sit between these extremes.

This white paper argues that a middle path exists. By combining size separation with fit-for-purpose dewatering, operations can achieve substantial improvements in tailings management at lower cost and risk compared to the bookends of conventional wet storage or pressure-filtered tailings.

2. PROBLEM STATEMENT AND INDUSTRY CONTEXT

2.1 Tailings Dam Failure: A Persistent Crisis

Between 2019 and 2023, more than 20 tailings dam failures occurred across Brazil, India, China, Australia, Canada, Bolivia, South Africa, Tanzania, Peru, Mexico, Angola, and Turkey. These events released more than 25 million cubic metres of tailings and water, killed more than 400 people, caused significant damage to community infrastructure and resources, and inflicted major environmental harm. In particular, the catastrophic

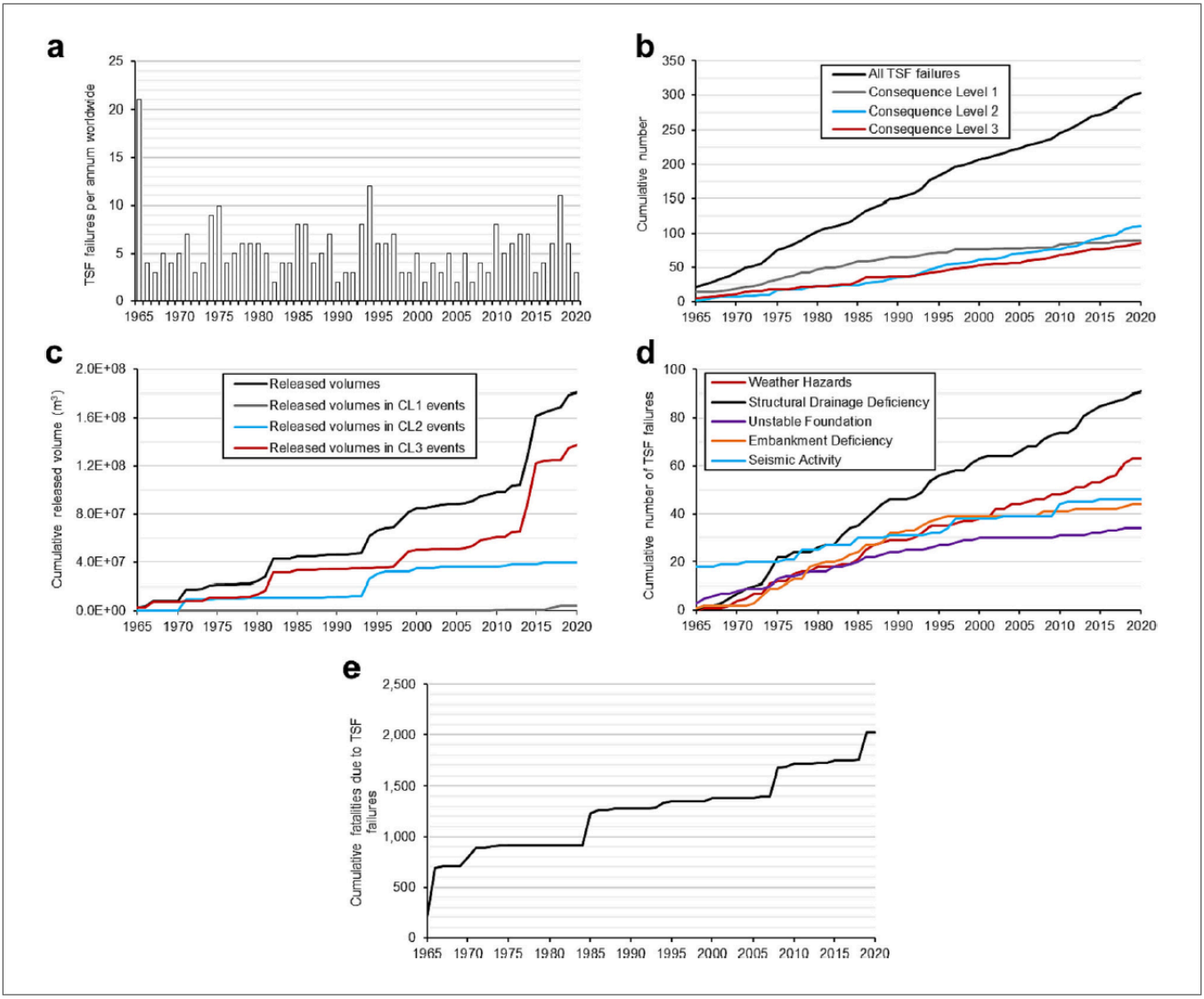


Figure 1. Tailings dam failure trends 1965–2020: (a) failure frequency; (b) cumulative failures by consequence level; (c) cumulative released volumes; (d) failure causes; and (e) cumulative fatalities. Data from Rana et al. (2022).

dam failures near the towns of Mariana (2015) and Brumadinho (2019) focused global attention on the mining industry's century-long history of poor performance in tailings management.

The statistical picture is concerning. During the past 65 years, tailings storage facilities have continued to fail at a rate of approximately five events per year (Figure 1a). The severity of failures has increased with a shift from localised containment breaches to large-scale off-site releases (Figure 1b) and accompanied increase in released volumes (Figure 1c). Failures attributable to water-related issues (i.e. weather, placement, and drainage deficiencies) are increasing (Figure 1d), and the rate of fatalities has not decreased despite decades of incremental improvements in management practices (Figure 1e).

The consequences extend beyond the immediate human and environmental toll.

Regulators, communities, and investors have responded with increasingly stringent requirements. Industry guidelines and quality assurance practices are increasingly onerous, spanning the Australian Government Leading Practice Guidelines, ANCOLD and CDA guidelines, the Global Industry Standard on Tailings Management (GISTM), the Mining Association of Canada's Towards Sustainable Mining (TSM) protocol, individual company standards, ICOLD Bulletin 194, the SME Tailings Management Handbook, and the widespread adoption of

Independent Tailings Review Boards (ITRBs).

Yet the failures continue. This raises a fundamental question: if management improvements alone have not reduced the failure rate, what else must change?

2.2 Why Dams Fail

The key factors driving tailings dam failure are water atop and within the impoundment, the dam wall construction method, and the quality of ongoing governance. The industry is currently working to address all three. GISTM Requirement 3.2 (ii) requires mining operators to use alternatives analysis to find the safest way to store mine waste. The primary goal is to reduce the amount of waste and water left in large, above-ground dams. Upstream construction methods are now prohibited in three major mining countries (Brazil, Chile, and Peru) or by corporate policy. Management and quality assurance practices have been substantially strengthened through the tailings frameworks.

Notwithstanding, many tailings storage facilities still store approximately 50% water by volume. Most operating sites do not precisely quantify the volume of water in their impoundments. Tailings management initiatives tend to first focus on improved design and management of tailings containment facilities, and the industry is still growing in understanding of how best to dewater and store tailings in a cost-effective way. Therefore, there is work to do to fundamentally shift the stability and behaviour (including liquefaction risks and runout potential) of the stored material.

2.3 Project Development Context

The commercial pressures on tailings management are intensifying. Demand for commodities, particularly copper, continues to grow while ore grades decline. Economies of scale may have reached their practical limits. Project net-present-value (NPV) discounting can underestimate the true whole-of-life cost, particularly for closure and mine-life extension. Future liabilities are often discounted at the same rate as revenue, and that is a practice that warrants scrutiny because future cash cost thresholds for investments (which drive the discount rate) are often set much higher than the discount rate for future costs, which do not discount at the same rates. This leads to underestimating future closure provisions or liabilities in current dollar terms.

Water is a source of tension across virtually all mining projects, regardless of jurisdiction and climate. It is frequently the single largest source of stakeholder concern during project approvals, and inadequate water access can limit project scale or economic return. In arid environments such as northern Chile, seawater desalination can cost up to US$4 per cubic metre or more if capital is amortised, making water entrained in tailings a direct and substantial operating cost or throughput constraint. Entrained water simultaneously represents the largest risk to dam stability and the largest opportunity for operational improvement.

An estimated 282.5 billion tonnes of tailings are stored globally (Figure 2) and several operating mines are now conducting studies to remove material from existing tailings dams to generate additional storage capacity. This is an expensive remediation of a problem that upstream process design could have mitigated. Operators are facing genuine threats of production curtailment or shutdown due to exhausted tailings capacity, with new facility permitting timelines extending up to a decade.

2.4 The Filtration Cost Barrier

The default industry response to the demand for "drier" tailings has been wholesale pressure filtration. While effective at reducing moisture content, pressure filtration imposes substantial capital and operating costs. For high-grade projects, these costs are often tolerable. For low-grade, high-throughput operations, which produce the vast majority of global tailings, pressure filtration and placement of the dry material can impose a 10% to 25% margin reduction that can render projects uneconomic.

This cost barrier has created a false dichotomy in the industry: either accept conventional wet tailings disposal with its associated risks or adopt expensive pressure filtration and accept the economic penalty. The technical approaches described in this paper demonstrate that wholesale tailings filtration is not the only alternative to conventional disposal. A spectrum of intermediate solutions exists, and

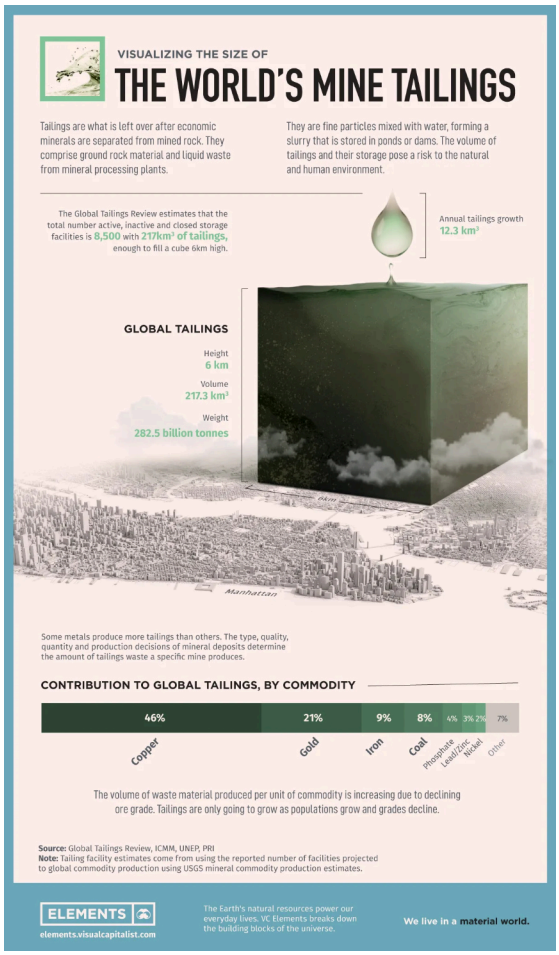


Figure 2. Visualising the scale of the world's mine tailings: approximately 282.5 billion tonnes in storage globally, with copper operations contributing 46% of production. Source: Visual Capitalist (LePan, 2021), based on Global Tailings Review data (Franks et al., 2020).

several can be implemented at costs that improve project economics rather than eroding them.

