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Geotechnical challenges for final landform: a case study at Werris Creek

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Abstract

Final landforms for open pit mine closure must ultimately demonstrate that they are safe, stable and non-polluting by meeting long-term performance expectations. These landforms are typically designed and shaped using waste rock material at low-angle geometries. Consequently, closure landforms are typically developed to meet conservative design acceptance criteria (DAC), incorporating elevated factors of safety to address long-term uncertainties associated with hydrogeological rebound, progressive material degradation and evolving geomechanical conditions.

As open pit operations approach completion, progressive reshaping of in-pit and ex-pit waste rock dumps in accordance with the final closure geometry operate under the assumption that the remaining resource extraction will not compromise the final landform. Significant unplanned instability late in the mine life may compromise the DAC through undermining the confidence in the geotechnical model, consequently raising questions about stability thresholds and whether closure requirements can still be achieved or a substantial redesign is required.

This paper presents a case study of an open pit coal mine that experienced a major endwall failure within the final 6 months of resource extraction. This occurred during advanced stages of landform development, posing significant challenges to both operational continuity and closure compliance. The study details the integrated geotechnical assessment undertaken to characterise the failure, and risk mitigation strategies implemented to enable continued resource recovery alongside adaptive slope redesign and waste placement methodologies.

The case study outlines the modifications to the final landform design to achieve long-term stability and closure performance objectives which included re-establishing the confidence in the geotechnical model. The outcomes demonstrate the importance of adaptive closure planning, robust monitoring and contingency-based design frameworks in managing late-stage geotechnical instability and ensuring sustainable post-mining landforms.

Keywords: *final landform, slope stability, design conformance*

1 Introduction

Werris Creek open cut mine is located approximately 5 km south of the township of Werris Creek in the Gunnedah Basin, New South Wales, Australia (see Figure 1).

The Werris Creek mine was operated by Werris Creek Coal Pty Ltd, which was wholly owned by Whitehaven Coal and had been in operation since 2005. Coal extraction was completed in April 2024, with the final rehabilitated landform completed in May 2026. The mine was a multi-seam, open cut coal operation mined from south to north using truck and shovel equipment in a haulback mining configuration. The production rate was typically 2.0–2.5 million tonnes of run of mine (ROM) coal per annum.

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The resource was hosted in a steeply dipping, synclinal structure forming an ellipsoidal-shaped bowl approximately 3,200 m long, 1,200 m wide and up to 200 m deep. The surrounding area comprises flat to undulating terrain comprising mainly pastural farmland.

