Closure and the Long-term Behaviour of Tailings Dams: Using Industry Experience to Fill in the Gaps

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ABSTRACT
Mining activities result in the production of waste streams, referred to as tailings, which are commonly stored in tailings dams. Historically, these structures were designed to be safe for a mine's active life and for scenarios with return periods that range between 50 and 1000 years. This has become problematic as the life of a tailings dam (operation and post-closure) may far exceed these time frames. Combined with the potential catastrophic consequences of a failure, these structures pose a risk to the environment and the public following mine closure. Unfortunately, there is limited information published on how these structures age over time. To aid in filling in this knowledge gap, interviews were conducted with individuals with experience with tailings dams and closure. The participants included world-renowned experts, consultants, and mine operators. This paper presents a summary of key interview results and discusses the implications to tailings dam closure in Alberta.

RÉSUMÉ
Les activités minières génèrent un flux de déchets, ou résidus miniers, entreposés couramment dans des digues à stériles. Historiquement, ces structures sont conçues pour être sécuritaires pour l'existence active d'une mine et pour des scénarios ayant des périodes de retour de 50 à 1000 ans, engendrant une nouvelle problématique car la durée de vie d'une digue à stériles (exploitation et post-fermeture) peut facilement excéder ces échéanciers. Considérant les conséquences catastrophiques potentielles dues à une rupture, ces structures présentent aussi un risque pour l'environnement et le public après la fermeture de la mine. Malheureusement, très peu de données sont publiées sur le vieillissement de ces structures. Pour combler cette lacune, des entretiens ont été menés auprès d'experts de renommée mondiale, de consultants et d'exploitants miniers tous ayant de l'expérience avec ces digues et la fermeture. Cet article présente un sommaire des données pertinentes des entrevues et discute des conséquences pour la fermeture d'une digue à stériles en Alberta

1 INTRODUCTION

Alberta's mining industry consists primarily of coal and oil sands mines with varying lifespans. These two industries pose an interesting dichotomy as tailings dam closure approaches. A few of the major differences between these two industries includes the size and complexity of the dams, the type of tailings contained, the construction materials and methods, and the experience of the operators (Alberta Energy Regulator 2019, Morgenstern 2010). While very different problems in terms of degree of risk, both industries are currently in need of guidance on the long-term behaviour of tailings dams and how this behaviour influences reclamation and closure. To aid in this effort, a series of interviews were conducted with industry professionals with experience with tailings dams and closure. The intent of this process was to aid in filling in the knowledge gap regarding how tailings dams age and to identify areas of significant uncertainty. This paper presents a summary of the outcome of the interview process and the implications to tailings dam closure in Alberta.

2 BACKGROUND

Closure practices for tailings facilities are relatively new and subject to constant evolution. Practitioners are still debating the answer to the question of 'when is a dam no longer a dam' (Al-Mamun and Small 2018, OSTDC 2014). This concept is tied closely to the life of the tailings dam. Various organizations define the lifecycle of a mining dam differently (CDA 2014, ICOLD Committee on Tailings Dams 2013, MAC 2017, OSTDC 2014). The beginning phases (site selection and design to construction to operation) are all similar but deviate when closure is initiated. The differences between organizations have important implications as it can result in confusion in industry when approaching closure, abandonment, and decommissioning. The end goal of these phases is typically the creation of a landform, which is generally described as being "physically, chemically, ecologically, and socially stable" (ICOLD Committee on Tailings Dams 2013). In an attempt to bridge the gap between the point where a facility is regulated as a dam and the point where it could be classified as a landform and undergo custodial transfer back to the crown, OSTDC (2014) and Al-Mamun and Small (2018) propose an intermediate step whereby the dam is converted to a mine waste structure (Al-Mamun and Small 2018) or a solid earthen structure (OSTDC 2014). This process is advantageous as the facility would no longer be regulated as a dam and thus would no longer need annual performance reviews or inspections. Al-Mamun and Small (2018) presented the work of the Canadian Dam Association Mining Dams Committee (CDA-MDC), which proposes that a tailings dam could be converted to a mine waste structure assuming that it satisfied the following non-dam criteria:

1. “Ponded water could not be available to a possible failure of the perimeter structure that can propagate the failure.
2. Tailings located upstream of the perimeter structure cannot flow if the perimeter structure is removed (i.e. are not fluid like).
3. Tailings that may be located upstream of the perimeter structure cannot migrate through the structure or the foundation.
4. That conditions will not develop in the future that could violate the previous three criteria.”

