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Common systemic drivers of closure cost underestimation for earthworks

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Abstract

Despite increased scrutiny from regulators, financiers, and stakeholders, mine closure cost estimates continue to systematically underestimate closure costs. This paper examines recurring technical and commercial drivers of underestimation observed across a broad range of mine closure studies, with a focus on rehabilitation earthworks.

Drawing on a review of both internal and third-party closure cost estimates, supplemented by comparisons with measured production and cost data from implemented works, this paper identifies a consistent pattern of optimistic assumptions embedded within many estimates. A major issue is overestimating equipment productivity by relying on standard production values without adjusting for site constraints or considering the specific nature of the work. These assumptions can materially distort unit rates when applied to large-scale rehabilitation tasks.

This paper also explores the impact of over-optimistic volumetric assumptions, particularly for landform reprofiling and reshaping activities. Simplified geometric models frequently underestimate actual material movements, double handling and trimming losses when compared to surveyed as-built outcomes. In addition, a recurring source of underestimation is the inadequate allowance for indirect costs, including contractor preliminaries, temporary works, supervision, management activities and quality control.

For practitioners, this paper provides a structured lens for stress-testing closure cost estimates by explicitly linking assumptions to observed cost variance. Rather than advocating for conservatism, the findings highlight where targeted adjustments, validation against measured data, and more transparent treatment of indirect costs can materially improve the defensibility and credibility of closure cost estimates.

Keywords: *cost estimation, continual improvement, risk, earthworks*

1 Introduction

Accurate mine closure cost estimates (CCEs) are critical for closure planning, financial provisioning and regulatory compliance. Closure liabilities are typically material, and underestimation can affect project valuation, financial assurance and closure readiness (ICMM 2019; Sanders et al. 2024).

Despite improvements in guidance and tools, CCEs continue to underestimate actual costs. Reviews of historical estimates show that costs often increase as projects approach closure; frequently exceeding earlier estimates and expected accuracy ranges (Dunow & Kalisch 2022; Sanders et al. 2024).

The consequences are significant. Underestimation can result in insufficient provisioning, increased regulatory scrutiny and elevated corporate risk (ICMM 2019). It can also reduce the perceived value of progressive rehabilitation, limiting its integration into mine planning and execution.

Previous studies have documented substantial divergence between consultant-prepared CCEs and realised closure costs, even where similar datasets and estimating approaches are applied (Espezua & Vasquez 2023),

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and have explored the inadequate management of risk cost within many estimates (Byrne 2024; Lilford 2025). Underestimation is often attributed to optimism bias; however, this explanation alone is insufficient. A more telling approach is to examine the assumptions embedded within estimates and understand how they differ from actual execution conditions.

This paper examines common technical and commercial assumptions that contribute to underestimation in CCEs. The analysis draws on multiple estimates and compares them with design, tender and measured construction data.

The focus is on rehabilitation earthworks, where large volumes and complex operating conditions increase the impact of inaccurate assumptions. During the review, 3 recurring drivers of underestimation were considered:

1. optimistic volumetric assumptions
2. overestimated equipment productivity
3. omission or understatement of indirect costs and ancillary activities.

By linking these assumptions to observed cost outcomes, the paper aims to provide a practical basis for improving the accuracy, transparency and defensibility of CCEs.

2 Data sources and methods

2.1 Data sources and scope

This assessment is based on a review of 4 CCEs prepared for large rehabilitation earthworks scopes at operating mine sites. The estimates represent typical industry approaches, including standardised reclamation cost estimation (SRCE) models and first-principles spreadsheet-based methods.

The measured cost data and tenders utilised for comparison with CCEs are sourced from real projects; however, all data have been de-identified to protect confidentiality. No project names, operators or commercial details are disclosed.

The analysis draws on 3 primary data sources:

- CCEs and supporting calculation sheets (see Table 1 for a description of each estimate)
- detailed closure designs and tenders, providing a more developed view of scope, quantities and execution approach
- measured data from implemented rehabilitation works at sites where the authors of this paper have supported delivery.

Client discussions have also been used to provide context, particularly where scope definition or cost allocation practices influence outcomes.

