VECCO CRITICAL MINERALS PROJECT

SOILS AND LAND SUITABILITY ASSESSMENT

PREPARED FOR
VECCO INDUSTRIAL PTY LTD

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ENVIRONMENTAL SOLUTIONS

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AARC	AARC Environmental Solutions Pty Ltd
ASC	Australian soil classification
BoM	Bureau of Meteorology
CEC	Cation exchange capacity
EA	Environmental authority
EC	Electrical conductivity
ESP	Exchangeable sodium percentage
EPM	Exploration permit for minerals
HIL	Health investigation levels
LUT	Land Utilisation Type
ML	Mining lease
PAWC	Plant available water capacity
PMU	Preliminary Mapping Unit
PSA	Particle size analysis
SLSA	Soil and Land Suitability Assessment
SMU	Soil management unit
WRD	Waste rock dump

Executive Summary

This report provides a soil and land suitability assessment of the Vecco Critical Minerals Project, in the Gulf region of northern Queensland. The objectives are to describe and map soil management units (SMUs), determine land suitability classes for these SMUs for pasture grazing, and assess suitability and limitations of soils for stockpiling and rehabilitation.

The Study Area for the soil assessment focused on the proposed mine and infrastructure areas. The soil assessment comprised 59 soil and land surface observations, including 14 detailed soil profile description and sampling sites. Three soil management units (SMUs) were identified for the Study Area and described and classified for suitability as follows:

Soil management unit (SMU)	Surface area (ha)	Proportion of Study Area (%)
Mitchell	2302	73
Soapberry	42	2
Gum	801	25
Total area	3145	100

SMU	Conceptual description
Mitchell	Grey Vertosols / Dermosols with a sandy surface and clay content increasing with depth occurring on gently inclined or near-level landforms. Occasional gilgai present. Predominantly Feathertop Wiregrass and Mitchell grass tussock grassland.
Soapberry	Reddish brown, deep, sandy soil on gently inclined or near-level landforms. Sand to loamy sand texture throughout with little or no A horizon material. Wild Plum/Beefwood/Bloodwood lowlands.
Gum	Reddish brown clay loam sandy soil unit on gently inclined or level landforms. Sandy clay loam to medium clay texture throughout with little or no A horizon. Western bloodwood lowlands.

SMU	Land suitability class for dryland grazing	Land suitability class for dryland cropping	Limiting factors
Mitchell	4	4	Total precipitation, soil moisture availability
Soapberry	5	5	Soil moisture availability
Gum	5	5	Soil moisture availability

It is considered that the Mitchell SMU is suitable for low intensity cattle grazing, carefully managed with the implementation of intensive cattle management regimes to support this land use. The Mitchell SMU would benefit substantially from periods of rainfall and/or flooding when the soil would hold moisture available for pasture growth for much longer than the other SMUs.

Recommendations are given for the topsoil management of the dominant soils within the SMUs. Recommended stripping depths and potential volumes of topsoil and subsoil material are shown below.

SMU	SMU area (m^2)	Topsoil stripping depth (m)	Potential topsoil volume (m^3)	Subsoil stripping depth (m)	Potential subsoil volume (m^3)
Mitchell	23,020,000	0.2	4,604,000	0.2 – 0.6	9,208,000
Soapberry*	420,000	0.2	84,000	0.2 – 0.5	126,000
Gum*	8,010,000	0.2	1,602,000	0.2 – 0.5	2,403,000
			Total topsoil = 6,290,000 m^3	**Total subsoil = 11,737,000 m3**	

It is preferable that topsoils from Gum and Soapberry SMUs are ameliorated with an admix of the clay subsoil material from the Mitchell SMU and organic matter (as a hay mulch) to ensure establishment of pasture grasses and natural vegetation quickly and to avoid erosion and degradation, and enhance organic matter fertility in the longer term.

1 Introduction

1.1 Overview and scope of the report

AARC Environmental Solutions Pty Ltd (AARC) was commissioned by Vecco Group Pty Ltd (Vecco) to conduct a Soil and Land Suitability Assessment (SLSA) on the Vecco Critical Minerals Project (the Project).

This SLSA documents the nature and distribution of major soil types in the Study Area and assesses their suitability for the land use of dryland grazing and cropping. This assessment also references environmental characteristics and values relating to land use and suitability, as well as provides recommendations for the management of soil resources within the Study Area.

1.2 Objectives

This report provides an assessment of the soils and land suitability of the Study Area with the following objectives:

- Describe and map soil management units (SMUs) within the Study Area, according to the *Australian Soil and Land Survey Field Handbook* (National Committee on Soil and Terrain 2009), *Guidelines for Surveying Soil and Land Resources* (McKenzie et. al. 2008) and *Australian Soil Classification* (Isbell and National Committee on Soil and Terrain 2021);
- Describe and map land suitability classes of the survey area in accordance with *Queensland Soil and Land Resource Survey Information Guideline VEG/2018/4460 Version 2.0 (Department of Resources 2021), The Guidelines for Agricultural Land Evaluation in Queensland – Second Edition* (DSITI and DNRM 2015), *The Regional Land Suitability Frameworks for Queensland* (State of Queensland 2013) and *The Technical Guidelines for Environmental Management of Exploration and Mining in Queensland – Land Suitability Assessment Techniques* (State of Queensland 1995);
- Identify soils that require specialised management due to wetness, erosivity, depth, acidity, salinity and soils that have a predisposition to land stability issues;
- Soil sampling for in-field determination and laboratory analyses of physico-chemical characteristics relevant to soil type description and characterisation, soil condition, and potential physical and chemical limitations;
- Assess the suitability and limitations of soils for stockpiling and use in mine rehabilitation; and
- Assess the erosion potential of the rehabilitated site using the WEPP model for the analysis.

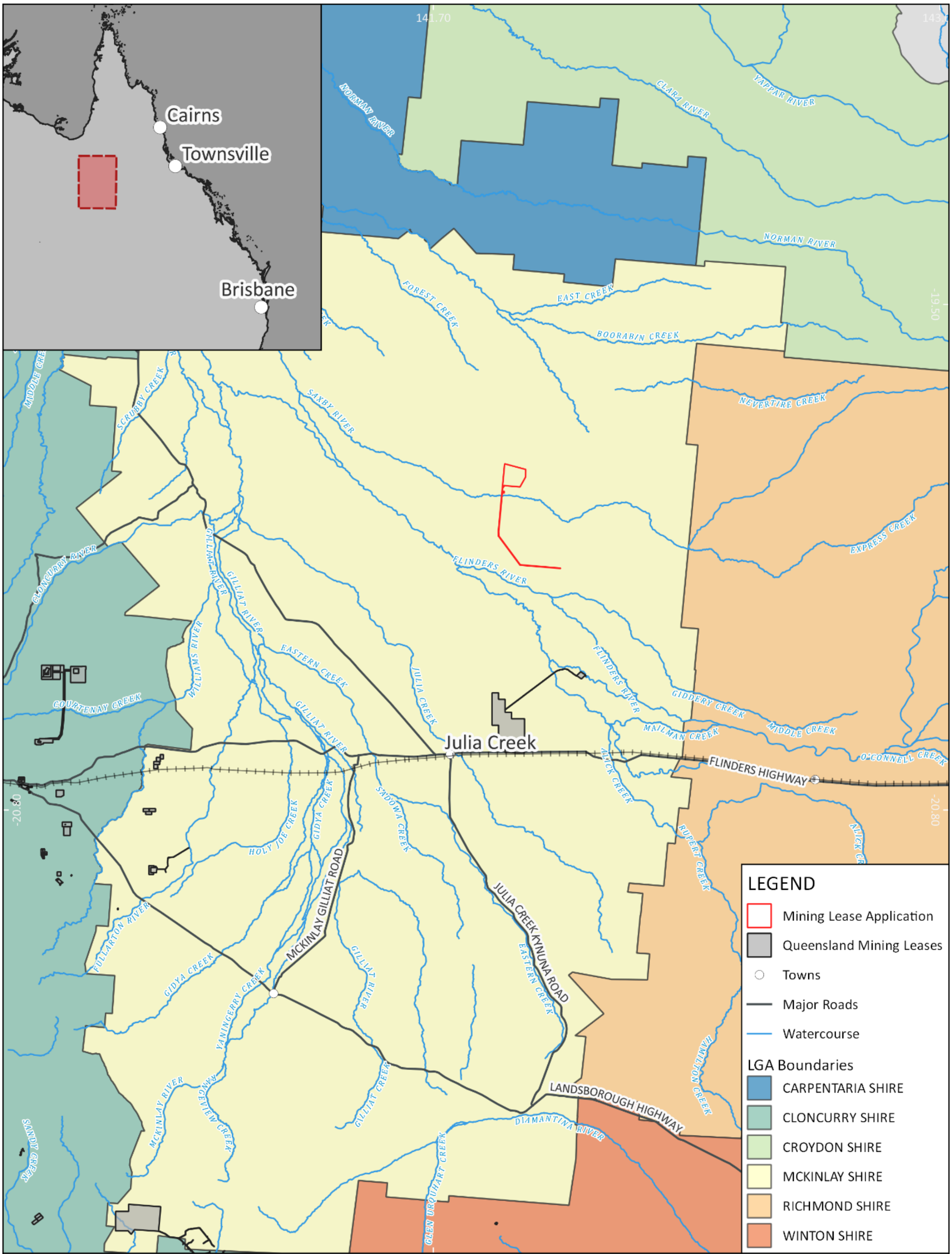
2 Study Area and resource information

The proposed Project Mining Lease Application (MLA) boundary (the Project Area) is located in the North West Minerals Province, approximately 70 km north of the Julia Creek township and 515 km west of Townsville in Northwest Queensland. The rural townships of Cloncurry and Richmond are located approximately 125 km west and 145 km east of the Project, respectively. The regional location of the Project Area is presented in Figure 1.

