Risks of Dormancy: Reducing Tailings Risk After Operations, Before Closure

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ABSTRACT: Recent catastrophic tailings dam failures (Mount Polley, Samarco, Brumadinho) have substantially altered mining industry thinking in regard to risk. What is perhaps less well known, is that some failures have taken place while the facility is non-operational, or dormant (Merriespruit, 1994, Brumadinho, 2019). This paper asks a few questions:

- In moving beyond the operational phase, could a tailings dam be exposed to elevated risks?
- What might these risks be?
- What measures would be needed to avoid or control such risks?
- What guiding principles should be uppermost in closure thinking?

The purpose of this paper is to raise awareness of heightened risk associated with cessation of operations, dormancy or poorly managed closure, and to provide interventions, tools and remedies to reduce risk. The paper lists twelve precautionary guiding principles which may be applied to dormant tailings facilities to prepare for the period after operations cease, and before closure is achieved.

1 INTRODUCTION

Many tailings facilities are well operated, to very high standards, employing leading practice engineering. Morgenstern (2010) highlighted in his keynote address to a previous Colorado conference that "*It is the view of the Writer that the dam safety system applied to the Alberta oil sands industry is the best in the world*".

So why is it that catastrophic failures continue to occur on an annual basis? In pursuing (like many of us in the industry) answers to this vexing question, Morgenstern (2019) addressed a more recent keynote to the Canadian Dam Association annual conference in Calgary. He considered 22 significant failures over the past 55 years and found good reason why failures continue to occur: weakness in engineering: a failure to apply already well-known geotechnical engineering principles to tailings dam safety.

This paper delves further into the causes of tailings failures and finds a disturbing trend: Many failures have occurred when a tailings dam is dormant (alternatively moth-balled or non-operational), and before closure has been achieved.

This paper is not intended as a step-by-step guide as to how to engineer a tailings facility, nor even how to proceed with closure. It also does not seek to replace the many excellent postgraduate level courses now available at universities such as the University of Alberta, University of British Columbia, and many others.

Instead, the paper seeks to highlight awareness of the risks of dormancy: suggesting twelve guiding principles which are required after operations cease, and before closure can be embarked upon.

2 A SNAPSHOT OF THE ROLE OF DORMANCY IN HISTORIC TAILINGS FAILURES

2.1 *A view on the statistics*

Accurate statistics on the total number of tailings dams worldwide are unpublished and unavailable. Broad estimates range from as low as 5000 to over 30,000 facilities. While several countries have very accurate records, many others do not.

The recent questionnaire distributed by the Church of England yielded responses for under 2000 facilities. Grid-Arendal (2020) lists 1938 facilities on the online global tailings portal and categorizes them into status. Just over 40% were listed as active. Many fascinating analyses will no doubt be produced from this list, but this list includes less than 10% of all tailings facilities worldwide.

Wei et al. (2013) record that at time of writing there were over 12,000 tailings dams in China alone.

Very few tailings dams have been comprehensively closed. Significantly less than 10% of the facilities listed on the global tailings portal may be comprehensively closed.

Most tailings dams are neither actively operating nor closed. Multiple thousands of dams are simply dormant.

2.2 *Brief reference to the role of dormancy in tailings failures*

2.2.1 *El Cobre, Chile, 1965*

According to Dobry & Alvares (1967), Dams 1 and 2 were dormant and not in use. Dam 3, upstream of Dams 1 and 2, failed spectacularly, causing substantial cascading damage, especially to Dam 2 as a result of an earthquake. Many lessons were learned from this failure, including an immediate and subsequent ban on upstream construction of tailings dams in Chile.

Dam 2 was not protected because it was simply dormant and not fully closed and therefore vulnerable.

An additional lesson relevant to this paper is that dormant dams need to be protected from risks such as the cascading failure of adjacent dams.

2.2.2 *Stava, Italy, 1985*

The Stava facility had recently been dormant and had been recommissioned.

According to Simeoni et al. (2017), referencing Lucchi (2005), “In 1969, in order to deal with increased mining production, it was necessary to construct a second basin just upstream of the first one. The dam of this second basin was raised without any provision either for anchoring it to the ground or for draining. As the dam grew higher, the base of its embankment grew wider until eventually it rested partly on the silt of the lower basin. The decant pipes were placed inside the basins and discharged outside by passing through the dams. For a period (1978 to 1982), the basins were not in use. Activity resumed in 1983 and continued until the collapse of the structures in July 1985”.

In disturbing agreement with the causes of the El Cobre failure twenty years earlier, the damage to dormant dams and tragic loss of life from the errors of adjacent site location causing cascading failure, were repeated.

