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Dirt, design and downpours: the Maules Creek Coal Mine landform case study

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Abstract

Geomorphic landform design is increasingly adopted to create safe, stable, self-sustaining post-mining landscapes that integrate with surrounding topography and drainage systems. While conceptually robust, translating design principles into operational reality often exposes gaps between modelling assumptions, construction tolerances, material availability and site-specific constraints.

This paper presents a case study of Whitehaven's Maules Creek Coal Mine in New South Wales, Australia, exploring where implementation diverged from design intent. Challenges included drainage performance, erosion control, material variability, constructability limitations and sequencing constraints within an active mining environment. It analyses how survey control, quality assurance processes and operational interface influenced outcomes, and how early design decisions impacted long-term landform performance and liability risk.

A critical factor influencing landform performance was the exposure of partially completed slopes to severe weather events. High-intensity rainfall and extreme run-off conditions resulted in erosion in the form of rilling and localised slope instability where rehabilitation works had not yet fully stabilised. These events highlighted the sensitivity of geomorphic landforms during transitional construction phases and the need to manage exposure risk between bulk earthworks and final surface treatment.

Seasonal timing also proves significant in the planning phases. Delays that push topsoiling and revegetation into less favourable climatic windows reduce establishment success and increase vulnerability to erosion. The case study demonstrates that effective geomorphic implementation requires not only sound design, but also careful scheduling to ensure landforms are stabilised prior to peak rainfall periods. The paper highlights opportunities that arose from these challenges. Adaptive management, closer integration between design and operations, improved construction verification and refined modelling led to measurable gains in landform stability and performance. It underscores the importance of early cross-disciplinary collaboration and realistic constructability. Key learnings centre on governance through internal inspections and quality assurance processes, reiterative modelling, climatic risk management, and embedding geomorphic principles into mine planning from concept to stabilisation.

Keywords: *planning, rehabilitation, geomorphic landform design, landform stability, erosion, landform construction*

1 Introduction

Interest in mine rehabilitation and closure practices has increased in recent years as many mining operations across Australia approach the end of their operational life and transition towards closure. Alongside this shift, there has been a growing move away from traditional rehabilitation approaches toward the adoption of geomorphic landform designs. Geomorphic landform design aims to improve long-term landform performance by enhancing stability, reducing erosion risk and promoting more natural hydrological function.

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An additional benefit is the creation of landforms that more closely resemble the surrounding landscape. In contrast to traditional rehabilitation methods, which typically rely on linear slopes and contour banks to manage run-off, geomorphic landform designs use natural slope geometries and drainage networks intended to mimic the surrounding landscape all while creating safe, stable and non-polluting landforms (Hancock et al. 2019).

While the principles of geomorphic landform design are well established, the implementation of these principles within operational mining environments can present a range of practical challenges that may not be fully appreciated by operators who are transitioning from traditional methods. Unlike traditional rehabilitation methods, which typically rely on relatively simple slope geometries and engineered drainage controls, geomorphic landform designs incorporate more complex topographic features intended to replicate natural landscape processes. As a result, careful consideration of construction tolerances, material properties and drainage features remains important to achieving the intended design outcomes. Variations in construction conditions and exposure to extreme weather events can influence both the short- and long-term performance of the landform. However, Slingerland & Dressler (2022) demonstrated that geomorphic landform designs are generally more resilient to construction variability and surface roughness than conventional landform designs, with landform-scale topography exerting a greater influence on erosion performance than micro-topographic variations. Accordingly, while construction quality remains important, geomorphic designs can provide greater flexibility during construction while maintaining long-term landform stability and performance.

This paper examines the implementation of a geomorphic landform design at the Maules Creek Coal Mine (MCCM) in New South Wales, Australia, as it transitioned from traditional rehabilitation approaches. The case study explores the practical challenges which were encountered during the construction phase, including construction constraints, material variability and the influence of extreme weather events. Observations from the construction process and early landform performance provided valuable insights into how geomorphic designs perform under operational conditions. These experiences informed improvements to subsequent rehabilitation designs and influenced adjustments to construction methodologies to better align design intent with practical implementation.

