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Let's reimagine our legacy of mining

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Abstract

If the mine you are operating will be stuck with your company forever – would you do something different?

As miners, the industry is expert at delivering safely at a price. Closure, traditionally, is pushed to the back of the productive life and given a myopic magnifying glass once a year to make sure its cost does not impair the balance sheet. The problem is that society demands more of us; governments are less willing to allow relinquishment, and there is real risk if the mine is sold off and the new company goes bankrupt, it will return to the balance sheet and reputation.

We realise that how we optimised the mine life in the past is not necessarily the best when we apply a modern set of optics. With the value of hindsight this paper examines case studies of mines in BHP Legacy Asset's portfolio to compare short- and long-term closure thinking and showcase important aspects of closure. Aspects of closure that we need to consider in an integrated way such as: risk; technical; closure; water; social closure (now more commonly known as 'just transition'); stakeholder management; innovation; climate change; operational integration, and change.

BHP Legacy Asset's stewards 23 sites in various stages of closure across the USA and Canada; 200 people including contractors; 108 dams in 23 different facilities and 12 water treatment plants, most of which BHP did not mine but acquired in transactions. Costs are real and, in some cases, forever.

The industry needs to become expert at reimagining how to operate with closure in mind. It requires an integrated approach: mining, geology, data, geospatial, geotechnical, finance, environment, water, renewables, community, and legal. The industry needs to be able to make the case for outcomes that have long-term benefit, but which may require an increased short-term cost.

If the tension between short-term demands and long-term outcomes are realistic, beneficial to the environment and community, the industry can promote our licence to operate, and we can all be proud of our legacy.

Keywords: *closure, technology, water treatment, risk, community, climate change, monitoring*

1 Introduction

Closure professionals need to challenge our operations and mining companies with a simple question: if the mine you are operating will be stuck with your company forever – would you do something different?

The industry is expert at delivering safely at a price. Closure, traditionally, is pushed to the back of the productive life and given a myopic magnifying glass once a year to make sure its cost does not impair the balance sheet. The problem is that society demands more of us; governments are less willing to allow relinquishment, and there is real risk if the mine is sold off and the new company goes bankrupt, it will return to the balance sheet.

The industry needs to become expert at reimagining how to operate with closure in mind. It requires an integrated approach: mining, geology, data, geospatial, geotechnical, finance, environment, water, renewables, community, and legal. The industry needs to be able to make the case for outcomes that have long-term benefit, but which may require an increased short-term cost.

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It is acknowledged that how we optimised the mine life in the past is not necessarily the best when we apply a modern set of optics. With the value of hindsight this paper examines case studies of mines in BHP Legacy Asset's portfolio to compare short- and long-term closure thinking and showcase important aspects of closure. Aspects of closure that we need to consider in an integrated way such as: risk, technical, closure, water, social closure, stakeholder management, innovation, climate change, operational integration, and change.

The BHP Legacy Assets sites span North America from coast to coast and from the frozen north to the Sonoran Desert. There is a site representing almost every climatic setting, geology, hydrogeology, and geochemical context found in the BHP portfolio.

The Legacy Assets team stewards 23 sites in various stages of closure across Canada and the United States of America (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 a new life, either divest, relinquish, repurpose or to manage longer term in the most effective way. Innovation and site-specific knowledge are needed to remediate and apply treatments depending on the site, such as: soil contamination, surface water, groundwater plumes, water and land rights, tailings stability, demolition, stakeholder expectations, mine opening closures, and proof of closure solution. Legacy Asset activities for BHP include:

- Tailings physical stability risk mitigation: to eliminate permanent population at risk down gradient of tailings storage facilities.
- Closure and risk mitigation studies: to fully characterise (geophysical, geochemical and hydrology).
- Closure and remediation projects: to execute source remediation, erosion control and rehabilitation of land and water.
- Care and maintenance: to conduct water treatment, security, maintain regulatory and environmental compliance and maintain rehabilitation structures and tailings dams.
- Stakeholder engagement: to rebuild relationships and engage on closure expectations and limitations.

Closure outcomes are underpinned by BHP values and prioritise safety, risk, environment, and social value including as appropriate, repurposing.

For many of our sites there is no formal mechanism to relinquish the liabilities. Only two have relinquished in the last year and most sites are expected to be held in perpetuity. Most people who visit are surprised at the amount of investigation, project works, non-process infrastructure, maintenance, environmental monitoring, and technical work is done.