Table 1 Description of closure cost estimates (CCEs) used to inform the assessment

Estimate	Description
CCE-1	Mature iron ore operation in the Pilbara region of Western Australia The estimate was prepared using the standardised rehabilitation cost estimation (SRCE) model. Informed by progressive rehabilitation works conducted at the site
CCE-2	Mature iron ore operation in the Pilbara region of Western Australia. The estimate was prepared as a class III first-principles spreadsheet-based model
CCE-3	Mature iron ore operation in the Pilbara region of Western Australia The estimate was prepared using the SRCE model
CCE-4	Mature gold operation in the Pilbara region of Western Australia. The estimate was prepared as a class III first-principles spreadsheet-based model Informed by progressive rehabilitation works conducted at the site

2.2 Analytical approach

The analysis compares assumptions used in CCEs with reference data derived from design, tender and operational sources. This allows commonly applied estimating assumptions to be tested against more detailed or realised conditions.

For each systemic driver considered, assumptions embedded within the reviewed CCEs are:

1. identified and extracted
2. compared with relevant reference datasets
3. assessed to determine the direction and magnitude of divergence.

Where multiple reference datasets are available, results are presented as ranges rather than single values to reflect variability in conditions and execution methods. The focus is not on defining a single 'correct' value but on identifying consistent patterns of underestimation and their underlying causes.

2.3 Data treatment and interpretation

All datasets have been normalised where required to enable comparison across different studies, equipment classes and work types. Measured data are interpreted in the context in which they were collected, including operating conditions, work front constraints and construction sequencing.

The analysis does not attempt to re-estimate closure costs. Instead, it examines how standard estimating practices can lead to systematic bias when simplifying assumptions are not validated against design or operational data.

In particular:

- Design data provide a realistic representation of constructability and material movement.
- Tender data provide a market-tested view of scope, productivity and indirect costs.
- Measured data provide direct evidence of actual performance during execution.

2.4 Limitations

The dataset is limited to projects for which design, tender or measured data were available, and therefore does not capture the full range of closure conditions. However, similar assumptions were observed across all reviewed CCEs, suggesting that the behaviours identified are systemic rather than project specific.

3 Systemic driver 1: volumetric assumptions

Volumetric assumptions are a primary driver of CCEs for rehabilitation earthworks and have a direct influence on total closure liability. Many estimates rely on simplified geometric approaches developed at early study stages. While these provide a practical starting point, they can underestimate actual material movement if not validated or adjusted.

Comparison with design and measured data shows that common simplifying assumptions – such as idealised cross-sections, balanced cut-and-fill and nominal layer thicknesses – do not reflect typical construction conditions. These assumptions do not adequately account for ramps, irregular geometries, double handling or trimming requirements.

Even modest underestimation at the unit level can result in material cost impacts when applied across large landforms.

3.1 Waste rock dump reprofiling volumes

A common method for estimating reprofiling volumes uses idealised cross-sections applied along a slope length (Figure 1). This approach is widely used in SRCE and first-principles models due to its simplicity. Alternative methods include the use of software to measure the cut-and-fill volume between a survey surface and 3D design. The methods used to calculate the waste rock dump (WRD) reprofiling volume for each estimate are presented in Table 2.

For each estimate, the reprofiling volume for a representative WRD from the CCE was compared with the volume derived from an idealised cross-section multiplied by the mid-slope length and the reprofiling volume measured during rehabilitation works or determined by the detailed design (Table 3).

Comparison with detailed designs and measured outcomes shows that this method generally underestimates reprofiling volumes unless correction factors are applied. Key drivers of variance include:

- irregular as-tipped geometries
- ramps and access constraints
- corner and transition areas
- rehandle requirements.

Across the examples reviewed, simplified methods underestimated volumes for all but the simplest landforms. In some cases differences were material, particularly where designs required significant rework to achieve final landform geometry.

In the examples of CCE-1 and CCE-2, the designs included taller lift heights (20–50 m high), and were tipped out in two or more lifts separated by berms. In the case of CCE-2, the reprofile volume was also impacted by complex interface with the surrounding environment. In the case of CCE-3, a cursory review identified that insufficient berm widths had been retained between lifts to enable the proposed design to be implemented. Hard constraints at the toe of the WRD meant that to implement the design, significant volumes of the WRD were required to be rehandled; this is considered more an oversight but highlights the importance of challenging reprofiling assumptions within a CCE. For CCE-4, the additional reprofiling volume compared to the idealised cross-section method was attributed to the management of ramp areas, variance in the as-tipped berm profile and management of corners on the landform.