The Project Area is wholly located within the Shire of McKinlay local government area (LGA), and the local authority is the McKinlay Shire Council. The LGA has been identified as a priority area in the *North West Regional Plan 2010*. The McKinlay LGA covers an area of 40,818 km^2 and supports a population of approximately 1,050 residents, with key localities including Julia Creek, McKinlay, Kynuna, and Nelia.

2.1 The Study Area

The Study Area comprises the majority of the Projects Mining Lease Application, excluding the access track (Figure 2). The access track represents an upgrade of an existing track along property boundaries and will likely remain as permanent infrastructure post mining. For this reason, the Study Area for the soil assessment focused on the proposed mine and infrastructure areas.



Project Locality

Vecco Critical Minerals Project

Client	Vecco Industrial Pty Ltd
Date	31-08-2023
Author	L.Morgan
Projection	GDA2020 / MGA zone 54
Scale	1:1300000

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Figure 1 Project locality in the Flinders River catchment.

Figure 2 Project Study Area north of the Saxby River

2.2 Regional climate

The climate of the region is relevant to the land suitability assessment and options of agricultural regimes. The Project is located within a region described as sub-tropical with monsoonal influence, with a winter dry season and summer wet season that can result in periods of inundation over much of the region during the summer (Bureau of Meteorology 2022). Long-term climate data (2013 to current) were retrieved from SILO/LongPaddock for 141.90 °E, -19.95 °S (Queensland Government n.d.), presented in Figure 3.

Rainfall records indicate annual rainfall is 480.9 mm/year. The majority of rainfall occurs during rainfall events in the wet season (November to March), with dry conditions persisting for the majority of the year. The mean annual evaporation within the Study Area is 2784.4 mm, approximately six times higher than average rainfall, meaning there is a constant potentially high soil water deficit.

The mean monthly maximum temperature is highest in December (39.3°C), dropping to 28.3°C in June before rising in subsequent months. The mean monthly minimum temperature ranges between 11.4°C to 25.0°C throughout the year, with an annual mean minimum temperature of 19.1°C. Only the summer maximum temperatures are potentially detrimental to crop growth.

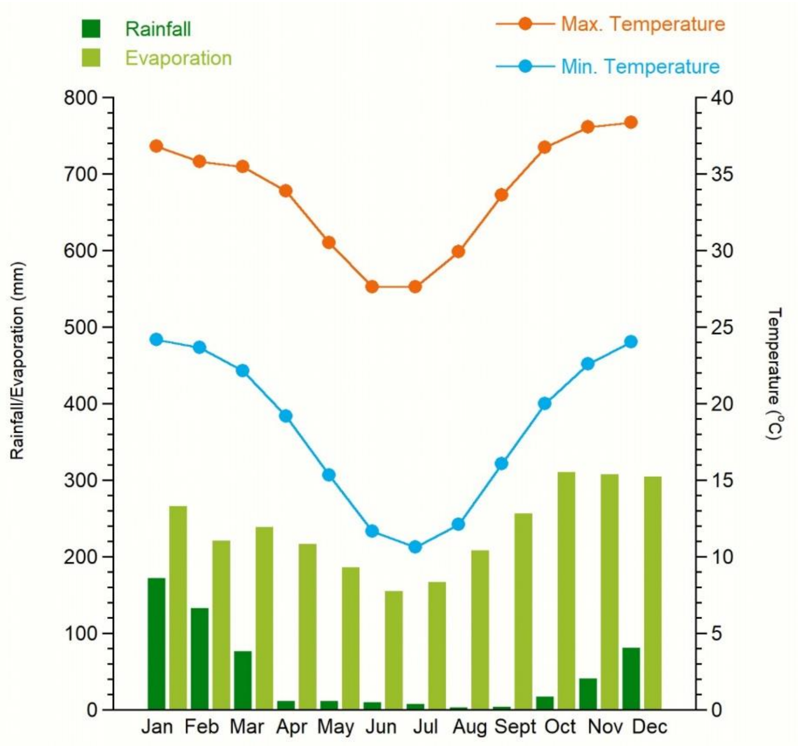


Figure 3 Climate data (2013 to 2023) from SILO/LongPaddock for 141.90 °E, -19.95 °S (Queensland Government n.d.)

2.3 Regional geology

The Project is situated on the Euroka Ridge, a regional scale feature that separates the Carpentaria and Eromanga Basins. The regional geological features are shown in Figure 4 along with the main geological formations relevant to the Project site (JTB 2018).

The Euroka Ridge is a major Proterozoic basement high feature trending northeast between tectonic blocks of the Mt Isa Inlier Eastern Fold belt to the Georgetown Inlier. Basement rock comprises coarse metamorphic sediments and granites. Several perpendicular smaller scale ridges of the Mt Fort Bowen and Mt Brown-St Elmo ridges occur towards the centre of the Euroka Ridge.

The Carpentaria Basin is comprised of Early Cretaceous to Middle Jurassic age, fluvial to shallow marine dominated sediments. The Carpentaria Basin is the northern lateral equivalent of the Eromanga Basin (and Surat Basin, further to the south). The Cretaceous formations drape over the basement ridges. The Cretaceous Toolebuc Formation which hosts the Debella Vanadium Deposit is an upper marker formation of the stratigraphic sequence (JBT 2018).

A thin cover of Karumba Basin unconsolidated Quaternary sediments cover much of the region. The Karumba Basin contains a thin sequence of fluvial, shallow marine and lacustrine sediments (JBT 2018).

The stratigraphic sequence across the Project Area is summarised below (JBT 2018).

Table 1 Stratigraphic sequence summary (JBT 2018)

Age	Sequence	Formation	Description	Typical Thickness (m)
Quaternary	Recent alluvium (Q/Qw/Qa/Qpa)	-	Soil and clays.	0 – 2
	Cenozoic sediments (Cz)	-	Miscellaneous unconsolidated sediments	-
	Carpentaria-Karumba and Northern Eromanga Basin	Wondoola Beds (TQw)	Unconsolidated sands, clay, and gravels	5 – 10
Cretaceous	Carpentaria-Karumba and Northern Eromanga Basin	Allaru Mudstone (Ka)	Mudstone with minor interbedded siltstone and infrequent sandstone.	10 – 100
		Toolebuc Formation (Ko)	Banded shelly limestone and bituminous shales.	8 – 15
	Northern Eromanga Basin	Wallumbilla Formation (Ku)	Blue to grey mudstone with minor interbedded carbonaceous sandstone.	150 – 180

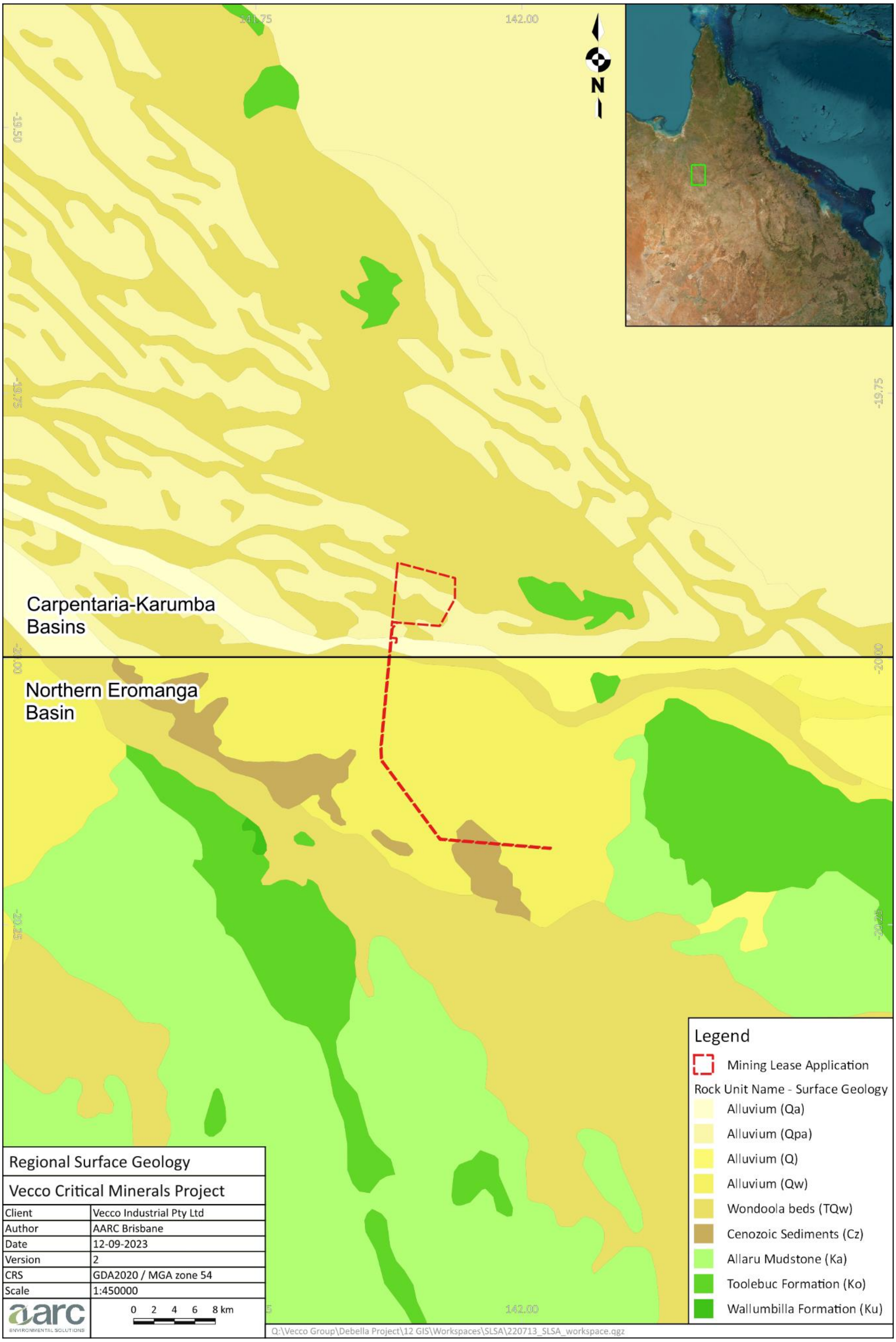


Figure 4 The main surface geology in the region of the Project

2.4 Local geomorphology

2.4.1 Topography

The topography of the Study Area is generally flat to gently undulating, with elevations ranging between 130 m and 150 m Australian Height Datum (AHD). The topography of the Study Area is representative of the surrounding region, being generally flat alluvial clay plains with sandy alluvial deposits as slight near-level rises, is presented in Figure 5.