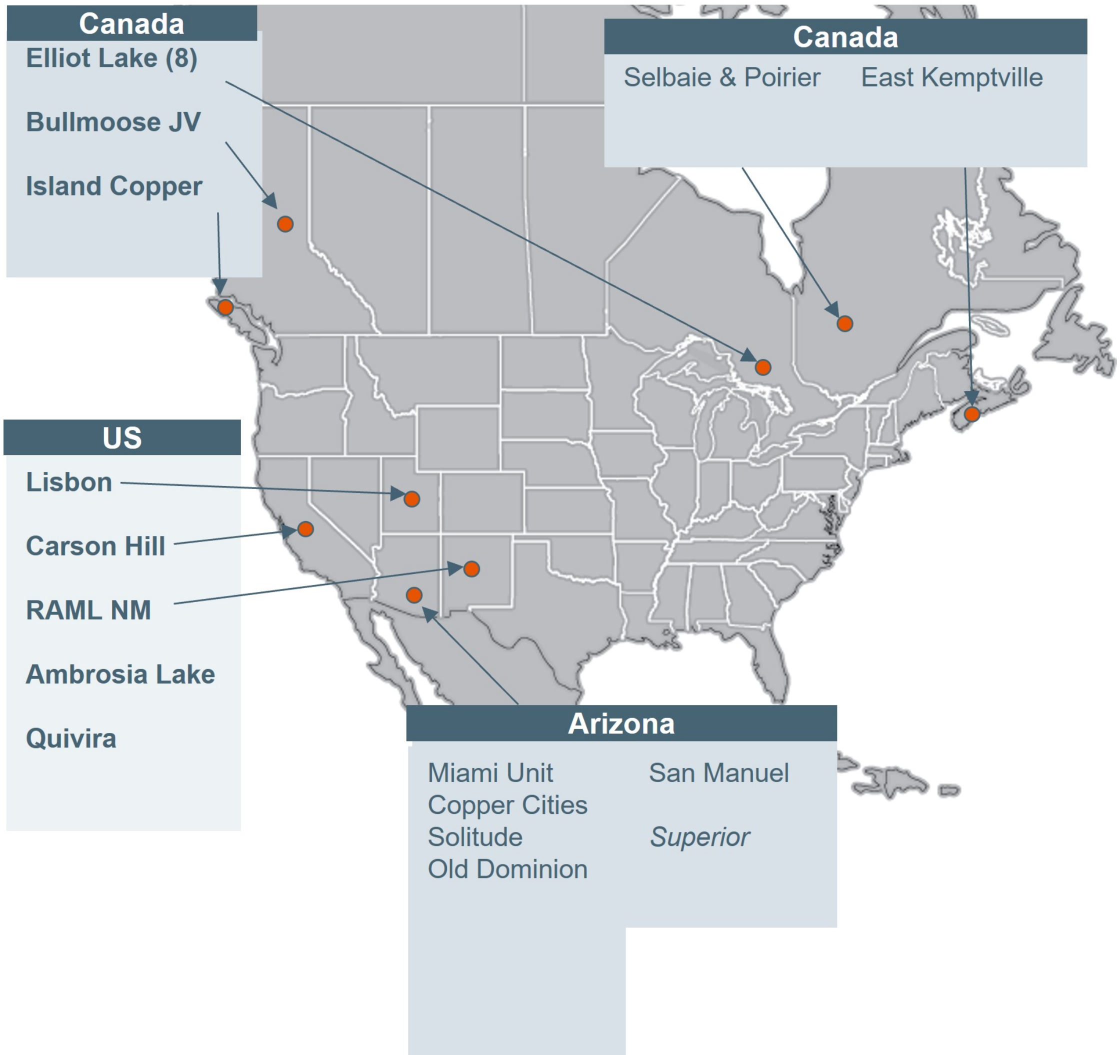

Figure 1 BHP Legacy Assets locations

2 Closure risks

Closure risk is a good way to view the challenges and priorities needed in Legacy Assets. Legacy Assets does not produce revenue – rather we spend money to reduce and remove risk from the business.

Over 50 material risks to Legacy Assets can be categorised into seven large buckets, shown in Figure 2. They include: water, tailings, covers, community, soil, and infrastructure. Risk mitigation and treatment activities include: buttressing tailings dams, treating water, repairing covers, soil collection and replacement, closing old mine shafts and historic openings, and managing subsidence. Sufficient lead times and good relationships and processes are required to obtain support and agreements from regulators, communities, and tribes to do conduct risk mitigation work.

Water comprises the largest proportion of closure risk, also illustrated in Figure 2. Whether in the arid, water scarce western US or wet Canadian north, water is the golden thread that connects tailings, closure and social value activities and risks. The greatest risk is the perception of adversely impacting water offsite. BHP's reputational risk is what is at stake. There are multiple lower-level risks of losing containment or upset, none of which is material. They include: tailings, surface and groundwater, storm events, dam failures, loss of containment and tsunamis. Climate varies, hence Arizona water is scarce and there is pressure on water rights. Climate is a modifier for work. Sites are exposed to frequent floods and fires and emergency drills for facilities are routine. As non-producing sites, our annual operating costs are reflective of the water management, water treatment as well as maintenance and surveillance of our infrastructure (including tailings dams) required to ensure that our sites remain safe, stable, and non-polluting.

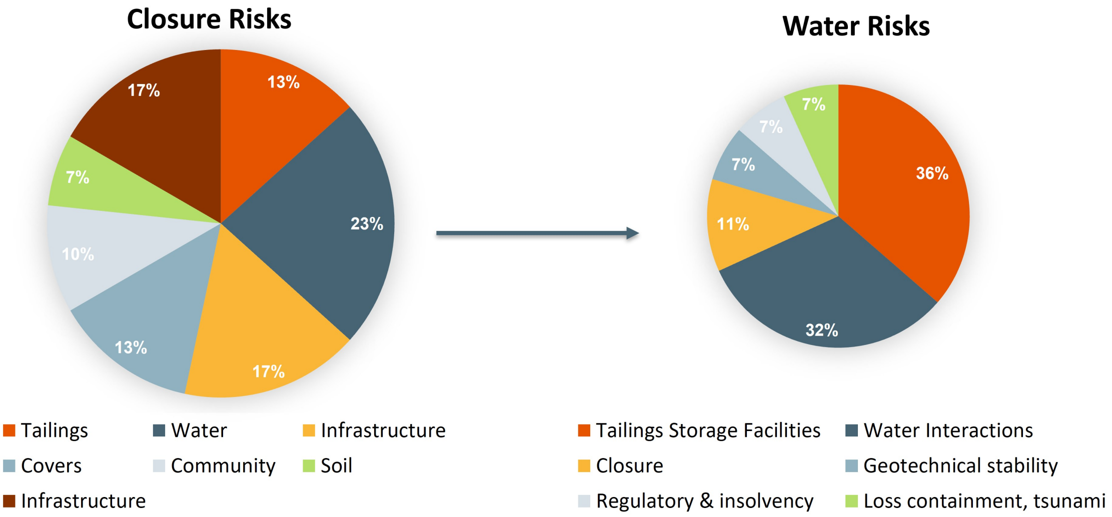

Figure 2 Closure risk with an expansion on the categories for water risk

3 Closure case studies

It is acknowledged that how we optimised in the past is not necessarily the best when we apply a modern set of optics. With the value of hindsight this section focuses on some good outcomes and shortfalls. Good outcomes have focused on long-term thinking, robust science and stakeholder collaboration. Shortfalls have resulted from short-term goals hindering long-term outcomes and a lack of consideration of local conditions.

