Office of the **Queensland Mine Rehabilitation Commissioner**

Property development planning for grazing on rehabilitated mined land in the Bowen Basin

Technical paper 2

Queensland Government

Prepared by: Highlands Environmental on behalf of the Office of the Queensland Mine Rehabilitation Commissioner

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Executive Summary

The Bowen Basin region has been subject to significant human development over the past 60 years, primarily for beef cattle grazing and open-cut coal mining. The coal mining lifecycle irreversibly transforms land resources, which are described by the United Nations as the physical, biotic, environmental, infrastructural, and socio-economic components of a land unit. The 'rehabilitation phase' attempts to (re)develop affected land resources to establish a stable condition (*Environmental Protection Act 1994* (Qld), s111A). To achieve a stable condition, rehabilitated land must be safe and structurally stable, not cause environmental harm, and be able to sustain a post-mining land use. A common proposed post-mining land use is beef cattle grazing.

The land use requirements (assessed as land suitability) for beef cattle grazing are well understood, at least at a paddock- or landform-scale. However, the same cannot be said for broader-scale agricultural land development requirements in the post-mining landscape. This technical paper defines and describes those requirements and presents a leading practice approach to the agricultural development of rehabilitated mined land that is suitable for cattle grazing in the Bowen Basin. It has a landscape-scale focus and is set out as a step-by-step guide.

Step 1 – Designing post-mining landscapes

Spatial scales - Design landforms to be part of larger, rolling landscapes. Use ridgelines to site infrastructure (e.g., fences, tracks) and define sub-catchments that drain passively without the need for engineered drainage structures.

Know your materials - Characterise (quality and quantity) all soils, spoils, and mineral wastes because not all materials are suitable for use in rehabilitation.

Place material deliberately - Use block modelling to ensure there is a 'place for everything, and everything in its place' in the post-mining landscape.

Step 2 – Planning for suitable land use

Know your land types – Rehabilitated mined land that is suitable for beef cattle grazing is a new, unique grazing land type (i.e., 'Rehabilitated Mined Land' grazing land management land type).

Map your property and resources - Use a graphic information system to capture, manage, analyse, and map agricultural land resource information and develop the 'property master plan'. This will enable the whole property to be viewed in perspective and make it easier to make informed property development decisions.

Step 3 – Deciding on priorities

When to introduce livestock - Introduce cattle grazing as soon as practicable onto areas of rehabilitated mined land that is suitable for beef cattle grazing.

Develop grazing standards - Develop rehabilitated mined land specific pasture utilisation, forage (dry matter) retention, and groundcover thresholds.

Step 4 – Planning property improvements

Watering points - Plan to reticulate water to multiple troughs that are not further than 1-2 km apart in each paddock to encourage even pasture utilisation and avoid land degradation. Fence dams and watercourses to exclude stock.

Fencing - Plan a property fencing layout that is paired to landscape features (e.g., ridgelines, watercourses, and land type boundaries) rather than a geometric grid pattern.

Access tracks - Site a network of access tracks that connect all paddocks and critical property infrastructure across the post-mining landscape.

Retained mining infrastructure - Retain mine infrastructure that directly supports beef cattle grazing activities.

Step 5 – Maintaining land

Erosion control - Use forage budgeting to maintain >70 % groundcover and site infrastructure correctly to minimise erosion in the post-mining landscape.

Burn pastures regularly - Develop a fire plan and implement burning regimes to reduce wildfire risk, reinvigorate pastures, and control woody weeds.

Monitor and mitigate pasture rundown - Monitor and mitigate pasture rundown in rehabilitation areas but never use mechanical disturbance to stimulate N-mineralisation.

1 Introduction

The Bowen Basin region has been subject to significant human development for agriculture and mining since the early 1960s. Between 1963 and 1976 a government-financed agricultural land development scheme cleared more than 4.5 million hectares (ha) of mainly native *Acacia harpophylla* brigalow scrub. The 'brigalow scheme' as it became known, awarded land to eligible developers with ongoing development conditions such as clearing of vegetation and installation of fences, watering points, and other property improvements. The land was mainly developed for beef cattle grazing and sown to exotic perennial grasses, the most widely sown and economically important grass being *Cenchrus ciliaris* (buffel grass).

Large-scale mechanical coal mining also commenced in the 1960s at Moura (1961) and then Blackwater (1966), though small-scale coal mining had begun much earlier at the Blair Athol and Callide fields. Today there are 90 metallurgical and thermal coal mines in Queensland (Queensland Government, 2022a). Most are located in the Bowen Basin where open-cut strip-mining methods that rely on draglines to remove overburden and uncover coal seams have long dominated production. Total land disturbance by coal mining now approximates 170,000 ha and to date less than 50,000 ha has been subject to some form of rehabilitation (Queensland Government, 2022a).

Coal mining has a life cycle that begins with exploration, proceeds through development and production phases, and ends with rehabilitation and closure. The most active and profitable production phase is temporary, perhaps a few decades in duration, but its impacts on land resources available for the subsequent rehabilitation phase are transformative and permanent. These 'land resources' are the physical, biotic, environmental, infrastructural, and socio-economic components of a land unit (FAO, 2023). The mining production phase dismantles land resources and the (progressive) rehabilitation phase attempts to reconstruct them. Though rehabilitation aims to achieve a stable condition (*Environmental Protection Act 1994* (Qld) (EP Act), s111A), agricultural land resources (e.g., the quality and quantity of soil) are typically degraded by the mining process and have a reduced capacity to sustain agricultural production (Grigg et al., 2000). Most coal mine rehabilitation has a beef cattle grazing post-mining land use (PMLU) (Short, 2023) and the rehabilitation phase in the mining life cycle attempts to (re)develop land resources to sustain this agricultural use.