2.2.3 *Merriespruit, South Africa, 1994*

The Merriespruit No. 4 dam was in a dormant phase at the time of failure. Deposition of tailings was taking place on an emergency basis, as a result of slurry pumping underperformance in delivering tailings to the actively operated alternative location.

Fourie et al. (2001) noted “In March 1993 the decision was taken to suspend tailings deposition on the northern compartment of the dam (i.e. the compartment that breached on February 22, 1994). For reasons that were attributed to poor communication, unauthorized deposition of tailings still took place on this compartment from time to time after March 1993”.

In other words, Merriespruit No. 4 stood dormant for almost a full year before the failure occurred.

2.2.4 *Mount Polley, Canada, 2014*

In common with many other mining operations, and in similar fashion to the economics of the Stava facility, Mount Polley had been returned from a state of dormancy, and returned to service, prior to the failure.

As noted in the Mount Polley Breach Report (Morgenstern et al. 2015), "As a result of low copper prices, the Mine suspended operations from October 2001 to February 2005. A small staff was maintained at the Mine and they managed the TSF water balance carefully, making sure that sufficient freeboard was maintained. Towards the end of the Care and Maintenance period, mine development in preparation for start-up was underway and surface water accumulated in the TSF. It was recognized at this time that plans would have to be developed to discharge water to the environment".

When one rereads the Mount Polley report years later, it is apparent that a multitude of actions were taking place all at the same time just before the failure occurred. Unless a strategic view is taken for a tailings facility, similar risks may arise.

As observed in the report: "Something had to give, and the result was oversteepened dam slopes, deferred buttressing, and the seemingly ad hoc nature of dam expansion that so often ended up constructing something different from what had originally been designed. Ultimately, the tortuous, incremental nature of this process, and the constraints under which it was conducted, caused it to lose sight of basic precedent."

The care of a dormant tailings facility cannot be ad hoc. Neither can its return to active deposition be.

2.2.5 *Brumadinho, Brazil, 2019*

The Brumadinho facility was dormant at the time of failure. Deposition had not occurred on the dam for two and a half years.

Robertson et al. (2019) observed that "Dam I was developed to store tailings that were produced during mining operations at the Córrego do Feijão Mine.… Dam I was constructed over a 37-year period from 1976 to 2013 in 15 stages…. No new raisings were constructed after 2013, and the placement of tailings ceased in July 2016."

Troubling signs of rising risk associated with dormancy are included in the report, such as "Water management within the tailings impoundment that at times allowed ponded water to get close to the crest of the dam".

3 SOME RELEVANT DEFINITIONS

In order to more fully explore some of the risks faced once a tailings facility ceases operation, it is perhaps useful to define a few terms used in this paper:

- Dormancy: The (unacceptable) condition of a tailings facility in the time period between the cessation of operations and the start of reclamation and closure activities. This can vary from months to years. No assumption is made about activities in the mine or in other tailings facilities – mining may be active or suspended or ended. As implied by the term, insufficient attention is paid to a tailings facility which is allowed to remain in a state of dormancy, instead of being decommissioned.
- Latency: The condition of existing but not being very noticeable or well developed. In the context of dormant tailings facilities, may apply to conditions or processes that are evolving slowly, not necessarily noticed, and that might threaten the safety of the structure.
- Time bomb: A situation that is likely to cause serious problems at some future time. It may at present be only latent.
- Black Swan event: A Black Swan is a rare, unexpected event. That is, it is truly rare (hardly ever happens) and it is far outside of the collective experience of a group of people, so that they would not consider it to be possible. It can have positive or negative consequences, but those consequences are usually extreme.
- Fragility: The condition of being weak, easily damaged or easily broken.
- Robust: The condition of being strong, able to survive being used a lot and not likely to become weak or break.

- Resilient: Able to quickly return to original shape or serviceability after being subject to stress and/or shock.
- Anti-fragility: The opposite of fragility. In its fullness, a condition beyond robustness or resilience; an ability to not only survive stress and/or shock, but to improve as a result of that stress and/or shock.

4 RISKS TO MANAGE IN MOVING FROM OPERATION TO CLOSURE

Mining commodities are cyclical in nature, and as such, the operational status of tailings facilities can change very quickly, as mine owners adapt to market changes. Tailings facilities may cease operations very unexpectedly, temporarily, or permanently.

Unless this eventuality is planned for, a state of dormancy may result, in which closure is neither anticipated nor implemented, and the facility may face unexpected risks, with few resources to manage the risks. What are some of these risks?

