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

doi:10.36487/ACG_repo/2515_57

When mine closure lacks dollars and sense: common pitfalls and practical solutions in mine closure planning

Alexandra Hood [a,*], Taylor Dillon [a] , Chloe Crossley [b]

[a] *ERM, USA*

[b] *Teck Alaska Incorporated, USA*

Abstract

Mine closure presents complex, multidimensional challenges that are frequently underestimated, resulting in substantial financial, operational and environmental liabilities. These challenges are particularly acute in remote environments, where logistical limitations and environmental constraints significantly amplify cost overruns and planning oversights. This paper critically examines four common interrelated pitfalls recurrently observed in mine closure planning: (1) unverified closure assumptions, such as the overlooked necessity of stockpiling appropriate rock materials; (2) missed cost efficiencies and ineffective interim solutions, exemplified by failing to strategically leverage existing onsite equipment or adequately plan material handling; (3) inadequate baseline data collection and misinterpretation, such as disregarding early geochemical indicators leading to costly remediation; and (4) impractical or overly conservative closure designs, including specifications for cover materials that cannot be realistically achieved with available site equipment.

Drawing upon practical case studies from mines across North America, this paper illustrates how neglecting basic operational details – right down to deciding 'where all the doorknobs go' – can escalate into expensive, avoidable complications. We advocate for a backward-planning methodology that begins by clearly defining the desired end state and subsequently aligning available resources, operational practice and realistic environmental criteria to achieve meaningful closure outcomes that align with closure objectives. This approach facilitates early verification of critical assumptions, improves cross-departmental communication and aims for closure designs to remain practically achievable without resorting to costly external interventions. Ultimately, the paper emphasises the importance of transforming mine closure from a theoretical, top-down checklist into an adaptive, iterative, and resource-conscious process so closure strategies are both environmentally and financially responsible.

Keywords: *mine closure, remote environments, cost escalation, onsite equipment, closure planning, resource management, environmental safety*

1 Introduction

Successful mine closure planning demands more than meeting regulatory requirements; it requires a proactive and integrated approach that addresses the operational realities and inherent risks which, if ignored, can escalate long-term costs. In today's margin-tight mining landscape, every dollar of unmitigated risk can multiply into millions in post-closure liabilities, directly eroding project net present value (NPV). Despite improvements in closure guidance, persistent gaps remain. Small, seemingly insignificant oversights, such as verifying the suitability of materials for closure activities or confirming baseline conditions, frequently compound into significant challenges at closure. Acknowledging this risk-cost dynamic upfront sets the stage for the backward-planning methodology that follows. This paper explores four major planning pitfalls commonly observed in mine closures, using real-world scenarios and practical examples. By emphasising a

[*] Corresponding author. Email address: alex.hood@erm.com

backward-planning methodology, the paper aims to guide mine operators towards more effective, achievable and cost-efficient closure strategies.

2 Methodology

In our study we harnessed a combination of our firsthand observations and experience alongside a qualitative analysis of diverse mine closure scenarios throughout North America. Our focus was directed towards mines that have either recently embarked on the closure process or have established a proven track record of effective long-term management and monitoring practices.

To enrich our evaluation, we reviewed a wide array of publicly accessible documentation, including regulatory filings, technical literature, industry guidelines, and proceedings from relevant conferences. To maintain confidentiality while sharing insights, we categorised our personal lessons learned into four distinct themes. Subsequently, we supplemented these insights with additional publicly available examples that could effectively illustrate our key points. Each case was examined to pinpoint practical instances of both the pitfalls and successes associated with closure planning. A significant aspect of our analysis is the introduction of a backward-planning methodology, which serves as a crucial evaluative framework. This approach not only facilitates a deeper assessment of existing closure plans but also provides a pathway for enhancing their effectiveness. By employing this methodology, we aim for a more robust understanding of the complexities involved in mine closure and to promote the development of best practices that can lead to successful outcomes for both the environment and impacted communities.

3 Closure challenges illustrated by practical examples

3.1 Unverified closure assumptions

Critical assumptions that form the basis of closure plans often go unexamined, leading to unforeseen gaps in resources and operational challenges. Frequently, teams proceed with overly optimistic outlooks and ignore warning signs that may impact project development.

The consequence? Essential requirements at closure (such as materials, equipment and permits) that were presumed to be secured end up being absent or insufficient. Before long, small oversights accumulate into significant issues, all traceable back to an initial assumption that went unverified during the mine's early years. Common assumptions that often remain unchecked until late in the mine's life or at the start of the closure period include:

- Availability of appropriate materials: assuming there will be enough topsoil, rock or growth medium for reclamation without prior stockpiling or quality testing
- Readiness of equipment and infrastructure: presuming that the current onsite equipment can handle specialised closure tasks (like ultra-fine grading or seedbed preparation) or that it will still be available when needed, despite the possibility that those assets could be sold or depreciated by the time of closure
- Regulatory and environmental conditions: relying on lenient or static criteria such as expecting today's groundwater quality or slope stability criteria to apply in the future. This assumption can result in inadequate planning and budgeting for active water treatment plants, structural stabilisation or other engineered controls that may be required if natural recovery is insufficient or regulations tighten over time.