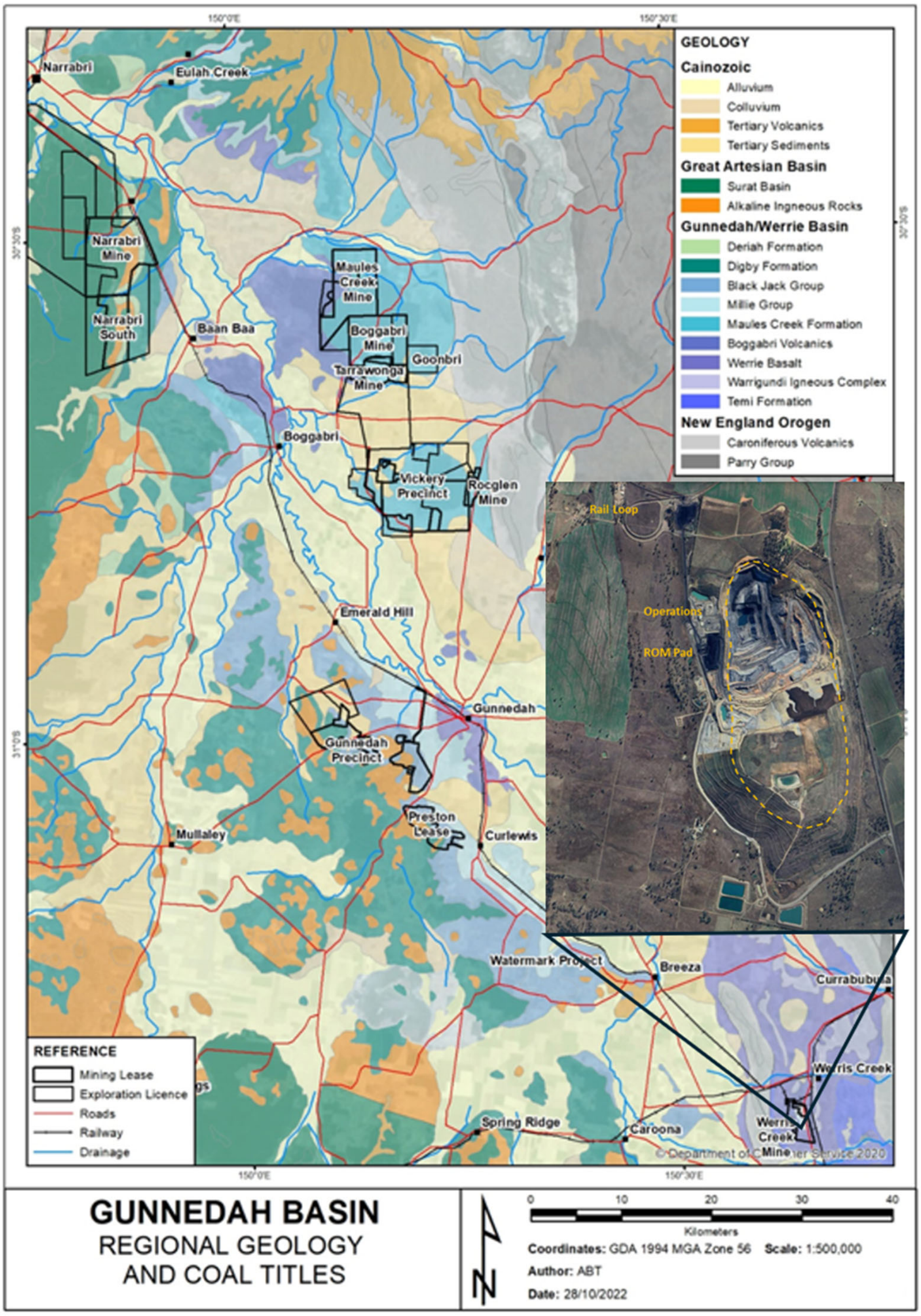

Figure 1 Werris Creek mine layout during operation

In early 2023, during the final 6 months of operation, a large block of in situ material failed along the northern end of the eastern slope. The failure is reported to have occurred following several days of progressive ground deformation and cracking while coal extraction was continuing and being actively managed through the site's hazard management system.

At the time of the event, significant portions of the final landform were under review to improve the long-term groundwater model and minimise rehandling. The timing and location of the failure presented a significant challenge to closure planning as it directly undermined confidence in the geotechnical model that underpinned the final landform design and associated design acceptance criteria (DAC). With key stakeholders raising fundamental questions as to whether the final landform geometry could still achieve the long-term stability objectives without substantial redesign, particularly given the limited opportunity for additional investigation, the advanced stage of landform construction, and the constraints imposed by the remaining mining sequence. This paper presents a case study of the failure investigation and subsequent reassessment of the geotechnical model identifying the knowledge gaps, ensuring they were addressed, and how the DAC were adapted to manage the residual risk to achieve long-term stability of the final landform.

2 Engineering geological setting

2.1 Local geology

The Werris Creek coal deposit is situated within the Werrie Gunnedah Basin, a structurally controlled synclinal basin representing an isolated remnant of Early Permian coal measures preserved within a northwest-trending syncline of the Greta Coal Measures.

The Werris Creek Coal Measures (also referred to as the Willow Tree Formation) comprise a sequence of at least 9 coal seams, designated A through G, with G seam forming the lowermost stratigraphic horizon. Seam depths range from approximately 10 m at subcrop to more than 180 m within the synclinal axis. Individual seam thicknesses reach up to 8 m, although more commonly range between 3–4 m. The depth of weathering varies from approximately 10 to 50 m, with a general increase observed from the southeast towards the northwest across the deposit.

The overburden and interburden lithologies exhibit significant variability, with intact rock strengths ranging from low to high. Floor conditions are locally characterised by weak bedding parallel horizons which may act as planes of weakness and contribute to localised geotechnical instability. Bedding dips are steep proximal to subcrop (up to ~35°), flattening progressively towards the synclinal core.

The basin is structurally complex, containing multiple fault structures with interpreted displacements of up to 5 m. Additionally, several igneous dykes have been intersected, particularly within the northern extent of the open pit.

A representative geological cross-section (Figure 2) highlights the dominant structural geometry, notably the steeply dipping coal seams along both the western and eastern limbs of the syncline.

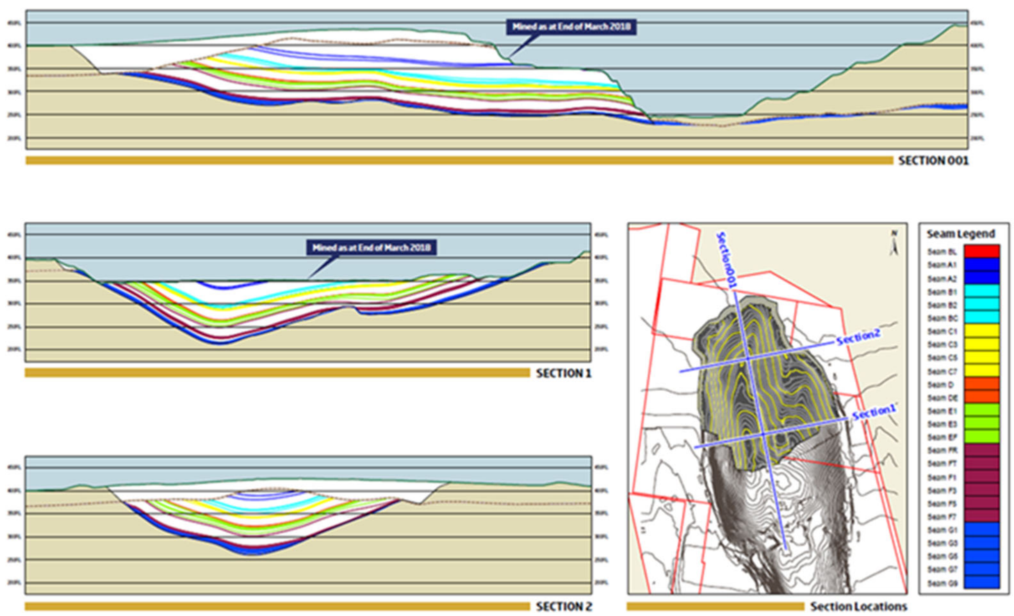

Figure 2 Typical cross-section through the deposit

2.2 Local structure

The coal deposit is hosted within a closed synclinal structure with a longitudinal axis oriented approximately north-northwest(NNW)–south-southeast. Bedding dips adjacent to the subcrop are steep, locally reaching up to ~60°, and progressively decrease to sub-horizontal orientations towards the synclinal axis.

Structural interpretation, informed by drillhole data and mapping from historical underground workings, identified multiple fault structures with displacements of up to approximately 2 m. In the southern extent of the open cut, a complex, NNW-trending graben structure was modelled, exhibiting cumulative displacements of up to 5 m. The influence of this feature diminished as mining advanced northward; however, several discrete NNW-oriented fault zones with individual displacements of up to 7 m were subsequently exposed in the highwall. These observations indicate that faulting persists beyond the confines of the synclinal structure and is regionally continuous.