Criteria 4 proposed by Al-Mamun and Small (2018) is difficult to assess and poses a challenge for industry as there is still significant uncertainty regarding the long-term behaviour of these facilities. The life cycle of a tailings dam using the intermediate step of a mine waste structure is provided in Figure 1.

Following the 2013 Obed Mountain Mine failure and the 2014 Mount Polley failure, the Alberta Chamber of Resources (ACR) assembled a dam integrity task group (later the Dam Integrity Advisory Committee (DIAC)) to investigate and support the dam safety system in Alberta (Boswell et al. 2018). A review of Alberta’s dam safety system indicated that it was among the best in the world (Boswell et al. 2018). DIAC is actively working on contributing to the improvement of dam safety in Alberta. Their list of activities to be tackled includes working with dam regulators to discuss the principles of closing dams (Boswell et al. 2018).

Alberta is making ongoing progress towards tailings dam closure. This is evident by the release of the new Alberta Dam and Canal Safety Directive (the Directive), which includes details on closure, decommissioning, and abandonment (Government of Alberta 2018). The Directive defines closure as “a process of modifying and establishing a configuration for a dam or canal with the objective of achieving long-term physical, chemical, ecological, and social stability, and a sustainable, environmentally appropriate after-use” and decommissioning as “complete removal or breach of a dam or canal so that the structures can no longer retain, store, or divert water, including water containing another substance such as fluid waste or flowable tailings that may pose safety or environmental concerns” (Government of Alberta 2018). Further, the Directive defines abandonment as when “a dam or canal is permanently removed from service and not maintained for later return to service” (Government of Alberta 2018). The Directive does not distinguish between tailings dams and water dams as it pertains to the processes of closure, decommissioning, and abandonment. The current expectation in Alberta is walk away closure where closure occurs and the land is certified and undergoes custodial transfer back to the Crown, relieving the owner of responsibility (Morgenstern 2012). For this to occur, mine owners are required to reclaim the land to stable, resilient, functional ecosystems with an equivalent land capability to the original landscape (Government of Alberta 2015).

Dam safety often has a strong focus on the design, construction, and operation stages. The lengthy time frames associated with the life of a mining dam can often be overlooked. In light of this, the technical community’s commitment to investigating the ‘dam, no dam’ question is admirable, demonstrating responsible and sustainable mining practices. The effort demonstrated by organizations like CDA and DIAC is also extremely timely, given the impending closure of a number of facilities in Alberta. The fact remains that further information is needed regarding the long-term behaviour of these facilities such that a regulating body would be willing to regulate one of these structures as a mine waste structure. The interviews conducted by the authors are an attempt to begin to bridge this gap. The interviews are part of a larger research initiative at the University of Alberta that aims to investigate how tailings facilities age to aid in risk management following mine closure.

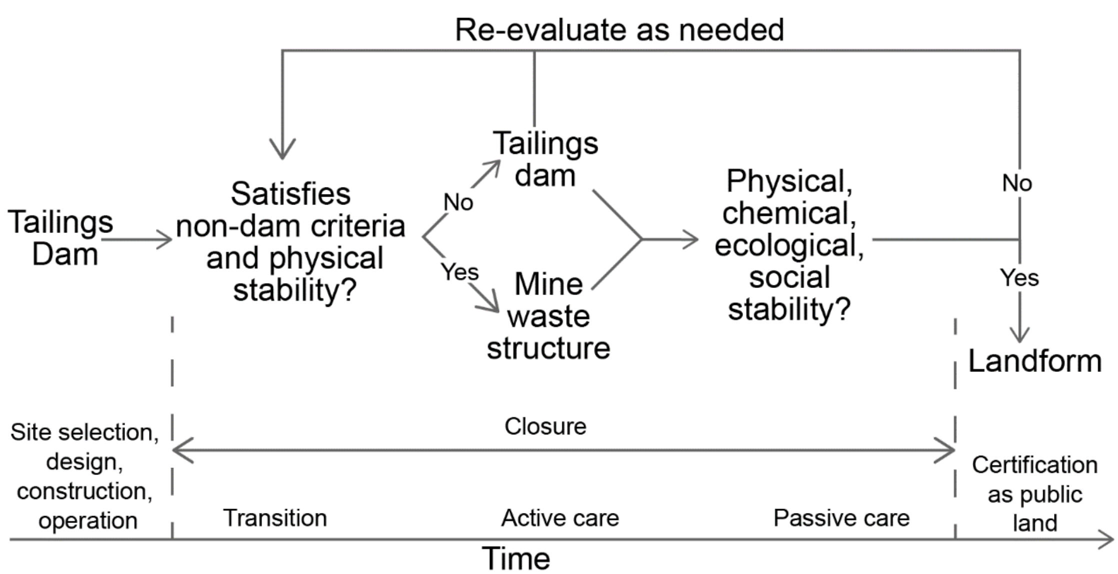

Figure 1. Tailings dam life cycle – from dam to landform (modified from Al-Mamun and Small 2018)