These assumptions can all lead to significant risks and unforeseen costs, ultimately jeopardising the success of reclamation efforts and the long-term sustainability of the site. Meeting current regulations is only table stakes; robust closure planning must also satisfy internal risk-governance thresholds and protect shareholders against long-term liabilities

Several closure plans we reviewed assumed that competent rock would be available to construct safety barriers around open pits at closure. However, in each case, little material had been stockpiled during operations and the available rock was unsuitable for long-term performance. One site, for example, had friable limestone overburden and several others had potentially acid-generating waste rock. During operations, the geotechnical quality of the waste rock was overlooked, leaving material that was either too weak or chemically reactive. These ‘oops’ moments triggered a frantic search for solutions: importing quarried rock from offsite at great cost, or redesigning barriers with substandard materials and hoping for the best. In either case, the result was unplanned material costs and project delays; a direct outcome of unverified assumptions about material suitability. These experiences underscore the importance of conducting thorough geotechnical and geochemical assessments before project initiation and maintaining monitoring throughout operations.

In another case, a mine plan optimistically predicted that all stripped topsoil would remain viable in stockpiles for eventual rehabilitation. As the closure date approached it became clear that the quantity of recovered topsoil only covered a minor section of the intended area. Compounding the issue was that no measures had been taken to preserve the seed bank and microbial life, rendering the material largely infertile. Faced with this shortfall, operators had to choose between using treated overburden (which was deficient in fertility), sourcing alternative material offsite or purchasing materials from other suppliers, a significant challenge in a remote location. These alternatives increased closure costs and extended timelines, highlighting how an unchecked assumption (‘we’ll have enough topsoil’) can lead to costly and avoidable setbacks.

The underlying reasons for such oversights appear to stem from optimism bias and isolated planning. Mine planners, concentrating on extraction, typically assume that future closure teams will somehow ‘make do’ with whatever remains. Assumptions are carried forward in planning documents without thorough examination – sometimes for many years – until someone finally seeks verification. By that time, earlier chances to collect data or materials have slipped away. This can result in emergency actions later, including adding or upgrading water treatment plants or moving large amounts of hazardous waste to different locations, all at a steep expense. From both operational and financial perspectives, unverified assumptions introduce substantial risk. In minor cases, they can trigger unforeseen design revisions, add work packages, inflate budgets and spark contractor claims. In more severe instances they may compromise safety performance and threaten compliance with environmental regulations. Regulators are not sympathetic to claims of “we expected to have X, but we don’t”. These circumstances can result in rejected closure permits or requests for further mitigation. Yet regulators are only one potential gatekeeper; if performance still falls short, the company must close the gap itself to protect shareholders, sureties and long-term asset value. As a result, mining companies may face costly and extended monitoring periods and cannot release sites as planned. In conclusion, failing to verify early whether essential closure components (materials, data, approvals) are truly available is like building a house without a sturdy base – eventually it will fail.

The solution is straightforward: consider every major assumption in a closure plan as a risk that needs to be evaluated and confirmed. As we will explore, laying the necessary groundwork beforehand prevents a considerable number of issues (and expenses) when it’s time to permanently close. Robust risk evaluation and management during the planning phase not only safeguards financial commitments but contributes to maintaining operational integrity throughout the closure process. By establishing a thorough risk management system, stakeholders can pinpoint potential challenges early and create strategies to address them, thus facilitating a smoother transition into closure.

3.2 Missed cost efficiencies and poorly executed interim measures

Opportunities to minimise closure liabilities through progressive reclamation and effective cost-saving strategies often are not investigated due to poor planning or unrealistic assumptions about operational potential. Simply put, operations can miss out on financial gains during operations – or end up spending excessively later – because they failed to integrate closure considerations into their daily operations. This is an example of being short-sighted: prioritising immediate production or small savings while neglecting the longer-term implications.

When the time for closure arrives, companies often discover that straightforward actions they could have implemented earlier – at a fraction of the cost – have since morphed into costly remediation programs capable of bankrupting an operation, as illustrated by Royal Oak Mines, Pegasus Gold Corp., Anvil Range Mining Corp. and Blackjewel LLC. This oversight not only undermines the financial health of the operation but also raises environmental and social challenges, potentially escalating to reputational damage and regulatory scrutiny if left unchecked. Companies must recognise that proactive planning for closure is not merely an operational necessity but a strategic imperative that can safeguard their future viability and enhance stakeholder trust.

