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Mitigating risks associated to tailings through an enterprise risk management approach

C. LePoudre, SNC-Lavalin, Environment and Geoscience, Canada
F. Oboni, Riskope Inc., Canada
A. Dassa, SNC-Lavalin, Canada
C. Oboni, Riskope Inc., Canada
M. Al-Mamun, SNC-Lavalin, Environment and Geoscience, Canada
H. Sangam, SNC-Lavalin, Mining and Metallurgy, Canada
A. Hébert, SNC-Lavalin, Mining and Metallurgy, Canada
M. Arpin, SNC-Lavalin, Mining and Metallurgy, Canada

Abstract

Tailings management is one of the critical parts of any mine project. Although it does not generate any direct revenue, it represents significant risk to the surrounding communities and the environment, and consequently to the entire mine site, the project's longevity, and its license to operate. With mounting pressure coming from communities, government agencies, and financial institutions to consider the environmental and social consequences of tailings decisions, an efficient tailings management is not only a necessity, it also makes sense from an overall profitability and productivity standpoint.

Tailings facilities are generally large, complex, and interconnected with other key components of the mine operations. But, traditionally, mine managers were preoccupied with safety and productivity primarily in relation to ore extraction and processing, while tailings management risks were not always integrated to the enterprise level risks. To efficiently manage and mitigate risk for a mine project, the impact of tailings management risks should be evaluated at an enterprise level with appropriate risk management tools.

Based on decades of experience supporting mining, metallurgy, and hydro-dam companies with tailings facility and water dam management, we believe miners can adopt integrated enterprise risk management practices aimed at actively managing the underlying risk factors associated with tailings by adopting an Enterprise Risk Management (ERM) approach. The companies that bring tailings management considerations and associated risks to the corporate or enterprise level can not only better manage, respond to, and mitigate these risks, but can also right-size their tailings investments. An ERM approach will also encourage dialogue and exchange with all stakeholders, contributing to furthering sustainable development

goals and strengthening the ability to obtain and maintain a social license to operate. In turn, organizations can avoid steep fines and operational delays, and mitigate difficulties in obtaining funding and insurance.

In this paper, we will explore:

- the importance of managing tailings risks at an enterprise level;
- what ERM is;
- the holistic assessment of risk consequences; and
- tailings management risks at each phase of the mine lifecycle and how to apply ERM to tailings management practices.

Introduction

Tailings management and the effective management of risk associated with tailings storage facilities are increasingly being viewed as paramount to the successful productive and post-productive life of a mine project. But, traditionally, mine managers were preoccupied with safety and productivity mostly in relation to ore extraction and processing. With increasing scrutiny from the communities neighboring mine sites as well as regulators, investors and insurers, these concerns have grown beyond the core revenue-generating activities and have expanded to the residues generated by the mining and ore processing stages, with tailings being of particular concern given their risk profile. As such, forward-thinking mine owners are turning to holistic risk management systems such as Enterprise Risk Management (ERM) as a means of establishing and maintaining safer, more robust tailings facilities and, overall, more profitable organizations. In the process, they are avoiding the steep consequences of tailings incidents, while right-sizing tailings investments and paving the way towards enterprise-wide sustainable development and greater longevity for their mine sites and organizations. In short, the adoption of ERM and the inclusion of tailings risks as part of this contributes directly to strengthening mine companies' value to shareholders.

Based on decades of experience supporting mining, metallurgy and hydro-dam companies with tailings facility and water dam strategies and management, we believe that the most forward thinking miners can adopt integrated enterprise risk management practices aimed at actively managing the underlying risk factors associated with tailings. Bringing tailings management decisions to the enterprise level across the life of mine allows for:

- More accurate understanding of tailings risks;
- Right-sizing investments made in managing risks by avoiding over and under investment;
- Accessing pooled enterprise-funds for those tailings risks that are prioritized at the enterprise level;

- Promoting the attainment of sustainable development goals and the Social License to Operate (SLO).

In turn, this promotes the development and maintenance of stronger and safer tailings facilities and the avoidance of steep fines, operational delays, loss of market capitalization, reputational damage and other consequences associated with the loss of the SLO and tailings failures.

In this paper, we will explore:

- the importance of managing tailings risks at an enterprise level;
- what ERM is;
- the holistic assessment of risk consequences;
- tailings management risks at each phase of the mine lifecycle and how to apply ERM to tailings management practices.

Tailings incidents: A significant risk to manage

Tailings facilities present significant risks to the entire mine site and its stakeholders including neighboring communities. As pointed out by the International Commission on Large Dams (ICOLD), tailings facilities are among the largest man-made structures on earth, some of them in excess of 200 meters tall, placing them, in height alone, between the great pyramid of Giza and the Eiffel tower (ICOLD, 2001). In addition to their size and the volume of their contents, their longevity presents a compounding of existing risks. As they are intended to live on throughout the life of mine and beyond closure, they have the potential to leak or, worse yet, break and inundate surrounding areas causing material human and ecological damage. In these cases, the companies that have sustained a failure are brought to the forefront of media coverage and face market capitalization losses as well as swift cost recuperation by governments, resulting in millions and, in some cases, billions of dollars of fines. There are also costs associated with production stoppages, in the case of contained waste storage facilities, that impede the revenue generating capability of the mine. Further, criminal charges have been levied against mine personnel for loss of life resulting from tailings failures.

The average cost of severe tailings incidents, based solely on fines levied to the mining companies that sustain a failure, is around $540 million (EarthWorks, 2015; Newland Bowker and Chambers, 2015) with recent damage settlements in the billions of dollars. Even more significant than the amounts fined immediately following a failure is the long term reputational impact. This alone can carry significant penalties for future growth, making it more difficult for mine operators to secure the investments, the insurance and the social license required to continue operating and to initiate new projects.

The significant costs associated with a tailings failure is combined with pressure on miners to establish and maintain safe and robust tailings facilities from key stakeholders such as government organizations, regulators and the communities surrounding mines. This has galvanized miners to take these perspectives into account in view of preserving their mine sites' and their organization's longevity.

Why consider tailings risks at an enterprise level?