2 Site description

MCCM is located within the Narrabri Shire in northwest New South Wales, approximately 45 km southeast of the township of Narrabri. MCCM is an open cut thermal coal mining operation that commenced production in 2015. The mine is currently approved to extract up to 13 million tonnes of coal per annum under its existing approval, with operations permitted to continue until 2034. The mine operates in a semi-arid climate characterised by hot summers, with temperatures exceeding 40°C, and cool winters with average daytime temperatures of approximately 17–18°C and minimum temperatures commonly approaching 2–4°C. Rainfall is moderate, with a mean annual average of approximately 650 mm. Precipitation is typically summer-dominant and generally occurs as short-duration, high-intensity storm events, with comparatively little rainfall experienced during the winter months as per the Australian Bureau of Meteorology climate statistics (Bureau of Meteorology n.d.).

MCCM is situated in the Gunnedah Basin. This is a Permian sedimentary basin, which is characterised by the coal measures that are being mined within the operation. The overburden materials consist of fine- to medium-grained sedimentary rock which can vary in its erosion potential depending on the clay content and weathering profile (Hansen Bailey 2011). Strategic placement of these soils is required during the rehabilitation process to ensure that those with a higher erosion potential are capped with soils which are less prone to dispersion. The topsoils which are recovered from the pre-mining landscape are variable in type, ranging from sandy loams generated in the forested areas through to heavy clay soils on the plains. The management of these soils is extremely important as the structures can be destroyed through inappropriate stockpiling or movement, leading to loss of structure and higher erosive potential (Tordoff et al. 2000).

3 Rehabilitation landform design context

As part of the original mine approval, rehabilitation was aligned to the traditional approach with the final landform containing 'gentle slopes to allow drainage to preferred paths on the slopes' (Hansen Bailey 2011). These engineered, benched landforms were consistent with rehabilitation practices within the Gunnedah Basin at the time (Figure 1).

In 2019, a trial was undertaken to assess the application of a geomorphic landform design, with the primary objective of creating a stable landform capable of achieving long-term closure outcomes. The design incorporated irregular slopes, ridgelines and drainage lines that mimic natural landscape processes and facilitate the controlled movement of water across the landform, reducing reliance on engineered structures such as contour banks (Figure 2). An additional benefit of this approach was the ability to use greater volumes of available spoil material while maintaining landform stability and functionality.

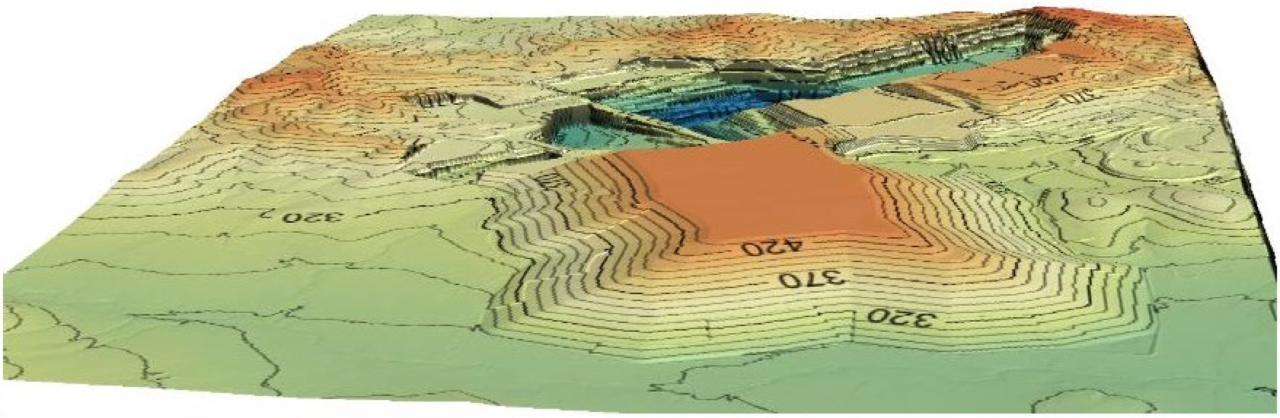

Figure 1 Original MCCM rehabilitation design (pre-2019)