Equally critical is visibly protecting shareholder value and debt covenants. Integrated mine-closure guidance (Brock 2021) and recent capital-markets analyses (Isherwood 2023) show that every dollar of unfunded liability can shave several dollars off project NPV and trigger surety bond downgrades. When progressive reclamation metrics, cost-reduction pilots, and baseline datasets are tracked and reported in hard numbers – hectares restored, tonnes of acid rock drainage (ARD) risk material isolated, dollars of future liability avoided – the C-suite and board can see that capital is being responsibly shepherded rather than deferred. Data-driven dashboards, championed by institutional investors as part of environmental, social and governance disclosure frameworks (Li et al. 2023), translate closure work into risk-adjusted NPV and tail risk reduction, giving executives the sureties they need to keep funding and de-risking the balance sheet. In short, real data does not just satisfy regulators; it speaks the language of investors and underpins the long-term licence to operate.

A significant example emerges from the handling of overburden. At a specific site, planners discovered what seemed to be an economical approach: reducing the thickness of the cover soil intended for a reclaimed waste dump, thereby cutting down costs for material transport. In theory this seemed advantageous – less material meant lower expenses. Nevertheless, in practice, the specified depth (just a few centimetres) surpassed the precision limits of the mine's heavy machinery Bulldozer operators struggled to evenly spread soil that thinly over a large area. Some sections ended up with an excess (resulting in a waste of valuable topsoil) while others had inadequate coverage (leading to bare ground) (Pearce et al. 2006). The operation became less efficient as teams had to go back to fix low areas and ultimately the company was forced to move additional soil for adequate coverage, which negating the intended savings. A preliminary field test or equipment showcase could have revealed this practical restriction, allowing for a more viable cover design. The irony is profound: a plan designed for cost savings ultimately resulted in higher expenses due to poor execution and a lack of foresight.

Another frequent mistake is not effectively utilising the available resources for interim closure activities. With adequate planning, these materials could be allocated for progressive rehabilitation, providing the potential to monitor effectiveness and adapt the closure strategy early. However, if the operations and closure teams fail to collaborate, these opportunities are often overlooked. In one example it was determined that a large onsite crusher could have been repurposed in its final years to crush demolition debris and oversized rock for cover material. Instead, the crusher was sold when the ore supply was depleted and, upon closure, they were forced to hire a contractor with a mobile crusher at three times the expense. Likewise, haul trucks that could have been employed to backfill an open pit during the production stage were removed from the site, leaving the closure team to face millions in contractor fees. These situations highlight a deficit in the progressive reclamation approach – viewing closure tasks as a vital component of operations rather than an afterthought post-mining. Why do these inefficiencies happen? A significant reason is poor communication and collaboration between operational and closure planning teams. The individuals managing the mine are usually (and justly) concentrated on achieving production goals or managing ever-emerging operational challenges and, without a clear closure delegate, closure planning that can be postponed. There is also a tendency for optimism or overestimation regarding what can be accomplished at the last moment. Managers might believe, for instance, that they can swiftly dismantle infrastructure and restore the site rapidly after the final ounce of gold is extracted – misjudging the logistical difficulties and expenses involved.

From a financial perspective, the implications are evident in significant budget overruns and studies show that most mine closures surpass their initial budgets by anywhere from 20 to 100% (Isherwood 2023). A key reason behind these overruns is the tasks that could have been completed or improved earlier but are postponed until the costly post-production phase. Inadequate progressive reclamation leads to larger disturbed areas left for closure, which results in increased final rehabilitation costs and heightened financial assurance requirements (since regulators base bonds on the least favourable, unreclaimed conditions). In fact, the majority of closure projects are found to be poorly funded for closure, a statistic that underscores systematic errors and missed opportunities to reduce liabilities at an earlier stage. Regulators are increasingly seeking evidence of progressive remediation efforts. A company that reaches the end without a plan may encounter stricter inspections, elevated bond obligations or potential penalties (Kalisch & Dunow 2022).

On the other hand, showcasing gradual, data-rich rehabilitation advancements can effectively alleviate regulator apprehensions while clearly articulating to communities, the C-suite, and the board that the company is proactively safeguarding shareholder value. Transparent metrics – such as hectares restored, tonnes of hazardous material safely isolated and quantified future liabilities avoided – not only establish credibility but also facilitate meaningful and collaborative dialogue with stakeholders. This transparency proves unequivocally that capital is being managed responsibly rather than simply being deferred, significantly de-risking the company's licence to operate.

Conversely, neglecting these cost efficiencies is akin to watching low-hanging fruit rot on the vine. The true squandered opportunity emerges when practical, closure-aware methods aren't embedded into mine plans from the outset. A proactive, realistic strategy involves aligning waste haulage timing with backfilling activities, training operators in reclamation grading techniques, dedicating a modest annual budget for pilot rehabilitation trials and rigorously validating all proposed cost-reduction strategies against actual site capabilities before deployment. By synchronising day-to-day operations with clearly defined closure objectives, mines can progressively shrink future liabilities, reduce risks and ensure that theoretical cost savings don't balloon into significantly larger expenditures due to inadequate execution or oversight. Ultimately, the goal is straightforward: making certain every dollar saved today doesn't become five dollars spent tomorrow.

