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USA regulations and state of practice for the closure of tailings dams—an update

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Abstract

This paper presents the progress in developing guidelines for States and the United States mining industry for the closure of a tailings storage facility. In 2022, the United States Society on Dams (USSD's) published a white paper describing the misalignment and inconsistency between industry practice and regulations for tailings storage facility closure at legacy and new mine sites in the United States. Since its publication, the US has made progress in educating and informing the mining community on the safe transition of a tailings dam from operation to closure in a sustainable and environmentally responsible manner and considering its potential as a benefit to the community. The Association of State Dam Safety Officials (ASDSO) Tailings Dam Regulatory Committee and the Federal Emergency Management Agency (FEMA) are finalizing an update to the Model State Dam Safety Program that includes a Tailings Dam Supplement that will begin to fill the gap in the National Dam Safety Program publication relative to tailings dams. This Tailings Dam Supplement will address planning, risk management, design, construction, operation, and closure for consideration in the regulation of tailings dams. Under contract to FEMA, the USSD is developing technical guidelines for tailings dams, including closure considering transition through the closure process and potential measures to meet long-term dam safety deregulation. Additionally, education and certification programs are now available through a network of industry and collaborating universities for the safe operation and closure of tailings dams. An update on these and other guidelines that can be used by States to become aligned with the leading Practice for tailings storage facility closure.

Keywords: *Tailings Dam, Tailings, Tailings Storage Facility, United States Mine Closure Regulations, United States Society on Dams, White Paper*

1 Introduction

In April 2022, the USSD published a white paper review of the United States of America (US) mine tailing storage facility (TSF) closure regulations to determine how they compare with leading industry guidelines. The review was based on state regulations and TSF industry practice between 2018 and 2020 in the US. The study concluded that state regulatory programs across the US generally cite consistent TSF closure objectives, although the design and implementation approach and specific criteria can vary considerably. At the federal level, technical guidance for a TSF closure is limited, focusing on designing an operating tailings dam with little attention to closure. Similarly, closure of abandoned and legacy mine sites that are under Federal programs such as the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the Uranium Mill Tailings Remedial Action (US Department of Energy) as well as state-

specific programs. These regulations for closure of TSFs in the US are varied and often overlapping without a consistent approach (USSD, 2022).

This paper provides an update in the development of TSF guidelines for both state regulator programs and technical tailings dam safety guidance by ASDSO and USSD as well as other programs available in filling the gap in TSF closure regulations.

Comprehensive closure planning for existing, new, and legacy TSFs requires a thorough understanding of closure criteria and objectives. Closure planning is used to establish practices that deliver:

- Consistent implementation;
- Meeting closure objectives including impoundment elimination, physical and geochemical stability;
- Post-mining land use that meets property owner priorities while focusing on regional and local resource development and conservation plans, if established; and
- Technical and economic practicality.

The USSD white paper provided a summary of TSF closure requirements in twenty-seven (27) states representing the different climate regions in the US. The authors compared closure regulations of selected states with the closure criteria by the international and national organizations to understand the alignment or misalignment with the current regulation. The reader is referred to the white paper for the industry and federal TSF closure programs comparison.

The USSD Tailing Dams Committee contributes to the USSD Vision of a world class organization dedicated to advancing the role of dams in society and building the community of practice. The Committee is charged with promoting safe, environmentally, and socially responsible practices for tailings dams and collaborating with other national and international professional organizations involved with tailings dams. The USSD white paper is available at https://www.ussdams.org.

2 State TSF closure requirements

The USSD white paper included the closure requirements in twenty-seven (27) states representing different climate regions in the US. The climate regions are states grouped together that have similar monthly average temperatures based on an eighty-nine-year period of record from 1895 to 1983 (Koss, 1984). Figure 1 shows the climate regions and states selected for the white paper review.