2.3 Groundwater

The pre-mining groundwater table is located only a few tens of metres below surface. In the early mining stages, mine dewatering and slope depressurisation were managed solely through sumps and pumping water from the bottom of the pit. No active depressurisation was undertaken or considered necessary.

3 Pre-2023 closure conditions

Coal mines that are undertaking studies for or implementing closure plans are subject to a regulatory framework for environmental management and approvals that includes consideration and assessment of post-mining landform safety and stability. Geotechnical specialists who are required to undertake assessments of safety and stability will rely on their training, skills and experience to do so. Definitions of ‘geotechnically safe’ and ‘geotechnically stable’ are provided for alignment with geotechnical usage. From a geotechnical perspective, an assessment of safety is likely to rely upon, and thus follow, an assessment of stability.

Prior to the slope failure in early 2023, closure planning for Werris Creek was progressing through the modification of the approved landform or modification 5 (mod 5). The proposed modification represented a shift from a previously approved fully backfilled pit to a closure strategy incorporating a single residual void. This approach was intended to reduce material rehandling requirements and improve the long-term groundwater regime associated with the final landform.

Progressive landform reshaping had commenced in southern areas of the pit in anticipation of closure, under the assumption that the remaining mining sequence would not adversely affect the stability or achievability of the proposed final landform configuration.

The proposed mod 5 landform was supported by a series of geotechnical assessments completed between mid-2021 and 2022, focusing on evaluation of the financial year 2022 (FY22) final landform shell geometry. These assessments included 3D limit equilibrium (LEM) modelling undertaken using Slide3 and considered both short-term and long-term groundwater conditions (Figure 3).

Stability performance was assessed against selected Factor of Safety (FoS) criteria consistent with industry practice. The assessments concluded that the proposed landform geometry would achieve acceptable stability performance under the adopted geotechnical model assumptions.

The assessments also recognised inherent limitations in the available site-specific dataset, including uncertainty associated with material strength characterisation, structure continuity and groundwater conditions, and recommended that appropriate conservatism and monitoring be applied where uncertainty remained.

Progression of the proposed mod 5 landform relied on several key assumptions, including:

- that geological and structural conditions encountered during the remaining mining sequence would remain consistent with those represented in the geotechnical model

- that material strength parameters assigned to key lithological units were representative at a slope scale
- that progressive mining and landform development activities late in the mine life would not introduce new instability mechanisms that would compromise long-term closure performance.

These assumptions were considered reasonable at the time based on historical operational performance and the outcomes of the geotechnical assessments supporting the proposed closure modification.

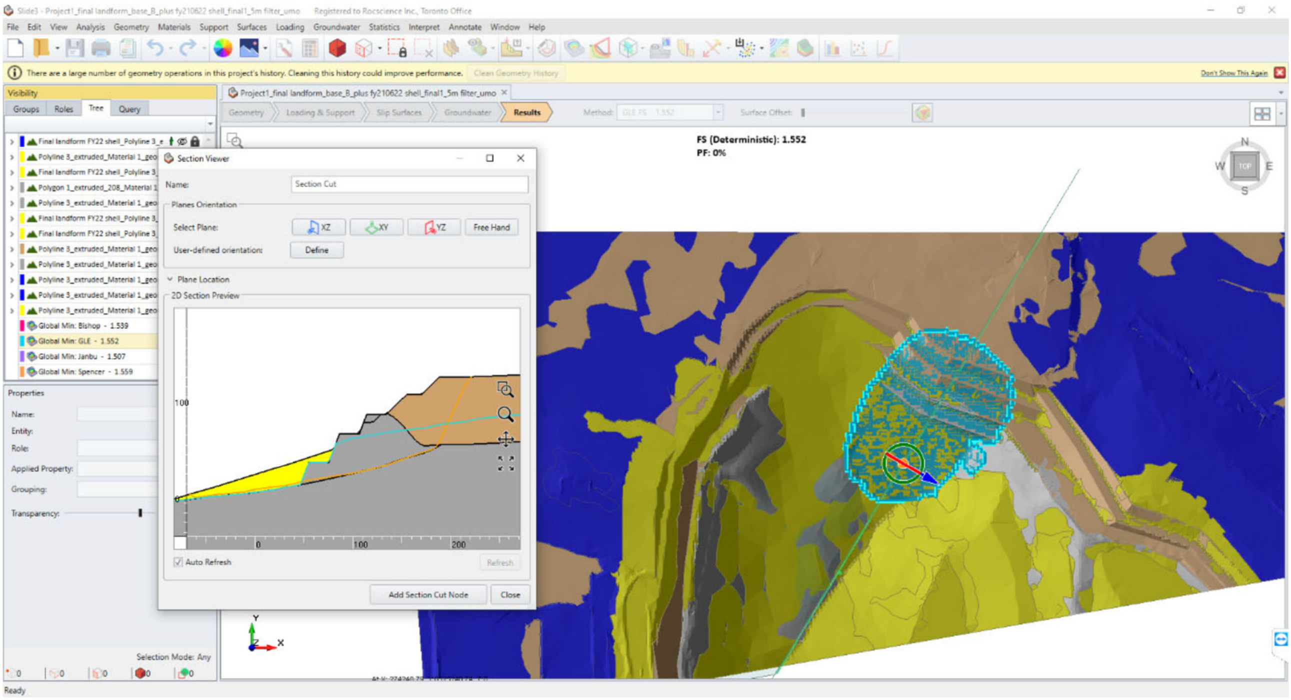

Figure 3 3D analysis output of the modification 5 landform

4 Slope failure incident

4.1 Failure mechanism

In early 2023 a large block of in situ material dislodged from the northern end of the eastern slope during the final stages of extraction of the steeply dipping coal seam from the base of the wall. From reports, this is understood to have occurred following ongoing creep and cracking of the ground surface. Initial inspection of the area (Guy 2024) indicated the following features:

- a large and extensive headscarp that extended beyond the 'failure zone' several metres to the north
- an extensive side shear evident in the mid-slope haul road that was particularly prominent in the south where the topography was open and less in the north where confinement is provided by the pit topography
- buckling at the toe with no break out observed but a bulging and cracking of the rock mass was noted
- opening up of cracks within the body of the displaced mass.