2.4.2 Watercourses

The Study Area is located within the Flinders-Norman Drainage basin in north-west Queensland, which encompasses an area of 109,298 km^2 and contains the Cloncurry River, Flinders River and Saxby River sub-catchment areas (DES 2013). The Project is located within the Saxby River sub-catchment, which covers a total area of 10,147 km^2. Catchment flows from the Project Area ultimately discharge through the Saxby River into the Gulf of Carpentaria via the Flinders River.

The Saxby River is a series of ephemeral channels situated approximately 2 km to the south of the Study Area, where the river flows west before turning north-west for the remainder of its course, converging with the Flinders River 200 km north-west of the Project Study Area. Periods of flow are generally restricted to the wet season between the months of December to late March. No tributaries are mapped to traverse the Project MLA Study Area (Figure 5).

2.4.3 Land use and vegetation

The Study Area is located within the Southern Gulf natural resource management (NRM) region. The land surrounding the Project is currently used for low intensity cattle grazing of native pastures and resource exploration activities. The predominant land use of northwest Queensland is low intensity cattle grazing. The Project Area incorporates two working properties (in 3 lots) under beef cattle production. The land is not utilised for cropping or other higher production land uses.

The Project Area is wholly located within the Gulf Plains (GUP) bioregion. The bioregion covers 12.7% of Queensland, with a total area of 219,109.4 km^2. The Gulf Plains bioregion is characterised by extensive alluvial plains and coastal areas. The tropical savanna vegetation comprises mainly eucalypt and tea-tree open woodlands.

Figure 5: Project Study Area and related watercourses

2.5 Previous soil and land resource assessments

2.5.1 Recent land resource assessments

As part of the North Queensland Irrigated Agriculture Strategy (NQIAS), the Flinders and Gilbert Agricultural Resource Assessment (FGARA) provides a description of the physical environment within the Flinders catchment to identify resources available for irrigated agriculture (Petheram et al. 2013). The Study Area is mapped within the extent of this assessment.

Based on the FGARA (2013), the Study Area is mapped within cracking clays derived from the fine-grained sedimentary rocks of the Great Artesian Basin Rolling Downs Group. These soils store moderately large amounts of water and can grow annual crops but not deep-rooted perennial crops. The risk of secondary salinisation is high for these soils and they require careful management.

A land suitability assessment was also conducted as part of the FGARA, described in Bartley et al. (2013). The land suitability assessment concluded that very large areas of the Flinders catchment are moderately suitable (Class 3) for a wide range of crops and irrigation methods.

A soil and land suitability assessment (SLSA) has been recently undertaken for the St Elmo Vanadium Project 75 km to the south of the Project site (Multicom Resources Ltd. Saint Elmo Vanadium Project Environmental Impact Statement, 2022). The project site comprises four main soil mapping units (SMUs):

B1 Moderate to deep clay soils on gently undulating to undulating plains.

Bs1 Moderate to deep clay soils in and near stream channels and drainage lines.

W1 Deep reddish-brown clay soils on gently undulating plains and rises.

Sh1 Shallow loamy sands located on low rises.

SMUs B1 and Sh1 have similarities to the soils found in the Project area, although the latter appear to be deeper at the Project area. The B1 deep clays soil was found to be moderately suitable (Class 3) for beef cattle grazing using the superseded LSAT1990 guidelines (not used for this Project analysis) and also Class 3 for dryland cropping land uses, whereas the SH1 soil was found to be unsuitable to any sustainable productive land use.

2.5.2 Land types

The spatial representation of the land types of Queensland is described as the Grazing Land Management (GLM) land type mapping, outlining grazing land that has characteristic patterns of soil, vegetation and landform that are easily recognisable in the specific region (FutureBeef 2011). The following sub-sections describe the land types occurring within the Study Area.

2.5.2.1 Mitchell grass

Mitchell grass land type occurs in flat undulating plains, often adjoining and sometimes mixed in with bluegrass browntop plains and/or flooded plains. The landscape is predominantly treeless plains with whitewood, vine tree/supplejack and areas of gidgee and corkwood wattles and coolabah and gutta-percha on the edge of flooded areas. Soils are grey-brown heavy cracking calcareous clays with uneven, self-mulching and often ashy surfaces, and with some areas of pebbly downs.

2.5.2.2 Bauhinia sandy forest

Bauhinia sandy forest are observed in outwash sandy plains comprising low-to-moderately dense woodland of bauhinia, beefwood, whitewood, emu apple, deadfinish, ironwood, arid peach and paperbarks. The underlying soil is defined as red to yellow, light grey uniform or light textured deep sandy soils.

2.5.2.3 Sandy forest country

Timbered sandy plains with low-to-moderately dense woodland of bauhinia, beefwood, deadfinish, arid peach, paperbarks, and long-fruited bloodwoods occurring in stands. Soils are described as deep sands, mainly brown soils of light texture.

2.5.3 Atlas of Australian soils

The *Atlas of Australian Soils* (broadscale national mapping at 1:1,000,000 scale) describes the Study Area being wholly within grey, self-mulching, cracking clays on very gently undulating plains. The soil type is described as uniform fine cracking, smooth-faced peds with grey clay horizon underlain by grey, mottled clay (Bureau of Rural Science 1991).

2.5.4 Land systems of the Leichhardt-Gilbert area

The report *Lands of The Leichhardt-Gilbert area, Queensland* (Perry *et al.* 1964) (mapped at a scale of 1:1,000,000) notes the Study Area as containing the land system units described in the following sub-sections.

2.5.4.1 Balbirini land system

The Balbirini Land System is characterised by gently undulating treeless plains with heavy soils carrying Mitchell grass pastures. Flat plains are sloping gently towards the coast. Surrounding soils are calcareous cracking clay with gilgai, occupied largely by blue grass – browntop downs, as well as small areas of Mitchell grass downs and sparse woodland.

2.5.4.2 Bylong land system

The Bylong Land System is described as sandy outwash plains, with local elevations of approximately 3 m. The landscape comprises of deep sandy soils (brown soils of light texture), and moderately dense low woodland vegetation (up to 6 m). The associated grass layer is three-awn-ribbon grass, which has a sparse ground cover and low forage production. A feature of the community is that most of the trees and shrubs are grazed by stock.

2.6 Current classifications

2.6.1 Strategic cropping land

The *Regional Planning Interests Act 2014* (RPI Act) regulates impacts from resource and other regulated activities on identified areas of regional interest. This includes strategic cropping areas (SCAs), which consists of areas shown on the strategic cropping land (SCL) map. SCL is land that is, or is likely to be, highly suitable for cropping because of a combination of land's soil, climate and landscape features.

The Study Area is not mapped within the SCL trigger map, the RPI Act does not apply (viewed on Qglobe, DoR 2022).

2.6.2 Agricultural land classification

The agricultural land classification (ALC) is a hierarchical scheme based on interpreted land evaluation information (DSITI and DNRM (2015). There are four classes, ranging from Class A to D, implying a decreasing range of land use choice and an increase in the severity of land use limitations and/or land degradation. The ALC is used to inform government planning schemes and regional plans as required for agriculture state interest provisions of the State Planning Policy.

The Study Area is mapped with approximately 640 ha of Class A1 land, meaning that the land is considered suitable for a wide range of current and potential broadacre and horticultural crops with nil to moderate limitation to production. Further analysis of remotely sensed imagery and climate data would indicate that this classification of A1 is probably incorrect and that a more restricted Class of A2, or even B, may apply. The outcome of this current assessment does not support the assignation of Class A1 to the Study Area, and accords with a lower, more restricted ALC class.

The remaining land (approximately 2400 ha) is classified as Class B land, indicating land that is suitable for sown pastures and may be suitable for a wider range of crops with changes to knowledge, economics or technology.

3 Soil and land assessment methodology

3.1 Standards and guidelines

Methods employed throughout this study followed procedures detailed in the

- *Australian Soil and Land Survey Field Handbook* (National Committee on Soil and Terrain 2009),
- *Guidelines for Surveying Soil and Land Resources* (McKenzie et al. 2008),
- *Queensland Land Resource Assessment Guidelines* (DES and DoR 2021),
- *Regional Land Suitability Frameworks for Queensland* (State of Queensland 2013), and
- *Guidelines for Agricultural Land Evaluation in Queensland (2nd edition)* (DSITI and DNRM 2015).

3.2 Survey design

The relevant form of soil survey for land suitability assessment is commonly referred to as free survey (DES and DoR 2021). It is suited to all but the most detailed-scale survey and has been employed here to map and check soil boundaries while also characterising soil management units (SMUs) by soil types. Detailed soil profile sites, representative sites for sampling, and observation sites were selected to best represent all soil types and the unit boundaries present in the Study Area.

3.2.1 Survey scale and observation intensity

For the Study Area, a medium-density survey of a scale between 1:25,000 to 1:100,000 is the most appropriate based on Schoknecht *et al*. (2008), refer Appendix C, Table 52. The final publication scale of 1:35,000 for the Study Area fell within the specified range.

To achieve a mapping scale of 1:25,000 to 1:100,000, Schoknecht *et al.* (2008) suggest a minimum sampling density of one site per 100 ha with data collection comprising site descriptions for detailed soil profile (Class I) (15 to 35% of sites), representative profile sampling for lab analysis (Class III) (1 to 5%), and mapping observations (Class IV) (55 to 83%). The recommended observation densities for different cartographic scales are outlined by Schoknecht et al. (2008), and presented in Appendix C, Table 53.

A total of 59 ground observations were noted within the Study Area of 3145 ha, albeit with some sites being outside the final Study Area boundary.