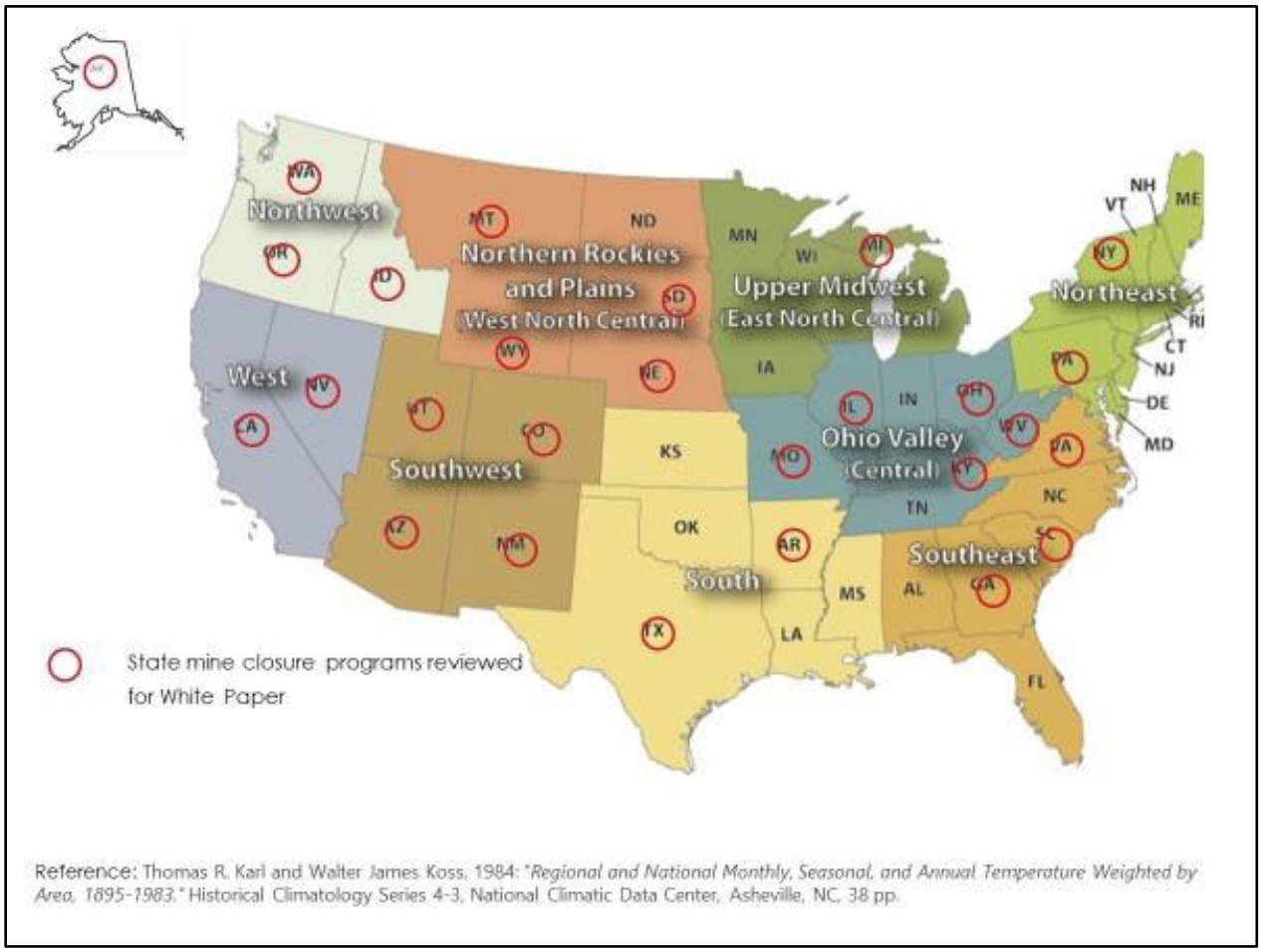

Figure 1: State mine closure programs selected for white paper and US climate regions

State regulatory programs within the regions reflect requirements associated with the types and methods of mining, and environmental and climatic conditions. However, states within a region generally have different closure requirements. State regulatory programs for closing a TSF include multiple state agencies. The agencies may have jurisdiction throughout the entire mining life cycle, or during certain phases such as operations or closure. The TSF may continue to be regulated as a dam until all elements of closure are demonstrated, including eliminating not only its impounding ability but also hazard potential classification in the event of tailings release and mobility.

