Mine Closure 2023 - Behrooz Abbasi, Jeff Parshley, Andy Fourie & Mark Tibbett (eds)
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doi:10.36487/ACG_repo/2315_008

Lessons learned from 20+ years post-closure care of BHP's legacy mine sites in North America

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Abstract

In the past, mine closure across the industry was mostly about meeting regulatory compliance with a focus on physical stability of the reclaimed landscape and revegetation of disturbed areas, with a preference for the lowest cost option. Today, BHP is focused on achieving optimised closure outcomes on a fit-for-purpose, site by site basis in consideration of sometimes competing interests such as obligations, corporate values, stakeholder expectations, and cost. It is acknowledged that how some sites were developed and/or closed in the past was not necessarily the best in terms of post-operations life when we apply a modern set of optics. Using hindsight from experiences within BHP's Legacy Assets, this paper presents numerous lessons learned in support of achieving optimised closure outcomes and objectives for mine sites. Key lessons learned include:

- *Relinquishment is a great aspiration for closed mine sites, but sites should be developed, operated, and closed in the event long-term care and maintenance becomes a reality.*
- *Closure-related decisions should be based on risks, not solely on regulatory compliance. It is acknowledged that most jurisdictions are moving to a risk-based as opposed to a prescriptive-approach for final closure of sites. In some jurisdictions, however, mine closure regulations are not stringent enough to force owners into a risk-based approach, supported by robust science and thorough technical assessments to select an optimised closure strategy.*
- *Selecting an optimised mine closure strategy should be based on the undiscounted value of estimated closure and post-closure costs. If closure strategies are selected based on present value of these costs, the industry tends to favour strategies that offer the least number of opportunities to build social value while at the same time, leaving the site/owner exposed to higher closure risk due to issues such as changing societal and regulatory demands, climate change, and emerging chemical species of concern.*

Keywords: *legacy mine sites, mine closure, case studies, lessons learned, relinquishment, divestment, risk-based approach, undiscounted vs. discounted costs, closure options assessment*

1 Introduction

In the past, mine closure across the industry was mostly about meeting regulatory compliance with a focus on physical stability of the reclaimed landscape and revegetation of disturbed areas, typically with a preference for the lowest cost option. The state-of-practice for mine closure is focused on achieving optimised closure outcomes on a fit-for-purpose, site by site basis in consideration of sometimes competing interests such as obligations, corporate values, stakeholder expectations, and cost (ICMM 2019).

It is acknowledged that how some sites were developed and/or closed in the past was not necessarily the best in terms of post-operations life when we apply a modern set of optics. Using hindsight and lessons learned from 20+ years post-closure care and maintenance of legacy mine sites within BHP's Legacy Assets (BHP-LA) portfolio, this paper presents several key messages in support of achieving optimised closure outcomes and objectives for mine sites.

2 Background

BHP-LA stewards a portfolio that includes 20 sites in various stages of closure and post-closure across Canada and the US (Figure 1). The sites are primarily the result of liabilities acquired through mergers and acquisitions. These sites mined and processed copper, zinc, uranium, tin, and gold. The aim is to progress these sites towards one of three closure outcomes: relinquishment, divestment, or ongoing management in the most effective manner. Repurposing initiatives have been implemented at several sites including a wildlife sanctuary and a historical mine park (Sommerville & Ferguson 2022).

Figure 1 BHP Legacy Asset sites across North America

Activities at BHP-LA sites include (adapted from Sommerville & Ferguson 2022):

- Tailings dam risk mitigation work across 32 tailings storage facilities comprising 108 dams,
- Closure risk mitigation studies,
- Remediation projects, typically in support of greater geotechnical stability and improved source control and protection of sensitive receptors,
- Care and maintenance with a considerable focus on collecting and treating contact water, and
- Stakeholder engagement to build relationships and consult on closure expectations and limitations.

BHP-LA sites are situated in varying climatic settings, ecosystems, hydrogeologic settings, and regulatory jurisdictions. An abundance of water exists at most Canadian legacy sites, which potentially offers social value opportunities for local communities, but at the same time, closure risks may be higher due to potential for flooding and overtopping of dam structures. On the other hand, water in the US southwest is relatively scarce, with regulations continuing to evolve in support of maximising protection of surface and groundwater resources. The commonality for all BHP-LA's sites is that they stopped processing ore more than 19 years ago and possess knowledge bases with varying levels of robustness. While opportunities exist to share learnings across the portfolio, each site requires careful consideration of site-specific conditions to ensure effective, sustainable remedial solutions are implemented.

