OVERVIEW OF CURRENT STATE OF PRACTICE FOR CLOSURE OF TAILINGS DAMS

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ABSTRACT

The mining process produces slurry wastes known as tailings, which are stored in containment structures called tailings dams. Following mine closure, tailings dams are subject to natural forces as the dam transitions into a landform that is compatible with the natural landscape. This poses a significant technical and regulatory challenge as tailings dams that are designed to be safe during the mine's active life also need to perform safely long after mine operations are finished. Underperformance of these structures can result in significant risks to public and environmental safety, as well as impacts to future land use and economic activities in the vicinity of such structures. To prevent failure of these large structures after mining, their long-term behavior must be understood and incorporated into closure design, ideally from its conception and initial design. Challenges lie in the limited information available regarding how these structures age over time and forecasting loading and environmental scenarios over long time periods (weather events, seismicity, human activity, etc.). Ultimately, the goal of tailings dam closure is to reduce future risk of failure to the environment and public to a degree that is both practical and economical. This paper presents a summary of the current state of practice for closure of tailings dams nationally and internationally.

INTRODUCTION

A number of significant tailings dam failures have occurred over the last six years, including the Obed failure in Alberta in 2013, the Mount Polley failure in British Columbia in 2014, Fundão failure in Brazil in 2015, the Cadia failure in Australia in 2018, and the Cieneguita failure in Mexico in 2018 (Bowker and Chambers 2017, Wise 2018). The consequences of these failures have varied greatly from limited loss of containment to fatalities and extensive contamination. These consequences have also been accompanied by considerable financial losses, loss of social license to operate, and others. Furthermore, the work presented by Bowker and Chambers (2017) suggests that the number and severity of tailings dam or tailings storage facility (TSF) failures are expected to increase.

Overtopping, slope instability, and earthquakes are considered the top three causes for active tailings dam incidents, with additional causes including foundation instability, seepage, structural inadequacies, erosion, mine subsidence, and unknown causes (ICOLD Committee on Tailings Dam and Waste Lagoons 2001). The five tailings dam failures listed previously could be attributed to one or more of these causes. However, root cause analysis of the Mount Polley failure revealed that the root causes of failure were primarily organizational in nature, indicating deficiencies in the safety management system (MEM 2015). In the case of the Obed failure, a similar conclusion can be reached, as the specified operational water level in the pit was exceeded continually throughout operations and a spillway was never constructed despite being specified in the design (Provincial Court of Alberta 2017).

In their evaluation of the underlying causes of tailings dam failures and incidents, the ICOLD Committee on Tailings Dam and Waste Lagoons (2001) noted that it was lack of consistency and attention to detail which led to a high incident frequency. This further highlights the need for robust tailings dam safety management systems and opens a question regarding their implementation and compliance for tailings dams after closure. In this regard, a number of tailings dams in the oil sands have reached or are close to the end of their active service life (OSTDC 2014). These structures are at various stages in closure and some may be attempting to undergo delicensing as dams in the coming years.

Tailings dams in the oil sands industry are complex structures due to a number of key characteristics, including (OSTDC 2014):

- Upstream construction is used extensively. However, construction may occur with a

combination of the upstream, downstream, centreline, and modified centreline methods.
- Dams may be constructed with hydraulically placed tailings or compacted fill from overburden and interburden material, tailings sands, coke, or a combination.
- The type and characteristics of tailings deposited varies greatly and continues to change throughout time technology develops.
- Dams are often constructed on weak foundations resulting in flat slopes and very large structures.

The large size of these structures and the variation in construction method, construction materials, and tailings contained all complicate the design and closure of these structures. Furthermore, earlier structures were designed for operating conditions, with consideration of failure mechanisms that could occur during the mine's active life. As a result, tailings dams in the oil sands industry pose a significant design challenge and can become a public and environmental hazard if not properly managed. In this regard, the regulatory regime needs to promote and facilitate the development of closure strategies that include a robust and sustainable safety management system.