A tailing site presents important interdependencies with the other infrastructures that make up a mine site. Tailings storage facilities are also, by far, the most sensitive infrastructure of a mining operation with respect to potential risk for the surrounding environment and community. Indeed, issues with a tailings facility can cause severe interruptions to all mine operations and significant repercussions for the enterprise as a whole. Similarly, decisions in other areas of the mine can impact the robustness of tailings facilities. It is therefore important to consider risks related to tailings facilities as an integral part of mine operations and encompassing a review of all hazards while managing these alongside other prioritized enterprise risks.

A recent environmental incident linked to tailings in the Solomon Islands at the closed Gold Ridge Mine illustrates the importance of addressing risks from an enterprise perspective (Special Broadcasting Service, 2016). A weir, a low dam structure built on top of the tailings dam, had been constructed to protect the mine's tailings dam from flood waters, a risk identified by the dam engineers. The weir was built to allow for flood waters accumulating on top of the tailings dam to flow away without affecting the integrity of the dam. While this approach successfully addressed the risk posed to the dam as identified by the dam engineers, the weir poisoned thousands of people by letting contaminated water flood the valley downstream and opened up the company to fines and litigation. The environmental risk had not been properly taken into account in this situation. An enterprise-wide perspective would have facilitated exchanges between the dam engineers and the environment, health and safety managers to avoid this incident and find a strategy that could mitigate the salient risk dimensions and satisfy stakeholder concerns, such as increasing the volume that could accumulate safely on top of the tailings or building better diversion ditches.

Considering tailings at an enterprise level is easier said than done. There are innumerable risks across the different groups and sectors of a mine. How to make sense of these without causing analysis paralysis or, worse yet, the dismissal of significant risks for less important ones? This is where ERM can set methods, processes, systems and a governance structure to oversee all risks, allowing mine management to effectively manage their enterprise level risks, such as those prioritized for tailings.

What is Enterprise Risk Management (ERM)?

ERM is an ongoing and iterative approach that is concerned with managing enterprise-wide risks and addressing the interdependencies that exist between them, where any component can influence another. It is supported by ERM processes and systems to facilitate its systematic application and by a set of governance roles to ensure effective oversight. ERM allows for an enterprise level view of tailings risk, bringing in perspectives from across the organization to best identify, assess, prioritize and treat these. This approach, when effectively carried out, allows miners to focus on the important risks, reducing the resources wasted on unnecessary mitigation activities and improving the overall risk profile of the organization.

Some key elements of ERM are:

- **a dedicated risk manager working across all business areas** to identify and study enterprise wide risks and their implications;
- **cross business unit collaboration** to more accurately understand and prioritize risks as well as define effective solutions;
- pooling of enterprise resources to mitigate prioritized risks, including those pertaining to tailings management

As opposed to the more traditional sectoral risk management, a well-conceived ERM approach allows miners to clearly distinguish between operational-tactical risks and strategic risks. By bringing risks involving tailings implications to the enterprise level, these may be properly evaluated and gauged as strategic risks in pertinent cases as opposed to operational-tactical risks. This opens up a clearer perspective as to whether prioritized strategic risks involving tailings are tolerable or intolerable as well as manageable or unmanageable (Oboni and Oboni, 2014).

ERM is also led by a dedicated Chief Risk Manager or officer who works across all sectors to identify and assess enterprise wide risks. Risks are identified, evaluated and managed across all sectors of the mine to prioritize those of material importance to the mine site and company as a whole. This allows for cross-sector elements of risks to be considered and, therefore, a more accurate understanding of risks. Considering these cross-sector elements involves interaction and collaboration with all sectors and stakeholders, including technical specialists from across the organization, government agencies, regulators, investment organizations and communities neighboring mine sites.

In order to effectively manage enterprise risks, Chief Risk Managers have a seat among the top line executives of any mine organization so that they are exposed to enterprise-wide strategy and decisions. As tailings considerations and risks are brought in at this level, they work across all business areas and silos to identify and study these risks and their implications so that they can best prioritize them against other enterprise level risks.

The three main steps of risk management are as follows when adopting an enterprise-wide perspective:

1. **Risk Identification and Assessment** – this step involves identifying the risks **across the enterprise** and then quantifying them by assigning a likelihood or probability (p) of that risk arising and identifying the associated consequences (C) across business units. In other words, **Risk is expressed quantitatively as 'p × C × u'**, where p = probability, C = the sum of all consequences including those that are direct, indirect, social and otherwise associated with the multi-dimensional nature of the risks studied and u = an uncertainty modifier where engineering studies have not been conducted and engineering judgment is used instead. As ERM involves looking at all facets of a given risk, including those that are cross-sector and concerning all stakeholders, **all consequences are looked at beyond the typically evaluated direct consequences.** Further details on the consequence portion of tailings risks is provided in the following section, 'Consequence side of risk assessment'.
2. **Risk Prioritization** – this step involves the **prioritization of enterprise risks** according to p and C to determine which to address first according to priorities, tolerance thresholds and particularly the intolerable part of each risk as well as the overall risk tolerance of the mine site and organization. Tolerance to risk is usually reflected in an organization's corporate risk matrix which assigns a score to the various risks assessed. Tolerance thresholds are defined before prioritization and independently from the risk values to avoid biasing the results.
3. **Risk Treatment -** finally, a mitigation mechanism is assigned to best manage prioritized risks. If the risk is deemed greater than tolerance criteria, then efforts will be placed to manage it should it arise. When comparing alternative risk treatments, it is important to take into account risks as part of NPV comparisons where initial investment costs are weighed against the long term costs associated with mitigating risks over the lifetime of a tailings facility.

The consequence side of tailings risks

In determining the consequence side of the risk equation, **ERM takes into account both direct and indirect consequences for the mine site, corporation, community and environment**. Typical direct consequence dimensions associated with tailings facility management risks are indicated in Figure 1 below.