4.1 *Planning risks*

Dormancy at worst, or a decommissioning phase, at best, should be contemplated, as a risk. What happens if the tailings facility must curtail or cease operations unexpectedly? This must be planned for.

4.1.1 *No plan at all*

Despite all that has happened in the tailings industry in the past six years, there are still active tailings operations around the world today which do not have a closure plan in place. Some closure plans have not included a risk assessment. A Failure Modes and Effects Analysis (FMEA) is now a requirement for each phase of a tailings facility in British Columbia, Canada (BC Government 2016).

One of the risks that should be considered in an FMEA, is the possibility that a facility could cease operations suddenly. This is the risk of dormancy. A phase of decommissioning should be entered immediately, to address risk. Risks do not go away by themselves: when left to themselves, risks tend to increase rather than diminish.

4.1.2 *Starting too late*

Planning for closure cannot start too early. A sound life cycle plan for a tailings facility commences with planning for closure during the design phase.

The profitability of a mine declines over time, as reserves are depleted, ore grades deteriorate, equipment becomes inefficient and outdated, and staff and community morale wanes. This is often the backdrop against which tailings facility closure must take place. Early planning for closure and dormancy can provide a defense against these limitations.

4.1.3 *Short sighted mine planning*

Tailings plans typically do not look far enough. A true life of mine plan looks way beyond ten years. A trend in recent Geotechnical Review Board (GRB) advice is to look at both life of mine as well as closure time frames.

4.1.4 *A lack of integrated planning*

If a mine should suddenly cease tailings deposition, planning and preparedness for closure might find itself out of sync with operational realities.

More than one tailings plan the authors worked on over the years, relied on a different technology for operations to that required for closure. Unless plans for the facility are integrated, the risk of dormancy remains a real threat.

There is a need for mid-range planners, who can match the short-term requirements of operations while not losing focus on the longer term demands of closure.

4.1.5 *Inflexibility of plans*

Closure plans (and plans to deal with dormancy) need to be adaptable and able to evolve to account for changes in:

- commodity price,
- mine ownership and management,
- regulation,
- materials,
- operations,
- performance of structures and
- weather.

4.2 *Risks arising from decision making based solely on financial information*

Some risks imposed upon tailings facilities derive from the nature of the decision-making process. Most mining companies are privately owned and are measured within annual and quarterly financial windows. This is a substantial influence on operational decisions, including those impacting on tailings. This introduces many potential risks, for tailings operations and closure planning:

4.2.1 *Ignorance of mining commodity cycles*

Saving for closure costs early and during the life of mine to avoid the vagaries of uncertain commodity fluctuations is prudent.

An approach to mine planning and closure which ignores commodity cycles is naïve at best, and a target for prosecution, at worst. Overly optimistic reserve and mine valuations make matters worse.

4.2.2 *Ill fated, continued reliance on NPV instead of Life Cycle Costing*

So much has been written by Van Zyl (2009) and many others. Ongoing reliance on Net Present Value (NPV) instead of the ethical alternative of Life Cycle Costing to guide closure decisions can no longer be excused and will lead to a loss of social license to operate. Even within NPV analysis, discounting is used to justify deferring almost any decision with long term implications, especially in high inflation economies.

4.2.3 *Shortage of funds and materials (such as crushed rock)*

Apart from the shortage of funds, other resources may be missing:

- Equipment
- Materials, such as crushed rock
- Emergency supplies
- Power supply

As noted in Mount Polley Report (Morgenstern et al. 2015), “The design was caught between the rising water and the Mine plan, between the imperative of raising the dam and the scarcity of materials for building it.”

A sound decommissioning and closure plan considers the restrictions of reduced access and limited resources and provides accordingly.

4.2.4 *Avoiding expensive Sustaining CAPEX*

Certain designs are predicated on the regular expenditure of Sustaining CAPEX. This might include adding an extra stage of slurry pumps or implementing a berm step back to control erosion and stability or relocating a decant point to move the pond away from a vulnerable slope.

Such designs are inherently fragile, since it is all too easy to defer such expenditure, and to continue to rationalize such deferrals for many years: “Nothing fell down; Let’s not fix what’s not broken; it was an overdesign anyway; we’ll use the observation method.” We have all heard the rationalizations.

4.2.5 *“Mothballing” to avoid decommissioning and closure*

Mothballing or the temporary cessation of operations, without the necessary precautions of decommissioning and closure, may be simply lighting the fuse for the time bomb of catastrophic failure for hydraulic fill structures. Mothballing continues to happen.