State programs may have different regulations and programs for various minerals. Coal and uranium programs, which are typically more detailed and consistent with federal requirements, with more general programs having jurisdiction for hard rock ore and processing. The objective of reviewing the state regulatory requirements was to understand the variability of TSF closure programs from state to state by comparing key components for TSF closure that include:

- Engineer responsible for TSF closure plan, or Engineer of Record responsible for design and implementation of TSF closure plan.
- TSF reclamation plan including bonding and requirement for progressive reclamation.

- Elimination of impounding capability and hazard potential.
- Physical stability criteria.
- Geochemical stability criteria.
- Post-reclamation land use, care and maintenance.

At the time of the review for the white paper, none of the State TSF closure programs addressed all the above components and no two state TSF closure programs addressed the same components. TSF closure regulations include general goals or objectives, with more specific requirements detailed in permitting guidance documents for states with a larger mining presence. Table 1 summarizes examples of goals and objectives from specific State programs for closing a TSF.

Table 1: Summary of state regulatory objectives for TSF closure

Elimination of Impounding Capability
New Mexico requires controlling surface runoff to minimize erosion. *Idaho* will allow some areas of the TSF to have ponds for wildlife habitat, with a maintenance-free spillway or diversion to manage runoff and prevent water storage behind the tailings dam. *Pennsylvania* requires backfilling, grading, drainage control, and vegetation stabilization measures with positive drainage and elimination of the ability to impound water for TSF closure.
Physical Stability
New Mexico addresses long term stability with requirements to minimize erosion. *Idaho* requires the TSF at closure to be stable and in a maintenance-free condition. *Pennsylvania* requires backfilling, grading, and vegetation for stabilization measures and meeting static and seismic slope stability criteria. *Illinois* requires confirmation that the tailings are not flowable or would become flowable under seismic loading. *Minnesota* requires contouring the TSF, stabilization, and vegetation measures for physical stability. *Texas* reclamation requirements include control of erosion effectively and sufficiently to sustain vegetation where required and consistent with anticipated land use.
Geochemical Stability
New Mexico addresses the protection of groundwater resources in their closure requirements. *Pennsylvania* requires treatment and isolation of acid-forming or toxic materials to minimize adverse impacts on plant growth and land use. Minimize water quality changes so that approved post-mining land use is not adversely affected and comply with water quality standards. *Illinois* requires surface materials that cannot support vegetation to be covered with soil to a minimum depth of four feet. *Minnesota* requires dust control, hydrologic impact, and mitigating the impact on wetlands in their closure requirements.
Land Use and Sustainability

Arizona requires the development of vegetation consistent with post-mining land use considering technically /economically practical given site-specific characteristics. *New Mexico* requires the restoration of the environment to a self-sustaining ecosystem after mining operations cease. *Pennsylvania* requires deed restrictions to prevent alterations to the structure and use of the site to impact its safety or compromise environmental protection negatively.
Progressive Reclamation
New Mexico requires mines to restore the environment to a self-sustaining ecosystem with long-term and post-closure monitoring. *Arizona* requires developing vegetation consistent with post-mining land use, considering technically and economically practical given site-specific characteristics. *Colorado* requires complete reclamation within five years once a phase of the mine life is complete. *Idaho* mine closure includes returning the land to a productive condition relative to pre-mining land use. *Pennsylvania* requires deed restrictions to prevent alterations to the structure and use of the site that could negatively impact the safety of the structure or compromise the environment's protection.
Post-Closure Maintenance and Monitoring
Alaska requires financial assurance for permanent mine features if a closed TSF remains a jurisdictional dam. *Montana* requires that the Operation, Maintenance, and Surveillance Manual include monitoring parameters for closure, such as seepage, phreatic surface, and pore pressure. *Illinois* and *Pennsylvania* include monitoring of phreatic level and pore pressure in support of the jurisdictional release.

