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Closure costing/rehabilitation liability maths: why doesn't it add up?

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Abstract

Estimation of closure and rehabilitation liabilities is undertaken throughout the mining lifecycle for different purposes. However, often rehabilitation and associated liability estimation does not yet form part of what is considered core business for mining operations, so the rigour of the process and comprehension of how to approach this may be limited.

Reconciling rehabilitation budgets with updated liabilities after progressive rehabilitation and associated closure studies or activities often results in queries on why the overall rehabilitation liability has not dropped by approximately the same or a similar amount to the expended rehabilitation budget. Specifically, financial assurance (rehabilitation security) estimates may be required to be lodged in part or in full and may have significant impacts on cash flow, especially for more junior operators.

Without a linear relationship between rehabilitation budgeting and expenditure versus decrease in financial assurance, and with operational pressures and competing priorities, environmental professionals may have difficulty advocating for and receiving adequate rehabilitation budgets. Silos may also exist between mine planning and environment/compliance. Limited incentives for senior management and short-term and long-term mine planners specifically to drive improved closure planning/costing and progressive rehabilitation may also impact the ability to secure and implement appropriate rehabilitation budgets. This may be further compounded by perceptions of net present value for rehabilitation without appropriate context on rehabilitation risks (i.e. longer-term impacts of delaying rehabilitation often result in increased rehabilitation challenges, costs, and financial pressures).

Low confidence levels in cost estimation and which aspects should be considered or included, a limited closure knowledge base, lack of alignment between closure stakeholders on closure vision/objectives/completion success criteria, and inaccuracies in closure costing assumptions may all impact financial assurance and liability estimations and consequent reconciliation of rehabilitation budgets. Without visibility on reliable rehabilitation liability estimates and impacts on finance from undertaking associated activities, rehabilitation may become mainly driven by compliance rather than considering the financial advantages that progressive rehabilitation brings. This has been a driver in recent Queensland and New South Wales rehabilitation reforms to push progressive rehabilitation.

Using recent case studies, the author illustrates examples of why anticipated decreases in rehabilitation liabilities are often not realised and provides suggestions for improving the likelihood of achieving more reflective rehabilitation liability accounting. When rehabilitation liabilities are more reflective, the direct relationship between rehabilitation expenditure and reduced financial assurance can be established, which increases the likelihood of mining operations recognising associated financial benefits.

Keywords: *closure costing, rehabilitation liability, financial assurance, closure cost estimates, rehabilitation expenditure*

1 Introduction

Mining operations have a variety of processes and supports required to accomplish the objective of extracting ore from geological materials in an economical way. A technical support team ranging from exploration geologists to mine planners, mining engineers, processing personnel, maintenance personnel, environmentalists, and mine operators is often required. The complexity of operating sites with diverse options for design, schedule, and methodology (drill and blast, mining, processing, waste management, water management, etc.) for mining variable ore bodies with constraints related to geographic location, legislative context, and local values can be significant. Many aspects of the complex decisions made for mine planning impact the site layout and composition and influence the challenges faced for rehabilitation and closure.

Mining companies are required to estimate the costs of executing mine closure and to characterise these financial aspects. Closure and rehabilitation cost estimates have varying purposes based on type; the main ones generally are:

- For sudden unplanned or imminent rehabilitation and closure of existing disturbance to meet acceptable company standards and legal obligations. (This may include costs not required to be provisioned for within regulatory financial assurance.) These costs may be relevant to the operator themselves or administrators (bankruptcy, insolvency, or receivership) and likely would draw on an internal closure provision based on future costs with a present value for current disturbance.
- For life-of-mine or life-of-asset rehabilitation and closure of projected disturbance and rehabilitation at the end-of-mine life to meet acceptable company standards and legal obligations based on scope. (This may include approved and/or unapproved projects and extensions.)
- For regulatory financial assurance required by government entities to fund mine rehabilitation and closure to meet title and legislative requirements should an owner or operator be unable (operator economic collapse, dissolution or similar) or unwilling to do so. (This typically requires some guarantee towards reducing the likelihood that the state, country and/or people incur financial liability for site closure and use third-party costs. It may be based on disturbance that is current, or at a snapshot in time, or the maximum approved extent.) Closure execution would likely be undertaken by a local or national authority drawing on the external regulatory financial assurance held.
- For financial accounting liabilities to comply with accounting obligations and principles, including meeting legal and other obligations and commitments for current disturbance. This typically reports future costs with a present value excluding potential offsets in a set reporting period.