3 Lessons learned

3.1 Develop, operate and close in the event long-term care becomes a reality

Environmental Resources Management (2018) conducted a survey of 57 closed mines in 2018. Of the sites surveyed, less than 9% had been successfully reclaimed and relinquished, 91% were still managing water, and one-third of these sites were actively treating water. Only one site in BHP-LA's portfolio has been relinquished since 2004. The current closure base plan for most sites is care and maintenance in perpetuity; however, through a vision of 'Reimagining the Legacy of Mining', BHP-LA is actively evaluating its legacy sites, or portions of them, for added social value opportunities. Currently, only the 'mill areas' at BHP-LA's Lisbon and Ambrosia Lake uranium properties in the US have a pathway to relinquishment (to the federal government once the sites' respective uranium source material license conditions are fulfilled for soil, groundwater, and infrastructure and the US Department of Energy accepts the sites for long-term care and maintenance). One of the key lessons learned across the industry and specifically from experiences within BHP-LA's portfolio is that while relinquishment is a great aspiration for closed mine sites, owners should develop, operate, and close their sites in the event long-term care and maintenance becomes a reality.

3.2 Importance of maintaining a robust, current site knowledge base

A site's knowledge base is the foundation for all other steps in the closure management or planning process (ICMM 2019). A site knowledge base should include all available and relevant contextual information (baseline, local, regional, and global) at a level of detail that allows risks to be understood and is fit-for-purpose. In this context, fit-for-purpose means that it reflects domain knowledge maturity and considers the time required until implementation of risk controls or to achieve closure objectives. The knowledge base should also consider the complexity, value, level of risk, and uncertainty for the site. It should incorporate feedback and learnings from within and between sites/assets from progressive closure activities, outputs of closure management activities, closure-related operational and functional plans and initiatives, regional and industry guidance, bright spots, and case studies. The knowledge base should be periodically reviewed by subject matter experts (SMEs) and/or objective reviewers.

BHP-LA is in the process of conducting a Current Conditions Assessment (CCA) for each of its legacy sites. The CCAs are intended to consolidate site history and characterization information, supported by conceptual site models identifying key contaminant sources, pathways, and receptors, to identify key data gaps in the knowledge base and evaluate the risk of such gaps. The CCAs, which are conducted using a standardized approach to assembling domain-based site characterization information, also support a qualitative evaluation of specific knowledge base elements against industry standards and corporate requirements. In addition to the identification and prioritization of activities or investigations to address key information gaps in a site's knowledge base, the CCAs are also proving to be of considerable value to inform new employees and consultants about the current level of knowledge prior to embarking on new projects.

The CCA process has revealed that careful consideration needs to be given to the scope of post-closure monitoring for non-operating sites with the intent of a gradual reduction in frequency and suite of parameters for specific program elements such as surface and groundwater quality monitoring. Far too often the desire is to reduce the scope for post-closure monitoring once key parameters meet a certain target or trend in a favourable direction as a cost-savings measure. BHP-LA is having to expand the scope of post-closure monitoring at a couple of its legacy sites (i.e., returning to the level of monitoring originally established for early stages of post-closure monitoring) due to potential emerging issues from an environmental risk perspective. BHP-LA has learned that monitoring programs need to be focused on key performance indicators with built-in triggers to support early detection of potential emerging issues and resulting adaptive management.

3.3 Conducting collaborative closure options assessments with metrics

Closure option assessments (OAs) are critical to understand the full spectrum of options that may be available for successful closure of a site or domain. They should be conducted at a level of detail that is fit-for-purpose, becoming progressively more refined over time as the knowledge base matures and potential new risks and opportunities are identified. Closure OAs can be conducted for the site as a whole (i.e., for selection of optimised closure outcome(s), post-closure land use(s), repurposing or social transition options), for multiple domains or at the single domain level (i.e., to assess options for implementing a specific closure method). Closure OAs require multi-disciplinary and multi-functional SME inputs to ensure robust outcomes and can take different forms, from well-defined processes such as multiple accounts analysis to a site-specific closure outcome screening tool (ICMM 2019).