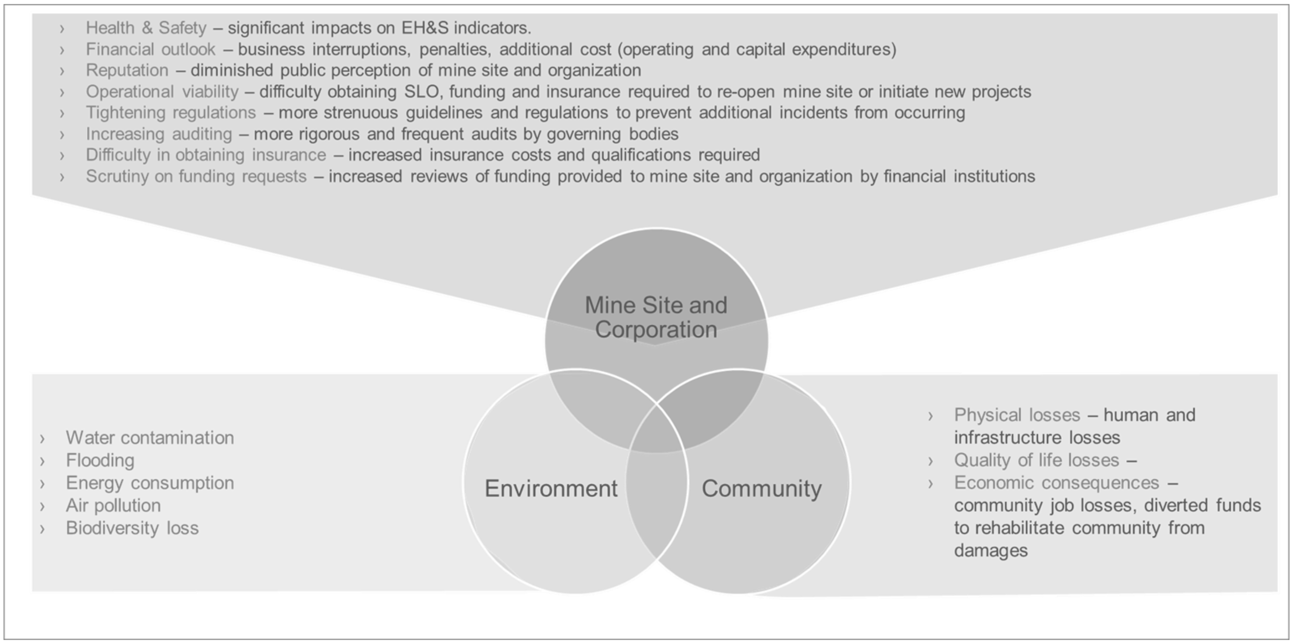

Figure 1: Direct consequences of tailing risk materialization

These concern not only the mine site and organization itself, but also the neighboring community and environment. This allows for risks to be prioritized in terms of their overall impact, enabling enlightened decision concerning which risks to treat and how.

At a closed asbestos mine site assessing its options for tailings haulage, an ERM approach led to the decision to build an aerial tramway as opposed to relying on hauling trucks. The dry tailings needed to be hauled and restored to solve important stability issues and allow a drastic reduction in dusting (aerial fibers dispersion).This decision was made based on the risk assessment that indicated that an aerial tramway would address the following:

- environment and social concerns by minimizing dust;
- safety issues by avoiding hazardous and unsafe roads;
- remediation costs as the trams are mounted on a platform that is easily dismounted;
- revenue potential as the electricity created by the tramway was sold back to the grid.

By taking a holistic view onto direct consequences of tailings facility risks for the mine site, corporation, community and environment, an ERM approach also reinforces the attainment of a mine's sustainable development goals. Beyond just complying with regulations and guidelines by governing bodies, taking community and environmental concerns into account when managing risks is imperative to protecting the long term viability and longevity of any mine site and organization. A recent example concerns a mine that followed all applicable regulations, but did not consider the damages caused to the neighboring community by the dust produced from its tailings facility. Based on complaints, legal proceedings were initiated. The mine company in question has been defending its actions since to avoid penalties and retributions. Had this mine considered and prioritized the risk of environmental damage and quality of life loss to its neighbors, it could have saved the significant legal fees and reputational damage it incurred.

As such, engaging in ERM works to both strengthen tailings facilities as robust mine infrastructure and to provide a structured platform with which to engage neighboring communities to understand and address their concerns. This, in turn, bolsters public acceptance of and support of the mine site, which contributes directly to the obtainment and maintenance of a social license to operate, furthering the attainment of sustainable development goals.

In addition to these direct consequence dimensions, an ERM platform will take into account the four systemic interdependencies that are ever-present to mining projects and operations as shown in Figure 2 below. These make up the indirect consequences of risks that complement the more direct consequences described above.