The USSD white paper provides specific details of the TSF closure program review for selected states with respect to key closure elements. Some states have made changes that provide leading regulatory programs for TSF safety, stability, reclamation, and management strategies that address tailings dam closure based on experience with mine closures and performance, or in response to international tailings dam incidents.

Examples of leading states include Montana and Alaska were regulatory requirements prominently addresses closure feasibility and risk assessments during the design phase to assess operation and closure targeting as-low-as-reasonably practical (ALARP) criteria (a risk-based approach to closure), independent review and expert review panels and post-closure financial assurance. Pennsylvania and Illinois provide static and seismic slope stability criteria and analysis methodology guidance for closure, and procedures to address hazard potential in support of delicensing and relinquishment. Pennsylvania and West Virginia require eliminating the TSF pond but allowing for small ponds, wetlands, and other similar features for post-mining land use.

3 Industry TSF closure practices

TSF closure practices for industry were based on closure criteria developed by international and national committees. The state and industry TSF closure practices are compared to understand the alignment or misalignment with the state regulations described in the previous section. The industry organizations have goals to advance the mining sector's safety, social and environmental performance. These organizations include the International Council on Mining and Metals (ICMM), Mining Association of Canada (MAC), International Organization for Standardization (ISO), and International Committee on Large Dams (ICOLD) along with country affiliates such as the Canadian Dam Association (CDA) and Australian National Committee on Large Dams (ANCOLD). Table 2 provides a comparison of state and industry TSF closure criteria.

Table 2: Comparison of state and industry TSF closure criteria

Industry Closure Criteria	Common State Closure Criteria
Elimination of Impounding Capability	
ICMM considers the possible modes of failure that could occur post-closure. The TSF dam risk category determines the post-closure condition. ICMM provides approaches for adapting to climate change and the importance of understanding the overall site water balance without specific requirements on eliminating the impounding capability of the TSF as this may not always be feasible for a particular site. In addition, a water cover may be the only means for closure at some sites. ICOLD provides conditions for impounding tailings by defining the three stages of closure, including transition, active care, and passive care. A TSF requires little to no maintenance in passive care and is a waste management structure with similar characteristics of the surrounding natural features. If the structure must remain as a dam, then spillways and other hydraulic structures should be in place to safely convey runoff from the facility to reduce the risk of failure.	States simply require either eliminating the impounding capability of the TSF or continue in post-closure under a dam safety program. However, most dam safety programs are for water dams instead of tailings dams. The TSF closure objectives include surface water management, prevention of water storage behind the structure, and minimizing/ preventing erosion of the dam, tailings, or cover materials as an absolute instead of reviewing failure modes and risk. States like New Mexico require controlling surface runoff to minimize erosion. Idaho will allow some areas of the TSF to have ponds for wildlife habitat, with a maintenance-free spillway or diversion to manage runoff and prevent water storage behind the tailings dam. Pennsylvania requires backfilling, grading, drainage control, and vegetation stabilization measures with positive drainage and elimination of the ability to impound water for TSF closure.
Physical Stability	
Some mine owners approach the physical stability of a tailings dam at closure different than during its operation. A tailings dam's operational life can be as short as less than 20 years, whereas closure is for perpetuity.	Physical stability requirements for tailings dams vary from State to State and tend to use vague statements like "maintenance-free condition," "be stable," "no flowable tailings under seismic loading." Illinois, Pennsylvania, and a few other state programs include

