Vulcan South LEM Report

Landform Evolution Modelling Study

Vitrinite Pty Ltd

1571-21-C3, 13 March 2023

Report Title	Vulcan South LEM Report, Landform Evolution Modelling Study
Client	Vitrinite Pty Ltd
Report Number	1571-21-C3

Revision Number	Report Date	Report Author	Reviewer
0 [DRAFT]	17 January 2023	RN	JO/GR
1	31 January 2023	RN	JO/GR
2	2 February 2023	RN	JO/GR
3	13 March 2023	RN	JO/GR

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1 Introduction

1.1 OVERVIEW

Vulcan South (the Project), which is managed by Vitrinite Pty. Ltd., owner of Qld Coal Aust No.1 Pty. Ltd. and Queensland Coking Coal Pty. Ltd. (Vitrinite), is a proposed open pit and highwall mining operation located to the southeast of Moranbah, in Central Queensland. The Project is located immediately south and west of Vitrinite's initial mining project, the Vulcan Coal Mine (VCM), located on Mining Lease (ML) 700060. The location of the Exploration Permits (Coal) (EPCs) and the Project ML area are shown in Figure 1.1.

A Progressive Rehabilitation and Closure Plan (Draft PRCP) (METServe, 2022) for the Project has been prepared to meet the requirements of section 126C and 126D of the Environmental Protection Act 1994 (EP Act) and the *Guideline – Progressive rehabilitation and closure plans* (PRCP guideline) (DES, 2021). Section 3.6.1 of the PRCP guideline (DES, 2021) outlines that final landform design is a key component of rehabilitation and closure planning. The Draft PRCP provides rehabilitation goals and the methodology proposed to meet these goals including the proposed cover designs for the six waste rock dump (WRD) landforms proposed for the post-closure mining land use (PMLU).

WRM Water & Environment Pty Ltd (WRM) has been engaged to undertake landform evolution modelling (LEM) for the six WRD's to provide supporting information for the PRCP to:

- determine the long-term stability of the PMLU rehabilitated landforms and the level of potential environmental risk of emplacing rejects materials in the waste rock dumps (WRD); and
- analyse the future stability of the proposed landform cover designs and justify the reasonability of the targeted landform design objectives as outlined in the PRCP.

The WRD's assessed for the Project are shown in Figure 1.2 to Figure 1.4 and defined as Rehabilitation Area 1 (RA1) and Rehabilitation Area 2 (RA2) in the Draft PRCP and include the:

- Ex-pit WRD's (RA1):
  - Vulcan North ex-pit WRD;
  - Vulcan Main ex-pit WRD; and
  - Vulcan South ex-pit WRD.
- In Pit WRD's (RA2):
  - Vulcan North in-pit WRD;
  - Vulcan Main in-pit WRD; and
  - Vulcan South in-pit WRD.

The LEM assessment undertaken as part of this report tests the adequacy of the proposed WRD embankment slope and cover design detailed in the Draft PRCP. The results of the assessment can be used to inform landform rehabilitation design, demonstrate how the results support the current targeted landform rehabilitation objectives and demonstrate the requirements for long-term stability of the landforms.

1.2 REPORT STRUCTURE

The report has been structured as follows:

- Section 2 presents the methodology used to undertake the LEM assessment;
- Section 3 summarises the findings of the assessment;
- Section 4 discusses recommendations as an outcome of the study; and
- Section 5 is a list of references.

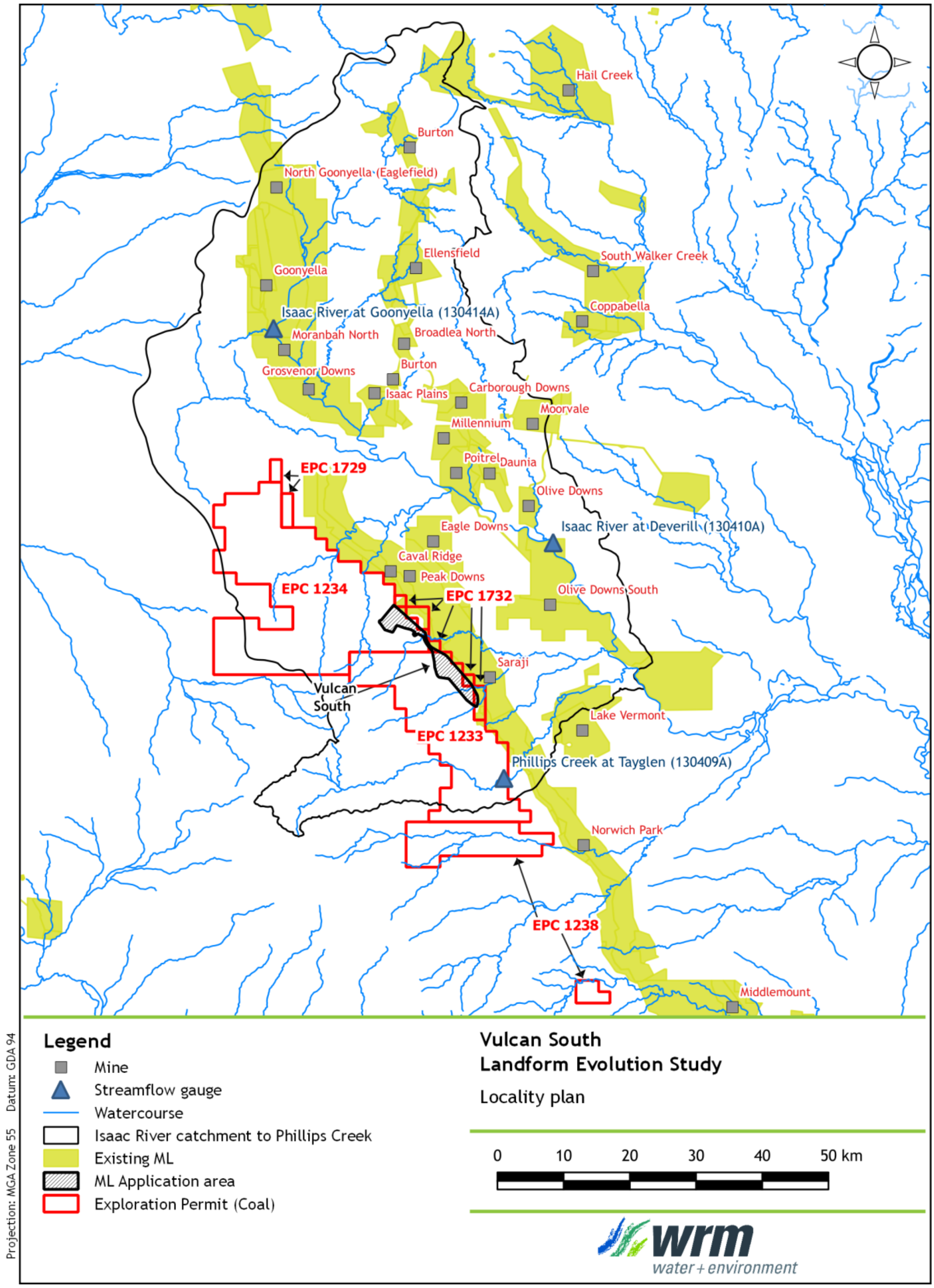

Figure 1.1 – Locality

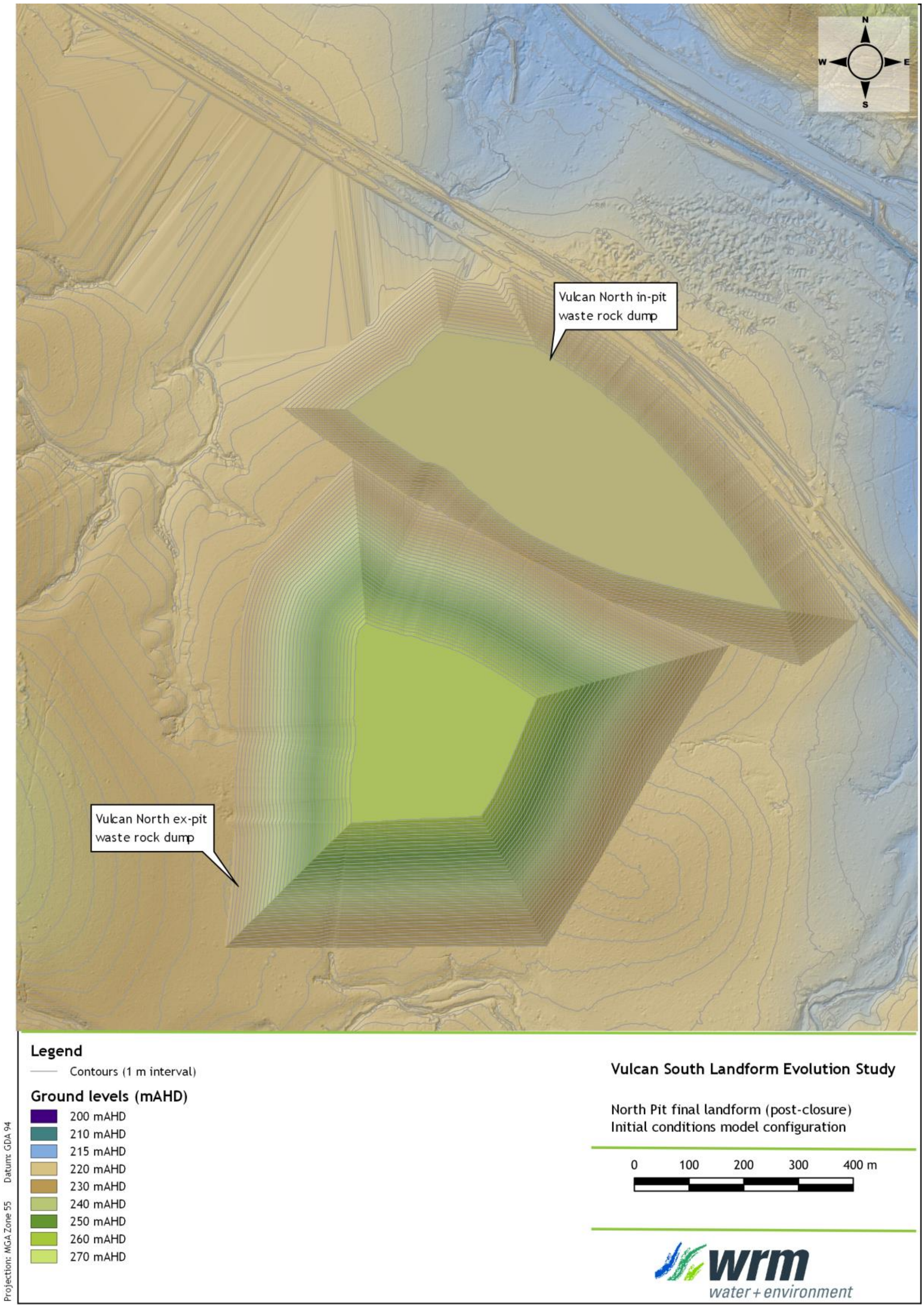

Figure 1.2 – Vulcan South final landform and rehabilitation areas – Vulcan North pit