The idealised cross-section method is a useful tool for quickly estimating reprofiling volumes but without appropriate correction it is prone to underestimating true reprofiling volumes. Wherever possible, reprofiling volumes should be sourced from 3D designs. Where this isn't possible and an idealised cross-section method is adopted, inclusion of a correction factor of between 1.2 and 1.35 (depending upon WRD complexity) is appropriate. Even where 3D designs are available it can be observed that the final reprofiling volume can vary and should be considered when undertaking range analysis or defining contingency allowances, especially for more complex designs.

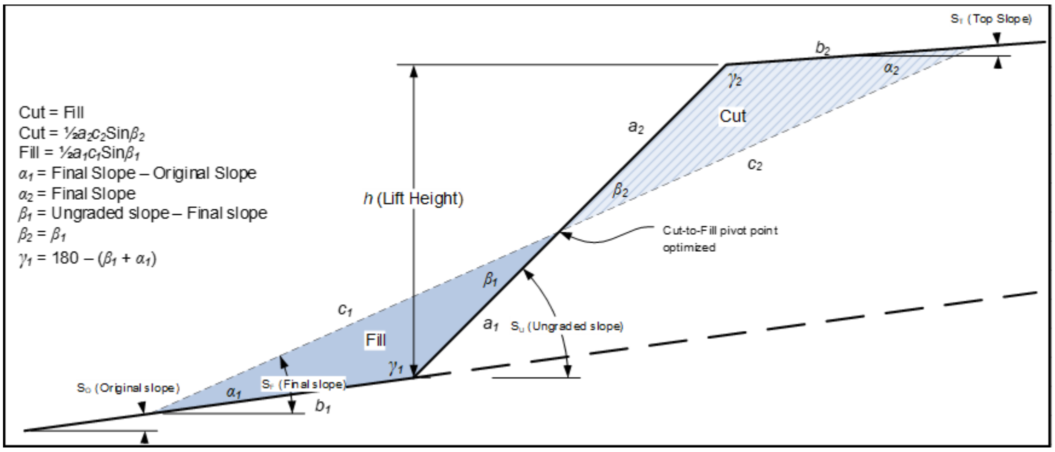

Figure 1 Optimised geometric model utilised to estimate cut-and-fill reprofiling volume (SRCE Software 2026)

Table 2 Description of methods used to determine waste rock dump (WRD) reprofiling volume within the closure cost estimates (CCEs)

Estimate	Method
CCE-1	Sourced from detailed designs where available, otherwise from concept level closure designs prepared during mine plan development; typically 25–50% greater than the default reprofiling volumes estimated using the standard calculation approach utilised in SRCE
CCE-2	Volumes sourced from preliminary 3D designs (e.g. Figure 2); allowance for 40% rehandle volume within the quantity
CCE-3	Calculated using an idealised cross-section for the batter/berm design, multiplied by the mid-slope length (standard SRCE volume calculation); no allowance for rehandle or impacting factors such as rework
CCE-4	Calculated using preliminary 3D designs developed for each WRD, based upon sections separated at 100 m

