Mine Closure 2025 – S Knutsson, AB Fourie & M Tibbett (eds)

doi:10.36487/ACG_repo/2515_46

Bats, bunds and very old bones: navigating ecological, community safety and heritage challenges in closing legacy mines

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Abstract

In response to increasing pressure to bolster resources and reserves, and fuelled by strong commodity prices, market speculation or other factors, a mining company sometimes take ownership of a legacy mine and its liabilities from another company. Depending on its age and history, the mine may have an approved closure plan in place, but this is not always the case. Indeed, it's common for legacy mines to be acquired with little or no site data, forcing closure practitioners to effectively become forensic scientists to piece together a site's history and closure risk profile. If a closure plan exists, it may not meet current regulatory or other requirements. Even when rehabilitation has been conducted historically, the standards and practices of the day may not reflect the expectations of today.

If a legacy mine is to be re-opened, a closure plan can be developed according to contemporary standards, though it is recognised that closure outcomes might realistically be less than desired. Achievement of acceptable closure outcomes will also be constrained if a legacy mine moves to closure without going back into production. So what happens next?

Taking responsibility for closing and transitioning a legacy mine can pose significant practical, financial and reputational risks, so it's important to adopt a strategic approach to site acquisition and closure planning for an acquired mine that takes into account the practical limitations and opportunities associated with a site and looks for innovative solutions. However, this can be difficult to do, especially as the complexity of closing legacy sites is usually only realised after completion of additional studies. Consequently, it is important to share experiences of success and lessons learned in this regard. This paper draws on international case studies to discuss key ecological, public safety and heritage challenges associated with closure of legacy mines and explore processes that can be used to achieve the best possible post-mining outcomes, along with practical suggestions on addressing challenges that can't be fixed.

Keywords: *legacy mines, closure strategy, closure outcomes, social-ecological resiliency, cultural heritage*

1 Introduction

The term "legacy mine" is often used as an umbrella term which encompasses a range of historical mines, including those that have been abandoned or orphaned, or are derelict. Where mining titles or leases no longer exist for these sites, responsibility for their management and closure may have transferred or defaulted to government or another third party. However, legacy mines also include historical and inactive mines that remain under private ownership. These include sites at which planned closure has commenced but may not have been completed; sites on care and maintenance which could re-open at some point; and sites that shut down before the planned end of mine life (unplanned closure) and at which closure works may not have occurred, in part or in full.

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Legacy mines under private ownership are sometimes acquired with an intent to re-open or redevelop the site. However, there are times when a legacy mine moves to closure without going back into production which can constrain achievement of acceptable closure outcomes due to engineering, financial or other limitations. So, what happens next?

This paper provides an outline of mine acquisition processes and discusses some of the ecological, community safety and heritage issues associated with legacy mines, along with suggested processes to achieve the best possible post-mining outcomes. In addition, it provides some practical suggestions on managing legacy mine challenges that can't be fixed.

2 Mine acquisition

The mining world is ever-changing, driven in part by mining acquisitions. According to industry analytics by GlobalData, there were 754 acquisitions in the global mining sector in 2024 totalling USD 99.73B, which marks a 4% increase since 2023 (Jenns 2024). These transactions not only reshape company portfolios but also underscore key trends such as the growing focus on critical minerals and regional consolidation (Costmine Team 2025). While mining companies continue to face increased scrutiny from investors on how investment is deployed, a recent survey by EY (one of the 'big four' accounting firms) found that all of the mining and metals companies that responded to the survey planned to undertake some form of transaction over the following 12-month period (Mitchell 2024).

Mining companies acquire other miners or their portfolio of assets for a host of reasons, including bolstering resources and reserves, strong commodity prices, diversification of commodities or geographies, synergies and consolidation for great value, access to new technologies, increased market share or elimination of competition, economies of scale, risk reduction, market speculation or opportunism, and other factors (Palmer 2024; Patel 2024). The sale of these companies or assets may be voluntary or involuntary (for example, in cases of bankruptcy).

While data are available on the number of abandoned mines in countries such as Australia (see, for example, Government of Western Australia 2021), Canada (Government of Canada n.d.) and the United States (Office of Surface Mining Reclamation and Enforcement n.d.), it is harder to obtain data on the number of inactive and legacy mines that are still owned by private companies and therefore could be subject to transfer as part of mine divestment/acquisition. However, Werner et al. (2020) indicate that 89% of mines in Australia can be classified as inactive and that 68% of these are classed as neglected. With such a high percentage of inactive mines that are presumably still under some form of private ownership, and assuming similar levels of occurrence in other jurisdictions, there is a reasonably good chance that mine divestment/acquisition processes will result in the transfer of legacy mines. Indeed, transactions that strengthen a company's portfolio inevitably include some sites that are either economically unviable in their current form or were closed by their previous owners, but further closure works are needed. In acquiring these sites, the new owner usually assumes responsibility for closure, remediation and rehabilitation (Latham et al. 2024).