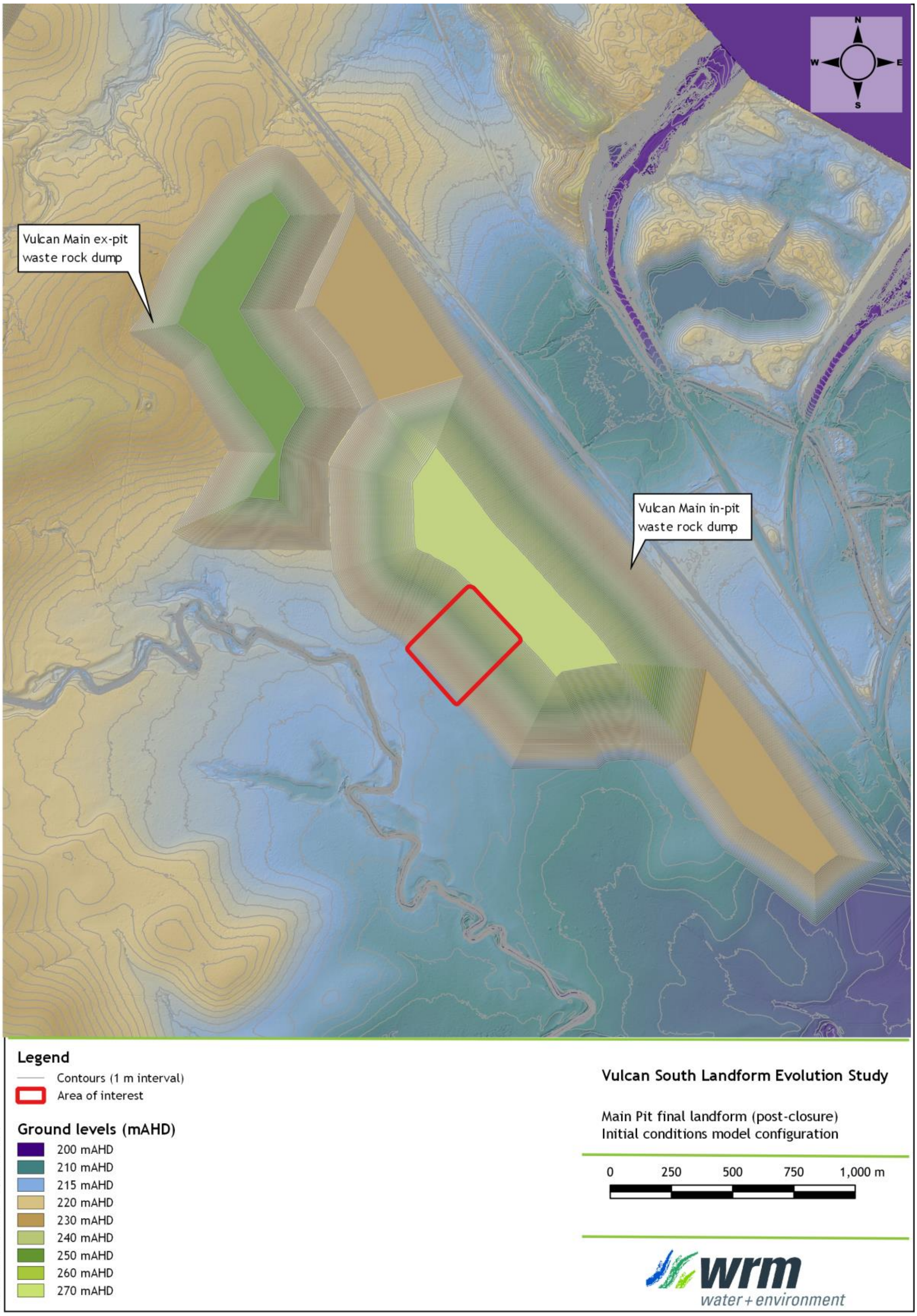

Figure 1.3 – Vulcan South final landform and rehabilitation areas – Vulcan Main pit

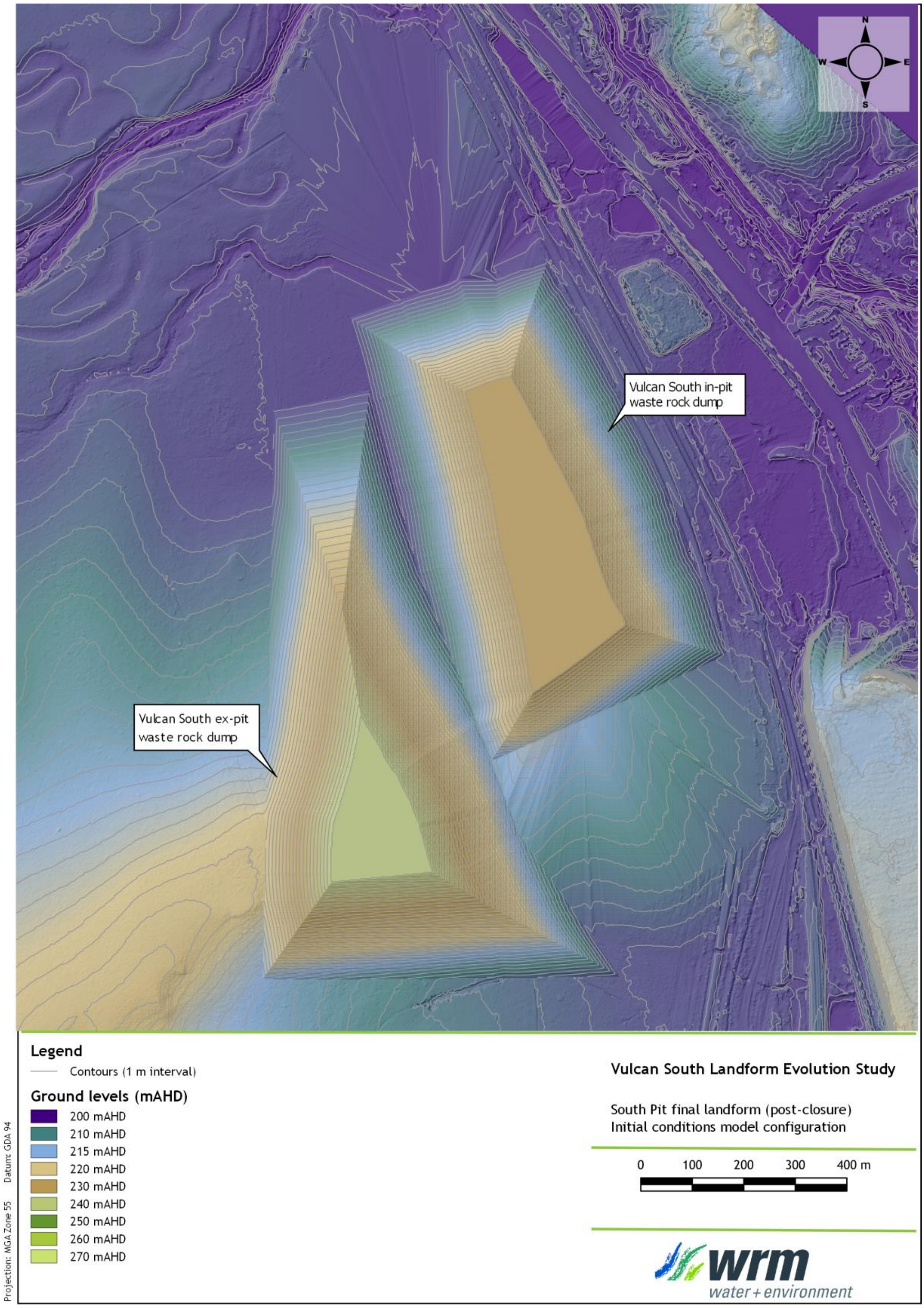

Figure 1.4 – Vulcan South final landform and rehabilitation areas – Vulcan South pit

2 Methodology

2.1 OVERVIEW

This section of the report describes the methodology used to undertake the LEM assessment. Construction of the final landform including the cover, final slope and drainage has not yet been completed and detailed designs of the landforms have not been developed. To provide the supporting information for the PRCP, the LEM assessment has focussed on the design of the embankment slope and cover.

Figure 1.2 to Figure 1.4 shows conceptual digital elevation models (DEM) of the proposed final landforms at the Project. The six WRDs incorporate batter slopes of 15% with a relatively flat plateau. The six landforms were assessed to determine the longest batter slopes. The longest batter slope lengths for each landform were:

- up to 105 m for the Vulcan North in-pit WRD;
- up to 250 m for the Vulcan North ex-pit WRD;
- up to 380 m for the Vulcan Main in-pit WRD;
- up to 220 m for the Vulcan Main ex-pit WRD;
- up to 205 m for the Vulcan South in-pit WRD; and
- up to 210 m for the Vulcan South ex-pit WRD.

The longest batter slope on the six landforms (excluding proposed batter drainage) is located on the Vulcan Main in-pit WRD at the area of interest shown in Figure 1.3. This batter slope is 380 m long from the crest to the toe.

The assessment has therefore focussed on the Vulcan Main in-pit WRD batter slope, which is called the **representative batter slope** in this report. If this batter slope is shown to be acceptable, it can be inferred that the other batter slopes would be acceptable because they have the same slope and cover design.

The following rehabilitation scenarios, obtained from the Draft PRCP, were assessed using the LEM:

- Scenario 1: Bare earth/unvegetated landform slope representing a failed vegetative establishment phase during early years of rehabilitation;
- Scenario 2: Rock mulched landform (30% rock mulching) prior to vegetation establishment;
- Scenario 3: Rock mulched landform (30% rock mulching) with 30% grass/vegetation cover;
- Scenario 4: Rock mulched landform (30% rock mulching) with 50% grass/vegetation cover; and
- Scenario 5: Rock mulched landform (30% rock mulching) with 70% grass/vegetation cover representing successful rehabilitation of the landform.

The assessment provides information on the ability of different cover management scenarios to resist erosion assuming no drainage works are undertaken. The proposed drainage would potentially reduce the batter slopes, at least in the short term to further assist in the management of erosion of the batter.

2.2 MODELLING APPROACH

The LEM tool SIBERIA within the CAESAR-lisflood (CAESAR) platform was used for the assessment. SIBERIA is a geomorphological / landscape evolution model that simulates catchment erosion and depositions for time scales from hours to 1000's of years. SIBERIA models soil erosion and deposition of the landforms by assessing rainfall-runoff drainage directions which are used to determine the area contributing/flowing through grid cells of the model. The model then calculates continuity equations for flow and sediment transport which determines erosion rates/depths output by the model.

The model parameters were first validated against the predicted soil loss rates provided in the Draft PRCP which are based on localised parameters (local rainfall erosivity, Limpopo soil erodibility, etc.). The validated parameters were then used to assess the erosion potential of the representative batter slope. The above rehabilitation scenarios for the representative batter slope were assessed for two timescales including:

- The first 10 years post mining to represent the establishment phase of site rehabilitation; and
- A period of 100 years post mining.

The LEM assessment was then undertaken for all six WRD's to provide an indication of what the landforms would look like after 100 years.

2.3 AVAILABLE DATA

The key input parameters to SIBERIA include:

- The proposed landform design in .DXF file format (see Section 2.3.1);
- Sediment and particle distribution information and sediment transport information representative of the materials proposed to be used for rehabilitation of the landform (see Section 2.3.2);
- Geotechnical data of the rehabilitated WRDs (see Section 2.3.3); and
- Geochemistry of the waste rock material (see Section 2.3.4)
- The surface water assessment (see Section 2.3.5).

2.3.1 Topography

Figure 1.2 to Figure 1.4 shows concept DEMs of the proposed final landforms provided by Vitrinite dated 11 March 2022.

The DEMs were processed using 12D and QGIS software prior to input to the CAESAR model. The input resolution to CAESAR was a 2 m grid cell size.

The concept DEMs do not include the suite of drainage measures that are proposed for the WRD plateau and embankments. Therefore, model results using the concept DEMs are slightly conservative as the inclusion of these drainage measures would reduce erosion risks.

2.3.2 Soil and land suitability

AARC prepared the *Vulcan South Soil and Land Suitability Assessment* (AARC, 2022) report for the Project, herein referred to as the soils report. The soils report documents the characteristics of the existing material available for use for the rehabilitation of the WRDs.