Based on the initial observations and morphology, the slope failure appeared to be a translational or sliding-type failure with a major fault structure defining the headscarp and a possibly steep and weak bedding parallel plane that the mass was sliding on. Figure 4 below shows a drone image of the failure soon after occurrence, with the key features clearly shown.

Figure 4 Unmanned aerial vehicle drone image of the initial slope movement

An idealised cross-section through the failure was developed with the geological and geotechnical data available at the time of the incident (Figure 5). This was based on the geomorphology of the failure and key features noted in the failure mass.

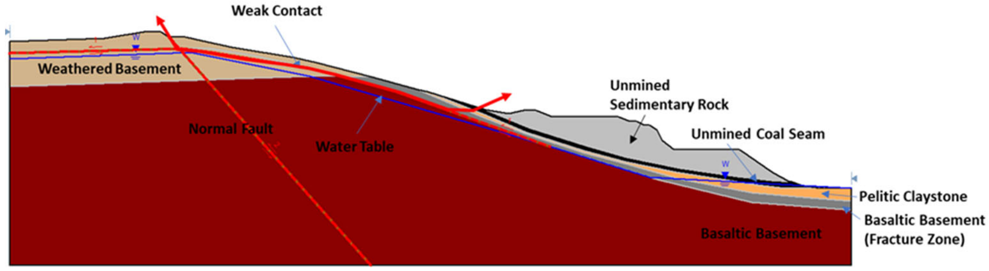

Figure 5 Cross-section through the failed slope

4.2 Failure back-analysis

To accurately characterise the slope failure mechanism and inform the design of stable slope configurations it is essential that the geotechnical model reflects in situ conditions and is demonstrably representative of the governing geotechnical controls. The 3D slope stability model geometry was developed by integrating the defined geotechnical domains with the site-specific geological and structural framework of the deposit (Guy 2024).

Back-analysis was undertaken focusing on the identified instability within the eastern slope, with the objective of calibrating material properties to replicate observed failure conditions. The analyses were performed using Slide3 (Rocscience Inc.), applying 3D limit equilibrium methods.

Model validation was conducted qualitatively through comparison of the simulated failure surface with deformation data derived from slope stability monitoring radar, enabling both spatial and material property calibration as follows:

- spatial validation. The unconstrained model reproduces the observed failure location and geometry

- material property validation. Calibrated material parameters yield an FoS of 1.00 ± 0.05 under failure conditions.

Final model validation involved direct spatial overlay of the back-analysed Slide3 failure surface (light blue) with the radar-derived deformation extents (red zone), demonstrating strong correlation between predicted and observed behaviour. The validated model output is presented in Figure 6.

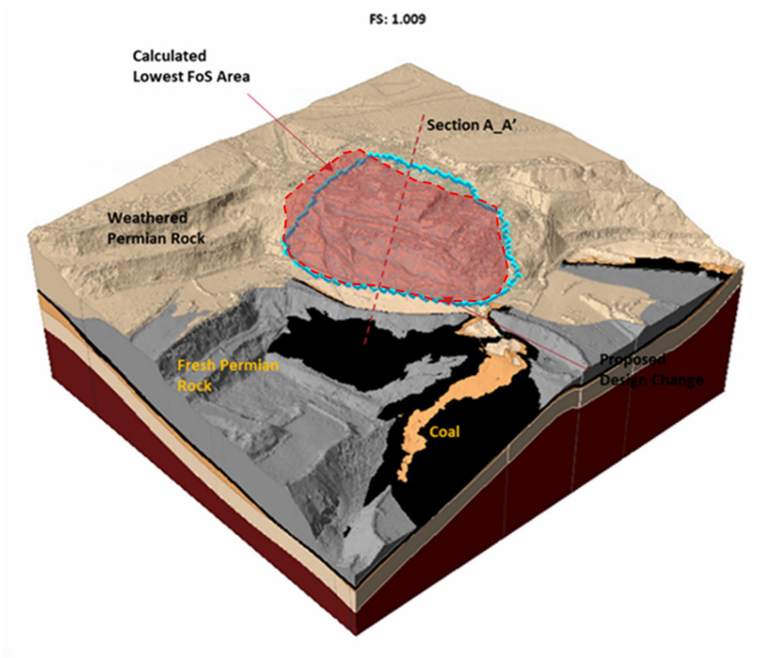

Figure 6 3D limit equilibrium model output of the slope failure

4.3 Slope stability mitigation

Continued extraction of remnant coal resources from the base of the failed mass was required to achieve planned production targets and complete mining within the affected area. To facilitate this, a mitigated landform was developed with the following geotechnical and operational objectives:

- reduction of the driving forces through removal of material from the upper portion (head) of the slope
- retention of sufficient toe buttressing to maintain overall slope stability during extraction of the remaining resource
- establishment of a safe and practical operating environment for ongoing mining activities.

Hydrogeological conditions were assessed as having a negligible influence on the failure mechanism. Drillhole data indicated that the failed rock mass was relatively dry, with instability interpreted to be predominantly gravity driven. As such, no depressurisation or dewatering measures were incorporated into the remediation strategy.