2.5 Root Causes: What the Industry has Missed

Several fundamental issues have been overlooked or insufficiently appreciated:

The critical size fraction is approximately minus 20 µm. Despite calls from specialists, the industry has historically referred to fines as minus 75 µm, reflecting a historical minimum laboratory sieve size. However, the dewatering performance appears to be driven by particle sizes much finer than that. 20 µm is probably a reasonable practical separation size for ultrafine cycloning. However, it could also be the case that the actual particle size that most impacts dewatering could be finer than 20 µm, perhaps only 10 µm or less. The industry has not widely recognised that this ultrafine fraction is the primary driver of dewatering difficulty. Addressing it specifically, rather than treating the entire tailings stream as a single entity, unlocks substantial improvements in dewatering performance.

Clay dispersive behaviour and process water chemistry. Metallurgical and geotechnical engineers are unfamiliar with the concept of clay dispersion and its influence on the ultrafine content and subsequent dewatering, consolidation, and rheological properties of the tailings. The phenomenon is governed by the chemical quality of the plant process water chemistry which is often ignored.

Natural breakage patterns produce poor size distributions. Conventional comminution circuits generate particle size distributions (PSDs) that are inherently difficult to dewater and store. The PSD is an artefact of the grinding process and mineralogy (such as clays).

Process improvements benefit the entire value chain. Preconcentration, coarsening the grind size, and minimising the production of ultrafines simultaneously reduce energy consumption, decrease water demand, debottleneck throughput, and can increase the internal rate of return (IRR). It can also enable more viable tailings and coarser waste storage and placement strategies.

Industry silos inhibit optimal outcomes. Mining engineers, mine planners, geologists, metallurgists, tailings engineers, and geotechnical engineers typically operate in separate disciplines and operate with distinct professional languages and, often, organisational KPIs. CEEC's perspective is that outcomes improve when practitioners achieve at least a foundational level of knowledge in adjacent disciplines to enable cross-functional optimisations.

Containment is not the same as resolution. The industry's historical approach has been to better contain the problem within tailings facilities rather than reduce or eliminate the quantity of water in advance of storage. Existing management frameworks, while essential, address the consequence of water-saturated tailings rather than focusing on the cause of dewatering and its solutions.

Process simplification is out of date. The historical drive to economies of scale and flowsheet simplification no longer holds as a paradigm for tailings. The declining grades and grain size of orebodies has moved us into a new paradigm that demands more nuance in the design approach.

3. VISION AND TECHNICAL HYPOTHESIS

3.1 Vision

The authors propose that the problems the mining industry faces around tailings are solvable at positive internal rate of return (IRR). Creating a positive business case is the most powerful pathway to achieving sustainable outcomes. Solutions that rely on regulatory compulsion or corporate goodwill alone are vulnerable to economic downturns and management changes.

However, significant barriers still remain, including:

- the paradigm that alternative approaches carry higher risks than conventional practice;
- business and corporate cultures that reward conformity;
- investor sentiment shaped by catastrophic failures rather than technical opportunity;
- knowledge siloes that prevent practitioners from seeing the integrated picture;
- knowledge gaps;
- constrained development timelines;
- preferences to replicate rather than invent.

3.2 Technical Hypothesis

This paper advances the following technical hypotheses:

- Managing particle size distributions (PSD) by optimising mill grind targets and/or performing tailored size separations ahead of dewatering equipment will lead to more efficiently dewatered tailings.
- Dewatering approaches can be tailored to suit the tailings properties and best deposition and placement strategy.
- The downstream storage requirement should drive the upstream process design.

These hypotheses rest on several supporting concepts. Particle size and clay content are the dominant variables affecting dewatering efficiency of stored tailings. Fine particles hold water due to their high surface area and, in the case of clays, water adsorption potential dramatically slowing drainage and increasing the energy required for dewatering. Coarser particles drain freely.

Related to the above is the mine process water chemical quality which determines the potential for clays within the tailings to disperse. The consequences of dispersed versus non-dispersed clays are significant for dewatering as well as for rheological and depositional processes.

It generally does not make engineering or economic sense to dewater coarse and fine material together. The conventional approach forces the entire dewatering system to be designed for the most difficult fraction, even when that fraction may represent only 20% to 40% of the total mass.

Treating the entire tailings PSD through conventional dewatering equipment can cause cascading problems, for example coarse particles accelerate wear in centrifuges and consume volumetric capacity in filters.

If this hypothesis is correct, then many projects could reduce cost and risk while improving environmental outcomes by shifting from a single dewatering circuit to handle the complete tailings stream to an alternative that dewaters and places individual size fractions, tailored to a revised deposition and placement plan.

4. CLASSIFYING TAILINGS

Effective tailings management requires a common framework for understanding and communicating tailings properties.

Currently, no such universal framework exists. Metallurgical engineers and geotechnical engineers use different measurement systems, different terminology, and different conceptual models to describe the same material. This section establishes the key parameters used to classify tailings and explains the relevance to dewatering and storage design.

4.1 The Classification Gap

4.1.1 No common language

Metallurgical engineers characterise slurries using the relationship between solids concentration (percent mass) and the rheological parameter yield stress (Pa), operating in the domain of slurries from dilute feed through to thickened products. Geotechnical engineers characterise the same material using moisture content (mass of water divided by mass of solids) and Atterberg limits (liquid limit, plastic limit, shrinkage limit), operating in the domain of saturated to unsaturated soils. Atterberg limits are a proxy for rheological behaviour.

The correlation between % moisture and solids % is not linear especially at high moisture contents. An 18% moisture content corresponds to 85% solids by mass, not 82% as an intuitive subtraction from 100 might suggest, because the two metrics use different denominators. This apparently simple unit conversion error is widespread in practice and has led to specification errors between process and geotechnical disciplines across multiple projects (Figure 3).

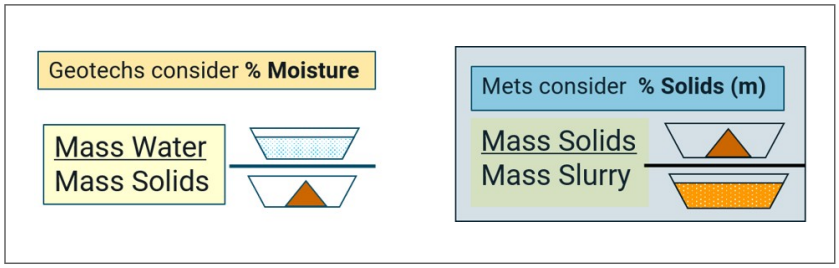


Figure 3. Geotechnical moisture content versus metallurgical solids content.

4.1.2 No common classification method

Geotechnical engineers commonly use the Unified Soil Classification System (USCS; Figure 4) for natural soils, classifying material by particle size (an intrinsic property) and Atterberg limits (a water-quality-dependent property) into cohesive and non-cohesive groups. However, USCS was not designed for processed mineral tailings, and its categories do not adequately capture the properties that control how tailings behave during dewatering, storage, or failure.

In 2021, ICOLD introduced *Bulletin 181: Tailings Dam Design Technology Update* which proposed classifying tailings into five groups with associated property templates (Figure 5). This represents progress, but the framework remains incomplete for cohesive (clay-containing) tailings where water chemistry interactions fundamentally alter physical behaviour.

4.2 Three Key Classification Questions

For tailings containing clay minerals, three questions determine dewatering and storage

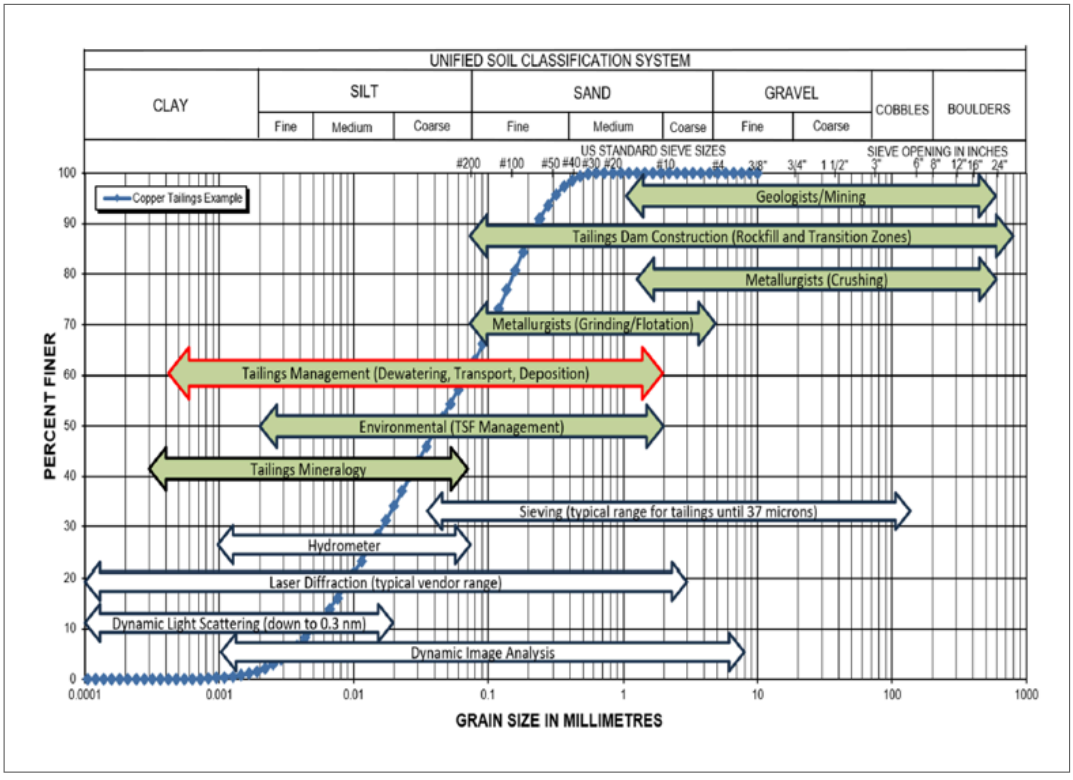


Figure 4. Unified Soil Classification System (USCS) with overlaid measurement domains for different engineering disciplines. Note the disconnect between metallurgical and geotechnical measurement ranges for the same tailings material (Engels et al., 2025).