The soils report (AARC, 2022) notes that the surface soils across the Project area mainly consist of the Limpopo soil management unit (SMU) and these soils are proposed to be used for the rehabilitation of the WRD's. The topsoil is dominated by sand (79%) with 8% silt, 10% clay and 3% gravel. The sandy surface soils are non-sodic and not likely to be vulnerable to dispersion. However, clay subsoils (below 0.5 m) are sodic and susceptible to dispersion.

The soils report derived the erosion rates specific to the Limpopo SMU using the Revised Universal Soil Loss Equation (RUSLE). RUSLE is calculated using rainfall erosivity (for local conditions), soil erodibility, slope-length gradients, cover and management, and conservation/support practice factors. Table 2.1 summarises the predicted erosion rates for the proposed cover management strategies using the Limpopo SMU.

Table 2.1 – Predicted soil erosion rates of the Limpopo SMU as a factor of slope and cover from the Draft PRCP

Scenario	Cover management	C	Gradient (%)	A (t/ha.y)
1	Bare ground (pre-vegetation)	1.000	15	306.4
2	30% rock mulch (pre-vegetation)	0.325	15	99.58
3	30% rock mulch with 30% grass cover	0.100	15	30.64
4	30% rock mulch with 50% grass cover	0.050	15	15.32
5	30% rock mulch with 70% grass cover	0.018	15	5.52

2.3.3 Geotechnical assessment

Blackrock Mining Solutions Pty Ltd (Blackrock) prepared the geotechnical assessment memorandum *Vulcan Complex – Jupiter Final Landform Slope Stability Assessment* (Blackrock, 2020), herein referred to as the geotechnical report. The geotechnical report assessed the stability of the proposed WRD embankment design used for the Vulcan Coal Mine project. Blackrock concluded that the generally accepted Factor of Safety (FoS) criteria for long-term slopes should be greater than 1.5, and should be adopted for the Vulcan South project WRD embankment design.

2.3.4 Geochemistry assessment

RGS Mine Waste and Water Management prepared the *Geochemical Assessment of Waste Rock, Coal Reject and Coal* (RGS, 2022) for the Project, herein referred to as the geochemistry report. The geochemistry report documents the characteristics of the waste rock material proposed to be emplaced to form the post-mining Vulcan North, Vulcan Main and Vulcan South in-pit and ex-pit WRD landforms. A summary of the conclusions of the geochemistry report on the waste rock material are as follows:

- *The overwhelming majority of the waste rock materials have low sulfide content, excess acid neutralising capacity (ANC), and are classified as non-acid forming (NAF) (Barren). These materials have a very low risk of acid generation and a high factor of safety with respect to potential for generation of acidity.*
- *Coal reject materials have relatively low sulfide content and excess ANC. As a bulk mixed material, it is expected that coal reject will be classified as NAF and have a relatively low risk of generating acidic drainage. Co-disposal of reject materials in waste rock dumps is likely to have a beneficial impact on the quality of the reject leachate.*
- *Coal is likely to have similar geochemical characteristics to coal reject materials and will be temporarily stockpiled at the ROM area prior to being transferred to the CHPP. As is standard practice at coal mining operations in the Bowen Basin, any surface runoff and seepage from the ROM coal stockpile will be monitored for quality and managed in the mine water management system as part of the Water Management Plan.*
- *Initial and ongoing surface runoff and seepage from mining waste materials is expected to be pH neutral to slightly alkaline and have a low level of salinity.*
- *There is no significant metal/metalloid enrichment in mining waste materials compared to applied guideline values and median crustal abundance in un-mineralised soils.*
- *Most metals/metalloids are sparingly soluble at the neutral to slightly alkaline pH of leachate expected from bulk NAF mining waste materials. Dissolved metal/metalloid concentrations in surface runoff and leachate from bulk NAF mining waste materials are expected to be low and unlikely to pose a significant risk to the quality of surface and groundwater resources at relevant storage facilities.*

- *NAF waste rock materials should be amenable to revegetation as part of rehabilitation activities, although, gypsum and fertiliser addition may need to be considered for sodic materials to limit dispersion and erosion and to provide a reasonable growth medium for revegetation and rehabilitation.*

2.3.5 Surface water assessment

The surface water assessment (WRM, 2022) presents the proposed conceptual drainage design of the six post-closure landforms. The proposed drainage design of the six final landform WRDs (to be confirmed during detailed design) include indicative alignments for surface water drains, plateau drains, contour banks and drop structures. These drainage control structures decrease erosion risk ratings once implemented during detailed design of the landforms. The surface water assessment also provides mapping of the post-closure landform within the floodplain extent. The landforms are generally located out of areas of high velocities and depths (i.e. along or adjacent to major creeks and drainage lines).

2.4 REHABILITATION CRITERIA

Figure 2.1 shows the recommended cover design to optimise plant growth for rehabilitation of the Vulcan North, Vulcan Main and Vulcan South in-pit and ex-pit WRD landforms, obtained from the Draft PRCP. The topsoil layer is proposed to allow a suitable vegetative cover to establish to prevent erodibility of the landform. Where required, gypsum, organic matter and fertilizer will be mixed with the waste rock materials to reduce the sodicity and reduce the potential for dispersion and erosion (RGS, 2022).

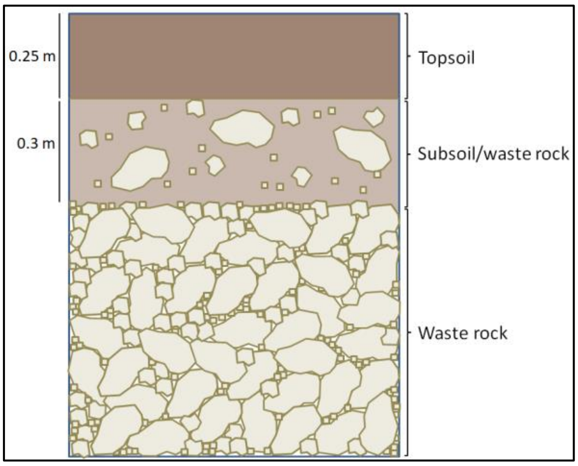

Figure 2.1 – Cover design to optimise plant growth

The Draft PRCP also provides defined rehabilitation goals for each PMLU. The criteria of relevance to this assessment are summarised in Table 2.2. The following is of note from the Draft PRCP:

- *Despite no need for a cover that protects waste rock from oxidation, waste rock will be placed in such a way to facilitate vegetation re-establishment. Following the return of waste rock to the open cut pit, at least 300 mm of subsoil (removed from the pits prior to mining and stockpiled) is to be spread over the rock. This will enhance the water-holding capacity of the soil and provide a more favourable growing environment for vegetation. Given the vulnerability of local subsoils to dispersion, some waste rock will be mixed with the subsoil (approximate ratio of rock to subsoil of 1:3), to provide protection from erosion, in the unexpected event that that rock mulch cover and developing grass cover doesn't provide adequate protection, and the overlying topsoil becomes eroded in places.*
- *Topsoil will be spread over the subsoil/rock mix at a depth of 250 mm to provide a favourable medium for plant establishment. Note that this cover design varies slightly between rehabilitation areas due to material availability and rehabilitation*

requirements. In addition, a number of topsoil and subsoil ameliorative measures will be implemented, wherever required, to ameliorate poor soil structure, low moisture retention and low nutrient concentrations that may be encountered with the Limpopo SMU.

- *Amelioration measures that can be utilised where required, include the application of organic matter, fertiliser, rapid establishing cover crops, and hydro mulching.*

Table 2.2 – Rehabilitation objectives, indicators and completion criteria outlined in the Draft PRCP (METServe, 2022)

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
PMLU A: Low-intensity cattle grazing					
A1	Land is to be stable	a) Indices of Landscape Function Analysis (Tongway and Hindley 2004). b) Depth of active rills and gullies	Sites are to be monitored at the time of planting and then every two years for 10 years after planting.	a) Landscape function analysis scores for soil stability, infiltration/runoff and nutrient cycling have started to plateau, and the plateau values predicted from sigmoidal curves fitted to the data are equivalent to or exceed values at analogue sites. b) No active rill or gully erosion deeper than 25 cm present.	a) This methodology has been widely applied to rehabilitated mine sites across Australia, and is strongly correlated with soil aggregate stability, soil nutrient cycling and water infiltration (Tongway and Hindley 2004). b) Provides a supplementary observational method of early erosion detection and early intervention.
		Percentage cover of rock, woody debris, litter, grasses and herbs within a 10 m × 50 m plot.	Late wet season (February-May), every two years for 10 years after planting.	Grazed land maintains a percentage groundcover of between 50% and 96% on slopes up to 10% and between 70% and 96% on slopes between 10-15%.	A percentage cover of ≥50% protects slopes from erosion (Loch 2000; Waters 2004; Carroll et al. 2010). Cover ≥70% is required to achieve background rates of erosion on slopes steeper than 10% (AARC 2021). Excessive groundcover inhibits the recruitment of trees and shrubs, and a maximum value of 96% cover was observed within reference sites in stable, unmined vegetation communities (METServe 2020).
A2	Land is to be non-polluting	Levels of contamination present following remediation efforts that take place after infrastructure decommissioning and removal.	Prior to the commencement of topsoil placement.	A site suitability statement prepared by an approved auditor is to conclude that land is not contaminated and is suitable for the PMLU.	This indicator requires assessment to achieve rehabilitation milestone 2 but does not need to be re-assessed at rehabilitation completion unless a new source of potential contamination occurs (e.g., a hydrocarbon spill).
		Water quality at permanent monitoring locations downstream of the Project.	Annually, following rain events.	Surface water in downstream monitoring locations is to remain within site specific water quality monitoring limits, once established.	Site-specific surface water quality triggers are based on baseline surveys undertaken at the site.
		Groundwater quality within permanent monitoring bores.	Quarterly.	Groundwater in downstream monitoring locations is to remain within site specific water quality monitoring limits, once established.	Site-specific surface water quality triggers are based on baseline surveys undertaken at the site.