International Council on Mining and Metals guidance on financial concepts of mine closure (Brock et al. 2019; ICMM 2019) outlines these closure cost estimate types (sudden closure, life-of-mine/life-of-asset, regulator cost estimate/financial assurance and financial liability cost estimate).

The Initiative for Responsible Mining Assurance Standard for Responsible Mining Principle 2: Planning and Managing for Positive Legacies Chapter 2.6 addresses planning and financing for closure and requires third-party closure costs aligned with regulatory financial assurance.

Within each of these closure cost estimates may be costs other than decommissioning, demolition, waste disposal, earthworks, management, maintenance, and monitoring. These other costs are considered based on the type of estimate and company approach, including costs for lease/property holdings, employee redundancies, further approvals required, etc. (Haymont 2012).

When mine closure rehabilitation is planned and executed, commercial and finance expectations are often a corresponding reduction in remaining financial assurance or liability or at least removal of associated rehabilitation activities for which costs have been expended. This is practical given the drive for return on investment for expenditures by boards and shareholders of mining companies. However, within the balance sheet for a mining operation, generally assets are often tangible and well understood, while mine closure liabilities and closure planning are usually only well understood closer to the end-of-mine life.

Despite having closure cost estimation processes in place, often the detail and technical components required to implement a rigorous estimation process may be lacking until late in the life-of-mine, such as within two to five years of closure. This is often a function of mine re-optimisation and planning during the mine life to address additional orebody information, changes in economics, and other factors. Even then, the accuracy and representativeness of closure cost estimates are dependent on the extent to which closure planning and design are completed and site-specific risks and opportunities with associated treatments and costs are confirmed as practicable and appropriate.

Key challenges to the simple mathematics of closure cost estimates minus expenditures equalling the cost for executing remaining closure works include the mine closure knowledge base, the closure cost estimation process (including accuracy and assumptions), and how rehabilitation and closure are executed. Four case studies based on Australian operations are summarised to illustrate these challenges and how key issues may be addressed.

2 Typical closure costing approaches

Overall closure cost estimations and provisions assume that they cover the full cost of rehabilitation and closure for whichever type of estimate is undertaken. Estimates may be a rough order of magnitude, which is inaccurate with a broad range of possible outcomes (typical of conceptual closure cost estimates), or definitive where significant information and resources/studies are available to allow accurate estimation (typical of detailed closure cost estimates) (Sebastien n.d.).

Closure cost estimate quantities are calculated into the closure estimate based on ‘Quantity’ × ‘Unit Rate’ for proposed rehabilitation strategies and assumptions. This is typical of closure cost estimation tools/calculators used in Australia. Where tools/calculators are used, oftentimes the unit rate default is a general averaged benchmarked rate; the accuracy of this rate depends on site-specific characteristics, ranging from locality and market competitiveness to volumes of material to be moved (for larger volumes generally there is greater economy). These rates oftentimes cover a range of mining scenarios, from small quarries to moderate-sized metalliferous mines to large-scale coal mines; for context, as an example of the difference, the ore processing capacity for these may be <1 million tonnes per annum (mtpa), 5 mtpa and >10 mtpa, respectively. It is impossible for default rehabilitation rates to be equally representative of every mine site.

Closure estimates may include a blanket contingency, specific risk-related contingency/contingencies allocated based on assessment of the project’s risk profile and certainty (factor-based deterministic method common to road and rail projects), or a range analysis and/or probabilistic costing (range-based deterministic method) (Commonwealth of Australia 2018). Where relevant, in lieu of detailed assessments, blanket percentages may be assigned for project management and administration and/or for monitoring and maintenance.

Blanket contingencies are used in regulatory financial assurance cost estimates for Queensland (Department of Environment and Science [DES] 2021), New South Wales (NSW) (Department of Planning and Environment [DP&E] 2017) and the Canadian Government of the Northwest Territories (GNWT) and Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC) (GNWT 2017) cost models for estimating closure and rehabilitation costs. The option for detailed evaluation using the GNWT RECLAIM cost model and factored risk is outlined within the guideline for closure and reclamation cost estimates for mines (Land and Water Boards of the Mackenzie Valley [MVLWB] 2022).

Detailed closure cost estimates typically include probabilistic closure costing to address uncertainties in mine closure costs (Hutchison & Dettore 2011).

Where more information and detailed design, etc., are available, bottom-up estimating for a specific, granular scope of work and activities required may be undertaken in a format such as work breakdown structure. Where closure planning and designs are mature, this would allow for detailed assessment of costs for project management, land holdings, monitoring programs, etc., instead of assigning blanket percentages.