This sampling/observation density exceeds the minimum requirements of a conventional qualitative land resource survey based on the recommended observation densities for a mapping scale of 1:35,000 (Table 2). The number of laboratory analysis samples sites (Class III) also exceeded the upper recommended range to improve the accuracy of soil descriptions and mapping.

Table 2 Survey observation density and types

Survey area (ha)	Objectives	Mapping scale	Minimum sampling density @ 1 site/100 ha	Detailed soil profiles (Class I)	Representative profiles for analysis (Class III)	Mapping observations (Class IV)	Total
3145	• General suitability for various forms of land use • Planning for low intensity land uses	1:35,000	31	14	6	39	59

3.3 Desktop analysis

A desktop analysis was conducted prior to field sampling. This analysis comprised background research and evaluation of available information for the Study Area. Resources used included:

- The *Digital Atlas of Australian Soils* (Bureau of Rural Science 1991). Australian soils were mapped at a scale of 1:2,000,000. Although this scale is broad, it provided a foundation for understanding the soils that may be present in the study area.
- *Australian Soil Resource Information System* (ASRIS 2011). The resource provides the best publicly available soil and land information in a consistent format across Australia at seven different scales.
- Reference information for land systems: *Land Systems of the Leichardt-Gilbert Area, Queensland* (Perry *et al.* 1964)
- Reference information for grazing land management: *Land types of Queensland* (FutureBeef 2011) and associated Grazing Land Management land types spatial data (V7) (DAF 2022).
- Agricultural resource assessment for the Flinders Catchment as part of the FGARA (Petheram et al. 2013). This assessment provided recent soils data collected across northern Australia, including land suitability assessments detailed in Bartley et al. (2013).
- Government maps featuring regional topography, geology, contour data and watercourse locations were used to help refine mapping boundaries, particularly where soil types are a function of gradient.

3.3.1 Preliminary mapping units (PMUs)

Desktop analysis suggested three (3) preliminary mapping units (PMUs) occurring within the Study Area. The distribution of soil types may be observed through variations in landform and vegetation. As outlined in, and interpreted from the legacy data from Section 2.5, the Study Area will primarily consist of cracking clay soils, with some gilgai, under grasses and sparse eucalypt woodland, with a secondary distribution of deep sandy soils under eucalypt/tea-tree woodland/shrubs. Therefore, preliminary studies suggest the occurrence of the following soil types:

- Cracking clay soils in Mitchell grass plains;
- Deep sandy soils in timbered sandy plains; and
- Deep sandy soils in outwash sandy plains.

The image-interpreted boundaries of these were approximated on field maps for field validation, modification, and sampling.

3.4 Field investigations and sampling

AARC completed field sampling for the SLSA during 6–8 May and 2–4 Aug 2022, with this consisting of 14 detailed soil profile sampling sites (Classes I & III observations) and 39 surface assessments (Class IV observations).

Sampling site locations were determined based on the desktop analysis, PMUs, landforms, and vehicle access. Visual assessments were conducted continually while traversing the landscape to confirm major soil types and boundaries between soil units. The GPS coordinates of each location were recorded.

Detailed soil profile observations were undertaken at 14 sites within the Project boundaries. A petrol-driven percussion soil sampling kit was used to retrieve cores to a maximum depth of 1.2 m. The sampling procedure involves a motorised percussion driver to drive sampling tubes into the soil, and a lever to extract the tubes.

Soil samples were collected from profiles at standard depths of 0–10 cm, 20–30 cm, 50–60 cm and 70–80 cm. Samples were sealed in clean, plastic zip-lock bags and labelled with the Project code, site number, date and depth of sampling.

Land surface and landform parameters recorded included micro-relief, substrate, site disturbance, landform (slope, relief, elevation, morphological type, landform element, and landform pattern), runoff, erosion, surface coarse fragments, rock outcrops, surface condition, and dominant vegetation type. Field sheets and recorded parameters are presented in Appendix E.

Soil profile morphology was described in the field (refer Appendix E) in terms of whole profile permeability and drainage, and for each horizon: horizon type, horizon depth, boundary type, soil colour, mottles, texture, coarse fragments, structure, segregations, consistency, and field pH (using a Manutec soil pH test kit).

The sampling equipment was washed thoroughly between samples to avoid contamination.

3.5 Soil characterisation and mapping

3.5.1 Soil type classification

Soil classification was undertaken using the methodology specified in *The Australian Soil Classification* (Isbell and the National Committee on Soil and Terrain 2021). Soil Management Units (SMUs) were then defined based on grouping soils of like soil morphology, parent material, and land attributes in accordance with the *Guidelines for Surveying Soil and Land Resources* (McKenzie *et al.* 2008). Each SMU has been described with the attributes and limitations of the soil interpreted using the *Guidelines for Agricultural Land Evaluation in Queensland – Second Edition* (DSITI and DNRM 2015) to determine their suitability for agricultural land uses.

3.6 Laboratory analysis

Samples from a total of six (6) sites were chosen for analysis through Australian Laboratory Services for NATA approved physical and chemical analyses. Samples from all standard depths at the chosen sites were analysed to:

- confirm the classification of the described soil profile;
- assist in the description of soil physical and chemical characteristics;
- assist in the determination of land suitability classes; and
- assist in the identification of soils that would require specialised management.

3.7 Interpretation of physico-chemical data

The characteristics and chemical data for each SMU have been described in section 4. The following guidelines were used to assist in interpretation of the SMU physical and chemical properties and to determine ratings and categories of the assessed soil parameters:

- *Interpreting Soil Test Results* (Hazelton and Murphy 2016);
- *Soil Chemical Methods of Australasia* (Rayment GE and Lyons D 2011);
- *Soil analysis: an interpretation manual* (Peverill et al. 1999)*;* and
- *Interpreting soil analyses – for agricultural land use in Queensland* (Baker and Eldershaw 1993).

Broad descriptions of relevant soil parameters are outlined in Appendix A.

3.8 Land suitability assessment

Land suitability refers to the adequacy of land for a defined use. Land suitability assessment considers environmental factors including climate, soils, geology, geomorphology, erosion, topography and the effects of past land uses. The classification does not always represent the current land use. Rather, it indicates the potential of the land to be used for specific agricultural activities. The aim of this land suitability assessment is to evaluate the suitability of the Study Area for dryland grazing and dryland cropping (sorghum), prior to further development of the mine.

The assessment for land suitability (dryland grazing and dryland cropping) has been carried out in accordance with the methods described in:

- *Guidelines for Agricultural Land Evaluation in Queensland* (2nd edition) (DSITI and DNRM 2015); and
- *Regional Land Suitability Frameworks for Queensland* (State of Queensland 2013).

Although the land that includes the Study Area is currently under extensive grazing as will be the post-mining land use, the assessment for dryland cropping is necessary to comply with the above guidelines for land suitability. There is no direct suitability assessment for dryland grazing, thus a restricted cropping regime has been substituted (see section 5.1.1). Within the region some cropping of sorghum, amongst other crops, is undertaken on similar soils. Therefore, this land use was taken as locally representative dryland cropping scenario for land suitability assessment purposes using the *Guidelines for Agricultural Land Evaluation in Queensland*.

3.8.1 Land suitability classification

The five land suitability classes used for assessing land are defined in Table 3. Land is considered less suitable as the severity of limitations for a land use increase. The land suitability class reflects the score of the most limiting attribute for a given SMU. An increase in limitations may reflect either:

- reduced potential for production;
- increased inputs to achieve an acceptable level of production;
- increased inputs to prepare the land for successful production; and/or
- increased inputs required to prevent land degradation.

Table 3 Land suitability class description (DSITI and DNRM 2015)

Class	Suitability	Limitations	Description
Class 1	Suitable	Negligible	Highly productive land requiring only simple management practices to maintain economic production.
Class 2	Suitable	Minor	Land with limitations that either constrain production, or require more than the simple management practices of Class 1 land to maintain economic production.
Class 3	Suitable	Moderate	Land with limitations that either further constrain production, or require more than those management practices of Class 2 land to maintain economic production.
Class 4	Unsuitable	Severe	Currently unsuitable land. The limitations are so severe that the sustainable use of the land in the proposed manner is precluded. In some circumstances, the limitations may be surmountable with changes to knowledge, economics, or technology.
Class 5	Unsuitable	Extreme	Land with extreme limitations that preclude any possibility of successful sustained use of the land in the proposed manner.

3.8.2 Land suitability classification procedure

The land suitability assessment process classifies SMUs delineated in the field survey according to their suitability for each selected land use. The development of the suitability framework and attribution of SMUs occurs concurrently, the process of land suitability assessment is illustrated in Figure 6.