Prior to making the decision to acquire a mining project, a company needs to take all reasonable steps to ensure that its business decision is based on accurate and comprehensive information including the profile of risks and opportunities. Due diligence is essential to ensuring that major business transactions are robust, transparent and defensible, and requires a focused, balanced and adequately resourced technical appraisal and valuation process conducted by a multidisciplinary team (Greenwich Capital 2025). Although international due diligence guidance is largely silent on the inclusion of mine closure considerations (Leahy & Farrer 2023), these need to be assessed as closure risks, opportunities and costs can affect the transaction value and potential for return on investment.

As with all processes, there are limitations to the due diligence process, but it is important to ensure that a review be conducted of available closure plans and associated information including the closure risk register and closure liability estimates, along with the cost of community investment, and the residual environmental, social, financial and reputational risk and opportunities, and for these to be incorporated into the business case for acquisition which forms the basis of investment decisions (Latham et al. 2024). Depending on its age

and history, a legacy mine may have an approved closure plan in place along with a detailed closure cost estimate, but this is not always the case. Indeed, it's common for legacy mines (particularly very old mines) to be acquired with little or no site data, forcing closure practitioners to effectively become forensic scientists to piece together a site's history and closure risk profile. If a closure plan and cost estimate do exist, they may not meet current regulatory or other requirements. Even when rehabilitation has been conducted historically, the standards and practices of the day may not reflect the expectations of today. A known pathway for asset relinquishment and transitions reduces business risk (Latham et al. 2024), but can be unclear for legacy mines, particularly those without an approved closure plan.

Taking responsibility for closing and transitioning a legacy mine can pose significant practical, financial and reputational risks (Armstrong et al. 2023) so it's not a decision to be taken lightly. However, once a legacy mine site has been acquired, it is usually expected that a closure plan will be developed or updated according to contemporary regulatory requirements. The content of that plan will depend on what the new mine owner intends in relation to the future of the mine. If there are plans to operate the mine in the foreseeable future, or if the mine is placed and care and maintenance pending a decision to proceed to operations, there is likely to be an opportunity to integrate mine planning and closure planning in a manner that addresses historical disturbances as well as future disturbance. However, there are many examples where a mine proceeds to closure without returning to operations. For example, BHP has 23 legacy sites in North America, most of which it acquired in transactions but never operated (Ayres 2023), while Rio Tinto currently manages 45 legacy assets in France alone (Latham et al. 2024). Regardless of whether a legacy mine recommences operations or goes to closure without first going back into production, it is important that closure planning takes into account the practical limitations and opportunities associated with the site and looks for opportunities for innovation. However, it is possible that sites may end up being managed by a mining company or other organisation for very long periods and possibly in perpetuity (see Section 5).

3 Ecological, public safety and heritage challenges

3.1 Overview

The ecological, community safety and heritage challenges associated with a legacy mine will depend on the location, context, scale and characteristics of the site, the condition of the mine when site activities ceased, the standard of management that occurred during operations, and the environmental and other events that have occurred at the mine since cessation of operations, including authorised and unauthorised activities. Effective management of these challenges requires characterisation of hazards and specification of risks and opportunities to achieve agreed or desired closure outcomes (Armstrong et al. 2023), but there may be a lack of knowledge about the previous operations and resulting environmental and social impacts, and/or current conditions, which makes it difficult to identify and rank closure and rehabilitation risks and opportunities (Werner et al. 2020). Where information exists, there may be inconsistencies in methodologies used for collection and analysis of data, differences in prior and current regulatory requirements, and changes in stakeholder expectations (Armstrong et al. 2023).

A primary objective when planning closure of a legacy mine is to ensure public safety and install safeguards around hazardous areas, but it is also vitally important to protect wildlife habitat and cultural resources, a process which takes a holistic approach to conservation (Bat Conservation International 2024). Examples of ecological, public safety and heritage issues and challenges associated with legacy and other types of historical mines are provided in Table 1, with selected issues discussed in Sections 3.2–3.4.