Tailings Type	Symbol	Description (compare)	Example of mineral/ore
Coarse tailings	CT	Silty SAND, non-plastic	Salt, mineral sands, coarse coal rejects, iron ore sands
Hard Rock tailings	HRT	Sandy SILT, non to low plasticity	Copper, massive sulphide, nickel, gold
Altered Rock tailings	ART	Sandy SILT, trace of clay, low plasticity, bentonitic clay content	Porphyry copper with hydrothermal alteration, oxidized rock, bauxite. leaching processes
Fine tailings	FT	SILT, with trace to some clay, low to moderate plasticity	Iron ore fines, bauxite (red mud), fine coal rejects, leaching processes, metamorphosed/weathered polymetallic ores
Ultra Fine tailings	UFT	Silty CLAY, high plasticity, very low density and hydraulic conductivity	Oil sands (fluid fine tailings), phosphate fines; some kimberlite and coal fines

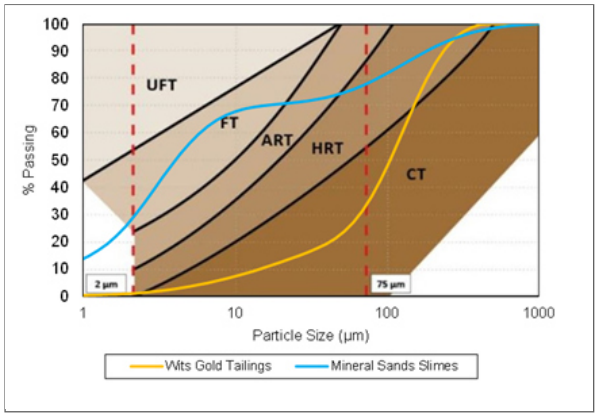


Figure 5. ICOLD Bulletin 181 tailings naming system with accompanying particle size classification template. Chart adapted by Andrew Vietti.

behaviour:

- What is the quantity of fines in my tailings?
- What is the quantity of active clay within the fines?
- Does the water induce dispersive behaviour?

These questions are outlined in the following sections.

4.2.1 What is the quantity of fines in my tailings?

The critical threshold is hypothesised to be the minus 20 µm fraction, which should be defined as "fines" rather than the traditional geotechnical convention of minus 2 µm for "clay". This hypothesis is supported by research demonstrating that the minus 20 µm fraction is the valid criterion for classifying tailings behaviour in dewatering and backfill applications (Verburg, 2001).

4.2.2 What is the quantity of active clay within the fines?

Not all fines are created equal. The distinction between active (swelling) clays and non-active minerals is critical. Active clays, principally the smectite group (montmorillonite, beidellite, nontronite) and vermiculites, have charged surfaces that interact with water and dissolved ions (Figure 6). Their edges carry a charge that is pH dependent, while their surfaces carry a permanent negative charge that can exchange cations in solution.

Despite this, there is no industry alignment regarding the preferred methods to characterise the nature of the swelling behaviour. The methylene blue index (MBI) method, standardised under ASTM C837, provides a simple and practical measure of clay surface charge and activity (Kaminsky et al., 2024). A tentative threshold of 10 to 15 meq/100g separates active or swelling clays from non-active minerals. Another method is cation exchange capacity (CEC). Table 1 summarises the CEC and surface area of common clay minerals, illustrating the enormous differences in surface reactivity.

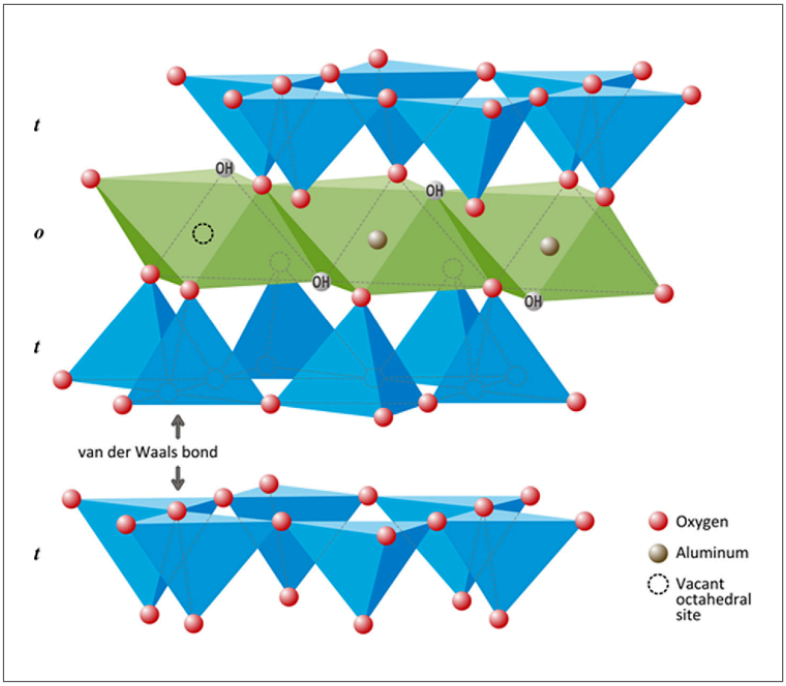


Figure 6. Clay mineral layer structure showing 2:1 phyllosilicate arrangement with van der Waals bonds, oxygen layers, and shared aluminium-hydroxide sheets. Mondal et al. (2013)

Smectite clays have a total surface area of 800 m^2/g compared to 15 m^2/g for kaolinite, a factor of more than fifty. This surface area directly correlates with the clay's capacity to adsorb water and resist dewatering. In practical terms, a tailings stream containing 5% smectite by mass can exhibit worse dewatering behaviour than one containing 30% kaolinite.

Table 1. Cation exchange capacity and surface area of common clay minerals. Source: Mitchell et al. (2025).

Mineral	CEC (meq/100g at pH 7)	Internal Surface Area (m^2/g)	External Surface Area (m^2/g)	Total Surface Area (m^2/g)
Kaolinite	3–15	0	15	15
Smectite	80–150	750	50	800
Vermiculite	100–150	750	<1	750
Illite	10–40	5	25	30
Chlorite	10–40	0	15	15

4.2.3 Does the process water induce dispersive behaviour?

Even when active clays are present in tailings, their dispersive behaviour depends critically on the water chemistry (Figure 7).

A slurry can be dispersive or non-dispersive depending on the ionic character of the process water. Dispersive slurries resist settling, flocculation, and dewatering. Non-dispersive slurries behave more favourably and are substantially easier to achieve solid-liquid separation.

The dispersive behaviour of tailings containing active clays is analogous to the well-studied class of agricultural soils known as saline and sodic soils (Figure 8; Fitzpatrick et al., 1994; Rengasamy, 2018). Three water quality parameters determine the dispersive potential of the soil:

1. conductivity (measured in mS/cm), where values below approximately 2.0 mS/cm indicate low total dissolved salt content, which tend to be highly dispersive;
2. sodium adsorption ratio (SAR), where values above approximately 6.0 indicate sodium-dominated "soft water" that promotes clay dispersion, while low SAR values "hard water" with elevated Ca^{2+} and Mg^{2+} tend to resist dispersion;
3. pH, where values in the range of 8 to 10, when combined with high SAR above 6, further promote dispersion.

The interaction between these parameters and the active clays not only affects the slurry sedimentation and dewatering behaviour but also produces distinct rheological behaviours. Thickened dispersive slurries exhibit a characteristic weakly

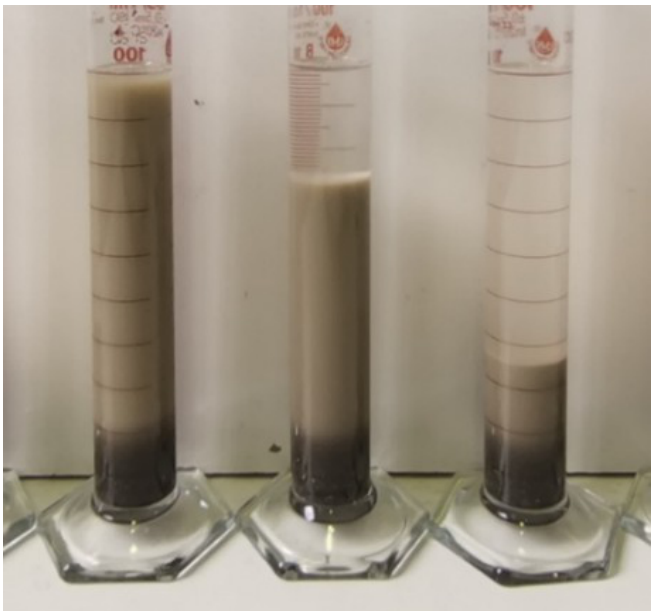


Figure 7. Jar test demonstrating dispersive behaviour: non-dispersive slurry (middle and right) settle clearly, while dispersive slurry (left) remains in suspension (de Krester et al., 2023).

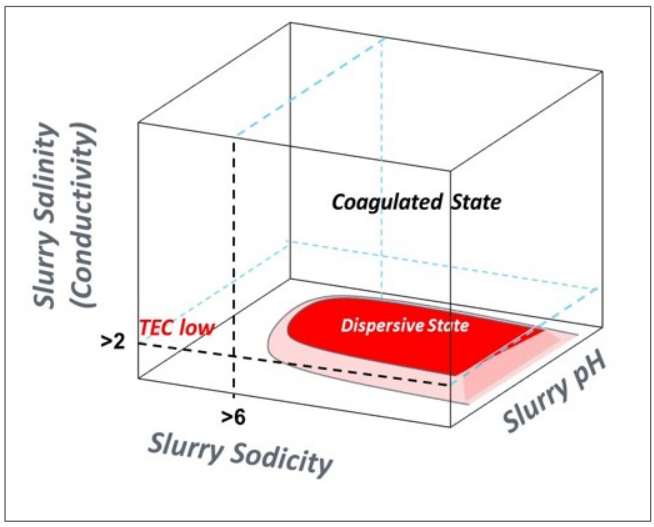


Figure 8. Three-dimensional dispersive state diagram: at low salinity (conductivity <2 mS/cm) and sodicity >6, tailings are highly dispersive. As salinity increases, only very high-sodicity tailings remain in the dispersive state (Vietti, 2012).

convex (or "banana" shaped) yield stress curve, while thickened non-dispersive slurries produce a strongly convex (or "hockey stick" shaped) rheology curve. As salinity increases, only tailings with very high sodicity remain dispersive. At very high salinity (seawater concentrations), essentially all tailings will settle regardless of clay content.

This understanding has direct practical implications. If the process water is found to be potentially dispersive during test work, the first metallurgical intervention should be to condition the water chemistry before it contacts clay-bearing ore. Uncontrolled dispersion leads to poor flocculation, no effective solid-liquid separation, clay reporting to thickener overflow, silt bed development in underflow, low-density discharges, and clays accumulating in the supernatant pond.

4.3 Metallurgical Approaches to Tailings Management

Two fundamental metallurgical strategies emerge from the above classification framework which have direct practical implications: reducing the fines fraction and conditioning the process water.