4.2.6 *Mine bankruptcy or foreclosure*

At least two tailings facilities known to the authors have recently failed or narrowly avoided failure while the company owning the mine was undergoing bankruptcy procedures. Are tailings risks even considered in mining foreclosure?

4.3 *Regulatory risks*

The regulation of mining and mine waste disposal requires interaction between mine owner and regulator in many areas, including permitting and approval of mine operating and closure plans. As further reported in section 5.5 of this paper, Alberta, Canada is an example of a jurisdiction in which regulatory and mining teamwork is relatively effective. Unless the regulatory interaction occurs efficiently, several risks may arise during the dormancy, decommissioning and closure phases:

4.3.1 *Poorly defined closure acceptance process*

Historically, the process for regulatory approval of waste or tailings facility closure plans in many jurisdictions has been uncertain, iterative, even tortuous, and very time- and resource- consuming (Morgenstern 2012, Boswell 1996). Usually, the applicant engages the regulator, while neither has a complete picture of what is required. Prevailing law and regulations usually stop short of defining the detail. Stakeholder and environmental issues tend to confuse matters further, and the requirements for closure often take a great deal of time to be defined and agreed to.

Most mining jurisdictions have not yet sufficiently defined a practical closure acceptance process, nor achieved maturity in implementing tailings closure. End use planning, stakeholder engagement, release of water to the environment and administrative delays are some of the challenges that have been encountered.

Morgenstern (2012) reports on the early struggles in Alberta with achieving true closure for an overburden waste dump at Syncrude, known as Gateway Hill. Eventually true closure was successfully achieved, but only after a closure acceptance process had been developed, agreed and implemented, between the mine and the regulator, over a ten-year period. These early lessons paved the way for a better collaboration in Alberta between regulators and mining, including publication of guidelines (Kupper et al. 2014, subsequently in the process of substantial revision), development of metrics and practical implementation of administrative measures.

4.3.2 *Non-holistic regulation*

A chain is only as strong as its weakest link. The many components of mining and closure regulation require holistic thinking and implementation.

4.3.3 *New risks arising from imposed regulations/interventions*

For a mining economy to thrive, investors require a measure of certainty. Ever-changing rules and requirements erode investor confidence.

Morrison (2018, 2019) reports on some of the difficulties encountered in Brazil with the introduction of substantial, new tailings regulations over the past five years. A ban on upstream construction has required the immediate cessation of tailings deposition for many facilities.

4.3.4 *Disallowed discharge of water*

In the absence of release water guidelines and criteria, even in case of emergency only, the storage of excess water on tailings facilities remains one of the single largest risks for hydraulic fill structures.

4.3.5 *Jurisdictional conflicts and/or gaps in addressing closure*

The regulation of mine and tailings closure requires significant collaboration between different levels of government, and between different departments within each regulator. Unless regulations and administration are implemented collaboratively, a fragmented approach will usually result in prolonged delays and high cost to the mine and to the environment.

4.4 *Technical risks*

Neither time nor space affords opportunity within this paper to fully describe many of the technical risks faced during dormancy, decommissioning and closure, many of which are well reported in conferences, an excellent example of which is this Tailings and Mine Waste series within the USA and Canada. Previous papers by many leading practitioners have provided insight into the technical risks of tailings dams, for many decades.

Instead, a few salient technical risks are simply listed below, for reasons of currency:

- Settlement, and the absence of geotechnical readiness for reclamation (Sawatsky et al. 2018).
- Absence of water treatment.
- Ponded water.
- Impact of climate change on reclamation strategies.
- Co-disposal with other wastes.
- Long-term reliance on external tailings facilities.
- Absence of comprehensive closure plans for deep in-pit deposits.

5 GUIDING PRINCIPLES FOR MANAGING RISKS AFTER OPERATIONS CEASE, AND BEFORE CLOSURE IS IMPLEMENTED

Once a facility ceases operation, new risks are introduced. In addition, some risks previously considered to be under control, may reappear at heightened levels. Faced with this scenario, what remedies and interventions could be available to the dam owner or person responsible for dam integrity?

5.1 *Recognize the risk of dormancy, and the critical role of decommissioning in reducing risk*

Recognition of the risk of dormancy is an important first step. Whether active closure is immediately being considered, or whether the facility is non-operational, dormant or “moth-balled”, growing new risks as outlined in the section above, require dedicated attention.

Two phases in the life cycle of tailings facility development are often overlooked:

- Commissioning – the transition between construction, and operation: preparing, equipping, and making the facility ready for operation.
- Decommissioning – the transition between operations and closure: taking out of service and making safe.