Table 1 Potential ecological, public safety and heritage challenges associated with the closure of legacy mines

Issue	Examples of potential challenges
Ecological	• Impacts on flora and fauna assemblages and habitats due to erosion and sedimentation, changes in groundwater quality and quantity, loss of waste containment (including tailings), dust lift-off from disturbed areas (including dust from tailings contaminated with heavy metals), leakage of pollutants from waste disposal facilities including waste rock dumps, tailings storage facilities, landfills, etc. (Bell et al. 2001; Pepper et al. 2014; Bennett 2016; Salmi et al. 2022) • Habitat fragmentation (Ashby & van Etten 2021) • Loss of soil and/or changes in soil structure, chemistry, biota and processes (Bennett 2016) • Colonisation of mine structures by fauna, including protected bat and other species (Hall et al. 1997; López-González & Torres-Morales 2004; Moran et al. 2023; Bat Conservation International 2024) • Loss of biodiversity due to poor rehabilitation outcomes (Pepper et al. 2014; Ashby & van Etten 2021) • Introduction and/or spread of weeds, pests and/or pathogens (Ashby & van Etten 2021)
Public safety	• Injury or death due to the presence of hazards such as unsecured shafts and tunnels, steep open pits, pit lakes, deteriorating infrastructure, and unstable slopes and surfaces (Pepper et al. 2014; Bennett 2016; Salmi et al. 2022) • Subsidence or collapsing ground (Bell et al. 2001; Bennett 2016; Salmi et al. 2022) • Asphyxiation in enclosed spaces (Mai 2023) • Contamination of drinking water sources or irrigation water due to acid generation, metals mobilisation, etc. (Bennett 2016) • Contamination of crops by airborne or waterborne pollutants (Ashby & van Etten 2021) • Exposure to heavy metals, radioactive substances and/or fibrous materials (Bennett 2016; Cornelissen et al. 2019; Ashby & van Etten 2021)
Heritage and cultural values	• Increased awareness of, and potentially ease of access to, heritage sites, coupled with the reduced protection of these sites without a site presence (author's own experience) • Loss of sense of place and exclusion from environmental management of traditional lands (Boulot & Collins 2023) • Changes to the ability to utilise land post-closure for cultural and other purposes (Barnes et al. 2020; Boulot & Collins 2023)

3.2 Bats and other ecological issues

Even though a mine has ceased operations does not mean that things stand still at the site. Indeed, it's quite common for legacy mines to provide habitat for fauna species and it appears that the fauna species most studied in this regard are bats. Depending upon location, airflow, temperature, humidity and other factors, bats may use different portions of a legacy mine for roosting and foraging, and hibernacula (a place for bats to hibernate in winter) (Burghardt 2003; López-González & Torres-Morales 2004; Moran et al. 2023).

Bats generally prefer adits to shafts, with the more complex mines often being the more valuable as they provide a range of microclimates (National Parks and Wildlife Service 2001).

Many bat species rely on abandoned and legacy mines for habitat, especially where their natural habitat is threatened (Gonsalves et al. 2021). For example, approximately one third of Australia's insectivorous bat species are known to rely on mines (Hall et al. 1997) and a strong association of bat species with habitat features provided by abandoned and legacy mines has also been recorded in the US (National Park Service 2022; Moran et al. 2023) and in Mexico (López-González & Torres-Morales 2004). Consequently, efforts to close and rehabilitate these mines are a potential threat to bat populations (Burghardt 2003). While it might be tempting to use this as a reason to leave mine features used by bats unrehabilitated, these pose public safety hazards as well as risks to larger species of wildlife and livestock, so effective closure strategies that limit public access while allowing utilisation by bats are needed. One popular method to mitigate loss of bat habitat when historical underground workings are closed is to install bat-compatible closures such as steel gates or grates (Moran et al. 2023), though responses vary between species (Tobin et al. 2018; Gonsalves et al. 2021).

While there exists a significant volume of literature on the ways in which bats utilise and benefit from legacy or other historical mines, the importance of these to other wildlife is less well understood (Moran et al. 2022; Grajal-Puche et al. 2024). Noting that complete ecosystem recovery relies on key trophic interactions involving fauna, rehabilitation programs must consider the requirements of fauna groups that promote long-term, functional, biodiverse fauna assemblages (Cross et al. 2022). Key to this is understanding the behavioural responses and movement ecology of animals within landscapes undergoing rehabilitation (Cross et al. 2020a). Monitoring of 50 abandoned mines in Colorado in 2017–20 by Armstrong et al. (2022) recorded more than 48 vertebrate species at these sites, with fauna visitation observed throughout the day and night. This study found that the mines were used for shelter (particularly among the smaller species such as mice, voles, woodrats and squirrels), food sources including seed traps, sources of minerals at surface or dissolved in water, and reproduction. Further, these sites acted as information centres for communal scent-marking areas for pumas, bobcats, American black bears and common grey foxes (Armstrong et al. 2022).

The information presented above raises the question of what happens to the fauna resources at a legacy mine when a mining company implements mine closure and rehabilitation? Further, will the company be doing more damage than good to fauna habitat in actively rehabilitating a legacy mine, particularly if it's inhabited by threatened or endangered species?

