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Reimagining closure at Mt Bischoff

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Abstract

Mt Bischoff mine is a historic tin mine located in the northwestern region of Tasmania, with a complex legacy of underground mining activity spanning 125 years of operations. More recently, open pit mining led to construction of ex-pit mine rock stockpiles and waste rock dumps. One of these, the Happy valley waste rock dump (HVWRD), contains non-acid-forming (NAF) and potentially acid-forming (PAF) materials and has contributed to generation and mobilisation of acidity, metal(loid)s and sulphate. Advancing closure execution of the open pit operation was presented with the challenge of an existing approved closure plan compliant with permitting requirements, albeit having identified long-term performance risks and uncertainties relative to long-term water quality objectives. This paper presents improved understanding of system behaviour that identified water transport as the dominant control mechanism. By integrating stakeholder feedback and updated technical conceptualisations, the project developed a defensible pathway towards reimagining site closure.

A central technical shift in the site's approach to closure was an improved understanding of the dominant residual risk. While earlier rehabilitation efforts for the HVWRD focused on limiting oxygen ingress, further assessment revealed that substantial acidity had already been generated and stored within the HVWRD landform and was being transported by water movement to the base/toe of the landform. Consequently, the closure strategy was reimagined to focus on management of water transport as the key driver rather than oxygen ingress alone.

The resulting current closure design adopts an optimised and integrated landform plan that features relocation of the HVWRD into the main pit as a result of the substantive challenges in managing water flow through the landform, which is situated in the steep and narrow Happy Valley. This approach also reduces water management risks associated with the main pit, specifically regarding storage and water quality. Execution of the strategy involves dewatering the pit, which was deemed as being required for subsequent backfilling with mine rock sourced from the HVWRD (both NAF and PAF materials), and installing a barrier- type cover system that would result in very low net percolation. This case study demonstrates that reimagining closure through a performance-led lens can enable a successful relinquishment trajectory that meets both regulatory and corporate requirements.

Keywords: *mine closure, water management, cover system, landform design*

1 Introduction

The Mt Bischoff mine is located in the northwestern region of Tasmania, approximately 1.5 km north of the town of Waratah. The tin deposits at Mt Bischoff were discovered at Tinstone Creek in 1871 and marked the

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first significant mineral discovery on the west coast of Tasmania (John Miedecke and Partners 2006). Mining has occurred in various forms at Mt Bischoff since the 1880s. In 2006 Bluestone Mines Tasmania Joint Venture Pty Ltd (BMTJV) received approval to mine certain areas of the site.

BMTJV actively mined at Mt Bischoff between 2008 and 2010 (BMTJV 2017). The main areas disturbed by BMTJV's activities include the main pit, Browns Face waste rock dump and the Happy Valley waste rock dump (HVWRD). Mining of the main pit ceased in July 2010. The site was placed into care and maintenance at this time and the main pit allowed to fill with water. In 2016 BMTJV commenced planning to decommission the site and relinquish the mining leases (BMTJV 2017). The 90% closure design is currently under development by Okane Consultants (Okane), with the mine closure plan (MCP) scheduled for submission in mid-2026. Closure execution is intended to commence following receipt of the requisite approvals.

The mine rock generated at Mt Bischoff over the decades of mining is known to generate acid and metalliferous drainage (AMD). AMD occurs at Mt Bischoff as a result of both historic mining operations by others and mining by BMTJV.

Many approved and compliant MCPs for sites with AMD challenges can still struggle to meet environmental expectations over the long term because, without adequate source control, ongoing generation and mobilisation of contaminants from mine materials can continue, making predicted post-closure water quality difficult to achieve in practice. As a result, these closure plans may rely on perpetual collection, conveyance, storage and treatment of AMD generated by landforms, or propose management measures that are operationally and institutionally challenging to sustain over the long term, even where regulatory compliance has been achieved in the short term.

The Mt Bischoff MCP prioritises a source control-focused strategy to mitigate long-term AMD impacts of the closed site on the surrounding environment. Key measures include relocation of AMD-generating materials from the HVWRD to the main pit, subsequent to dewatering of the pit, and constructing a cover system using non-acid-forming (NAF) materials sourced from a borrow area over the main pit backfill to limit oxygen and water ingress. In addition, exposed AMD-generating worked areas, including shallow pit walls and floors, were identified as potential long-term sources of contaminant loading, requiring management, if left exposed. These areas were therefore incorporated into the closure strategy through targeted cut-and-fill activities followed by cover system placement. This integrated approach, aligned with BMTJV's commitment to leaving a positive environmental legacy, is designed to deliver the best achievable closure outcome for the site, the environment and the local community.