3.1 Closure done well – Elliot Lake Ontario, Canada

Elliot Lake is in Ontario Canada. It is a beautiful region with many lakeside holiday cottages. A total of 12 uranium mines operated from 1956 to 1996 in a community population of 25,000. BHP acquired eight of those mines. There are two aspects of closure done well: social and environmental.

3.1.1 Social closure at Elliot Lake – a good process

The entire region was faced with closure at the same time due to an alternative higher grade uranium region. The town of Elliot Lake was created for the mines. Towards the end of the mine life of operations there were extensive and collaborative talks between mining companies, federal government, and provincial governments. The community desired and was successful in repurposing the town into retirement living. The transition included employee adjustment programs and an extension to a few operations for one year to support the transition. There was a housing employee purchase program and mechanisms to ensure market conditions for houses were maintained with the surplus of houses. Residual housing transferred to 'retirement living' with funding by the government to support marketing and establishment of a 'not-for-profit' management corporation.

Today Elliot Lake's population is over 11,000. Regular presentations to Regional Municipal and First Nation Councils are done along with community education of the history of the area. Community engagement established user groups such as naturalists, hiking, model airplane clubs, senior's camping facility and a fish hatchery. Most user groups use land access agreements. Success in community repurposing requires drive from these types of user groups.

3.1.2 Technical closure at Elliot Lake – good outcomes

Elliot Lake has also been successful in technical aspects of closure, specifically understanding and making the best use of site-specific environment and climatic conditions.

Annual precipitation in the Elliot Lake area is 954 mm with 183 mm as snow fall. In this climatic region water covers are more successful than vegetation covers in controlling acid generation from tailings and rock dumps. There is a vegetation cover in the area, as well as a water cover, so a real comparison is available. The lime usage to treat water runoff from the vegetation covers is 750 t lime a year compared to our water covers that use 4–5 t of lime a year. Figure 3 below shows the extent of the water cover at our Quirke tailings dam.

Figure 3 Quirke tailings dam – water cover

Elliot Lake's current closure status is management in perpetuity. Site activities include dam surveillance on 69 containment dams, water monitoring, water level monitoring and maintenance, five water treatment plants treat 8.5 Ml–20 Ml per year. Water is treated with lime, with routine maintenance on water treatment plants. Annual removal of vegetation is carried out on structures and 127 culverts. There is approximately 100 km of road network to maintain. Additional water treatment is required to manage radium levels. We also monitor fish population and perform sediment monitoring.

3.2 Closure shortfalls – Selbaie Quebec

Selbaie is a site in Quebec, Canada. Selbaie copper mine was a surface and underground mining operation. Operations occurred between 1981 and 2004. The site is 95 km from the nearest community and the climate conditions are 850 mm of precipitation, 590 mm evaporation and an average temperature of 0°C. It is a harsh and remote area.

3.2.1 Current closure at Selbaie – suboptimal outcomes

What currently remains on the Selbaie site now is an overburden rock dump and tailings dam, both with 1 m vegetated cover and a pit lake. Water is collected through a series of drains, treated, and discharged to the pit lake and then offsite to the environment. Approximately 2.2 million cubic metres of water is treated with 300 tonnes of lime per year, which is a lot of lime. Sludge is stored in the pit lake which has an estimated 250 years of sludge storage remaining.

As mentioned in Section 3.1.2, high rainfall environments with vegetative covers are often not as successful as water covers. As this site has only a vegetative cover, the site is faced with potential in perpetuity water treatment and high lime use. In addition, the water collection and monitoring system requires pumps and buried drains which incur ongoing maintenance costs as drains get constrained with sediment.

3.2.2 Selbaie – what would you do differently?

The overburden dump cover performance and ongoing challenges with drain performance means the original plan for seasonal treatment only was not realised. Water treatment and an associated workforce was required all year-round resulting in increased closure labour costs and lime use. High treatment costs are compounded by the remote location.

Figure 4 shows a profile over time of closure costs. There are two lines: the original 2004 estimation and the 2021 estimation (trends only as values are commercially sensitive). The initial peak shows the closure execution costs of capping dams and site clean-up. A few years into closure the increased site workforce presence and lime resulted in a doubling the annual operational costs. Further external changes required tailings and climate adaptations which resulted in further costs to upgrade pump stations and spillways. More investigation was conducted in areas of hydrology, hydrogeology, water quality, geotechnical and geochemical.

A rough estimate of closure costs as a proportion of copper unit revenue produced over the operational life indicates that initial closure cost was 17% and the revised cost is now 36% of the revenue. The closure cost has more than doubled. With the benefit of hindsight, overburden should have been placed in the pit and the water collection system been gravity based. It is very difficult now to justify relocation of overburden back into the pit. Further study continues to improve outcomes around site exposure for people and water treatment.