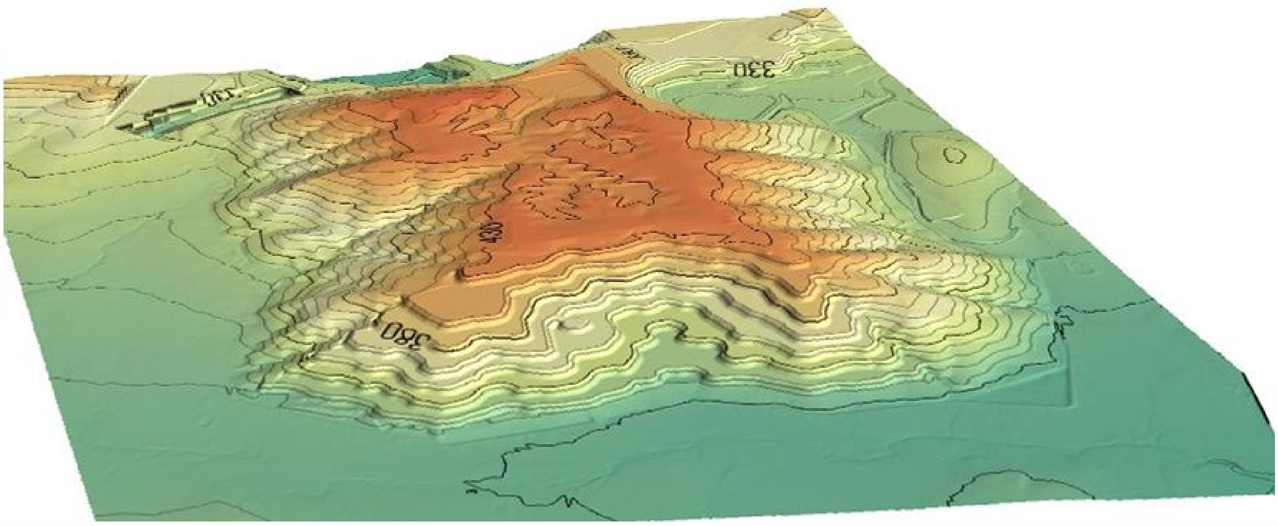

Figure 2 Geomorphic MCCM rehabilitation design (2019+)

The trial included detailed engineering designs and implementation of a geomorphic landform over approximately 100 ha of already dumped overburden. Following completion of the designs, execution of groundworks commenced early 2019, with final slopes completed by December 2019 and drainage works ongoing into January 2020. During the first year following landform construction, the site experienced a series of intense rainfall events, resulting in failure of some drainage structures and, subsequently, adjacent slopes.

The design and landform failure provided several key learnings and marked an important step in the site's transition from traditional to geomorphic rehabilitation method. The lessons derived from this process are discussed in the following section.

4 Transitioning to a geomorphic rehabilitation approach: understanding design versus performance

This section assesses the transition from a traditional to geomorphic rehabilitation approach at MCCM, focusing on landform performance and the key learnings derived from implementation under operational and climatic constraints.

4.1 Landform design

Aligned to project approvals, the original out-of-pit dumps were constructed in a sequence aligned with a traditional rehabilitation approach. Dumps were placed in uniform lifts to a defined height, enabling slopes to be pushed out to consistent angles and forming straight, uniform batters. This typically resulted in linear slopes supported by engineered drainage features such as contour banks and channels (NSW Resources Regulator 2021). Following slope shaping, rehabilitation operators installed contour banks and drainage structures to manage run-off, with these structures commonly used to control flow and reduce erosion on constructed slopes (Minerals Council of Australia 2009).

In contrast, geomorphic landforms are inherently non-uniform, incorporating ridgelines and drainage features to manage water movement across the landform, and their construction requires controlled and variable placement of material during the planning phase to achieve the cut-and-fill balance (Hancock et al. 2019). Critically, where material is over-placed, or where retrofitting is required to accommodate previously dumped material, the resulting as-built landform can deviate from the design specification. These deviations can alter drainage behaviour, resulting in increased flow velocities or the concentration of run-off in areas not equipped to manage large run-off volumes, which can adversely impact landform stability and performance, something which was not fully acknowledged by site at the time.