The Association for the Advancement of Cost Engineering International defines five levels of cost estimate, from Class 5 (rough order of magnitude) to Class 1 (highest accuracy expected) (AACE International 2021). Some technical scopes are easier or more practicable to achieve a Class 1 estimate (e.g. demolition) than others (ASTM International 2019).

A combination of operating environment and rehabilitation budgets and closure cost estimates are used to understand the overall financial cost of rehabilitation and closure. Operating budgets may include closure-related costs, such as rehabilitation trials, research, progressive rehabilitation, maintenance, and monitoring.

The largest and longer-term costs, risks, and liabilities generally drive the closure costs such as tailings rehabilitation, management and rehabilitation of landforms containing potentially acid-forming material and active water treatment. This typically mimics the Pareto Principle where, for any given event, 80% of outcomes (or outputs) are asserted to result from 20% of all causes (or inputs).

3 Key challenges

This paper is based predominantly on experience within NSW (DP&E 2017) and Queensland (DES 2021) financial assurance processes, which relate to the NSW Rehabilitation Cost Estimate (RCE) Tool (version dated 2 May 2022, State of New South Wales 2017) and the Queensland Estimated Rehabilitation Cost (ERC) calculator.

3.1 Understanding of mine closure knowledge base

Given the complexities of mining operations (and the proclivity to approach rehabilitation and closure with typical operational skills and experience), there may be limited understanding of what inputs and knowledge are required to support representative closure planning and cost estimation of the required type. In addition, operational constraints, including budget and reliable mine planning to facilitate rehabilitation and trials (considering fluctuating market prices), often impact the closure knowledge base upon which estimates are built.

Often, the extent of technical requirements for closure design and execution may be driven by both personnel experience and closure technical knowledge as well as external factors, such as regulatory progression and maturity. The current rehabilitation reforms within NSW and Queensland require technical information to support rehabilitation planning aspects, including post-mining land use, cover designs, landform long-term stability, rehabilitation materials balance, revegetation, and groundwater modelling and prediction. Understanding potential risks and issues/challenges for closure, then developing the knowledge base to inform rehabilitation strategies, criteria, monitoring, etc., is key.

The legal and other mine closure obligations/commitments and key environmental, biophysical, and other baselines and operational considerations support the mine closure knowledge base. Understanding constraints to the feasibility of closure scenarios can also be important in developing reasonable outcomes.

Some of the following considerations impact the overall closure costs:

- Compliance/obligations.
- Mine planning/engineering (mine methods, mine design, mine scheduling, haulage, etc.).
- Landform design.
- Material types and management.
- Resource sterilisation.
- Drainage and water management.
- Progressive rehabilitation experience (resilience, success, etc.).

In addition to the organisation's perspectives on closure, stakeholder perspectives and concerns from landholders to government agencies are important. Local knowledge on legacies, cultural significance, agricultural practices, etc., may be critical to closure planning and strategies. Misalignment on key aspects, including closure vision, can result in the need to rework in design and on the ground and associated additional closure costs.

The more developed the knowledge base, the greater the detail that can be incorporated in the cost model. An example of varying levels of detail for some key mine closure aspects is presented in Table 1.

Table 1 Examples of varying maturity levels in mine closure planning

Aspect	Limited maturity – conceptual	Moderate maturity – conceptual/feasibility	High maturity – detailed (≤5 years from closure)
GIS	Post-mining land uses, existing rehabilitation and disturbance, domains.	Life-of-mine disturbance and rehabilitation footprint, conceptual landform.	Final landform and features, monitoring locations.
Physical stability	Assumption based on design and baseline conditions, concept strategy.	Stability assessed, predictions and likely mitigations identified for erosion and seismicity risks, etc. (e.g. laying back pit wall, buttress, etc.), failure mode and effects analysis and supporting studies, closure design including schedule of quantities and integration with operations.	Field testing (e.g. cone penetration testing) and surveillance.
Geochemical stability	Geochemistry predictions pre-mining or operational, concept strategy.	Geochemical assessment of geological material, assessment of leaching and water quality risks, state of existing potentially acid-forming landforms and success of strategies determined to a high level, conceptual covers identified where required, cover trials.	Cover requirements and design, cover materials sources and constructability schedule, contaminant source modelling, water quality prediction and treatment strategies (if required), success criteria.