3 METHODS

The research presented in this paper consists of an aggregation and evaluation of expert opinion regarding the potential evolution of tailings structures after mine closure. The interviews were designed to provide information related to the long-term physical failure modes of coal and oil sands tailings dams, potential triggers and indicators of failure in the long-term, monitoring and surveillance of tailings dams, risk communication challenges, and closure and reclamation challenges in Alberta. The process emphasized the lack of consensus amongst practitioners regarding long-term geotechnical behaviour and the way in which poorly founded assumptions could become a potential source of failure in the long-term.

Fourteen interview questions were developed by the authors to learn from the expertise and experience of the participants regarding how tailings dams change over time. The Research Ethics Board at the University of Alberta approved the interview questions and methods prior to the start of the study. All participants were required to read and sign an informed consent form. Twenty-three interviews were conducted with individuals with experience with tailings dams. The interviewees included seven consultants, eight world-renowned experts, five mine operators, and three regulators. Of the twenty-three interviewees, 83% were geotechnical engineers.

All of the interviews were conducted by the first author over the phone or in person. The interviews were 60 minutes to 90 minutes long, and interview responses were recorded by hand or on a computer. Following the interview, the responses were transcribed. Participants were given the opportunity to skip questions during the interview and remove any of their responses up to eight weeks after the interview.

Following the completion of the interviews, the responses were analyzed using QSR NVivo 12.0 by coding which allows for commonalities and themes in the data to be easily identified (QSR International 2018). The initial round of analysis involved coding each interview individually. This stage of analysis allowed key themes to be identified within each question and highlighted discrepancies in thought between different practitioners, which served to emphasize the need for further research on the long-term physical behaviour of these structures. Following the first round of analysis, coding proceeded in an iterative manner as new themes and patterns emerged. This process allowed for the identification of key topics and relationships between various concepts. At this time, the interview analysis has been used to:

- Identify uncertainty as it pertains to tailings dam evolution, risk, and failure; and
- Identify challenges related to closure and long-term behaviour of tailings dams.

4 RESULTS AND DISCUSSION

Seven key themes were identified during the interview process, including:

- Changing failure modes;
- Closure challenges;
- Development of hazards and triggers;
- Impact of recent tailings dam failures;
- Long-term monitoring and surveillance;
- Potential closure scenarios; and
- Risk communication

This paper presents the results of three out of the seven key themes, namely: tailings dam closure challenges, development of hazards and triggers, and changing failure modes. It should be noted that the information presented is limited to interview responses and does not provide an overview of literature resources related to the various themes. Readers should be aware that the interview questions were specific to the coal and oil sands industries in Alberta. Many interviewees used examples from other industries, but analysis of the results was performed with Alberta in mind. The authors believe that the interviews provide extensive insight into the long-term physical behaviour and challenges associated with tailings dam closure; however, readers are cautioned to remember that tailings dam closure is site specific. This should always be kept at the forefront during the evaluation of the long-term behaviour and risks of a facility.

4.1 Tailings Dam Closure Challenges

One of the themes discussed were the challenges to tailings dam closure. This theme allowed for identification of areas of potential improvement and areas of uncertainty that contribute to the inability to close a tailings dam. The major challenges identified fell into the following categories: cost, human, regulator, risk, technical aspects, and time frame. All of the identified challenges from the interview analysis with supporting quotes from the interviews are provided in Figure 2. Some of the categories have been further discretized. The most common challenges discussed by interviewees were cost, time frame, risk, and the lack of goal posts from the regulator. The remainder of this discussion will focus on these topics. It should also be noted that fluid fine tailings (FFT), mature fine tailings (MFT), consolidation of fluid tailings, and the inability to discharge water were identified as key technical challenges to closure within the oil sands.