3.3 Inadequate baseline data collection and ignored early indicators

Comprehensive baseline data is essential for demonstrating regulatory compliance, informing technically and environmentally sound closure strategies, and supporting successful closure implementation. However, mining companies frequently underestimate this requirement, resulting in future regulatory challenges and unexpected issues. Imagine a detective attempting to crack a case with only half the evidence available – that's akin to a closure planner operating without sufficient baseline information. Without a complete understanding of the pre-mining conditions it becomes extremely challenging to demonstrate that successful closure has been reached or that specific impacts were unavoidable (Chaloping-March 2008). Sadly, a lack of baseline diligence is common, especially in regions where legislation is non-prescriptive. Whether driven by budget constraints, lack of understanding or optimism bias, some operators conduct minimal monitoring during operations, only to discover they are missing vital evidence upon closing. This oversight not only complicates the closure process but also raises ethical concerns about accountability and environmental stewardship, ultimately jeopardising both community trust and regulatory compliance.

Consider a situation where early geochemical signs were overlooked. In several projects, preliminary assessments indicated the likelihood of increased metals leaching. Nevertheless, the company opted not to gather further data since it was not mandated by regulations. This decision may seem reasonable; however, with the changing landscape of legislation in other nations, it suggests that at the very least, stakeholder perception would factor into mine closure decisions. Fast forward to the closure phase: the company was unable to fulfill its obligations and comply with local quality standards. Without comprehensive baseline data, the company found it challenging to differentiate between naturally occurring background metals and those resulting from mining activities. Regulators, observing these figures and reluctant to rely on regional baseline data, imposed a costly array of measures and years of further monitoring. The superficial adherence to compliance in the early stages ultimately led to significant consequences. It's understandable why experts point out that without adequate baseline data, mines struggle to grasp fundamental closure risks from the very start (Lambeck 2009) – in this instance, transforming a manageable issue into a multimillion-dollar remediation endeavour (Brown 2019).

In another similar instance a site chose not to collect additional baseline data prior to operations as they assumed that regulators would acknowledge the known elevated arsenic levels prevalent within the region (Rad & Berndtsson 2019). However, when they sought closure, regulators inquired: "How can you demonstrate that the post-closure conditions are equal to or superior to the conditions before mining?" The company possessed only scant pre-mining data to support its claim, and its attempts to posthumously collect regional data, a common practice, were rejected (Rad & Berndtsson 2019). Consequently, uncertainties emerged regarding whether certain remaining contaminants were genuinely elevated naturally in the region (and thus not the company's liability) or resulted from mining activities. Lacking comprehensive baseline surveys, the regulator remained unconvinced by regional studies indicating that the levels were naturally high, and it is likely that a costly excavation will be required to achieve closure. This leaves the site in a prolonged state of ambiguity; much longer than if the problem had been recognised and, after discussions with regulators, closure actions had been agreed upon rather than presuming the outcome. The message is clear: you cannot assert that you achieved the target if you never accurately gauged the starting point.

Effective communication and cooperation with all parties involved throughout the closure planning process are critical to enhancing operations and preventing costly delays, ultimately resulting in a more successful project outcome (Mahame et al. 2018). Insufficient baseline data and overlooked indicators often lead to significant operational, financial and regulatory setbacks. Operationally, data gaps undermine informed decision-making during closure planning, increasing the risk of misjudging emerging issues or underestimating their long-term implications. From a financial perspective, the costs of unplanned remediation, extended monitoring or long-term treatment can be staggering. Rather than confidently demonstrating that closure criteria have been met and moving towards reduced monitoring, passive closure, alternate land uses or (potentially) relinquishment, companies may face decades of ongoing water treatment or be forced to conduct expensive environmental studies to satisfy authorities. These outcomes drive up financial assurance burdens and affect the company's balance sheet or, in the event of a default, shift the burden to public funds. Increasingly, full site relinquishment is becoming less and less attainable as evolving regulations and growing awareness of long-term environmental liability make governments more reluctant to release operators from responsibility. As a result, regulators become significantly more cautious in granting closure or releasing bonds. This cycle of uncertainty not only hinders the timely closure of sites but also places an immense strain on resources, diverting attention away from proactive environmental management and long-term sustainable practices.