It is important that the risk of closure and rehabilitation activities on the fauna resources associated with legacy mines and the species that use these resources is not underestimated, but also that a mining company's capacity to implement effective site rehabilitation and the recreation of fauna habitat is not overestimated. It is not uncommon for companies to include closure outcomes and criteria relating to fauna return to rehabilitation areas in their mine closure plans, but these are often based on the assumption that fauna species will passively return once native vegetation has been reinstated (Cross et al. 2020a). Indeed, a study of the presence of monitor lizards (varanids) in rehabilitated sites by Cross et al. (2020b) has shown that fauna presence in rehabilitation areas may not indicate persistence. Although evidence of monitor lizards in rehabilitation areas was recorded, it was found that there were significantly fewer signs of varanid presence in rehabilitation areas than reference bushland. It was concluded that this was because rehabilitated landscapes, particularly those in early successional stages, usually lack established vegetation cover and present increased metabolic costs and higher predation risks so were not being used by prey species. Consequently, predator species such as monitor lizards were only traversing, not persisting in, rehabilitation areas (Cross et al. 2020b).

While the use of rehabilitation areas as transport corridors illustrates the role that they play in connecting habitat fragments, it also demonstrates that signs of fauna presence in rehabilitation areas does not necessarily translate into long-term sustainable utilisation. Providing fauna refuges (e.g. hollow logs) to mitigate the metabolic costs and predation risks in areas undergoing restoration may aid in facilitating the return of varanids and of other animal populations, particularly during the early stages of vegetation

establishment, but complete ecosystem recovery relies on key trophic interactions involving fauna, so rehabilitation programs need to consider how to promote long-term, biodiverse and functional fauna assemblages (Cross et al. 2022b).

3.3 Bunds and other public safety needs

Legacy mines are inherently dangerous places and there is a high risk of injury or even death when these are accessed without appropriate authorisation and controls. Safety hazards at legacy mines include the presence of open pits with unfettered access; unsecured shafts and tunnels; unstable structures that could collapse without warning; and enclosed spaces with asphyxiation risks due to the presence of carbon monoxide and methane. Further, environmental issues such as acid drainage or other forms of contamination may also pose risks to human health (Government Accountability Office [GOA] 2020). Despite attempts to prevent public access, many legacy mine sites report regular public access for mountain biking and other recreational activities (Harrison & Kiejda 2022).

It is important that public safety risks are assessed during due diligence processes and that allowance is made for appropriate controls in the business case for acquisition. If the legacy mine is likely to re-open and further site operations occur, there is an opportunity to implement safety controls ahead of and during operations, and for the cost of these to be incorporated into the site's capital expenses and operating budget. However, if a legacy mine proceeds to closure without going back into production, risk assessment and prioritisation are required to identify key risks that require immediate attention.

3.4 Very old bones and other heritage issues

Legacy mines can include remnants of a bygone era that offer a tangible connection to the innovation and hard work that shaped modern societies and provide insight into other aspects of community life, including customs and traditions, technical knowledge and other features (Sánchez-Dajlala et al. 2025). For example, Britain's largest and only open Neolithic flint mine (Grime's Graves) comprises a labyrinth of tunnels and shafts dug around 2650–2500 BC and which were in use at the same time that Neolithic people were constructing monuments such as Stonehenge and Avebury (English Heritage 2024). The risk of losing these features and the stories they tell when the mine is decommissioned and rehabilitated is a topic of growing concern in the field of heritage conservation, where the focus is on environmental aspects rather than cultural aspects (Sánchez-Dajlala et al. 2025).

Creativity is required to transform environmental liabilities into cultural assets, but adaptive re-use is a valuable tool to achieve a balance between environmental conservation, urban regeneration, cultural heritage protection and financial investment (Sánchez-Dajlala et al. 2025). We need to understand how local communities perceive the heritage value of legacy mines and consider how best to address these values, if possible, in a mine closure plan. However, this is not to say that legacy mines should remain unrehabilitated or that preservation of mining heritage should take priority over site remediation, or that all historical mines warrant preservation.

The Monarch Mine is located at Francistown, Botswana, and provides an opportunity to step back to the period 1100 to 1400 AD. Gold was discovered and worked during this period by predecessors of the BaKalaga, who were included within the society of the Great Zimbabwe culture when this was at its zenith. The mining area was rediscovered in 1889 and named the Monarch Mine, with surface and underground mining and mineral processing occurring on a discontinuous basis until the mid-1990s (Lewis 2001). With its long history and proximity to Francistown, it could seem logical that the mine be declared a heritage site and ultimately a tourism attraction, but this is unlikely to occur as the archaeological features at the mine that could have been used to classify it as a heritage site were modified or destroyed by mining and there are safety concerns regarding the underground workings (Kologwe 2022). Further, elevated heavy metals levels have been detected in soils at the mine, along with the risk of exposure to livestock and humans, making a tourism or similar post-mining land use unlikely at this stage (Manyiwa et al. 2023).