As part of updating internal closure management plans and in support of the vision 'Reimagining the Legacy of Mining', BHP-LA has embarked on a process of conducting closure OAs to evaluate potentially viable, improved closure outcomes for its legacy sites. Previous closure OA workshops involved large groups of people with diverse skill sets discussing and debating conditions of the site and available options. The major drawbacks with this approach were:

- Decisions were recorded as consensus decisions for all participants in the workshop even though many people may have disagreed with a decision or direction (or portion) of the workshop;
- There was no ability to weight different opinions of participants based on specific knowledge or expertise that they may have in a particular area (e.g., geotechnical engineers opinion on dam safety versus corporate affairs);
- The loudest voices in the room generally dominate so good insights could be missed from participants who were quieter;
- There was not a quick way to see the true 'consensus position' of participants and focus discussion on areas where there was high divergence of opinions;
- Intellectual participation was often low as a result of many people feeling that their opinion was not necessarily needed or heard;
- There were not clear evaluative metrics to guide a common scoring approach; and
- There was often very little tangible direction for closure activities/works after significant resource expenditure for the workshops.

BHP-LA has developed a new approach for conducting closure OAs to address drawbacks noted above. The new approach requires at least one representative from each SME group to be in attendance. Closure options are developed ahead of the workshop by a small working group, but at the start of the workshop, participants are asked for input on potential new or modified closure options to be evaluated. The smaller working group also develops the anticipated risks and benefits of each option, which are reviewed with SMEs and edited during the workshop. During the workshop, the comprehensive list of options is presented and a brainstorming exercise completed to see if any other options could be identified. Once the final list of available 'blue-sky' options has been identified for evaluation, each SME in the workshop receives a small dry-erase whiteboard and a set of five paddles with numbers (scores) ranging from 1 to 5, with 1 being 'bad' or not favourable and 5 being 'good' or very favourable (Figure 2). For each option, SMEs are asked for their input on the following evaluation criteria:

- Likelihood of the option being endorsed by the company (0 to 100%)
- Current readiness to proceed with the option (1 to 5)
- Effort to achieve readiness to proceed with the option (1 to 5)
- Estimated time to achieve readiness to proceed with the option (years)

- Estimated time to execute the option (years)
- Desirability of the option (1 to 5) in terms of:
  - Monetary value
  - Social and environmental value
  - Non-financial benefit to BHP

Figure 2 BHP-LA SMEs showing their scores during a closure OA for the San Manuel, AZ legacy site (photo courtesy of BHP)

Scoring is entered into a spreadsheet with specific scoring from each participant recorded against their name/position in a data collection table. A linked summary sheet is shared by the facilitator so 'live' scoring of the options, where average, minimum and maximum scores can be viewed by SMEs as options are being evaluated. This facilitates discussion where there is diverging opinions but also accelerates evaluation where there is already a narrow consensus position. For example, if one of the SMEs has a considerably different score compared to other SMEs, they are asked to share their rationale for their score, which in some cases results in SMEs modifying their scores based on the arguments/discussions that occur. At the end of the workshop, the summary of scores is examined to determine which options are mutually exclusive and which options can be pursued in parallel for further evaluation.

BHP-LA has learned the following lessons when it comes to completing closure OAs: they require input/opinions from a variety of SMEs for areas that influence an assessment of potentially viable, alternate closure outcomes for closed mine sites and more specifically, the addition of a 'live' scoring system to record the opinion of each SME present in the workshop on pertinent evaluation criteria provides much greater feedback as closure options are being assessed.

3.4 Carson Hill Gold Mine case study

The former Carson Hill gold mine is in eastern California in the upper foothills of the Central Sierra Nevada. The climate is Mediterranean, with hot dry summers (average 32°C) and cool wet winters (average 10°C), and a mean annual rainfall of 750 mm. Underground and placer mining occurred at the site from the late 1840s to the 1940s. In 1986, Carson Hill Gold Mining Company, owned by WMC of Australia, excavated a side-cut to access ore for heap leaching of gold using cyanide extraction technology. The operation resulted in the construction of four waste rock piles and three heap leach pads that are now referred to as Waste Management Units (WMUs). Open pit mining and heap leaching operations ceased in October 1989. The leach pads were rinsed to neutralise and remove cyanide and other constituents of concern (COCs) that were considered a threat to water quality. The waste rock piles were regraded and revegetated concurrently with mining and were considered stable and reclaimed at the end of mining. The California Regional Water Quality Control Board, Central Valley Region (CVRWQCB) approved closure of the WMUs as Group C mining waste, and between 1992 and 1994, the site was closed in accordance with an approved closure plan.

In 1996, a third-party purchased the closed property from WMC for operations including mining of spent ore from the WMUs and rock from the open pit, as well as commercial rock crushing, screening, and aggregate washing (Figure 3). As part of the 1996 Purchase and Sale Agreement, WMC retained final closure and environmental liability responsibilities for the property, which was transferred to BHP through acquisition of WMC in 2005.