Overall, the major restriction to tailings dam closure noted by participants was the lengthy time frames associated with tailings dam closure. The overarching expectation is that the reclaimed facility should be safe in perpetuity. To some in perpetuity means 1000 years and to others it means ‘until the glaciers return’. Regardless, the time associated with tailings dam closure introduces a degree of uncertainty that many are uncomfortable with especially when combined with the expectations associated with walk away closure. Interestingly, the time frame challenge is strongly linked to many of the other closure challenges. For example, selection of design criteria and development of a design basis were noted as being a closure challenge (Figure 2). This is often difficult because of factors like climate change, changing design floods and earthquakes, perpetual degrading forces, and changing downstream populations, which are all linked to the time frame. One participant noted that “it’s not just that we don’t currently know certain things. There are some things that are simply unknowable”.

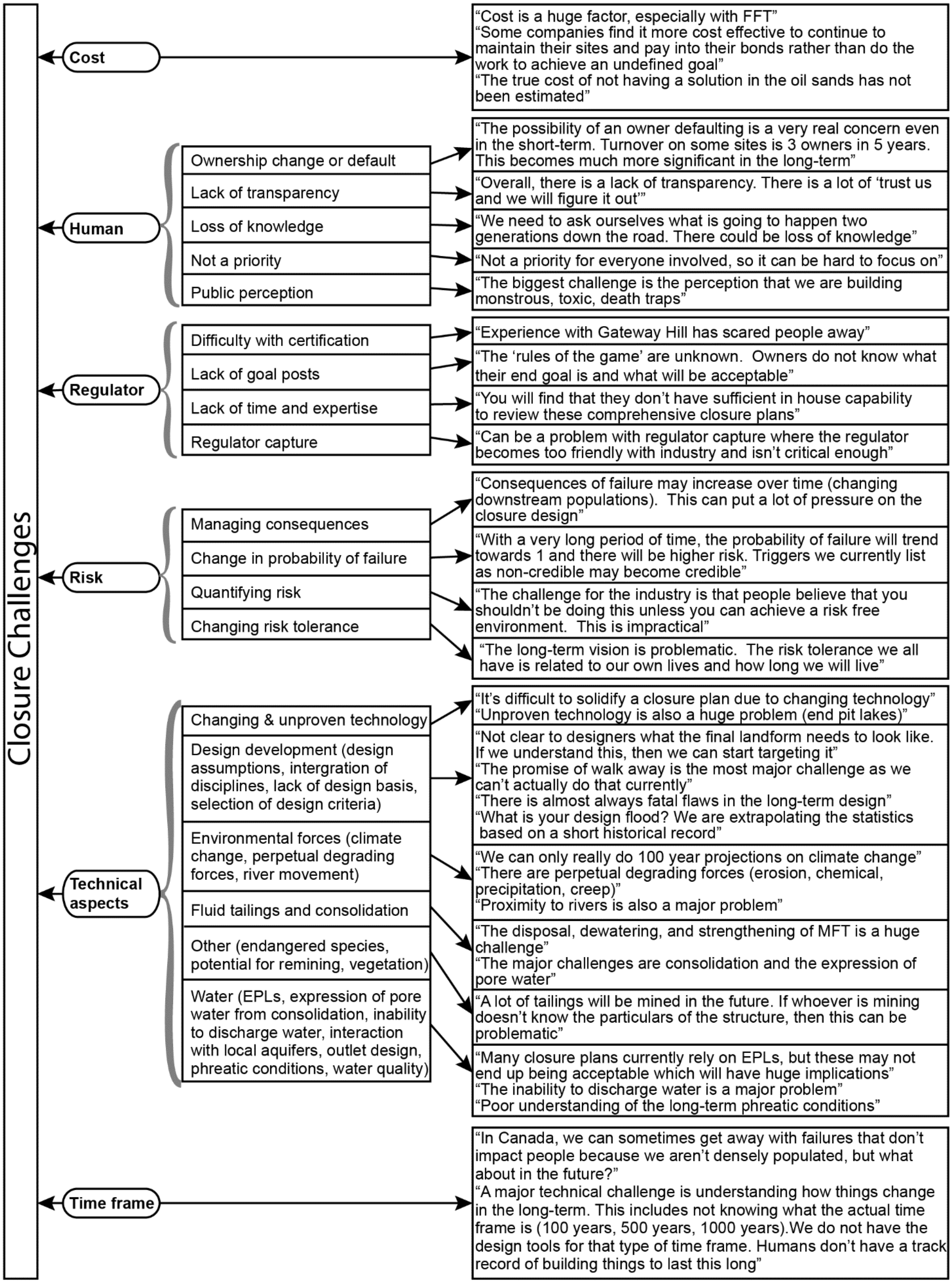

Figure 2. Identified closure challenges based on interview analysis with supporting quotes

The regulator was perceived as a challenge to tailings dam closure, specifically with regard to the amount of guidance provided on dam closure and certification. Interview responses related to the regulator primarily expressed a desire for more guidance on the expectations and requirements for closure (or the 'goal posts' of closure) and what will be considered acceptable to the regulator. It was noted that this lack of guidance is a deterrent to some mine operators to perform reclamation and close their facilities as they may spend a lot of money without the desired outcome. Some participants went a step further to indicate that the lack of a clear ruling by the regulator on the use of end pit lakes (EPLs) and water discharge criteria is a major challenge to closure in the oil sands.