4.3.1 Reduce the fines fraction

Coarser grinding targets and cyclone classification can shift the tailings PSD towards coarser distributions that are inherently easier to dewater. The relationship between tailings classification and dewatering cost is relatively straightforward; as the proportion of fines decreases, the dewatering required becomes simpler and cheaper. Sand-dominated tailings can be dewatered by gravity in drainage piles or with screens. Silt-dominated tailings require vacuum filters. Clay-dominated tailings demand pressure filters, centrifuges, or chemical dewatering with high dosages of flocculant. Moving material from a finer category to a coarser category through upstream process design achieves step-change cost reductions in the dewatering circuit for that fraction. Of course, the strategy for the fines fraction can then be tailored, but on a smaller volume basis.

4.3.2 Condition the process water

For fine tailings with active clays and dispersive water, conditioning and controlling the process water circuit chemistry can fundamentally change the tailings behaviour, specifically for the fines fraction (de Krester et al., 2023). This converts an uncontrolled dispersive system, where solid-liquid separation and dewatering is difficult and deposition outcomes are poor, into a controlled system where conventional thickening and filtration dewatering approaches can function much more effectively.

4.4 Summary of Classification Framework

Clays are not simply small particles. They are colloidal, with charged surfaces that form network structures and bond with water through Van der Waals forces, making dewatering inherently difficult. Their behaviour is driven by pH, ionic strength of the solution, the calcium-to-sodium ratio, and the manner in which they first disperse. Critically, their behaviour can be fundamentally changed by managing the water chemistry and controlling the dispersion characteristics. These are metallurgical levers available to the process engineer that can transform tailings from a waste disposal problem into a manageable material.

5. THE PHYSICS OF DEWATERING

The preceding section established the relevance to tailings dewatering of fines content, active clay activity, and dispersive behaviour. Now we turn to why those properties matter quantitatively and the physics of water flow through packed particle beds. Understanding these relationships is essential for rational thickener and filter dewatering design.

5.1 Darcy's Law: Relating Permeability to Dewatering in Equipment

Flow through a packed particle bed is governed by Darcy's Law:

$$Q = \frac{K \times A \times dP}{\mu \times L}$$

Where Q is flow rate (m^3/s), K is permeability (m^2), A is filter area (m^2), dP is the pressure differential (Pa), μ is water viscosity (Pa.s), and L is cake thickness (m).

This equation identifies the engineering levers available for improving dewatering. Increasing pressure (dP), from vacuum through to pressure filtration, adds cost through more robust

equipment. Increasing filter area (A) adds cost through more or larger equipment. Reducing cake thickness (L) helps but is limited by practical throughput constraints such as cake discharge. The remaining variable, permeability (K), is the key to cost-effective dewatering and it is controlled primarily by particle size distribution. Permeability can also be measured by forcing a fluid of known viscosity through a sample and measuring the flow or pressure (rearranging the above equation). In effect, filtration tests are just an approach to measure the fundamental permeability of the material.

This equation and material permeability, which is a material characteristic, are generally unstated in material characterisation testwork programs.

5.2 Kozeny-Carman: Why Size Dominates

The Kozeny-Carman equation relates permeability to porosity and the Sauter mean diameter (d32):

$$\mathrm{K} = \frac{\varepsilon^3 \times {d_{32}}^2}{180 \times (1-\varepsilon)^2}$$

The key insight is that permeability scales with the square of particle size. This non-linear relationship produces dramatic consequences across the particle size range relevant to tailings and the relative filtration time (Table 2).

A twenty-fold reduction in particle size produces a four-hundred-fold increase in filtration time. Even acknowledging that the Kozeny-Carman equation cannot yield perfect estimates of permeability, this result does. This relationship alone explains why wholesale pressure filtration of mixed tailings can be expensive. The system must be sized for the filtration time required by the finest fraction, even though the coarser fraction could be dewatered orders of magnitude faster.

Table 2. Example: effect of particle size on permeability and filtration time.

Particle Size	Relative Permeability	Relative Filtration Time
100 µm	100x	1x
50 µm	25x	4x
20 µm	4x	25x
10 µm	1x	100x
5 µm	0.25x	400x

Furthermore, it is important to recognise that the Kozeny-Carman equation in practice can grossly overpredict the permeability of clay-bearing materials due to two key factors:

1. Many voids within clay aggregates contain immobile water bound by electrostatic forces, reducing the effective porosity available for flow.
2. The Kozeny-Carman equation assumes that mine tailings and clays are spherical, whereas they are often angular and platelike, further increasing resistance. The actual permeability of clay-rich tailings can be 10 to 100 times worse than the Kozeny-Carman prediction.

5.3 Compressibility

For compressible filter cakes, the specific cake resistance (α), hydraulic resistance by a filter cake to fluid flow, increases with applied pressure typically following a power law (Table 3). The compressibility index (n) determines how effectively additional pressure translates to improved dewatering:

Table 3. Compressibility index by material type.

Material Type	Compressibility (n)	Classification
Sand, coarse minerals	0.1–0.3	Low
Calcium carbonate	0.19–0.50	Low to moderate
Typical mineral tailings	0.4–0.8	Moderate
Talc, phyllosilicates	0.47–0.70	Moderate to high
Clay-rich materials	0.5–0.9	High
Hydroxide sludges	>1.0	Very high

Higher compressibility means that increasing pressure gives diminishing returns on filtration rate. For clay-rich cakes with "n" approaching 0.9, doubling the applied pressure may increase the specific resistance by 80%, effectively negating much of the expected throughput improvement. This can lead to filtration challenges for more compressible material and means that higher pressures are not always a viable solution.

Particle shape further compounds the problem.

Flat, platelike particles, characteristic of phyllosilicate clays, orient during compression to create preferential barriers to filtrate flow through the cake. Bourcier et al. (2016) developed correlations showing that shape-dependent

Table 4. Specific cake resistance by material type.

Material Type	Alpha at 1 bar (m/kg)	Notes
100 µm glass beads	$6.4x10^{7}$	Incompressible reference
10 µm glass beads	$6.4×10^{9}$	100x increase for 10x size reduction
Coarse mineral particles (>100 µm)	$1x10^{9}$-$1×10^{10}$	Easy filtration
Fine minerals (20-100 µm)	$1×10^{10}$-$1x10^{11}$	Moderate difficulty
Ultrafine minerals (<20 µm)	$1×10^{11}$-$1×10^{12}$	Difficult filtration
Talc (similar size to $CaCO_3$)	$7.4×10^{11}$	12x higher due to platelet shape
Kaolin (fine, clay-rich)	$1×10^{12}$-$1×10^{13}$	Very difficult
Colloidal clay	$6.3×10^{13}$	Requires flocculants

coefficients produce compressibility values significantly higher for plate-like particles than for spherical particles of the same size.

5.4 Specific Cake Resistance

Laboratory and industrial measurements of specific cake resistance (α) span six orders of magnitude across the range of materials encountered in tailings processing, as shown in Table 4.

Work by Kinnarinen et al. (2015) on calcium carbonate grinding demonstrated that when the D10 reduced from 4 µm to 1 µm, the specific resistance increased by 7 to 10 times. Given that clay particles are typically 1 to 2 µm in size, even modest clay contents can dominate the filtration behaviour of the entire tailings stream.

5.5 Drainage Anisotropy

Drainage within deposited tailings is highly anisotropic. Horizontal permeability is typically 5 to 20 times greater than vertical permeability, and in some cases exceeds 100 times for layered deposits. Three mechanisms drive this anisotropy:

1. **Hydraulic segregation** creates alternating coarse and fine layers, cross-bedding structures, and distinct beach and slime zones that create preferential horizontal flow paths.
2. **Particle orientation during sedimentation** causes clay particles to align normal to vertical loading during consolidation, creating preferential horizontal flow paths.
3. **Consolidation-induced anisotropy** causes vertical compression to preferentially close vertical pores while horizontal channels remain more open.

This anisotropy has a profound implication for dewatering equipment and deposition design. The rate of dewatering could be significantly increased by choosing drainage paths that are perpendicular to the direction of applied compressive force. Several of the advanced dewatering and storage concepts described later in this paper exploit this principle.

5.6 The Core Problem: Mixed Streams

The central engineering problem emerges from the physical constraint that a tailings feed containing 40% fines forces the entire filtration system to operate at the resistance dictated by the finest fraction, even though 60% of the material could be dewatered with much simpler and lower-cost equipment.

5.6.1 The bimodal distribution problem

Many tailings streams are effectively bimodal, with coarse gangue minerals and fine clays or weathered minerals creating two distinct populations. Consider a typical example with 65% coarse and 35% fines. The coarse fraction alone has a permeability of approximately $1x10e^{-10}$ m^2 (fast drainage). The fines fraction alone has a permeability of approximately $1x10e^{-13}$ m^2 (slow drainage). When mixed, the resulting permeability is approximately $1ex10^{-12}$ m^2: the fines dominate.

Based on the authors' experience and supporting unpublished laboratory data, a critical fines (<20 µm) threshold exists at approximately 25% to 30% fines content. Above this threshold, fines form a continuous matrix that controls the permeability of the entire bed. Adding more coarse material above this threshold provides minimal benefit because the effective Sauter mean diameter remains controlled by the fine fraction. The relationship between filtration time and fines content is non-linear: laboratory work by Hassan et al. (2025) on bimodal calcium carbonate suspensions confirmed that at low fines content, coarse particles dominate dewatering behaviour, but as fines increase, a threshold is crossed where

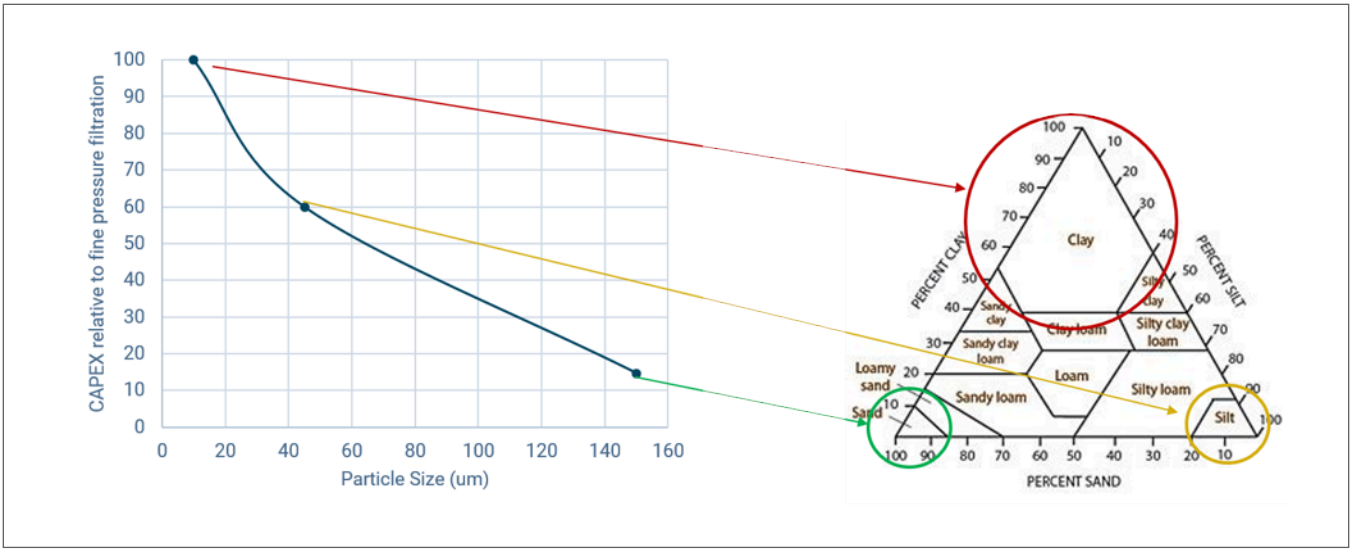


Figure 9. Difference in capital cost relative to whole stream pressure filtration.

fines dominate and filtration times increase dramatically.