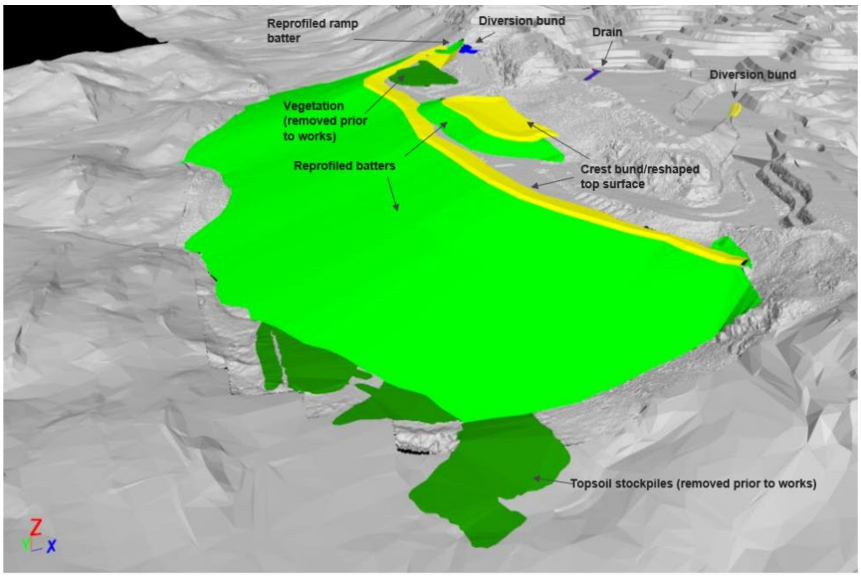

Figure 2 Example of design utilised to calculate the reprofiling volume of a waste rock dump within a closure cost estimate

Table 3 Waste rock dump (WRD) reprofiling volumes within closure cost estimates (CCEs) compared with actual reprofiling volumes for a representative WRD

Estimate	Idealised cross-section method reprofiling volume	Value contained within the CCE	Actual reprofiling volume	Variance from CCE volume estimate
CCE-1	20,200 m^3	30,555 m^3	31,774 m^3	+4.0%
CCE-2	147,330 m^3	212,486 m^3 (excluding rehandle allowance)	195,362 m^3	-8.1%
CCE-3	537,594 m^3	537,594 m^3	4,900,000 m^3	+922%
CCE-4	175,404 m^3	172,428 m^3	212,598 m^3	+21%

3.2 Waste rock dump armour volumes

Where required, WRD armouring can present a high-cost item for CCEs. Rock armour is typically specified as a minimum thickness with an allowable tolerance thickness than this minimum value (e.g. +200/-0 mm). Most estimates assume placement at exactly this thickness, based on the final compacted volume. The assumption applied in determining rock armour volumes for each CCE is presented in Table 4.

All estimates utilised the final spread thickness of the armour layer to determine the rock armour volume. CCE-2 included a load factor for this volume to account for the difference in the loose bulk density within the haul truck as opposed to the compacted bulk density following spreading and track rolling of the armour. No estimate reviewed included an allowance for surplus material spread beyond the minimum target thickness.

For comparison, 4 WRDs where closure works were completed and sufficient survey data was available to measure the finished rock armour volume were assessed to compare the target rock armour thickness per the design with the volume measured on the survey following the completion of armour works (Table 5). The measured rock armour volume ranged from 22–35% greater than the design thickness. Generally, a higher uplift was observed for taller lift heights and where no GPS machine guidance was utilised.

It is noted that the volumes assigned in CCEs are typically the finished surface (the compacted material), which has a higher bulk density than the loose material within the haul truck. Calibration from a comparison between truck count data and measured volume identified a load factor of 0.85 (i.e. 1 m^3 of loose material within the haul truck resulted in 0.85 m^3 of compacted armour material). As load and haul activities are typically costed based upon truck capacity, this is an important factor to consider within CCEs and was only included in one of the CCEs reviewed.

None of the CCEs reviewed included a volume uplift factor for armouring. As was demonstrated in Table 5, if adopting a minimum armour thickness specification, it is almost certain that some additional armour will be required to implement the design. It is recommended that the uplift factor should reflect the assumed construction tolerances for the works as well as the complexity and slope length for armouring. In most cases, an uplift factor of between 110 and 135% is likely to be appropriate.

Estimating armour volumes on a finished surface basis, without allowance for tolerance or material state, systematically underestimates required material movement and cost.

Table 4 Rock armour assumptions applied within the closure cost estimates (CCEs)

Estimate	Waste rock dump rock armour treatment
CCE-1	Assumed cover placed at the exact target thickness on all reprofiled slopes
CCE-2	Assumed cover placed at the target thickness with a 15% load factor on 70% of the batter
CCE-3	Assumed cover placed at the exact target thickness on all reprofiled slopes
CCE-4	Assumed cover placed at the exact target thickness on all reprofiled slopes

Table 5 Measured rock armour volume at completion compared to the design volume surface calculated using the minimum required thickness

Waste rock dump	Design rock armour volume	Measured rock armour volume	Volume uplift factor	Description
WRD-1	25,700	31,865	124%	Concave, 20 m height, GPS machine guidance
WRD-2	193,691	261,168	135%	Concave, 40 m height
WRD-3	13,201	17,851	135%	Concave, 50 m height
WRD-4	8,117	9,867	122%	Linear, 20 m height, GPS machine guidance

4 Systemic driver 2: equipment productivity

CCEs typically calculate unit costs by combining equipment hourly rates with assumed productivity. While hourly rates are generally well understood, productivity assumptions are a major source of uncertainty. This review of equipment productivity focuses on batter reprofiling.