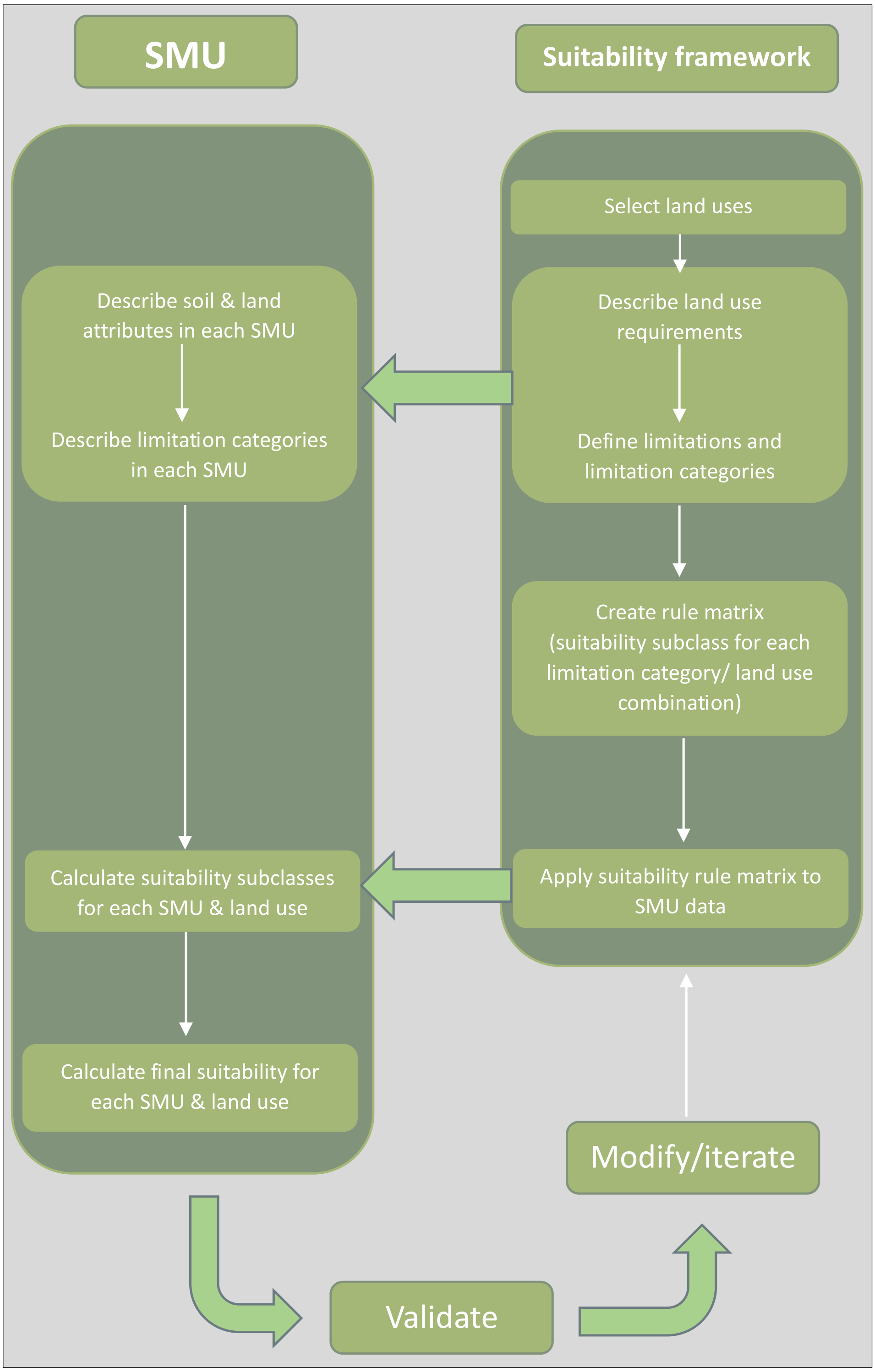


Figure 6 Land suitability classification procedure, adapted from DSITI and DNRM (2015)

4 Soil survey results

4.1 Soil management units (SMUs)

4.1.1 Mapped areas

Three SMUs have been described within the Study Area. Table 4 details the SMUs present, with the spatial distribution of the mapped SMUs (mapped at a publication scale of 1:35,000) shown in Figure 7. The coordinates for each sampling site are provided in Appendix E. Data from sampling sites has been extrapolated to determine SMU areas across the entire Study Area.

Table 4 SMUs identified within the Study Area

SMU	Surface area (ha)	Proportion of study area (%)
Mitchell	2302	73
Soapberry	42	2
Gum	801	25
Total	3145	100

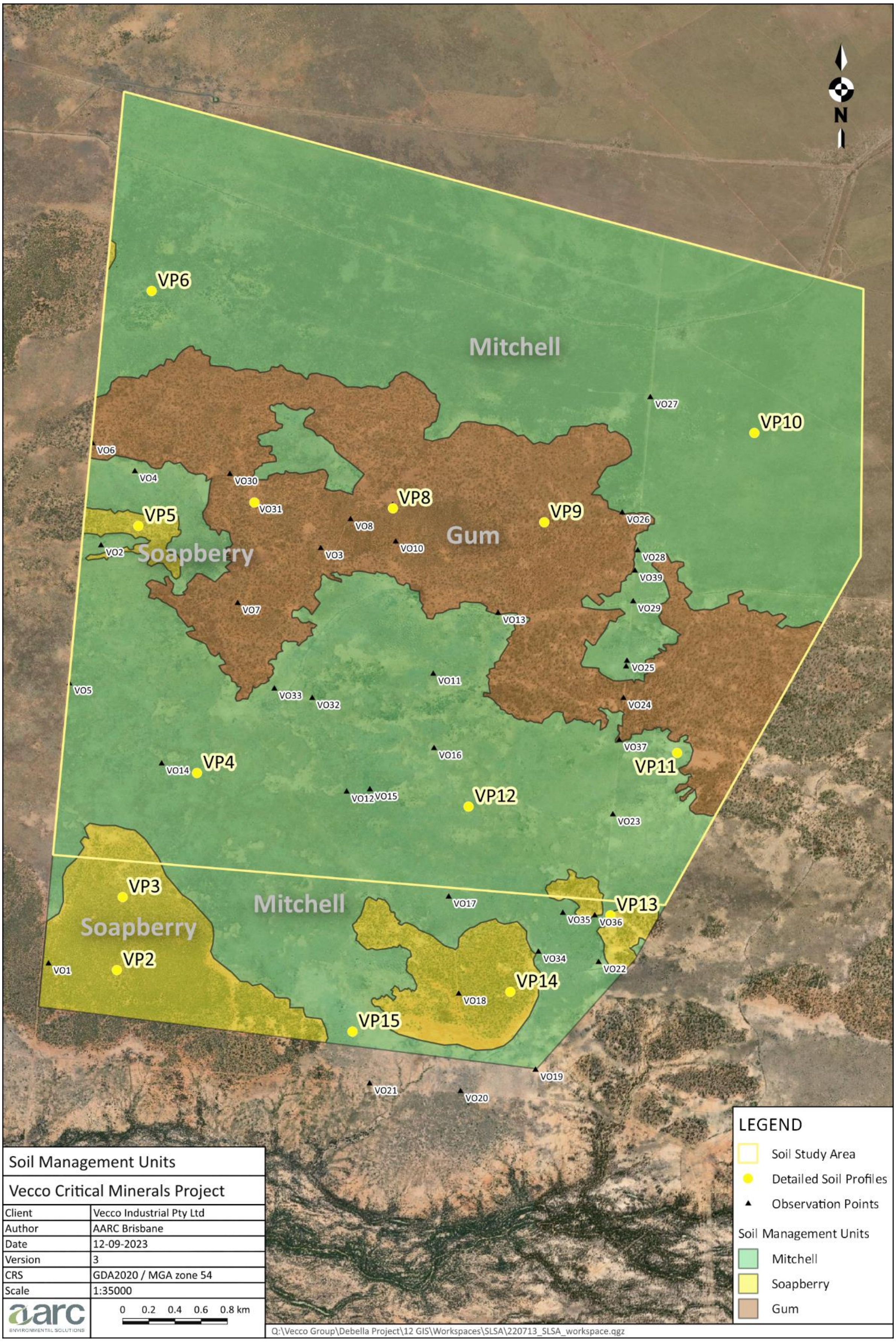


Figure 7 Distribution of SMUs (1:35,000) for the Study Area

4.2 SMU descriptions

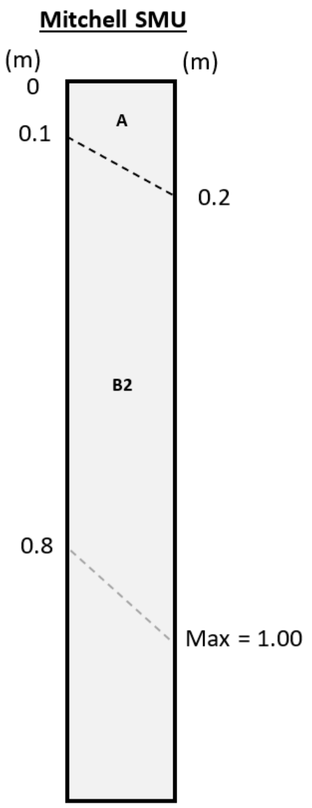
4.2.1 Mitchell SMU

Predominantly deep, Grey Dermosols with Grey Vertosols occurring on gently inclined or near-level plains within an old alluvial landscape. This SMU is distributed throughout the majority of Study Area as regions of palaeo-drainage and flood channels. The soil consists either of a sandy surface, or self-mulching sandy clay surface, with clay content increasing with depth. Vegetation is predominantly feathertop wiregrass and Mitchell grass tussock grassland.

Photo 1: Mitchell SMU landscape and land surface

Mitchell SMU

Area / % total	2302 ha / 73%
Observation sites	VO2, VO4, VO5, VO14, VO11, VO12, VO14, VO15, VO16, VO17, VO19, VO20, VO21, VO22, VO23, VO25, VO27, VO28, VO29, VO32, VO33, VO34, VO35, VO38, VO39
Sample sites	VP4, VP6, VP10, VP11, VP12, VP15
ASC	Vertosol; Dermosol
Land System	Balbirini
Geology	Wondoola Beds (TQw)
Vegetation	Feathertop wiregrass, with silky browntop, *Astrebla spp*. and *Eragrostis spp.* tussock grassland. Shrub layer dominated by whitewood and the environmental weed mimosa bush. The tree layer is almost entirely absent, though there is the occasional emergent whitewood and beefwood.
Landform	Plains
Slope	0 – 1 %
Surface condition	Firm, minor surface cracking with surface crusting, occasionally self-mulching, 40% ground cover with occurrence of minor surface microrelief (normal/linear gilgai)
Runoff	Slow
Permeability	Moderately permeable
Drainage	Well drained



SOIL PROFILE DESCRIPTION

Horizon	
A	*Light brownish grey (10 YR 6/2), sandy loam to sandy clay loam, pH 7 – 7 ½, massive and granular or 10 – 20 mm weak and angular blocky, no mottles or segregations*
B2	*Greyish brown (10 YR 5/2), medium clay, pH 8 – 8 ½, 20 – 50 mm angular block/subangular blocky, no mottles or segregations*

4.2.1.1 Chemical analysis of soil profile

The neutral pH in the upper soil profile of the Mitchell SMU is within a suitable range for plant growth; it is not expected to limit the availability of essential nutrients above 0.5 m depth.