The slope remediation design was developed to enhance stability while also aligning with final landform requirements, necessitating the concurrent execution of coal extraction and stabilisation earthworks. Ongoing monitoring was implemented throughout operations, utilising slope stability radar and routine visual inspections through their hazard management process to quantify both the spatial extent and rate of slope movement, thereby informing operational decision-making and risk management, and ensuring operator safety during a dynamic situation.

Monitoring data was progressively integrated with updated 3D LEM analyses using Slide3, allowing the geotechnical model to be iteratively refined as remediation and mining activities progressed. This approach enabled confirmation of key modelling assumptions, assessment of the effectiveness of interim stabilisation measures and evaluation of alternative remediation pathways as site conditions evolved. The combined use of real time monitoring and progressive 3D stability modelling provided a basis for operational decisions, ensuring that remediation strategies were technically sound and adaptive while maintaining operator safety as the primary consideration throughout the mitigation works.

4.4 Methodology

As part of the day-to-day measurement tools, regular onsite UAV (unmanned aerial vehicle) scans and photos of the slope provide up-to-date topography as earthworks are undertaken to provide mining engineers with volumes for dump and coal planning. UAV data is collected by lidar ranging whereby sensors use light energy emitted from a laser to scan the ground and measure the ranges of what bounces back. The end result is a rich set of elevation data that can be used to produce high-resolution maps and 3D models of natural and man-made objects.

The following methodology was proposed to provide meaningful updates to key stakeholders during the proposed mitigation and mining earthworks:

1. Establish a routine flyover with the UAV to provide a regular detailed topographical surface. Triangulate and trim the surface for the area of interest.
2. Update the 3D Slide3 model at regular intervals using the latest topographical surface to reflect progressive excavation and remediation activities.
3. Add any other features like tension cracking or water seepage to the model. Update the location of the fault where encountered.
4. Re-run the stability analysis to confirm key assumptions, assess the evolving FoS and evaluate the effectiveness of interim stabilisation measures.
5. Use the outcomes of the slope stability radar data to validate the progressive Slide3 results, helping to inform operational decision-making and appropriate remediation pathways towards a safe and stable landform.

5 Evaluating the geotechnical model

Following the slope failure, the level of geotechnical knowledge underpinning the design of the eastern slope and final landform was reviewed. Although the mine had operated for an extended period without major instability, the failure highlighted limitations in the original geotechnical dataset and the need to refine the existing geotechnical model for long-term closure design. In particular, the available core laboratory testing was limited, site-specific material strength data were sparse, and exposure-based inspections and back-analysis opportunities had been relatively limited prior to the event.

The absence of earlier large-scale failures had contributed to a degree of confidence in the prevailing geological, structural and material strength assumptions, which were considered appropriate based on observed operational performance to that point. However, the late-stage nature of the failure demonstrated that acceptable operational performance does not necessarily equate to a high level of confidence in long-term slope or landform stability, particularly under post-closure conditions.

In response, a geotechnical reference report (GRR) was developed to consolidate the historic geotechnical knowledge, and a gap analysis was undertaken to improve model confidence and better understand historic and site-specific geotechnical conditions. The GRR defined the baseline geological, structural, hydrogeological and geotechnical assumptions used in stability assessment, explicitly documenting the level of knowledge, sources of data and associated uncertainties for each model element (Table 1).

The resulting gap analysis was then able to be used to assess the geotechnical model elements' potential to influence the long-term stability of the final landform.

This GRR-based review and gap analysis was critical in re-establishing confidence in the geotechnical model following the failure and ensuring that subsequent remediation and closure designs were founded on an explicit understanding of uncertainty rather than implicit assumptions carried forward from operational performance alone.

Table 1 Pre-failure model evaluation

Model element	Level of knowledge	Gap in understanding
Geology/strata model	Moderate to high	Definition around strata outside of the resource
Structural model	Moderate	Model confined to the resource Complexity not known
Material strength properties	Moderate	Generic properties assumed due to no or limited test data
Groundwater pressure model	Moderate	Observational-based groundwater model Limited direct measurements available
Methods of analysis	Moderate	Failure mechanism recognised but not fully understood or modelled. 2D analysis underrepresenting the complexity of the geotechnical model
Field performance observations	Moderate to high	All field performance observations are based on visual inspections only

Integration of a targeted post-failure drilling program was undertaken in and around the failure zone to improve characterisation of the rock mass and defect conditions controlling slope behaviour. A series of dedicated geotechnical drillholes were completed to obtain oriented core, allowing detailed assessment of lithology, rock mass quality, defect frequency, orientation and persistence. Downhole acoustic televiewer surveys were used to supplement core logging and provide continuous structural data, particularly where core recovery was poor or structural definition was ambiguous.

The combined drilling and televiewer datasets were used to refine the geological and structural models, confirming the presence of multiple fault structures and locally developed weak planes associated with the folded stratigraphy. These data addressed key gaps identified in the GRR, reducing reliance on inferred or regional assumptions and enabling more representative assignment of rock mass and structural parameters in the stability analyses. The improved definition of defect geometry and rock mass conditions directly informed the updated geotechnical model, increasing confidence in the interpreted failure mechanism and in the subsequent assessment of final landform stability.

6 Post-failure mitigation landform

The post-failure mitigation landform was developed while mining was ongoing, under conditions where the slope instability needed to be actively managed to maintain safe operations and enable continued resource recovery. At the same time, any remediation and interim landform development was required to align with the long-term objective of achieving a stable, closure-compliant final landform. This necessitated an integrated approach in which short-term risk management, operational constraints and long-term closure performance were considered concurrently.