2 Evolution of source control in mine rock stockpiles

2.1 Mechanisms of oxygen resupply and high internal landform airflow capacity

Throughout the mid-1980s and into the early to mid-2000s the predominant thought process in respect of source control for mine waste, whether tailings or mine rock material, was to maintain the material in a completely saturated condition and/or utilise a cover system, whether it be a dr' cover or a wet cover, to manage the ingress of oxygen. The application of source control methodologies for managing AMD risks in mine rock landforms has evolved through a series of field-scale trials and research programs, including research at the University of Saskatchewan and work undertaken at the Kidston gold mine in Queensland, Australia. Williams et al. (2006) describes this approach, with the focus on managing net percolation† through engineered cover systems as a primary mechanism for limiting AMD generation. However, at Kidston

† Net percolation refers to the portion of infiltrating water that moves downward through a cover system or waste material and exits the root zone or engineered barrier, ultimately contributing to seepage or recharge of underlying materials. It is commonly expressed as a water flux (e.g. mm/year) and represents the net balance between water entering the profile (infiltration) and losses due to evapotranspiration and lateral drainage.

the cover system to manage net percolation was only placed on the upper, flatter surface of the mine rock landform (i.e. not on the slopes).

Given the mine rock landform at Kidston was constructed by end-dumping material from lift heights that caused material segregation, and the mine rock contains a substantive percentage of coarser-textured material with relatively low water content (as-placed), the resulting landform can be described as having a high internal airflow capacity. This enables a continuous resupply of oxygen for ongoing oxidation of mine rock containing sulphide minerals. Temperature differences between the inside and outside of the landform can generate density-driven airflow, where warmer internal pore gas rises and induces a pressure differential that draws atmospheric oxygen into the landform. Given there is no cover system on the outer batter slopes, there is a continuous resupply of oxygen deep, laterally and vertically within the landform; thus a continuous generation of acid.

This behaviour has also been observed at the former Equity Silver mine site in British Columbia, Canada, where changes in internal pore gas composition were recorded, in this case carbon dioxide and oxygen, despite placement of a cover system over the mine rock landform surface and slopes. These observations contributed to an improved technical understanding that the dominant mechanism controlling oxygen resupply into mine rock landforms is advective gas transport rather than diffusion (O'Kane 1995).

2.2 Wetting up and draindown of the landform

Additional considerations include the type of dissolved constituents generated through mineral weathering, the mineralogical composition of the waste material and the rate of porewater movement through the profile. A lower net percolation rate in a covered landform, relative to net surface infiltration into an uncovered landform, can reduce water flux but may also increase solute concentrations in porewater due to reduced dilution. As a result, the total solute mass flux (i.e. solute load) may not necessarily decrease. Alternatively, solute concentrations may remain unchanged, in which case the total solute load (i.e. mass flux of dissolved constituents) would decrease due to the reduced water flux associated with lower net percolation. Regardless of the net percolation rate, the mine rock landform or waste storage facility will 'wet up' as well as 'draindown' over time, resulting in fluctuating internal water levels. Hence it is challenging to define an acceptable level of residual risk in respect of AMD seepage from the base and toe of the landform solely based on achieving a lower net percolation rate through a cover system(s) placed on the upper flatter landform surface.

'Wet up' (and time to wet up) is defined in this context as the condition where a 'drop of water' at the surface of a waste storage facility (WSF) results in a pressure response at the base of the WSF to 'push a drop of water' out of the base. This does not represent porewater velocity (the time for the drop of water to move through the full height of the WSF). In addition, different areas of a WSF wet up faster/slower due to material thickness, all other factors controlling wetting being the same; also, the material will drain due to gravity before the system is fully wetted up. Hence seepage from the base of a WSF will occur before the entire WSF is fully wetted up. Finally, a wetted up condition does not necessarily imply saturated conditions; it simply describes the steady-state volumetric water content of the material for the given surface infiltration (or net percolation) rate, depth of material, texture of material, etc.