Figure 3 Former aggregate operation near Carson Hill open pit and WMU-1 with green geomembrane interim cover in the background c. 2020 (photo courtesy of BHP)

Infiltration of rainwater through the vegetative covers into the WMUs resulted in periodic overtopping between 1994 and 2000 and again in 2006. Waters from the WMUs flowed into the surrounding waste piles and native rock materials, resulting in impacts to water quality with elevated concentrations of TDS, sulphate, cyanide, nitrate, and certain metals including arsenic, cadmium, chromium, copper, nickel, and selenium. Although closure of the heap leach pads was approved by relevant regulatory agency in the early 1990s, the CVRWQCB concluded in 2005 that groundwater quality at the site did not meet applicable standards and required the development and implementation of certain corrective actions.

In summary, the original, regulatory approved mine closure plan for Carson Hill failed, requiring BHP-LA to develop and implement a new closure plan through regulatory orders in the mid-2000s. Based on classification of WMU waste material and closure requirements in the 1990s, WMC was permitted to simply regrade and revegetate the heap leach pads. Given the local climatic conditions and the fact the WMUs are underlain by a double liner system, it was only a matter of time before the 'bathtubs' filled up and overtopped. Overtopping could have been prevented if an alternative reclamation approach was implemented in the 1990s, such as preventing infiltration into the WMUs, managing water that accumulated within the WMUs, or removing the waste material.

BHP-LA has been collecting and treating mine-influenced water at the site since 2007 as well as installing and maintaining interim geomembrane covers over the WMUs; however, BHP's options for final closure were limited because the site and WMU materials were owned by another party. BHP-LA performed interim closure measures for more than a decade working alongside the owner of the property, while also contemplating reacquiring the property to gain full control of activities at the site. The most recent and successful attempt at reacquisition took 3 years of planning and negotiations and concluded in November 2021. This case study highlights two important lessons:

- Decisions associated with final closure or reclamation of a site or domain should be driven by risks, not solely regulatory compliance. It is acknowledged that most jurisdictions are moving to a risk-based as opposed to a prescriptive-approach for final closure of sites. In some jurisdictions, however, mine closure regulations are not stringent enough to force owners into a risk-based approach, supported by robust science and thorough technical assessments to select an optimised closure strategy.
- If another entity wants to buy a closed mine property, seller's diligence on the buyer is key. This includes financials but also operational policies and practices. The 'divestment' should also consider how future operational decisions will balance potentially competing interests, particularly if the seller will retain closure liability as part of the divestment or under applicable regulation.

3.5 Selbaie Mine case study

The former Selbaie mine, located in northwest Quebec, Canada, is about 130 km north of the nearest community (La Sarre). Selbaie was a surface and underground copper-zinc mine, which operated between 1981 and 2004. Key features of site development included an open pit, ~18 Mm^3 of potentially acid-generating (PAG) tailings stored in a ~180 ha tailings management area (TMA), and ~16 Mm^3 of PAG waste rock stored in a ~70 ha waste rock dump (WRD) (Figure 4). Post-closure characterisation of the tailings and waste rock materials showed >90% of samples having a neutralisation potential ratio less than one with a median sulphur content of 1.45% (Wood 2020). Contact seepage water collected from around the TMA and WRD is conveyed to the Water Treatment Plant (WTP) for treatment using slaked lime. Treated water is subsequently routed to the Pit Lake for polishing prior to discharge to the receiving environment (Wawagosic River), provided the quality meets discharge requirements as outlined in the site's Certificate of Authorisation and Government of Quebec's Directive 019. Selbaie is situated in a relatively cold, semi-humid climate with an average annual temperature of 0°C, ~850 mm of precipitation, and ~590 mm of potential evaporation.