The implication is that for tailings with fines content above the critical threshold, the most effective engineering intervention is not to build a bigger filter, it is to separate the fine fraction from the coarse fraction before dewatering, and to match the dewatering equipment to each stream's characteristics.

5.7 Thickener and Filtration Performance

The percentage passing 20 µm is also a useful benchmark for predicting both thickener and filter throughput performance. Increasing clay content reduces thickener underflow density (because clay network structures develop yield stress at lower solids concentrations) and reduce filter throughput (because clay-bearing cakes resist water flow). Data from multiple operations indicate that thickener underflow density decreases and filter throughput decreases with increasing active clay content, as expressed by methylene blue index (MBI) value.

An important observation from laboratory testing is that high clay samples that were dried and reconstituted with tap water can exhibit different filtration rates than undried samples. This suggests that the initial dispersion conditions (how clays first contact water) permanently influence the long-term behaviour, reinforcing the importance of controlling water chemistry from the outset of the process. A potential mechanism may be that ions are adsorbed into the interlayer spaces within clay structures from previous hydration stages, which can modify the longer-term behaviour of the clays even when exposed to different water sources. Further work is required to better understand this phenomenon.

5.8 Cost Fundamentals

The cost implications of particle size and clay content on dewatering equipment are dramatic. Pressure filters capable of processing clay-sized material are substantially more expensive to acquire and operate than vacuum filters for silt-sized material, which in turn are more expensive than dewatering screens for sand-sized material.

By separating tailings into constituent size fractions and directing each to the appropriate dewatering method, the total dewatering cost can be reduced more than 40% compared to processing the mixed stream through pressure filtration (Figure 9).

The mental model to adopt is related to the size of the capillaries between the solid particles as it is this size that governs permeability. This is more reflective of the dewatering equations, rather than focusing on the solids fraction.

6. DEWATERING STRATEGIES AND PROCESS DESIGN EXAMPLES

The preceding sections discussing tailings classification, fines and clay behaviour, and

dewatering physics, collectively establish the technical case for stream separation. The physics described above points towards a clear design philosophy:

1. Separate tailings streams by particle size.
2. Control process water chemistry to reduce clay dispersion.
3. Match dewatering equipment to each stream's characteristics.
4. Design the overall system with the downstream storage requirement in mind.

This section describes the practical technologies and flowsheet configurations that implement this philosophy.

6.1 Stream Separation and Split Dewatering

Multiple approaches for stream separation already exist in the industry (Figure 10):

- **Coarse sand separation** uses cyclone classification to produce a sand fraction (typically +100-150 µm) that can be dewatered on screens or by gravity drainage and directed to tailings storage facility (TSF) wall construction or codisposal.
- **Deslimed silt recovery** uses high-frequency vibrating screens to dewater the deslimed silt fraction after cyclone classification, producing a low-moisture product suitable for stacking or codisposal.
- **Ultrafines treatment** uses centrifuges to process the fine fraction that would otherwise require pressure filtration.

All of these unit operations are continuous, which eliminates the need for intermediate storage tanks that batch-operated pressure filters require. This simplification further reduces capital costs and operational complexity.

6.2 Ultrafines Removal Strategy

A case study demonstrates the substantial impact of ultrafines removal. For a project with a tailings P_{80} of 38 µm, the total plant tailings when processed on a vacuum filter achieved approximately 250 kg/m²·h at 24% moisture. This would conventionally require pressure filtration.

By removing only the minus 20 µm fraction via cyclone classification, the deslimed product (P_{80} of approximately 48 µm) achieved approximately 1,000 kg/m²·h on a horizontal belt filter at 17% moisture.

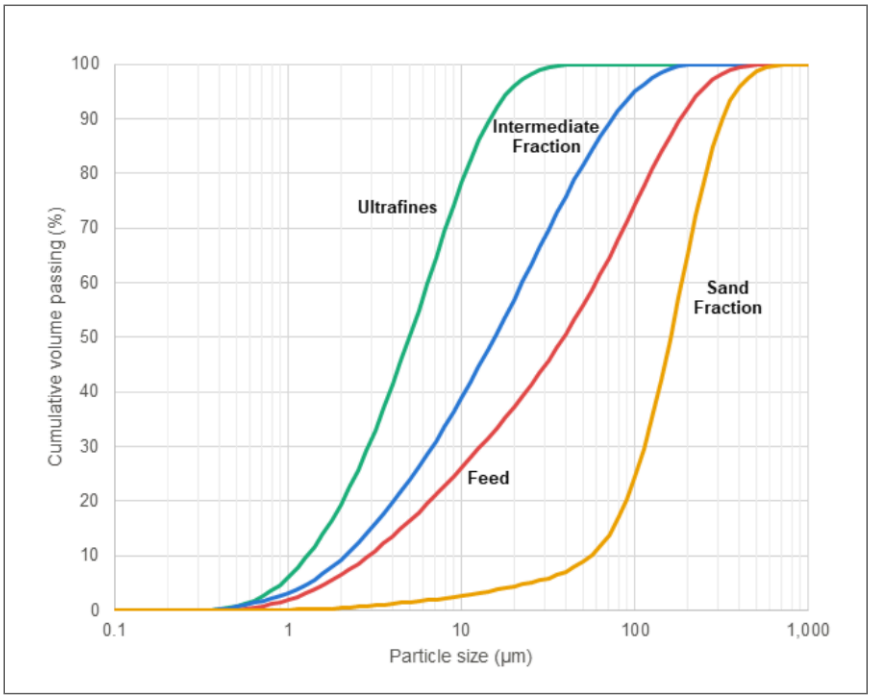


Figure 10. Typical particle size distributions achievable through stream separation: feed (red), sand fraction for wall construction (orange), intermediate fraction for belt filtration (blue), and ultrafines for centrifuge treatment (green).

This is a four-fold improvement in throughput with a significant reduction in moisture. The minus 20 µm fraction, which controls the filterability of the whole stream, represented a minority of the total mass but dominates the dewatering system's performance.

The implication is that a P_{80} of 38 µm, which is conventionally "too fine" for horizontal belt filtration, becomes viable for vacuum filtration when the ultrafine tail is removed. This avoids the expense of pressure filtration for the bulk stream.

Alternative dewatering methods such as in-line flocculation and screening of the fines can provide a low-cost solution (example: Figure 11).



Figure 11. In-line flocculation and static screening: flocculated tailings discharged onto a gravity screen for primary solid-liquid separation.

6.3 Layered Horizontal Belt Filter Pre-Coat

An innovative approach, applied in phosphate and copper tailings, dewaters the coarse and fine streams by layering them successively on a horizontal vacuum belt. Coarse material from cyclone underflow is placed first to form a high-permeability pre-coat layer. Fine material from cyclone overflow is placed on top. The fines drain through the high-permeability coarse layer, exploiting the permeability contrast between the two fractions.

The key physics indicate that the permeability ratio between the coarse pre-coat and the fine layer is typically 100 to 1,000 times. The pre-coat is expected to reduce the average effective specific cake resistance by 30% to 80%.

The combined cake discharges as a single product (Figure 12), and the coarse layer ensures good release from the cloth with less blinding. The capital cost can be significantly less than an equivalent pressure filter installation.

6.4 Electrophoretic Dewatering

Electrokinetic geosynthetic (EKG) materials retrofitted to belt filter presses can further improve dewatering performance in full-scale trials. In sewage cake applications, solids content increased from approximately 20% to 31% dry solids. In diamond mine tailings applications, solids content increased from approximately 62% to 75% dry solids. While still emerging in the minerals sector, electrophoretic dewatering offers particular promise for fine-grained, clay-rich tailings where conventional pressure-driven approaches face diminishing returns and highlights the fundamental mechanisms of clay-driven dewatering behaviour.

6.5 High-Throughput Surface Paste

Early paste thickening methods have historically underperformed expectations due to rheological challenges in paste thickeners, leading to a poor industry reputation, but these have largely been overcome. Multiple sites have had operational challenges with paste thickeners and failure to consistently achieve the target underflow density

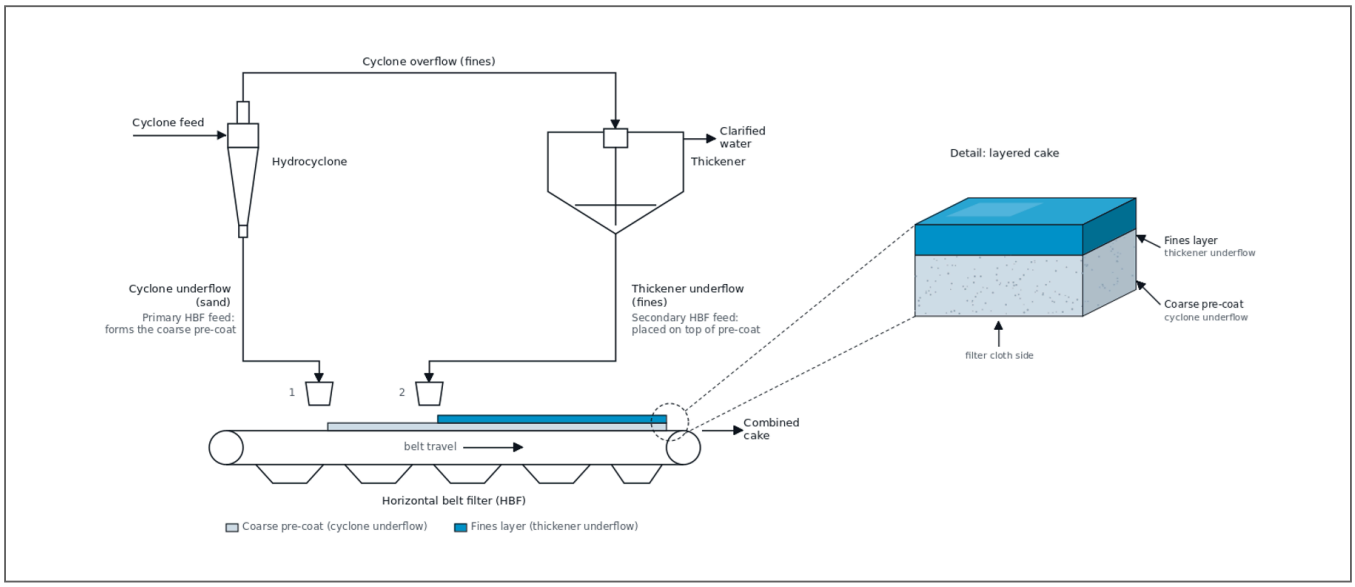


Figure 12. Layered HBF pre-coat concept: cyclone underflow forms the coarse pre-coat layer on the belt, with thickener underflow (fines) placed on top.

due to the difficulties of operating in a high yield stress regime.