Most estimates (both first-principles- and SRCE-derived) rely on production handbooks such as the Caterpillar Performance Handbook (the Cat Handbook) (Caterpillar 2022) to derive dozer productivity. The Cat Handbook provides estimated production curves for a range of dozing distances (e.g. Figure 3) and correction factors for several aspects including operator experience, materials, dozing method, visibility, efficiency and the dozing grade.

The resultant production rate generated using the Cat Handbook presents the estimated maximum production rate that a dozer can realise, (Caterpillar 2022) assuming the blade is fully utilised (not generally the case given the high standards required for WRD batter reprofiling works), and does not consider trimming works (a standard requirement following bulk reprofiling). It also does not consider the potential for finishing dozing or rework to achieve the final design tolerances that are specified for most rehabilitation earthworks programs (e.g. Figure 4).

The method used to calculate productivity, and the treatment for additional trim works or other dozer time in batter reprofiling, are presented in Table 6 below. The modelled reprofiling production rates (inclusive of any allowances for rehandle, detailed reprofiling and trim) and the measured productivity rates are included in Table 7.

The data indicates that using the Cat Handbook values without including sufficient allowance for shaping and trim activities will systemically overestimate productivity rates and therefore result in the underestimation of closure costs. Even where very conservative settings were adopted, measured productivity could be as much as 73% lower than predicted productivity. Only one WRD had a measured productivity higher than that utilised in the CCE; however, this was only due to the inclusion of a 40% allowance for final shaping and rehandle, and an additional 5 hours/hectare for final trim. The Cat Handbook remains a valuable tool in informing the development of production rates in dozers but it must be utilised with awareness that this presents the maximum productivity rate and is not representative of cases when a significant portion of dozer time can be spent during rehabilitation works, when only a portion of the blade is being utilised.

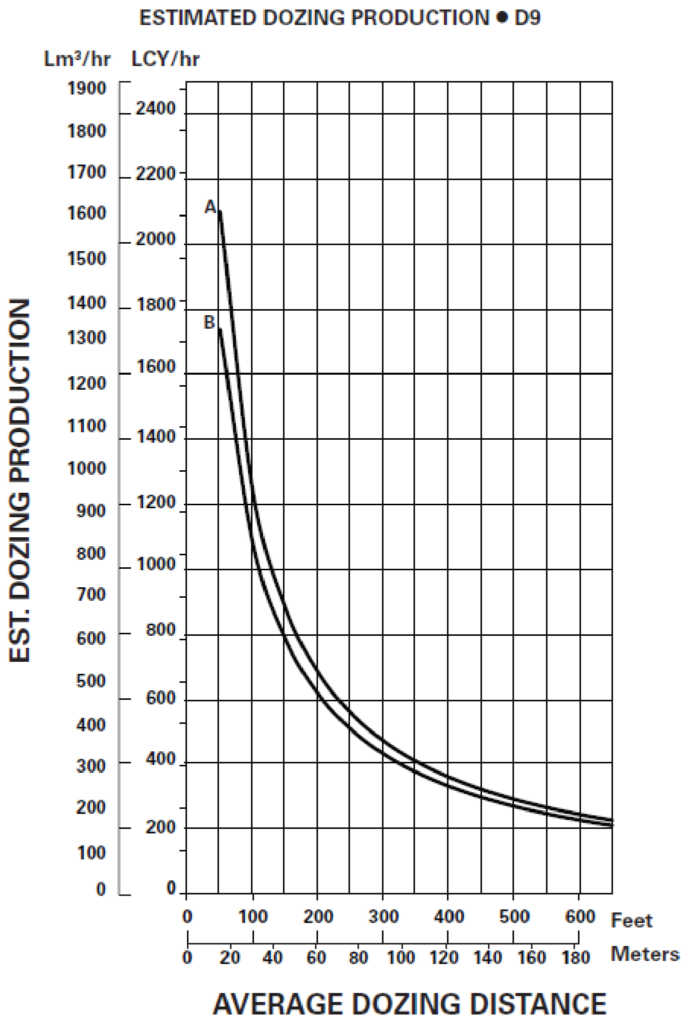

Figure 3 Example dozer production curve for a D9 dozer (Caterpillar 2022)