Industry Closure Criteria	Common State Closure Criteria
Consequently, the design criteria for hydrologic and seismic minimum exceedance probability can be 1 in 5,000 years during operation to 1 in 10,000 years post-closure. ICMM defines physical stability as a stable landscape that limits long-term erosion potential and environmental degradation. The tailings dam should have little risk to humans and the environment and be compatible with the post-closure land use. ICOLD provides conditions for stability, and it ranks providing a stable structure over the long term as the highest priority for closing a TSF. The geochemical, ecological, and other forms of stability is not achievable without a stable structure. Dam break analysis methods for TSFs are becoming more advanced in simulating non-Newtonian tailings flows to predict inundation limits from a hypothetical breach. For a TSF that cannot transition to a mine waste structure, a dam break analysis focused toward credible failure modes provides a means to assess failure's consequences and to inform emergency response plans.	specific prescriptive stability criteria for closure and relinquishment of tailings dams.
Geochemical Stability	
The industry and states are in alignment with geochemical stability objectives for tailings dams. Both the industry and states are motivated to protect the environment. Industry uses isolation and treatment as necessary for acid-forming and toxic materials.	States provide specific requirements for the protection of groundwater resources in their closure requirements. Minimize water quality changes so that approved post-mining land use is not adversely affected and comply with water quality standards. Some states still rely on prescriptive requirements such as a minimum depth of cover soil over non-supporting vegetation tailings instead of other methods that can achieve the same goal.
Land Use and Sustainability	
The industry is leading the way in post-closure land use and sustainability. ICMM, for example, suggests providing a clear definition for post-closure land use at the beginning of the mine project so that Land use and sustainability can	State guidance and regulation for post-closure land use are general without suggestions and advice for developing a mine with post-closure in mind. For example, some states require restoration of the environment to a self-sustaining ecosystem after

Industry Closure Criteria	Common State Closure Criteria
be part of the TSF design and operation. ICMM also provides specific methods for good practices in post-closure planning, such as developing maps of the post-closure landscape and evaluations for post-closure land use for universal capability areas as part of mine planning.	mining operations cease, with limited options in post-closure uses.
Progressive Reclamation	
Progressive closure and reclamation is the ongoing effort to advance closure activities during mine operation, recognizing that it can take an extended period for TSF closure and that initiating closure in some areas during operations can aid in developing procedures and reducing risks. Industry and states are in line with progressive reclamation since most states release portions of the closure bond once a part of the TSF is closed successfully.	State programs include progressive implementation and timely reclamation performance during mine operation with provisions to complete timely restoration within a period after cessation of activity.
Post-Closure Maintenance & Monitoring	
The industry is changing the post-closure care, maintenance and monitoring process for tailings dams that remain functional as a water-impounding structures. There are recommended practices by mine owners and industry organizations such as ICMM and ICOLD for monitoring.	Some states with active mines require monitoring specific parameters such as seepage, phreatic surface, and pore pressure for those facilities that continue to function as a dam after closure. Many of the requirements are from water dams, and may not apply to tailings dams.

The industry promotes early planning for closure in the feasibility and design stage (ICMM, 2019), including evaluation of the role of technologies to improve tailings characteristics and attain physical and geochemical stability for the long term (MAC sponsored study; KCB, 2017). As a TSF progresses through operation, the industry recommends the operator update closure plans and implement measures during operation to transition and enhance closure practices (ICMM, 2019). Also notably, ICMM participated as a co-convener in the Global Tailings Review and supports the establishment of the resulting Global Industry Standard for Tailings Management (GTR, 2020), and is continuing to develop and improve guidance for tailings dam closure. More about GISTM and other industry driven programs on TSF closure is discussed in the next section.

4 TSF closure practice programs

International organizations such as ICMM and ICOLD provide a forum for mine owners and engineers to create state-of-art closure guides based on successful closures in the different parts of the world that the mines operate. In the US, organizations like ASDSO, FEMA, and USSD are beginning to look at closure from a regional perspective. In general, states seem to borrow technical criteria from water dam and environmental regulations instead of having a program focused on TSF closure practice, which would benefit both the industry and state in managing the closure as an asset instead of a liability. Since preparation of the USSD white paper, a considerable amount of progress has been made in advancing TSF closure guidelines. Current programs aimed at advancing TSF design, operation and closure practices are provided in the following sections.