3.4 Design feasibility and over-engineering

Due to the level of uncertainty and projected life span of facilities, closure designs can become overly cautious, leading to challenges in implementation and unnecessary costs (Lourel et al. 2022). There exists a natural inclination in mine closure planning to pursue the Cadillac of closure designs. After all, engineers and environmental consultants aim to guarantee stability, avoid pollution and comply with regulatory requirements. As a peer review of mine closure plans pointed out, cost models and designs are often founded on layered conservatism and outdated assumptions – implying that each individual in the process adds an additional buffer, leading to a plan that is far beyond what is realistically necessary or achievable (Limpitlaw & Mitchell 2013). When designs exceed realistic expectations, they can become unfeasible to implement with the resources available at the site, or simply far more expensive than is necessary to achieve the closure goals. In some instances, designs may appear sound on paper but fail to consider the actual site conditions or equipment, resulting in the need for rework at a later stage. Striking the right balance is crucial: sufficiently robust to safeguard the environment and public yet not so intricate that it jeopardises the project's viability or becomes unfeasible to construct as intended. When that balance shifts too far into over-engineering territory we encounter ludicrous situations, such as demanding a closure cover capable of withstanding a meteor strike when all that was required was to prevent rain from affecting the waste rock.

One instance of an impractical design involved a cover system that was designed without looking at the available equipment on site. When the company proceeded to build a test plot, it was determined that no equipment onsite could screen to the grain size needed for two of the trials. A straightforward solution would have been early collaboration between designers and the operations team. The upside, however, was that they thought to trial cover options early and had time to revise and adapt. Discovering that the design was unfeasible in the field saved considerable time and expenses. But companies are not always this lucky: design flaws and impractical solutions frequently stem from inadequate communication and insufficient interdisciplinary teamwork. In many cases, closure designs are developed by specialists who are disconnected from the onsite conditions or day-to-day realities, leading to oversight in material accessibility, equipment capability or constructability. Moreover, the mining industry's cultural inclination to emphasise caution in documentation can result in overly detailed specifications that surpass regulatory standards without providing any additional advantages. Effective communication and collaboration among all parties involved are crucial to closing the gap between conceptual designs and real-world application, ensuring that closure strategies are both practical and advantageous. Implementing regular interdisciplinary meetings and feedback loops can significantly enhance understanding among team members, fostering a more cohesive approach to addressing potential design challenges and improving overall project outcomes (Henderson et al. 2013).

The repercussions of impractical or excessively complex designs usually manifest as delays in implementation, significant budget overruns and, at times, even issues with compliance (Suh 2016). When a design cannot be executed as initially intended, projects often go into a repeated cycle of onsite re-engineering. Contractors create change orders, schedules are delayed and tensions rise among stakeholders. From a financial viewpoint, the mine may need to tap into more of its contingency funds or seek extra financing – a conversation that any mining CFO would rather not have.

Excessive complexity in closure design can drive up project costs, an important consideration given that many closures already go over budget by significant margins. Design inefficiencies are a major contributor to these overruns. Furthermore, an overly complex or impractical design can threaten regulatory compliance if it fails to deliver the intended outcomes. For instance, if a highly specific cover specification is not satisfied because it proves unfeasible, the actual condition might not function as anticipated (for example, more percolation may occur than what the design permitted). Consequently, the site could become non-compliant regarding water quality or stability, which would require additional remedies. In the most unfavourable scenarios, excessive complexity can stifle innovative thinking: individuals become so fixated on adhering to a stringent plan that they overlook simpler alternatives. Moreover, if the overly complicated design is implemented, it could burden the site with unnecessary features that require ongoing maintenance, thus raising long-term operation and maintenance expenses without equivalent advantages.

The secret to steering clear of this error lies in confirming that closure designs are appropriate for their purpose and based on real-world conditions. This entails engaging operations staff during the design process, performing field tests on essential components, and questioning whether each design element significantly aids closure goals or is merely included as a precaution. A reverse-planning strategy can be beneficial: begin by specifying the closure results needed (such as water quality standards and slope stability parameters) and then work backwards to identify the most straightforward design that achieves those results with the available resources.

Another protective measure is to incorporate peer reviews or third-party evaluations of closure plans, at least one of which emphasises constructability. Frequently, an external reviewer will pose challenging questions such as, "Have you actually attempted this with a dozer?" or "Is this material truly obtainable in the assumed quantities?" Such examination can lead to adjustments that eliminate unnecessary intricacy. In conclusion, when considering mine closure, the optimal design is one that can be constructed and works in harmony with nature rather than against it. Over-engineering beyond what is necessary wastes resources and rarely adds value. Often the smart, straightforward solution is not only more cost-effective but also more likely to be successful in the long-term. By prioritising practicality and fostering collaboration throughout the design process, mine operators can evade the pitfalls of over-engineering and deliver closure strategies that are both financially viable and technically robust.

4 Results and discussion

The analysis reinforces that successful mine closure planning must begin early and be integrated into daily operations so no vital details are overlooked. Too often optimism bias, the tendency to overestimate positive outcomes and underestimate risks, leads teams to dismiss seemingly trivial operational details at the start. The proverbial 'where do all the doorknobs go' issue from the abstract can escalate into significant budget overruns and regulatory challenges by the time of closure. Thus a prudent approach involves incorporating local onsite expertise from the beginning so that design criteria remain attainable with current resources, which avoids last-minute expensive fixes. By emphasising resource-efficient, site-specific solutions, mine closure planning evolves from a theoretical, top-down initiative into a practical, flexible and outcome-focused process. In simpler terms, it is only by anchoring closure strategies in the daily realities of the mine site that we can guarantee closure plans that ultimately yield both economic and logical benefits. From the difficulties discussed in Section 3, four interconnected insights surfaced, each underscoring where traditional closure methods frequently fail and how a more realistic approach can lead to improved results.