From time to time the presence of very old bones and other non-mining artefacts at a legacy mine also provide the impetus to maintain the site, in part or in full, for heritage and/or tourism purposes. For example, the presence of a significant fossil of a large marine reptile in Rio Tinto's Le Thoronet pit in the Provence Alpes Côte d'Azur region of France has led to a commitment to create an eco-park at the site (Latham et al. 2024). First Nations' cultural values can also drive decisions regarding post-mining land uses, closure designs, closure implementation and other aspects. It is recognised that First Nations' cultural and environmental values are closely aligned and that effective engagement with traditional owners is key to incorporating these values into closure and rehabilitation programs (Kemp et al. 2023), along with opportunities for co-creation of landform designs and "hands-on" involvement in closure and rehabilitation works (Barnes et al. 2020). See Section 4.4 for further discussion.

4 Processes to achieve the best possible post-mining outcomes

4.1 Balancing current expectations with past practices

Mine closure planning processes have evolved significantly over the past few decades and mining companies are encouraged, and sometimes even pressured, by regulators and other stakeholders to ensure that closure of legacy mines meets contemporary regulatory and other relevant standards. However, this is not always possible, and companies can find themselves trying to balance current expectations with the practicalities of closing a mine that was designed and operated in accordance with past practices that are no longer considered adequate. Consequently, a pragmatic approach is needed that balances the benefits and costs of closure strategies and options. One such approach is a closure feasibility study.

In mining, feasibility studies are typically completed to allow companies to make decisions regarding capital investment and other aspects of project development. These structured and often gated processes guide projects through design, construction and operations in a way that manages risk, secures investment and ensures project delivery. Mine closure feasibility studies are not simply development studies in reverse, but also aim to manage risk, secure funding and ensure delivery (Globalscapes 2024). A well-designed and executed feasibility study is a powerful tool in identifying and managing closure risks and opportunity, and allows a mining company to develop, and subsequently refine, a closure execution scope, schedule and costs based on those risks and opportunities. They also provide a holistic structure to investigate the practicality of closure options including application of the best practicable technologies and innovations. If the expected benefit of a closure strategy or option is commensurate with cost, this can be implemented and its success measured against the performance objectives established during the feasibility study. However, if there are no justifiable rehabilitation, remediation or other closure options for a site (or portion thereof) based on the benefit versus cost, then alternative risk management options that could reduce the risk as low as reasonably achievable need to be developed (Webster 2011).

4.2 Prioritising key risks

There are instances where previous management and the existing condition of mining and processing features facilitate their closure. For example, Berthelot et al. (2019) reports that the robustness of the original design criteria and objectives enabled tailings facilities at the legacy Elliot Lake uranium mines in Ontario, Canada, to meet current expectations through supplement investigations and studies without significant physical modifications to those facilities. However, as discussed by Ayres (2023), not all sites developed and/or closed in the past are well positioned post-operations when we apply a modern set of optics. For these sites, Ayres (2023) recommends that closure-related decisions be based on risks, not solely on regulatory compliance.

There are numerous risk assessment guidelines available, along with numerous examples of risk-based assessments, to determine remediation, rehabilitation and closure of legacy mine hazards, including the Porcupine Camp case study discussed by Sulatycky et al. (2011). This is of relevance to this paper as Porcupine

Camp, which is also located in Ontario, comprises a large land package of amalgamated historical mines sites resulting from decades of mergers and acquisitions.

The Porcupine Gold Rush started in 1909 and by 1929, the Porcupine mining district had become a major player in the global industrial mining industry (Jorgenson 2018). However, the cyclical highs and lows that are typical of the mining industry saw many small companies consolidate, merge and even abandon their mines, leaving legacies for future generations (Sulatycky et al. 2011). As a result, when Goldcorp acquired 51% of the Porcupine Joint Venture from Placer Dome in 2006, the company inherited a rigorous requirement to rehabilitate historical mine hazards including deteriorating infrastructure, contaminated soils, dozens of tailings deposits, and hundreds of mine shafts, raises and open stopes which presented risks to the public and the environment (Sulatycky et al. 2011). Consequently, a risk-based exercise was conducted to prioritise mine hazards at these mines, and a program of reclamation and rehabilitation works was undertaken. These are described in detail by Sulatycky et al. (2011) so are not repeated here but, in summary, they have included stabilisation of mine openings to prevent inadvertent access by the public, and physical and chemical stabilisation of tailings facilities.

The Porcupine acquisition trail did not stop with Goldcorp, with the operations then transferring to Newmont Mining Corporation and now transferring to Discovery Silver Corp (Discovery Silver Corp 2025). However, this has not stymied the ongoing rehabilitation of legacy mining features at Porcupine, with Newmont Mining Corporation (2025) reporting that dozens of historical mining properties are being reclaimed so that the land can be used productively by local communities, and Discovery planning to invest significantly in site restoration and progressive rehabilitation to ensure that all sites are properly remediated and are available for future use by the community (Discovery Silver Corp 2025).