In addition, 'Draindown' is the additional water that drains due to gravity from a porous material if the supply of water at the top of the material is reduced. For example, take a 20-litre bucket and fill it with dry beach sand. Drill holes in the base of the bucket that allow water, but not sand, to drain from the bucket. Apply a relatively higher rate of water to the top of the bucket. Initially, the water will fill up storage capacity within pore spaces of the dry sand and eventually water will start to leak out the holes; and will continuously leak as you supply water to the top of the bucket. The leakage rate will be the same as the rate of water supplied to the top of the bucket, provided water is not spilling out over the edges of the bucket. When the water supply at the top of the bucket is reduced, the leakage rate at the bottom does not immediately equate to the reduced application rate at the top; rather, it remains high and then gradually decreases as water in the sand drains down. If the application rate is reduced substantively, or even made zero, the sand will take some time to draindown due to gravity. The water retention characteristics of the sand and the height of the sand will also influence draindown rates and timing (i.e. draindown rates are a function of the volume of pore space and how finer- or coarser-textured the beach sand is).

2.3 Definitive case study demonstrating fully evolved conceptualisation of performance

Monitoring of the landform by O'Kane & Waters (2003) and Waters & O'Kane (2003) documented commercial-scale monitoring and performance of mine rock landform cover systems and internal gas/temperature/moisture dynamics at the Mt. Whaleback site in Western Australia from ~1996 to ~2002. The Mt Whaleback mine rock landform comprises large volumes of waste rock, including carbonaceous pyritic black shale material with elevated sulphide (sulphur) content, relative to typical potentially acid-forming (PAF) waste rock. This material exhibits higher reactivity due to its elevated sulphide content, presence of carbonaceous material and associated propensity for oxidation.

In this case study it was observed that some of the pyritic black shale is more reactive than typical PAF material, resulting in elevated temperatures within the landform, including localised self-heating and instances of spontaneous combustion under certain conditions. The site documented the key mine rock placement parameters, including lift height, material size, and geochemical characteristics, as well as as-built conditions following placement (i.e. post-placement conditions such as exposed or covered surfaces and associated moisture, oxygen, seepage and water quality conditions). These factors influence post-placement conditions of the landform and its capacity for continuous resupply of oxygen deep within the waste rock landform.

In short, the conceptual model governing acid generation (i.e. internal landform airflow capacity, and differences in temperature inside and outside the landform) and wetting up and draining down, as described for Kidston, was validated through field-scale observations. As documented by Waters & O'Kane (2003), this validation informed subsequent changes in mine rock landform construction, including the use of reduced placement lift height (to reduce material segregation) and incorporation materials/layers with higher water-retention capacity on top of each lift within the landform, thereby limiting oxygen transport into deeper zones and reducing ongoing acid generation.

Less acidity, combined with a more uniform and predictable water flow pattern and increased hydraulic retention time, allows for more opportunity to capitalise on available neutralisation capacity. This can substantially refine the source term representation in modelling, reflecting improved understanding of how the landform is constructed and performs. Notwithstanding the improved understanding for source term modelling, the key outcome is less acid generation. This results in less reliance on cover system performance and reduces the need for collection, conveyance, storage and treatment of seepage waters adversely impacted by AMD.

3 Implications for wetting up and draining down

The mechanisms of airflow capacity and ongoing resupply of oxygen (and thus ongoing sulphide oxidation and acid generation) are influenced by landform construction and material placement practices adopted at the HVWRD. These include factors such as lift placement methodology, material segregation and resulting internal structure, which control the development of pore-space connectivity and airflow capacity within the landform. HVWRD construction records and seepage monitoring data demonstrate that despite the landform being constructed utilising state-of-the-art methods at the time, PAF and NAF material within the landform was generating sulphate, metal(loid)s and acidity in drainage from the base of the landform, which required management. Further, it was demonstrated that extending time frames, enabling periods of continued wetting up and draining down, would eventually exhaust the neutralisation capacity within the landform, and ultimately cause a step change in seepage water quality and thus an increase in AMD risk (in the context of both probability and consequence effect).

There is a long history of acidity and oxidation products being generated and stored within the HVWRD; therefore, the key concern is not oxygen ingress alone but the movement of water through these stored products that results in the flushing of contaminants into the toe of the landform. Therefore, focusing solely on a cover system to manage oxygen ingress would not result in an acceptable level of residual risk in respect of AMD impacts. Similarly, focusing on managing net percolation, while positive, would result in long-term draindown, leaving the challenge of constructing an effective cover system in the steep and narrow valley setting.