Modern guidelines for agricultural land development in the Bowen Basin have existed since 1986 (Bourne, 1986). With a similar approach to that used by FAO (2023), development guidelines and associated grazing land management guidelines (Queensland Government, 2011) are built on the concept of 'land types'. Here, land types are defined as areas of grazing land that have characteristic patterns of soil, vegetation and landform, and development potential and management recommendations based on land use suitability (Queensland Government, 2011; 2015).

The land use requirements (assessed as land suitability) for beef cattle grazing on rehabilitated mined land are well understood (Short, 2023), at least at a paddock- or landform-scale. However, up until now, no guidance has been available about the broader-scale agricultural land development requirements for post-mining landscapes suitable for beef cattle grazing. This technical paper sets out the agricultural land development requirements for rehabilitated mined land that is suitable for beef cattle grazing. To achieve functional post-mining landscapes for beef cattle grazing, these requirements will need to be a considered throughout the mining life cycle. This paper informs mine planning, production and rehabilitation phases of mine life, because many opportunities are only available during the active mining phase prior to rehabilitation (e.g., selective placement of spoils into landforms based on geochemistry).

This is the second in a series of technical papers on beef cattle grazing PMLU rehabilitation in the Bowen Basin. The intent of these papers is to provide clear, practical, straightforward advice for rehabilitation practitioners, government regulators, rehabilitation graziers, and other stakeholders.

- Technical paper 1 – Rehabilitated mined land suitability for beef cattle grazing in the Bowen Basin.
- Technical paper 2 – Property development planning for grazing on rehabilitated mined land in the Bowen Basin.

2 Step by step guide to rehabilitated mined land development for beef cattle grazing

Following is a step-by-step guide for the development of rehabilitated mined land for beef cattle grazing as a PMLU. It is aimed at achieving the best possible beef cattle grazing PMLU through appropriate planning and execution during the active mining and rehabilitation phases.

2.1 Step 1: Designing post-mining landscapes

To achieve a stable condition (EP Act, s111A) in rehabilitation with a beef cattle grazing PMLU, strategic mine planning processes will need to incorporate an optimised final landscape design that considers PMLU requirements (see Short (2023) for detail). After that, operational mine planning processes can lay out the path to achieving rehabilitation requirements in rolling three-monthly forecasts and shorter-term plans that detail equipment and material movements. The principles outlined in this technical paper can be used to inform strategic and operational mine planning policies, practices, and actions. These include planning at an appropriate spatial scale, understanding material characteristics, and the selective handling and placement of materials into landforms to create functional post-mining landscapes fit for beef cattle grazing.

2.1.1 Spatial scales

Planning at an appropriate spatial scale is critical to delivering functional post-mining landscapes, designed to meet the needs of a beef cattle grazing PMLU. There are five embedded spatial scales to consider in post-mining landscape design (Table 1).

Table 1. Spatial scales to consider in post-mining landscape design

Name	Scale	Description
Region	Hundreds of kilometres (km)	The Bowen Basin is a vast region about 600 km long and up to 250 km wide. At this scale there is a distinct relationship between geology, soils, and vegetation, and natural processes that influence the function of entire regional ecosystems. The Bowen Basin is part of the larger Brigalow Belt Bioregion described in Neldner et al. (2019).
Landscape	<5 km	“Landscape” is everything that we can see from a particular viewing point (e.g., a plain with hills in the background) (McKenzie et al., 2008). On flat ground this is about 5 km maximum distance due to the curvature of the earth. Stakeholder engagement indicates that beef cattle graziers likely view coal mine rehabilitation at this level, including how artificial landforms tie into the surrounding natural environment, and will function and be managed after mining (Henderson and Lazarow, 2007).
Landform	<2 km	“Landform” is the fundamental mine design building block, which is typically inter-ramp and less than 2 km across. It is likely that most mine planners view rehabilitation at this level, with an inner focus on site issues and the construction of inter-ramp spoil emplacements or dumps. To aid description, classification, and communication, landforms should be viewed as a mosaic of tiles of odd shapes and sizes. The larger tiles are called landform patterns and are themselves a mosaic of the smaller tiles called landform elements. Landform patterns and landform elements are described and named by the values of their landform attributes (e.g., slope, morphology, etc) (NCST, 2009).
Pattern	<600 m	About 40 types of landform patterns are defined, including, for example, terrain features like hills and plains (NCST, 2009).
Element	<40 m	More than 80 types of landform elements are defined, including, for example, cliff, ridge, and flat (NCST, 2009).

Post-mining landforms created by open-cut coal mining are built of landform patterns and landform

elements. The composition of these has an enormous impact on landscape process (e.g., hydrology, geomorphology, and soil formation and erosion), and the suitability of rehabilitated land for cattle grazing as a PMLU, and the potential for land degradation. Slope, for example, which measures the rate of change in elevation in the direction of the steepest descent, is a primary terrain attribute or descriptor of landform elements (McKenzie et al., 2008; NCST, 2009). To be suitable for beef cattle grazing, landform slope values will not be greater than 12 % grade (Short, 2023) assessed as modal slope or the most common class of slope occurring within a landform pattern (see NCST (2009) for guidance on this). Though this attribute is often the sole constraint in post-mining landform design, morphological types of landform elements (e.g., the location of crests and ridges) are also critically important in planning to deliver functional post-mining grazing landscapes.