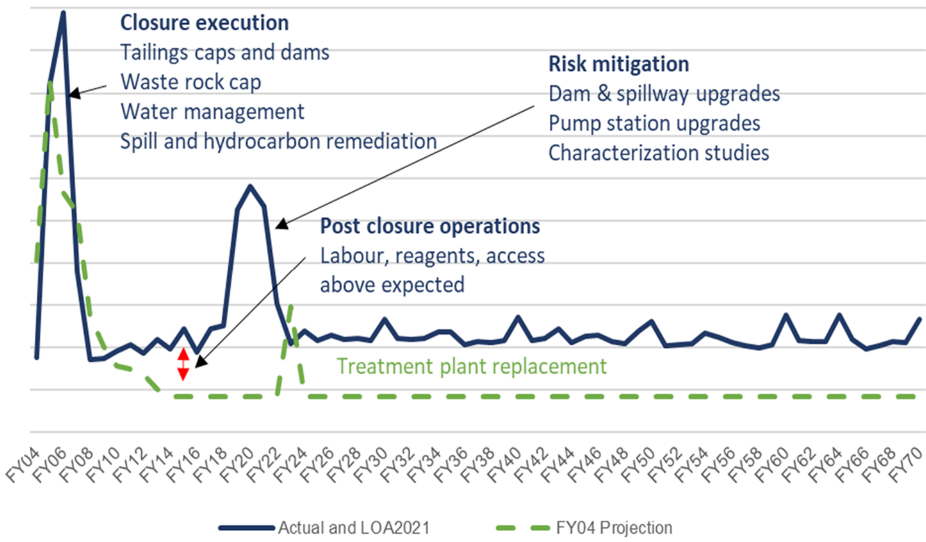

Figure 4 Selbaie closure cost profile – projected and actual

4 Water

Water risks comprise a quarter of the BHP Assets' closure risks. They relate to groundwater, surface water, regulatory and stakeholder risks with water elements. Whilst some success has been achieved in water management and treatment, some challenges remain. Understanding water takes time and remedies take many years to demonstrate success. Additionally, expectations change over time: for example, there is an emerging desire to limit lime consumption to reduce carbon footprint and to eliminate evaporation as a remedy to make more water available to the environment. This section will demonstrate results from leading practice groundwater modelling and a novel approach to water treatment.

4.1 Water activities in legacy sites

Legacy Assets has many water-related features: 108 tailings dams, 29 tailings storage facilities (TSF), 31+ rock storage facilities, seven open pits, 23 underground mines (UGM), 12 water treatment facilities (WTF), 20+ pump stations. There are 2,500 monitoring locations from which 95,000 parameters are collected.

Water management activities include: operation, maintenance, and surveillance. There are environmental monitoring programs with supporting data management systems. Increased low-cost remote cloud-based data collection systems are being introduced. With many sites this requires some standardisation at many sites for efficiency.

Water treatment includes: acidity and metal removal techniques such as lime treatment, barium chloride which also reduces radium, and a bioreactor. Evaporation treatment is used in warmer climates, and there is one reverse osmosis plant.

Reducing water risk is a priority. Recent improvements across sites include removing the risk of working on water through removing water sample collection and pump stations on the shore instead of barges and another is installing double-walled pipe with leak detection.

4.2 Groundwater plume – leading practice and lessons

Groundwater can take many years to investigate and model. The case study discussed is from Lisbon, Utah. This was an underground uranium mine operating between 1972 and 1989. The mill and mine site have been reclaimed. The site does not have permanent personnel, visits occur for scheduled tailings and environmental monitoring and inspection.

There are some tailings impoundments which we believe have contributed to plume migration. The map in Figure 5 shows modelling of the plume migration over 70 years. To be clear, this migration is without treatment – a treatment is expected. The plume, untreated, migrates outside of the site boundary. Treatment options currently being considered include well head treatment or buy land, so it is contained.

An important point is the time it has taken to understand the plume. There have been 10 years of monitoring, field investigation and study. It will take another two years to arrive at a remedy. Once the remedy is in place, treatment is needed for potentially 10 years. The lesson here is to start monitoring beyond regulatory compliance monitoring and understand risk and impact early, understand conditions when placing overburden facilities and to make sure the cover design is robust, in theory it is required to perform forever!

There is also a lesson in methodology – new way of looking at uncertainty. The Groundwater Modelling Decision Support Initiative is a global modelling initiative that attempts to improve the approach and application of groundwater models in decisions. It does this through presenting uncertainty as a probability or the likelihood of an undesirable or planned event occurring. This allows a risk-based approach to be applied to decisions, rather than relying on a prescriptive outcome.

Ultimately with Lisbon, the good news is there is a pathway to relinquish this when agreed outcomes for groundwater, soil and construction have been met.