4 Case study: Mt Bischoff and the Happy Valley waste rock dump

4.1 Challenges of the existing landform

The closure of the Mt Bischoff site is uniquely constrained by its high relief topography and the legacy of historical mining activity. The HVWRD was constructed in a steep-sided valley with natural gradients that presented immediate physical challenges for traditional rehabilitation and closure methods. The mine rock was largely placed at its angle of repose, creating steep slopes that were not originally designed for long-term integration of a cover system (Figure 1). Implementing a sustainable cover system on these gradients would require significant reprofiling to achieve constructability and geotechnical stability, and the narrowness of the valley limits the footprint available for such earthworks. Additionally, the 200-m elevation drop from the upper closure domains to the settling pond (located at the toe of the HVWRD to receive runoff and sediment) creates high hydraulic gradients, increasing the risk of erosion and sediment transport if the landform were to be covered in place.

Figure 1 Mt Bischoff Happy Valley waste rock dump and an example of its steep slopes

Geochemically, HVWRD represents a significant source hazard risk. With approximately 70% of the material comprising total sulphur content > 10% and classified as high-capacity PAF material, the landform possesses a large reservoir of stored acidity. While indigenous dolomite initially provided a degree of neutralising capacity (buffer capacity), technical assessments indicate that this capacity is finite. Modelling suggests that as the internal neutralising capacity is progressively depleted, the system approaches a critical threshold beyond which seepage water quality deteriorates rapidly. This represents a transition point rather than a precisely defined single value, although it is associated with a shift from a buffered pH range of approximately 5.5–4.5 to conditions where pH can decrease to < 4.0, accompanied by a rapid increase in dissolved solute concentrations. Historically, similar behaviour has been observed as neutralisation capacity is exhausted, with a marked decline in pH from the buffered range of approximately 5.5–4.5 to more acidic conditions (< 4.0), typically occurring over a relatively short period as acid generation becomes dominant.

The decision to move away from a cover in-place strategy was driven by the realisation that the dominant residual risk is not influenced by oxygen ingress alone but also by water movement through the HVWRD and mobilisation of acidity and oxidation products stored within the landform. Because a substantial load of oxidation products and acidity had already accumulated within the landform pore space, a cover system focused on limiting oxygen would only reduce new acid formation. It would not prevent ongoing flushing and leaching of the existing contaminant load by infiltrating water and lateral seepage through the steep landform.

Further, given the high rainfall (2,180 mm/year on average) and the inherent draindown lag time, it was determined that the probability of in situ management, even with proposed controls in place, would result in unacceptable impacts on water quality, driven by continued interaction between water, air (oxygen ingress) and reactive mine rock. These impacts would pose a significant risk to the protection of the Waratah and Arthur River catchments.

4.2 Failure modes and effects analysis

To address key technical and closure risk(s) associated with the HVWRD landform, a collaborative failure modes and effects analysis workshop was convened in 2019, bringing together technical experts and stakeholders. The objective was to systematically identify and rank potential failure modes and associated risks to inform a defensible closure pathway. The workshop identified several high-priority failure modes associated with the existing HVWRD landform configuration, including potential contamination risks to Waratah River through poorly managed AMD seepage, large-scale geotechnical instability of the steep HVWRD slopes during seismic or extreme weather events, and potential long-term limitations to achieving post-mining land use objectives.

The evaluation also utilised a multiple accounts analysis (MAA) to compare 3 primary options: maintaining the status quo, implementing a new cover-in-place system for the HVWRD and full relocation of the HVWRD into the main pit. The MAA allowed for a weighted assessment of factors that are often difficult to quantify, such as long-term environmental liability, heritage preservation and the evidence base required to support future regulatory relinquishment processes.

Specific failure modes highlighted during the workshop included the potential for surface water management systems to be overwhelmed, resulting in mobilisation of sediment and PAF material, and the risk that any in situ cover system may not effectively ensure that offsite water quality requirements can be met for the protection of the receiving environment. The analysis concluded that, while relocation would require a higher initial capital investment, the complete relocation of the HVWRD material to the main pit was the only strategy that effectively decoupled the high-risk geochemical source hazard from the sensitive Happy Valley (and downstream receiving) environment.

By backfilling the main pit and installing a barrier-type cover system, the project replaces a legacy of long-term active management with a geotechnically stable and geomorphically integrated landform. This approach results in an acceptable cost-benefit ratio and residual risk profile, as well as a clear trajectory towards lease relinquishment.