At MCCM, the trial geomorphic slope abutted an existing traditional linear slope. Run-off from the traditional slope was directed into a retrofitted drainage structure designed to capture flows from both landforms (Figure 3). This drainage structure was designed to accommodate a 1 in 100-year storm event.

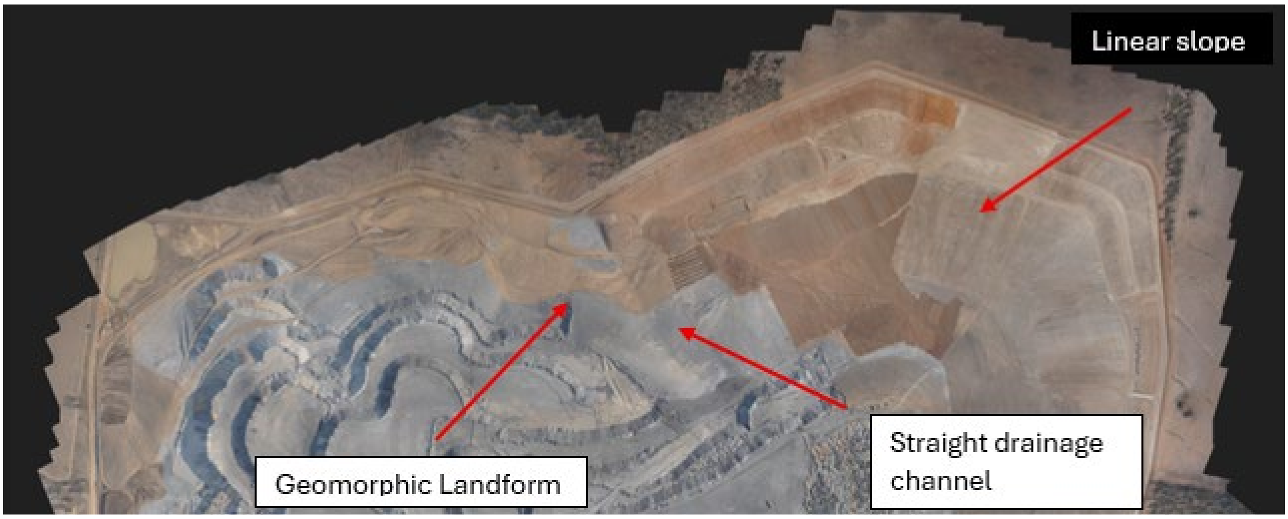

Figure 3 Image taken during construction showing the geomorphic landform and drainage structure abutting the traditional linear rehabilitation

Construction of the geomorphic landform and, specifically the drainage structure and adjacent slopes, was still underway during onset of the traditionally wetter summer season, which began with an intense storm in

January 2020. Topsoil was also still stockpiled to the left of the drainage structure, and rock lining was yet to be installed. The combination of an exposed geomorphic slope (rock and vegetation cover) and the concentration of run-off from the adjacent linear slope resulted in flow velocity contributing to the erosion and damage. This led to failure of the drainage structure, and material wash-down (Figure 4).

Figure 4 Status of the geomorphic landform adjacent to the failed drainage structure following an intense summer storm (January 2020)

Discharge from the drainage structure flowed into a perimeter surface drain designed to convey run-off to a sedimentation dam. The outlet entered the surface drain at approximately 90°, directing flow into the opposite batter. This caused localised erosion of the surface drain wall, breaching containment, and allowing water to flow into a non-operational area of the mine.

4.2 Climate influence

During the trial construction period (2019–2020), the Narrabri region was experiencing a prolonged drought that commenced in 2017, with 2019 recorded as both the driest and hottest year on record (BOM 2020).

Prior to the first storm event, only 5.6 mm of rainfall had been recorded on the rehabilitated slopes following construction, with the largest individual event being 2.8 mm. On 16 January 2020, the first significant rainfall event occurred following a prolonged period of elevated temperatures exceeding 40°C. This short-duration, localised storm delivered approximately 55.6 mm of rainfall over a short period. As a result, damage was sustained to a number of incomplete drainage structures, with sediment mobilised into the perimeter drain. A second storm event occurred on 8 February 2020, further exacerbating the damage. The peak rainfall intensity for this second event occurred for a 3-hour duration, with an annual exceedance probability (AEP) of just below 1% [greater than a 1 in 100 average recurrence interval (ARI)], indicating a rare event. This storm event combined high-intensity, short-duration rainfall with unlikely longer-duration rainfall totals. A total of 88.8 mm of rain fell in a 6-hour period, with 83.6 mm of this falling within a 3-hour period.

