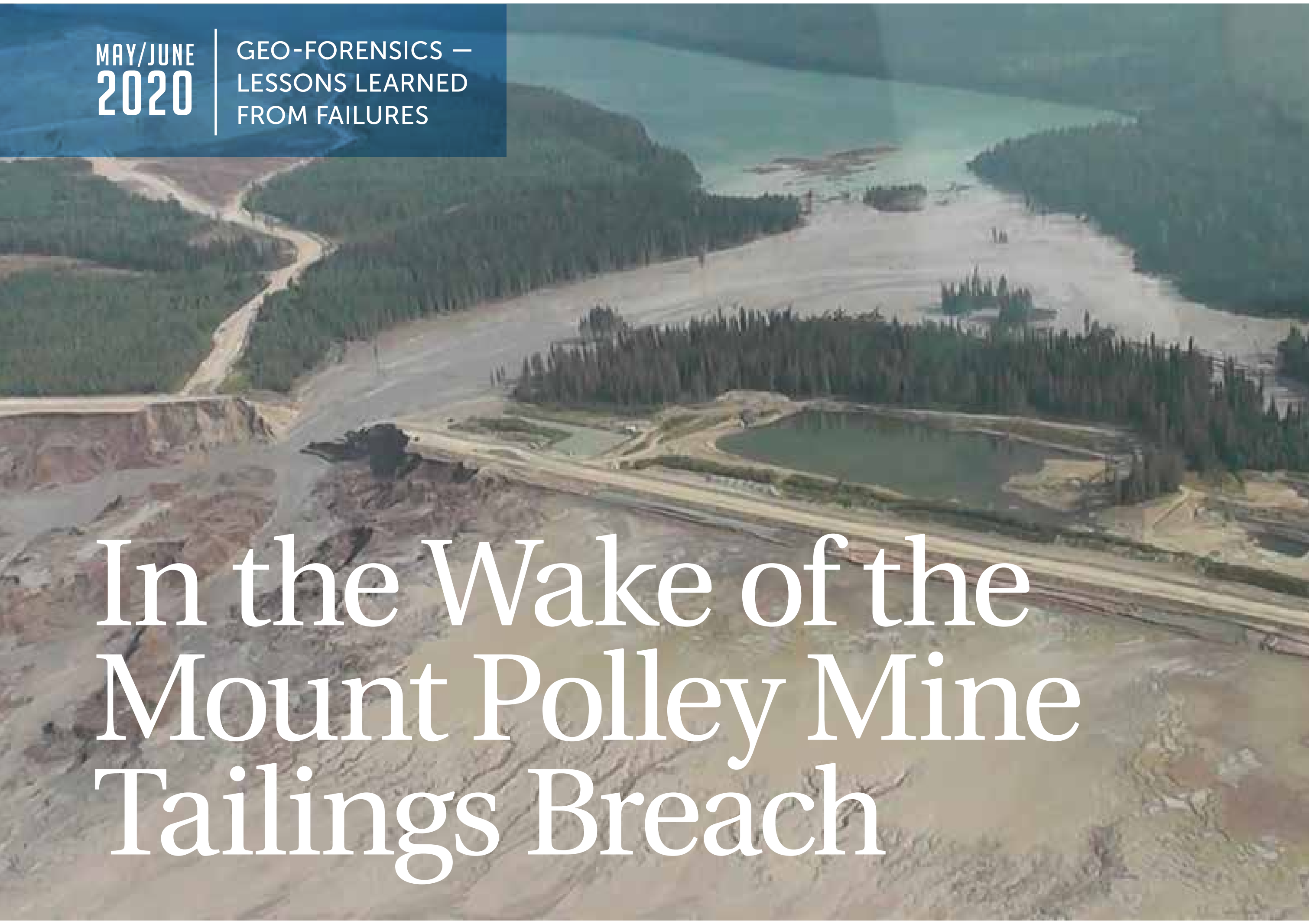

In the Wake of the Mount Polley Mine Tailings Breach

Mt. Polley dam failure. (Top Photo: Reuters.)

Tailings Dam Design, Innovation, and Practice Changes

By Harvey N. McLeod, P.Eng., P.Geo.

The Mount Polley tailings dam in British Columbia (BC), Canada, failed in 2014, spilling approximately 21 million m^3 of water and tailings (estimated as approximately 50/50 water and tailings) into Hazeltine Creek, Polley Lake, and Quesnel Lake. In January 2015, the Ministry of Energy and Mines (MEM) issued a report by the Independent Review Panel (Panel) that assessed the failure. At the same time, it also launched a separate investigation, led by the chief inspector of mines, into the root cause of the problem, the failure mechanism, and the operational and governance aspects that contributed to the failure. This report was issued in November 2015.