As mining and remediation activities advanced, the revised landform configuration evolved progressively through regular collaboration between the geotechnical and mine planning teams. The final closure outcome comprises a single residual void in the northwestern corner of the pit, with the remainder of the excavation backfilled and recontoured to tie into the surrounding natural landform. The residual void has an irregular-plan geometry with a maximum slope height of approximately 150 m, and is anticipated to equilibrate to a long-term static water level of approximately RL 355 m (Figure 7).

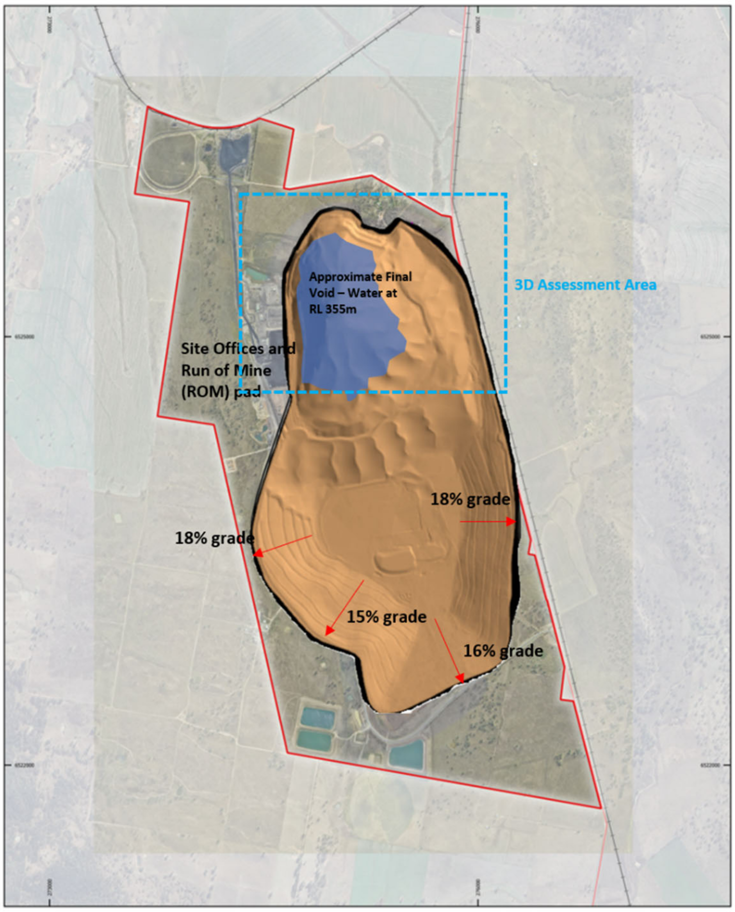

Figure 7 Post-slope failure final landform

For interim mining conditions at Werris Creek, slope design criteria target a minimum FoS of ≥1.20 under limit equilibrium conditions, increasing to ≥1.30 in areas proximal to critical infrastructure. For final landform slopes, the selection of an appropriate FoS must reflect the level of confidence and reliability associated with the input parameters and modelling assumptions. Key drivers of slope stability include material strength characteristics, structural framework, groundwater conditions (including long-term recovery and drawdown assumptions), and the governing failure mechanisms, all of which may vary spatially across the site.

The Werris Creek geotechnical model, as documented in the site GRR, remains constrained by limited site-specific data relating to material strength parameters and hydrogeological conditions. Notwithstanding these limitations, operational experience over approximately 20 years has provided valuable empirical insight into the dominant modes of instability across the deposit.

On this basis, a long-term design criterion of FoS ≥1.50 was adopted for final landform slopes. This higher target reflects the need to accommodate potential long-term degradation mechanisms, particularly within weathered materials, and to account for residual uncertainty in the input assumptions.

The proposed final landform geometry was assessed through a series of stability analyses using both 2D and 3D modelling approaches, developed with the GRR as the baseline framework. Analyses consider both short-term (transient) and long-term (equilibrium) groundwater conditions, with the latter assumed to recover to the regional groundwater level. Results from the stability assessments indicate that the proposed final landform satisfies the minimum FoS criteria considered appropriate for long-term closure at the site. Results are presented in Figures 8 and 9.

The resulting final landform therefore represents an outcome that was not only responsive to an active late-stage geotechnical hazard but deliberately shaped to satisfy long-term closure objectives. By integrating hazard management, progressive remediation and closure-focused DAC during the final stages of mining, the approach ensured that operational decisions did not compromise, and in fact directly supported, the achievement of a stable and closure-compliant landform.