Another closure challenge tied to the time frame is risk and how difficult it is to quantify in the long-term. The risk discussion primarily focused on changing consequences, probability of failure, and risk tolerance over time. Participants noted that over time the probability of failure will trend towards 1 as non-credible triggers become credible. Due to this, they suggested that we should be focusing on minimizing the consequences of failure, which is further complicated by factors like changing land uses and downstream populations over time. It was also noted that quantifying changing risk tolerance over time of relevant stakeholders is difficult.

Cost was identified as a major challenge from two different perspectives: the operator and the public. From the operator perspective, interviewees noted that the cost of closure is rarely estimated correctly resulting in a lack of funding for closure. It can also be difficult for operators to invest money into closure without knowing the regulator goal posts for acceptance. From the public perspective, many participants expressed concern regarding the potential for a company to default leaving the public to pay for the cost of reclamation.

What can industry do to proceed towards closure of these facilities? The lengthy time frame associated with closure will always be a major source of uncertainty. As engineers, scientists, or regulators, we cannot claim to predict the future and must always be aware of our own hubris to avoid complacency. This requires extensive documentation and review – elements that are currently in place in Alberta under the Dam Safety Program. The interviews identified a need for more research into the long-term behaviour of tailings dams and the practicality of designing for in perpetuity such that walk away closure is feasible (Morgenstern 2012). The interviews also showed a desire from industry for further guidance from the regulator. Some individuals commended the Alberta Energy Regulator (AER) on their commitment to dam safety, noting that their intent and motivation for closure is there, but that they may not yet be capable of walking through the process of tailings dam closure. The regulator's commitment to dam safety and the development of closure practices is evident with the release of the new Alberta Dam and Canal Safety Directive in 2018 and the current collaboration with DIAC. The reality is that regulator processes can often be slow and involve complex policy issues.

4.2 Developing Hazards and Triggers

The development of hazards and triggers during dam evolution was a theme that developed during interview analysis. Dam evolution, hazards, and triggers all influence the way in which failure modes will change over time for a specific facility. These processes can be complex and difficult to anticipate, especially when combined with the element of time. This is further complicated when an effort is made to evaluate the compounding effects of various dam changes and the development of hazards and triggers. The hazards and triggers identified by interviewees are provided in Table 1, and features of the dam that may evolve over time, as identified by the interviewees, are provided in Figure 3.

Table 1. Hazards and triggers as identified by interviewees

Category	Category Description
Environmental forces	Climate change, erosion, fires, precipitation events, river movement, seismic events (including induced seismicity), thermal effects (freeze-thaw and desiccation)
Excessive cost	Lack of funds for managing closure
Humans	Future activities (change in surrounding land use, land development, recreational activities), reclamation construction, regulatory environment, upstream and downstream populations
Material properties	Change in material properties over time as identified in the dam evolution process (i.e. loss of strength)
Seepage and water movement	Changes to dam structure (cracks, sink holes, slopes), drainage system failure, MFT lens, overland flow via herd pathways or human created paths, changes to the phreatic surface and pore water pressure, pipe failure, pond on reclamation surface, preferential flow paths through burrows
Spillways	Blockage (beaver dams, debris, denning of bears), buoyancy in sand channels, failure of erosion control, icing, sedimentation
Stress changes	Beaver activity, precipitation events, slope changes, toe erosion
Vegetation	Deep root systems, failure of vegetative cover