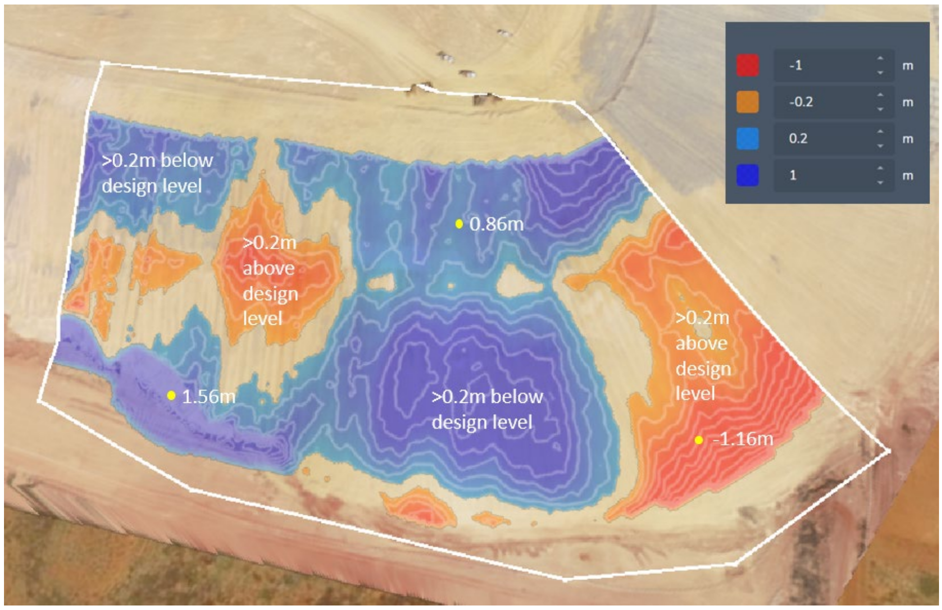

Figure 4 Rework area following survey of a reprofiled batter slope

Table 6 Methods used to determine waste rock dump (WRD) reprofiling production rates within the closure cost estimates (CCEs)

Estimate	CCE treatment for estimating WRD reprofiling production rates
CCE-1	SRCE method (Cat Handbook), assuming D10 dozer, poor operator skill and 30 min/hr efficiency; the most conservative setting available in SRCE. Reprofiling doze distance calculated based on idealised cross-section method. No additional allowance for trimming
CCE-2	Cat Handbook, assuming standard operator skill, 0.76 weight correction, 0.8 visibility correction and 45 min/hr efficiency. Included a 40% allowance on the volume to account for additional dozing for long push areas and rehandle. Reprofiling doze distance calculated based on designs developed for each WRD. Allowance of 5 hours per hectare for trim with a D9
CCE-3	SRCE method (Cat Handbook), assuming D8 dozer, standard operator skill and 50 min/hr efficiency. Reprofiling doze distance calculated based on idealised cross-section method. No additional allowance for trimming
CCE-4	Dozer modelling completed based upon measured cycle times and blade capacity, corrected for a blade factor. Reprofiling doze distance calculated from conceptual design sections. Additional allowance of 5–25% for rehandle. Model included a 15% uplift on hours included to account for dozer trim

Table 7 Comparison of modelled versus measured reprofiling production rates (including bulk reprofiling and trim) for batter reprofiling for a representative waste rock dump closure cost estimate (CCE)