In Alberta, tailings dams are regulated by the Alberta Energy Regulator (AER) under the Water Act and Water Regulation in the Dam Safety Program. The AER's Dam Safety program implements a risk-based approach to dam safety with an emphasis on dam safety management systems (Eaton and Paz 2016). Tailings dams in Alberta adhere to guidelines from the Canadian Dam Association (CDA) and the Mining Association of Canada (MAC). Oil sands operators are required to reclaim tailings ponds, mining sites, and other disturbed land to stable, resilient, functional ecosystems with a land use equivalent to the original landscape (although it may differ) as described in the Tailings Management Framework (Government of Alberta 2015). In this end game scenario, closure occurs and the land is certified such that it is transferred back to the Crown relieving the operator of ongoing obligations and responsibilities indicating a "walk away" scenario (Morgenstern 2012). The fact remains that there have been very few examples of successful walk away scenarios globally. As closure becomes more imminent, the need for clear guidance and regulation becomes more important, including the requirements for a strong safety management system.

This paper provides a review of the current state of practice for closure of tailings dams nationally and internationally. This includes an examination of closure regulations and guidelines from a technical and practicable viewpoint.

STATE OF PRACTICE

Several international and national committees and organizations exist whose aim is to advance the social and environmental performance of mine sites and tailings dams by outlining best available practices (Roberts et al. 2000). Following the best practices outlined by various national and international bodies may be optional, but laws and regulations for TSFs are not. Regulations can take a prescriptive approach which dictate methods and/or quantitative criteria to be achieved. Alternatively, regulations can take a performance-based approach and outline target performance levels to be achieved.

National

Regulations in Alberta, British Columbia (BC), and Saskatchewan will be discussed as well as guidelines from CDA (2014), MAC (2017), and OSTDC (2014). Regulation of dam safety in Canada is a provincial and territorial responsibility (CDA 2014). Guidance on dam safety is further provided by organizations such as CDA, MAC, and the International Committee on Large Dams (ICOLD) with specific reference made in regulations and guidelines to refer to these organizations for guidance on design throughout the life cycle of the dam, including closure (Government of Alberta 2016, MEM 2016, Ministry of Environment 2008). Alberta's proposed updated Dam Safety Guidelines also make reference to OSTDC (2014) for closure guidance. BC and Alberta, unlike Saskatchewan, both have dedicated mining dam safety programs with regulation and guidelines specific to the design of tailings dams, including closure. Al-Mamun and LePoudre (2016) conducted a review of national regulations for closure in the context of tailings dam delicensing.

Currently, the Government of Alberta is working to improve their dam safety regulatory system by issuing new Dam Safety Guidelines following the Mount Polley failure and the Auditor General of Alberta (2015) Report (Government of Alberta 2016). It is expected that the new guidelines will move away from a prescriptive approach to dam safety noting that selection of appropriate factors of safety (FOS) should be based on careful site specific considerations such as the consequence of failure, uncertainty in material properties and subsurface conditions, implementation of an effective risk management system etc. (Government of Alberta 2016). In BC, mining dams are regulated by the Ministry of Energy and Mines under the Mines Act and the Health, Safety, and Reclamation Code (HSRC). In contrast to expected changes in Alberta, the HSRC specifies minimum design criteria for seismic and flood design, criteria for design slopes, and minimum static FOS with reference made to design in accordance with other guidelines (MEM 2016, 2017). The HSRC code and guidelines also have an emphasis on risk management practices and a tailings management system based on continual improvement using a cycle of planning, implementation, monitoring and surveillance, and review and improvement (MEM 2016, 2017). This commitment to a tailings management framework aligns with the guidance provided by MAC (2017). As discussed, Saskatchewan does not have a formal tailings dam safety program and does not provide information on design of TSFs for operation or closure.

All three provinces require mine operators to submit a reclamation and decommissioning plan for their mine site. Similar to Alberta, the expectation in BC is that the land is reclaimed such that the end land use capability is not less than before the mining operation existed with long-term physical and geochemical stability of the surrounding environment (Government of Alberta 2015, MEM 2017). In Saskatchewan, the objective is to reclaim to a standard that is safe for traditional land use with a condition that is consistent with the surrounding physical and biological environment requiring little or no maintenance (Ministry of Environment 2008).

Despite the lack of a dedicated tailings dam safety program, Saskatchewan has one of the most advanced systems for long-term management of mine sites (including TSFs) through their Institutional Control Program (ICP) (Ministry of Energy and Resources 2009). The ICP is a formal regulatory process for the long-term monitoring and management of provincial lands once a mine operator has fulfilled its decommissioning and reclamation obligations and the site has undergone custodial transfer back to the government (Ministry of Energy and Resources 2009). When the ICP takes control of a site, the control may be active and involve monitoring, surveillance, and remedial works or passive including land use restrictions, maintaining records etc. (Ministry of Energy and Resources 2009). The program will ensure that sites are monitored and maintained in accordance with the monitoring and maintenance plan submitted by the site holder using the funds provided by the site holder (Ministry of Energy and Resources 2009).