Limited courses on mine closure planning are currently offered internationally, and the level of detail for assimilation in these courses must be limited to allow achievement of learning objectives. Often, an experienced specialist may be required to provide support and guidance on mine closure and inform on a working understanding of mine closure.

Based on the mine rehabilitation and closure knowledge base, the main inputs to the closure cost estimate can be determined: rehabilitation and closure strategies, GIS and associated quantities, and assumptions.

3.2 Understanding of closure cost estimation

3.2.1 General

Understanding the extent of closure planning requirements, risks, considerations, and inclusions is helpful in closure cost estimation. During the author's time as a mine closure consultant from 2012 to 2022, she found that guidance on closure cost estimation inclusions, considerations and assumptions was generally high level, typically provided by regulatory government (NSW Resources Regulator 2021) or corporate mining groups.

Cost estimation guidelines typically identified the geophysical battery limits for the estimate, purpose, method of calculation (tool/calculator for use and general basis; i.e. first principles approach, unit rates, measurements, etc.) and key inclusions and exclusions (e.g. NSW, Queensland, and Western Australia (WA) cost estimation guidelines).

The NSW Rehabilitation Cost Estimation Handbook (DP&E 2017) Section 2.4.5.1 provides a thorough list of rehabilitation and closure aspects to be considered in the regulatory financial assurance cost estimation process. However, the considerations for cost estimation differ based on the type of cost estimate required.

Even between states in Australia, regulatory financial assurance requirements may differ; for example:

- The Queensland ERC and NSW RCE are both based on rehabilitation activities that may require more than one rate and activity to be applied to varying types of disturbance and domains to complete full rehabilitation; for example, an area may require termination of services, building demolition including footings, general reshape, growth media application, ripping and seeding of the footprint, followed by rehabilitation maintenance and/or repair.
- WA has a Rehabilitation Liability Estimate (RLE) developed as part of the assessment for the Mine Rehabilitation Fund and associated levies to be paid by title/tenement holders. The RLE is based on a per hectare rate for various categories and classes of disturbance and does not specifically reflect costs for project management, monitoring, and contingencies in addition to this.

Given the sometimes-limited closure experience and technical cost estimation expertise from operational personnel, some common areas of misunderstandings in the cost estimation process are encountered. These include:

- Scope – this may differ based on cost estimate types and closure knowledge base, life-of-mine, and regulatory and other obligations.
- Rates – again based on cost estimate types (third party or internal), and most appropriate and representative (e.g. default rates versus benchmarked site-specific rates).
- Content inclusions –
  - Composition of decommissioning and demolition estimates (Does the estimate include termination of services, hazardous material removal and disposal, demolition waste disposal? What extent of buildings are covered? Are new buildings included? etc.).
  - Rehabilitation strategies (modifications, designs, estimates of volumes, borrow and material sourcing/salvage strategies, etc.).
  - Rehabilitation treatments (amelioration, hydromulching, growth medium generation, maintenance, etc.).
  - Rehabilitation rates (e.g. some dam rehabilitation rates include liner removal and disposal, sediment removal, rehabilitation of dam slopes, etc.; some demolition rates may include reshaping surface, ripping, and seeding; some rehabilitation rates include sourcing material only, while others include sourcing and spreading).
  - Escalation of rates (Are individual rates escalated or is the overall closure cost escalated where relevant, preventing double ups? Should rates be escalated based on the type of cost estimate?).
  - Off-lease assets (Should they be included based on the type of cost estimate? Is there other provisioning, such as bonds or operational budgets, that cover these?).
  - Study costs (Should the estimate include closure studies and research costs, development of a closure plan?).
  - Proposed disturbance and/or rehabilitation (Should this be included based on the type of estimate? What extents should be calculated?).
  - Human resources and social (Should the estimate include retrenchment, social impact assessments, stakeholder engagement programs, etc.?).

- Post-closure management of long-term risks and liabilities (physical, hydrological and geochemical stability), both predicted and unpredicted.
- Project management of site closure until relinquishment, including development of closure plans.
- Transfer of rehabilitated land/asset to a new entity for long-term management and/or beneficial land use.

- Calculations – conversions for units, double ups or exclusions of activities or quantities.

All of these aspects provide areas that could result in incorrect closure cost estimation.

Even confirmation of number of mine openings, reclaim tunnels, hoppers, and dams may require validation in the cost estimation process, as many times this information may not be documented or collated in a straightforward format for use. Routinely changing values, including number of boreholes, lengths of pipelines, lengths of powerlines, etc., would require review for inclusion in the closure cost estimate.