Estimate	Dozer utilised (or Caterpillar equivalent)	Doze distance (per the CCE)	CCE modelled productivity	Measured productivity	Variance
CCE-1	D9	16 m	522 m^3/hr	143 m^3/hr	-73%
CCE-2 (WRD-A)	D10 with D9 trim	120 m	177 m^3/hr	255 m^3/hr	+44%
CCE-2 (WRD-B)	D10 with D9 trim	50 m	299 m^3/hr	288 m^3/hr	-4%
CCE-3	D8	13 m	449 m^3/hr	NA	NA
CCE-4	D9	110 m	309 m^3/hr	188 m^3/hr	-39%

5 Systemic driver 3: uncosted activities and indirect costs

The third systemic driver of underestimation assessed within the review is insufficient consideration given to ancillary and enabling activities and the underestimation of indirect costs. Ancillary activities can refer to a wide range of items but, in the context of this paper, refer to predicable and necessary items that enable the rehabilitation works, such as establishing access, construction of temporary ramps, establishment of go-lines, and recovery of soil and/or rock materials from landform footprint areas.

One common misconception for cost estimates is that uncosted but required activities are addressed via the inclusion of a contingency. In a CCE the purpose of contingency is a specific allocation of resources required in addition to the base estimate as a provision for inherent uncertainty (such as a reasonable variance of assumptions) and/or contingent risks (Byrne 2024; Engineers Australia 2025; AACE International 2022). They are not intended to account for ancillary activities that aren’t costed within the CCE. Where ancillary or enabling activities aren't defined it is common practice to include them as an allowance (Engineers Australia 2025).

Indirect costs refer to a range of costs that aren't tied to the physical works, including owners' management costs, mobilisation, management costs and post-closure monitoring costs. This review has focused on indirect contractor's costs specifically.

5.1 Ancillary activities

Each of the CCEs was assessed to consider ancillary and enabling activities associated with WRD rehabilitation. These are general provisions or costs included for enabling activities (i.e. those excluding reprofiling activities, cover construction, water management controls, growth media placement or rehabilitation activities). The management of these ancillary activities within the CCEs reviewed are included in Table 8.

The cost impact of these items can be considerable. For execution works at the CCE-1 site, the costs associated with establishment and removal of temporary ramps, establishment of go-lines and other ancillary works was reported as approximately 10% of the total direct costs. For the execution works at the CCE-2 site, 13% of total direct costs for WRDs and ramps were associated with ancillary and uncosted day-rate works.

Inclusion of an appropriate allowance for ancillary activities should be adopted where appropriate.

Table 8 Closure cost estimates (CCEs) treatment of ancillary waste rock dump (WRD) closure activities

Estimate	Treatment of ancillary WRD closure activities
CCE-1	No inclusions or allowances
CCE-2	Allowances included topsoil recovery, temporary access ramps, upstream water management and toe bund construction
CCE-3	No inclusions or allowances
CCE-4	No inclusions or allowances

5.2 Indirect costs

For each CCE, the percentage of the contractor's (or owner's, where works are costed assuming the use of the owner's fleet) indirect costs was determined as a proportion of direct costs (Table 9). Costs included contractor staffing, overheads and mobilisation/demobilisation costs. The CCEs had an indirect cost percentage of between 14.7–18% of direct costs.

In comparison, for operational sites with an ongoing progressive rehabilitation campaign, the measured proportion of indirect costs ranged from 14–15.7%. For programs undertaken on a campaign basis with full mobilisation and site establishment, indirect costs ranged from 27–97% of direct costs (based on a review of 8 completed programs or final tenders. See Table 10).

The settings within the CCE were generally reasonable for projects where progressive or ongoing rehabilitation works are undertaken; however, they didn't typically account for fixed monthly costs for standalone rehabilitation projects or short-campaign projects where mobilisation and establishment costs are proportionally much higher than in larger, longer-term campaigns.

Table 9 Percentage of contractor/owner fleet indirect costs as a proportion of direct costs in closure cost estimates (CCEs)

Estimate	Percentage
CCE-1	15.6%
CCE-2	14.7%
CCE-3	14.8%
CCE-4	18.0%

Table 10 Measured or quoted percentage of contractor indirect costs as a proportion of direct costs for campaign rehabilitation projects (excludes progressive/ongoing rehabilitation)

Project	Contractor	Percentage
1	A	77.7%
2	A	45.9%
3	A	76.2%
	B	97.1%
4	A	81.1%
	B	43.1%
	C	26.9%
	D	89.9%
Mean		**67.2%**
Median		**77.0%**

6 Recommendations

CCEs are commonly influenced by optimistic assumptions relating to volumes, productivity and indirect costs. These issues are not isolated: they are consistently observed across multiple estimates and have a material impact on total closure liability.