4.1 Early verification of closure assumptions is essential

One important discovery is that assumptions about closure that lack verification can subtly jeopardise an entire closure strategy. Numerous mines operate under the belief that certain materials, equipment or site conditions will be adequate for closure without ever confirming these beliefs during their operations. The example of the safety barrier discussed in Section 3 highlighted this clearly: a site anticipated having ample suitable rock for pit safety berms, only to find out close to closure that the available rock was either too weak or chemically inappropriate. This mistake resulted in a costly rush to find alternative materials at the last minute. Likewise, some operations assumed that natural water quality or geochemical conditions would remain stable, a belief later proven wrong by the discovery of acid-generating rock that had not been tested. These instances highlight the costly reminder that 'hope is not a plan' regarding closure. All significant assumptions – whether they concern material availability, geochemical stability or equipment efficacy – need to be regarded as potential risks and should be proactively confirmed through testing or trials long before they are needed. In closure planning, just like in carpentry, it's wise to 'measure twice, cut once': verifying essential factors early on can save substantial costs and complications later, ensuring there are no unpleasant surprises as the mine nears its closure phase.

4.2 Align cost-saving measures with operational realities

A key takeaway is the necessity of anchoring cost-efficiency efforts in actual operational capabilities. Proposals for reducing closure expenses or initiating temporary rehabilitation strategies may seem appealing on paper but can fail in practice if they overlook the constraints of personnel and equipment. For example, one proposed cost-saving measure involved reducing the thickness of the overburden cover applied across the site. In theory, this approach minimised material usage and expenses. However, in practice, the plan required a level of accuracy that the site's bulldozers and operators were unable to provide (Pearce et al. 2016). Consequently, the uneven coverage and additional rework ultimately increased costs. Cost efficiencies erode when planners and corporate teams set unrealistic targets without fully engaging the operational staff. Meaningful engagement via consultations, feedback sessions and onsite walk-throughs with those responsible for executing the work is essential for actually achieving targets (Pierce & Wen 2006).

Any cost-reduction strategy or innovative reclamation step should, wherever practicable, be validated – whether through onsite trials, desktop modelling, structured peer review or direct feedback from the personnel executing the tasks. The level of scrutiny can be scaled to the risk involved: the less vetted the approach, the more exposure the project assumes. In our analysis, the most effective sites were those that incorporated closure activities into everyday operations; for example, gradually rehabilitating unused sections with the equipment already available or organising small-scale tests of a new cover application method during regular work hours. This early integration offers a dual advantage: it highlights practical limitations and obstacles (before they turn into expensive failures) and seamlessly incorporates progressive reclamation into the mining workflow. In summary, closure planning and mining operations ought to be closely aligned; when cost-reduction initiatives are in harmony with what operators can realistically accomplish, closure processes become more efficient and considerably less likely to produce unexpected challenges.

4.3 Comprehensive baseline data safeguards compliance and feasibility

Too often mines downplay full environmental and geochemical surveys, only to pay later in monitoring, re-handling or litigation. Several sites dismissed early acid-rock-drainage flags; by closure, active acid generation forced a multimillion-dollar waste-rehandle and water treatment campaign. Another lacked pre-mining water quality records so regulators withheld sign-off until years of extra sampling proved contaminants were naturally high (Bussière 2010). Baseline datasets set the bar by which closure success is judged and give operators hard evidence that criteria are met or conditions are natural (Gemson et al. 2019). Upfront, comprehensive surveys guide realistic design, calm regulators and avoid the expensive ‘prove-it-after’ trap (Ram et al. 2013). In short, a robust baseline is minor in cost, major in pay-off – knowledge that safeguards compliance, feasibility and the schedule.

4.4 Practical closure design outperforms over-engineering

The findings suggest that closure designs that are feasible and buildable surpass those that include conservative elements and rigorous standards beyond what is required by regulations or functionality (Byrne 2019). Introducing unnecessary complexity such as strict tolerances, unusual materials or several backup layers frequently extends procurement timelines, presents constructability issues and leads to budget excesses without equivalent decreases in environmental hazards. A widely cited example involves a tailings-cover system that specified an exceptionally narrow grain size distribution for the soil layer. Field crews working with standard earthmoving equipment could not consistently meet the specification, forcing the operator to import screened material and rent specialised processing units. The design change resulted in schedule delays and significant cost escalation, outweighing the marginal reduction in infiltration expected from the finer gradation (Rykaart et al. 2019). Conversely, operations that adopted simpler, performance-based designs calibrated to local conditions achieved their closure objectives more efficiently. Common success factors include the use of locally available materials (e.g. onsite rock and soils) rather than scarce imported media; appropriate, moderate safety factors that address dominant risks without unnecessary redundancy; and pilot trials or demonstration plots to confirm constructability before full implementation (Demers 2024). When designs align with the site’s equipment, workforce capabilities and climatic constraints, construction proceeds smoothly, budgets remain stable and performance targets are met. Over-engineering, by contrast, merely shifts risk from environmental performance to financial viability and stakeholder confidence. In summary, designs should be matched to site realities and limited to what is necessary to achieve regulatory and functional end points. Unwarranted complexity imposes avoidable costs and may jeopardise timely closure certification.