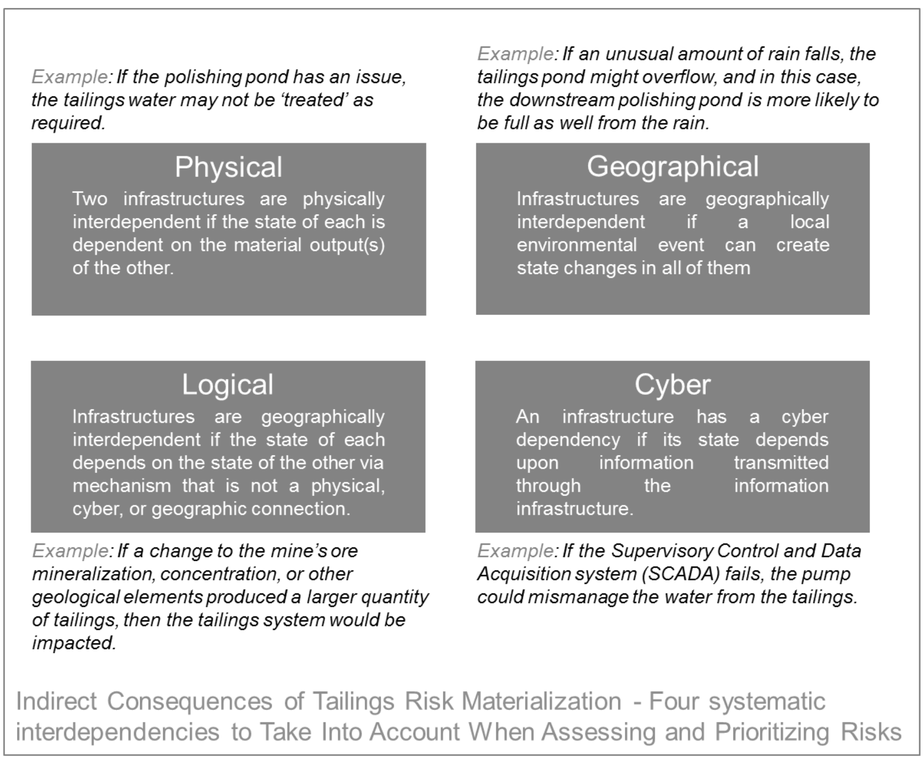

Figure 2: Indirect consequences of tailings risks materialization – four systemic interdependencies to take into account when assessing and prioritizing risks

When managing tailings facilities, these indirect consequences are key to consider as often tailings incidents arise from the chain reaction of several small consequential issues. When only looking at the direct consequences of a risk, its relative importance can be minimized, leading to inadequate risk management. Once direct and indirect consequences are well understood, these are reviewed in terms of corporate and social risk tolerance criteria to determine if any surpass the threshold accepted and warrant immediate treatment. **Overall, adopting ERM allows miners to more accurately understand the risks they face, the interdependencies that they present, as well as how to prioritize and address them.**

Applying ERM to tailings requires systematic consideration of tailings risks from an enterprise perspective, looking at both direct and indirect consequences throughout the organization. This allows for risks involving tailings to be considered at an enterprise level. However, the application of ERM to tailings also requires adapting tailings management practices throughout the different stages of a mine's lifecycle. In the next section, we will explore key tailings risk management considerations at each stage of the life of mine and highlight how ERM can be applied.

Developing and maintaining safe and robust tailings facilities throughout the life of mine

While the most important decisions concerning tailings facilities are those that take place during the scoping /pre-feasibility stage at the very beginning of a mining project, there are important risk management actions and considerations throughout each stage of the life of mine, as shown in Figure 3. These are further explored below.

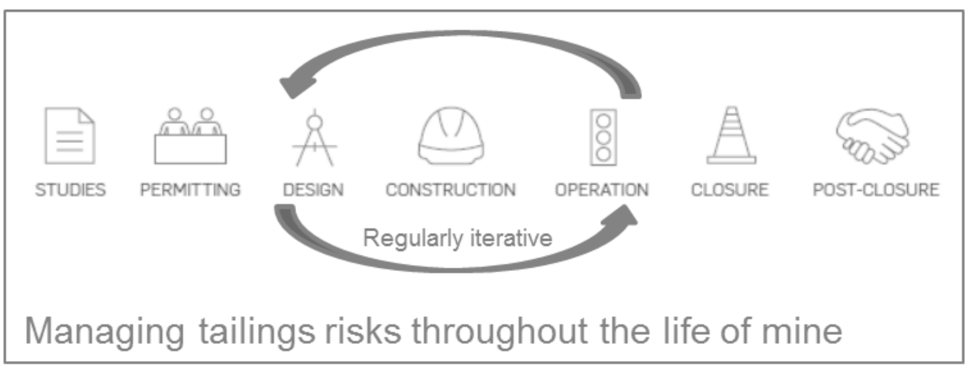

Figure 3: Managing tailings risks throughout the life of mine

Studies stage (scoping, pre-feasibility, feasibility, etc.)

Select evaluation criteria – Prior to reviewing available tailings technology and site options in initial and subsequent trade-off studies, evaluation criteria should be defined according to applicable regulations, guidelines and the following main dimensions: community, economy, viability and environment as well as any applicable industry guidelines and regulations. In Figure 4, the main tailings management considerations to take into account when defining evaluation criteria are highlighted. This constitutes a first step in adopting an ERM approach towards sustainable development.