Important outcomes of the investigations led to recommendations for improved professional practice and improved regulatory requirements. Engineers and Geoscientists of BC (EGBC), formerly the Association of Professional Engineers and Geoscientists of BC, prepared a *Professional Practice Guideline for Site Characterization for Dam Foundations in BC* (*Guideline*; October 2016). The Panel recommended that the *Guideline* be created after it was determined that the lack of appreciation of the complex geological history of the foundation soils was one of the key root causes of the failure. Additionally, MEM initiated an immediate review of relevant regulations (Health, Safety and Reclamation Code for Mines in British Columbia) and required all dam owners to review and report on foundation conditions and safety of their dams. This is the story behind how we got where we are today in BC.

Mt. Polley Tailings Dam Failure — What Happened and Why?

Construction of the dam started in 1996, and raising of the dam was carried out commensurate with the production of tailings. The Mt. Polley dam is a U-shaped structure, over 4 km in length and up to 50 m high. An earth fill starter dam was initially raised partially upstream, and was later configured into a centerline geometry cross section. The dam cross section comprised a compacted, low-permeability glacial till central core, with filter zones and compacted rockfill on the downstream slope. The upstream slope was supported with a mix of dozer-tracked tailings and rockfill interlayered with the beached tailings. Leading up to the failure, the dam's Owner was trying to get an environmental permit to discharge surplus water from its reservoir. The permit was ultimately rejected, which led to accumulation of approximately 10 million m^3 of water being retained by the dam. Ultimately, it was the release of the surplus water that contributed to the catastrophic consequences of the failure.

Tailings dams worldwide have failed for a variety of reasons, but many, such as

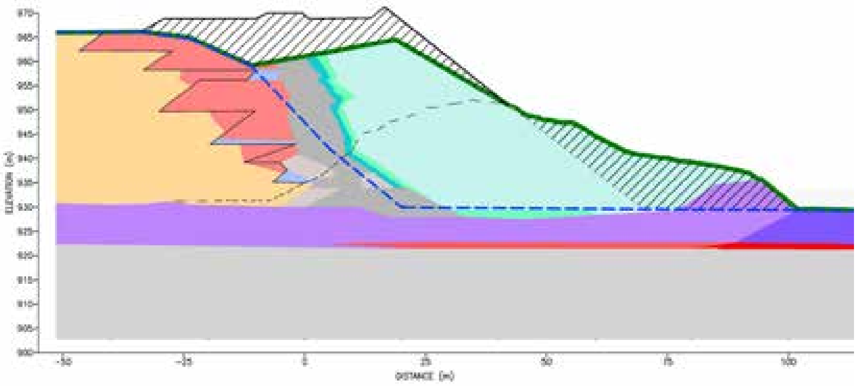

Figure 1. **Section showing "slump" of Mt. Polley dam prior to the overtopping erosion/failure.**

Figure 2. **Rehabilitation with constructed habitat wetland in Hazeltine Creek. (Photo: Mount Polley Mining Corp.)**

Cadia in Australia (2019), Aznaocollar in Spain (1994), and Sullivan in Canada (1992), have been caused by a poor understanding of the complexity and/or the geotechnical properties of the soils and rock that the tailings dams were founded upon. Without a competent foundation, even the best designed and constructed dam is doomed to failure. British Columbia, with its complex geological history, can have subsurface profiles of interlayered clays, sand, and till (mixtures of sand/silt/clay/gravels) of quite variable strength and distribution. This geology is due to the complex formation and melting patterns of the glaciers that have occurred over the last 10,000 to > 35,000 years.

The Mt. Polley dam failed because of an unidentified glacial clay layer that caused the dam to "slump" (i.e., the dam crest dropped approximately 3-5 m as depicted in Figure 1). This slumping allowed the impounded water to flow over the crest of the dam, initially very slowly. However, within approximately 1½ hours, the flow rate continued to increase and eventually led to catastrophic release of water and tailings.

Fortunately, no one died, and the tailings and impounded water that were released were not particularly toxic. Environmental effects were primarily limited to physical impacts to Hazeltine Creek and Polley Lake, and loss of low-quality aquatic habitat in Hazeltine Creek. A large portion of the released tailings was deposited 15 km downstream of the dam in Quesnel Lake, the deepest freshwater lake in Canada. Since the failure, progress has been made on rehabilitating the impacted areas: more than 500,000 native trees and shrubs were planted, 3+ km of new trout-spawning and rearing habitat were created, and Hazeltine Creek was reconstructed to control erosion of the residual tailings with channel bank re-sloping and placement of erosion-control materials. Monitoring of the water quality in Quesnel Lake indicates that the deposited tailings are physically and chemically stable and are not releasing metals into the lake. Overall, the terrestrial and aquatic ecosystems are showing positive signs of recovery as shown in Figure 2.