Improving estimate reliability requires targeted adjustment of these assumptions to better reflect expected execution conditions.

6.1 Volumetric assumptions

Wherever possible, quantities should be derived from 3D designs. Where simplified methods are required, apply correction factors to reflect known sources of variance.

For WRD reprofiling it is recommended to apply a correction factor of approximately 1.2–1.35 when using idealised cross-sections, depending on landform complexity and observed conformance with tip-to designs.

For rock armour:

- Allow for construction tolerance where thickness is specified as a minimum.
- In most cases, adopting a thickness between the target and allowable maximum provides a reasonable basis.
- Apply an uplift factor (typically 120–135%) to account for placement variability.

- Account for the difference between loose and compacted material volumes when estimating load and haul requirements.

Where adequate information exists, consideration should be given to the rock armour material balance and the source of potential rock armour.

6.2 Equipment productivity

Recommendations for determining assumed equipment productivity include:

- Treat handbook-derived production rates as maximum achievable values, not typical field performance.
- Explicitly allow for bulk dozing, shaping (including rework) and trimming activities.
- Based on measured data, apply a productivity reduction or time allowance equivalent to approximately 40–70% additional dozer hours relative to bulk production estimates to account for these additional activities, depending on work complexity.

6.3 Ancillary activities

Recommendations for ancillary activities are:

- Identify and include enabling works required to implement the design (e.g. access, temporary ramps, material recovery).
- Where not separately defined, apply an allowance of between 10–15% of direct costs, depending on site complexity.

6.4 Indirect costs

For indirect costs it is important that the indirect cost assumptions align with the intended delivery model. In particular:

- For progressive or ongoing rehabilitation, lower indirect cost proportions may be appropriate.
- For standalone or campaign-based closure works
  - Allow for full mobilisation (and multiple mobilisations/demobilisations where this is built into the productivity assumptions for fleet scaling), site establishment and support functions
  - Indirect costs are likely to exceed 45% of direct costs and may be significantly higher for short-duration works.

6.5 General recommendations

In general it is recommended that all assumptions informing key costing activities are stress tested to ensure that they are appropriate. The objective is not to introduce blanket conservatism but to ensure that estimates reflect how closure works are actually likely to be executed. To undertake this stress testing, the following framework could be adopted:

1. Identify the assumption category (volume/productivity/indirect costs).
2. Validate it against reference datasets.
3. Apply correction factors where the design maturity doesn’t meet an appropriate threshold.
4. Test the sensitivity of a volumetric uplift, productivity reduction or indirect escalation.
5. Reconcile it with the execution context (e.g. post-closure execution campaign versus a progressive rehabilitation campaign).

7 Conclusions

This study shows that closure cost estimates (CCEs) are consistently influenced by a small number of recurring assumptions that lead to underestimation. Across the datasets reviewed, 3 drivers were evident:

- underestimation of rehabilitation earthwork volumes
- overestimation of equipment productivity
- insufficient allowance for ancillary activities and indirect costs.

These assumptions are often embedded in standard estimating approaches and can persist without being tested against design, tender or measured execution data.

The analysis demonstrates that relatively small differences in volumes, productivity or indirect cost allowances can result in substantial divergence at the total closure liability level, particularly for large earthworks scopes.

Improving estimate reliability does not require blanket conservatism. Instead it requires the targeted adjustment of key assumptions using available reference data and a clearer link between estimate inputs and expected execution conditions.

While this study focuses on specific aspects of rehabilitation earthworks, the behaviours identified are relevant to a broader range of closure activities. Strengthening how these assumptions are developed and validated will improve the accuracy, transparency and defensibility of CCEs, and support more reliable financial provisioning and planning over the life of mine.

Use of artificial intelligence disclosure statement

In the preparation of this work the authors used Microsoft CoPilot to preprocess and merge costing data spreadsheets, and to review and edit text. The authors have reviewed the content and edited it where required, and take full responsibility for said content.

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