Electro-conductivity (EC_{SAT}) values and chloride concentrations are considered low, this SMU is not affected by issues associated with salinity and toxic chloride concentrations (Rayment and Lyons 2011).

Cation exchange capacity (CEC levels) for this SMU is considered low to medium throughout the profile (11.4 – 13.8 milliequivalents (meq)/100 g). The medium CEC levels still can allow moderate to high availability of nutrients in the topsoil, with all exchangeable cations within levels ideal for plant growth.

Non-sodic conditions occur in the top 0.3 m of the profile, observed as a low ESP levels. However, subsoils from 0.5 m are expected to display sodic properties, demonstrated by increased pH and concentration of free sodium in subsoil (ESP 7 – 13). This is further supported by Emerson class 2 at 0.5 m depth observed at some profile sampling sites (VP4 and VP11), which indicates slaking with some dispersion of aggregates.

Table 5 Chemical properties of the Mitchell SMU - representative site VP12

Depth (m)	pH	EC_{SAT} (dS/m)	Cl (mg/kg)	ESP (%)
0 – 0.1	7.0	0.124	<10	1.1
0.2 – 0.3	8.5	0.220	< 10	1.9
0.5 – 0.6	9.0	0.480	< 10	6.8
0.7 – 0.8	9.2	0.765	20	13.1

Depth (m)	CEC (meq/100 g)	Exchangeable cations (meq/100 g)				Ca/Mg Ratio	Emerson test class
		Ca	Mg	K	Na		
0 – 0.1	11.4	7.5	3.2	0.3	0.1	2.3	3
0.2 – 0.3	13.8	11.9	1.6	< 0.2	0.3	7.4	4
0.5 – 0.6	13.0	10.5	1.6	< 0.2	0.9	6.7	3
0.7 – 0.8	12.5	9.1	1.8	< 0.2	1.6	5.1	2
Nutrient distribution in topsoil (%)		67.6	28.8	2.7	0.9	-	-

4.2.1.2 Physical analysis of topsoil

Topsoil typically displays weak-to-moderate structure, due to dominant sand fraction (55%) with lesser clay (29%). Risk of dispersion and erosion in the surface layer is considered low, although organic matter content is considered very low. Water holding capacity of this soil is considered to be medium (estimated plant available water capacity - PAWC of ≥ 150 mm; see Section 5.1.3.2), being restricted by very high evaporation rates especially from macro-voids.

Extractable nutrients are considered poorly balanced with both phosphorus and nitrate concentration, below appropriate levels for healthy plant and crop growth (Hazelton and Murphy 2016) although capable of supporting a healthy native vegetation while sufficient soil water is available. Sulphate in the topsoil is considered marginal for crop and improved pasture growth while potassium content is above suitable concentrations.

Extractable metals were mostly present at ideal concentrations, except boron with concentrations below the ideal range for pastures.

Table 6 Surface soil (0-10 cm) properties of the Mitchell SMU

Particle Size Analysis (%)				Soil Particle Density (g/cm^3)	Organic Matter (%)
Clay	Silt	Sand	Gravel		
29	13	55	3	2.65	0.7

Extractable Nutrients (mg/kg)				Extractable Metals (mg/kg)				
Phosphorus	Potassium	Sulphate	Nitrate	B	Cu	Fe	Mn	Zn
< 5	256	< 10	1.2	< 0.2	< 1	13.0	8.16	< 1

4.2.2 Soapberry SMU

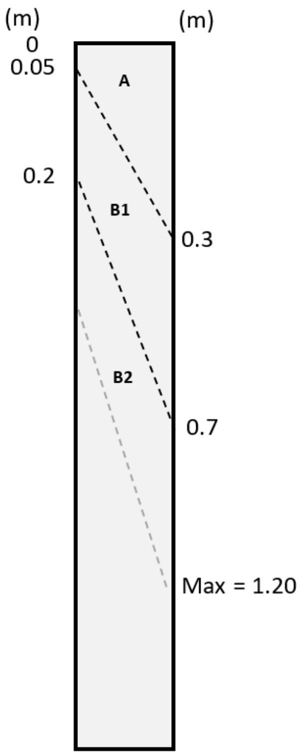
Reddish brown, deep, sandy soil occupying the southern region of the study area, on gently inclined or near-level plains. The profile generally exhibits little or no A horizon material and therefore often comprises a B horizon with a sandy texture throughout. Vegetation associated with this unit includes wild plum (*Terminalia platyphylla*) and beefwood (*Grevillea striata*), with western bloodwood (*Corymbia terminalis*) and whitewood (*Atalaya hemiglauca*) associated in the upper canopy, and *Melaleuca spp.* in the sub-canopy.

Photo 2: Soapberry SMU vegetation landscape and land surface

Soapberry SMU

Area / % total	42 ha / 2%
Observation sites	VO1, VO18, VO22, VO36
Sample sites	VP2, VP3, VP5, VP13, VP14
ASC	Arenosols
Land System	Bylong
Geology	Wondoola beds (TQw)
Vegetation	Low woodland dominated by wild plum (*Terminalia platyphylla*) and beefwood (*Grevillea striata*), with western bloodwood (*Corymbia terminalis*) and whitewood (*Atalaya hemiglauca*) associated in the upper canopy, and *Melaleuca spp.* in the sub-canopy. Shrub layer consisting of sparse currant bush and *Flueggea virosa.* Ground cover vegetation primarily feathertop wiregrass (*Aristida latifolia*) and silky browntop (*Eulalia aurea*).
Landform	Plains
Slope	0 %
Surface condition	Varies between firm and hard setting surfaces, or soft and loose surfaces. Ground cover varied between 20% to 40%.
Runoff	Very slow
Permeability	Highly permeable
Drainage	Rapidly drained

Soapberry SMU



SOIL PROFILE DESCRIPTION

Horizon	
A	*Pinkish grey (5 YR 7/2) or reddish grey (5 YR 5/2), loamy sand, pH 6, massive and single grain to weak granular, no mottles or segregations*
B1	*Reddish brown (5 YR 5/3), loamy sand, pH 5, massive and single grain, no mottles or segregations*
B2	*Reddish yellow (5YR 7/6), loamy sand, pH 5, massive and single grain to weak sub-angular blocky, no mottles or segregations*

4.2.2.1 Chemical analysis of soil profile

The pH of the Soapberry SMU is slightly to moderately acidic throughout the profile, remaining within a suitable range for plant growth. The profile is non-saline and non-sodic, indicated by low EC_{SAT}, Cl and ESP values.

CEC is extremely low throughout the solum (1.2–1.8 meq/100g), influenced by lack of clay and organic matter in the profile. All exchangeable cations are well below the favourable range for the healthy plant nutrition.

Poor aggregate stability is observed within the profile as a result of sandy soil texture. Although the profile is considered non-sodic (ESP < 6%), the solum is at risk of slaking where aggregates break down without dispersion (Emerson test Class 3).

Table 7 Chemical properties of the Soapberry SMU – representative site VP2

Depth (m)	pH	EC_{SAT} (dS/m)	Cl (mg/kg)	ESP (%)
0 – 0.1	5.8	0.092	< 10	< 0.1
0.2 – 0.3	6.4	0.138	< 10	1.3
0.5 – 0.6	6.6	0.161	40	1.9
0.7 – 0.8	6.3	0.230	30	2.1

Depth (m)	CEC (meq/100 g)	Exchangeable cations (meq/100 g)				Ca/Mg Ratio	Emerson test class
		Ca	Mg	K	Na		
0 – 0.1	1.2	0.8	0.2	<0.1	< 0.1	4.0	3
0.2 – 0.3	1.8	1.2	0.4	0.1	< 0.1	3.0	3
0.5 – 0.6	1.5	1.0	0.3	<0.1	< 0.1	3.3	3
0.7 – 0.8	1.6	1.1	0.3	<0.1	< 0.1	3.7	3
Nutrient distribution in topsoil (%)		66.7	16.7	8.3	8.3	-	-

4.2.2.2 Physical analysis of topsoil

The topsoil is dominated by sand (90%), with low clay content (8%), contributing to loose, massive to weak granular structure at best. This, in conjunction with the very low organic matter content, suggests very poor structural stability of the topsoil layer, thus being prone to both wind and water erosion.

Water holding capacity of this soil is considered to be medium (estimated plant available water capacity - PAWC of 125 - 150 mm; see Section 5.1.3.2), being restricted by very high evaporation rates, low organic matter, poor structure and high porosity (large inter-particle voids)Of extractable nutrients, sulphate is present at marginal concentrations for crop health, while phosphorus, potassium and nitrate concentrations are very low, even for Australian semi-arid soils, for healthy improved pasture and crop growth, but adequate while sufficient soil water is available. Micronutrients are all present at low to marginal concentrations for healthy crop and improved pasture growth.

Table 8 Surface soil (0 -10 cm) properties of the Soapberry SMU

Particle Size Analysis (%)				Soil Particle Density (g/cm³)	Organic Matter (%)
Clay	Silt	Sand	Gravel		
8	2	90	< 1	2.57	0.9

Extractable Nutrients (mg/kg)				Extractable Metals (mg/kg)				
Phosphorus	Potassium	Sulphate	Nitrate	B	Cu	Fe	Mn	Zn
< 5	< 100	< 10	1	< 0.2	< 1	6.63	2.44	< 1.0

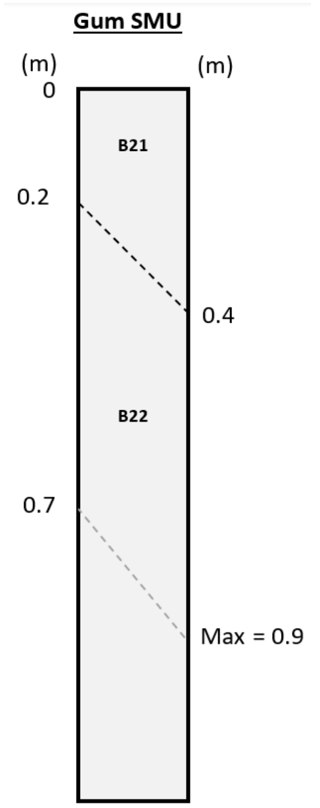
4.2.3 Gum SMU

Reddish brown, clay loam sandy soil occupying the central region of the study area, on gently inclined or near-level rises. The profile consists of only a B horizon with sandy clay loam to medium clay texture throughout. Vegetation associated with this unit includes bloodwood and *Corymbia spp.* woodlands.