Some key questions to understand whether the closure cost estimate inputs are likely to be representative include whether all relevant disturbance and rehabilitation is captured, growth media or other rehabilitation material deficits are accounted for, the full rehabilitation strategy is costed, and recent representative rates (circa three years maximum) are used.

A summary of some of the key reasons closure costing/rehabilitation liability maths generally doesn't line up is presented in Table 2.

Table 2 Some key reasons closure costing/rehabilitation liability maths doesn't line up (not mathematical)

Aspect	Reason closure/rehabilitation maths doesn't add up	Example
Mine closure knowledge base	Increased confidence in closure knowledge or increased knowledge base.	Detailed design including material quantities, area, cut-and-fill, blast volumes, etc., for final spillway versus provisional sum previously.
Technical information	Completion of assessments for long-term closure objectives, such as physical stability, chemical stability.	Additional requirements identified for long-term stability of final landform and success, including addition of a buttress, cover/cap.
Process	Inappropriate process undertaken to estimate representative closure liability.	Inappropriate strategies and unrepresentative rates and disturbance areas used.
Regulatory	Completed changes to regulatory requirements or closure obligations not included in cost.	New requirements (e.g. additional contingency), changes to rates, changes to approach and assumptions for estimate, additional granularity included.
Economic	Changes to economics or understanding of requirements impacting economics.	Reduced rates based on material volumes required, changes to equipment and labour rates, reflection of area demand, including location-based cost differences.

Aspect	Reason closure/rehabilitation maths doesn't add up	Example
Operational	Performance-based changes and learnings not assessed or considered in cost estimate; transfer of asset to another operator results in changes to integration of closure planning, including progressive rehabilitation.	Modified revegetation or landform strategies not costed; mine asset under new operator changes process of integration with closure resulting in increased costs and/or risk; e.g. landform establishment, progressive cover placement and rehabilitation, rehabilitation maintenance.

Challenges occur across the full mine lifecycle, and some proposed solutions that have been successful for mining operators at different times in the lifecycle are summarised as:

- Pre-mining (mine planning and approvals) – limited information may exist to inform technical studies – for example, cover depth and detailed design, groundwater recovery at closure, tailings consolidation rates. Where appropriate, local area benchmarks and information as well as research may be utilised to inform closure planning.
- Construction and operations – limited planning for closure water system and flows may impact overall water management systems and cumulative impacts downstream. Conceptual closure water design/systems and flows could be developed and used to assess construction and operational systems. Additionally, change management systems for new processes and surface disturbance should include a high-level assessment of impacts on closure and determine whether further assessment is required prior to implementation of modifications. A regular review of closure cost estimates (rates, assumptions and more), a review of closure risks throughout the mine lifecycle, and assessing impacts to closure planning under new ownership and practices has also proved helpful during operations including optimising closure integration in the lifecycle.
- Unplanned or temporary closure – often operations do not have a list of critical actions if unplanned or temporary closure is decided. Conceptual closure plans can identify high-level critical controls that could impact closure (and compliance) to guide response if this occurs. Longer-term items and planning can also be identified alongside requirements for consultation, etc., around modified final landforms considering approvals, etc. Importantly, progressing detailed closure planning early during operations (including investigations where beneficial) is beneficial when unplanned or temporary closure is required in prioritising the closure risks and critical controls, including expenditure.
- Post-closure execution (monitoring and management) – issues may include not providing for some closure costs. As detailed closure planning progresses, monitoring programs related to success criteria and residual risk should be developed, including timelines, frequencies, analytes, review costs, reporting, etc. Additionally, corporately, the holding costs for leases, etc. and likely required approvals if relevant should be provided for considering the time expected for approvals and execution.
- Relinquishment and liability transfer – some costs including take or pay costs, residual risk payments, landholder payments or arrangements and more may not be included as they are not well understood. Consultation on the state processes and landholder expectations including increasing detail of post-mining land use transfer and planning (including for example packaging beneficial land with areas requiring management) should be undertaken during operations as the life cycle progresses to completion.

The identified solutions and other proposed should be considered on a site-specific basis for relevance, risk and likely success prior to application.

3.2.2 Accuracy

The progression of cost estimates from Class 5 to more precise costings may be driven by company policies, financial audit/review findings, and regulatory requirements linked to life-of-mine and mine closure.