Ironically, underground paste plants are reliably able to deliver a very consistent underflow density to fill underground stopes. However, these approaches blend dewatered filter product (from filters or screens) with thickener underflow in a pug mixer to produce a high-density paste. By locating the mixer close to the deposition point, pumping requirements can be minimised. If the deposition slope can be matched to the local topography, the need for containment walls is reduced or eliminated and high-throughput surface paste can be achieved.

Table 5. Cost comparison—pressure filtration versus split dewatering (100 kt/d).

Parameter	Pressure Filters	Combination (screen, horizontal belt filter, centrifuge)	Comments
Solids (%w/w)	84.5	84	Similar solids content
CAPEX (USD M)	200	90	Capital cost halved or less
OPEX (USD M/y)	100	56	Operating cost approximately half

6.6 Dewatered Tailings via Split Dewatering

Where higher final densities are required, sand can be dewatered to a lower moisture content and mixed back with the finer fractions. This approach can achieve moisture contents similar to pressure-filtered tailings at approximately half the capital and operating cost.

For a reference case of 100 kt/d, an example comparison is in Table 5.

This comparison assumes that approximately half of the tailings mass is available in a sand fraction (+100 µm). The combination approach uses hydrocyclones for stream separation, horizontal belt filters for the intermediate fraction, and centrifuges for the ultrafine fraction.

6.7 New and Emerging Approaches

Several emerging technologies may offer additional improvements:

- **Vibrating roller compactors** retrofitted to horizontal belt filters may be able to increase throughput by approximately 30% or more at the same moisture or reduce moisture by approximately 3% or more at the same throughput (or a combination of both).
- **Combined waste rock and filtered tailings** combines filtered tailings with waste rock to produce a geotechnically stable material.



Figure 13. Large-scale pressure filter installation. While effective for achieving low moisture content, pressure filtration imposes substantial capital and operating costs that can be halved through split dewatering approaches.

- **Larger tailings filters** are achieving 15% to 20% reductions in total installed cost through increased unit capacity (example: Figure 13).
- **Direct sand dewatering from coarse particle flotation** allows sand-sized tailings to be dewatered directly on screens, eliminating the need for any wet tailings handling of this fraction.

7. TAILINGS STORAGE AND DEPOSITION STRATEGIES

The method of tailings storage determines the water recovery, closure liability and long-term risk profile, and should be the starting point for process and project design. The physical properties of the tailings along with the topography, site conditions, and project criteria directly determine which

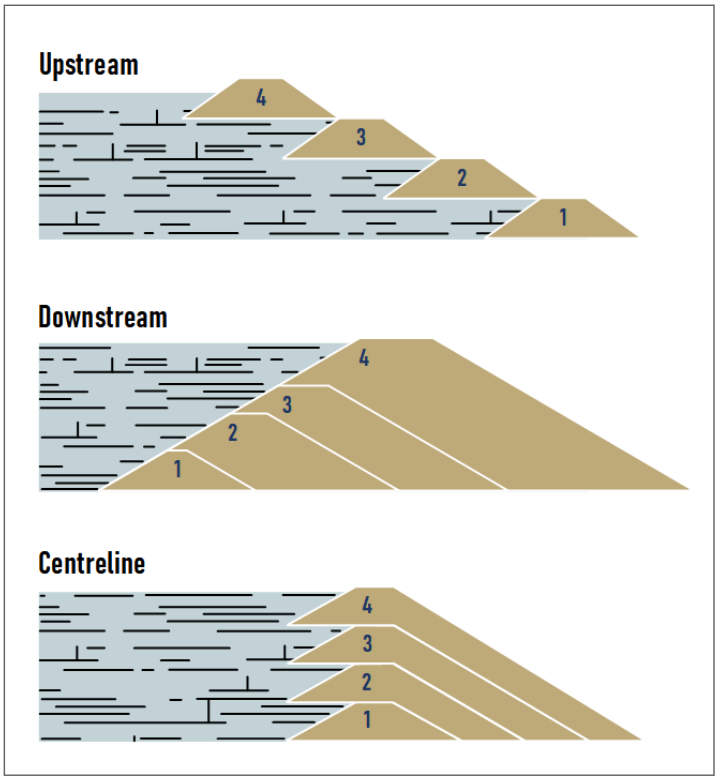


Figure 14. Tailings dam embankment construction methods: upstream, downstream, and centreline. Upstream construction (top) is prohibited in many jurisdictions due to the risk of liquefaction of the tailings material within the embankment.

dewatering and storage options are feasible.

The following sections of this white paper present a brief overview of:

- the context of water removal for conventional tailings storage facility (TSF) dam safety;
- conventional tailings placement practices;
- removing water and storing thickened paste;
- preconcentration to minimise the quantity of fine tailings;
- sand separation and placement;
- codisposal methods;
- layered codisposal—Hydraulic Dewatered Stacking (Anglo American).

7.1 Dam Safety Context

The probability of tailings storage facilities failure across the industry is unacceptably high and, therefore, work is required to reduce failure rates. Much of the work to date around reducing TSF failure risks has been focused on the method of embankment construction (upstream, downstream, or centreline), as outlined in Figure 14.

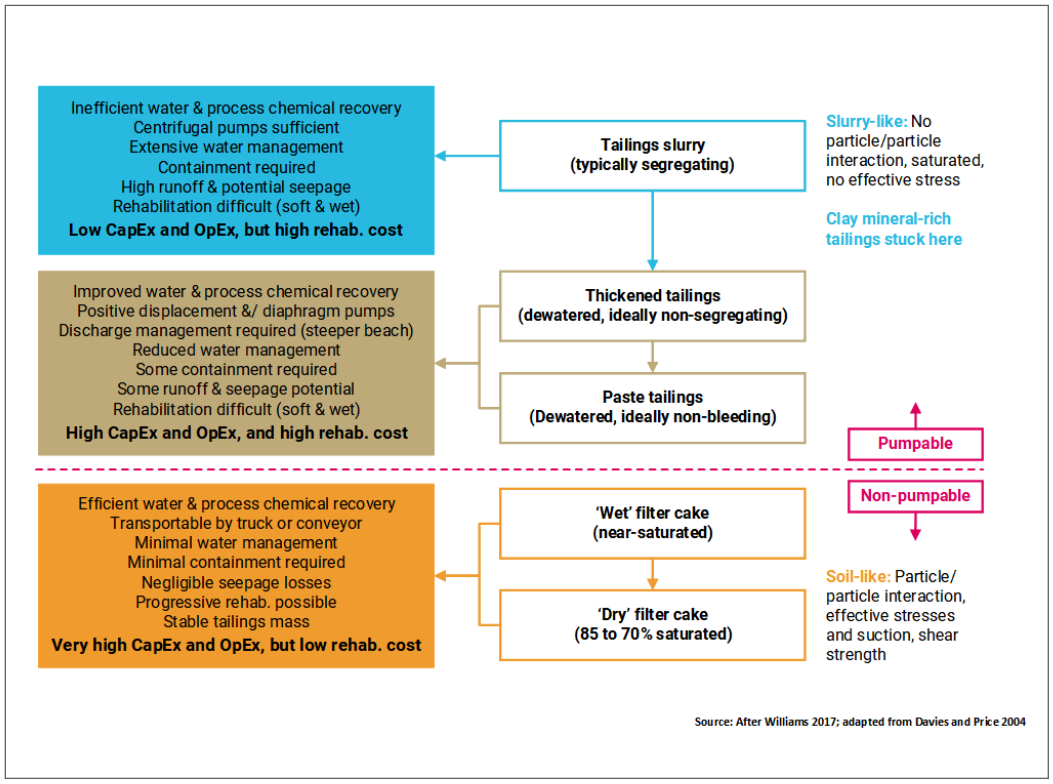


Figure 15. The tailings continuum: linking tailings form (slurry through to dry filter cake) with placement method and embankment construction approach. *Note*. Adapted from *Towards Zero Harm: A Compendium of Papers Prepared for the Global Tailings Review*, by D.J. Williams, 2017. This figure was adapted by Williams (2020) from Davies and Rice (2004).

Other improvement areas are related to management strategies for tailings storage facilities, and compliance through various standards and processes (such as GISTM).

While TSF containment design and management strategies are worth focusing on, one of the most critical technical factors related to TSF risk and consequence assessments is minimising water storage in the TSF. After all, the consequences of

dam wall failure for storage of dry solids are relatively minor, given the runout potential is significantly reduced, as compared to large impoundments where the contents are fully saturated and often with excessive free and ponded water.

Figure 15 shows the tailings continuum, indicating the different behaviours of saturated and unsaturated solids.

7.2 Conventional Tailings Placement

In a conventional waste management approach, run-of-mine (ROM) ore passes through crushing, milling, and flotation with fine tailings directed to a TSF. If the mine has a 2:1 strip ratio, a comparable amount of coarse waste is available for TSF buttressing if the geotechnical characteristics are acceptable.

BHP's Escondida, for example (Figure 16), uses conventional thickening to approximately 55% solids with slurry transport to a large facility, accepting lower water recovery and higher water supply costs for desalinated water. Conventional TSF's generally achieve low beach angles, of ~1%, meaning they typically require a TSF wall to contain the material. They can also include significant decant ponds from which water is recovered back to the process plant.



Figure 16. Escondida conventional TSF example.

7.3 Central Thickened Discharge (CTD) or Down Valley Discharge (DVD)

If the tailings is dewatered to a paste, the slurry rheological characteristics shift to higher viscosities and yield stresses, and the deposition angle increases. For example, Figure 17 presents a steeper deposition slope from paste thickened tailings.

If producing higher-density tailings with a steeper beach angle, the methods of tailings placement can change. For example, central thickened discharge (CTD) or down valley discharge (DVD) approaches can be used to minimise the embankment requirements, minimise ponded water, and generally also improve water recovery when compared to conventional TSFs. These concepts are described and illustrated well by Fitton (2017), highlighting work completed by Eli Robinsky in the 1970s, as seen in Figures 18a and 18b.