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
A3	Weeds listed under the *Biosecurity Act* are not to exceed densities typically present in unmined, grazed landscapes within the MLA and neighbouring areas.	Percentage cover within a 10 m × 50 m plot	Between February and April, every two years for 10 years after planting.	Rehabilitated areas are to have ≤0.2% cover of *Parthenium hysterophorus* **AND** rehabilitated areas are to have ≤0.1% of *Harrisia martinii* **AND** Any other weeds listed under the *Biosecurity Act* are to be present in densities of <1 individual per hectare.	Completion criteria are based on the densities of each weed recorded during ecological surveys of the region prior to mining (METServe, 2022). As weed densities vary by soil type, only data from soil types present within the MLA are incorporated into the completion criteria.
A4	Pasture is to be as productive within rehabilitated areas as in neighbouring unmined areas within the same soil management unit.	Pasture mass (t/ha) of ungrazed plots	Sites are to be monitored at the end of the growing season (April-May) six and ten years after planting.	Rehabilitated areas are to have a pasture mass that is not statistically significantly different (with adequate sampling to detect ≤10% difference between groups) from unmined areas within the same soil management unit measured at the same time.	Pasture mass is the standard unit of productivity used widely in the grazing industry (Cayley and Bird 1996).
A5	Rehabilitated land is to have the same land suitability class for grazing as pre-mining score.	Land suitability class	Sites are to be monitored six and ten years after planting.	Rehabilitated areas are to have a land suitability class of 4 or lower.	Prior to mining, the land had a suitability class for cattle grazing of 4 (AARC 2022).
A6	The species richness of grasses that make up the pasture in rehabilitated areas is to be as high as in neighbouring unmined areas within the same soil management unit.	Species richness (number of species) of grasses contained within a 10 m × 50 m plot.	Sites are to be monitored soon after planting (Feb-Apr) and then every two years for 10 years after planting.	The species richness of plots in rehabilitated areas is to equal or exceed the 10th percentile among equivalent plots in reference sites on the same soil management unit.	Because the relative densities of each species are expected to differ between rehabilitated and reference sites due to differences in grazing history (reference sites are all grazed), species richness is favoured as an indicator over indices of diversity (the latter incorporate relative abundance).
PMLU B: Low-intensity cattle grazing with Habitat for Threatened Species					

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
B1	Land is to be stable	a) Indices of Landscape Function Analysis (Tongway and Hindley 2004). b) Depth of active rills and gullies.	Sites are to be monitored at the time of planting and then every two years for 10 years after planting.	a) Landscape function analysis scores for soil stability, infiltration/runoff and nutrient cycling have started to plateau, and the plateau values predicted from sigmoidal curves fitted to the data are equivalent to or exceed values at analogue sites. b) No active rill or gully erosion deeper than 25 cm present.	a) This methodology has been widely applied to rehabilitated mine sites across Australia, and is strongly correlated with soil aggregate stability, soil nutrient cycling and water infiltration (Tongway and Hindley 2004). b) Provides a supplementary observational method of early erosion detection and early intervention.
		Percentage cover of rock, woody debris, litter, grasses and herbs within a 10 m × 50 m plot.	Late wet season (February-May), every two years for 10 years after planting.	Grazed land maintains a percentage groundcover of between 50% and 96% on slopes up to 10% and between 70% and 96% on slopes between 10-15%.	A percentage cover of ≥50% protects slopes from erosion (Loch 2000; Waters 2004; Carroll *et al*. 2010). Cover ≥70% is required to achieve background rates of erosion on slopes steeper than 10% (AARC 2022). Excessive groundcover inhibits the recruitment of trees and shrubs, and a maximum value of 96% cover was observed within reference sites in stable, unmined vegetation communities (METServe 2022).
B2	Land is to be non-polluting	Levels of contamination present following remediation efforts that take place after infrastructure decommissioning and removal	Prior to the commencement of landform development	A site suitability statement prepared by an approved auditor is to conclude that land is not contaminated and is suitable for the PMLU.	This indicator requires assessment to achieve rehabilitation milestone 2, but does not need to be re-assessed at rehabilitation completion unless a new source of potential contamination occurs (e.g., a vehicle accident leading to hydrocarbon spills)
		Water quality at permanent monitoring locations downstream of the Project	Annually, following rain events	Surface water in downstream monitoring locations is to remain within site specific water quality monitoring limits, once established.	Site specific surface water quality triggers will be established over time and present the most accurate measure of effect on water quality.
		Groundwater quality within permanent monitoring bores	Quarterly	Groundwater in downstream monitoring locations is to remain within site specific water quality monitoring limits, once established.	Site specific groundwater quality triggers will be established over time and present the most accurate measure of effect on water quality.

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
B3	Weeds listed under the *Biosecurity Act* are not to exceed densities typically present in unmined, grazed landscapes within the MLA and neighbouring areas.	Percentage cover within a 10 m × 50 m plot	Between February and April, every two years for 10 years after planting.	Rehabilitated areas are to have ≤0.2% cover of *Parthenium hysterophorus* **AND** rehabilitated areas are to have ≤0.1% of *Harrisia martinii* **AND** Any other weeds listed under the *Biosecurity Act* are to be present in densities of <1 individual per hectare.	Completion criteria are based on the densities of each weed recorded during ecological surveys of the region prior to mining (METServe, 2022). As weed densities vary by soil type, only data from soil types present within the MLA are incorporated into the completion criteria.
B4	Pasture is to be as productive within rehabilitated areas as in neighbouring unmined areas within the same soil management unit.	Pasture mass (t/ha) of ungrazed plots	Sites are to be monitored at the end of the growing season (April-May) six and ten years after planting.	Rehabilitated areas are to have a pasture mass that is not statistically significantly different (with adequate sampling to detect ≤10% difference between groups) from unmined areas within the same soil management unit measured at the same time.	Pasture mass is the standard unit of productivity used widely in the grazing industry (Cayley and Bird 1996).
B5	Rehabilitated land is to have the same land suitability class for grazing as pre-mining score.	Land suitability class	Sites are to be monitored six and ten years after planting.	Rehabilitated areas are to have a land suitability class of 4 or lower.	Prior to mining, the land had a suitability class for cattle grazing of 4 (AARC 2022).
B6	The species richness of grasses that make up the pasture in rehabilitated areas is to be as high as in neighbouring unmined areas within the same soil management unit.	Species richness (number of species) of grasses contained within a 10 m × 50 m plot.	Sites are to be monitored soon after planting (Feb-Apr) and then every two years for 10 years after planting.	The species richness of plots in rehabilitated areas is to equal or exceed the 10th percentile among equivalent plots in reference sites on the same soil management unit.	Because the relative densities of each species are expected to differ between rehabilitated and reference sites due to differences in grazing history (reference sites are all grazed), species richness is favoured as an indicator over indices of diversity (the latter incorporate relative abundance).

ID	Rehabilitation Objective	Rehabilitation Indicator	Assessment Timing	Completion Criteria	Justification
B7	Koala food trees are to have a similar dominance within rehabilitated vegetation communities as they did in vegetation present on site prior to mining	Proportion of the total basal area of woody vegetation at the site that comprises *Eucalyptus crebra*, *Eucalyptus populnea* or *Eucalyptus camaldulensis*.	Sites are to be monitored six and ten years after planting.	*Eucalyptus crebra* and/or *Eucalyptus populnea* are to constitute 21% of the total basal area of woody vegetation on sand plains. **AND** *Eucalyptus camaldulensis* is to constitute 33% of the total basal area of woody vegetation along Hughes Creek, Barretts Creek, and drainage line 2, 3, 4 and 7.	Relative dominance of Koala food trees is based on secondary site data gathered from nine sand plain reference sites and three riparian reference sites (METServe, 2022).
B8	Trees are to be sufficiently tall to be used by Koalas and to escape browsing by cattle (except RA1).	Mean height of the tallest ten trees per hectare	Sites are to be monitored six and ten years after planting.	The mean height of the tallest ten trees per hectare is ≥4 m.	The Queensland Environmental Offsets Policy defines non-juvenile Koala habitat trees to be those with a height greater than 4 m (DES 2020). Such trees are also beyond the reach of cattle.
B9	Density of woody vegetation within rehabilitated areas is to be sufficient for Squatter Pigeons	The mean Normalised Difference Vegetation Index (NDVI) calculated using Landsat imagery captured following at least two months without rain (e.g., late dry season)	Sites are to be monitored at the time of planting and then every two years for 10 years after planting.	Rehabilitated areas are to have a mean NDVI between 0.1240 and 0.1778	Ecological surveys of the local region found that Squatter Pigeons are confined to vegetation with a density that falls within the range of NDVI values used as the completion criterion (METServe, 2022).
B10	Availability of food for the Glossy Black-cockatoo is restored to pre-mining levels	Basal area of the food tree Casuarina cristata	Sites are to be monitored six and ten years after planting.	Rehabilitated areas where the ground is level and soil management unit “Orange” has been used as topsoil are to have a minimum basal area of 0.5 m^2/ha stems of Casuarina cristata per ha.	Casuarina cristata was mostly restricted to Orange soil units pre-mining. Where present, C. cristata had a basal area of 0.5 to 5.83 m^2/ha (based on three reference sites).
B11	Diversity of food for the Greater Glider is restored to pre-mining levels	Species richness of Eucalyptus and Corymbia species in a 10 m × 50 m plot.	Sites are to be monitored six and ten years after planting.	Rehabilitated areas on the Zambezi soil management unit are to contain Eucalyptus camaldulensis and at least one other species of Corymbia or Eucalyptus.	Three secondary sites sampled in riparian reference sites all contained E. camaldulensis and one other Eucalyptus or Corymbia sp.

2.5 SIBERIA MODEL PARAMETERS

Table 2.3 shows the SIBERIA model parameters that are used to define the landform evolution and mean annual erosion. The Beta1 parameter represents the different cover types, which was derived iteratively to match the predicted erosion rates given in the draft PRCP for each cover type. Table 2.4 shows adopted parameters for each cover management scenario.

Table 2.3 – SIBERIA model parameters

Parameter	Description
Beta1	*Coefficient b1 in the fluvial sediment transport formula*
Beta3	*Coefficient between discharge and area in the sediment transport formula*
m1	*Exponent on the discharge m1 in the sediment transport formula*
m3	*Exponent on the area in discharge used in the sediment transport*
n1	*Exponent on this slope n1 in the sediment transport formula*

Source: User Manual for SIBERIA (Version 8.30) (Wilgoose, G., 2005)

Table 2.4 – Adopted SIBERIA model parameters

Scenario (see Section 2)	Parameter				
	Beta1	Beta3	m1	m3	n1
1	*0.01780*	*1*	*1.5*	*1*	*2*
2	*0.00560*	*1*	*1.5*	*1*	*2*
3	*0.00164*	*1*	*1.5*	*1*	*2*
4	*0.00082*	*1*	*1.5*	*1*	*2*
5	*0.00030*	*1*	*1.5*	*1*	*2*

2.6 MODEL CALIBRATION

Table 2.5 compares the average erosion rates in tonnes per hectare per year predicted by the SIBERIA model and those given in the Draft PRCP and shown in Table 2.1 for the five proposed landform cover management scenarios. To be consistent with the values given in the Draft PRCP, the SIBERIA model results are provided for the average erosion rate for the 15% landform slope after 100 m of slope travel across 100 m. The average erosion rate was calculated using a cross sectional average of erosion depths across the landform embankment (at 100 m) over a 10-year simulation.

Overall, the adopted SIBERIA model parameters shown in Table 2.4 produces erosion rates similar to the values estimated in the Draft PRCP (using the RUSLE) for the five proposed landform surfaces. Note that the predicted erosion rates are based on theoretical assessments and are not derived from field observed erosion data, meaning they are only suitable for comparative purposes only. The erosion rates within the model were scaled to match theoretical calculations for predicted soil losses and therefore predictions produced by the model are somewhat predetermined.

The approach used for this assessment should be validated once the post-mining landform is established. This can be undertaken once data has been collected from the rehabilitated landform by comparing observed rill/deposition depths over cross-sectional areas of the landform to the calculated rates.

Table 2.5 – Representative slope calibration results

Scenario	Average erosion rate (t/ha.y)		Difference
	RUSLE[a]	Siberia Model	
1 – Bare earth (pre-vegetation)	306.40	306.95	0.2%
2 - 30% rock mulch (pre-vegetation)	99.58	98.70	-0.9%
3 - 30% rock mulch with 30% grass cover	30.64	30.74	0.3%
4 - 30% rock mulch with 50% grass cover	15.32	15.32	0.0%
5 - 30% rock mulch with 70% grass cover	5.52	5.58	1.1%

[a] Values adopted from the Draft PRCP

2.7 EROSION RISK ASSESSMENT CRITERIA

For this assessment, erosion depth has been used as the erosion risk assessment criteria as given in Table 2.6. Erosion risk assessment criteria was derived from the rehabilitation criteria (see Section 2.4) for the landforms and the milestones outlined in the Draft PRCP. It was deemed that erosion model outcomes which achieved a very low erosion risk would satisfy the rehabilitation criteria and the landform cover design could be considered stable.