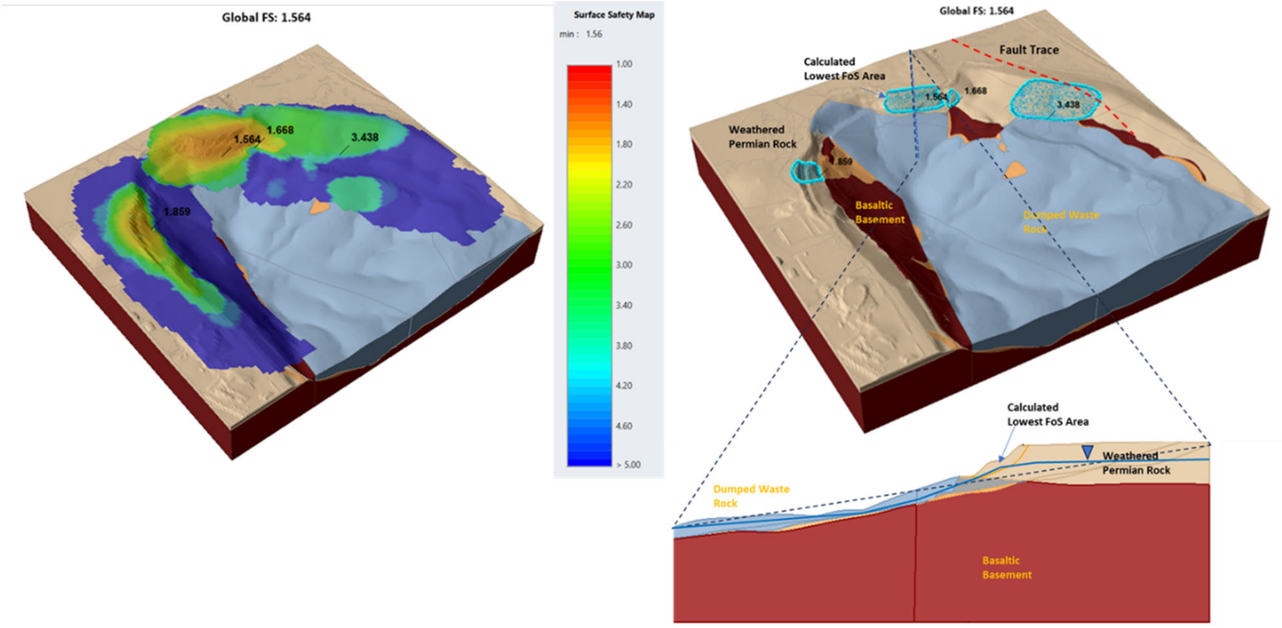

Figure 8 Final landform (FLF): short-term groundwater condition

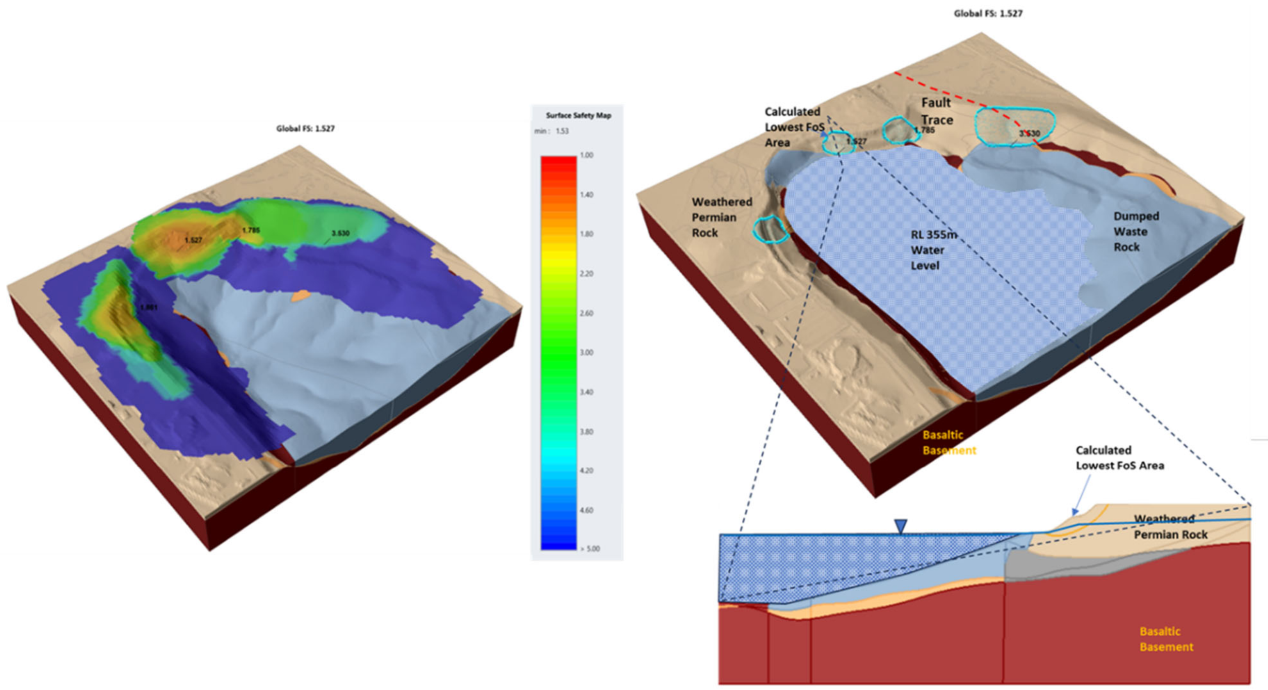

Figure 9 Final landform (FLF): long-term groundwater condition

A progression of the concurrent slope failure mitigation, final resource extraction, and formation of the final safe and stable landform is presented in Figure 10.

Figure 10 Eastern slope progression to final landform

7 Model reliability

Guidance developed under the Large Open Pit (Read and Stacey 2009) project frameworks presents 'data uncertainty' classifications linked to 5 project stages (conceptual through to operations); however, in practice, many operations do not achieve level 5 or operations data maturity across the full life of mine prior to mining. While such classifications may be appropriate for defined mining horizons (e.g. initial production phases), they are not necessarily representative of conditions over the entire mine life. Accordingly, model uncertainty should be treated as a dynamic parameter, subject to continuous reassessment as new data is acquired, rather than as a static classification fixed at a given project stage.

In addition, recent work undertaken through the ACARP-funded Project C34028 completed in May 2024 (Simmons et al. 2024), Guidelines for Assessment of Geotechnically Safe and Stable Post-Mining Landforms, introduces a model uncertainty rating worksheet. This approach aligns conceptually with the LOP data uncertainty framework but advances the methodology by assigning quantitative weightings to individual model components based on their relative influence on overall geotechnical model performance and stability outcomes.