CDA (2014), MAC (2017), and OSTDC (2014) all have an emphasis on using risk-based approaches for tailings dam design and operation. The MAC (2017) guidelines emphasize the importance of a tailings management framework for safe, sustainable, and environmentally responsible management of TSFs throughout the entire life cycle, including closure and post-closure, with risk management as a key to success. MAC (2017) notes that long-term liability and risk can be reduced by designing and operating tailings facilities with a long-term view. Aligning with this, CDA (2014) recommends using a risk-based approach for assessing closure strategies especially given the expected time frames (passive care can last for hundreds of years). These lengthy design periods can make it difficult to design for closure due to potentially changing downstream populations, regulatory environments, etc. CDA (2014) provides minimum design criteria for inflow design floods, seismicity, and FOS for different stages in the life cycle with criteria becoming more stringent for the passive care phase. CDA (2014) notes that the designer and owner can increase beyond these levels if they wish to reduce the risk or can go lower if the regulator agrees. The tailings management framework provided by MAC (2017) is designed to be flexible so that it can adapt to changes that occur in the long-term and be used for different sites, owner policies, regulatory requirements, and stakeholders (MAC 2017).

According to CDA (2014) and OSTDC (2014), a dam may be delicensed as a dam if it is transformed into a permanently stable landform where the residual risks for the structure have been reduced to a level compatible with that of natural analogues. This principle aligns with the BC HSRC code which indicates that an operator may be released from permit obligations if the dam can be considered a landform (MEM 2017). In this way, the desired “walk away” condition could be achieved (CDA 2014). OSTDC (2014) provides a framework by which a tailings dam could be

Table 1. Summary of Key Aspects of National State of Practice

Alberta	British Columbia	Saskatchewan	MAC	CDA	OSTDC
• AER Dam Safety Program • Non prescriptive • Requires reclamation & decommissioning plan • Walk away closure • References CDA, OSTDC, ICOLD, MAC	• MEM Dam Safety Program • Prescriptive • Requires reclamation & decommissioning plan • Walk away closure • References CDA, ICOLD, MAC • Specifies minimum design criteria	• No dam safety program • Requires reclamation & decommissioning plan • Institutional Control Program • References CDA	• Risk-based • Tailings management framework • Sustainable development with a long-term view	• Risk-based • Specifies minimum design criteria	• Risk-based • Framework for dam delicensing based on transforming dam into a landform

transformed to a solid earthen structure and delicensed as a dam. This process is based on a performance and risk-based approach. An important element of this process is recognizing that natural areas in the oil sands area undergo geomorphic evolution that can result in slope instability, surface erosion, wave and river erosion, groundwater level fluctuation, fires, etc. (i.e. there is not zero risk in the natural environment) (OSTDC 2014). As such, the solid earthen structure will not have zero risk, but by transforming a structure into a solid earthen structure, the risk is reduced by reducing the consequences and probability of failure (OSTDC 2014). A summary of the key aspects discussed with regard to the national state of practice is provided in Table 1.

International

ICOLD, International Council on Mining and Metals (ICMM), United Nations Economic Commission (UNEC), and the International Standards Organization (ISO) are just a few of the international organizations undertaking work with respect to mine site and tailings dam closure to outline best available practices for mine operators. An overarching objective common to all is “sustainable development”, defined by the Brundtland Report as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development 1987). In line with this, MAC (2017) states that TSFs should be designed under the assumption that they are permanent landscape features, and ensuring that short-term benefits do not outweigh long-term risks.

A mounting body of evidence regarding the long-term costs of acid rock drainage, surface and ground water contamination, and air pollution resulting from poorly or improperly closed tailings dams has proven a powerful motivator in the industry. Concerns are predominantly related to water quality as physical stability is often assumed to increase over time. However, as DeJong et al. (2015) has noted, the geotechnical state of a tailings dam and its components can be altered over time. The growing expectation globally is that tailings dams be chemically and physically stable for a period in excess of 1000 years (ICOLD Committee on Tailings Dams 2013). This design life necessitates the use of regionally appropriate probable maximum precipitation (PMP) and maximum credible earthquake (MCE) events in geotechnical assessments, but also (and less commonly recognized) the cumulative effects of multiple events. Features such as spillways and surface drainage outlets should be designed with the same attention to detail as failure of these systems could result in failure of the closure landform.