Table 2.6 – Erosion risk assessment criteria

Erosion risk	Erosion depth (m)	Observations
Very Low	< 0.15	• Erosion depth only affecting uppermost topsoil layer. • Land is stable, only minor active rills or gully erosion no deeper than 0.15 m. • Negligible effects on receiving environment. • Vegetative cover established and effective.
Low	0.15 – 0.25	• Erosion depth affecting up to the topsoil layer. • Land is stable, only minor active rills or gully erosion no deeper than 0.25 m. • Minor risk of sedimentation to downstream waterways. • Reduced ability for topsoil layer to restore cover over time.
Moderate	0.25 – 0.55	• Erosion depth affecting topsoil layer and subsoil layers in some areas of the landform. • Increased sedimentation of downstream waterways. • Exposure of subsoil/waste rock material to runoff (however classified NAF and unlikely to generate saline runoff).
High	> 0.55	• Erosion depth greater than topsoil layer and rehabilitative cover has failed. • Great risk of sedimentation of downstream waterways. • Exposure of compacted waste rock material to runoff (however classified NAF and unlikely to generate saline runoff). • Rehabilitation works required to restore cover.

Note: Erosion risk criteria was derived based on rehabilitation objectives outlined in the Draft PRCP

3 Findings

3.1 REPRESENTATIVE SLOPE ASSESSMENT

Table 3.1 summarises the erosion risk assessment results for the full length of the representative batter slope for the five proposed cover management scenarios. Results are provided for the maximum erosion depths across the representative slope of 380 m. This is the longest slope length on any of the landforms proposed across the Vulcan North, Vulcan Main and Vulcan South proposed final landforms. To minimise error caused by boundary effects, the maximum erosion depth along the slope was assessed above the end of the batter slope and landform toe drain as the drainage configuration along the toe of the landforms are yet to be finalised and will likely include some form of works to prevent erosion.

Table 3.1 – Erosion risk assessment results

Scenario	Maximum erosion depth (m)	
	10-year model simulation	100-year model simulation
1 – Bare earth (pre-vegetation)	1.20	N/A
2 - 30% rock mulch (pre-vegetation)	0.60	2.50
3 - 30% rock mulch with 30% grass cover	0.35	1.10
4 - 30% rock mulch with 50% grass cover	0.20	0.80
5 - 30% rock mulch with 70% grass cover	0.10	0.50

N/A – Bare earth 100 year simulation could not be processed with SIBERIA as limits of erosion were too high

Figure 3.1 to Figure 3.5 show figures of the final landform along the representative batter slope for the five rehabilitation scenarios after 100 years. The following is of note:

- Scenario 1 – Bare earth (pre-vegetation) has a high erosion risk for both the 10-year and 100-year simulations. For the 100-year simulation (shown in Figure 3.1):
  - The embankment is predicted to fail completely after 35 years of simulation time. Within the 35 year simulation time, rilling and gully erosion exceeds high erosion risk criteria along the full length of the embankment. Erosion depth greater than topsoil/subsoil layers;
  - Drainage control measures (wide contour banks, benching, drop structures, etc.) would be required at 20 m intervals to prevent exceedance of the high erosion risk criteria rilling and gully erosion;
  - Failure of rehabilitative cover and entire embankment slope and will require remediation works to re-establish cover;
  - Subsoil layer and compacted waste rock material layers would be exposed to environment; and
  - Great risk of sediment loads transported to downstream receiving waters.
- Scenario 2 – 30% rock mulch (pre-vegetation) has a high erosion risk for both the 10-year and 100-year simulations. For the 100-year simulation (shown in Figure 3.2):
  - Rilling and gully erosion exceeds high erosion risk criteria along the majority of the length of the embankment. Erosion depths greater than topsoil/subsoil layers;

  - Drainage control measures (wide contour banks, benching, drop structures, etc.) would be required at 30 m intervals to prevent exceedance of the high erosion risk criteria rilling and gully erosion;
  - Majority of the rehabilitative cover and embankment slope would fail and will require remediation works to re-establish cover;
  - Subsoil layer and compacted waste rock material layers exposed to environment; and
  - Great risk of sediment loads transported to downstream receiving waters.
- Scenario 3 – 30% rock mulch and 30% grass cover has a moderate erosion risk for the 10-year and high erosion risk for the 100-year simulations. For the 100-year simulation (shown in Figure 3.3):
  - Rilling and gullying exceeds high erosion risk criteria along the majority of the length of the embankment. Erosion depths greater than topsoil/subsoil layers;
  - Drainage control measures (wide contour banks, benching, drop structures, etc.) would be required at 40 m intervals to prevent exceedance of the high erosion risk criteria rilling and gully erosion;
  - Embankment fails the design criteria less than 100 m down the face of the slope;
  - Subsoil/waste rock material layer exposed to environment; and
  - Great risk of sediment loads transported to downstream receiving waters.
- Scenario 4 – 30% rock mulch and 50% grass cover has a low erosion risk for the 10-year and high erosion risk for the 100-year simulations (shown in Figure 3.4):
  - Rilling and gullying exceeds high erosion risk criteria along the majority of the length of the embankment. Erosion depth greater than topsoil/subsoil layers;
  - Drainage control measures (wide contour banks, benching, drop structures, etc.) would be required at 60 m intervals to prevent exceedance of the high erosion risk criteria rilling and gully erosion;
  - The upper slopes are relatively stable but rills exceed rehabilitation criteria depths along the lower slope for the 100-year simulations;
  - Some of the embankment may require remediation to ensure cover remains suitable; and
  - Great risk of sediment loads transported to downstream receiving waters.
- Scenario 5 - 30% rock mulch and 70% grass cover has a very low erosion risk for the 10-year and moderate erosion risk for the 100-year simulations. For the 100-year simulation (shown in Figure 3.5):
  - Rilling/gullying exceeds the moderate erosion risk criteria along the majority of the length of the embankment slope. Erosion depth affecting topsoil layer and subsoil layers in some areas of the landform;
  - Drainage control measures (wide contour banks, benching, drop structures, etc.) are recommended to reduce slope lengths to a maximum spacing of 100 m intervals as per the soils report (AARC, 2022) to mitigate erosion risk via rilling and gully erosion;
  - The upper slopes are suitably stable, vegetative cover is established and effective; and
  - Increased risk of sediment loads transported to downstream receiving waters.

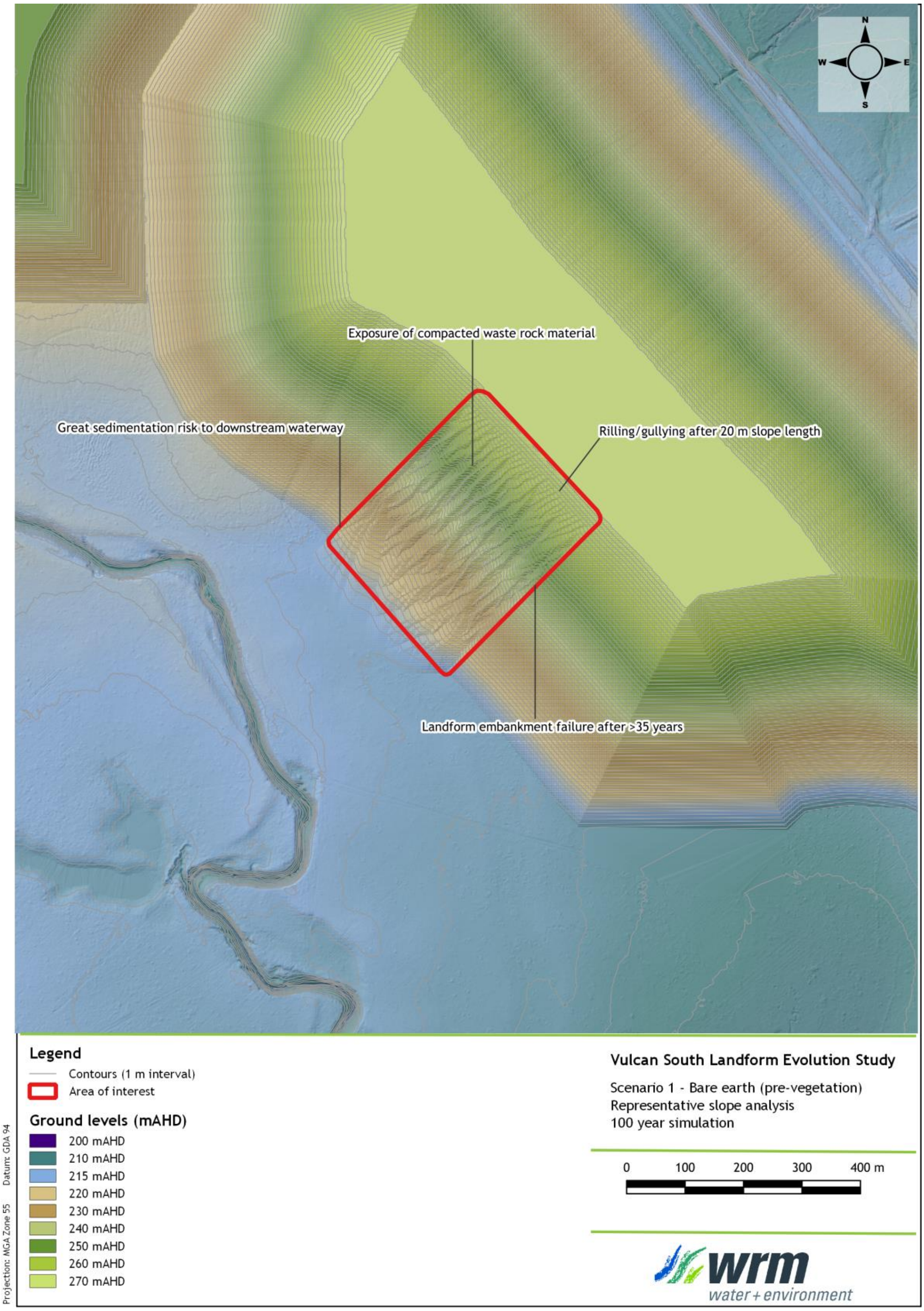

Figure 3.1 – Predicted rill/gully erosion for Scenario 1 – Bare earth (pre-vegetation) for the representative batter slope, 100 year simulation