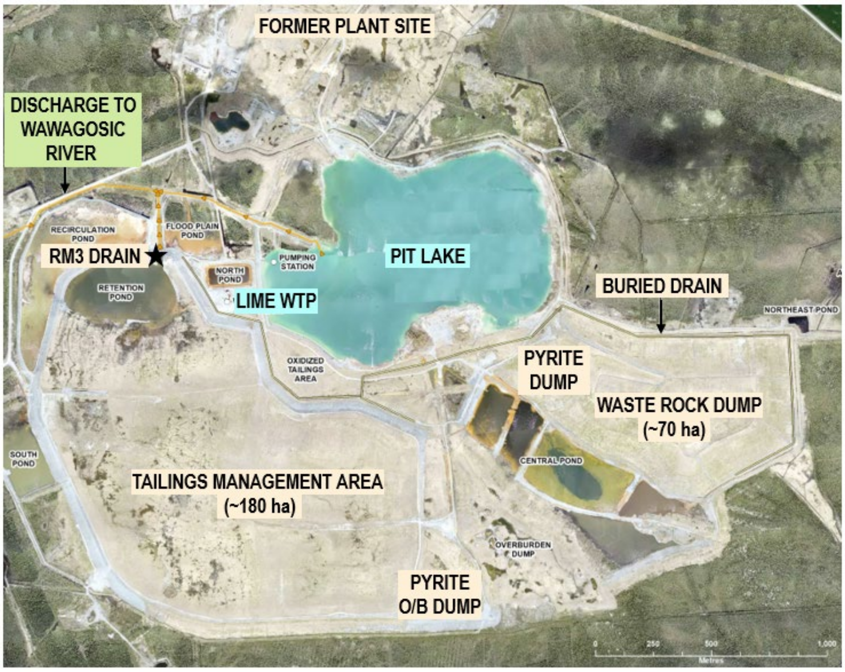

Figure 4 Reclaimed Selbaie mine layout of key features (adapted from Wood 2020)

Selbaie was reclaimed between 2004 and 2006 including re-contouring and covering the WRD and TMA with 1 m of sandy-silt glacial till, with a saturated permeability of about 10^{-5} cm/sec, followed by seeding with native grasses and legumes. The primary design objective of the WRD cover system was to limit percolation of meteoric water into the underlying waste material, while the primary design objective of the tailings storage facility cover system was to eliminate surface contact water while allowing sufficient infiltration to keep the tailings mass saturated, thereby mitigating oxidation of sulphidic-rich tailings. In retrospect, two major issues exist from a cover system design perspective: 1) the local till material is too permeable to act as an effective hydraulic barrier in a wetter climate, and 2) the same cover system design was used on both facilities but with different design objectives. Performance of the reclaimed WRD is discussed first followed by performance of the reclaimed TMA.

3.5.1 Performance of reclaimed WRD

Performance of the reclaimed WRD is reviewed from two perspectives; first, its ability to reduce net percolation rates and resulting seepage volumes and second, its ability to function as a stable landform. The estimated net percolation across the WRD cover system is an estimated 45% of precipitation on a mean annual basis based on water and load balance modelling of the site (Wood 2020). This has resulted in the need to collect a considerable volume of contact water for treatment; on average, BHP-LA treats about 2.4 Mm^3 of contact water requiring about 3,000 t of lime annually, with an estimated 98% of the total acidity loading coming from the WRD (Wood 2020).

The surface and seepage collection and conveyance systems for the reclaimed WRD are highly engineered and maintenance intensive (Figure 5). For example, plateau runoff water that accumulates in the south drainage channel drains into a manhole that feeds a high-density polyethylene (HDPE) pipe buried in the outer slope of the WRD. Toe seepage from the WRD along the east and north sides is collected in a 300 mm diameter perforated HDPE pipe embedded in sand and gravel. Unfortunately, due to geochemical reactions in the buried drain, precipitates build up to the point where the drain and chimney features need to be cleaned out annually. Furthermore, due to relatively low gradients, lack of an underlying compacted soil or geosynthetic liner coupled with localised differential settlement, it is hypothesized that very little plateau runoff water reaches the perimeter drainage channels at the toe of the WRD.

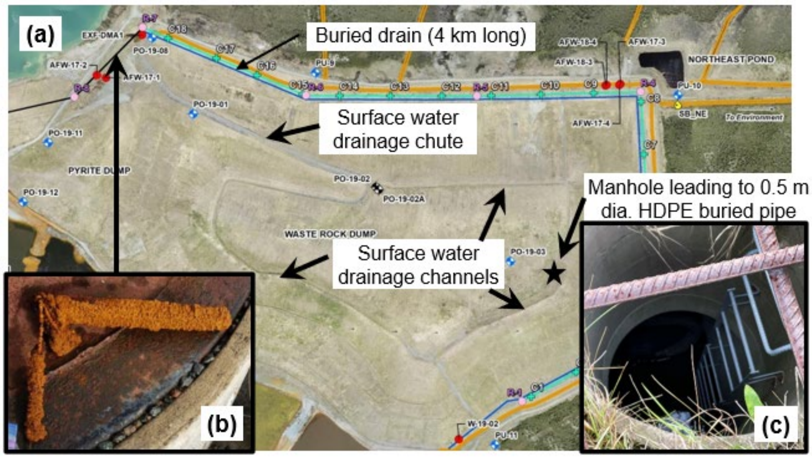

Figure 5 (a) Reclaimed Selbaie WRD site layout (Wood 2020); (b) Example of precipitate build-up inside buried drain (photo courtesy of BHP); (c) Manhole feeding HDPE pipe for draining WRD south plateau surface water (photo courtesy of BHP)