Table 1 shows recorded February 2020 rainfall intensities and corresponding estimated AEPs for rainfalls up to 3-hour duration at the MCCM weather station. The AEPs were estimated by comparing the recorded rainfalls to design rainfall intensities from the Bureau of Meteorology for durations up to 3 hours (BOM, 2016). The data indicate that the rainfall intensities for durations between 5 and 30 minutes have AEPs of approximately 35–40% (equivalent to around a 1 in 2 ARI), which represents frequent events. The rainfall intensities for durations of 1.5–2 hours have AEPs of around 3% (equivalent to around 1 in 33 ARI), representing infrequent events.

Table 1 Rainfall data from the MCCM weather station(8 February 2020)

Duration	Rainfall (mm)	Intensity (mm/h)	AEP (%)	ARI (years)	Peak recorded between
5 min	8.0	96.2	35.6	2.32	14:00–14:05
10 min	12.0	72.0	40.2	1.9	13:55–14:05
15 min	15.8	63.2	34.3	2.4	13:55–14:10
30 min	21.0	42.0	35.7	2.3	11:55–12:25
45 min	32.6	43.5	14.2	6.5	11:25–12:10
1 hour	41.6	41.6	7.6	13	11:20–12:20
1.5 hours	56.0	37.3	3.1	32	11:20–12:50
2 hours	61.6	30.8	2.8	35	11:20–13:20
3 hours	83.6	27.9	<1	>100	11:20–14:20

While not uncommon for the region, the intense summer storms observed at MCCM in January and February 2020 demonstrated that the combination of prolonged drought, reduced material stability and partially completed drainage structures, when subjected to high-intensity rainfall, resulted in a significant increase in run-off and erosion potential. This led to degradation of the landform and the observed drainage and slope failures (Figure 5).

Figure 5 Status of geomorphic landform following second intense summer storm (February 2020)

The landform was also in its most vulnerable state during this period, as vegetation had not yet established across the rehabilitated surfaces. Dressler & Waygood (2025) identified that geomorphic landforms are subject to additional erosion risks during the revegetation phase, when surface materials are more vulnerable to erosive forces and vegetation cover has not yet developed sufficiently to provide surface protection. As vegetation cover develops, erosion rates reduce and landform stability progressively improves through increased surface protection, improved infiltration and reduced run-off velocities (Hancock et al. 2019; Dressler & Waygood 2025). Consistent with these findings, MCCM landform evolution modelling identified the period prior to vegetation establishment as representing the greatest risk to long-term landform performance, with stability improving substantially as vegetation cover developed.

4.3 Material and operational constraints

The adverse drought conditions experienced at the time also had a negative influence on the materials used for rehabilitation.

Compaction of drainage structures was difficult to achieve, as the dry spoil materials were more difficult to compact into a suitably stable foundation. To compensate, operators undertook multiple passes. However, this resulted in further breakdown of soil structure rather than improved compaction, resulting in poorly bound and unstable surfaces. When high-intensity rainfall events occurred, these surfaces rapidly lost cohesion, resulting in severe erosion and, in some cases, failure of the drainage structures.

Compounding the spoil issues, the topsoils were also affected by the drought conditions. The clay-based soils had dried and hardened. When re-spread over shaped landforms, they formed a dense surface layer that reduced infiltration; which resulted in more water reporting across the slopes and to the drainage structures. This exacerbated the strain on the drainage structures, with water using any variations within the landform as a preferential flow path. As a result, not only the drainage structures were under pressure, but the slope itself saw multiple instances of rill erosion from the movement of water (Figure 6).

Figure 6 Erosion across the constructed geomorphic landform (following 8 February 2020 rainfall event)

Following the initial extreme weather event (January 2020), slopes became saturated and unsafe for equipment access, preventing rectification works from being undertaken. As a result, the already damaged slopes and drainage structures remained exposed. Prior to repairs being completed, the February 2020 summer storm occurred, further exacerbating the existing damage and significantly increasing erosion and structural degradation across both the slopes and drainage network.