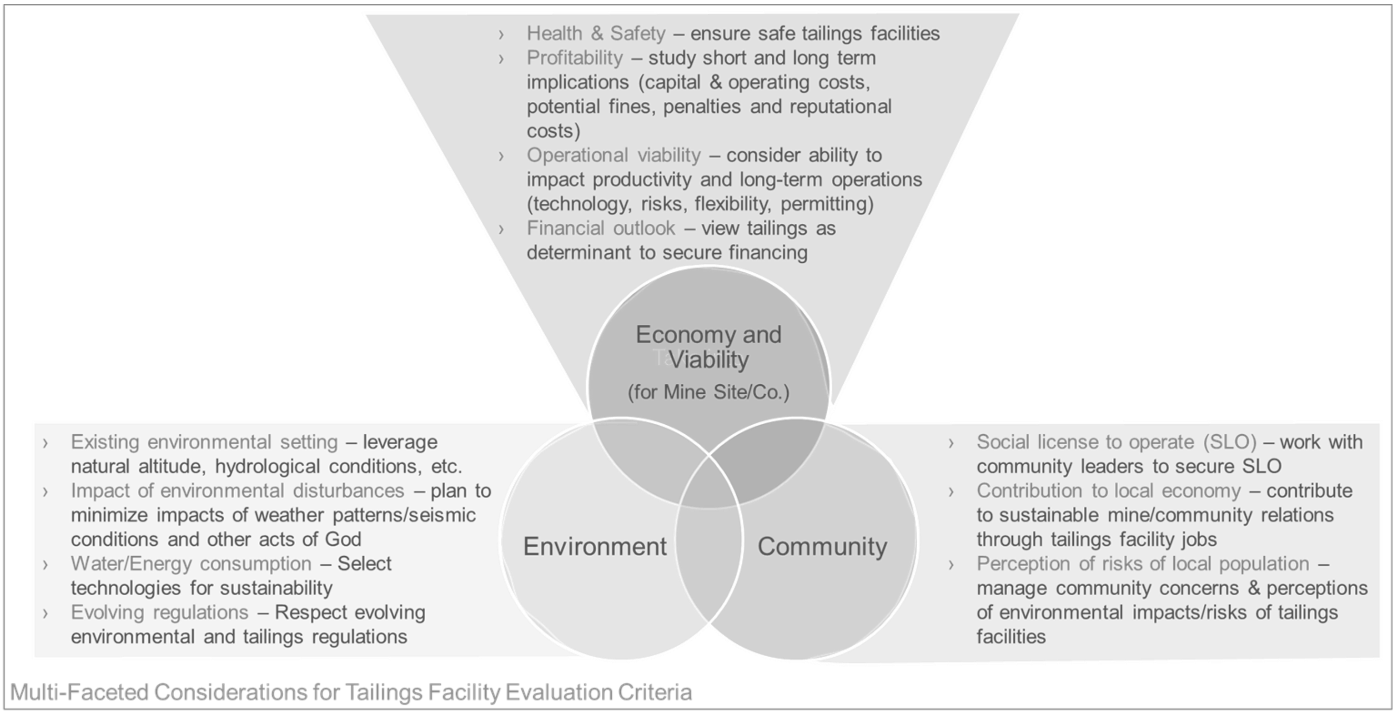

Figure 4: Multi-faceted considerations for tailings facility evaluation criteria

Conduct risk assessments as early as possible and at every step of a project - As early as the project's inception or pre-feasibility stage, it is important to conduct an initial risk assessment that will be revisited and detailed at every step of the project. This will help avoid the consequences of underlying unmitigated risks (also referred to as 'infant tailings facility diseases'), such as designing a tailings facility without taking into account key considerations, such as the power needs of the drainage process. In this case, the infant tailings facility disease would manifest as a drainage issue in the event that a power plant was unable to produce the required output for this process.

The results of the tailings risk assessments should be included in the ERM repository of the mine and updated with each new assessment. The ERM repository is essentially the hazard and risk register database used across the company and includes all ancillary documentation and results. **The use of ERM systems, designed for flexibility and scalability, facilitate the frequent updating of risk assessments and the ability to make enlightened decisions at every step of the project.**

ERM systems formalize the identification, assessment and treatment assignment of risks. In order for an ERM system to facilitate these steps and institutionalize ERM processes, it should be:

- Convergent – converging all risks and hazards in one system.

- Scalable – buildable from pre-feasibility onwards as understanding of risks is refined.
- Drillable – allowing for quick querying by type and characteristic; for example, even in a database with 10,000 fields, a user should be able to quickly identify the risks that impact public opinion or the hazards that are linked to a risk of fire and specifically to chemical fires.

A mine company engaged in the pre-feasibility stage of a $3B project, which required large infrastructural CAPEX due to the peculiar characteristics of the tailings system, was diligent in conducting its risk assessments, having these reviewed by third party ERM specialists and including these in its ERM repository. The project's ERM system indicated that tailings and other elements would expose the corporation to intolerable risks in many areas. Based on this, the mining company in question decided to abandon the project and saved itself from draining unplanned financial resources for a negative overall return.

Choose tailings management technologies – The selection of technologies should be made according to holistic evaluation criteria that include the weighting of risk associated with typical failure modes as balanced against their cost. **Key to making the right decision concerning tailings technologies is considering information from across the mine organization, as recommended by ERM practice and the ISO (International Organization for Standardization) in its risk and asset management certifications (ISO 31000 and 55000).** This ensures that these evaluations and selections are treated as more than just an engineering concern. By breaking information silos and gathering specialists from across the organization to select tailings management technologies and methods, quantitative risks generated by hazards as diverse as seismicity, hazmat and cyber-attacks are considered along with more basic risks such as pipe corrosion and slope instability.

As mining and metallurgy companies have put more emphasis on balancing the costs of tailings facilities with the inherent risks, miners are looking for the best available technology that is economically achievable (BATEA). This has increased the adoption of alternative tailings disposal methods and bulkier, more robust types of tailings dams, such as centerline and downstream built dams that resemble water dams. With these dams, expansion takes place by building outward as opposed to upstream atop dried tailings. These enhanced methods of tailings disposal and tailings dam construction help to avoid instability issues that can occur as the tailings dam grows and in the event of unexpected precipitation or seismic events. As each mine presents a unique combination of characteristics that lends itself to one tailings disposal method versus another, it is important to consider the advantages, challenges and risks associated with each when selecting which to adopt for your tailings facilities.

Select tailings facility site – While some mines are limited in the site options to select for tailings facilities, it is not uncommon for dozens of alternatives to be considered. Making the right choice can significantly mitigate the risk of failure while minimizing the cost associated with getting mine waste to the tailings facilities. **Given that the site of the tailings facility presents implications for the entire mine site, the selection of the tailings site should include information from across the organization, as per the ERM philosophy, to accurately understand and minimize risks associated with the location of the tailings facility.** Some of the considerations to take into account are:

- ability of underlying and neighboring soils to support a given tailings facility – an undetected weak layer of soil underneath the dam embankment was the main cause of the Mount Polley tailing incident (Independent Expert Engineering Investigation and Review Panel, 2015);
- proximity and positioning relative to populated areas, archeological heritage sites, important flora (e.g. reforestation efforts) or fauna (e.g. animal migration path);
- hydrological profile and water balance;
- seismicity.

Define initial design criteria – The definition of design criteria should take place as early as the front end study phases. This ensures that applicable regulations, best practice codes, corporate policies and values are taken into account throughout the rest of the project. As part of the research involved in developing design criteria that are reflective of the company's objectives, the understanding and evaluation of the company's risk landscape and definition of the risk tolerance lead to efficient prioritization.

Keep the end in mind – Closure of the tailings facility should be assessed in the study phase, such as the type of cover, to ensure that this won't need to be reconfigured and will last well after facility closure. Tailings facility should be designed to allow for progressive closure throughout the life of mine (close as you go.) Keeping the end in mind from the very beginning also ensures that there is no lack of funds to put in place for remediation activities necessary for risk mitigation once the mine is near the end of its useful life and will be generating less revenue.