Post-mining landforms for cattle grazing PMLU should maximise the extent of gently inclined slopes (<12 % gradient) in an undulating or rolling landscape of aggregated landforms. Crests and ridgelines will define sub-catchments, which should drain passively, without the need for engineered drainage structures (e.g., contour banks and geofabric/rock-lined water ways) and be erosionally stable. Runoff concentrates into preferential flow paths caused by roads, tracks, fence lines and firebreaks and this can lead to rill and gully erosion (Queensland Government, 2011). For this reason, it is best to site this infrastructure along ridgelines. As this affects the size and layout design of paddocks and laneways used to move livestock, the area between ridgelines should be maximised and the location of ridgelines in the post-mining landscape should be a primary landform design consideration. It will be difficult to avoid soil and land degradation in beef cattle grazing PMLU rehabilitation if modal terrain slope and morphological types of landform elements (e.g., crests, ridges, slopes, flats, etc) are overlooked by mine planners in the design of post-mining landforms and landscapes.

Key Point. Design landforms to be part of larger, rolling landscapes. Use ridgelines to site infrastructure (e.g., fences, tracks) and to define sub-catchments that drain passively without the need for engineered drainage structures.

2.1.2 Know your materials

The quality and quantity of soils, spoils, and mineral wastes (i.e., coarse rejects and fine tailings) encountered throughout the Bowen Basin is variable. These materials may be benign with no harmful characteristics and useful for constructing post-mining landscapes, highly saline and hostile to plants, or highly sodic and unstable when wetted. Some spoils and mineral wastes are sulphide-bearing and capable of generating acid and metalliferous drainage (AMD) (INAP, 2014). Due to this variability, all materials should be characterised in terms of quality (i.e., geochemistry) and quantity (i.e., volume), and landforms designed and constructed with these material properties in mind. Short (2023) lists indicators that should be used to characterise soils and spoils, and threshold limits that define suitable and unsuitable materials.

Mine planning should schedule material movements so that hostile and unstable materials that are not suitable for use in rehabilitation are buried and/or encapsulated deep within landforms. Benign or suitable materials should be selectively placed near to the dump surface and used to construct new soils called Spolic Anthroposols (Isbell and NCST, 2021). There is little value in having a very good landform design if the underlying waste is hostile or unstable, and there are insufficient resources to construct a new soil profile.

Key Point. Characterise (quality and quantity) all soils, spoils, and mineral wastes because not all materials are suitable for use in rehabilitation.

2.1.3 Place materials deliberately

To deliver an optimised post-mining landscape which meets or exceeds beef cattle grazing PMLU requirements, a comprehensive block model should be prepared. A block model is a simplified representation of materials that can be thought of as stack of computer generated “bricks” that represent small volumes of spoils, soils, and other materials. Each brick contains estimates of data such as geochemical characteristics that make it suitable or otherwise for use in rehabilitation. The bricks are arranged in an XYZ grid system that can be dismantled (mined), moved (hauled), and put back together (landform construction). Together with an appropriate materials management and

placement plan developed in conjunction with the mining schedule, this will ensure that there is a *'place for everything, and everything in its place'* in the post-mining landscape, including soil replacement appropriate to landform patterns and elements.

There are many commercial brands of mining block model software (e.g., Vulcan, Surpac, Minesight and others) and several block model types (e.g., inverse distance models, ordinary Kriging and others). According to Poniewierski (undated) most block model types differ by how data populates blocks, how estimates within blocks are presented, and how blocks are physically constructed and represented. Regardless of which brand and type of model used, successful post-mining landscape delivery will hinge on compositional elements being regularly updated through ongoing materials characterisation over the life-of-mine. Failure to do this may potentially result in inappropriate material placement resulting in rehabilitation that cannot demonstrate a stable condition (EP Act, s111A) and a post-mining landscape that is not suitable for beef cattle grazing PMLU.

Key Point. Use block modelling (or an alternate, equivalent method) to ensure there is a *'place for everything, and everything in its place'* in the post-mining landscape.

2.2 Step 2: Planning for suitable land use

Short (2023) presents a regional land suitability framework for beef cattle grazing PMLU rehabilitation in the Bowen Basin. This should be applied using traditional agricultural land evaluation methods (Queensland Government, 2015) by persons with proven competencies in land and soil resource assessment. It will be necessary to understand and map land types and agricultural land resources in post-mining landscapes used for beef cattle grazing.

2.2.1 Know your land types

The Bowen Basin overlaps parts the Fitzroy and Burdekin grazing land management (GLM) regions, in which more than 50 grazing land management types have been identified (Future Beef, 2011a). A 'land type' is an area of grazing land with characteristic patterns of soils, vegetation, and landform. Land types form the basic management units for all agricultural property mapping, assessment, and planning.

Most grazing landscapes in the Bowen Basin will comprise several land types, and the inherent characteristics of the land and soil in each land type determine its suitability for beef cattle grazing. If the pre-mining land type is not suitable for development for grazing of improved pastures, then the post-mining landscape will likely be unsuitable too. However, where rehabilitated mined land is assessed as suitable for beef cattle grazing PMLU according to the framework in Short (2023), then this is an additional or novel GLM land type which is unlike all unmined types. Following is a representation of rehabilitated mined land as a GLM land type in the Fitzroy region (i.e., FT32 Rehabilitated mined land).

Rehabilitated mined land

Landform	Human-made landscape with slopes up to 12 %, flats, and microrelief up to 0.4 m.
Woody vegetation	Negligible woody vegetation.
Expected pasture composition	Sown exotic and native species.
Preferred	Queensland bluegrass, desert bluegrass, forest bluegrass, black speargrass, Curly Mitchell grass, kangaroo grass.
Intermediate	Native millet, curly windmill grass, brigalow grass, pitted bluegrass, tall chloris, yabila/star grass, barbwire grass.
Non-preferred	Dark wiregrass, fairy grass, slender chloris, bottlewasher grasses, purple lovegrass.
Annual grasses	Flinders grass, small burr grass.
Suitable sown pastures	Buffel grass, Katambora Rhodes grass, Bisset creeping bluegrass, Gatton panic, shrubby stylo, Caatingo stylo, siratro.
Introduced weeds	Parthenium. Parkinsonia. Unmanaged Leucaena.
Soil	Spolic Anthroposol (Isbell and NCST, 2021).
Description	Surface: hard setting; Surface texture: sandy clay loam; Subsoil texture: sodic clay.
Water availability	≥40 mm
Rooting depth	600 mm
Fertility	Low
Salinity	≤10 dS/m in rooting depth, higher below.