A positive aspect of the reclaimed WRD is that while the sandy-silt till cover material is prone to rilling and gullying, the coarser fraction of the glacial till material combined with the root mass of the native grasses has stabilised the cover system surface (Figure 6). The flora is currently dominated by native grass and legume species, but woody species are beginning to naturally colonise on the cover system surface, particularly in the wetter soil regimes on the north slope.

Figure 6 **(a) Area of former active erosion gullies on north slope of Selbaie WRD (photo courtesy of BHP); (b) Typical grass and legume species coverage on WRD cover system surface, ~17 years post-reclamation (photo courtesy of BHP)**

Many lessons have been learned from over 15 years post-closure care and maintenance at Selbaie, including the following from a landform design and surface water management perspective.

- The potential for plateau runoff waters accumulating near slope crests should be eliminated by using a saddle landform design (McKenna 2009; Figure 7). Two potential failure modes exist when you accumulate surface water near a slope crest; the first is the potential for surface water flowing uncontrollably over the slope crest due to a blockage in the drainage channel, and the second is the potential for focused infiltration of ponded water in the event of a channel blockage, which could lead to elevated pore-water pressures and subsequent instability of the slope below.
- When a plateau area incorporates a water-shedding landform, measures should be put in place to ensure the diverted surface water is conveyed off the landform to minimise the potential of this water infiltrating and percolating through the underlying waste material at some point further down-gradient. This can be accomplished by incorporating a geosynthetic or compacted soil liner below the rock armouring material within the drainage channel.

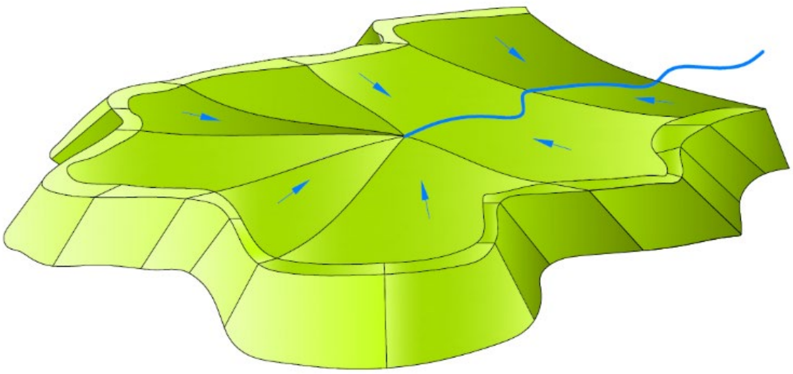

Figure 7 **Schematic of a saddle landform design (adapted from McKenna 2009)**

The chosen closure plan for the WRD was one of the lowest cost options and was approved by provincial regulatory authorities; however, it did not appropriately account for risks associated with long-term acid mine drainage from the WRD. In hindsight, the waste rock material should have been relocated to the open pit and submerged below water. This would have been two to three times the cost of covering the waste rock in place but would have reduced the current long-term management requirement. A large site characterization program was completed between 2017 and 2019 (Wood 2020) in support of developing alternate remedies to improve the projected long-term care and maintenance requirement at Selbaie.

The Selbaie WRD case study has resulted in the following lessons learned from a closure strategy perspective:

- If we select closure strategies based on present value of estimated total costs, the industry tends to favour strategies that leave the site/owner exposed to higher closure risk due to issues such as climate change, changing societal and regulatory demands, and emerging chemical species of concern.
- Selecting an optimised, cost-effective final cover system for a reactive waste storage facility in a wetter climate requires numerous supporting studies, including but not limited to soil-plant-atmosphere modelling, geochemical speciation modelling, saturated-unsaturated seepage modelling, groundwater flow and solute transport modelling, and a human health and ecological risk assessment (Ayres 2021). In short, spending time and money up-front to characterize current site conditions and numerically evaluating how a reclaimed facility will perform for a given cover system design over the long term can provide greater assurance that required design objectives will be achieved.