Permitting stage

Comply with applicable regulations and guidelines – Make a thorough inventory of all regulatory and governance frameworks that apply to the tailings facilities, including laws, acts, regulations, guidelines, requirements as per existing permits and best practices from leading reference organizations such as the Canadian Dam Association (CDA) and the ICOLD. While this is a necessary and important step, being proactive in managing tailings risks implies going beyond the applicable regulations and guidelines.

Understand local norms to obtain operational permits and technical licenses by authorities – Consulting local communities is a must to understand local norms, as these often call to fulfilling additional pre-requisites for permits and the specifications for these may vary depending on the local authorities and agencies governing the region in which the mine is located. An in-depth understanding of local requirements, such as the consultation of indigenous communities, is a must to enrich the perspectives gained on real and perceived risks facing the mine and its tailings facilities and to ensure that required approvals and authorizations can be obtained in time, mitigating the risk of operational delays. A recent example is Fortune Minerals in Saskatchewan which received all environmental approvals from the provincial government, but had significant local opposition that contributed to the shelving of the project.

Engage the local community and work towards obtaining a social license to operate (SLO) – Just as operational permits and technical licenses are required of mines to operate, the SLO should be planned for and invested in. The SLO, which refers to the acceptance and approval by mine stakeholders of a mine company and its activities, including the communities neighboring mine sites, is key as communities are growing more concerned with environmental, social and economic implications of mine sites in close proximity. Indeed, stakeholder groups are increasing their involvement and scrutiny of these projects. An in-depth understanding of and adaptation to the local landscape is key to ensure popular support and minimize risks associated with public disapproval and opposition. Without the acceptance of local community representatives, government agencies will be less likely to grant operational permits or licenses (Fraser Institute, 2012; Gunningham, Kagan and Thornton, 2004). Not only does a strong SLO facilitate and accelerate operational permit obtainment, it also decreases operating costs associated with vandalism, difficulties in hiring local skilled labor, legal action due to complaints and protests causing delays and shutdowns. Investing in obtaining an SLO at the very beginning of a project also facilitates the renewal of the SLO when a project is expanded or extended beyond the life of mine initially anticipated. Community engagement is best initiated as early as possible, ideally even before exploration activities begin (Fraser Institute, 2012), and should be maintained throughout the life of mine.

Figure 5: How a social license to operate (SLO) benefits risk mitigation

Regular communication and transparency regarding the mine site and its tailings facilities are key to establishing the mutual respect and trust needed for a SLO. Frank discussions on the risks, costs and benefits involved in mine site decisions ensure that stakeholders are given a platform on which to express their concerns and have these addressed. This works hand in hand with larger ERM practices to obtain and consider information from all concerned stakeholders, enriching mine management's understanding of the risks it faces. **ERM and the pursuit of a SLO thus work together towards robust, stable and durable tailings facilities** as detailed in Figure 6 below. If well maintained, the SLO can not only help reduce overall project costs associated with operational delays (Fraser Institute, 2012), it can also reinforce a mine company's reputation and the robustness of the tailings facility itself.

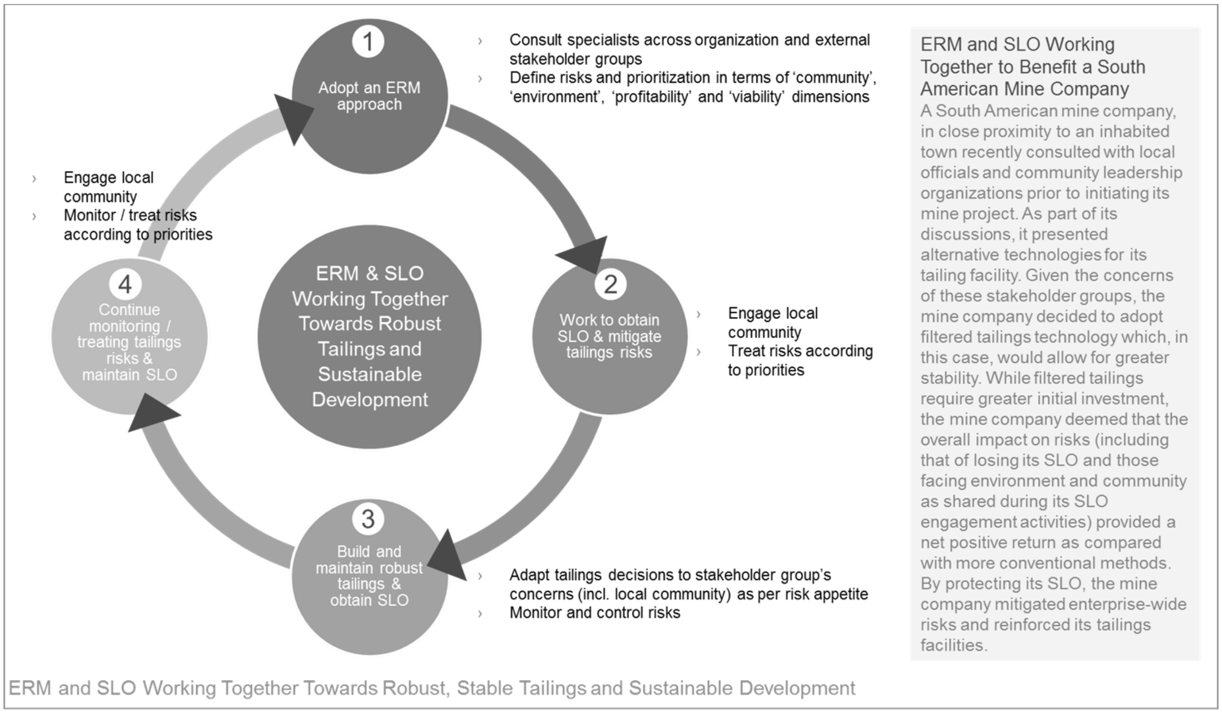

Figure 6: ERM and SLO working together towards robust, stable tailings and sustainable development

Design stage

Design for underlying and adjacent soils – One of the most critical engineering design considerations for a tailings facility, particularly for dams, is the nature of underlying and adjacent soils; the design of tailings facilities must be tailored to the grounds in which they will be built to avoid unstable foundations for example. To this end, a thorough geotechnical and hydrogeological assessment of the site is required before commencing design activities, as was the recommendation from the Mount Polley tailings incident of 2014. Without a solid geotechnical understanding of the underlying soils, tailings facility designs are often overcompensated for the lack of information by, for instance, planning for a build with shallower slopes, generating additional costs. Conversely, inadequate geotechnical site investigation, design and/or construction oversight can lead to missing critical information necessary for the proper accounting of risks surrounding the facility (Silva, et al.; 2008).