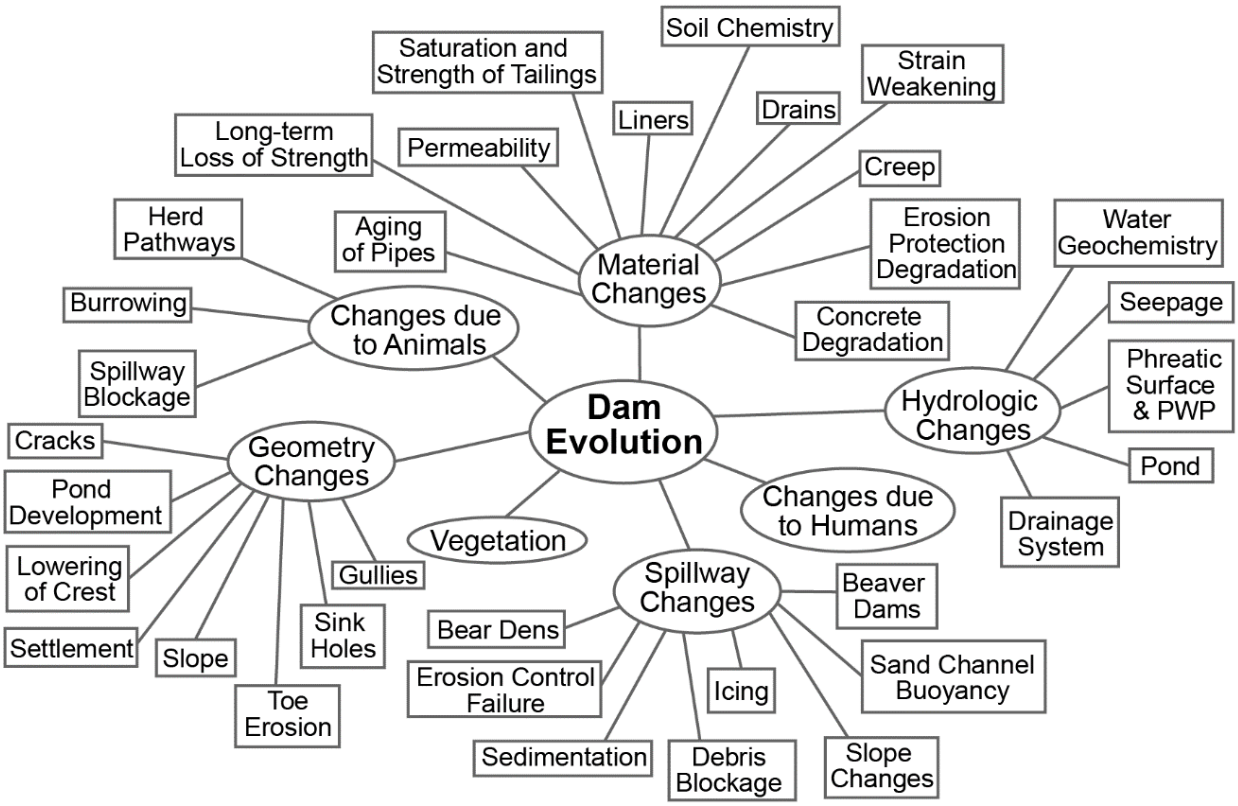

Figure 3. Dam evolution over time according to interview response

These dam evolution processes have the potential to result in the development of a hazard where a hazard is defined as a condition that has the potential to result in an undesirable consequence. Further, many of the features of dam evolution may also form hazards. For example, as the facility evolves, a pond may develop on the reclamation surface. This pond also forms a hazard. Again, it should be noted that the information provided in Table 1 and Figure 3 are not intended to provide a comprehensive list of all of the hazards, triggers, and dam evolution processes that could occur in the long-term. More so, they are intended to provide insight into the complex nature of planning and designing for closure.

It should be noted that individuals varied in their opinions on hazards, triggers, and changes to the dam over time. For example, there were conflicting opinions on the importance of surface erosion in the long-term. Most individuals noted that surface erosion is expected to get worse in the long-term; however, some participants stated that it is not expected to threaten the integrity of the dam. In contrast, others noted that erosion has the potential to lead to deep gullies that could intersect the crest and cause serious damage to the structure, potentially leading to a failure. While wind and water erosion are easily controlled during operations, this changes in the long-term when there is no longer staff present. An additional example is that many people noted that the phreatic surface will decrease in the long-term while others stated a number of conditions under which this may not be true (i.e. clogging of drains or aging of sands). Participants noted that there may also be factors that we are simply unaware of. For example, could the sand become clogged or cemented resulting in a decrease in the permeability and a subsequent rise in the phreatic surface? This discrepancy is particularly concerning as the assumption regarding the phreatic surface and pore water pressure (PWP) in the dam influences the assessment of the potential for failure modes to occur in the long-term (internal erosion, static liquefaction, etc.).