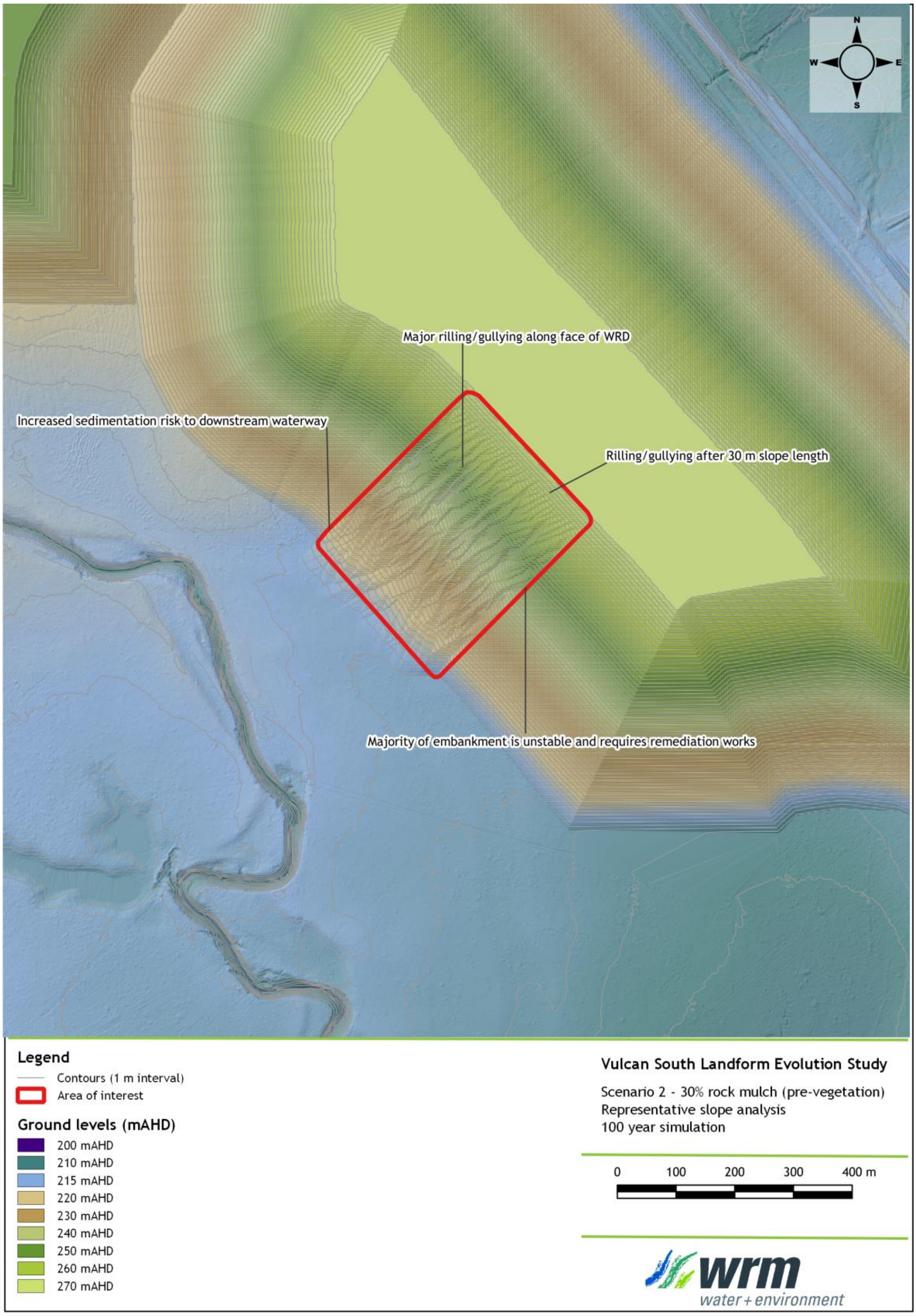

Figure 3.2 – Predicted rill/gully erosion for Scenario 2 – 30% rock mulch (pre-vegetation) for the representative batter slope, 100 year simulation

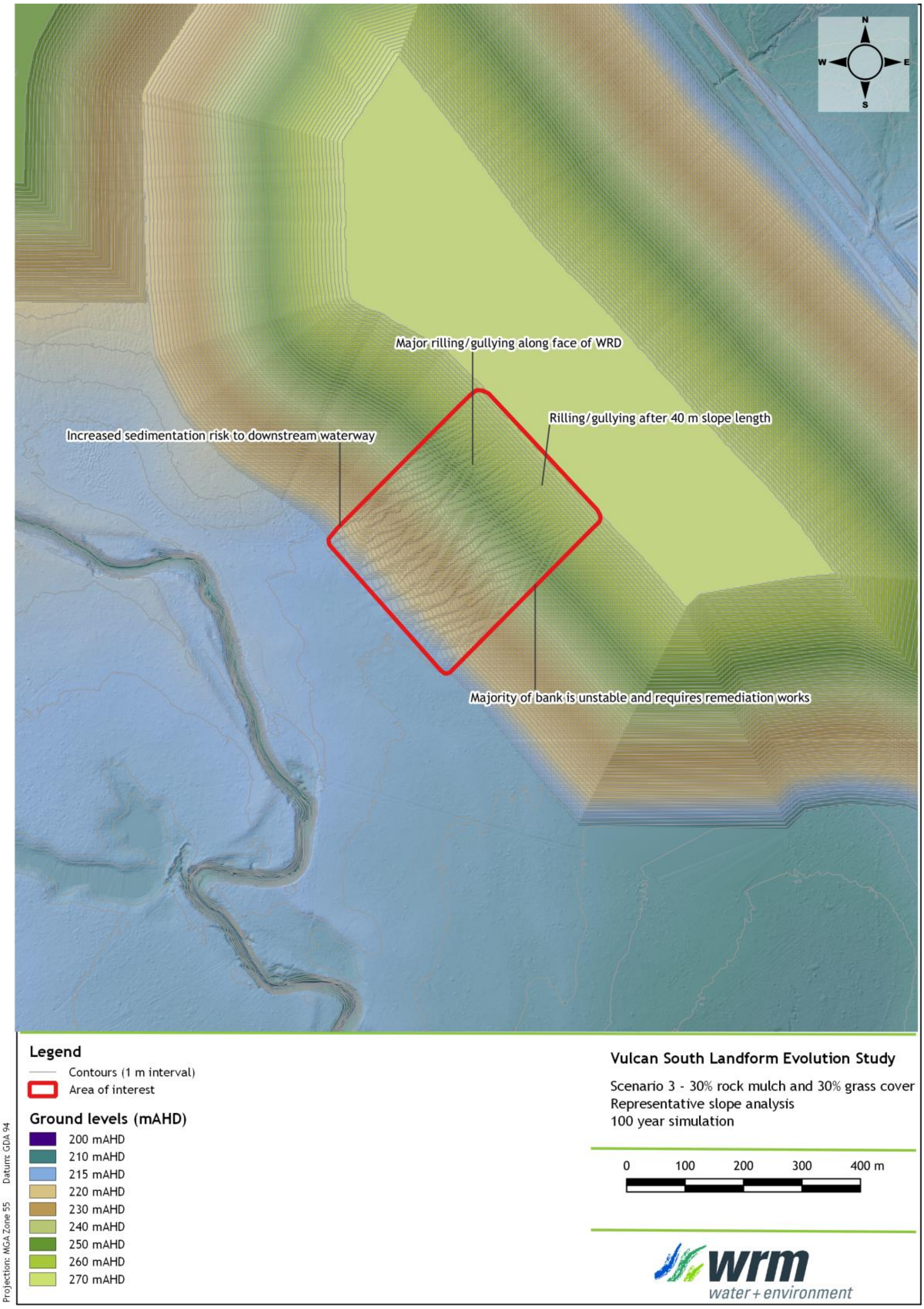

Figure 3.3 – Predicted rill/gully erosion for Scenario 3 – 30% rock mulch and 30% grass cover for the representative batter slope, 100 year simulation

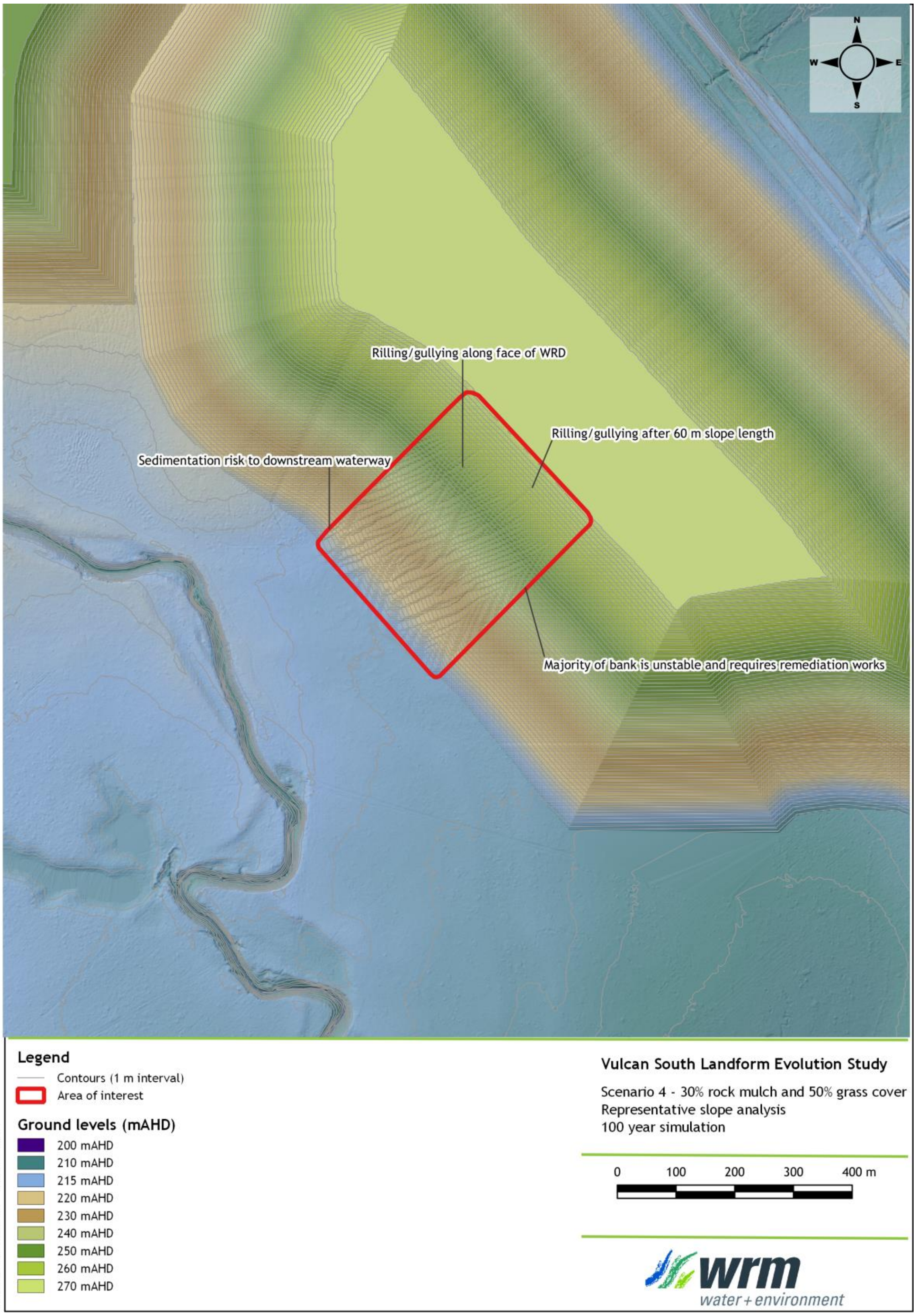

Figure 3.4 – Predicted rill/gully erosion for Scenario 4 – 30% rock mulch and 50% grass cover for the representative batter slope, 100 year simulation