4.3 Stakeholder engagement and consent

A strong and consistent theme in recent literature on stakeholder involvement in closure planning focuses on the importance of a consultative and collaborative relationship with external stakeholders built on a foundation of respect, trust and transparency. Not only is this a central feature of good practice guidelines such as the International Council on Mining & Metals (ICMM) Integrated Mine Closure Good Practice Guide (ICMM 2025), but there is increasing reference to this in the literature. For example, within this International Mine Closure Conference series, 17 papers presented at MC24 referred to some form of collaboration, up from 11 papers at MC23 and eight papers presented at MC22. These include examples from around the globe, including Canada (Kuzyk et al. 2023), France (Latham et al. 2024), Australia (Malan & Murphy 2024), Mongolia (Myagmarsuren et al. 2023) and Indonesia (Rahma et al. 2024). However, for most legacy mines, this dialogue has usually paused or ceased while the mine has been inactive. Depending on when the mine ceased operations and what consultation had occurred previously, there will be a need to commence or recommence stakeholder engagement following mine acquisition. This is likely to include a range of stakeholders, including traditional owners or First Nations peoples. Enabling indigenous input into closure and rehabilitation planning not only demonstrates respect for local knowledge and connection to country; it's also an important step in returning stewardship of the land and reconnecting people to place, especially if the mine was developed against the wishes of traditional owners. One mechanism for obtaining this input in planning the closure of legacy mines is co-creation of designs and plans for closure and rehabilitation, as discussed below.

4.4 Co-creation of closure and rehabilitation designs and plans

Kemp et al. (2023) state that, to be habitable, mine rehabilitation requires the restoration of cultural values as much as environmental and economic values, recognising that indigenous cultural values and environmental values are often closely aligned. However, some legacy mines are quite old and, depending on the age of the mine, may pre-date legislative and other drivers to identify a heritage site and investigate cultural values, so this information may not be available. This became apparent when a mine closure plan for an Indonesian gold mine that had been approved by the Indonesian Government in the 1990s was being updated to meet the requirements of the (at that time) newly introduced Indonesian Law Number 4 of 2009 on mineral and coal

mining (Government of Indonesia 2009). This legislation required that post-mining activity be completed to restore both environmental and social functions according to local conditions, though the focus was more on environmental restoration and ecosystem function (Setiawan et al. 2021) than the return of cultural or other social values. During plan preparation it became evident that some of the local community members were very concerned about the way in which a particular section of the mine's main access road would be rehabilitated. This level of concern was unexpected as rehabilitating that portion of road was not expected to be particularly challenging, but through further discussion it was found that local custom considered this specific part of the road to be a point at which the spirits of the departed crossed from this world to the next, and that the presence of the road had stymied this journey. Consequently, it was important to them that the road be removed and the land rehabilitated in a way that would once again allow the passage of spirits to the afterworld at that point. This topic had not been raised previously with the closure planning team so had not been addressed in the mine closure plan, despite its apparent cultural importance.

Interestingly, while subsequent Indonesian regulation (Government of Indonesia 2014) also requires that post-mining activity needs to restore the function of both the natural environment and social function according to local conditions, it also specifies that a closure plan be based on an approved feasibility study and environmental impact statement (Government of Indonesia 2014). While reference to this documentation provides additional guidance, it is possible that cultural value knowledge gaps will persist if the approved feasibility study and environmental impact statement pre-date contemporary requirements or do not provide the necessary information.

Even when baseline data on cultural values have been collected, it appears that few jurisdictional guidelines require consideration of these in planning mine closure beyond indigenous and stakeholder engagement. For example, in their review of indigenous engagement in mined land closure and rehabilitation in Australia, Bond & Kelly (2021) were unable to locate any guidelines for inclusion of Aboriginal and Torres Strait Islander communities in the co-design of final landforms. In addition, they found that existing instruments for indigenous engagement about, and involvement in, mining projects commonly focus on the construction and operational phases of a mining project and do not necessarily extend to the closure and post-closure phases. However, indigenous people can play a meaningful role in the co-creation and implementation of rehabilitation as well as the post-closure use and management of mined land located on their country. Indeed, Bond & Kelly (2021) identify that co-creation of the post-mining landscape by mining companies, governments and indigenous communities in a robust and meaningful way is seen as having the highest potential to both imbue final landforms with cultural values and significance (e.g. culturally appropriate amenities), and to realise localised economic opportunities (e.g. local content). Consequently, they have called for a proportionate application of stakeholder engagement at the end of mine life to support Australian indigenous intergenerational cultural practices, songlines and values. Further, they have suggested that a meaningful process include deep and sustained engagement as well as adequate funding to ensure proper landform design, appropriate sequencing of flora and fauna reestablishment, and reincorporation of mined land into culturally and spiritually relevant songlines (which are also known as dreaming tracks) about country.