Photo 3: Gum SMU landscape and land surface

Gum SMU

Area / % total	801 ha / 25%
Observation sites	VO3, VO6, VO7, VO8, VO9, VO10, VO13, VO24, VO26, VO30, VO31, VO37
Sample sites	VP7, VP8, VP9
ASC	Dermosol
Land System	Balbirini
Geology	Alluvium (Qpa)
Vegetation	Western bloodwood, though other *Corymbia* species such as cabbage gum (*Corymbia grandifolia*) and broad-leaved gum (*C. confertiflora*). Shrub layer consisting of sparse currant bush and *Flueggea virosa.* Ground vegetation cover dominated by feathertop wiregrass, with silky browntop and golden beardgrass (*Chrysopogon fallax*) associated.
Landform	Plains
Slope	0 %
Surface condition	Firm and hardsetting with surface crusting and 70% ground cover
Runoff	Slow
Permeability	Highly permeable
Drainage	Rapidly drained



SOIL PROFILE DESCRIPTION

Horizon	
B21	*Reddish grey (5 YR 5/2) or grey (5YR 6/1), loamy sand, pH 6, massive and single grain to weak granular, no mottles or segregations*
B22	*Reddish yellow (7.5 YR 7/8) or yellowish red (5 YR 5/6), sandy clay loam, pH 6 ½, massive and single grain to weak 10 – 20 mm sub-angular blocky, no mottles or segregations*

4.2.3.1 Chemical analysis of soil profile

The pH of the Gum SMU soils is moderately to slightly acidic throughout the profile, remaining within a suitable range for plant growth. This SMU has no salinity or sodicity limitations.

The CEC is generally low, influenced by the very sandy soil texture, and nutrient distribution is not ideal for sustainable plant health.

The soil is possibly dispersive (Emerson test Class 2 at 0.2–0.3 m depth), where any aggregates break down and may disperse slightly. Although the ESP values indicate non-sodic conditions, dispersive and slaking qualities in the upper 0.5 m of the soil are possibly contributed by poorly aggregated silt (and clay) fraction, low organic matter and acidic, non-saline conditions.

Table 9 Chemical properties of the Gum SMU – representative site VP7

Depth (m)	pH	EC_{SAT} (dS/m)	Cl (mg/kg)	ESP (%)
0 – 0.1	5.8	0.253	< 10	0.7
0.2 – 0.3	6.2	0.207	< 10	0.6
0.5 – 0.6	6.6	0.230	< 10	1.2
0.7 – 0.8	6.9	0.253	< 10	3.4

Depth (m)	CEC (meq/100 g)	Exchangeable cations (meq/100 g)				Ca/Mg Ratio	Emerson test class
		Ca	Mg	K	Na		
0 – 0.1	3.8	2.2	1.3	0.3	< 0.1	1.7	3
0.2 – 0.3	5.6	3.8	1.6	0.2	< 0.1	2.4	2
0.5 – 0.6	4.9	3.5	1.2	< 0.1	< 0.1	2.9	5
0.7 – 0.8	4.7	3.4	1.0	< 0.1	0.2	3.4	5
Nutrient distribution in topsoil (%)		56.4	33.3	7.7	2.6	-	-

4.2.3.2 Physical analysis of topsoil

The topsoil is dominated by sand (81%), with only clay (11%) and silt (7%) almost equally proportional. The sandy texture of the topsoil contributes to poor structure which forms single grain, loose and incoherent surfaces. The low organic matter content (0.9%) contributes little to the structural stability of topsoil layer. This leads to the topsoil being prone to wind and water erosion.

Water holding capacity of this soil is considered to be medium (estimated plant available water capacity - PAWC of 125 - 150 mm; see Section 5.1.3.2), being restricted by very high evaporation rates, low organic matter, poor structure and high porosity (large inter-particle voids)

Potassium and sulphate concentrations are present at suitable concentration for adequate plant and crop growth, given sufficient water availability, while phosphorus and nitrate were present at very low concentrations. Copper, Fe, Mn and Zn concentrations are considered suitable throughout the solum, while boron is present at low concentrations.

Table 10 Surface soil (0 -10 cm) properties of the Gum SMU

Particle Size Analysis (%)				Soil Particle Density (g/cm³)	Organic Matter (%)
Clay	Silt	Sand	Gravel		
11	7	81	1	2.59	0.9

Extractable Nutrients (mg/kg)				Extractable Metals (mg/kg)				
Phosphorus	Potassium	Sulphate	Nitrate	B	Cu	Fe	Mn	Zn
6	191	<10	1.3	< 0.2	< 1	21.4	3.49	< 1

5 Soil and land suitability assessment results

The land suitability outcomes for the Mitchell, Soapberry and Gum SMU are described in the following sub-sections.

5.1 Land suitability assessment

5.1.1 Land suitability and limitations for dryland cropping and grazing land uses

Soil and land attributes are selected to assess limitations of the Study Area and rank SMUs as suitability subclasses to the main suitability classes (see Section 3.8.1) for specific local land uses (land utilization types – LUTs: FAO, 1976; Dent & Young 1981). The LUTs assessed here are for rainfed sorghum (as an example of common local dryland cropping) and dryland extensive grazing for the Gulf Plains region. A list of limitations has been compiled for 13 districts throughout Queensland in the *Regional Land Suitability Frameworks for Queensland* (State of Queensland 2013). The Study Area is located within the Gulf Plains, where 13 limitations are specified for a list of dryland and irrigation crops.

The limitations outlined for the assessment of land suitability for various dryland cropping and grazing land uses in the Gulf Plains area are:

a) Regional

- Climate, precipitation (Cp);
- Climate, heat stress (Cs);
- Climate, frost (Cf);
- Climate, temperature variation (Ct);

b) By SMU

- Wind erosion (A);
- Moisture availability (M);
- Nutrient balance, pH (Nr);
- Physical restrictions (P);
- Soil depth (Pd);
- Water erosion (E);
- Wetness (W);
- Rockiness (R); and
- Gilgai microrelief (Tm).

The regional framework does not outline specific criteria for dryland grazing. Appropriate suitability subclass groups were allocated for dryland grazing, justified in Appendix B. The relevant Regional Frameworks limitations for the Study Area are detailed also in Appendix B.

5.1.2 Land suitability criteria for dryland cropping and grazing land uses for the Study Area

5.1.2.1 Climate, precipitation (Cp)

Rainfall records at the Julia Creek Airport Bureau of Meteorology (BoM) weather station was referred, indicating mean annual rainfall of 455.3 mm/year (Bureau of Meteorology 2022). The mean annual rainfall of the region is less than 500 mm, and a suitability subclass 4 was allocated for both LUTs, based on the suitability criteria of Group B (refer section B1.1).

5.1.2.2 Climate, heat stress (Cs)

Julia Creek is described to experience 154 days of extreme conditions (>35°C) per year (State of Queensland 2013). The Study Area is limited by severe heat stress (≥20 40°days), a suitability subclass of 2 was allocated for both LUTs, based on the suitability criteria of Group A (refer section B1.2).

5.1.2.3 Climate, frost (Cf)

Julia Creek is described to have a low risk of experiencing frost (State of Queensland 2013), therefore the Study Area is not limited by frost. A suitability subclass of 1 was allocated to both LUTs based on the suitability criteria of Group A (refer section B1.3).

5.1.2.4 Climate, temperature variation (Ct)

The regional climate data (refer section 2.2) indicates mean minimum temperatures of <15° occurs for 3 months (May to July). Based on the suitability criteria of Group A, a suitability subclass of 1 was allocated to both LUTs (refer section B1.4)

5.1.3 Land suitability criteria for dryland cropping and grazing land uses for SMUs

5.1.3.1 Wind erosion (A)

Rainfall data indicates annual rainfall of < 500 mm/year and surface soil texture of all three SMUs were described as Sand to Sandy Clay Loam. Table 11 provides the outcomes of the land suitability class assessment on the basis of climate and surface texture.

Table 11 Suitability subclass on the basis of climate and soil surface texture

SMU	Limiting features	Suitability subclass for Dryland grazing LUT	Suitability subclass for Rainfed sorghum LUT
Mitchell	Annual rainfall < 500 mm AND surface texture class 1 (sandy)	3	3
Soapberry	Annual rainfall < 500 mm AND surface texture class 1 (sandy)	3	3
Gum	Annual rainfall < 500 mm AND surface texture class 1 (sandy)	3	3

5.1.3.2 Moisture availability (M)

Soil water availability may restrict dryland pastures because of the effect on productivity. However, native pasture species within the study area generally comprise of tussock grassland (e.g., wiregrass and Mitchell grass) with drought dormancy allowing survival during extended periods and able to extract soil moisture from relatively dry soil.

The PAWC of soil is difficult to measure in the field, so surrogate soil properties are used instead to allocate soils into a subclass as outlined in the *Technical Guidelines for the Environmental Management of Exploration and Mining in Queensland* (1995). The Mitchell SMU was assessed with a PAWC of ≥ 150 mm, due to cracking clay properties. The Soapberry and Gum SMUs were assessed as PAWC 125 – 150 mm due to non-cracking, loams to clay loam textures and soil depth of > 125 cm (JBT 2018).

The surrogate field properties associated with PAWC, and the subclass determination of SMUs are provided in Table 12.