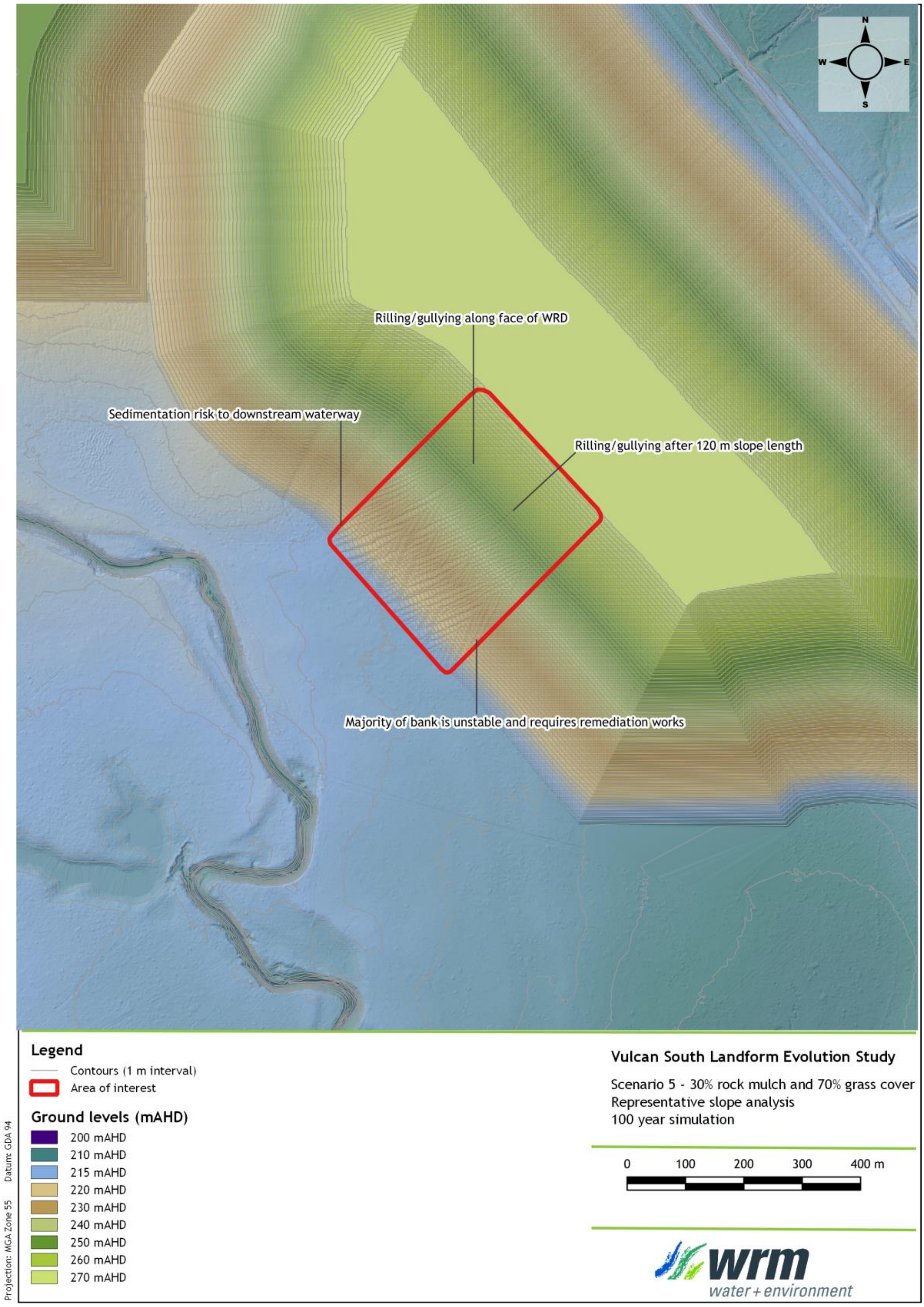

Figure 3.5 – Predicted rill/gully erosion for Scenario 5 – 30% rock mulch and 70% grass cover for representative slope, 100 year simulation

3.2 APPLICATION TO PROPOSED LANDFORMS

3.2.1 General

The representative slope assessment shows that slope lengths up to 380 m with fully established Scenario 5 vegetative cover achieves a 'moderate' erosion risk. However, the results show that slope lengths up to 120 m with fully established Scenario 5 vegetative cover would achieve a 'very low' erosion risk. With drainage control structures implemented during detailed design of the six landforms as recommended in the soils report (AARC, 2022) at a maximum spacing of 100 m, the six landforms should be considered as suitably stable against long-term erosion. On this basis, all batter slopes on the site would achieve a 'very low' erosion risk criteria with drainage control structures implemented because they have the same slope and cover design.

The adopted model parameters used for the representative slope assessment were used to highlight the potential erosion risk locations (areas of concern) for the full concept landform designs for the Vulcan North, Vulcan Main and Vulcan South in-pit and ex-pit WRD landforms. The model was run for the 100 year timeframe assuming Scenario 5 (30% rock mulch with 70% grass cover) rehabilitative cover management for the assessment. General observations of the stability/erosion risk assessment are:

- Concave (valley) sections of the proposed concept landform designs are subject to higher erosion risk as runoff naturally converges to these points along the landforms. With the implementation of rock chutes during detailed design of the landforms, erosion risks would decrease;
- Coarse sediment is predicted to accumulate along the toe drains of the proposed in-pit and ex-pit WRDs to reduce the downstream impacts;
- The upper slopes of the landforms would generally be considered stable in the long-term and have low risk of rilling and gully erosion; and
- Slope lengths of 100 m or less under Scenario 5 vegetative cover achieves a 'very low' erosion risk rating indicating that detailed design of the proposed WRD landforms implementing drainage control structures would be suitably stable in the long-term.

3.2.2 Vulcan North waste rock dumps

Figure 3.6 shows the predicted areas of concern for the concept Vulcan North in-pit and ex-pit WRD designs under the Scenario 5 vegetative cover. The maximum slope length for the Vulcan North in-pit and ex-pit WRDs is approximately 105 m and 250 m, respectively. The following is of note regarding the stability/erosion risk assessment:

- The Vulcan North in-pit WRD is predicted to have significantly less rilling and gully erosion across the landform because the maximum slope length of the landform is shorter than the representative batter slope length of 380 m. The majority of the landform would be considered stable in the long-term and have low risk of rilling / gully erosion.
- The Vulcan North ex-pit WRD is also predicted to have less rilling and gully erosion because the slope length is marginally shorter than the representative slope length of 380 m. Drainage control structures will be required to reduce erosion risks.

3.2.3 Vulcan Main waste rock dumps

Figure 3.7 shows the predicted areas of concern for the concept Vulcan Main in-pit and ex-pit WRD designs. The maximum slope length for the Vulcan Main in-pit and ex-pit WRDs is approximately 380 m and 220 m, respectively. The following is of note regarding the stability/erosion risk assessment:

- The southwest and northeast face of the Vulcan Main in-pit WRD both have maximum slope lengths of 380 m. The results show that these sections of the WRD are prone to the highest risk of rilling / gully erosion without drainage controls. Erosion risks at the benched areas (northern and southern sections) of the Vulcan Main in-pit WRD are significantly lower as slope lengths are shorter than the representative slope length at the benched areas.

- The Vulcan Main ex-pit WRD is predicted to have less rilling and gully erosion because the slope length is marginally shorter than the representative slope length of 380 m. Drainage control structures will be required reduce erosion risks.

3.2.4 Vulcan South waste rock dumps

Figure 3.8 shows the predicted areas of concern for the concept Vulcan South in-pit and ex-pit WRD designs. The maximum slope length for the Vulcan South in-pit and ex-pit WRDs is approximately 205 m and 210 m, respectively. The Vulcan South in-pit and ex-pit WRD are predicted to have less rilling and gully erosion because the slope lengths are shorter than the representative slope length of 380 m. Drainage control structures will be required reduce erosion risks.

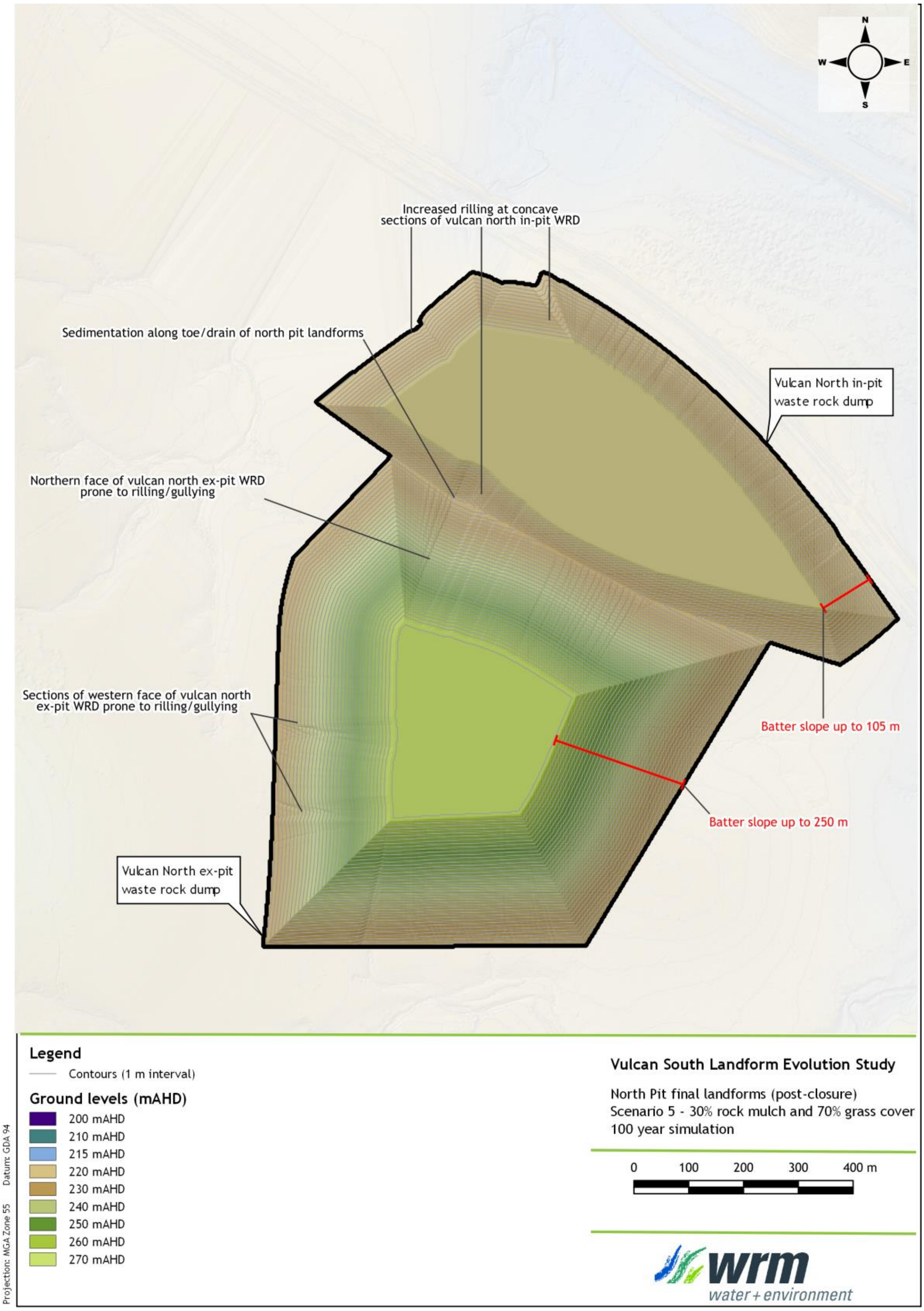

Figure 3.6 – Predicted rill/gully erosion for Scenario 5 – 30% rock mulch and 70% grass cover for the Vulcan North Pit waste rock dumps, 100 year simulation