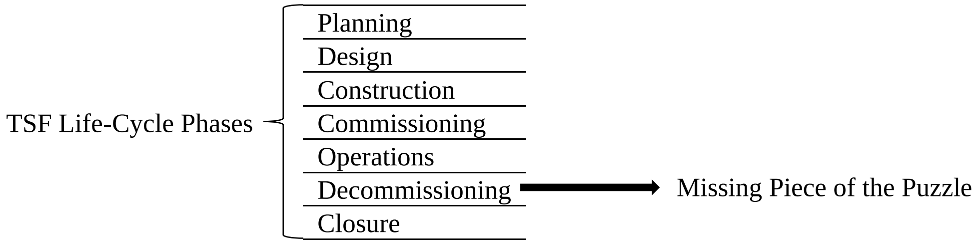

Figure 1. Decommissioning, the missing piece in the puzzle.

Preparing a facility for closure is not a trivial task. The facility may not be ready for closure. It needs to be decommissioned in an orderly manner, in order to control risk. This decommissioning phase needs to fill the gap between operations and closure.

In other words, recognize that a phase of dormancy may follow operations and needs to be properly managed. If it is, then decommissioning will provide protection to the facility until closure is implemented.

5.2 *Target reclamation readiness*

Leading mining sectors evaluate this condition in considering "reclamation readiness", by identifying and tracking key geotechnical performance criteria, such as:

- degree of consolidation,
- vulnerability to liquefaction, and
- settlement.

The process of advancing a facility to reclamation readiness may take many years. Careful planning should commence years before operations cease, to avoid rising risks and expensive emergency interventions.

Most tailings facilities are operated as hydraulic fill structures, and for good reason. The lower daily operating costs of slurry hydrotransport and beached deposition for separating solids from liquids is attractive and has been employed for many decades.

However, this technology may not immediately lend itself to ready closure, nor to managing and reducing long term risk. A transitional or decommissioning phase can be used to strengthen the defensive measures of the facility, by altering the operation of the facility as it nears the end of useful life, through:

- Reducing supernatant pond volumes, also leveraging the benefits of reducing the area occupied by the pond. (Rourke & Luppnow 2018, Boswell & Sobkowicz 2018).
- Reducing the mine process water inventory, including water treatment and release.
- Removing and treating fluid tailings.
- Reducing catchment areas to decrease risks associated with extreme precipitation and flooding.
- Compartmentalizing.
- Changing or reversing beach angles.
- Controlling the impacts of desiccation, especially dust generation and windblown erosion.
- Mulching of top surfaces, using rock or by providing a growing medium for vegetation.
- Improving drainage.

5.3 *Pursue antifragility*

Nassim Nicholas Taleb (2014) provides an excellent insight into the concept of antifragility.

While an awkward term, "antifragility" is the opposite of fragility, a condition beyond resilience and robustness (see definitions in Section 3). What is the difference between robustness, resilience and antifragility? Something that is robust or resilient resists shocks and stays the same or returns to the same serviceability. However, something that is antifragile, when exposed to shocks, gets better.

Some things benefit from shocks: they thrive and grow when exposed to volatility, randomness, disorder, risk, and uncertainty.

Not all systems can be made fully anti-fragile, but if that is the goal, then measures can be taken to move in that direction.

- The first step is to become less fragile and more robust. For example, in a personal or business sense, debt results in fragility, so avoid debt.
- Introduce redundancies into systems and processes to make them more robust.
- Contrary to much advice in the financial and engineering fields, optimization is not possible in a Black Swan world. Avoid efforts to optimize tailings facility systems but instead work on making them more robust, resilient and ultimately anti-fragile.
- Build reclamation surfaces and closure landscapes that have the potential to improve over time, even when subject to at least known stressors. Lessons from natural landscapes that have survived and thrived over time can be instructive, in this regard. Blight & Amponsah-Da Costa (2004) describe such a condition in the chapter contributing to a book on the subject: "Towards the 1000-year erosion-free tailings dam slope" based on Blight's visit to China where naturally occurring slopes were observed.

5.4 *Characterize Risk by considering True Decommissioning (not dormancy or latency)*

Section 4 of this paper has listed some of the key risks which are often overlooked after operations cease. In characterizing these decommissioning phase risks, there are key elements to bear in mind in the risk characterization process:

5.4.1 *Identify and characterize decommissioning risks well in advance*

Time is an important resource in planning for decommissioning. Environmental and natural processes may be harnessed in reducing human intervention. Well planned decommissioning can leverage many cost savings by using mine-based human and material resources during the operational phase, to prepare for decommissioning.