Sodicity	ESP up to 23 % at 0.5 m depth. Extremely sodic subsoils.
pH	5-6 – 8.4
Long-term carrying capacity information (A condition)	No data available on pasture growth rates to allow calculation of carrying capacity.
Enterprise	Breeding
Land use and management recommendations	Suitable for sown pastures as the light surface texture responds to small and infrequent rainfall. Maintain surface cover to reduce sheet erosion, nutrient loss, and pasture rundown. Erosion of roads and dams where subsoil left exposed.
Land use limitations	Soils are unstable and prone to extreme erosion and degradation following disturbance.
Conservation features and related management	It is important to maintain ground cover in the form of litter and pasture where possible as the soil B horizon is very sodic, dispersive, erosive, and hard to re-pasture.
Regional ecosystems	There is negligible growth of native trees, shrubs, and grasses in this land type. Hence, no existing mapping units correlate with this land type.
Land units; Agricultural management unit; soil associations	No existing mapping units correlate with this land type.

It is important to recognise rehabilitated mined land as a new, unique GLM land type because it will likely have different pasture productivity, short- and long-term cattle carrying capacities, land use limitations, and management requirements to surrounding grazing land types. It is leading practice to fence according to land types, to overcome the problem of stock grazing one land type in preference to another in the same paddock (Queensland Government, 2011). Persistent preferential grazing can lead to pasture decline and soil degradation in part of the paddock while the remainder is underutilised. For those reasons, rehabilitated mined land that is suitable for cattle grazing must be fenced separately to other land types.

Key Point. Rehabilitation that is suitable for beef cattle grazing PMLU is a new, unique grazing land type (i.e., Rehabilitated Mined Land GLM land type).

2.2.2 Map your property and resources

A comprehensive database of agricultural land resource information relating to the whole grazing property should be developed and maintained in a graphical information system (GIS). GIS connects data to a map, integrating location data (where things are) with all manner of descriptive data (what things are like there). There are many commercial brands of GIS to choose from (e.g., ArcGIS, MapInfo, QGIS, and others). GIS provides a foundation for mapping and analysis to inform future land use decisions and a framework for planning.

At landscape and landform scales, GIS will capture key information about the following areas:

- Rehabilitated mined land that is suitable/not suitable for beef cattle grazing PMLU.
- Rehabilitated mined land with alternative PMLUs (e.g., native ecosystem PMLU rehabilitation).

- Non-use management areas (NUMAs) (EP Act, s126(D)(2)).
- Surrounding unmined land types that may or may not be suitable for beef cattle grazing.

The ideal base would be a photo-mosaic of the property showing the completed and planned (digital terrain model) post-mining landscape. Other layers would include land types, detailed topography by light detection and ranging (LiDAR) survey, and the main features of the property. From an agricultural land development perspective, the most important features (existing and planned) of the property are:

- Land types
- Major ridgelines
- Watercourses
- Infrastructure (i.e., planned retained mine infrastructure including roads and tracks)
- Fences and watering points.

Areas requiring special management, including areas not suitable for a beef cattle grazing PMLU, should also be mapped. These may include final voids, mineral waste emplacements (e.g., coarse rejects dumps and tailings storage facilities) and contaminated land.

Using this graphical agricultural resource information, an optimised property layout plan for the post-mining landscape should be developed. This 'property master plan' will show the final post-mining landscape and all property developments required for a beef cattle grazing PMLU, including the location and nature of the following:

- Land types, including rehabilitation areas and unmined land
- Stock watering points, and water reticulation system
- Paddock fencing design, including laneways
- Infrastructure for stock husbandry and farm access (e.g., stock yards and roads)
- Areas requiring protection from grazing (e.g., waterways).

Working backwards from this optimised property layout plan, GIS layers can be developed showing the location and timing of temporary and permanent property features (e.g., fencing) and rehabilitation areas available for grazing in accordance with the mine plan. This will tie neatly to progressive rehabilitation and closure plan (PRCP) schedule rehabilitation milestones required to achieve a stable condition (EP Act, s126D(1)) and form the basis of an action plan to identify, describe, and schedule tasks necessary to achieve the property master plan.

Key Point. Use GIS to capture, manage, analyse, and map agricultural land resource information and develop the 'property master plan'. This will enable the whole property to be viewed in perspective and make it easier to make informed property development decisions.

2.3 Step 3: Deciding on priorities

Once an area of rehabilitation has been assessed as suitable for beef cattle grazing PMLU, development priorities should be set. A key opportunity will be deciding when to introduce grazing during the mine operational phase while mined land is progressively rehabilitated. This will allow land type specific grazing land management standards to be developed, well in advance of mine closure.

2.3.1 When to introduce livestock

Cattle should be introduced to suitable rehabilitation as soon as practicable following pasture establishment during the mine operational phase. Experience has shown that rehabilitated pastures that are not grazed become rank (i.e., overgrown) with limited grazing value and elevated fire risk. From a pasture agronomy viewpoint, cattle can be introduced to rehabilitation when seed has fallen from each species sown in the preceding season and self-recruitment is evident in the pasture sward. Never graze new pastures before they set seed. Though grazing of rehabilitation is recognised lower in priority to achieving and maintaining a stable condition (EP Act, s111A), introducing cattle will be useful to:

- Maintain pasture composition and prevent pasture becoming clumpy and rank
- Demonstrate sustainable cattle grazing as a PMLU to community and other stakeholders (Figure 1)

- Provide an opportunity for monitoring of land condition, pasture condition, carrying capacity, and cattle performance.