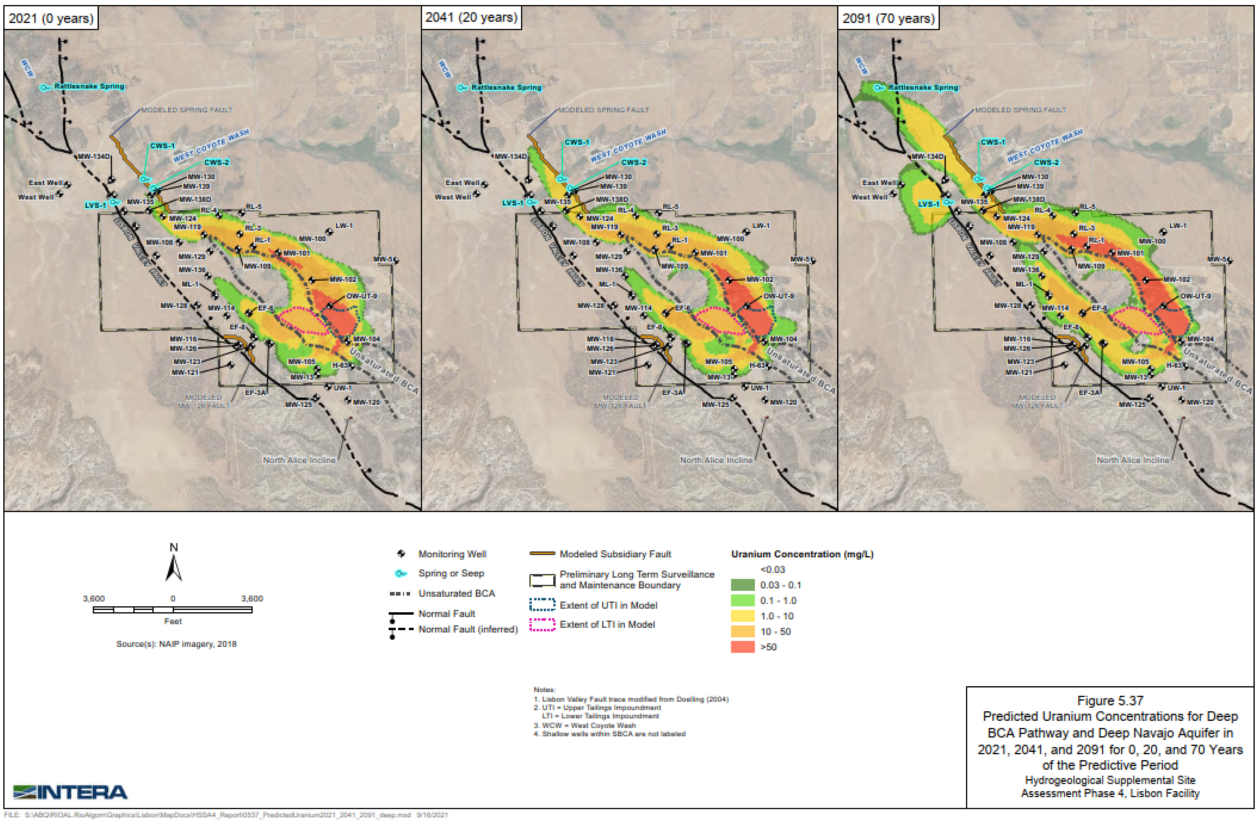

Figure 5 Lisbon Utah – groundwater plume migration without treatment

4.3 Island Copper – Canada: an innovative case study

One of our most innovative water treatment facilities is at Island Copper, British Columbia, Canada. Located on the northern coast of Vancouver Island, the former Island Copper open cut mine operated from 1971 to 1995, producing copper and molybdenum concentrates, as well as gold, silver and rhenium as by-products. After 24 years of ore extraction, the site was closed, with a large volume of water requiring long-term management and treatment.

Upon closure, the Island Copper open pit was flooded with sea water and then capped with a layer of freshwater from a nearby river. This resulted in the formation of three layers of water of different salinities within the pit, which are maintained due to their unique densities. This layered structure is used to manage and remove metals from acid rock drainage that occurs when rainwater drains off and through the nearby rock dumps into the pit lake. Treated water that complies with regulatory standards then flows from the top layer to the adjacent marine environment, as illustrated in Figure 6.

Treatment of the water in the pit lake is achieved through the biological process of phytoremediation. A low-cost liquid fertiliser is added to the top water layer of the lake year-round. The fertiliser promotes growth of phytoplankton cells, which bond to the metals and then sink to the bottom of the lake. As it sinks, the phytoplankton also provides a carbon source for oxidation in the middle sea water level, which creates low-oxygen conditions in this layer that further reduces metal concentration.

Treated water that complies with regulatory standards then flows from the top water layer to the adjacent marine environment, illustrated in Figure 6.

In 2004, an issue emerged that had the potential to jeopardise water quality. The boundary between the top and middle water layers was rising due to the continued addition of the acid rock drainage into the middle layer. If the boundary had continued to rise, a risk of release of middle layer water (not always compliant with regulatory standards for discharge) to the environment would have arisen.

The solution was an innovative in-lake water management system, called the Middle Layer Lifting System. This system harnesses the energy of downhill drainage from one of the rock dumps to draw or 'lift' water from the middle layer to the top layer in the pit. This has proven to be an effective way to maintain the boundary elevation and ensure water discharged from the site meets our environmental obligations. This pit costs one third of our lime water treatment plant at Selbaie.

The surrounding landscape was also rehabilitated to help manage mine drainage. Rock dumps were re-contoured and capped with soil, and more than 500,000 trees were planted. This has encouraged the return of wildlife to the area, including elk.

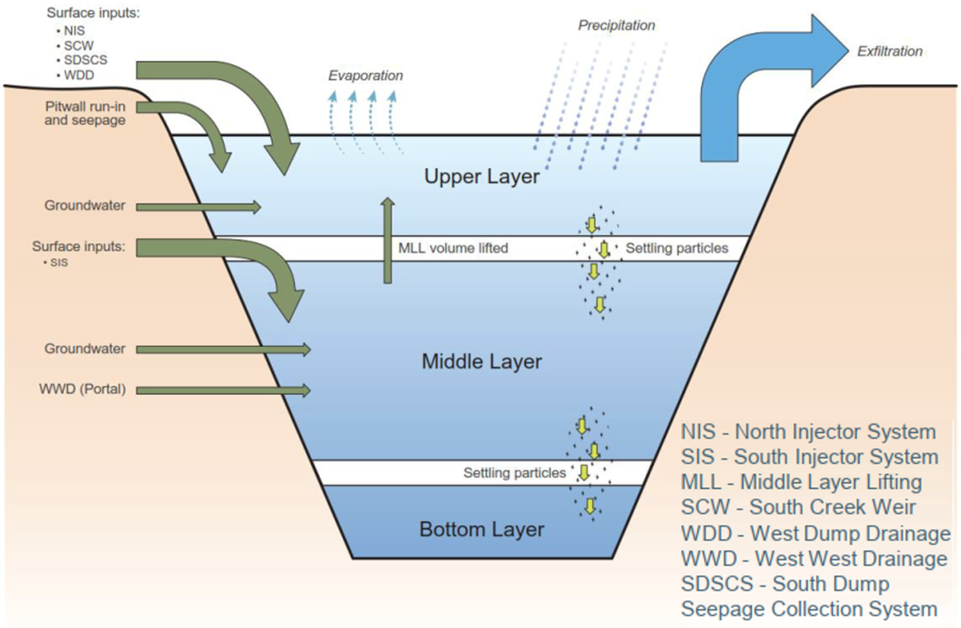

Figure 6 Island Copper water treatment using bioremediation

4.4 Water in closure – what would you do differently?

The key lessons for green fields and operational sites include:

- Regulatory compliance is never enough: regulatory compliance changes to reflect societal expectations and improved knowledge, hence achieving regulatory compliance will never be enough in a post-closure environment. Ensure impact assessments, controls and ongoing monitoring are risk based, rather than compliance based.
- Consider 'forever' in everything: all models, impact assessments, control plans should be considering the entire lifecycle of the asset, which may be forever. This provides for fully informed decision making.
- Consider the full cost, not just the discounted net present value (NPV) cost for fully informed decision making: deferral and low-cost options might make the NPV look good, but in the long run, the full cost is more.
- Identify material closure, including post-closure, risks that need to be managed during operations and build them into designs and operational plans: begin with the end in mind.
- Knowledge and data retention: knowledge is critical and must be retained for the closure and post-closure phases to avoid the requirement for rework and costly and time-consuming additional studies.