3.5.2 Performance of reclaimed TMA

Configuration of the Selbaie TMA evolved throughout mine operations due to changes in methods for tailings management (Wood 2020). As tailings production progressed, works to raise and upgrade containment dams were completed, some of which are now internal to the TMA (Figures 8 and 9). Dams were constructed with a compacted till core surrounded by waste rock on the upstream and downstream sides of the dams. A rock drain constructed near the top of Dam RM-3, referred to as the RM3 Drain, is the primary pathway by which water exits the TMA. The RM3 Drain was originally installed in 2004 to facilitate construction of a spillway for the Retention Pond; however, it was subsequently decided to leave the drain in-place as part of the final reclamation design to limit the potential for upwelling of contaminated tailings pore-water into the Retention Pond (SNC-Lavalin 2006).

Over time, the phreatic surface within the TMA has been receding, which is attributed to the operation of the RM3 Drain, acting as a 'sink', and relative ease for tailings pore-water to flow through the porous shells of the internal and perimeter dams. Unfortunately, this is contributing to the inability to meet the TMA reclamation design objective of keeping the tailings mass saturated due to the lowering of the phreatic surface and increased rate of acidification. If measures are not taken to slow or reverse the rate of tailings desaturation/acidification, modelling predicts that the TMA could contribute 35% of the site's acidity loading within 20 years (Wood 2020). It should be noted that the TMA cover system is performing as designed; the relatively poor performance of the reclaimed TMA from a water quality/loadings perspective is because operation of the RM3 Drain was not considered during original planning for closure of the TMA.

A field trial was conducted in 2021 to evaluate the feasibility/impacts of decommissioning the RM3 Drain. While shutting down the RM3 Drain will likely allow the TMA phreatic surface to rise, this could have an impact on the current geotechnical stability of the TMA perimeter dams, water quality in the Retention Pond, and seepage/exfiltration rates around the TMA periphery (WSP 2022). Water level and chemistry data were collected at various locations prior to and during a 4-week shutdown of the RM3 Drain as well as 4-week period following drain re-opening. The 2021 trial provided valuable field response data in support of confirming hypotheses regarding water levels and quality and most importantly, highlighted the complexity of the hydrologic and hydrogeologic conditions for a facility that was intended for passive closure. Observations and field response data collected during the 2021 trial will be used to predict potential impacts of decommissioning the RM3 Drain on dam stability, site water management, and the long-term closure strategy (Martin et al. 2023).

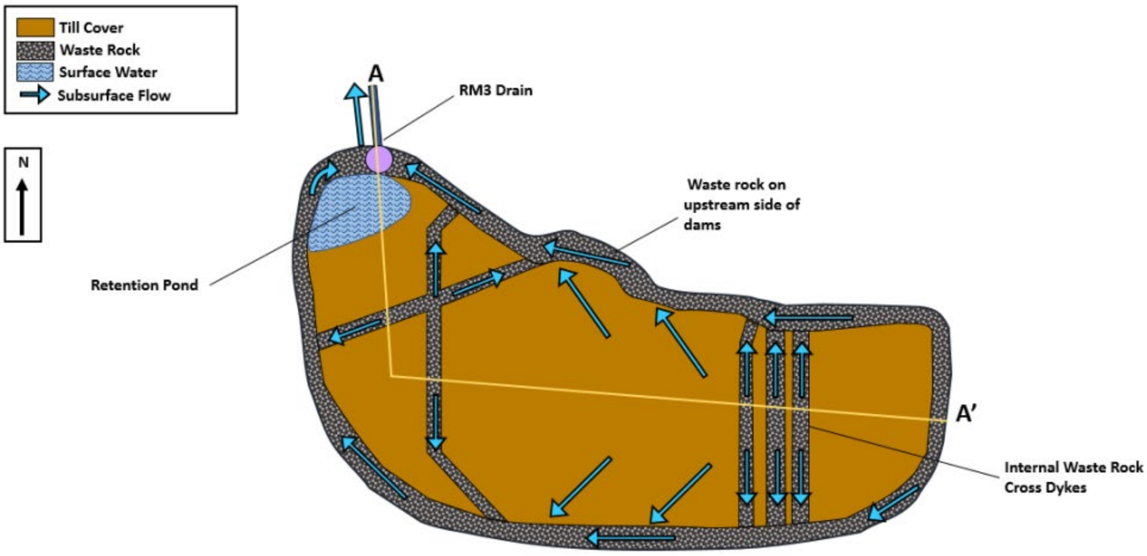

Figure 8 **Plan view of reclaimed Selbaie TMA illustrating preferred pathways for subsurface flow within the tailings mass (Wood 2020)**