Figure 17. Paste thickened tailings.

Sunrise Dam is an Australian CTD facility

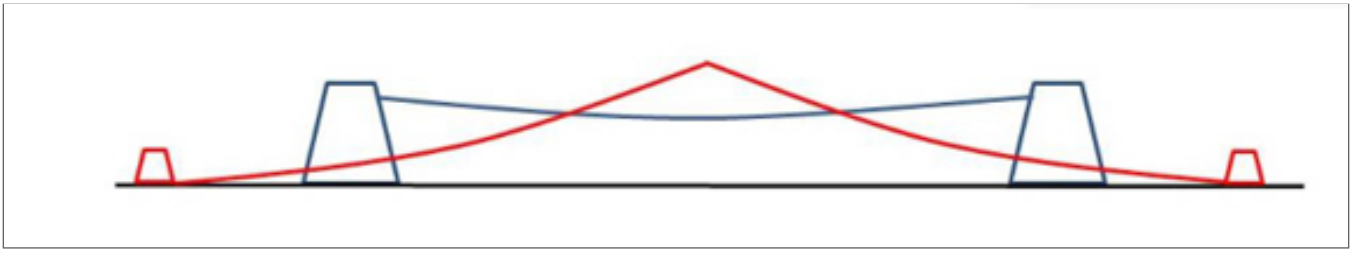


Figure 18a. A CTD (red) and a conventional tailings ring dyke (blue) of similar capacity. Courtesy of Fitton (2017).

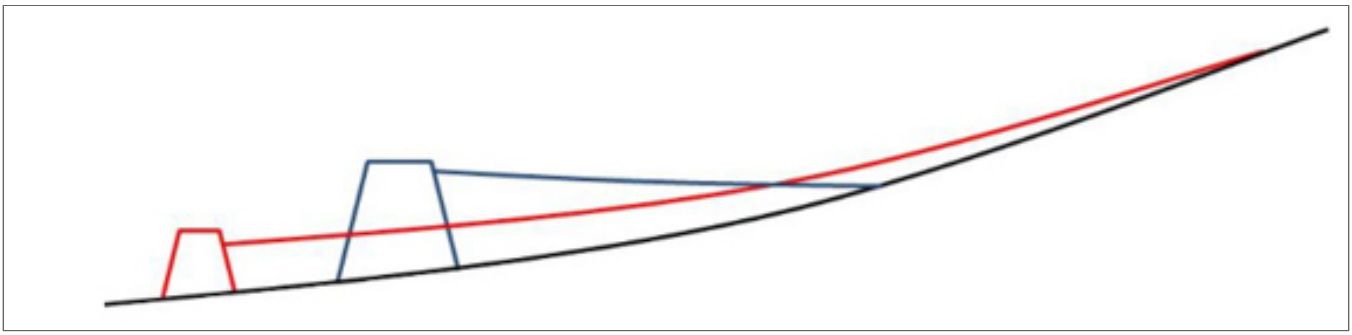


Figure 18b. A DVD (red) and a conventional valley dam (blue) of similar capacity. Courtesy of Fitton (2017).

with minimal wall buttressing (Figure 19).

Sierra Gorda is an example of a lower-Andean operation that deposits its tailings at a density that broadly matches the natural slope (Figure 20). Due to this, as the material dries and desaturates it stops flowing, and can be contained without significant TSF wall infrastructure in a series of cells. This approach, when operated correctly, has a low runout potential. Challenges are introduced when the method of dewatering (thickening only) cannot achieve the required underflow density. Much work has been done at Sierra Gorda to improve the performance of the tailings thickening system.

At the end of the spectrum, the image of a Patagonian gold mine in Figure 21 illustrates what can happen when tailings is dewatered to saturation levels. The fine product, in this case produced from a centrifuge with flocculant, has a high yield stress and is able to be conveyed, but also flows. It is very close to saturation moisture, however, so it is fundamentally stable.

Conventional paste thickened systems have historically been challenged by thickener rheology, rake torque constraints, and pumpability issues. However, the concept of blending filter product with thickener underflow close to the deposition point, rather than relying on a single paste thickener to achieve target density, has the potential to resolve the reliability concerns that have previously plagued conventional paste systems.

7.4 Progressive Waste Rejection

A progressive series of waste rejection (or pre-concentration) stages can dramatically reduce the volume of wet tailings requiring conventional



Figure 19. Sunrise dam CTD tailings facility.

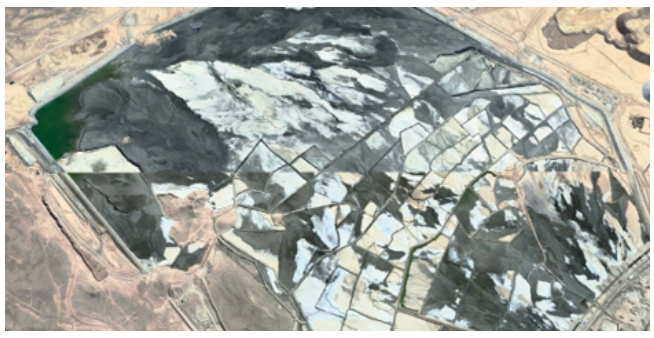


Figure 20. Sierra Gorda cell placement.



Figure 21. Centrifuged tailings, flowed downhill close to saturation.

storage, as outlined in Figure 22. By incorporating bulk sorting, screening, scat sorting, and mine or truck grade sensing, lower grade and/or higher competency material than would otherwise be processed can report to tailings and be rejected as coarse waste before entering the comminution circuit. This alone can reduce the wet tailings volume by approximately 20%, with the rejected material stored as conventional dry waste rock.

Adding coarse particle flotation, re-milling, and sand separation can further reduce wet TSF tailings to approximately 35% of the original tonnage, a 65% reduction.

This produces a ratio of approximately 5:1 coarse to fine material. Applying the fines filtration techniques discussed in this white paper can potentially further halve the wet tailings to 18% of the original tonnage, an 80% reduction in wet TSF tailings.

This ratio of coarse to fine material allows tailings to be managed differently, whereby coarse fractions provide a large volume of waste rock and sandy material for containing the tailings and improving dewatering.

7.5 Sand Separation and Placement

Sand separation from tailings, whether from coarse particle flotation facilities or by classification from the final tailings stream using hydrocyclones, is a cornerstone of next-generation strategies. Multiple

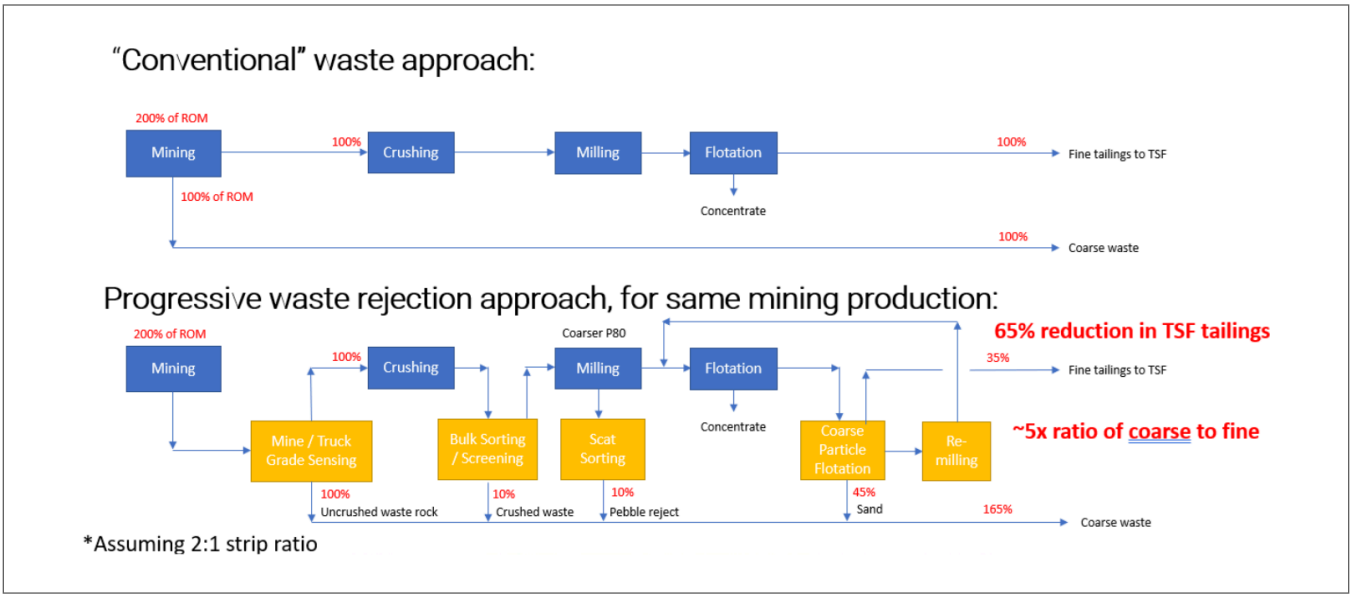


Figure 22. Progressive waste rejection block flow diagram.

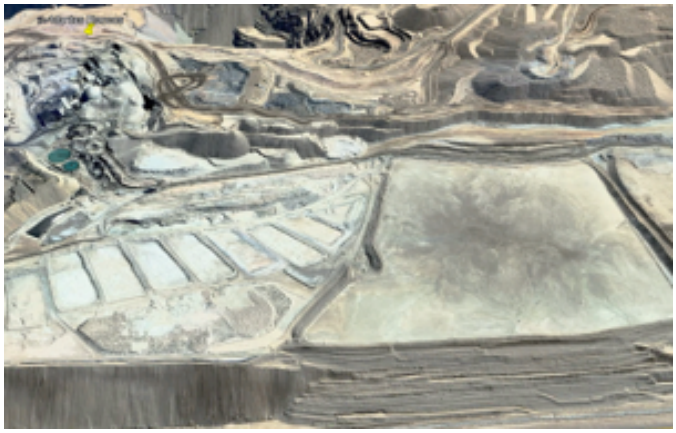


Figure 23. Mantos Blancos tailings sand storage.

dewatering options exist for the sand fraction, all substantially cheaper than fine tailings dewatering: dewatering cyclones discharging to stockpile, high-frequency dewatering screens, and screen and cyclone combinations. The dewatered sand can be placed as structural fill for TSF wall construction, used for codisposal with finer fractions, conveyed to waste dumps, or stacked with mechanical equipment.

The Mantos Blancos mine produces sand from its tailings (notably, without coarse particle flotation [CPF]), and this significantly reduces the volume of wet tailings storage and ensures wet tailings are safely contained (Figure 23).

7.6 Codisposal Methods

Codisposal exploits the void structure of coarser materials to "hide" finer fractions, producing a combined product with improved geotechnical properties (Figure 24). The principle is straightforward: with a typical void fraction of approximately 40%, two tonnes of sand can accommodate one tonne of fines in its voids, and by extension, four tonnes of waste rock can accommodate approximately two tonnes of sand plus fines within its void structure.