5 Stakeholders

Stakeholder engagement relating to closure before, during and after operations is essential. Beyond support for project approvals, ongoing consultation and co-operation contributes positively during operations. Repurposing ideas are best generated together to ensure sustainability post mining. Successful closure in Legacy Assets relies heavily on our corporate affairs teams. Two examples are discussed – a community repurposing and tribal engagement.

5.1 Community partnerships – repurposing for nature

In May 2022 at Elliot Lake, Ontario Canada, the 25-year anniversary of the Sherriff Creek Wildlife Sanctuary was celebrated (Figure 7). This is a shared stewardship between what is now BHP, the Penokean Hills Field Naturalists, a group of local dedicated volunteers, and the City of Elliot Lake on what was once the Milliken mine tailings management area. This fulfills our own vision of supporting the conditions for greater biodiversity and shared stewardship – returning and repurposing the land we have for greater biodiversity and shared stewardship – returning and repurposing the land we have temporarily stewarded for so long to the people who live here.

Figure 7 Stakeholder celebrations at Sherriff Creek Wildlife Sanctuary

5.2 Cultural heritage and tribal engagement

As there are sites that have been mined over 100 years ago, it cannot be assumed that sites have been assessed for areas of cultural significance. Closure activities include heritage surveys and tribal engagements. Treatments depend on the outcomes of consultations made and include recovery, preservation or protection. An important element in the work includes the use of tribal monitors. Our partners train tribal members to participate in archaeological surveys and to assist in the identification of areas of special interest to the tribes.

It is important to invest significant time to understand, be respectful, build and maintain relationships and to engage throughout the mining lifecycle to minimise impact on closure and provide for successful and agreed closure outcomes. It can be very interesting and enjoyable.

5.3 Stakeholders - what would you do differently?

The key lessons for green fields and operational sites include:

- Stakeholder engagement from the beginning needs to include closure and post-closure aspects: stakeholders understand mining is temporary and there needs to be agreement on what will be left, ensuring commitments are realistic and achievable.
- Social investment throughout the life of asset needs to consider the impact of mine closure: are we creating dependency or are we building alternative livelihoods, capacity and resilience?
- Identify material socio-economic and cultural closure, including post-closure, risks that need to be managed during operations and build them into designs and operational plans: begin with the end in mind.

6 Innovation trends in water

BHP reviewed some potentially disruptive solutions in water (Figure 8). Some common themes include a move away from lime dosing, increased recovery of freshwater from waste water and dry processing. It is important to share ideas and recovery to accelerate good outcomes. Legacy Assets has one example around evaporation and some future plans to recover value from water.

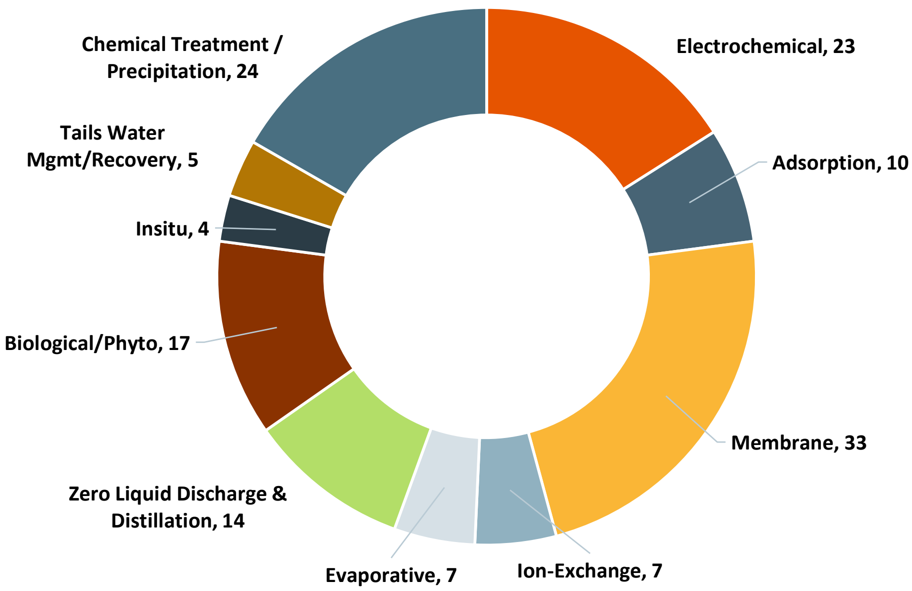

Figure 8 BHP assessment of trends in innovation for water

6.1 Evaporation

Carson Hill, California USA was an underground and open cut gold mine. The mine-impacted water includes sulphate and dissolved solids. The current treatment is through a reverse osmosis water treatment plant with the plant brine being eliminated through evaporation. The challenges include a limited evaporation season of five summer months; limited brine storage of 7 months, limited evaporation space and annual maintenance to manage the evaporation salts.

Carson Hill trialled technology called wind aided intensified evaporation (WAIV). This appears to be the first pilot study of this technology at a US mine site. Developed in Israel, there are active units in Israel and Australia. The units are created for water disposal at desalination plants with ≤100,000 parts per million total dissolved solids. It has a simple and environmentally-friendly design; it works like a 'swamp cooler'. Liquid is spread across the surface of hydrophilic 'sails' and a fan can be added to enhance airflow. The 19 × 7.6 m unit has the evaporative surface of 1.3 American football fields. Evaporate capacity is estimated at 4.9 M litres per year per unit. Figure 9 features a photo and schematic of WAIV.

The benefits site realised include reduced evaporation costs through lower labour costs, salt management, and annual geomembrane cover repairs. The system has potential year-round brine elimination. The footprint of the unit is much smaller and there is a reduced energy requirement, and it is possible to pair with solar energy. As it is modular, it can be easily expanded or moved around the site. This is an innovative technology that may provide sustainable, low-carbon, low-maintenance evaporation in a compact design.