4.1 A unified guideline for tailings dams in the US

Under contract to FEMA, the USSD is developing technical guidelines for tailings dams, including closure considering transition through the closure process and potential measures to meet long-term dam safety deregulation. USSD in a coordinated effort with ASDSO is developing regulatory and supporting technical guidance for designing, operating, and closing a TSF in the US. ASDSO is an internationally recognized organization with a mission "to improve the condition and safety of dams and lower the risk of dam failures through education, support for state dam safety programs, and fostering a unified dam safety community" (https://damsafety.org). In 1987 ASDSO created the Model State Dam Safety Program that provides a guide for state officials for developing state dam safety programs that will ultimately eliminate the unnecessary risks created by unsafe dams.

USSD is the United States national committee to the International Commission on Large Dams (ICOLD). The mission for ICOLD and its one hundred national committee members is to "*lead the profession in setting standards and guidelines to ensure that dams are built and operated safely, efficiently, economically, and are environmentally sustainable and socially equitable*." (https://www.icold-cigb.org). The committee on tailings dams was established by the Board of Directors of USCOLD (the predecessor of USSD) in the 1980s as a representative US committee to the committee on tailings dams and waste lagoons of ICOLD. The Committee on tailings dams is charged with, (a) promoting safe, environmentally and socially responsible practices for tailings dams and coal combustion impoundments through design, construction, operational performance, and reclamation; and (b) collaborating with other national and international professional organizations involved with tailings dams and coal combustion impoundments, such as the committee on tailings dams and waste lagoons of ICOLD.

In 2016, the ASDSO board of directors and the state representatives of ASDSO, acknowledged the importance of safe tailings dams to the economy and safety of individual states and in the US overall due to unacceptable high failure rate of tailings dams verses water dams. In 2020, USSD in collaboration with ASDSO, began developing a regulatory guidance document specifically addressing tailings facilities, which will be ultimately issued as part of an update to the "Model State Dam Safety Program". The update will consider applicable criteria from organizations that include ICMM, MAC, ISO, and ICOLD along with country affiliates such as the CDA and ANCOLD. The guideline will include the entire TSF life cycle including closure and intended to be a nationally recognized reference for technical guidance as well as national criteria within state programs.

The unified guideline will address TSF closure including surface water management, geotechnical stability, geochemical stability, progressive reclamation, and considerations for risk reduction, ownership, and

post-closure. As of the time of preparing this paper, the unified guidelines are in the review phase with a completion date targeted in 2025. When completed and implemented, the updated Model State Dam Safety Program will improve alignment across the country regarding closure requirements for tailings facilities in addition to design and operation requirements.

4.2 Tailings Center of Excellence

In 2021, the University of Arizona, Colorado State University and the Colorado School of Mines created a learning space focused on educating engineers on responsible and sustainable mine waste management. The Tailings Center of Excellence offers online and in-person short courses and workshops in tailing management for current mining professionals and engineers as well as inter-university certificates in relevant areas of tailings and waste management. It serves as a nexus for the dissemination of best practices and industry benchmarks and provides a venue for graduate education focused on mine waste to support the development of tailings engineers. The Center provides mine operators with real-time insight regarding TSF design, operation, and closure. The Center also leverages industry partnerships to keep pace with real-world needs. The Center's training program currently offers six short courses in Fundamentals of Tailings Management. Course six is focused on closing a TSF. Closure topics include TSF closure planning, decommissioning, TSF closure management during operation, closure, and post-closure monitoring, closure cost estimates, environmental liability, and financial assurance instruments. The course includes panellists from industry to address specific closure questions posed by the students.

4.3 Tailings and Industrial Waste Engineering

In 2021, the Tailings and Industrial Waste Engineering (TAILENG) research center collaborated with the Tailings Center of Excellence to offer the first course in the fundamentals of tailings engineering described in the previous section. Taileng is a consortium of faculty at four universities including Georgia Tech, Colorado State University, UC Berkely, and the University of Illinois. Headquartered at Georgia Tech, it is dedicated to studying mine tailings and industrial waste for safer waste storage systems and reduce the likelihood of failures. Its research focuses on innovative and economical technologies to advance the practice in the design, operation, and closure of tailings and industrial waste storage facilities. It is currently implementing a research program on the mechanical characterization of mine tailings materials. The Center will provide access to non-confidential data collected to external collaborators if they provide useful tailings properties to the Taileng's database.