The comparative assessment of model uncertainty pre- and post-failure presented in Table 2 adopts a weighted percentage scoring system reflecting the contribution of each input parameter to model reliability. The pre-failure assessment indicates an overall model reliability of approximately 68%, primarily constrained by the reliance on assumed or generic material strength parameters, structure continuity and the absence of site-specific calibration data. While the general failure mechanism had been conceptually identified, there was limited ground truthing to validate or constrain model inputs.

Subsequent investigation, including targeted data acquisition and refined analysis, has resulted in a significant improvement in model reliability to approximately 87%. This enhancement reflects the improved definition of material properties, structural controls and hydrogeological conditions.

These findings reinforce that geotechnical model uncertainty assessment should be an iterative process throughout the life of mine. Continuous identification of data gaps, coupled with prioritised investigation and targeted mitigation strategies, is critical to progressively increasing model confidence and ensuring robust stability assessment and landform design.

Table 2 Geotechnical model confidence assessment (table adapted from Simmons et al. 2024)

Model element	Weighting	Data confidence multiplier				Score: pre-failure	Score: post-failure	Comments: explanation of score increase
		Introductory (0.0)	Low (0.2)	Medium (0.6)	High (1.0)			
Geology/strata model	15%	Basic surfaces with unreliable or missing data	Assessment based on 'typical' regional conditions	Geological surfaces extracted from site geological model	Use of information such as drill logs and field mapping to define sub-geotechnical units within broader geological units	9%	12%	Knowledge was increased through targeted localised drilling within and around the failure area to enhance the strata model
Structural model	10%	No local information	Structure assumed typical of the region	Structure broadly understood from observation and experience at the site	Either no dominant structure OR structure well understood from mapping and drilling	6%	10%	Drilling and mapping of faults extending outside of the resource model have increased understanding of the structural aspects and failure mechanism of the slope. Faulting was confined to the coal measures and pre-failure resource
Strata/material complexity	5%	No local information	Strata or structure complexity is not well understood across the deposit	Strata and structure complexity is understood but not well defined across the deposit	Strata and structure complexity is understood and well defined across the deposit. Strata are quite uniform in thickness and properties	4%	5%	The structural setting (within a steep-sided syncline) was well understood Faulting complexity inside the resource was well defined but not external Knowledge of potential bedding parallel weakness/shears was assessed but not confirmed in drillcore
Material strength properties	25%	No local information	Derived from published data for the material classifications,	Derived from tests on key strata sampled from	Derived from site-specific tests on key strata	18%	23%	Material strength properties were based on limited testing but mostly 'site experience' or generic properties Further rock testing and back-analysis were able to provide a more localised dataset to use

			without specific regional data	sites within the region				
Groundwater pressure model	15%	No site measurements Concept model only	Pre-mining groundwater study OR sensitivity analyses included in stability analyses	>2 years measurement for site groundwater network, with interpretation	>2 years measurement of at least 2 piezometers at the slope in question, with associated groundwater analysis	9%	12%	Groundwater has been measured through observation and limited piezometers (mainly environmental monitoring bores) for most of the mine life Additional bores were added around the northeastern wall post-failure to proof the groundwater model
Method of analysis	10%	No quantitative analysis	Able to approximately represent the failure mechanism BUT there is limited industry or site experience on failure types	Able to accurately represent the failure mechanism AND there is limited industry or site experience on failure types	Able to accurately represent the failure mechanism and good correlation to site and industry examples	7%	10%	Failure mechanism at site was well understood (translational sliding) although in a basic form. Analysis was limited to 2D and not able to account for variability outside of a section line 3D analysis undertaken was able to account for the structural complexity and more accurately represent the slope and failure mechanism
Field performance observations	20%	Limited visual observation of slopes analysed	2–5 years of visual observation of the slope types in question	>5 years of visual observation OR >2 years of movement measurement at the slope	>5 years of movement measurement at the slope types in question	15%	15%	All field performance observations have been based on visual inspection until failure, after which a slope stability radar was utilised for 6 months Additional tools such as lidar comparison and InSAR were utilised post failure
					Total	68%	87%	A 32% uncertainty in the model highlights the assumptions and unknowns that were present A 19% increase in model certainty post failure provides a more reliable final landform design

8 Conclusion

The late-stage slope failure at Werris Creek occurred at a critical point in the mine life, when elements of the final landform were being progressively constructed. The event highlighted scope to enhance the original geotechnical model, including improved characterisation of geological and structural controls, increased use of site-specific material strength parameters, and enhanced understanding of long-term groundwater behaviour. Although earlier operations had not experienced major instability, the late-stage failure demonstrated that the geotechnical model required more detailed validation to support closure design.

The response to the failure required geotechnical hazard management, ongoing mining and closure planning to be addressed concurrently.

A structured gap analysis following the failure enabled targeted data acquisition and reassessment, leading to the development of a more robust and representative geotechnical model. This revised model underpinned both the remediation strategy and the updated landform design, ensuring that short-term stabilisation measures were aligned with long-term closure objectives. Integration of additional investigation improved structural definition, and refined material characterisation significantly enhanced confidence in predicted slope performance.

Crucially, the revised approach ensured that short-term operational decisions did not compromise, and instead actively supported, the achievement of a stable and closure-compliant final landform. Adoption of design acceptance criteria explicitly linked to model confidence, rather than operational precedent alone, provided a basis for managing residual uncertainty and long-term degradation processes.

Ongoing industry initiatives, including large open pit workflows and research programs such as those supported by ACARP (Simmons et al. 2024), reinforce the importance of iterative model development and validation throughout the mine life cycle.

This case study demonstrates that even where operational performance appears acceptable, a defined level of geotechnical model confidence must be established and maintained, particularly for closure planning. Robust, data-driven models supported by a clear assessment of uncertainty are essential to ensure that final landforms achieve both immediate stability requirements and long-term performance criteria.

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