Figure 1. Cattle grazing rehabilitated mined land (source: Rehabilitation case studies - Queensland Resources Council - Queensland Resources Council (qrc.org.au))

Key Point. Introduce cattle grazing as soon as practicable onto areas of Rehabilitated mined land GLM land type.

2.3.2 Develop grazing standards

There are no grazing land management guidelines for beef cattle grazing PMLU rehabilitation and these need to be developed for each mine site. Forage budgeting is an objective process for estimating safe stocking rates based on available pasture and animal intake over a period of days, weeks, or months. It is useful for calculating the difference between forage demand and forage supply in the short-term. Queensland Government (2011) outlines the basic process for forage budgeting as follows:

- Calculate how much forage is in the paddock
- Decide how much needs to remain after the animals are taken out to maintain pasture condition and ground cover
- Nominate the proportion of the pasture that is to be consumed in that period
- Work out how much each animal will eat per day
- Decide how long the animals are to stay in the paddock
- Calculate how many animals can be safely run for that period.

In more productive pastures on unmined land types, the historic aim was to have at least 40 % groundcover and 1,000 kg/ha of pasture at the beginning of the next summer storm period (Queensland Government, 2011). Contemporary standards for reef catchments suggest that more than 50 % groundcover is needed to maintain land in fair or good condition (Queensland Government, 2022b). However, for rehabilitated mined land used for cattle grazing, these thresholds are possibly too low to maintain land condition and prevent soil loss and land degradation. Grigg et al. (2001), for example, suggest that at least 70 % groundcover is required to control erosion on ungrazed pastures in Bowen Basin mine rehabilitation. This disparity points to the need for rehabilitation-specific pasture utilisation, forage (dry matter) retention, and groundcover thresholds to be developed to ensure sustainable land use. This can only be done when rehabilitation is grazed by cattle, the relevant data is collected and analysed, and graziers are consulted.

Site-specific grazing standards may be paramount at mine closure if there is a need for caveats on future management of the rehabilitated land that graziers are expected to comply with (Maczkowiack et al., 2012). This information may also be useful to reduce uncertainty with regards to residual risk payments (EP Act, s271-273), and the likelihood and consequence of rehabilitated land degradation in time to come. Mining companies can reduce closure risks by improving consultation with graziers (Maczkowiack et al., 2012) and developing site-specific grazing standards during the mine operational phase. It may take many years of monitoring and measurement to determine safe long-term productivity benchmarks. In the absence of any such criteria, a conservative grazing approach will be needed to maintain land condition in rehabilitation while benchmarks are being developed.

Key Point. Develop land type specific pasture utilisation, forage (dry matter) retention, and groundcover thresholds for Rehabilitated mined land GLM land type.

2.4 Step 4: Planning property improvements

Use GIS mapping to plan and record the best positions for watering points, fences, and other property improvements such as retained mine infrastructure. Design a water reticulation system in the first instance, followed by a paddock layout design that includes laneways, then access tracks, and finally site all other land use support infrastructure.

2.4.1 Watering points

After constructing a post-mining landscape comprised of landforms that are suitable for beef cattle grazing, access to good quality water in sufficient quantities is the next most important consideration for beef cattle grazing PMLU. There is a strong relationship between distance to water and (over)grazing pressure (Queensland Government, 2011). Where watering points are scarce or poorly located, pasture utilisation across the landscapes will be poor (Chilcot et al., 2005). In this situation cattle will overgraze pastures within walking distance of the watering point (typically less than 1 km), while there is still plenty of feed at the opposite end of the paddock to the water.

At a landform scale, however, some overgrazing and trampling of vegetation and increased erosion risks are unavoidable consequences of watering points. This is caused by cattle trailing in and out for water and camping nearby. To minimise potential land degradation, watering points should be located as follows:

- On relatively flat landform patterns that have stable, non-sodic soils including subsoils
- Not further than 1 – 2 km apart
- More than one watering point in each paddock
- In or amongst belts of trees or scrub (but not within or immediately adjacent to watercourses)
- With stock access from multiple directions (preferably 360-degree access).

As open-cut strip-mining methods tend to create post-mining landscapes that are linear or elongated, the distance between watering points is more important than the concept of water circles. The important issue is that stock should not have to walk further than 2 km to water on flat ground, or 1 – 1.5 km across undulating or rolling terrain in post-mining landscapes.

Watering points should be troughs, some of which may be portable if not entirely satisfactory locations can be found initially. Water reticulation systems can be either gravity flow from head tanks sited high in the landscape, or pressurised by pumps, or a combination of both. Gravity flow avoids any potential equipment failure in a pumped system. In a gravity pipeline system, the water storage tank is higher than all points in the delivery pipeline and no pump is required downstream of the storage. Troughs should be laid out as necessary across the landscape, then paddocks can be designed (i.e., fencing) and not vice versa. The costs of establishing a well-planned, gravity-fed stock watering system across the entire property is minor compared to the risks of land degradation caused by an inferior watering layout.

All open water bodies and watercourses on the property should be fenced to exclude cattle. This includes creeks and major drainage lines, dams, and depressions in the post-mining landscape that may hold water for extended periods following rainfall. This will assist to conserve riparian vegetation, promote streambank stability, and protect environmental values of waters (Queensland Government, 2011). Prohibiting stock access to open water will also prevent bogging and the animal health

implications of drinking water contaminated with cyanobacteria and stock effluent.