Default rates from calculators and tools are estimated based on periodic benchmarking and may reflect averages impacted by types of operation, location, market competition and other aspects. Figure 1 shows the financial assurance security deposits held by the State of NSW by financial year where a significantly higher percentage of mining and petroleum rehabilitation securities (and more of the assessed deposits listed) relate to coal vs. minerals (https://www.resourcesregulator.nsw.gov.au/rehabilitation/mine-rehabilitation#rehabilitation-security-bonds).

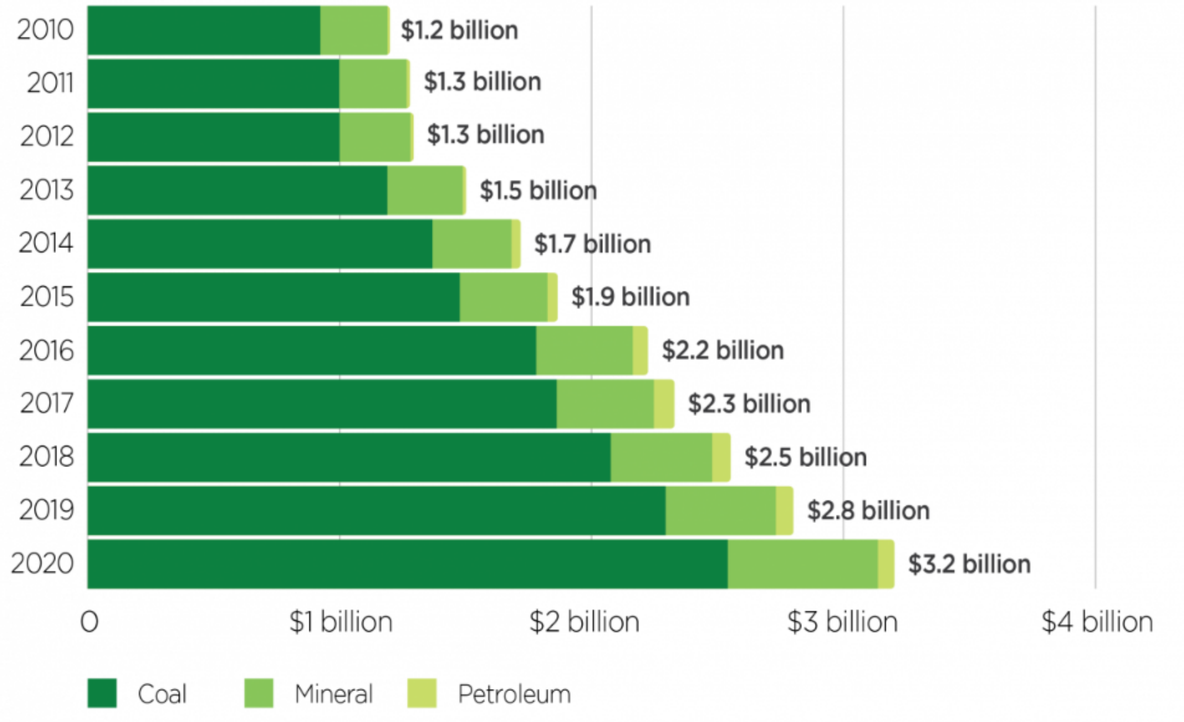

Figure 1 Rehabilitation and mine closure security deposits held by year by the NSW government

As closure planning increases in detail, more accurate inputs on key drivers for closure cost estimates including haul distances, material volumes, treatment strategies, etc. can be determined. Modifications required for final design including erosion and water management mitigations can be added as part of the outcomes of studies and works, e.g. drainage design (and associated schedule of quantities) including geotextile and riprap placement based on the outcome of erosion assessments and landform modelling considering the landform material characteristics.

Accuracy also relates to the source and considerations of the inputs such as ensuring the latest relevant footprint (approved or life-of-mine) is used for the cost estimate where appropriate. The GIS used should be representative of the site requirements, including all disturbance relevant to the cost estimate, and checked for errors/inaccuracies, including overlaps and topological errors. The latest GIS updates, growth media and rehabilitation material volumes, and other considerations, should be included in the process.

Accuracy of rates for rehabilitation and closure, whether internal or third party, should be reviewed or where relevant benchmarked to understand how site-specific context impacts the closure cost estimate. Where more detail is available, such as volumes of material to be moved, more representative (and sometimes lower) rates can be verified due to economies of scale.

The more accurate the inputs, the more likely the closure cost estimate will be representative of the costs to execute rehabilitation and closure.