4.4 Global Industry Standard on Tailings Management

As a result of the Córrego do Feijão Dam I failure near Brumadinho, Brazil, in January 2019, ICMM, in partnership with the United Nations Environment Program (UNEP) and the Principles for Responsible Investment (PRI), established the independent Global Tailings Review panel, which released the "Global Industry Standard on Tailings Management" in August 2020. The Standard's mission is zero harm to people and the environment from a TSF. The standard establishes a framework for tailings management and requires feasibility, design, risk, and performance monitoring through closure and post-closure care.

It sets voluntary standards for the safe and secure management of mine tailing facilities globally and includes principles applicable to closure and post-closure requirements. A key element of the GISTM is the adoption of external loading design criteria associated with an extreme consequence classification as the basis of design for passive closure of a TSF, regardless of its consequence classification. Specifically, this includes adoption of the 10,000-year annual exceedance probability (AEP) event for flood and

earthquake loading, or the maximum credible earthquake (MCE) or probable maximum precipitation (PMP). Adherence to the GISTM is essentially voluntary affording mine operators' flexibility as to how best to achieve the goal of zero harm. (GTR 2020).

Adoption and implementation of the GISTM is mandatory for member companies of the ICMM. The ICMM is essentially charged with implementing the GISTM through their member companies, who operate some of the largest TSFs in the world. Non-ICMM companies are encouraged to adopt and implement the GISTM, which may increasingly become a demand of financial institutions. On December 18, 2020, the UNEP and the PRI, together with the and the Council on Ethics of the Swedish National Pension Funds, announced a partnership to create an independent international institute to support implementation of the GISTM. Currently, an independent institute is under development.

4.5 Society for Mining, Metallurgy and Exploration Tailings Management Handbook

The Society for Mining, Metallurgy and Exploration (SME) published the Tailings Management Handbook: A LifeCycle Approach in 2022 (SME 2022). The Handbook supports education and competency-building of students, young professionals, and even those in their mid to late careers to support mine operations in filling roles in TSF design, operation and closure. A section dedicated to TSF closure planning and landform design is provided in Part II: Life-Cycle Planning in the Handbook. The closure section of the Handbook spans the lifetime of a TSF and how the closure process should integrate with the design and operation of the TSF and mine overall. It includes the requirements for the TSF closure team, closure governance, closure design, service life, characterization, cover design, geochemical stability, hydrotechnical stability, physical stability, and ecological stability. The section also includes the process for using a risk-based or risk-informed approach to closure as described by GISTM, CDA, ANCOLD and other technical guidance documents. Closure construction and monitoring among other closure topics are addressed in the Handbook.

4.6 Future Tails

Future Tails is an organization for global tailings management through a partnership between the University of Western Australia, mine companies Rio Tinto and BHP. Like North American organizations, Future Tails provides training programs to build talent and capability at a range of levels for safe TSF design, operation and closure. Participants in the training program can select from four levels. Executive, technical, engineering, and operations. Specific areas of research include static liquefaction, filtered and drystacked tailings, and numerical modelling for dam break studies.

5 Conclusion

The authors encourage states to be active in review and provide input to the updating and development of TSF guidelines for both state regulator programs and technical tailings dam safety guidance being prepared by ASDSO and USSD, considering the elements presented herein for closure and post-closure care.

Encouraging and allowing to demonstrate new closure philosophies and techniques when applicable could be a benefit to mine stakeholders. These include:

- Closure planning and progressive reclamation;

- Reprocessing tailings to recover economic metals;
- Co-disposal of tailings and other waste like overburden;
- Renewable energy (i.e., solar power farms, bio-energy, wind power, geothermal, etc.); and
- Risk-based closure to provide the best closure approach given a set of risk likelihood and consequences.

Tailings dams are more complex and expensive than many other mine elements, requiring responsible and cost-effective closure programs. Effective closure is a critical aspect of making an economic resource in the US and internationally.

Acknowledgement

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