When combined in the right ratios, the resulting material exhibits improved bulk density, enhanced stability, reduced water ingress, better geochemical performance (reduced ARD potential from oxygen exclusion), less dust generation, smaller footprint, and the ability to stack to greater heights. Three distinct methods are practiced:

- comingling where tailings and waste rock are transported independently and mixed mechanically at the storage facility;
- coplacement where materials are not mixed but placed in proximity;
- codeposition where materials are deposited in designed layers.

7.7 Layered Codisposal: Hydraulic Dewatered Stacking

The Anglo American hydraulic dewatered stacking (HDS) concept represents an innovative approach to in situ consolidation (Figure 25). The process involves cycloning tailings to produce a coarse fraction sand which is layered in a TSF. Sand channels within the facility provide permeable flow paths for water drainage.

The key physics exploit the halving of the drainage path. With two-way drainage (upward through the coarse layer and downward through the underdrain), the effective drainage path is halved. Since consolidation time scales with the square of the drainage path, halving the path produces a four-fold acceleration in consolidation.

More recent developments have led to simpler construction with sand berms, facilitating better dewatering through lateral water flow out of the tailings. This approach achieves comparable final densities to pressure

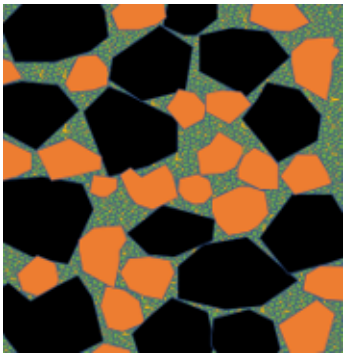


Figure 24. Illustrative mixture of waste rock, pebbles, sand, and fines.



Figure 25. Anglo American hydraulic dewatered stacking (HDS) approach.

filtration without requiring pressure filters for the fine fraction. Consolidation occurs in situ over 15 to 60 days.

7.8 Designing Tailings for Storage

The question, "How should we design our tailings?" reverses the conventional approach. Rather than accepting whatever the process plant produces and designing storage to accommodate it, the design philosophy asks:

1. What storage configuration is optimal for this site's closure objectives, topography, climate, seismicity, and risk profile?
2. What tailings properties must the process plant deliver to enable that storage configuration?

The overarching principle is to maximise the ratio of coarse, free-draining material to wet, fine material and to ensure that any remaining fines are managed through appropriate dewatering before storage.

8. CLOSURE AND LANDFORMS

Closure considerations should inform tailings design from the earliest stages of project development. The growing legacy of tailings facilities—50% of active dams were constructed in the last ten years—represents an escalating cost burden for companies and governments. In 2016 alone, approximately eight billion tonnes of tailings were placed globally. The costs associated with closure are substantial and, for conventional wet facilities, extend in perpetuity (Figure 26).

8.1 How Tailings Methodology Impacts Closure

The tailings deposition method chosen during operations directly determines the cost and complexity of closure. Three factors dominate:

- **acid rock drainage (ARD)** where oxygen and moisture ingress into stored tailings can generate acid and release metals;
- **physical stability** where wet tailings facilities require ongoing monitoring and maintenance to manage water levels, seepage, and structural integrity;
- **capping and regeneration** where the ability to cap and revegetate (or repurpose) a tailings facility depends on the surface trafficability, which is a direct function of the tailings moisture content and density.



Figure 26. Conventional wet tailings discharge: slurry disposal creates saturated, low-density deposits that resist consolidation and complicate closure. The stored water volume drives both the consequence of failure and the long-term liability.

8.2 Closure Cost and Complexity Spectrum

There is a clear relationship between the tailings storage method and the cost and complexity of closure.

Conventional wet tailings facilities sit at the most expensive and complex end of the spectrum, requiring long-term water treatment, ongoing geotechnical monitoring, engineered capping systems, and potentially perpetual care. At the opposite end, codisposed or dry-stacked tailings integrated with waste rock can be progressively closed during operations, with lower long-term liabilities. Moreover, landform design to suit community preferences for visual amenity, industrial reuse, or cultural value can have considerable influence on method.

The closure benefits of "designer tailings"—tailings whose properties have been engineered through the approaches described in this white paper—include smaller landforms that are simpler to permit and less expensive to rehabilitate (Wisdom et al., 2018); reduced air and moisture ingress which reduces ARD potential (Wickland et al., 2006); the ability to progressively close during the operating life; and minimised volumes of wet tailings requiring active management post-closure.

Climate factors significantly influence closure strategy.

In arid environments, evaporative drying can assist in achieving the trafficable surface conditions needed for capping. In wet climates, the same tailings may require engineered drainage and extended consolidation periods before capping is feasible. The dewatering strategy selected during operations should anticipate the closure requirements for the specific project climate.

9. CONCLUSIONS

The evidence presented in this white paper supports the following conclusions.

1. **The industry's tailings management paradigm requires fundamental change.** Despite improvement in management practices, the rate of TSF failures is still too high. Reducing excessive water stored within tailings facilities is a significant opportunity to improve stability, derisk failure consequences, and improve closure outcomes.
2. **The ultrafine fraction (minus 20 µm) and its clay composition is the dominant driver of dewatering performance and cost.** Ultrafine particles and clays overwhelm the dewatering behaviour through impacts on permeability and capillary behaviour and the impact is non-linear. Even a small amount of ultrafines can significantly reduce the dewatering performance of the coarser fractions.
3. **Ultrafine clay behaviour is controlled by water chemistry, not just mineralogy.** The dispersive or non-dispersive character of a tailings slurry depends on process water conductivity, sodium adsorption ratio, and pH. The water chemistry at first contact with clay-bearing ore and during dewatering can fundamentally change the subsequent dewatering and deposition performance.
4. **Size classification provides an opportunity to unlock lower-cost tailings dewatering solutions.** Coarse deslimed fractions can dewater and drain very easily by vacuum, screening, or gravity drainage. The ultrafine fractions can be managed in a variety of ways, with chemical flocculation and coagulation, thickening, belt press filters, centrifuges, filtration, mixing with coarser dryer fractions, or by using the coarser fraction as a filtration media. This approach can reduce capital costs by 40% to 70% while achieving equivalent moisture targets.
5. **Industrial precedents exist for many of these dewatering approaches.** However, as an industry we have not yet connected them together.
6. **Upstream processing opportunities further simplify tailings dewatering and storage.** Through a combination of preconcentration, coarse-particle flotation, and sand separation, the ratio of ultrafine to coarse tailings can be reduced, minimising the problematic fraction and enabling alternative storage methods.
7. **Tailings problems are solvable at positive internal rate of return.** Process modifications that improve tailings outcomes can simultaneously reduce energy consumption,

decrease water demand, debottleneck throughput, lower cut-offs, and improve orebody utilisation while derisking the tailings storage facility.

8. **Cross-disciplinary solutions are required.** The siloed approach, where process design, tailings engineering, and geotechnical design are conducted independently, is a structural barrier to optimising tailings outcomes.

10. RECOMMENDATIONS

The following recommendations are directed at mining companies, engineering consultancies, technology providers, and research institutions.

1. **Adopt PSD-based tailings design as standard practice.** All new project studies and existing operation reviews should evaluate tailored PSD management through size separation as an alternative to whole-of-stream dewatering. This evaluation should be conducted at prefeasibility stage or earlier, when flowsheet flexibility is greatest.
2. **Evaluate the minus 20 µm fraction specifically.** Metallurgical testwork programs should quantify the impact of removing or separately treating the minus 20 µm fraction on thickener performance, filtration throughput, and deposition behaviour. Standard filtration tests on the whole tailings stream do not reveal the improvement available from ultrafines removal.
3. **Characterise clay mineralogy and water chemistry early.** Every project should include methylene blue index (MBI) testing or XRD, water quality analysis (conductivity, SAR, pH), and rheological characterisation of tailings at different water chemistries as part of its standard metallurgical testwork program. This data is inexpensive to obtain and essential for informed dewatering design.
4. **Iterate tailings dewatering and storage approaches.** The optimal storage configuration for a given site, considering topography, climate, seismicity, water balance, and closure, should be iterated with the dewatering flowsheet. The process and storage design need to align.
5. **Invest in cross-disciplinary capability.** Engineering teams should include or develop practitioners with working knowledge across process, geotechnical, and mine planning disciplines. Joint workshops, secondments, and integrated study teams should be the norm rather than the exception.
6. **Challenge the conventional cost comparison framework.** Project economic evaluations should include the full lifecycle cost of tailings management, including closure liabilities, water treatment obligations, and the NPV impact of risk-weighted dam failure scenarios. Discounting long-term tailings liabilities at the same rate as revenue systematically underestimates the true cost of conventional wet storage.
7. **Support collaborative research through CEEC's Global Tailings Initiative.** The knowledge gaps identified in this white paper require industry-wide collaboration to address efficiently. Participation in CEEC's community of practice, contribution of case study data, and cofunding of targeted research will accelerate the adoption of improved practices.

11. NEXT STEPS

CEEC is now embarking on a laboratory testwork program with its partners and industry experts that aims to close information gaps around tailings understanding and dewatering performance. The work will aim to:

1. Standardise methods to characterise tailings.
2. Understand the fundamental dewatering performance of tailings and relate it back to the characterisation.
3. Assess how the characterisation and dewatering performance changes for different size fractions.
4. Test and demonstrate the impact of various "levers" that could be implemented in full-size plants, cost effectively.

12. CALL TO ACTION

This white paper has been prepared as part of CEEC's Global Tailings Initiative (GTI). The GTI exists to accelerate the adoption of responsible, low-impact tailings practices through collaboration across disciplines, organisations, and geographies.

CEEC invites industry participants to engage through three pathways:

Participate

- Join CEEC's tailings-focused community of practice for ongoing technical discussion and knowledge sharing.
- Attend future workshops and panel discussions building on the themes presented here.
- Engage through CEEC-hosted LinkedIn forums for open and candid exchange of views and experiences.

Contribute

- Submit examples and case studies from your operations for inclusion in future publications.
- Participate in research seeding activities to address the knowledge gaps identified in this paper.
- Collaborate on knowledge development through joint studies, data sharing, and peer review.

Provide Feedback

- Peer review the findings and technical positions presented in this white paper.
- Challenge the hypothesis with data from your own experience—the initiative benefits from rigorous debate.
- Share operational experience that confirms, refines, or contradicts the approaches described.

The conclusions and outcomes of CEEC's GTI activities will be compiled into industry-facing reports that are peer-reviewed and published in a non-attributive format following CEEC quality standards. Chatham House Rules apply to all workshop discussions.

The tailings challenge is too important and too complex for any single organisation to solve. Cross-sector collaboration, grounded in sound engineering and honest assessment of what works and what does not, is the path to a sustainable future for tailings management.

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