3.2.3 Assumptions

Early in the closure cost estimation process, assumptions may be made where there is not enough technical information, or the time required to ascertain more accurate information is not sufficient to determine inputs for the cost estimate. These assumptions may be based on previous predictions and not validated or reassessed for accuracy and representativeness. As the maturity of the closure planning and cost estimate progresses, these assumptions should be reviewed and verified or amended as relevant based on operational experience and information from monitoring, research, modelling, etc.

As per Section 2, uncertainty in assumptions can be reflected in closure cost estimates via blanket contingencies, risk-factored estimates or probabilistic costing. The higher the uncertainty in rehabilitation and closure aspects within the estimate, the higher the contingency, risk factor or probabilistic cost range would be. For example, where a revegetation strategy has been established to be successful, including meeting performance success criteria, a risk factor as low as 10% may be applied, versus where the revegetation strategy is generally unsuccessful with significant consequences, a risk factor as high as 100% may be applied.

In reconciling rehabilitation estimates and budgets, actual information from execution and performance of progressive rehabilitation provides a helpful indicator of validity of assumptions and where further technical or other investigation may be required.

Some assumptions may not be validated until much closer to closure based on practicality (e.g. contaminated site investigations under fuel facilities in operation may only eventuate after the facility is no longer in use). Where relevant, industry or specialist experience may assist in ensuring the assumptions are practical until investigations can be concluded and this information used for detailed cost estimation. The significance of the contribution or impact of assumptions to the closure cost estimate can be used as a driver to identify priority areas where further work is required to confirm that closure cost estimates are representative.

3.3 Rehabilitation and closure execution

While not directly due to the closure cost estimation process, there is an inherent assumption of machine and general task efficiency built into the rates used. Where these efficiencies are consistently or significantly below the assumed rate, the closure cost estimate may not reflect the fair value for rehabilitation within a reasonable margin and should potentially be higher.

With a significant focus on production performance and tracking, sometimes the tracking and even management and supervision of rehabilitation works as a non-production activity may be less stringent. Compared to production, rehabilitation areas may be smaller in size and volumes requiring movement, and/or located further away from the production areas. With sometimes competing priorities, limited experience in rehabilitation execution and cost tracking/delineation challenges, limited focus and management of rehabilitation activities may further impact the reliability and validation of cost estimates.

Communication silos between environment and mine planning, and limited incentives for senior management and short- and long-term mine planners specifically to drive improved closure planning/costing and progressive rehabilitation may impact the extent and quality of rehabilitation undertaken. Aspects of the accuracy of closure costs, as noted earlier, may relate to completed rehabilitation and outcomes of the assessment of performance and success.

Modification of cost code tracking for linkages with rehabilitation efforts and comparison of estimated rehabilitation and closure execution costs versus actual costs for completion can assist in identifying where estimated costs and potentially rates or other factors are not representative. Where rates, assumptions and other factors are not representative, realignment and modifications to calculations, etc., should be undertaken for more accurate estimation. Additionally, this may aid in identifying priority areas for improvement of rehabilitation and closure efforts and management as part of business improvements.

Key closure stakeholders in operations include commercial/finance, environment, mine planning, and mining operations. Where closure vision, objectives and completion/success criteria are not aligned, closure costing assumptions and expectations may be adversely impacted – for example, material segregation and encapsulation requirements, final landform at end of mining activities, provision for transition to closure (e.g. water management, tailings deposition, stockpiling rehabilitation materials).

A commercial approach or view may be held that reduction of closure liability or regulatory financial assurance estimates or limited increases should result from cost reviews related to operational budgets and project viability. Where achieving the reduction or limiting increase is the goal versus reviewing optionality and optimisation of design, these conflicts may also impact the cost estimation process and outcomes.

The rehabilitated asset should fulfil some beneficial post-mining land use. The post-closure asset may require management including residual risk and critical controls. Costs associated with transfer of the liability and associated residual risk should also be accounted for; however, especially in cases where a post-closure land user has not been identified or residual risk payments and assessments are not common practice, the estimate for transfer cost has significant uncertainty.

4 Case studies/examples

The author has developed and reviewed closure cost estimates for more than 12 years internationally and within Australia. Some case studies where closure costs were identified not to be representative and approaches undertaken to correct these are summarised in Table 3. Due to sensitivity of financial information, names of companies or sites have not been included.