Co-creation of landform closure designs is particularly relevant to songlines in Australian indigenous culture. Songlines are effectively oral maps of the landscape which connect different people and sacred sites and enable transmission of oral navigational skills in cultures that do not have a written language. Songlines can extend for long distances across Australia and are often mirrored by songlines in the sky, enabling use of the sky as a navigational tool; both as a compass and a mnemonic to remember the songlines on the ground (Norris & Harney 2014). Consequently, they are important in linking the oral history that maps culturally rich navigational and agricultural wisdom to the land and seascapes cared for by Aboriginal and Torres Straits Islander people (Bond & Kelly 2021). However, in their review, Bond & Kelly (2021) could not locate any accommodation of cultural values associated with songlines in planning final mine landforms.

In relation to the incorporation of cultural values into mine closure and rehabilitation, Jones & MacLean (2013) state that "what must be critically assessed is how the proposed land uses of the reclaimed landscape will provide the resources required to meet the end user's values of the land". This requires a thorough assessment of the cultural values of the people who may have used the landscape prior to mining and will

use the landscape following mine closure and transition to the next land use, along with an understanding of those ecological components of the landscape that provide the services to support these values.

4.5 Leveraging additional resources

As discussed in Sections 4.3 and 4.4, the expectation that mining companies will engage and collaborate with local communities and other stakeholders in the design and delivery of mine closure projects is steadily increasing. However, Alonzo et al. (2024) note that there are competing conceptualisations on how to work with local communities in rehabilitating legacy mines, and the interplay of people, policies, processes and other factors could either support or hinder a local community's involvement in legacy mine rehabilitation.

Much of the literature relating to community collaboration in closure planning and implementation focuses on successful collaborations with indigenous groups on a voluntary basis or through rehabilitation and other services provided under commercial contracts (Barnes et al. 2020; Alonzo et al. 2024; Keeling & Potvin 2025). Participation in these programs provides many benefits including the opportunity to be involved in work that is meaningful to indigenous people as custodians of the land, share indigenous ecological knowledge, repair past disputes and "heal the country", build knowledge of working in a mining context, become familiar with the use of new equipment and hone technical skills, develop commercial capability, enhance future employment options and increase self-confidence (Barnes et al. 2020).

Despite the benefits outlined above, and even when there is willingness to collaborate or partner with mining companies, non-government organisations (including indigenous organisations and conservation groups) are often constrained by a lack of available resources which limits their efforts. Further, it has been identified that both government and non-government organisations have limited their participation in projects to address environmental hazards at abandoned mines in the US because of concern about potential legal liability (GOA 2020). These organisations often want to help address environmental hazards at a mine site even though they did not cause them but were generally not doing so if they became responsible for obtaining the necessary environmental approvals and permits, and for conducting ongoing the monitoring required under those permits. Further, there were concerns about the risk of these "good Samaritans" being held responsible for meeting and maintaining environmental standards in perpetuity and even of becoming legally responsible for the entire cost of site remediation if they attempted partial clean-up (GOA 2020). This means that smaller-scale projects that could provide incremental improvements are often not initiated.

Although the US Environmental Protection Agency has developed administrative tools to facilitate good Samaritan participation in closure projects, there is still concern that these do not sufficiently alleviate legal responsibility and that additional legislative or other mechanisms may be necessary. However, GOA (2020) has identified several formal mechanisms for national and local collaboration to facilitate the leveraging of resources, such as establishment of working groups to ensure collaborative and efficient use of resources. This approach has also been adopted at the Raglan Mine in the Inuit territory of Nunavik in the Canadian province of Québec, where a Closure Plan Subcommittee was launched in March 2018 to establish and maintain a dialogue with the mine's Inuit partners about mine closure to integrate the traditional knowledge of the communities and to exchange the scientific knowledge (Keeling & Potvin 2025).

5 Addressing challenges that can't be fixed

Despite the mining industry's best efforts, some closure problems simply can't be fixed in a way that allows achievement of closure outcomes and site relinquishment or custodial transfer to another landholder. This has led to a recognition that some legacy sites will need to be managed in perpetuity by the mining company or another party. This situation could arise for many reasons. For example, a report on beneficial and productive post-mining land use published by the New South Wales Government (Australia) in April 2025 found that regulatory barriers and disincentives for transition to alternative land uses include a focus on restoring land to its pre-mining state, zoning restrictions and development consent requirements, historical commitments and a lack of incentives for adaptive land use. In addition, there are concerns regarding ownership and management of residual risks and liabilities in post-mining land use, the complexity of

regulatory systems and the investment barriers that these can create (Standing Committee on State Development 2025). Further, there may be changes to regulatory and societal expectations; modification and expansion of closure criteria (i.e. shifting “goal posts”); misalignment between legal obligations, corporate values, stakeholder expectations and costs; and other factors (Ayres 2023).