5.4.2 *In assessing likelihood consider a longer window than a simple annual period*

Conventional risk management usually considers annual probability in assessing likelihood and risk. This approach has limitations for closure thinking. It behoves the dam owner to consider medium- and longer-term risks for more special attention.

5.4.3 *Engage the full breadth of multidisciplinary knowledge and expertise*

Decommissioning (like closure) thinking and planning requires a broader range of disciplines than those tasked with day-to-day tailings operation.

5.4.4 *For longer term risk management, a focus on reducing consequence is preferred over reducing likelihood*

Robertson (2011) observed that unlikelihood is no defense at all, in the face of perpetuity. At a previous Colorado TMW conference, Boswell & Sobkowicz (2016) discouraged unlikelihood as a defense against extreme and imponderable consequences.

While addressing post-operating and closure risk, make use of the opportunity to reduce consequences, looking for “low hanging fruit”, while isolating and avoiding the hidden costs of long-term active care.

5.4.5 *Review and reevaluate risks regularly and address rising risks promptly*

Dormancy risks tend to grow and accelerate. Consider risks such as flooding, inundation, surface and internal erosion, freeze-thaw, etc. The adage is never truer: “a stitch in time saves nine”.

The province of British Columbia now requires a formal Failure Modes and Effects Analysis (FMEA) to be conducted, updated and submitted regularly, for regulatory scrutiny.

5.4.6 *Continued reliance on the observational method requires continued observation*

The above statement seems redundant but does reflect the implied risks of employing the observational method once active deposition and attention ceases. The observational method must either be continued, or adequately replaced.

5.4.7 *Recognize that Black Swans will occur*

Caldwell & Charlebois (2010) provide valuable insight into taking account of the influence of Black Swans (completely unforeseeable events) on tailings management.

5.4.8 *Recognize if you cannot mitigate a risk, you have to monitor*

It goes without saying that if a risk cannot be eliminated, reduced or transferred, then the long-term impact of the risk on the facility must be closely watched.

5.5 *Develop metrics for decommissioning and closure through effective collaboration between regulator and industry*

In section 4.3.1 of this paper, some of the significant risks faced during the regulatory process of tailings closure are described. How may these risks be addressed?

In Alberta, the following process has evolved in discussions over the past four years or so, with the regulator:

- One mine or dam owner raises an issue with the regulator. It could be closure parameters, implementation schedules and dispensations for new regulations, requirements for as yet undefined activities (such as release of water to the environment), etc.
- The regulator (typically more frequently AER on Energy dams, but also sometimes AEP on other dams) has then approached the Alberta Dam Integrity Advisory Committee (DIAC) to say: "We would like industry to help us define what parameters and standards we should use, and provide practical, measurable and existing leading practice direction, so that we can implement something fair and reasonable across the board that is also workable and practical, and supported by public and external stakeholders."
- DIAC would then consider the task in one of their subcommittees, and then forward material to the regulator, usually accompanied with a series of workshops, presentations, and discussion. There is often a lot of back-and-forth as the best approach is developed, discussed and confirmed.
- In other words, industry is invited to assist the regulator to define the process, parameters, and implementation. Of course, the regulator will always make their own decisions on the right balance to be achieved.
- This process is now working reasonably well. All parties are in support of this process.

Early experience supports the promise of prescribing and implementing practical, reasonable and equitable metrics for decommissioning and closure. As an alternative model, this presents avenues for more efficient collaboration between regulator and industry.

5.6 *Prepare a comprehensive plan to address post-operative risks*

Evaluation of risk and development of appropriate mitigation plans is a critical but also a standard exercise in the design, construction and operation of tailings facilities. This is normally carried out through various risk assessment methods (or a combination thereof), such as Failure Modes and Effects Analyses, Bow Tie Analyses, and for more complex issues, Multiple Accounts Analyses. These can be carried out at various stages during the design, construction and operation, which may overlap somewhat with one another.

It is essential to carry this risk assessment/mitigation approach through into the dormant period of a tailings facility, and then further into the reclamation and closure period. What is important from the perspective of this paper is that the same careful evaluation is required during dormancy as is required for all other stages of a tailings facility's life.

5.7 *Actively maintain mitigation measures*

In regard to the point in the previous section, mitigation measures need to be defined and carried out with the same level of care and attention to detail as during earlier stages of the life of the tailings facility. This could include a continued application of the observational approach, which requires ongoing monitoring and response to adverse performance, or in the event of inability to mitigate over time, the implementation of pre-emptive mitigation measures.