These discrepancies serve to emphasize the uncertainty associated with long-term dam safety where uncertainty may fall into one of the following three categories (Baecher 2016):

- Known-knowns (often referred to as aleatory uncertainty): uncertainty associated with the randomness of the world where the outcome is in question.
- Known-unknowns (often referred to as epistemic uncertainty): uncertainty associated with limited knowledge or data. This includes parameter and model uncertainty.
- Unknown-unknowns (deep uncertainty): uncertainties that are unforeseeable or uncontrollable.

From the long-term design perspective, the area of unknown-unknowns poses a significant concern. This category of uncertainty suggests that with significant research and experience it is unlikely what we would be able to comprehensively define all of the evolutionary processes, hazards, and triggers for a dam. While Figure 3 and Table 1 provide a significant portion of information on these topics, they allow us to identify areas of known-known uncertainty and known-unknown uncertainty – not unknown-unknowns. The complexities associated with the time frames required for tailings dam closure is an example of an unknown-unknown uncertainty. In order for closure to proceed towards the desired goal of walk away closure, the question of unknown-unknowns must be addressed.

4.3 Changing Failure Modes

To design for closure, the designers must understand the way in which failure modes change over time. This is not a simple task, especially with consideration of the closure challenges and the development of hazards and triggers over time as the dam evolves. Further, there is little precedent on which to base design assumptions.

Participants noted that failure modes will change drastically between construction, operations, and closure. As a result, it is expected that some failure modes will go away or be reduced in scale. This is expected to be site specific and variable depending on the mine. According to the ICOLD Committee on Tailings Dam and Waste Lagoons (2001), overtopping, slope instability, and earthquakes are the top three causes for active tailings dam incidents. Additional causes include foundation instability, seepage, structural inadequacies, erosion, mine subsidence, and unknown causes (ICOLD Committee on Tailings Dams and Waste Lagoons 2001). During the interview process, the failure modes discussed were:

- Foundation failure;
- Internal erosion;
- Overtopping;
- Seismic liquefaction;
- Slope instability;
- Spillway failure; and
- Static liquefaction.

A general summary from the interviews related to the changing failure modes is provided in Table 2.

Table 2. Changes to failure modes according to interview responses

Failure Mode	Changes to Failure Mode According to Interview Reponses
Foundation failure	The potential for foundation failure is expected to decrease with time.
Internal erosion	The responses varied with regard to the potential for internal erosion in the long-term. Some individuals noted that the potential will decrease over time as the expected seepage will reduce over time, especially in cases where the tailings are removed from the pond for closure. However, a number of people noted that this is expected to be a concern in the long-term, especially with consideration of evolving seepage systems. It was noted that a lack of warning of failure may be problematic in the long-term when there is no one actively caring for the facility.
Overtopping	The potential for overtopping is expected to decrease in the long-term in designs with a spillway. The highest risk is when the pond is at full height as closure works begin. Long-term settlement could result in the development of a pond, especially when combined with a large water catchment, which could increase the potential for overtopping. This could be increasingly problematic with the erosion of freeboard. A couple of participants noted that there is a critical point during reclamation works where there is a relatively small area that can handle the probable maximum precipitation before the outlet is constructed, which can increase the risk of overtopping. Overtopping may be critical in scenarios where a dam becomes non-operational and is abandoned without being closed.
Seismic liquefaction	The potential for seismic liquefaction will always be present. It is expected that the response to seismic loading will get better due to consolidation and the lowering of the phreatic surface (assuming this is true). Induced seismicity may become an increasing concern in the long-term. Seismicity is not currently considered to be critical in Alberta, but it could become more important in the future.
Slope instability	Slope instability may recede over time, but not always. For example, if there is a progressive failure, this may become more critical over time.
Spillway failure	Spillway failure was noted by some participants as being one of the biggest concerns in closure as a spillway failure may lead to a multitude of other problems with the structure. To attempt to mitigate this, spillways are often designed to be robust and may be large with huge rip rap channels, which can be extremely expensive. This may be problematic in cases where a structure is abandoned prior to reclamation works.
Static liquefaction	The responses varied with regard to the potential for static liquefaction in the long-term. Some participants noted that static stability is expected to increase in the long-term, assuming that the phreatic surface drops over time and the tailings de-saturate. Other participants noted that static liquefaction can never really be ruled out as a potential failure mode and may be re-invoked in the long-term due to stress changes from factors like erosion. Overall, responses indicated that the susceptibility to static liquefaction could get better or worse with time (i.e. consolidation of material versus a rising water table from the re-establishment of natural drainage patterns).