A Call to Action

The *Professional Practice Guideline on Characterization of Dam Foundations (Guideline)* was prepared by subject-matter experts from the fields of geology, geomorphology, and geotechnical engineering, as well as interested parties from regulatory agencies, First Nations, and industry. Tailings dams are very different from water resources dams because they are continually being raised over the life of the mine, which can span many decades, potentially with periods of insufficient care and maintenance due to cyclic variations in metal prices. The initial assessment of a site begins with desktop studies (e.g., satellite imagery, government reports, mapping) and progresses in stages with geophysics, drilling and in-situ testing and sampling, and laboratory testing. To understand the site geology and associated hydrogeological and geotechnical conditions, a good 3D model of the site is needed. This model is continually improved as the project moves through the design stage and into construction, and throughout the life of the mine. The *Guideline* provides a framework for characterizing bedrock geology, surficial geology and geomorphology, and geotechnical, hydrogeological, and seismotectonic conditions. The document also provides guidance about stages and levels of details of site characterization and requirements for documentation and professional responsibilities. Other items include risk assessments and climate.

The dam failure also prompted a review of, and revisions to, the regulatory requirements (*Health, Safety and Reclamation Code for Mines in BC*) for tailings dams in British Columbia. The review was led by a Code Review Committee (Committee) comprised of representatives from industry, First Nations, regulators, union/operators, and tailings dam subject-matter experts. The review examined tailings dam regulations from worldwide sources to learn what requirements other jurisdictions and countries have adopted, and to identify examples of good practices that could be adapted to BC. However, the Committee concluded that most of the existing regulations for tailings dams either 1) lacked any reference to tailings dam requirements, 2) were presumed to be covered under water dam or environmental legislation, or 3) were limited to just a few of the important considerations for safe tailings dams. They concluded that none of the existing regulations in other jurisdictions were written specifically for tailings dams.

Consequently, the Committee took a fresh approach to look at the key elements of a safe tailings dam from both design and governance aspects. The framework for the regulations (*Code*) included specific, measurable requirements that would become law, and referenced a *Guidance Document* that the Ministry could cite for more details on the requirements. The *Guidance Document* also provides a conduit for regular updating to reflect improvements in the state-of-practice. The *Code* has over 60 specific requirements for tailings dams, including a mix of governance, management, and technical requirements. The *Code* requirements are mostly performance-based, but, in some cases, prescriptive requirements are described for dams. Governance aspects include, for example:

- The mine manager shall notify the chief inspector of the retained engineer of record about assignment changes in the engineer of record, and the notification shall include an acknowledgement by the engineer of record.
- For a tailings storage facility design that has an overall downstream slope steeper than 2H:1V, the manager shall submit justification from the engineer of record for the selected design slope and receive authorization by the chief inspector before construction.
- A Tailings Management System shall be developed and maintained that considers the *Health, Safety and Reclamation Code for Mines in British Columbia* and includes regular system audits.
- An Independent Tailings Review Board shall be established unless exempted by the chief inspector.

Engineering aspects include:

- The engineer of record, as a qualified professional, has professional responsibility for assuring that a tailings storage facility or dam has been designed and constructed in accordance with the applicable guidelines, standards, and regulations.
- A tailings storage facility shall have a breach and inundation study or a failure runout assessment before commencing operation, or as required by the chief inspector.
- The minimum flood design criteria shall be a return period one-third of the way between the 1-in-975-year event and the probable maximum flood, and a facility that stores the inflow design flood shall use a minimum design event duration of 72 hours.


Figure 3. **Fundão Dam failure. (Photo: Reuters.)**

The Regulatory Status in BC Today

Five years afterward, significant changes in regulatory requirements and professional practices have been implemented in the province based on the findings from the failure. The *Code* has been implemented and is regularly monitored by MEM inspectors. In late 2019, the MEM started to develop the framework for a parallel Audit Group, whose responsibility will be to audit the application of the *Code*, and to review its effectiveness in achieving