5.8 *Maintenance during Tailings Facility dormancy*

In some cases, the ability to respond quickly (or at all) to observed inadequate performance (of any kind) raises the stakes in terms of facility maintenance. Maintenance items that under normal operations might have a low priority, under the conditions of a dormant facility take on a higher priority. This seems counter-intuitive to many, who tend to ignore low priority maintenance during periods of dormancy. However, a heightened attention to maintenance is the main defense against the development of adverse, latent conditions and in some cases, hidden time bombs.

5.9 *Continue with vigilance to inspect and report on the condition of the structure*

The longer a tailings facility continues in a dormant state, with little visually observable change, the greater the temptation to become complacent with both its condition and its performance. This is particularly true when there is a lack of the normal types of "stressors" (such as increased loading on a dam or its foundation from construction or from operations [e.g. beaching, pond level increases]) that result in continued, observable performance changes.

This vigilance could have been of life-saving value in the cases quoted in Section 2 above.

During dormancy, the changes in the condition of the structure may be much more subtle (e.g. slow internal erosion, gradually rising pore pressures that could trigger instability, etc.). Detecting these changes can require more diligence in assessing and monitoring for failure mechanisms that can develop slowly over time. A good example of this type of condition is the "sudden" appearance of sinkholes on the Bennett Dam in northern BC, 30 years after construction and initial reservoir impoundment (Stewart et. al. 1997).

5.10 *Ensure instrumentation is appropriate for inoperative phase*

Defining the requirements for instrumentation during the dormant stage of a tailings facility is related to previous sections (5.6 to 5.9). As during other stages of a tailings facility's life, the instrumentation must be selected, located and monitored in a fashion that is at least consistent with the anticipated failure modes and ongoing processes. These requirements may be significantly different than those established for the construction and operations stages, but no less important. Thought should be given to meeting changing regulatory requirements and maintaining long-term access to instruments (for readings and/or for maintenance). In addition, consideration should also be given to making the instrumentation system itself anti-fragile, which is particularly important for longer periods of dormancy

5.11 *Plan Effectively for True Closure*

Many unsuccessful attempts at true closure may be traced back to a lack of foresight and planning. Conversely, the benefits of timely and effective use of resources in introducing closure actions early, during the operational phase, cannot be overstated.

5.11.1 *Engage the closure approach*

Recently updated tailings guidelines as referenced in Section 6 and the References Section below, suggest a significant and early focus on closure, and closure planning. Closure is considered as a critical action which should start well before operations cease – in fact, as early as during the design phase.

A platinum tailings facility which was designed by one of the authors nearly four decades ago, commenced closure actions, including top-soiling and revegetation of the sideslopes of the upstream facility early in the operational life, long before closure was even considered. The advantages of this early initiative included the availability in an arid region, of (operational supernatant-fed) moisture for root growth and penetration and significant cost savings. The contractor even offered the service without additional charge, as enough personnel were already on site with ongoing surveillance and other routine responsibilities.

5.11.2 *Recognize the high costs of real closure*

Traditional mining economics has often relied on the NPV approach to decision-making. Van Zyl (2009) and others have pointed out the severe limitations of the approach, advocating instead, a life cycle approach to costing, economics and decision-making, which is less likely to allow postponement of closure activities for reasons of short-term financial benefit only.

The benefit of starting the planning for closure early, is that financial and other provision can be made slowly, over time, without placing extreme and unaffordable demands on the mine once its most profitable years have passed.

5.11.3 *Establish objectives and solutions*

A useful approach for closure planning is to pursue a risk management approach, targeting and prioritizing those risks which are highest, for closest attention.

As an example: many operations rely on a significant inventory of process water. However, large volumes of supernatant contained on a tailings facility have been shown to be a leading indicator of tailings failure (Boswell & Sobkowicz, 2018), and usually one of the highest risks. In developing strategies to reduce water inventory, closure planning will be addressing one of the highest risk items.

5.11.4 *Plan for both life of mine and closure*

Current review practice in the Oil Sands of Alberta, is to consider implications for both life of mine, as well as the closure phase. An important consideration is the selection of design life of the structure. Clearly, the risk profile and design life of the operating phase are substantially different from those in the closure phase.

5.11.5 *Engage early with regulators and stakeholders, to unlock innovative closure options*

Section 5.5 above has described the obvious benefits of regulatory engagement, which may be extended to conversations with other stakeholders.