In instances where legacy sites require perpetual management, mining companies may elect to maintain responsibility for their sites. For example, BHP is actively evaluating alternative optimal closure solutions for its portfolio of legacy assets through a vision of “Re-imagining the Legacy of Mining” and intends to divest or relinquish sites where possible, but has accepted that the current closure base case for most sites is care and maintenance in perpetuity (Ayres 2023). Further, not all companies have sufficient experience or expertise to develop alternative land uses. Consequently, it may be appropriate to work with third parties who can help realise the full post-mining potential of a site (Standing Committee on State Development 2025) or can take full responsibility for the site, as was the case for the former Beaverlodge uranium mining and milling operations in northeastern Saskatchewan, Canada.

The Beaverlodge mining and milling operations occurred between 1952 and 1982, with decommissioning and reclamation work completed in 1985. Following completion of this work, the properties entered a period of transition phase monitoring which was originally expected to last for 10 years. However, monitoring continued well beyond this point as no formal exit agreement or strategy was in place and stakeholder expectations regarding an appropriate end point for the transition phase were changing (Webster 2011).

In 2007, after significant stakeholder consultation, the Government of Saskatchewan proclaimed new legislation and regulations to establish and enforce an Institutional Control (IC) program. This program established a process for transferring decommissioned mining and milling properties to provincial responsibility once remediation is complete and monitoring demonstrates that the properties are safe, secure and stable/improving (Beaverlodge 2025a). Following development of the IC program and transfer of five relatively benign properties into IC, work commenced on how to reduce the residual risk associated with the remaining licenced properties. Consequently, the Beaverlodge management framework was developed to guide the assessment and decision-making process regarding potential additional remedial activities for the Beaverlodge properties. The management framework was developed through collaboration with the regulatory agencies and other stakeholders with an intent to balance current decommissioning expectations with the presence of legacy issues and past close-out agreements. It provides a stepwise approach to assessing risk and risk mitigation, and relies on cost-benefit evaluation to identify a final criterion that is acceptable to most of the relevant stakeholders. Ultimately, it ensures that all reasonable actions are taken to manage risk prior to proposing transfer of former mining properties to the IC program (Webster 2011).

Since 2009, 43 decommissioned properties have been released from licencing under the Federal Canadian Nuclear Safety Commission and 42 of these have transferred to the IC program, with the remaining property free-released due to the absence of historical mining/milling activities (Beaverlodge 2025b). In addition, a final closure report has been prepared for the remaining 27 decommissioned Beaverlodge properties to initiate their transfer to the IC program or to have portions free-released where applicable (Kingsmere Resource Services Inc. 2023). A monitoring program to be implemented as part of the IC program has also been developed (Beaverlodge 2025a).

6 Conclusion

The closure issues, opportunities and costs associated with a legacy mine can affect transaction value and potential for return on investment, so a decision to acquire such a mine (either as part of a package or as an individual site) is not one to be taken lightly. Further, taking responsibility for closing and transitioning a legacy mine can pose significant practical and reputational risks (Armstrong et al. 2023).

Once a legacy mine has been acquired it is important that closure-related decisions and processes be based on risk and opportunity, not solely on regulatory compliance (Ayres 2023). There will likely be a need to develop practical and potentially innovative solutions for those legacy closure challenges that may not be

readily resolved despite the best efforts. In some cases, these challenges may trigger the need for perpetual management.

The ecological, community safety and heritage challenges associated with legacy mines tend to vary from site to site depending on its location, history, site characteristics and other factors. These challenges are compounded where there is a lack of closure data, loss of institutional knowledge, and changes in regulatory requirements and stakeholder expectations. However, despite these differences, a common primary objective when planning closure of a legacy mine is to ensure public safety. It is also vitally important to protect wildlife habitat and cultural resources, and to take a holistic approach to conservation (Bat Conservation International 2024).

It is concluded that a pragmatic approach is needed as companies try to balance contemporary closure expectations with the practicalities of closing a mine that was designed and operated in accordance with past practices that are no longer considered adequate. Processes to achieve the best possible post-mining outcomes will vary from site to site but include prioritising key risks; comprehensive and collaborative stakeholder engagement; incorporating cultural values into mine closure and rehabilitation; co-creating designs and plans for closure and rehabilitation, if possible; and leveraging additional resources when needed.

Acknowledgement

My thanks to Donna Noonan for her visualisation of closure specialists as sometimes being akin to forensic scientists when faced with a limited knowledge base. My thanks also go to the reviewers for their constructive feedback.

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