Prepare adequate operations, maintenance and surveillance manuals (including emergency response) – As the facilities are being designed, the actions required for operating, up-keeping and responding in the event of an emergency or risk materializing should be duly documented and adhered to. Given that, throughout the lifespan of a mine and its tailings facilities, the teams performing each phase are often changed, it is important to be as comprehensive and detailed as possible, especially as this manual documents the procedures and processes for managing risks and any changes to the tailings facilities. Maintaining these documents up to date and respecting them is an important element of ISO 5500 certification and will help ensure that any deviations are properly addressed in operations or construction. Guidance widely accepted for preparation of an OMandS manual is provided by the Mining Association of Canada.

For example, in tracking and monitoring deviations from design to operations, such as spare parts replacement, especially for pumps, the operations team may notice an increased rate of spare parts replacements. This type of monitoring, which involves looking for risk signals, could indicate an underlying issue associated with operations and the tailings facility in particular. Understanding the trends can help operations teams to better understand evolving and emergent risks to intervene in time before a tailings incident occurs. The same logic applies for deviations from design to construction, where divergence in materials used for a dam, such as sand grade, or changes in the intent of the dam can increase the risk associated with the facility in question.

Design for final tailings facility size requirements, tailings types and adapted uses – As tailings facilities are progressively adapted to accommodate increasing volumes of tailings, their initial levels are built upon to expand; however, if the initial structure was not developed in view of the upper expansion limit, then the entire design needs to be revisited to avoid creating instability. Additionally, if the tailings facility is used other than initially intended, such as for water storage in addition to tailings storage, then the initial stability calculations should be revisited. This is especially important for upstream tailings dams. The Mount Polley tailings facilities were initially designed to be centerline dams, but then gradually were adjusted towards an upstream configuration. As the designs were not revised in consequence, the integrity of the facilities were compromised contributing to the tailings failure. A complete re-assessment of the tailings facility is required when major design decisions are altered. For instance, if a tailings storage facility was designed for slurry tailings and a decision was made to use a different type of tailings down the line, a complete re-assessment is required.

Design for closure – The design of a tailings facility should always be undertaken with the mine closure in mind. This helps to ensure that remediation objectives, such as avoiding free water accumulation, are kept in mind even before tailings facilities are constructed. One way this can take place is with progressive reclamation or the ‘close as you go’ method. By reclaiming sections of the facility while the mine is in operation, this end-in-sight thinking reduces ongoing risks and ensures that, once the mine is closed, the tailings reclamation activities are at a minimum.

Construction stage

Construct to design – It is important to check that designs are being respected and that construction is going according to design specifications. Alternatively, any changes made should prompt a holistic revision of the design documentation. This ensures that the risk assessments conducted in this stage are accurate as these are developed based on the 'as built' documentation. Rigorous quality assurance and quality control during construction is also necessary to ensure that the plans and technical specifications are being followed.

Continuous construction – As tailings facilities fill up, they are expanded to accommodate more tailings volume, generating a continuous cycle of construction. This can bring on instability if the facility design was not developed to accommodate the facility's size and if the designs were not wholly revisited accordingly. See also 'Design for final tailings facility size requirements, tailings types and adapted uses' above in the 'Design' section.

Operation stage

Operate as planned – Respect of operating parameters (e.g. water level, spillway operation, freeboard, etc.) as well as strict compliance with deposition plan and operation, maintenance and surveillance manual is a must.

Conduct regular inspections and review tailings facility stability – As the teams operating and conducting maintenance on the tailings facilities change throughout the mine lifecycle, it is imperative to conduct regular inspections on the tailings facilities and how these are managed to ensure that maintenance and the overall operations of the facilities are adequate. Beyond the usual dam safety inspections (DSI) and dam safety reviews (DSR), a daily inspection is recommended.

Revise environmental design assumptions – While mines undertake a thorough review of climate patterns and seismic statistics as part of initial studies and design planning, these environmental conditions may evolve with time. To assure the integrity of tailings facility designs, regular revisions of these parameters is required. This is particularly the case with hydrological design criteria. With changes related to flood occurrences, for instance, these design criteria must be adapted to reflect evolving climate conditions.

Update operating and emergency manuals – As the tailing facility and its environment evolve, it is important to revisit the operating and emergency manuals and ensure that these reflect current conditions.

Closure and post-closure stages

Remediate for persistent physical and chemical stability – As mentioned above, it is important to 'design for closure' so that closure objectives can be achieved more easily, neutralizing any residual physical / chemical instability or environmental threat. – See also '*Design for Closure*' in the Design section.

Post-Closure Monitoring – A post-closure monitoring period set forth by regulators / mine operators allows for observation of closure measures' effectiveness to ensure the physical and chemical stability of the remediated facilities. This is especially the case for tailings that are reactive, generating acid mine drainage or are leachable. It is usually recommended that monitoring be carried out over a period of 5-10 years to confirm that tailings facilities are stable in the long term and are not leaching metals or other contaminants into the surrounding environment.

Obtaining the release certificate – The results of post-closure monitoring will be reviewed by governmental authorities, where they exist, to determine whether the site is truly innocuous and therefore merits a release certificate. The issuance of this certificate represents a discharge, allowing the owner-operators to effectively 'walk away' from the tailings facility, having completed all remediation activities.

Benefits of adopting ERM and managing tailings risks at an enterprise level

As discussed in the sections above, engaging in ERM involves collaboration across business units and with key stakeholders outside the mining organization, such as regulators and communities neighboring mine sites. These interactions are meant to accurately understand tailings risks in terms of their cross-sector dimensions, dependencies and inter-relationships across the enterprise.