4.4 Design and construction quality assurance and control

As noted by Hancock (2004), it is essential that landform designs are modelled to identify potential weak points and understand water flow behaviour, ensuring that no single area is subjected to undue stress which could lead to erosion or structural failure. Prior to construction across the trial area, the initial MCCM landform was modelled using erosion modelling software. However, there were multiple iterations of the geomorphic design driven by material movements requirements, resulting in the modelling not being updated following changes to the materials balance. As a result, areas of the as-constructed slope were steeper than originally designed, with water conveyed faster than originally modelled.

Also, not all rehabilitation fleet dozers were equipped with GPS, with some relying on peg-based guidance to define construction lines. As a result, localised variations were introduced into the slope geometry (Figure 7). Figure 7 illustrates the variance between the design surface and the as-built landform, with green areas indicating close agreement with the design surface, while red and blue areas represent locations where the as-built landform was respectively above or below the design elevation. While much of the landform was constructed within acceptable tolerances, localised areas of over-placement and under-placement were evident across the rehabilitated slope. These variations contributed to localised departures from the design surface and were further exacerbated by the extreme wet weather events experienced during the establishment phase.

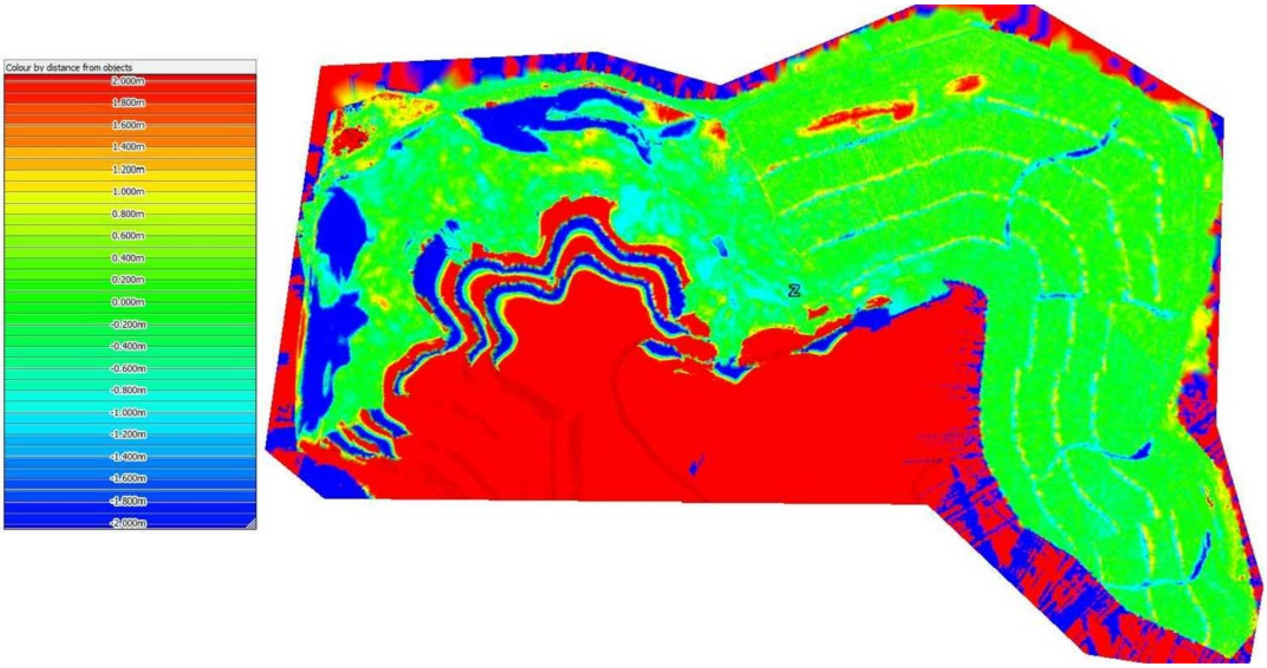

Figure 7 As-built survey showing elevation variance between the constructed landform and the design surface (green = minimal variance, red = above design, blue = below design)

One of the key controls in the implementation of geomorphic landform design is the use of ongoing survey verification throughout construction. While geomorphic landforms have been shown to be resilient to construction variability and surface roughness (Slingerland & Dressler 2022), significant departures from design intent can alter drainage pathways, influence flow concentration and affect overall landform performance. Continuous survey control allows these deviations to be identified and corrected during construction, ensuring that the as-built landform achieves the intended geomorphic function. Given prior experience with traditional rehabilitation approaches at MCCM, the importance of continual survey verification throughout the construction phase may not have been fully appreciated during the initial implementation of the geomorphic design.