Through personal experience and literature review a central theme emerges regarding the significance of integrating closure planning early and continuously into mining operations. Each issue – unverified assumptions, overlooked efficiencies, inadequate data and excessive engineering – originates from a disconnect between planning and actual conditions. By altering the conventional strategy and planning closure by working backward from the desired end state, mines can ensure that every operational choice aligns with future closure requirements or objectives. This reverse integration allows for the validation of materials, ongoing reclamation efforts, data collection and design improvements to occur throughout the mining process, rather than only after it concludes. The findings from the examples in this study demonstrate that when closure considerations are integrated into daily operations (instead of being treated as a separate, final task), the closure phase becomes safer, less costly, and significantly more likely to meet the expectations of regulators and local communities (Shaw et al. 2022). In summary, incorporating practicality at every phase of mine life transforms mine closure from a daunting obligation into a manageable and even routine component of mine development. These observations provide a basis for actionable recommendations aimed at industry professionals, as detailed below.

5 Conclusion

Ultimately, effective mine closure planning hinges upon proactive foresight and thoughtful preparation. This paper advocates for a strategic approach of 'reverse integration', beginning with a clearly defined closure vision or desired end state and systematically working backwards to assess assumptions and uncover gaps across operational stages – including baseline data collection, material availability and design practicality. By embedding closure and rehabilitation considerations into routine operations, mines can continuously test and refine assumptions, enhance logistical efficiency and minimise costly oversights. Aligning closure strategies with both financial practicality ('dollars') and operational realism ('sense') transforms closure from a burdensome obligation into a strategic asset. In essence, adopting this thoughtful reverse-integration methodology keeps closure planning grounded, cost-effective and feasible. It promotes environmental responsibility, enhances **s**ocial licence and ultimately bolsters stakeholder trust.

Acknowledgements

The authors would like to express their sincere gratitude to the numerous mining practitioners, industry experts and regulatory reviewers whose contributions have been instrumental in shaping this work. Their extensive knowledge and firsthand experiences have provided invaluable insights into the complex challenges associated with mine closure. Through their thoughtful input we have gained a deeper understanding of the practical difficulties that arise during the closure process, as well as the effective strategies that can be employed to address these issues. This collaboration has significantly enriched our research and enhanced the relevance of our findings in the context of sustainable mining practices. A special thank you goes to our champion reviewer, editor and guru Steve Boyce, whose thoughtful insights made this paper stronger.

References

Brock, D 2021, 'ICMM guidance and resources for integrating closure into business decision making processes', in AB Fourie, M Tibbett & A Sharkuu (eds), *Mine Closure 2021: Proceedings of the 14th International Conference on Mine Closure*, QMC Group, Ulaanbaatar, https://doi.org/10.36487/ACG_repo/2152_123

Brown, CT 2019, 'Will remediation ever be enough? The environmental pollution tragedy', *International Journal of Law,* vol. 5, no. 2, pp. 28–30, https://www.lawjournals.org/assets/archives/2019/vol5issue2/5-1-34-712.pdf

Bussière, B 2010, 'Acid mine drainage from abandoned mine sites: Problematic and reclamation approaches', *Advances in Environmental Geotechnics*, Springer Berlin Heidelberg, https://doi.org/10.1007/978-3-642-04460-1_6

Byrne, G 2019, 'Mine closure plans assumptions and optimism', in AB Fourie & M Tibbett (eds), *Mine Closure 2019: Proceedings of the 13th International Conference on Mine Closure*, Australian Centre for Geomechanics, Perth, pp. 1031–1038, https://doi.org/10.36487/ACG_rep/1915_82_Byrne

Chaloping-March, M 2008, *Managing the Social Impacts of Mine Closure: Mining and Communities in Benguet, Northern Philippines,* PhD thesis, University of Melbourne, Melbourne.

Demers, I 2024, 'Tools to improve mine closure: 10 years of research in integration of environment in the mine life cycle', *Research Directions: Mine Closure and Transitions*, vol. 1, no. e7.