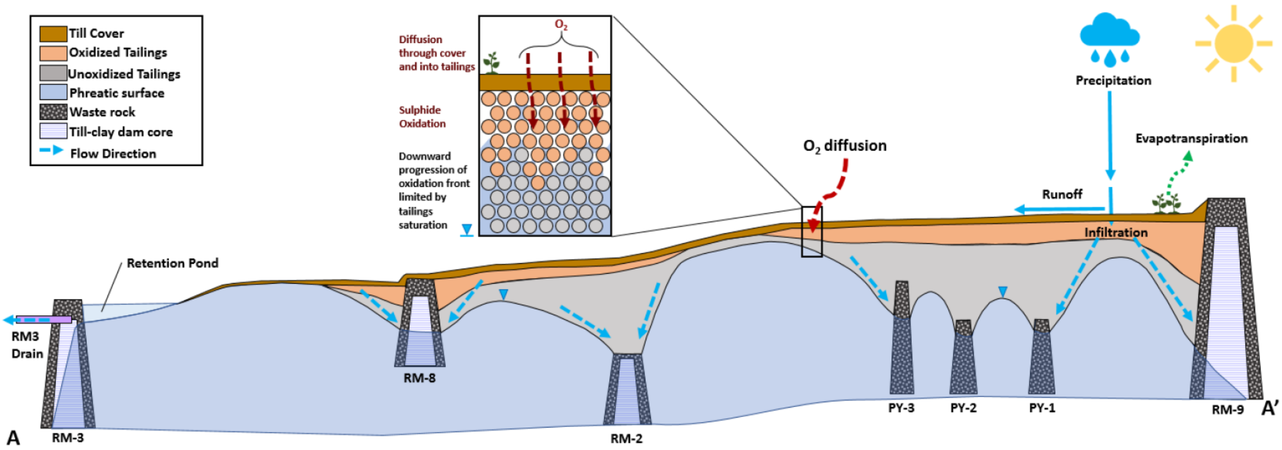

Figure 9 **Cross section of reclaimed Selbaie TMA illustrating preferred pathways for subsurface flow within the tailings mass (Wood 2020)**

Key lessons learned from closure and performance of the reclaimed TMA at Selbaie are as follows:

- Robust site/material characterisation programs as well as state-of-practice engineering analyses are paramount for developing a cost-effective and sustainable closure design for mine waste storage facilities, particularly for sites with reactive waste materials in a wetter climate.
- Proof of concept using field trials provide opportunities for learnings under site-specific conditions, particularly for complex/interconnected hydrologic and hydrogeologic systems, which are nearly impossible to replicate in the laboratory or with a numerical model.

4 Conclusion

BHP-LA stewards a portfolio that includes 20 sites in various stages of closure and post-closure across Canada and the US. The sites are primarily the result of liabilities acquired through mergers and acquisitions. Based on our historical learnings, the current closure base plan for most sites is care and maintenance in perpetuity; however, through a vision of "Re-imagining the Legacy of Mining", BHP-LA is actively evaluating its legacy sites to determine if there are alternative optimal closure solutions available for the sites. This includes consideration of value-add options from both a financial and social value perspective while minimising the residual risk posed by these sites. Using hindsight and lessons learned from 20+ years post-closure care at BHP-LA's sites, the following key messages are offered in support of achieving optimised closure outcomes and objectives for mine sites.

- Relinquishment is a great aspiration for closed mine sites, but sites should be developed, operated, and closed in the event long-term care and maintenance becomes a reality.
- Closure-related decisions should be based on risks, not solely on regulatory compliance. It is acknowledged that most jurisdictions are moving to a risk-based as opposed to a prescriptive-approach for final closure of sites. In some jurisdictions, however, mine closure regulations are not stringent enough to force owners into a risk-based approach, supported by robust science and thorough technical assessments to select an optimised closure strategy.
- Selecting an optimised mine closure strategy should be based on the undiscounted value of estimated closure and post-closure costs. If closure strategies are selected based on present value of these costs, we tend to favour strategies that offer the least number of opportunities to build social value while at the same time, leaving the site/owner exposed to higher closure risk due to issues such as changing societal and regulatory demands, climate change, and emerging chemical species of concern.

Acknowledgement

Permission from BHP to publish this paper is appreciated. Contributions to this article from my BHP-LA colleagues, including Kevin Ramsay, Brendan May, Debbie Berthelot, Joel Bauman, Sandra Ross, Tom Appleman, Ashley Gusikoski, Clara Balasko, and Kate Sommerville is also greatly appreciated.

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