5 Reimagined closure: backfill and source control

Relocating reactive mine rock into pit voids effectively resolves the inherent instability associated with steep slope geometries. Backfilling creates a more geomorphically stable landform with reduced slope gradients, which improves the constructability of cover systems and enhances long-term performance through reduced erosion potential and improved surface water management. This configuration enhances exclusion of atmospheric oxygen and infiltrating surface water. To maintain the integrity of the barrier-type cover on 2H (horizontal):1V (vertical) slopes, the design utilises a bituminous geomembrane (BGM). The approach is critical to mitigate veneer-type geotechnical stability risks as the BGM provides high interface shear strength and favourable frictional characteristics, supporting cover system stability and continuity under potential settlement stresses. Backfilling of the pit provides critical coverage of reactive pit walls, isolating sulphide-bearing faces and thereby reducing further exposure to oxygen and limiting secondary oxidation. This is particularly relevant in minimising ongoing contributions from exposed high walls that would otherwise act as a continuing source of solute generation and contaminated run-off. This intervention reduces the potential for pit walls to remain an active source of solute loading to the surrounding water system, thereby improving long-term water quality outcomes.

Relocating reactive material into the main pit is a fundamentally more constructible strategy compared to the theoretical challenge of constructing a cover on steep slopes (Figure 2). In Happy Valley, the mine rock deposited on steep natural slope angles results in gradients that restrict the safe operation of heavy machinery, and the long-term geotechnical stability of a multilayer cover system is highly uncertain. Constructing engineered barriers on steep slopes increases susceptibility to sliding, thinning and severe erosion. By relocating this material, the design context shifts from managing cover system construction on steep valley walls to placing material within a controlled pit environment with lower gradient backfill landforms. This transition enables more controlled construction conditions and improves confidence in achieving the intended performance of oxygen and water ingress control measures under field conditions.