The United States Surface Mining Control and Reclamation Act (SMCRA) (1977) outlines reclamation objectives, as well as construction, maintenance, and reclamation requirements for coal mines across the United States of America (USA). For example, tailings must be stabilized through construction of compacted layers with incombustible and/or impervious materials as necessary, such that they are stable and capable of regrading to blend with surrounding natural contours (95th US Congress 1977). Ponded water held by a dam is permitted post-closure so long as the dam meets minimum stability criteria, pond size is appropriate to the use, and the water quantity and quality meet discharge criteria (95th US Congress 1977). Coal is primarily used by local power plants in the USA. As a result, while enforcing such an intensively prescriptive act is expensive, the costs can be directly passed to the consumer so as to not impede implementation (Roberts et al. 2000).

A similarly prescriptive reclamation method is exemplified in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as the Superfund Program, introduced in 1980. Superfund has been widely criticized for being prohibitively expensive. The expectation is for sites to be cleaned-up to a pristine condition, regardless of risk or local context (Shanahan 1995). Due to the significant cost associated with this undertaking, only a small segment of sites on the national list have been completed (Shanahan 1995).

Due to the site specific nature of closure challenges, a performance-based approach is more typically chosen by regulators. South Africa requires that all land affected by mining operations be returned “to its natural or predetermined state or to a land use which conforms to the generally accepted principle of sustainable development” (Parliament of the Republic of South Africa 2002, 38.1d). The regulation goes a step further by holding directors of a mining company and members of a close corporation (a parent company, for example) jointly liable for any negative impact to the environment resulting from mining (Parliament of the Republic of South Africa 2002, 38.2). These types of performance-based approaches leave room for innovation and creativity while dictating end results.

In Western Australia, a performance-based approach is also taken; however, they require early and ongoing closure plan submissions, and reporting on TSF reclamation trials and/or research. This approach results in more regulator involvement. TSFs are decommissioned via the Environmental Protection Act (EPA) and TSFs are likely to be issued a “closure notice” requiring additional reporting, monitoring, and/or active maintenance after the dam is delicensed and considered a landform (DMP and EPA 2015). Relinquishment to the state is not typically considered where these closure notices have been issued (ANZMEC and MCA 2000). This system is most similar to the proposed approach in Canada and the Alberta oil sands.

Often in developing nations, no regulation exists; however, this is rapidly changing. Brazil, and in particular Chile, have recently updated their mine closure regulations. Chile now requires chemical and physical stability of all TSFs post-closure (Ministerio de Mineria 2015). In addition to international committee’s best practices and government laws and regulations, mining companies may also be bound to the environmental management principles of their financial backers (World Bank and IFC 2002, Equator Principles Association 2013). A mining company operating in a country without regulation may still need to abide by certain social and environmental standards at closure as a result.

Globally, the trajectory in designing for closure of tailings ponds is towards providing physical and chemical stability for a 1000-year design life, such that the definition of sustainable development is met. Delicensing of tailings dams through conversion to an equal or comparable land use capability is typical in most countries with advanced regulation; however, relinquishment remains rare.

DISCUSSION

Nationally and internationally the state of practice for tailings dam closure varies. Regardless, the societal expectation for closure and reclamation is for sustainable mining practices. As discussed, Alberta, Saskatchewan, and British Columbia all have an expectation that the land should be returned to a state similar to the pre-mining land. While Alberta and BC require walk away closure, Saskatchewan has taken measures to develop regulation specific to long-term management of mine sites. In this way, they have developed a path by which companies can relinquish their site responsibilities. It should be noted that site holders do not completely discharge their liability after the site has been transferred to the ICP (Government of Saskatchewan 2009). While the push in global and national guidelines and regulations towards risk-based design and management is promising in allowing the industry to adequately design for closure, there has still been a lack of evidence showing its ability to support the desirable goal of walk away closure. Morgenstern (2012) indicated that the current proposed walk away end game in the oil sands is likely not fit to achieve the desired goals. At the current time, the only area in the oil sands that has been returned to the Crown is an overburden dump referred to as Gateway Hill. This landform was chosen for its simplicity and the process still took about 10 years (Morgenstern 2012). In light of this, the question is if Alberta should be working towards developing an alternative to the current walk away end game such as the route taken by Saskatchewan which involves relinquishment and a perpetual care strategy. In the author's opinion, the goal for mine closure should be walk away closure; however, failure to plan for scenarios where this might not happen could be considered failure to uphold the public interest, a requirement under the APEGA (2013) Guideline for Ethical Practice.