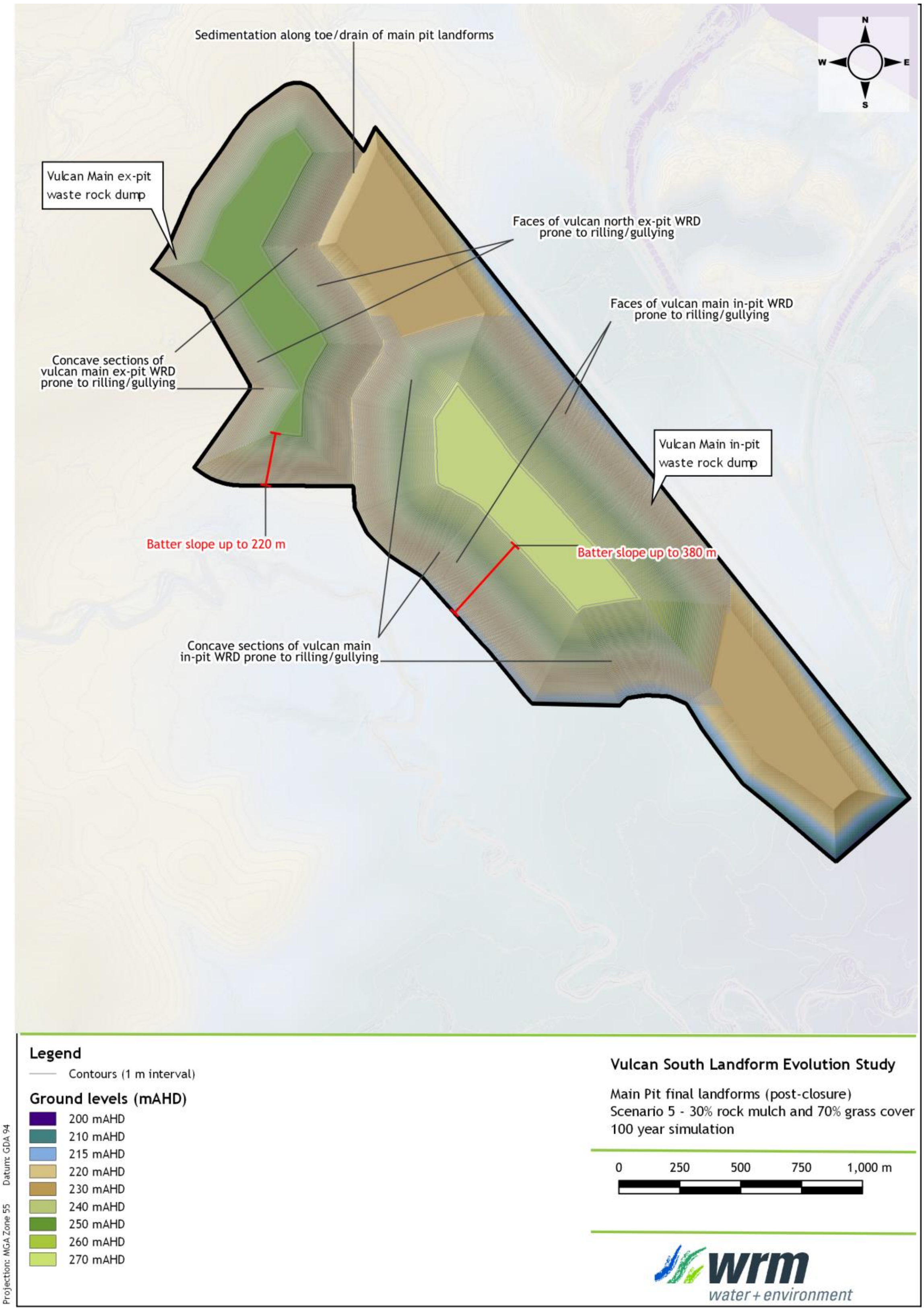

Figure 3.7 – Predicted rill/gully erosion for Scenario 5 – 30% rock mulch and 70% grass cover for the Vulcan Main pit waste rock dumps, 100 year simulation

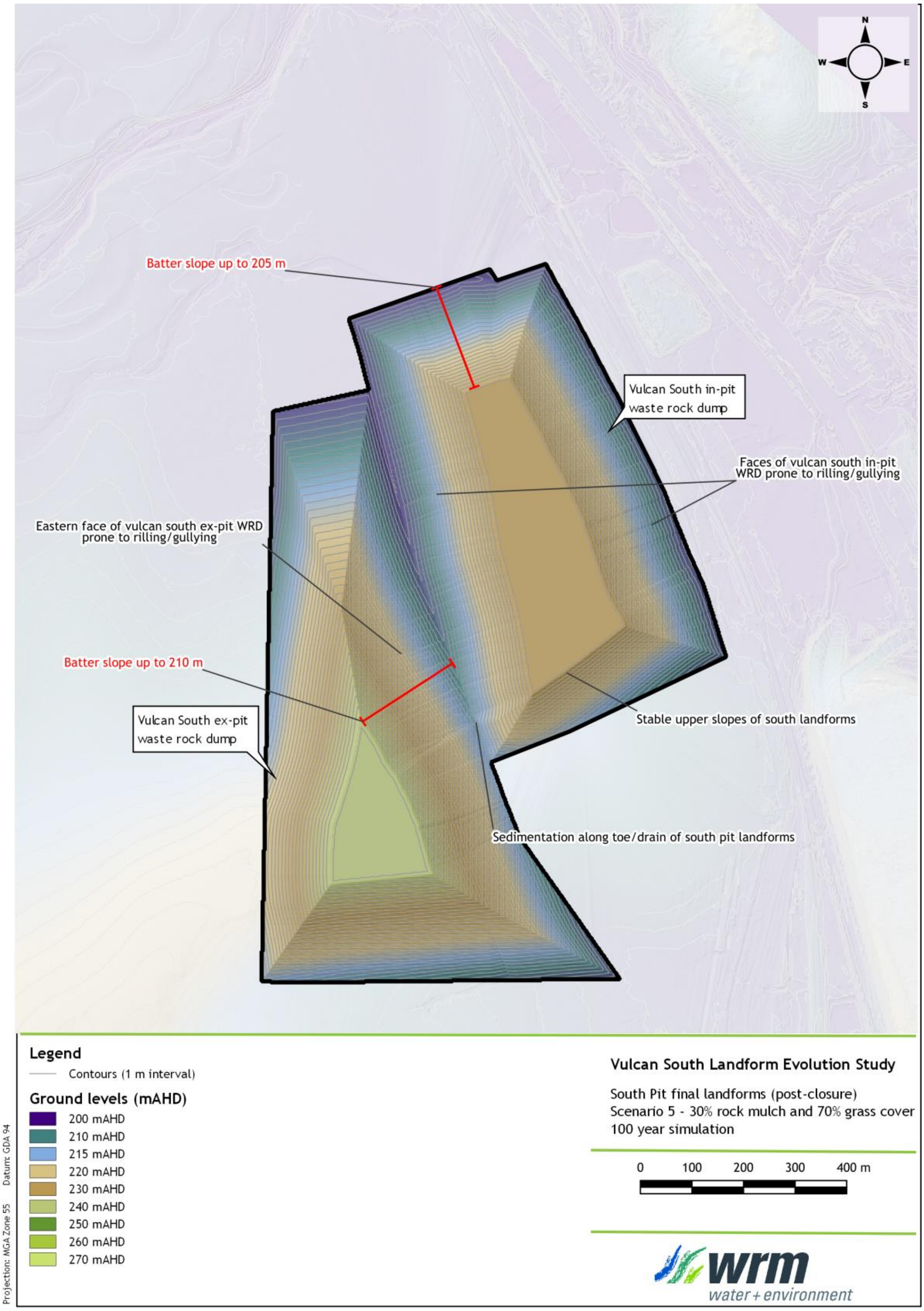

Figure 3.8 – Predicted rill/gully erosion for Scenario 5 – 30% rock mulch and 70% grass cover for the Vulcan South pit waste rock dumps, 100 year simulation

4 Summary and recommendations

4.1 LANDFORM ASSESSMENT

Table 4.1 summarises the erosion risk for the modelled scenarios against the erosion risk criteria. The LEM results show that the erosion of the landforms under Scenario 5 achieves a 'very low' erosion risk rating in the first 10 year vegetation establishment period. Over a 100 year timeframe, the erosion risk prior to the implementation of drainage control structures has a 'moderate' erosion risk rating. Under Scenario 5 with the implementation of drainage control structures at a maximum spacing of 100 m intervals, the LEM results show that a 'very low' erosion risk rating is achieved over the 100 year timeframe. The erosion objectives achieved include:

- Erosion depth only affecting uppermost topsoil layer;
- Land is stable, only minor active rills or gully erosion no deeper than 0.15 m;
- Negligible sedimentation effects on downstream waterways; and
- Vegetative cover is considered widely established and effective however may have reduced ability to recover in some areas.

The Scenario 5 vegetation cover would achieve the rehabilitation criteria objective for the Project with drainage control structures in place, as outlined in the Draft PRCP. Once the Scenario 5 rehabilitation cover management has been established across RA1 and RA2, rilling and gully erosion risk decreases. If the detailed design of the proposed landforms includes contour banks to reduce slope lengths along the WRDs, it is likely that erosion risk ratings would be reduced even further.

Table 4.1 – Summary of erosion risk

Scenario	10-year model simulation	100-year model simulation
1 – Bare earth (pre-vegetation)	High	High
2 - 30% rock mulch (pre-vegetation)	High	High
3 - 30% rock mulch with 30% grass cover	Moderate	High
4 - 30% rock mulch with 50% grass cover	Low	High
5 - 30% rock mulch with 70% grass cover	Very Low	Moderate

During the vegetation establishment 10-year timeframe, the cover management scenario likely to be in place is Scenario 2 which includes the rock mulch (30% cover) and limited vegetation, however, it is of note that some vegetation is likely to have established after a one-to-two-year period, as such the erosion risk rating results are conservative. Scenario 2 achieves a 'high' erosion risk rating over the 10-year timeframe, characterised as follows:

- Erosion depth affecting topsoil layer and subsoil layers of the landform;
- Great risk of sedimentation of downstream waterways; and
- Exposure of subsoil/waste rock material to runoff (however classified NAF and unlikely to generate saline runoff).
- The model results show that during the 10-year vegetation establishment period, contour banks would be required to reduce slope lengths and erosion rates.

Overall, the SIBERIA erosion modelling indicates that the rehabilitation areas RA1 and RA2

(Vulcan North, Vulcan Main and Vulcan South in-pit and ex-pit WRD landforms) would achieve the long-term rehabilitation criteria objectives outlined in the Draft PRCP once the Scenario 5 vegetative cover is established and drainage control structures are implemented to reduce slope lengths. The likelihood that the underlying waste rock material will be exposed is low.

4.2 RECOMMENDATIONS

It is recommended that the proposed rehabilitation areas (RA1 and RA2) are monitored up until the Scenario 5 rehabilitation cover management scenario has been fully established, and any rilling or gully erosion up until the target vegetative cover is established is remediated to the proposed landform designs for the Vulcan North, Vulcan Main and Vulcan South in-pit and ex-pit WRDs.

If it is found that Scenario 5 vegetative cover is difficult to achieve or the slope lengths between drainage control structures exceed 100 m, it is likely that erosion risk would be greater for the proposed concept WRD designs.

4.3 LIMITATIONS

The erosion results are representative of the nominated 10-year and 100-year post mining timeframes. The modelling does not evaluate timeframes longer than 100-years. The LEM assessment erosion rates would continue and erosion rill depths will increase when longer timeframes are considered as the erosion modelling does not consider vegetative growth or soil replenishment over the model simulation period.

Although the soil report and geotechnical report provide information on soil characteristics and slope stability, once detailed design of the landforms are available, field observations should be undertaken to monitor and gather site specific erosion data with proposed landform cover in place to compare against the predicted erosion rates, which are based on theoretical assessments and only suitable for comparative purposes only. The erosion rates within the model were scaled to match theoretical calculations for predicted soil losses and therefore predictions produced by the model are somewhat predetermined. The potential effects of climate change have also not been considered.

5 References

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METServe, 2022	*'Progressive Rehabilitation and Closure Plan – Vulcan South'*, Draft PRCP prepared for Vitrinite Pty Ltd by METServe, 2022.
RGS, 2022	*'01_2022014_Geochemical Assessment of Waste Rock, Coal Reject and Coal_Rev 01'*, prepared for METServe by RGS Environmental Consultants Pty Ltd, March 2022.
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Willgoose, 2005	*'User Manual for SIBERIA (Version 8.30)'*, Professor Gary Willgoose, Telluric Research, July 2005.