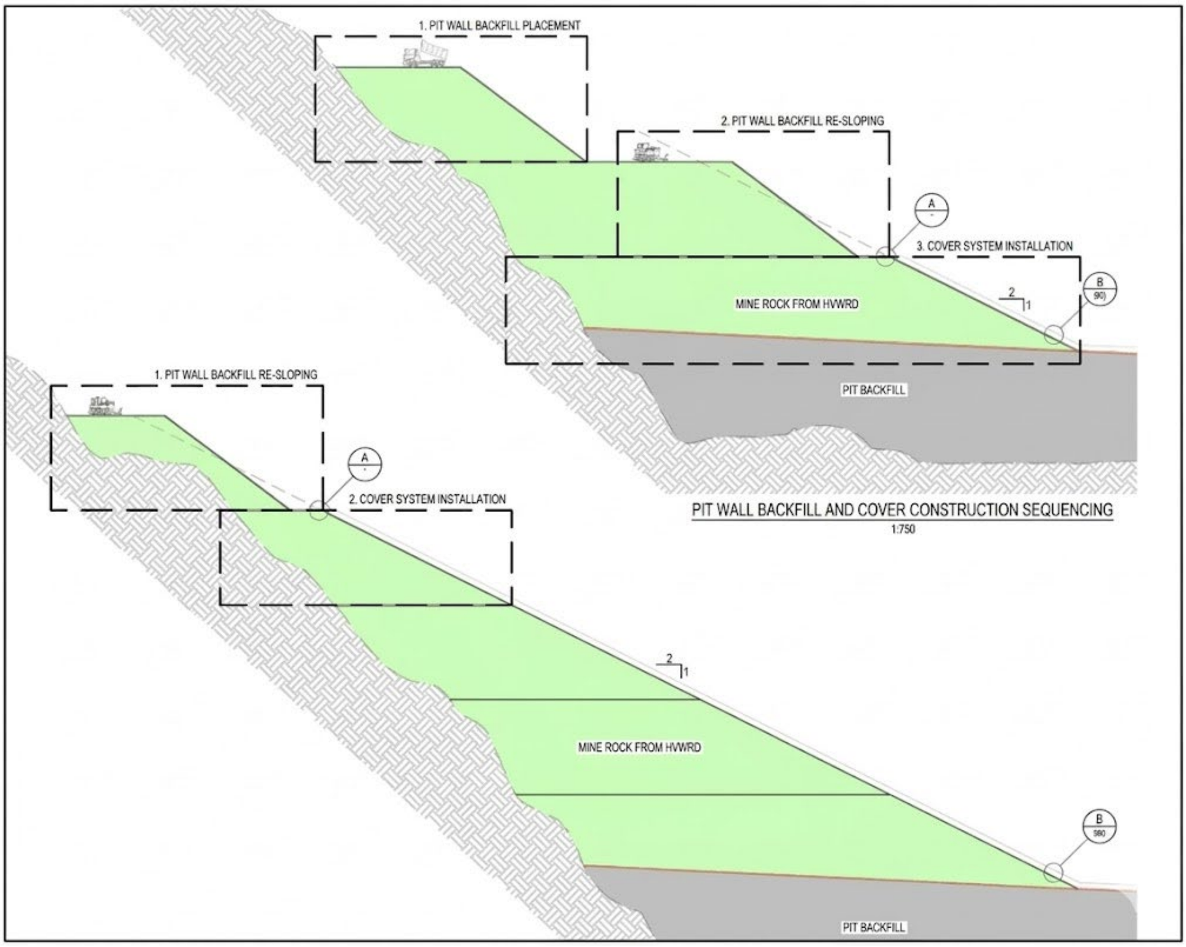

Figure 2 Backfilling and reprofiling of the north wall to achieve the isolation of reactive pit faces and long-term geomorphic stability

Ultimately, this case study reinforces that long-term water quality outcomes are closely linked to landform design and physical configuration, including factors that influence both hydrological behaviour and physical stability. A closure plan that is permitted and compliant on paper can nevertheless carry practical execution and long-term performance risks if key failure modes are not identified and addressed. By choosing a science-backed, executable backfill solution, the project seeks to establish a pathway towards eventual relinquishment of the mining lease, based on an accumulation of demonstrated performance over time. This transparent management of liability is essential for the industry to maintain the social and regulatory licences required to fast track future mineral developments in sensitive catchments.

6 Conclusion

The evolution of the Mt Bischoff closure strategy represents a critical shift in the industry's approach to acid and metalliferous drainage (AMD) management – moving from a binary non-acid-forming/potentially acid-forming classification to an advanced, performance-led source control model. By acknowledging that traditional cover-in-place strategies can rely on assumed long-term performance that is difficult to verify and maintain on steep legacy landforms, this project identifies a more defensible pathway through pit backfilling and geochemical isolation. It is acknowledged that pit backfilling is a well-recognised component of mine closure planning, but its implementation is often constrained by factors such as material handling costs, disturbance of reactive materials, AMD risks during construction, waste rock to void volume balance and potential sterilisation of remaining resources, as well as changing operational or ownership priorities. However, in the context of this case study, the proposed strategy demonstrates how these constraints can be addressed through an integrated design approach that prioritises source control. The suitability of pit backfilling at Mt Bischoff is driven by the availability and compatibility of reactive material for relocation, the opportunity to isolate sulphide-bearing waste within a controlled pit environment, and the ability to construct more favourable landform geometries that improve long-term hydraulic and geochemical performance. The evolution of closure strategy at the site illustrates that pit backfilling can be effectively applied where site-specific conditions allow, providing a defensible pathway for managing AMD risks compared to long-term reliance on cover systems on steep, reactive landforms.

The core message of this case study is that an executable closure plan is not merely a post-operational requirement; it is a fundamental tool for securing and maintaining social and regulatory licences. When companies adopt a transparent and comprehensive approach – identifying long-term water quality liabilities early and addressing them through robust engineering – they can prevent accumulation of unsustainable legacy costs and perpetual management burdens while also reducing time for environmental assessments and permitting.

Ultimately, successful closure requires solutions that are not only scientifically sound but also practical to implement at scale. This requires integration of engineering design principles with an understanding of long-term landform performance, including hydrological behaviour, geochemical stability and cover system function. Aligning these disciplines ensures that the final landform is not only compliant at closure but also remains stable and non-polluting over long time frames (millennia). In an era when the mining industry must fast track new projects to meet global mineral demands, the ability to demonstrate a clear, performance-based trajectory towards relinquishment is no longer optional – it is the prerequisite for future growth.

6.1 Limitations and assumptions

This paper has been written while engineering designs for the rehabilitation of the Mt Bischoff mine remain ongoing. While the overarching closure strategy has been committed to by BMTJV, the methodology presented is based on current design assumptions and is subject to refinement through detailed design, construction planning, regulatory review and field verification. Minor design updates may occur as part of regulatory review, and adaptive management onsite will be required during construction.

At the time of writing this paper, community consultation in the township of Waratah is ongoing. Community engagement sessions are focused on communicating the closure strategy outlined in this paper and aligning this with feedback on heritage preservation and appropriate post-mining land uses.

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