The incoming changes to the Alberta Dam Safety guidelines are anticipated to have a performance and risk-based approach to dam safety; however, the table of contents provided by the Government of Alberta (2016) indicated that only one page of guidance would be provided on the closure of mining dams with reference made to MAC, CDA, OSTDC, and ICOLD for further guidance. The authors are currently conducting a series of interviews with individuals with experience with tailings dams. The authors asked what the major challenges in tailings dam closure in Alberta are, including the ability to delicense and attain a reclamation certificate. Individuals noted a number of key challenges in Alberta with the primary challenges being the fluid nature of the tailings, the inability to discharge water, the regulator, and long-term projections and time frame. This indicates that clarity is needed from the Alberta regulator on tailings dam closure guidelines and expectations.

The global trajectory for closure design is towards a 1000-year design life. The concept of "in perpetuity" (as presently assumed in Alberta) is difficult to fathom, especially as these structures are constantly evolving due to geomorphic processes. For reference, and in order to appreciate the task-at-hand, the following was happening on our earth roughly 1000 years ago: (1) the *real* Duncan, King of Scotland, was murdered by his cousin "MacBeth", the next King of Scotland; (2) Viking explorer Leif Eriksson discovered North America and named it 'Vinland'; and (3) cliff dwellings were the preferred form of housing in what is presently the state of Colorado (Mesa Verde). What will the future be in another 1000 years?

In terms of design targets and evaluation criteria, "perpetuity" is essentially the same as a 1000-year design life. Both necessitate the use of PMP events, MCE events, and other extremes for design. These are known (or readily determined) values. The remaining challenges are in designing dams that remain stable throughout the cumulative effects of nature over 1000 years, and in integrating climate change, for which reliable projections currently only extend to the year 2100. As shown in Figure 1, the mine life of least one oil sands mine extends beyond this date.

Guidelines and regulations have included the required implementation of a safety management system (SMS) for a number of years now as shown by guidelines provided by organizations such as MAC. SMSs are important throughout the life cycle of a tailings facility, including closure, for failure prevention. In light of the root causes of the tailings dam failures witnessed in the last few years, focus of SMSs may require a shift towards implementation, auditing, training and knowledge transfer, and safety culture. This shift may require changes in the organizational structure for closure to complement the technical expertise (risk managers, social relations experts, etc.). A strong SMS will aid in adapting to the uncertainty associated with the long-term behaviour and management of tailings dams. Alberta's Dam Safety Program expects dam owners to have a dam safety management system that adheres to the guidelines outlined by CDA and MAC (Eaton and Paz 2016). Dam owners are requested to perform a self-assessment on: management commitment to dam safety, emergency readiness, design process, construction process, surveillance process, and if the dam is performing as expected (Eaton and Paz 2016). The AER then assesses the dam safety management system based on management, complexity, records management, and performance (Eaton and Paz 2016). Further research in collaboration between AER and the University of Alberta is ongoing for enhancing the regulator's available tools for assessing the adequacy of operators SMS in light of the characteristics of their storage facilities and foreseeable conditions at and post-closure.