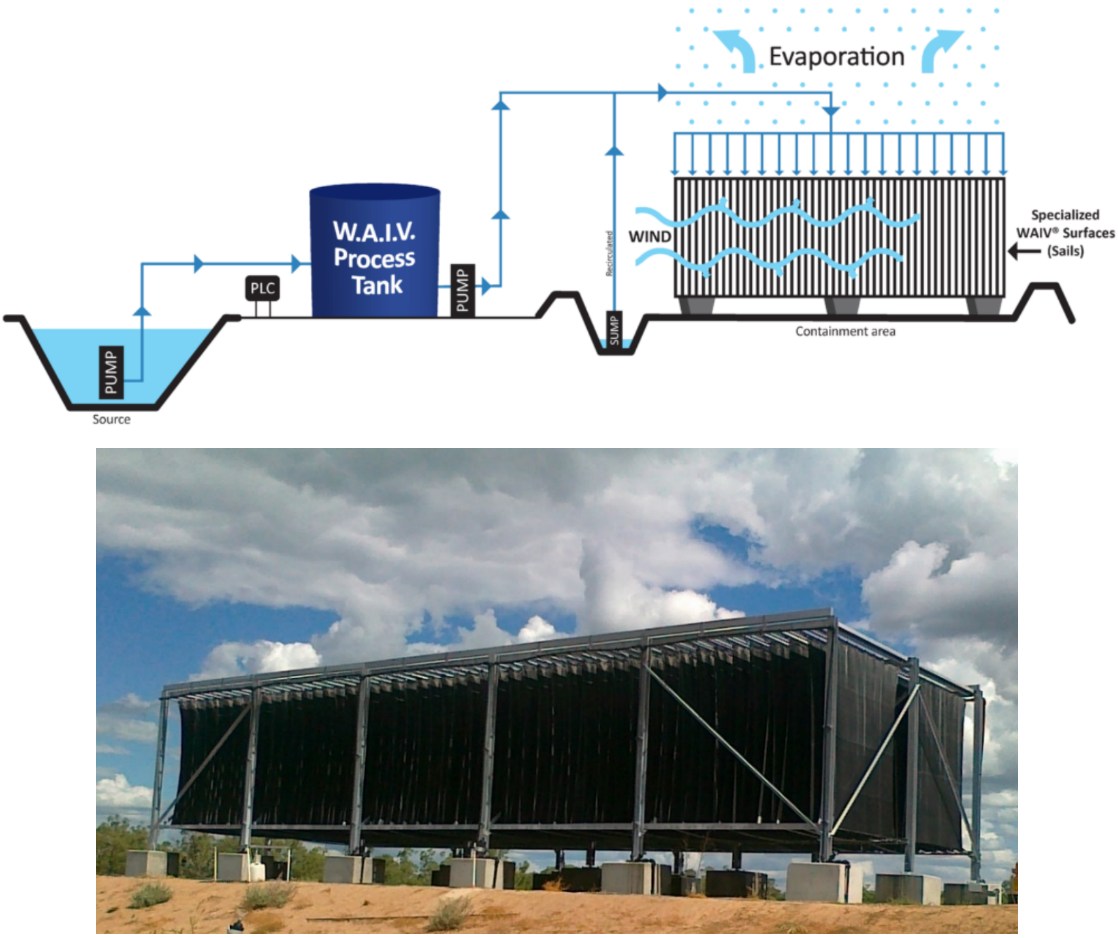

Figure 9 Evaporation pilot of WAIV technology. (a) Wind aided intensified evaporation process; (b) Full size WAIV® unit

6.2 Groundwater – resource recovery

Instead of treating impacted water as a waste, can value be generated? This question has prompted trials to evaluate potentially viable options to extract valuable inventory, such as copper, from our pit lakes.

Trials commence in the next year. Techniques will evaluate the use of traditional copper recovery technologies, such as precipitation on scrap iron, as well as innovative technologies to retrieve metals from wastes. At the copper cities site near Globe-Miami east of Phoenix Arizona, field studies will assess copper recovery efficiency as part of a greater water management and evaporation study at Deep Pit, which contains substantial dissolved copper.

Pit lakes have historically been viewed as waste to be managed. They now have the potential to generate a revenue stream and meet regulatory obligations to manage potential sources of contamination to the environment.

7 Climate change adaption

In Legacy Assets studies, climate change is a modifier. With more extreme events there is a larger range in design assumptions. Legacy Assets has a number of tailings facilities and many of them have upgraded some tailings spillways.

7.1 Tinhorn case study – remediated just in time

One example in Legacy Assets at Tinhorn, Arizona was remediated just in time, preventing site discharge (Figure 10).

Tinhorn includes a series of diversion and collection ponds with a purpose to catch the impacted runoff from leach piles and rock dumps. The facility was upgraded in 2021 and 2022. Upgrades included additional capacity, a membrane liner to the lower containment pond and diversions to reduce clean water inflow to the collection system.

Near completion, a major monsoon rainstorm hit on 13 August 2021 (5 cm inches in less than 30 minutes, a 1:100 year/24-hour storm event (two-hour event). The area received over 35 cm of rain in the 2021 monsoon season (compared to 20 cm inches all year in 2020).

The facility performed as expected: the upper pond filled with sediment (as intended) and all water was contained within the expanded and lined lower pond. Auxiliary pumping systems were put in place to help dewatering. Up-gradient diversion structures kept unimpacted stormwater out of the system. The upgrade very likely prevented an uncontrolled discharge from site. When designing for increased events it is important to consider how to prevent clean water entering impacted water facilities. This can potentially reduce design capacity and prevent clean water from being impacted.

Figure 10 Tinhorn wash Arizona – upgrading collection facilities for climate change

7.2 Climate change adaption – what would you do differently?

The key lessons for green fields and operational sites include:

- We make permanent modification to the land: these modifications must be made with consideration of forever. Design with climate change predictions in mind, build once and build right, with controls appropriate to future and extreme weather conditions. Over design early is still usually more cost-effective than replacement later.