5 Key learnings

Several key learnings have been gained from the initial design, construction and performance of the 2019/2020 trial geomorphic landforms at MCCM. These include:

- Designs must be modelled, developed and refined, based on area-specific rehabilitation criteria, prior to the construction of the landforms. While this is not always possible – especially on older operating sites, areas where dump designs were developed, reviewed and refined prior to overburden placement have always driven the most successful rehabilitation outcomes at MCCM. Furthermore, when the rehabilitation landform design dictates the dumping strategy, the risk of cut-and-fill deviations is significantly reduced.
- Reiterative modelling and survey verification are key controls in the design and construction of geomorphic landforms. Inconsistencies between the design intent and as-built landform can alter flow paths, influence local flow conditions (location, routing and velocity) and increase the risk of erosional instability. Climatic conditions need to be considered at the commencement of the rehabilitation planning. Although the frequency and intensity of extreme weather events can be unpredictable, modelling of local seasonality and the influence of climatic variability can significantly improve the outcome of rehabilitation performance.
- The period immediately following construction and prior to vegetation establishment represents the highest risk period for geomorphic landforms. Rehabilitation activities should therefore be scheduled to maximise opportunities for rapid vegetation establishment and surface stabilisation, reducing erosion risk and improving long-term landform performance.
- Utilisation of GPS on all dozers removes the need for peg-based guidance and improves adherence to design tolerances. This leads to a more accurate as-built landform, with operators able to continuously monitor and adjust to maintain compliance with the design.
- Continuous planning, survey and sign-off is required at every stage of construction. The introduction of robust inspection and test plans (ITPs) or Plan/Do/Check/Act cycles ensures that the design intent is consistently achieved. Additionally, this provides comprehensive records which can be reviewed in the event of future performance issues.

The outcomes of the 2019/2020 geomorphic landform designs and implementation trial defined a turning point in how MCCM approaches its rehabilitation planning. The site no longer adopts traditional landform designs. Since 2020, ongoing review and refinement of geomorphic landform designs has resulted in the seamless integration of the designs within annual mine planning, and continuous design, construction and performance improvements.

Forward forecasts are now reviewed to determine appropriate timing for rehabilitation activities. This allows reshaping, topsoiling and plantings to be undertaken within an optimal seasonality window. (MCCM now targets completion of rehabilitation in spring, allowing late spring rainfall to support germination of cover crops, providing both surface protection and increased infiltration across the constructed slopes).

The size of rehabilitation campaigns has also been reduced. Smaller catchment areas are easier to manage in terms of overland flow during high-intensity storm events (as commonly experienced in the Gunnedah Basin). Rehabilitation areas have been reduced in size, with individual areas being no more than 30–50 ha. This has resulted in reduced upslope surface run-off requiring routing across the rehabilitated landform and, consequently, reduced risk of erosion.

6 Conclusion

The performance of MCCM’s 2019/2020 geomorphic landform trial was strongly influenced by climatic conditions, with erosion processes closely linked to rainfall intensity, timing of rehabilitation activities, and the exposure of partially completed landforms.

MCCM has incorporated learnings across planning, design and modelling, construction and survey control and climatic considerations into subsequent rehabilitation campaigns following the landform failures which occurred during the 2019/2020 trial period. These learnings have allowed the mine to strengthen rehabilitation practices, improving alignment between design and dumping strategies, increasing the use of ITPs and survey verification at key stages of construction, and better staging of rehabilitation activities to align with optimal climatic conditions.

Through the combination of these measures, MCCM has been able to reduce the risk of failure within rehabilitation areas and improve landform performance.

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