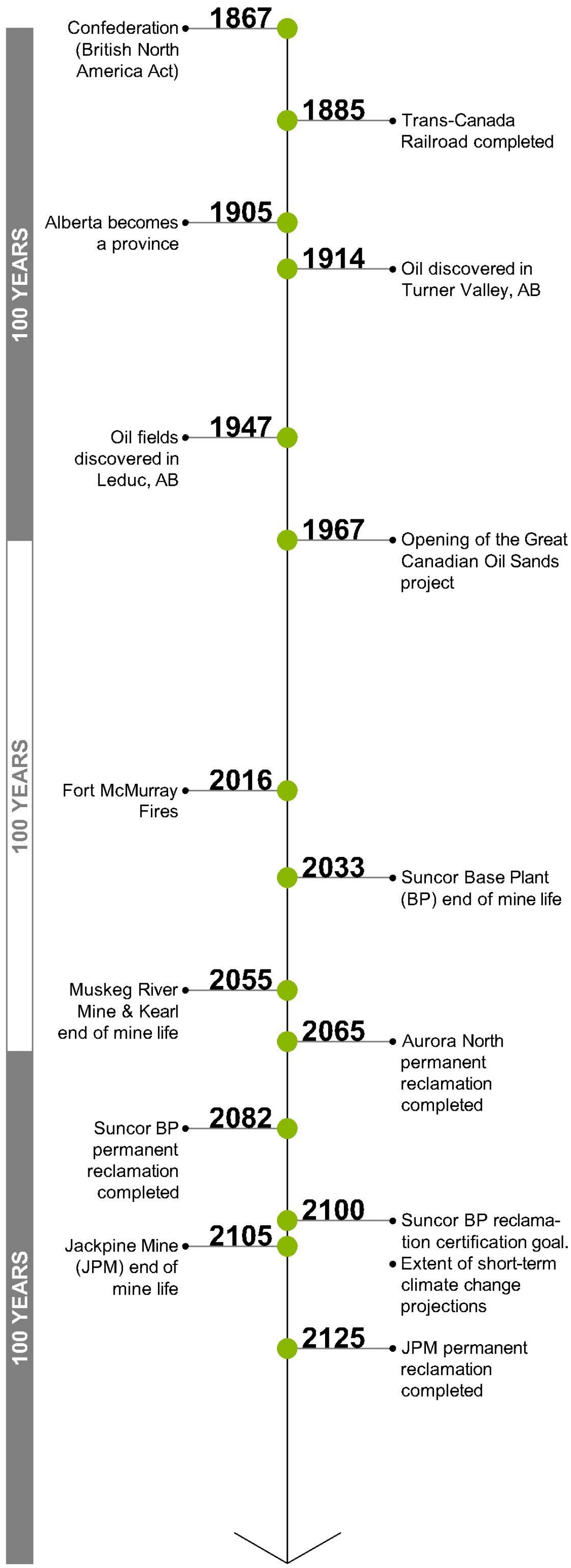

Figure 1. Canadian and oil sands evolution in consideration of 1000-yr design life

SUMMARY

The global expectation of tailings dam closure involves sustainable mining practices. Increasingly, this involves a risk or performance-based approach to closure. The authors' review of best practices nationally and internationally indicates that the following jurisdictions can be learned from:

- Regulatory framework for long-term management in Saskatchewan;
- Western Australia closure guidelines and regulatory review process; and
- Legislative framework in South Africa.

Each of these jurisdictions has a specific characteristic that can be learned from. From a long-term care perspective, Saskatchewan's ICP outlines a perpetual care strategy, including long-term monitoring and management, which may be required in some areas given how rare tailings dam relinquishment is globally (Ministry of Energy and Resources 2009). From a closure planning perspective, Western Australia provides specific closure guidelines outlining minimum expectations and has ongoing closure plan submissions throughout the life of the mine (DMP and EPA 2015). This model emphasizes the importance of regulator guidance and involvement in the closure design process, which should begin at the onset of mining. The legislative framework in South Africa requires that the land is returned to a state that conforms with sustainability principles and holds individuals within a mining company liable for negative environmental impacts (Parliament of the Republic of South Africa 2002).

The need for clarity and strong guidance regarding closure requirements from the regulator is becoming more and more imminent. Alberta is considered a leader in dam safety practices. With some of the largest dams in the world, any failure would be devastating to the industry as a whole. In this sense, nothing but the best is acceptable from a dam safety perspective. Similarly, this attitude must be carried forward to Alberta's approach to tailings dam closure and post-closure safety. Research is ongoing between the AER and the University of Alberta to investigate the long-term behaviour of tailings dams to aid in enhancing and assessing risk management tools for the purposes of tailings dam safety following mine closure.

ACKNOWLEDGEMENTS

The authors would like to thank the Vanier-Banting Secretariat for financial support of this research. The authors would also like to thank Tim Eaton (Senior Advisor, Closure and Liability Branch, AER) for his ongoing support throughout this research.

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