Table 3 Case studies of key challenges to simple mathematics in closure cost estimation

Challenge	Closure context and situation	Issues	Suggested treatment
Mine closure knowledge base	A coal mine subject to early closure had not completed detailed planning and investigations. After baseline investigations, the cost for closure was determined to be 15% higher than the internal provision estimate.	Poor maturity in closure planning based on life-of-mine expectations.	Mine closure planning guidance, including a knowledge gap assessment and risk assessment with key stakeholders for closure and rehabilitation.
		Inadequate process/rigour of internal closure cost estimation.	More thorough internal cost estimation process, including GIS review, site verification.
	A metalliferous mine looking to close a satellite operation had baseline studies from approximately 20 years prior assessed under different legislation (biodiversity, etc.).	Change in regulatory requirements and criteria.	Review the site baseline, considering approvals and current legislation (e.g. protected species).
	A more recent plan identified post-mining land uses considered more appropriate to the larger operation but potentially unachievable by the satellite site.	Inadequate review/consideration of satellite area characteristics in closure planning.	Reassess the satellite landforms and disturbance for achievability of criteria based on site-specific characteristics.

Challenge	Closure context and situation	Issues	Suggested treatment
Closure cost estimation process (accuracy)	Site GIS for a metalliferous mine excluded some disturbed and legacy areas and some dams. The GIS also had significant overlaps and errors.	Cost estimate quantities were incorrect and not all disturbance/rehabilitation was accounted for.	Correction of GIS. GIS review and site procedure to maintain accurate and up-to-date data.
	Rates used in cost estimates for a metalliferous mine were more than three years old without documentation to support validity as third-party rates.	Potentially inaccurate rates in use increase inaccuracy in estimation.	Benchmark third-party relevant rates and document rates and analysis.
Closure cost estimation process (assumptions)	A metalliferous mine was undergoing its first financial assurance review since acquisition. The regulatory financial assurance increased by >20% of the expected total.	Approval and other closure obligations not well known/understood. No closure cost estimation included in due diligence.	Include review of closure obligations as part of closure cost estimation process. Include closure cost estimation in due diligence.
	A coal operation was developing an unplanned closure cost estimate; however, approvals commitments for re-establishment of drainage post-mining were not costed.	No assumptions or provisional sum included for meeting closure obligations for drainage re-establishment.	Review likely location for drainage re-establishment, including length, activities and materials required and include in estimate.
Rehabilitation and closure execution	A liability estimate was developed to complete rehabilitation on coal pits and dumps, including highwall rehabilitation in an area. The estimate was verified by engineering to be +/- 15% of expected costs. Both estimates were overrun; the amount expended was not the amount by which the next regulatory financial assurance estimate was reduced, with a loss of >AUD 2 M in effort.	Poor delineation of costs expended from operations. Poor supervision of rehabilitation efforts. Significant modification of design in undertaking the work versus strategy in estimation.	Modify the cost code system to allow for tracking of site rehabilitation costs/effort. Improve rehabilitation effort requirements and resourcing. Confirm the detailed final design and implement periodic review processes during execution (e.g. survey).

Challenge	Closure context and situation	Issues	Suggested treatment
	Closure estimates for a historic coal operation did not include costs for management of critical controls until relinquishment and residual risk payment.	Historic site with little oversight and management previously required.	Review critical controls based on site closure risk assessment and budget.
		Regulatory requirements and assessment process for residual risk payments not yet fully established.	Consult with regulators on residual risk process and assessment. Develop an estimate for relevant payments (if required) and include in relevant cost estimate.

5 Conclusion

A wide range of potential issues exist in determining representative mine closure cost estimates that would allow the following simple mathematics in relation to expenditure:

Total closure cost estimate – expended closure costs = remaining cost for closure execution

Without visibility on reliable rehabilitation liability estimates and impacts on finance from undertaking associated activities, rehabilitation may become mainly driven by compliance rather than considering the financial advantages that progressive rehabilitation brings. This has been a driver in recent Queensland and NSW rehabilitation reforms to push progressive rehabilitation.

Key challenges include the mine closure knowledge base, closure cost estimation process, and process of executing rehabilitation and closure. Challenges occur across the full mine lifecycle, and solutions include progressing detailed closure planning early during operations (including investigations where beneficial), review of closure risks throughout the mine lifecycle, regular review of closure cost estimates from rates to assumptions, and assessing impacts to closure planning under new ownership and practices. The uncertainties and inaccuracies introduced by these challenges, as well as the focus and priority given to the rehabilitation and closure process, all impact the closure cost estimate. Rehabilitation reform frameworks in NSW and Queensland and other solutions identified within this paper as successful for operations promote address of aspects of these challenges; outcomes should assist in improving accuracy of closure cost estimates.

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