Key Point. Plan to reticulate water to multiple troughs that are not further than 1-2 km apart in each paddock to encourage even pasture utilisation and avoid land degradation. Fence dams and watercourses to exclude stock.

2.4.2 Fencing

In the past, many cattle grazing properties were fenced into given areas on a geometric grid pattern irrespective of natural features (e.g., soils, vegetation, land types). This has led to serious land degradation problems and fencing, along with other considerations, is a now a key component of contemporary, sustainable grazing land use. Instead of squares and rectangles, GIS mapping will show a post-mining landscape where 'natural' subdivisions already exist. Fence lines should follow these landscape features and be placed along ridgelines, watercourses, and land type boundaries, and should separate land that is suitable for beef cattle grazing from land that is not suitable.

Fencing along natural boundaries will sometimes be more difficult than fencing in a geometric pattern, but the advantages of easier access and more efficient use of land will more than compensate for this. Sometimes, compromises must be made to achieve the major objective and a fence must run down slope. If that is the case, it is preferable that the fence run at right angles to the contours, to shorten the distance where erosion may occur. To avoid land degradation and other issues, strive to do the following:

- Fence land so that each paddock has similar characteristics, for example all flat, all slope, all sandy soil, or all heavy clay. Where paddocks have varied conditions, manage them to minimise erosion in the most vulnerable areas. It may be worth constructing temporary electric fencing around these areas
- If the fence line is to be cleared with a maintained track at either side, choose non-eroding soil types as much as possible
- Avoid traversing long or steep slopes where possible unless on the contour, as resultant gullies can isolate the fence and render it useless
- When fencing near hills fence on the contour or near to the base of the hill at the point of greatest slope change
- When fencing on ridges, fence along the crest line as this is the point of minimum runoff (unless altered by a graded track with the windrows left to form a channel) and the fence should remain stable
- Fence off badly eroded areas. Don't fence close to gully heads unless action is planned to prevent further erosion of each gully
- When crossing gullies and depressions, ensure that fences are sited in a safe place and that the last strainers are well back from the edge the bank. Cross gullies and depressions at right angles
- In many situations, it is safest (though more expensive in the short term), to completely fence out major waterways
- When locating troughs to water more than one paddock, avoid siting troughs in the corner as this leads to serious problems.

Avoid steel fenceposts for permanent fence lines in the post-mining landscape, as subsoil salinity and sodicity will cause buried sections to corrode rapidly. Wooden or cement posts are preferred in this situation.

Key Point. Plan a property fencing layout that is paired to landscape features (e.g., ridgelines, watercourses, and land type boundaries) rather than a geometric grid pattern.

2.4.2.1 Laneways

Use fencing to create narrow laneways that connect as many paddocks as possible. A central laneway that connects most paddocks will make moving equipment and stock around the property efficient with limited labour. In some situations, it may be opportunistic to repurpose the low-wall-side haul road that runs the length of the mine as a central laneway. Laneways should be as narrow as

possible, typically <30 m width. Narrow laneways also reduce the amount of ground subject to the pressures of stock movement.

2.4.2.2 Gateways

The siting of gateways is another important aspect of fencing that is often overlooked. It is important to have them in the right places, not only for the ease of stock movement, but also to prevent erosion, water accumulation and wet patches. Generally, the siting of gateways in the corner of a paddock is an advantage for ease of stock movement. Gates should never be sited in drainage lines or on erosion prone soils.

A single gate in a long line of fence means that stock pads go straight from this gateway to the water point or the next gate, creating a real erosion hazard. Gates should be situated in several locations in a long line of fence and used alternatively to disperse stock movements. It is best practice to locate gates on higher, relatively flat ground.

2.4.2.3 Temporary fencing

Electric fencing and other temporary fencing solutions (e.g., virtual fencing) may be useful. Compared to permanent fencing, these options are quick and easy to install, move, and remove, and may provide effective solutions that allow grazing during the mine operational phase.

2.4.2.4 Cattle yards

There are plenty of good cattle yard designs available, mostly based on circular forcing yards. Select a proven design that promotes animal welfare and handler safety. Yards should be sited after considering the following:

- Access to laneways and as many paddocks as possible
- All-weather access for trucks
- Distance from offices and accommodation because of noise, dust, and smell
- Availability of water and electrical power
- Site drainage.

The soil surface in and around cattle yards and adjacent holding paddocks is often denuded of groundcover and highly disturbed by cattle hooves. As >70 % groundcover is needed to minimise erosion in rehabilitation (Grigg et al., 2001), cattle yards and holding paddocks should not be sited on rehabilitated land. This critical property infrastructure must be sited on another, unmined land type that has better drainage and lower erosion potential.

2.4.3 Access tracks

The paddock layout design, location of fences, laneways (central and otherwise), gateways, and cattle yards, will form the basis of an access track network that connects all paddocks and critical property infrastructure across the post-mining landscape. A well-designed track has the following features:

- Is part of a network for the whole property, thereby preventing haphazard and unnecessary road layouts
- Suits the paddock fence plan
- Lies above flood level
- Follows the contour of the land as much as possible
- Uses ridge tops and north and west facing slopes where possible, because these dry faster.
- Involves minimal cutting and filling
- Has a slight grade to stop water ponding on the track and creating boggy areas
- Has a slight cross-slope to encourage drainage (always dispose of windrows alongside tracks to prevent ponding)
- Uses cross-banks (i.e., ‘whoa-boys’) where necessary to control runoff.

Key Point. Site a network of access tracks that connect all paddocks and critical property infrastructure across the post-mining landscape.