- Assess material socio-economic and cultural closure, including post-closure, risks that need to be managed during operations with a climate change overlay, and build appropriate controls into designs and operational plans: begin with the end in mind.

8 Operational integration of closure material movement

Integration of closure considerations into operations can provide significant opportunities in outcomes and cost efficiencies. Materials handling is often the biggest cost and haulage during mining with big trucks is cheaper than very small construction trucks in closure. Planned and executed correctly, material is handled once. Perhaps material needs to be hauled over a little more distance, but it is still cheaper in the end. The paper by Sommerville & Heyes (2009) describes this opportunity in detail.

That paper details a case study the BHP Whaleback Iron Ore mine. The operation had several different overburden types – competent, less competent material that needed to be placed in layers and pyritic material (potentially acid forming) that needed to be encapsulated. The mine had also been operating for some time and there was potentially acid forming material already exposed on dumps. The additional complication was over the mine life more potentially acid forming material was being extracted and there was less inert material to encapsulate it. This was only identified through closure material inventory assessments being conducted early in the mine life and reviewed every time there was a change to the mine plan.

Two mine plans were scheduled. The first case used the shortest route for materials, with closure risk and impact control deferred until. The second case started with the end in mind and looked at the best time for source to destination materials movement. There was also an opportunity to use in-pit placement to help encapsulate. Starting with the end in mind indicated an opportunity to save 8% in haulage costs to do closure progressively.

Progressive closure also helps the mine to prove the concept of closure and allows a longer time to monitor closure performance; both of which build trust internally and externally and improves the confidence of closure scopes and associated cost estimates.

Challenging the planners to compare scenarios like this for all material closure scopes can generate solutions that benefit operations and closure outcomes. It is also important to understand water, soil and other closure parameters earlier to enable shorter lead times for closure execution and transformation to the next site land use.

9 Managing change

Change will happen in closure: climate change, new information, new technology, events like tailings failures that highlight new lessons, and changing societal and regulatory. With 23 sites and limited funding, triage is required to decide what is important, where the risk lies and what needs to be given priority. In some cases, such as Miami Avenue, an extensive study was not required – the remediation solution was straightforward. In other cases, such as Old Dominion, more study and community consultation will be required.

9.1 Miami Avenue, Arizona tailings – just do it

The Miami Avenue tailings facility in Arizona contained approximately 320,000 m^3 of tailings that were deposited between 1920 and 1921. It was classified as extreme as per Canadian Dam Association guidelines. Options included stabilisation or relocation. There was an opportunity to relocate it to a nearby open pit. Other than material movement project estimation, little investigation was done. The project started in 2019 and within 2.5 years the tailings was moved, and the risk removed.

9.2 Old Dominion tailings – social and environmental change challenges

Old Dominion tailings remediation involves social and environmental aspects. Old Dominion in Arizona was an underground copper mine that operated from 1880s to 1930s. It includes three tailings storage facilities. The area has been repurposed to a historic walking park. The community values the park, and it is a fabulous piece of mining history. The site is fully closed and rehabilitated to state and federal standards but has not received official release from all regulatory obligations. Engagement with the community on the park closure and future is underway. As the volume and remediation solutions are potentially costly and less is known about the tailings and contamination, time is needed to investigate and propose remediation.

9.3 Managing change – what would you do differently?

In managing change be honest and transparent about what is known and unknown. Talk about uncertainty and risk. Be outcome focused. Make sure outcomes are sustainable and long-term impacts and costs are understood. Too many times the lower cost solution has high long-term operating costs or impacts. Manage stakeholder expectations and have diverse professions to think in an integrated manner. Operations may not want to do execute activities in case requirements change – but if great work is done in operations, if sites are understood – just not from closure landforms, but surface and groundwater, soils, stability, social impacts, and repurposing ideas, there are greater opportunities for effective outcomes. Table 1 summarises change management in closure.

Table 1 Managing change in closure

To do when managing change	Avoid when managing change
Confirm what you do and don't know	Doing nothing – especially in operations
Dynamic – agile	Starting too late
Honest and transparent	Shortened horizons for remedies
Risk versus compliance mindset	
Range analysis	
Don't always need to study	
Take the longer-term view	
Solve for now and consider long-term impacts and costs	
Solve as an integrated team	
Align studies with outcomes	
Manage stakeholder expectations	

10 Closure is multi-disciplinary

Closure is multi-disciplinary and is a process not an event. Closure plays an important part at every stage of the lifecycle. It requires many disciplines to help imagine and plan the future, the legacy the site wants to leave.

Compared to mining operations Legacy Assets may have greater expertise in areas of closure, environment, hydrogeology, and hydrology. There are more dam engineers. There is daily engagement with legal and corporate affairs. Excellence is required in projects and execution as there is no revenue – money is given to take risk out of the business. Reliable data and land systems guide our decisions and keep records of commitments and site knowledge. Skills are needed in innovation, commercial agreements, working with regulators and getting permits. A safety and health team supports the operations. Budgets and business plans need to be done like every other operation. Trades and operators maintain infrastructure on sites. Outside of the closure team, the wider corporate and industry network assist. Community and stakeholder engagement will potentially unlock more ideas for repurposing in the future.

11 Conclusion

Integrated closure requires mines to keep records and understand of commitments and site knowledge, and to know and assess early in the mine life about land, soil, air, and water is vital. This allows sites to more effectively mitigate long-term impacts. Community engagement for consultation, repurposing and cultural heritage protection can also vastly improve outcomes and the sustainability of those outcomes.

The best time to implement this is before the mine even starts. It should be an integral and robust part of each mine's plan. A good challenge is 'If you had this mine in perpetuity would you do something different? Show me a plan where you could walk away with everything remediated a few years after the last ore is milled'.

The prize for our industry if we are excellent at finding the best outcome for each site is that mining companies can continue to mine and help build a better world. It is possible to reimagine our legacy – be it divesting, relinquishing, repurposing or getting it right so the asset is safe, stable, non-polluting, and low impact. It takes a village, and it starts today.

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