Gemson, WJ, Weaver, TR & Heemink, BL 2019, 'Key considerations that can make or break a closure-focused groundwater-monitoring program', in AB Fourie & M Tibbett (eds), *Mine Closure 2019: Proceedings of the 13th International Conference on Mine Closure*, Australian Centre for Geomechanics, Perth, pp. 1367–1375, https://doi.org/10.36487/ACG_rep/1915_107_Gemson

Henderson, JR, Ruikar, KD & Dainty, ARJ 2013, 'The need to improve double-loop learning and design-construction feedback loops: A survey of industry practice', *Engineering, Construction and Architectural Management*, vol. 20, no. 3, pp. 290–306, https://doi.org/10.1108/09699981311324014

Isherwood, D 2023, 'Five steps to improving financial provisions for mine closure', *Insights*, Turner & Townsend, Leeds.

Kalisch, B & Dunow, T 2022, 'Driving outcomes through transformational mine closure program delivery', in AB Fourie, M Tibbett & G Boggs (eds), *Mine Closure 2022: Proceedings of the 15th International Conference on Mine Closure*, Australian Centre for Geomechanics, Perth, pp. 513–524, https://doi.org/10.36487/ACG_repo/2215_36

Lambeck, RJ 2009, 'Mine closure or mind closure – are mining companies meeting their whole of life cycle, triple bottom line obligations?', in AB Fourie & M Tibbett (eds), *Mine Closure 2009: Proceedings of the Fourth International Conference on Mine Closure*, Australian Centre for Geomechanics, Perth, pp. 13–19, https://doi.org/10.36487/ACG_repo/908_Lambeck

Li, J, Zeng, Y & Yu, M 2023, 'ESG performance, institutional investors, and corporate risk-taking: empirical evidence from China', *Journal of Risk and Financial Management*, vol. 16, no. 3, https://doi.org/10.3390/jrfm16030150

Limpitlaw, D & Mitchell, P 2013, 'Mine closure – misplaced planning priorities', in M Tibbett, AB Fourie & C Digby (eds), *Mine Closure 2013: Proceedings of the Eighth International Seminar on Mine Closure*, Australian Centre for Geomechanics, Cornwall, pp. 3–13, https://doi.org/10.36487/ACG_rep/1352_01_Limpitlaw

Lourel, I, Todd, DJ & Liu, AY 2022, 'A step-by-step guide for evaluating the preferred closure scenarios using a hybrid options assessment model', in AB Fourie, M Tibbett & G Boggs (eds), *Mine Closure 2022: Proceedings of the 15th International Conference on Mine Closure*, Australian Centre for Geomechanics, Perth, pp. 503–512, https://doi.org/10.36487/ACG_repo/2215_35

Mahame, C, Bigirimana, T & Kundwa, MJ 2018, 'The role of effective collaboration for successful delivery of construction projects', *Proceedings of International Structural Engineering and Construction*, vol. 5, no. 2, article 133, https://journals.uran.ua/eejet/article/download/318451/309202/738927?utm

Pearce, S, Lehane, S & Pearce, J 2016, 'Waste material placement options during construction and closure risk reduction—quantifying the how, the why and the how much', in AB Fourie & M Tibbett (eds), *Mine Closure 2016: Proceedings of the 11th International Conference on Mine Closure*, Australian Centre for Geomechanics, Perth, pp. 691–706, https://www.imwa.info/docs/imwa_2016/IMWA2016_Pearce_71.pdf?utm

Pierce, GL & Wen, ME 2006, 'Planning for in-perpetuity mine closure costs', in AB Fourie & M Tibbett (eds), *Mine Closure 2006: Proceedings of the First International Seminar on Mine Closure*, Australian Centre for Geomechanics, Perth, pp. 487–492, https://doi.org/10.36487/ACG_repo/605_40

Rad, MN & Berndtsson, R 2019, 'Shortcomings in current practices for decision-making process and contaminated sites remediation', *Proceedings of the 5th World Congress on New Technologies (NewTech'19): ICEPR 155*, Avestia, https://doi.org/10.11159/ICEPR19.155

Ram, NM, McTiernan, L & Kinney, L 2013, 'Estimating remediation costs at contaminated sites with varying amounts of available information', *Remediation Journal,* vol. 23, no. 4, pp. 43–58, https://doi.org/10.1002/rem.21365

Rykaart, M, Hockley, D, Noel, M & Paul, M 2019, *International Review of Soil Cover Design and Construction Practices for Mine Waste Closure*, technical report, SRK Consulting.

Shaw, J, Pedlar-Hobbs, R & Chubb, D 2022, 'The role of key performance indicators throughout the mine life in achieving closure objectives', in AB Fourie, M Tibbett & G Boggs (eds), *Mine Closure 2022: Proceedings of the 15th International Conference on Mine Closure*, Australian Centre for Geomechanics, Perth, pp. 803–812, https://doi.org/10.36487/ACG_repo/2215_58

Suh, NP 2016, 'Challenges in designing and implementing large systems (overcoming cost overruns and missed project schedules)', *Axiomatic Design in Large Systems*, pp. 273–309, Springer, Cham, https://dx.doi.org/10.1007/978-3-319-32388-6_11