2.4.4 Retained mining infrastructure

It will often be advantageous to retain specific mining infrastructure post-mining to support cattle grazing PMLU. For example, light vehicle access roads, low voltage electrical power reticulation, water reticulation, hardstands, and sheds and accommodation buildings may each be useful for a grazing land use. However, mine infrastructure must only be proposed to be retained when a clear linkage to supporting cattle grazing PMLU can be demonstrated for each specific item (Table 2). Implications for estimated rehabilitation costs (ERC) calculations and PRCP schedule rehabilitation milestones should also be considered.

Table 2. Example retained mine infrastructure to support beef cattle grazing PMLU

Mine infrastructure	Beef cattle grazing PMLU support infrastructure
Lowwall haul road from point A to point B.	Central laneway for stock and equipment movement.
Shed XYZ.	Hay storage shed adjacent proposed cattle yards site.
Hardstand 123.	Site for new cattle yards.
Mine access road from highway intersection to Hardstand 123.	All weather access road to cattle yards.
Bore A.	Water source for header tanks 1 and 2 that reticulate to watering points in paddocks A, B, C, and D.

Key Point. Retain mine infrastructure that directly supports beef cattle grazing PMLU activities.

2.5 Step 5: Maintaining land

All grazing land types including rehabilitated mined land require ongoing maintenance. These are actions required to keep the grazing land productive. There are several inherent challenges associated with maintaining grazing land, not least of which is rainfall variability. In dry times poor forage budgeting can quickly lead to overgrazing and land degradation. Forage budgeting has been discussed previously (see section 2.3.2) and the *Stocktake GLM* app should be used to adjust stock numbers based on seasonal forage supply. Following are additional grazing land maintenance actions recommended for the Rehabilitated mined land GLM land type.

2.5.1 Control erosion

The key to controlling erosion on Rehabilitated mined land GLM land type areas is to maintain >70 % groundcover (Grigg et al., 2001; Grigg et al., 2002) before, during, and after grazing. Groundcover, primarily pasture species, protect soil by providing canopy cover (more than 5 cm above the soil surface) and contact cover (less than 5 cm above the soil surface). Canopy and contact cover both protect the soil against raindrop impact, but contact cover is more effective in protecting soils because it slows runoff so that water infiltrates the soil and deposits any dislodged sediment around the plants. Good contact cover is crucial on undulating Rehabilitated mined land GLM land type areas. The impact of grazing on soil loss is exponential (Grigg et al., 2002) and forage budgeting is critical to achieving and maintaining the requisite groundcover threshold. However, any activities that disrupt vegetation cover will usually result in accelerated erosion and potential land degradation.

Runoff concentrations caused by roads, tracks, fence lines and firebreaks, for example, can lead to rill and gully erosion (Queensland Government, 2011). Siting this infrastructure correctly is key to preventing erosion:

- Choose ridges, stable soil types, gravelly areas, and areas of minimum slope where possible
- Where it is necessary to traverse directly down slopes, make provision for drainage after choosing the most stable site. Use spur ridges wherever possible
- Avoid watercourses and the flood out area of watercourses
- Cross watercourses at right angles and in safe positions
- Remove all soil windrows from the edges of tracks and firebreaks and allow for cross-drainage
- Locate gates to suit a safe road position as opposed to taking the road to a gate as this can cause severe erosion and loss of the fence
- When crossing watercourses, try to select a site where bank height is minimal, and is not in a bend where turbulence is likely to occur.

In drainage lines where water runs with considerable force, total groundcover is required to prevent erosion and formation of gullies. This means drainage lines may need to be fenced, with regular slashing or selective grazing of the groundcover to maintain plant growth.

Key Point. Use forage budgeting to maintain >70 % groundcover and locate infrastructure correctly to minimise erosion in Mined Land Rehabilitation GLM land type areas.

2.5.2 Burning regime

Applied appropriately, fire is a useful tool for maintaining grazing pastures on Rehabilitated mined land GLM land as it:

- Reduces fire hazard (high fuel loads and wildfire risk)
- Controls woody weeds
- Removes old, rank grasses
- Stimulates new growth (Queensland Government, 2011).

A fire plan will need to be developed that includes protection measures (e.g., fire breaks) for young pastures less than 3 years old and native trees less than 5 years old and/or less than 2 m height, and a burning regime for older rehabilitation and adjoining unmined land types. A burning regime has three parts – timing (the season), frequency (how often) and intensity (how hot the fire is) (Future Beef, 2011c).

For Rehabilitated mined land GLM land type, there are at least three burning regimes to consider:

1. Ungrazed pastures in rehabilitation become rank and can contain more than 10 t/ha dry matter (Grigg et al., 2001). As little as 1 - 1.5 t/ha dry matter is sufficient fuel load to carry a grassfire, this amount of standing dry matter presents a significant fire risk. To manage the fuel load in ungrazed rehabilitation, a late summer or autumn burn of low intensity will be needed every 3 to 4 years. In practice this should only occur after a good wet season of at least average rainfall.
2. To reinvigorate grazed pastures in rehabilitation, and to even out patch grazing, an early summer burn of low intensity will be needed every 4 to 5 years. This will provide a flush of new green shoots and encourage cattle onto burnt ground. When a burn is followed by rainfall, recovery of standing groundcover in rehabilitation can be relatively rapid, less than six months (Grigg et al., 2001), though in less than ideal conditions recovery may take up to a year or two.
3. To control woody weeds including unmanaged leucaena and *Acacia* spp., a relatively intense fire may be required every 5 to 7 years (Chilcot et al., 2005). To achieve this, burn late in spring when temperatures are higher, taking particular care to establish firebreaks and other precautions. Burning for woody weed control is most successful when the target species is less than 2 m height.

When pastures are burned, most aboveground plant material (and some seed) is destroyed. This may appear to contradict requirements to maintain a high percentage groundcover for erosion control.