5.11.6 *Deal with closure risks early enough to avoid legacy challenges*

In 2008, the erstwhile Energy Resources Conservation Board of Alberta (ERCB, now known as the Alberta Energy Regulator, or AER), having become concerned about the steady accumulation of mature fine tailings (MFT) in the Oil Sands, issued Mining Directive 074, which introduced the first of a number of initiatives to measure, limit and curtail the generation of legacy MFT tailings. They obliged operators to set thresholds which would limit the long-term growth of legacy tailings. More recent lease owners have been set strict limits, to avoid the accumulation of legacy tailings.

5.11.7 *Facilitate sound decision making by accounting for the true value of closure solutions*

By embracing the full ethos of the principle of sustainable development, in recognizing the triple bottom line of economics, environment and society, the quality of decision-making may be improved.

5.11.8 *Schedule closure plan actions recognizing that mine decisions are guided by when money is spent*

Recognition of mining economics, and adapting closure interventions and expenditure to match mine financial planning and cash flow demands, is likely to deliver mining decisions that are more sustainable and suitable for tailings closure. Provision accounting for emergency dormancy would also appear to be prudent.

5.12 *Manage Water with Intentionality*

It may be argued that this point is in fact the most important: in the absence of water, none of the catastrophic tailings failures in history would have occurred.

5.12.1 *Remove the pond contents*

This may be not nearly as easy as it sounds, but it is an obvious fix for many structures, substantially reducing both the risk and the consequences of failure.

5.12.2 *The use of water covers to control emissions is outdated, and risky*

The control of fugitive emissions from mine tailings has traditionally been achieved through submerging the tailings below a water cap. The risks associated with the storage of water in above original ground facilities have now been found to significantly outweigh the benefits. Different technology options are readily available, and must be employed, including the engineering of final covers.

5.12.3 *Secure the deposit*

Ensure that the dam contents do not escape and damage the environment. It is important to look beyond mere management of water, supernatant and water inventory. It is just as important to recognize the risks associated with fluid tailings and liquefiable tailings, and to address the risk.

6 LITERATURE REVIEW

There are several published documents which provide guidelines and standards that relate to planning, closure and post-closure activities of tailings dams and impoundments, many of which are currently under revision as a result of changes in industry due to the recent tailings failures (e.g. Brumadinho).

One example of these guidelines is the 2019 Mining Association of Canada (MAC) Guide to the Management of Tailings Facilities, which outlines a tailings management framework which applies to all phases of the mine life cycle including temporary closure, permanent closure, post-closure and even reopening of closed facilities. The 2019 MAC guidelines not only provide a tailings management framework but also highlight the long-term risks of tailings facilities and the need to prioritize closure planning, which states "Designing and operating for closure requires a long-term view" and "It is important to ensure that short-term financial or operational priorities do not prevail over better design and operational practices that would have lower long-term impacts, complexity or risks" (MAC 2019).

It is not the intent of this paper to present a literature review of existing regulations, guidelines and standards, as they relate to dormancy, closure and post-closure activities. Several organizations have published relevant material, and most are in the process of updating their publications. The reader would do well to track the publications of:

- Canadian Dam Association (CDA)
- International Commission on Large Dams (ICOLD)
- The United States Society on Dams (USSD)
- The Association of State Dam Safety Officials (ASDSO)
- Federal Energy Management Agency (FEMA)
- Federal Energy Regulatory Commission (FERC)
- Alberta Dam and Canal Safety Directive (promulgated by AB AEP, supported by AER)
- BC Dam Safety Regulations (a broad array of publications)
- Australian National Committee on Large Dams (ANCOLD)
- International Council on Mining and Metals (ICMM)
- Global Tailings Standard (GTS)

7 CONCLUSION

If the mining industry is to protect its social license to operate, then thinking and action regarding tailings dam dormancy needs to change. The notion that a tailings facility or a mine may simply be "mothballed" until commodity prices improve, or closure can be afforded, or nature can remedy all ills, is fatally flawed.

Dormant tailings dams pose real, sometimes extreme risks. The risks require strategic intervention and ongoing vigilance from owners, managers, regulators, and consulting engineers.

Recent tailings failures have focused worldwide attention on active tailings dam operations. However, many thousands of dormant tailings dams worldwide continue to pose real risks to human beings and the environment. They cannot simply be studied or reviewed. They must be actively managed during their dormant state, as discussed herein, with the objective of achieving real closure in a short period of time.

The technology and engineering knowledge are readily available. They need merely to be harnessed, as described in the twelve precautionary guiding principles above.

The challenge for the mining industry is to move tailings from dormancy, through ordered decommissioning, to full closure.

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