A more accurate understanding of risks involving tailings informs a more effective prioritization of these against other enterprise-wide risks. This allows miners to right size their investment in managing tailings risks that bear an enterprise-wide relevance by avoiding over investment in inconsequential risks and under investment in significant risks. A clearer appreciation of risks involving tailings also allows mine executives to access pooled enterprise-wide funds for prioritized risk treatments, contributing to more effective tailings risk management and, ultimately, safer and stronger tailings facilities.

A recent example pertains to a mining company operating 20 dams across 3 sites without the aid of a robust ERM framework. ERM specialists were brought in to conduct a risk review and concluded that risk mitigation investments were systematically being poured into the dams with the lowest risk profiles as opposed to those with a higher risk profile. In order to avoid this situation and to effectively manage the most important risks facing them, mining companies should actively look to apply ERM to their projects and operations.

On top of contributing to a more effective use of available capital to manage risks, the cross-sector and stakeholder engagement that is core to ERM contributes directly to a better understanding of stakeholder concerns, promoting better community relations and SLO obtainment and maintenance. This, in turn reduces the risks associated with operational delays, fines and challenges in obtaining funding and insurance while, also, promoting the development and maintenance of safer and stronger tailings facilities

Conclusion and recommendations

In today's market context of increasing difficulty in obtaining capital funding, investments in non-productive mine facilities, such as those to store tailings, are highly scrutinized, despite their risk profile. Mine owners must walk a fine line of efficiently deploying capital while effectively managing tailings risks. By adopting ERM and applying it to tailings management, mining executives can better understand how to invest scarce capital while effectively managing tailings risks and furthering sustainable development goals, ensuring that they are getting the best value for their investment.

ERM, an approach to manage enterprise-wide risks, includes processes and systems as led by a Chief Risk Manager. By adopting ERM and applying it to tailings, mine management can not only right size tailings investments, but also develop and maintain safe and robust tailings facilities throughout the life of mine while furthering sustainable development goals.

A brief summary of the key considerations to minimize tailings management risk throughout the life of mine is as follows:

Studies stage (scoping, pre-feasibility, feasibility, etc.)

- Conduct risk assessments as early as possible and at every step of a project. Frequent updates are facilitated by adopting an ERM system.
- Avoid silos and ensure that the Risk Manager is empowered to work across business units to accurately define and prioritize risks and identify the most effective mitigative solutions; the same applies to selecting tailings technologies, methods and sites.
- Select tailings management technologies in light not only of initial investment required but also of potential long term maintenance costs involved to mitigate eventual risks.
- Keep the closure and post-closure phases in mind to design with the end uses in mind and ensure that required budgets are set aside for these phases.

Permitting stage

- Make a thorough inventory of applicable regulations, guidelines and best practices to comply with at the beginning of the Permitting stage.
- Go beyond the applicable regulations and guidelines by understanding local norms and requirements; these can be contingent upon the award of required permits. For example, the consultation of indigenous

communities, while not part of regulation, is a must to ensure that required approvals and authorizations can be obtained in time.

- An in-depth understanding of and adaptation to the local landscape is key to ensure popular support and minimize risks associated with public disapproval and opposition.
- Work towards obtaining a Social License to Operate (SLO). Not only does a strong SLO facilitate and accelerate operational permit obtainment, it also decreases operating costs associated with vandalism, difficulties in hiring local skilled labor, legal action due to complaints and protests causing delays and shutdowns.
- Regular communication and transparency regarding the mine site and its tailings facilities are key to establishing the mutual respect and trust needed for a SLO.
- Invest in maintaining the SLO. If well maintained, the SLO can not only help reduce overall project costs associated with operational delays, it can also reinforce a mine company's reputation and the robustness of the tailings facility itself.

Design stage

- Invest in geotechnical assessment of the tailings facility site to develop a solid geotechnical understanding of underlying soils. This avoids being overly cautious in the design of the tailings facility to compensate for the lack of information.
- Document comprehensive and detailed operations, maintenance and surveillance manuals, including emergency response. These should be detailed enough to allow for changing teams throughout the life of mine to understand the actions required and to track any deviations from design to operation or construction.
- Design for tailings facility size requirements and adapted uses so that the initial tailings facility structure is built in view of the upper expansion limit.

Construction stage

- Construct to design or holistically revise design documents in view of changes.
- With the progressive tailings facility expansion comes continuous construction. Should the upper expansion limit defined in the designs be surpassed, a holistic review of designs is required.

Operation stage

- Conduct regular inspections to ensure that progressive worsening conditions of the tailings facility are noted. As these can be slight over time, operations teams may not notice them.
- Update operating and emergency manuals with the evolution of tailings facilities and environmental conditions.

Closure and post-closure stages

- Remediation activities can be done progressively based on a 'close as you go' method. By reclaiming sections of the facility while the mine is in operation, ongoing risks are reduced and the cost for remediation activities are spread throughout the mine lifecycle as opposed to lumped during the non-revenue generating phase of the mine site.

Our key recommendations for applying ERM to tailings management are listed below:

- Empower a dedicated Chief Risk Manager to work across all business areas to identify, study and develop treatments for enterprise wide risks.
- Facilitate cross business unit collaboration to more accurately understand and prioritize risks as well as define effective solutions.
- Take into account both direct and indirect consequences for the mine site, corporation, community and environment.
- For indirect consequences associated with risks involving tailings facilities, consider the four main systemic interdependencies that exist between enterprise-wide risks: physical, geographical, geological and cyber related, so that risks can be effectively considered with an enterprise wide view.
- Support the obtainment and maintenance of a SLO as part of tailings risk management efforts.
- Leverage an ERM platform to track risks involving tailings facilities in an enterprise-wide risk repository.
- The platform should be:
    - scalable, drillable and offer prioritization based on corporate and societal tolerance
    - have the capability to discern scientifically between tolerable and intolerable risks, manageable and unmanageable risks so that Chief Risk Managers can distinguish between tactical/operational risks and strategic risks
- Allow access to pooled enterprise resources to mitigate prioritized risks involving tailings.

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