An individual noted that we need to anticipate that failure will occur in the long-term, but that we must understand what failure modes are analogous to the natural environment to determine what may be considered acceptable risk. Overall, responses supported the idea that we cannot build a structure, walk away, and expect it to be the same forever. As a result, we must build capacity into our systems to behave naturally in the long-term, meaning that we allow them to change, evolve, and mimic the environment. Regardless of this, participants noted that the physical stability should increase in the long-term. Participants varied in their opinions on changes to failure modes over time. This was largely based on initial assumptions made regarding dam evolution processes and the potential hazards and triggers that could be present in the long-term. The way in which failure modes change is highly site specific. Regardless, the interview results showed a higher degree of ambiguity regarding the importance of internal erosion and static liquefaction in the long-term, compared to the other failure modes. This clearly shows the importance of evaluating key assumptions when conducting failure mode analysis for the long-term. Further, the uncertainty associated with static liquefaction shows that significant research is needed to support the CDA MDC's requirements for a tailings dam to be classified as a mine waste structure.

5 CONCLUSIONS

The interviews conducted reflect the opinions of industry based on their experiences with tailings dam closure. Three major themes that emerged from the interviews were closure challenges, the development of hazards and triggers as the dam evolves, and the way in which failure modes change over time. The closure challenges identified by the interviewees were classified into the following categories: cost, human, regulator, risk, technical aspects, and time frame. Of these identified challenges, the time frame was identified as being the largest barrier to tailings dam closure and our ability to walk away from these facilities indefinitely. Interestingly, the time frame associated with closure influenced many of the other closure challenges, as well as the interviewees confidence in identifying hazards, triggers, and changing failure modes. The interviews showed a significant degree of uncertainty associated with unknown-unknowns, given the time frames associated with tailings dam closure. This suggests a need to explore alternatives to walk away closure for a design life of 'in perpetuity' in Alberta. The results indicate the further need for research into the way in which tailings facilities age and emphasizes the importance of consultation amongst experts, regulators, and practitioners to find a practical path forward for closing these structures in a safe, economical, and technically feasible manner. This work is part of an ongoing research initiative at the University of Alberta to take tangible steps towards this goal.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

Alberta Energy Regulator. 2019. Dam and Pond Map [online]. Available online: https://extmapviewer.aer.ca/DamSafety/index.html [accessed 25 March 2019].

Al-Mamun, M. and Small, A. 2018. Revision of Guidance of Landforms in CDA Mining Dams Bulletin – A Companion Paper with Additional Details, *Canadian Dam Association Annual Conference*, Québec City, Québec, Canada, 13-18 October 2018.

Baecher, G.B. 2016. Uncertainty in dam safety risk analysis, *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards,* 10(2): 92-108.

Boswell, J., Cavanagh, P., and Staples, L. 2018. Stewarding Dam Safety in Alberta: The Dam Integrity Advisory Committee (DIAC), *Sixth International Oil Sands Tailings Conference,* Edmonton, Alberta, Canada, 9-12 December 2018.

CDA. 2014. Application of Dam Safety Guidelines to Mining Dams, Canadian Dam Association (CDA), Ottawa, Ontario, Canada.

Government of Alberta. 2015. Lower Athabasca Region - Tailings Management Framework for the Mineable Athabasca Oil Sands, Government of Alberta, Edmonton, Alberta, Canada.

Government of Alberta. 2018. Alberta Dam and Canal Safety Directive, AEP Water Conservation 2018 No. 3, Government of Alberta.

ICOLD Committee on Tailings Dams and Waste Lagoons. 2001. Tailings Dams Risk of Dangerous Occurrences – Lessons learnt from practical experiences, Bulletin 121, International Committee on Large Dams (ICOLD).

ICOLD Committee on Tailings Dams. 2013. Sustainable design and post-closure performance of tailings dams, Bulletin 153, International Committee on Large Dams (ICOLD).

MAC. 2017. A Guide to the Management of Tailings Facilities Third Edition, Mining Association of Canada (MAC), Ottawa, Ontario, Canada.

Morgenstern, N.R. 2010. Improving the safety of mine waste impoundments, *Tailings and Mine Waste '10,* Vail, Colorado, USA, 17-20 October 2010.

Morgenstern, N.R. 2012. Oil Sands Mine Closure – the End Game: An Update*, 3rd International Oil Sands Tailings Conference*, Edmonton, Alberta, Canada, 2-5 December 2012.

OSTDC. 2014. De-licensing of Oil Sands Tailings Dams, Technical Guidance Document, Oil Sands Tailings Dam Committee (OSTDC).

QSR International. 2018. NVivo, Version 12.2.0.443, Plus Edition.