Fortunately, the drastic effect of fire is short-term, particularly when burning is conducted after rainfall. A cool burn will not damage the fibrous mass of grass roots beneath the soil surface, which remain alive, binding the soil and providing resistance to erosion. Tropical perennial grasses like buffel and Rhodes are considered fire tolerant and regenerate readily after fire when rainfall follows in the growing season. When fire is used correctly (timing, frequency, intensity) and the long-term benefits of burning outweigh temporary setbacks. Pastures should be spelled after fire to allow recovery before grazing, ideally until key species have set seed.

Key Point. Develop a fire plan and implement burning regimes in Rehabilitated mined land GLM land type to reduce wildfire risk, reinvigorate pastures, and control weeds.

2.5.3 Monitor and mitigate pasture rundown

Pasture rundown is the reduction of pasture growth over time due to the tie-up of soil nutrients (primarily nitrogen) in sown pastures. A reduction in pasture quantity and quality over time is expected in pastures sown in the Bowen Basin region (Chilcot et al., 2005). Buffel grass is particularly susceptible to rundown and in older pastures (>10 -20 years since establishment) on unmined GLM land types, carrying capacity may decline by 50 % (Peck et al., 2011). For Rehabilitated mined land GLM land type, however, the rate of pasture rundown in is not known. For that reason, rundown should be monitored and mitigated. To do so:

- Apply fertiliser at the time of sowing to promote pasture establishment and persistence
- Sow a range of N-fixing legumes inoculated with appropriate *Rhizobia* spp. bacteria
- Monitor soil N and general fertility at least every 5 years (i.e., soil testing)
- Maintain land condition (avoid overgrazing)
- Use fire to maintain pasture composition
- Oversow with legume seed following fire, if needed to maintain legumes in the pasture sward
- Apply fertiliser, if needed to maintain soil fertility for pasture growth.

Though mechanical disturbance (i.e., deep ripping or blade ploughing) to stimulate mineralisation of organic-N forms is sometimes used to mitigate pasture rundown in unmined GLM land types, this should be avoided on rehabilitated mined land because soil disturbance and loss of groundcover will increase risk of erosion and land degradation. Mitigating pasture rundown should be recognised lower in priority to achieving and maintaining a stable condition (EP Act, s111A).

Key Point. Monitor and mitigate pasture rundown in Rehabilitated Mined Land GLM land type areas but never use mechanical disturbance to stimulate N-mineralisation.

3 Summary

This technical paper sets out the agricultural land development requirements for rehabilitated mined land that is suitable for beef cattle grazing in the Bowen Basin region. To achieve functional beef cattle grazing post-mining landscapes, these requirements will need to be a considered throughout the mining life cycle.

The main steps to consider are:

Step 1 – Designing post-mining landscapes

Step 2 – Planning for suitable land use

Step 3 – Deciding on priorities

Step 4 – Planning property improvements

Step 5 – Maintaining land

As the area of certified rehabilitation is lagging cumulative disturbance in the Bowen Basin by a considerable margin (more than 150,000 ha), and statutory PRCP schedules now list when

disturbance will be rehabilitated, such an orderly approach is timely and needed. For many mine planners and rehabilitation practitioners, this will require a substantial departure from current approaches to rehabilitation planning and execution. Although minor modifications to the methods detailed in this technical paper will be necessary for a multitude of site-specific reasons, the general principles should be adhered to. The traditional approach, focussed on a narrow perspective of landform without the landscape-scale 'property master plan', will likely result in less-than-ideal land use and a higher risk of land degradation in the post-mining landscape.

4 Glossary

AMD	Acid and metalliferous drainage (INAP, 2014).
Annual	A plant that normally completes its life cycle within one year or season (Future Beef, 2011b).
Anthroposol	Human-made soil (Isbell and NCST, 2021).
Erosionally stable	An erosionally stable post-mining landform will have a rate of erosion not greater than the rate of soil formation, which is thought to be less than 4 t/ha/y (Grigg et al., 2001).
GLM	Grazing land management (Future Beef, 2011a).
Land type	A land type is an area of grazing land that has characteristic patterns of soil, vegetation and landform that are easily recognised by landholders in a region. A number of land types may be present on a single grazing enterprise. More than 240 land types from 16 Grazing Land Management (GLM) regions in Queensland have been described (Future Beef, 2011a).
Landform	The fundamental mine design building block, which is typically inter-ramp and less than 2 km across. It is likely that most miner planners view rehabilitation at this level.
Landform element	A sub-component of a landform type that (up to 600 m across) can be characterise mainly by its morphology (shape, steepness, orientation, moisture regime, etc.) (McKenzie et al., 2008).
Landform pattern	A sub-component of a landform type that (up to 40 m across) can be characterise mainly by its morphology (shape, steepness, orientation, moisture regime, etc.) (McKenzie et al., 2008).
Landscape	An aggregation of landforms. Typically less than 5 km across (McKenzie et al., 2008).
PMLU	Post-mining land use has the same meaning as in EP Act, s112.
Non-preferred	Native and naturalised exotic grasses that are perennial but are the least palatable and/or low yielding pasture species. The proportion of non-preferred species usually increases under heavy persistent heavy grazing (Future Beef, 2011b).
Perennial	A plant that normally lives for more than two years or growing seasons, fruiting more than once during its life (Future Beef, 2011b).
Preferred	Native and naturalised exotic grass species that are perennial, palatable, and productive plants (3Ps). Preferred species usually decline under persistent heavy grazing (Future Beef, 2011b).
Stable rehabilitation	Has the same meaning as in EP Act, s111A.
Suitable sown pastures	Pasture species (grasses and/or legumes) that are recommended to be sown on developed pastures replacing vegetation and/or native grasses. Low input oversowing of native grasses with adapted legumes may be recommended on some land types that are not suitable for pasture development (Future Beef, 2011b).

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