Figure 4. **Brumadiñho Dam failure. (Photo: Wikipedia.)**

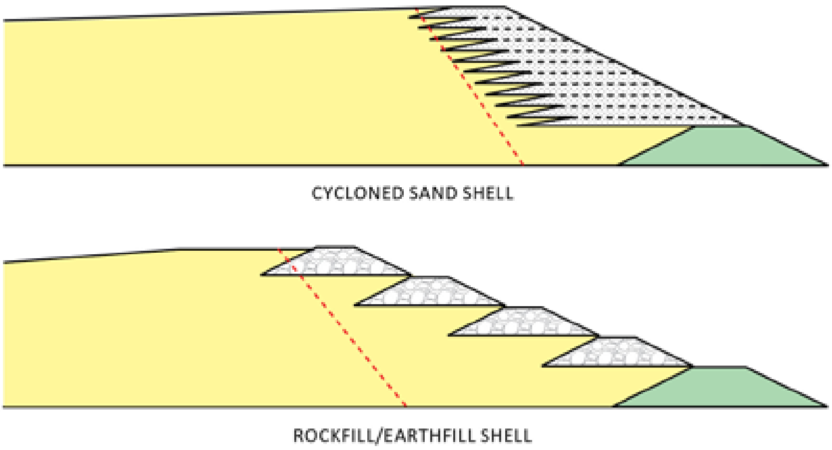

Figure 5. **Schematic of upstream construction method.**

the objective of safe dams. The development of the audit review is currently in progress, and will include periodic review of the *Code* itself to see if there are opportunities for improvement and, if required, to add additional requirements.

Key Practice Improvements

Since the Mount Polley failure, there have been two tragic, catastrophic failures of tailings dams in Brazil: Samarco's Fundão in 2015 (Figure 3), and Brumadiñho in 2019 (Figure 4). Both dams were constructed by applying variations of the upstream construction method, depicted in Figure 5. Trapezoidal embankments are constructed on top, toe to crest of each other, as the tailings are deposited, and the crest migrates further upstream. This method of construction relies on the strength of uncompacted tailings for support because the dam is constructed overtop previously deposited tailings.

These tragic accidents further demonstrate the need for improved professional practices. Such improvements were implemented after the Mount Polley failure, but since that time, the need for more improvements has become evident. The key practice improvements include:

- The Canadian Dam Association (CDA) *Application of Dam Safety Guidelines to Mining Dams* has updated its guidance to include descriptions of the responsibilities of the Engineer of Record and is also revising the guidance on requirements for factors of safety. CDA is also preparing a guidance document on dam break analyses.
- CDA developed a *Guideline for Dam Safety Reviews* (*DSR*) and has initiated training for DSRs in many countries.
- The Mining Association of Canada (MAC) revised its guideline for the *Operations Maintenance and Surveillance* (*OMS*) *Manual* for tailings dams.
- The International Council of Mining and Metals (ICMM) has recently drafted a guideline *Towards Sustainable Mining*, which covers the management and governance aspects of safe, responsible design and operation of tailings dams. The ICMM Guideline is currently under internal review.

The most recent Brumadiñho failure in Brazil (Figure 4) precipitated the initiation of a Global Tailings Review (GTR), which aims to develop a global standard for tailings dams. The GTR is supported by the International ICMM, the United Nations Environment Program (UNEP), and the Principles of Responsible Investment (PRI), the members of which, including the Church of England and the Swedish Pension Funds, have over 10 trillion U.S. dollars invested in the mining industry. The standard is in the consultation phase, which has included public presentations and industry meetings in numerous countries and an online, Internet-based forum for gathering and collating comments on the standard.

The International Commission on Large Dams' (ICOLD) Tailings Dam

Subcommittee completed *Bulletin No. 181*, *Tailings Technology Update* (note that the bulletin is posted on the ICOLD website and publication is in progress). The bulletin covers both laboratory and in-situ testing for obtaining geotechnical parameters for coarse to ultra-fine tailings. Tailings technologies incorporate a range of methods for dewatering, from cyclones to filter presses, as well as dam-design technologies. The ICOLD Tailings Dam Subcommittee has recently drafted a new bulletin titled *Tailings Dam Safety Guideline*, which has been distributed to member countries for review. The Guideline covers technical and governance aspects for safe tailings dams, focusing on site characterization, risk-informed design, factors of safety, geotechnical engineering, and hydrotechnical aspects. Guidance on classifying consequence of failure, selecting the necessary factors of safety, and flood and seismic criteria are covered. Dam break assessments for credible failure modes and dam break mechanisms are also covered.

Lessons Learned

Much has happened over the last five years with four tailings dam failures. Similar to how the practices of geotechnical engineering and engineering geology have advanced for more than a century, the profession's leaders have used these and preceding events to learn about their underlying causes and to apply those lessons through new design, construction, and governance practices. Advances in guidance for the design and governance of tailings dams will serve as the basis for safe tailings dams in the future. GS

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