Table 12 Suitability subclass on the basis of moisture availability

SMU	Limiting features	Suitability subclass for Dryland grazing LUT	Suitability subclass for Rainfed sorghum LUT
Mitchell	PAWC ≥ 150 mm	4	4
Soapberry	PAWC 125 - 150 mm	5	5
Gum	PAWC 125 - 150 mm	5	5

5.1.3.3 Nutrient balance, pH (Nr)

Chemical analysis of the soil profile details the pH throughout the profile (refer section 4.2.1.1, 4.2.2.1, and 4.2.3.1). Results for each SMU identified have been assessed with suitability outcomes presented in Table 13.

Table 13 Suitability subclass on the basis of pH

SMU	Limiting features	Suitability subclass for Dryland grazing LUT	Suitability subclass for Rainfed sorghum LUT
Mitchell	pH > 8.5	2	2
Soapberry	pH 5.5-7.0	1	1
Gum	pH 5.5-7.0	1	1

5.1.3.4 Physical restrictions (P)

Surface conditions of each SMU have been assessed and described in Section 4.2. Soil surface conditions for each SMU identified have been assessed with suitability outcomes presented in Table 14.

Table 14 Suitability subclass on the basis of surface conditions

SMU	Limiting features	Suitability subclass for Dryland grazing LUT	Suitability subclass for Rainfed sorghum LUT
Mitchell	Cracking clay soils with fine structure	2	2

SMU	Limiting features	Suitability subclass for Dryland grazing LUT	Suitability subclass for Rainfed sorghum LUT
Soapberry	No restriction or surface condition firm/hardsetting and light textures of sands and loams	1	1
Gum	Surface condition firm/hardsetting and light textures of sands and loams	1	1

5.1.3.5 Soil depth (D)

Description of the soil profile noted the maximum soil depths of each SMU, described in section 4.2. Table 15 provides the subclass determination of SMUs identified in the Study Area on the basis of maximum soil depth.

Table 15 Suitability subclass on the basis of soil depth

SMU	Limiting features	Suitability subclass for Dryland grazing LUT	Suitability subclass for Rainfed sorghum LUT
Mitchell	Deep (1.0 - 1.5 m)	1	1
Soapberry	Deep (1.0 - 1.5 m)	1	1
Gum	Moderate (0.5 - <1.0 m)	1	2

5.1.3.6 Water erosion (E)

Water erosion is ranked based on slope and soil dispersive characteristics. Soil with steep slopes and strong dispersive characteristics negatively impacts land suitability for agriculture as it can remove valuable topsoil resource, reduce the ability of soil to store water and nutrients, expose subsoil with poor physical and chemical properties, as well as cause deposition in low-lying areas.

The calculation of K factor was based on methodology described by Lu et al. (2001), the outcomes of calculations are provided in Appendix G. Table 16 provides the subclass determination of SMUs identified in the survey area on the basis of K factor and slope.

Table 16 Suitability subclass on the basis of K factor and slope

SMU	Limiting features	Suitability subclass for Dryland grazing LUT	Suitability subclass for Rainfed sorghum LUT
Mitchell	K factor 0.04 - 0.06 and slope <0.5%	2	2
Soapberry	K factor 0.02 - 0.04 and slope <0.5%	1	1
Gum	K factor 0.02 - 0.04 and slope <0.5%	1	1

5.1.3.7 Wetness (W)

The wetness limitation refers to any excess water both in and on the soil profile. The adverse effects of excess water include reducing plant growth, impeding oxygen supply to plant roots (possibly leading to denitrification) and increased risk of plant disease. Table 17 provides the assessment of site drainage and subclass determination.

Table 17 Suitability subclass on the basis of permeability and drainage

SMU	Limiting features	Suitability subclass for Dryland grazing LUT	Suitability subclass for Rainfed sorghum LUT
Mitchell	Well drained – Drainage class 5, permeability class 3	1	1
Soapberry	Rapidly drained – Drainage class 6	1	1
Gum	Rapidly drained – Drainage class 6	1	1

5.1.3.8 Rockiness (R)

Table 18 provides the subclass determination of SMUs identified in the survey area on the basis of rockiness. The presence of high stone content in soils may influence soil properties such as increasing infiltration rates while decreasing soil erosion, susceptibility to compaction, soil water storage and the surface area available for plant establishment.

Table 18 Suitability subclass on the basis of rockiness

SMU	Limiting features	Suitability subclass for both LUTs
Mitchell	Not rocky or significantly rocky	1
Soapberry	Not rocky or significantly rocky	1
Gum	Not rocky or significantly rocky	1

5.1.3.9 Gilgai microrelief (Tm)

Microrelief refers to local relief (up to several metres) around the plane of the land (National Committee on Soil and Terrain 2009). Impacts of microrelief on the suitability of land for agriculture are only experienced when soil displays severe melon-hole gilgai. Ponding of water in the depressions can compromise growing conditions directly impacting on productivity.

Field observations indicate the presence of gilgai in Mitchell SMU, however, vertical intervals were identified as <0.3m. No gilgai were observed in the Soapberry and Gum SMU. The microrelief for each SMU identified has been assessed, with subclass presented in Table 19.

Table 19 Suitability subclass on the basis of microrelief

SMU	Limiting features	Suitability subclass for both LUTs
Mitchell	No gilgai or vertical interval <0.3 m	1
Soapberry	No gilgai or vertical interval <0.3 m	1
Gum	No gilgai or vertical interval <0.3 m	1

5.2 Summary of land suitability for dryland grazing and cropping in the Study Area

Table 20 provides a summary of the assessed land suitability limitation for the LUTs of dryland grazing and dryland cropping (rainfed sorghum). In the Study Area, both LUTs are most limited by moisture availability in all SMUs.

The Mitchell SMU was assessed with an overall land suitability class of 4 for both LUTs; defined as currently unsuitable land, which is presently considered unsuitable due to moderate to severe limitations, primarily soil water availability (high evaporation rates and dry season soil drought) and precipitation (highly seasonal, but not taking surface water supply, e.g. through inundation, into account). It must be borne in mind that the land suitability method defined by the Queensland State Government

i) uses criteria with a narrow selection of land suitability descriptors typically used in agricultural land evaluation, and

ii) uses criteria threshold values that are generally low.

The Framework procedure is also not directly related to the environment being studied here for dryland grazing but is for semi-arid lands in general, outside of the central and coastal productive lands of Queensland. The suitability ratings are more directed to sustainable cropping in this instance whereby the suitability for extensive native pasture grazing could be less restrictive than for dryland cropping. The assessment identified plant available water as a major constraint to the LUTs being assessed, according to the standard, generalised criteria. Combined with limited rainfall and subsequent low soil moisture availability these can possibly constitute severe limitations to dryland cropping and improved pastures. This is not so applicable to native pasture grazing, although periodic flooding conditions can change that evaluation for a season or two. The Class 4 rating also relates to the variability of the climate whereby in La Nina season the rating could be upped to class 3 or maybe 2 temporarily, whereas El Nino events would make this land close to unsuitable (Class 5) for these LUTs for sustainable productivity. This uncertainty in suitability evaluation points to the need for more appropriate soil water storage thresholds and better recognition of rainfall pattern parameters and flooding frequencies for evaluating grazing LUTs in the Western Zone.

The overall land suitability class from the Regional Frameworks methodology of the Soapberry and Gum SMU is Class 5 for both LUTs; defined as unsuitable land with extreme limitations that preclude its productive use. Both SMUs are restricted by soil moisture availability, with light textured soil properties limiting water storage capacity due to high permeability and drainage properties. This result can be tempered by the fact that these criteria are not best suited to an extensive grazing of native pastures LUT.

Although the land suitability framework provides guidance in determining land suitability outcomes, this determination should also give consideration to historical and existing land uses that may or may not be considered 'sustainable'. In this instance, it is acknowledged that the pre-mining land use for the Study Area is low intensity cattle grazing on native pastures. It is therefore accepted that native pastures are adapted to the essentially adverse soil characteristics for sustainable production.

On this basis, it is considered that the Study Area is suitable for low intensity cattle grazing with native pastures, carefully managed with the implementation of appropriate management regimes to support this land use (see section 7).

Figure 8 shows the distribution of land suitability classes for both dryland grazing and cropping land, as can be best determined by the Queensland Government Framework land suitability procedure, across the Study Area. Table 21 provides the area of land under each of the resultant suitability classes.

Table 20 Summary of land suitability assessment (Regional Frameworks)

	Mitchell SMU		Soapberry SMU		Gum SMU	
Limitation	**Dryland Grazing**	**Rainfed Sorghum**	**Dryland Grazing**	**Rainfed Sorghum**	**Dryland Grazing**	**Rainfed Sorghum**
Precipitation	4	4	4	4	4	4
Heat stress	2	2	2	2	2	2

Limitation	Mitchell SMU		Soapberry SMU		Gum SMU	
	Dryland Grazing	Rainfed Sorghum	Dryland Grazing	Rainfed Sorghum	Dryland Grazing	Rainfed Sorghum
Frost	1	1	1	1	1	1
Temperature variation	1	1	1	1	1	1
Wind erosion	3	3	3	3	3	3
Moisture availability	4	4	5	5	5	5
Nutrient balance, pH	2	2	1	1	1	1
Physical restriction	2	2	1	1	1	1
Soil depth	1	1	1	1	1	1
Water erosion	2	2	1	1	1	1
Wetness	1	1	1	1	1	1
Rockiness	1	1	1	1	1	1
Gilgai microrelief	1	1	1	1	1	1
Overall suitability rating	**4**	**4**	**5**	**5**	**5**	**5**

Table 21 Results of the land suitability assessment showing area of land by suitability class

Land Suitability Class	Area (ha)	
	Dryland grazing	Dryland cropping
Class 1 – Suitable land with negligible limitations	0	0
Class 2 – Suitable land with minor limitations	0	0
Class 3 – Suitable land with moderate limitations	0	0
Class 4 – Currently unsuitable land	**2302**	**2302**
Class 5 – Unsuitable land	**843**	**843**

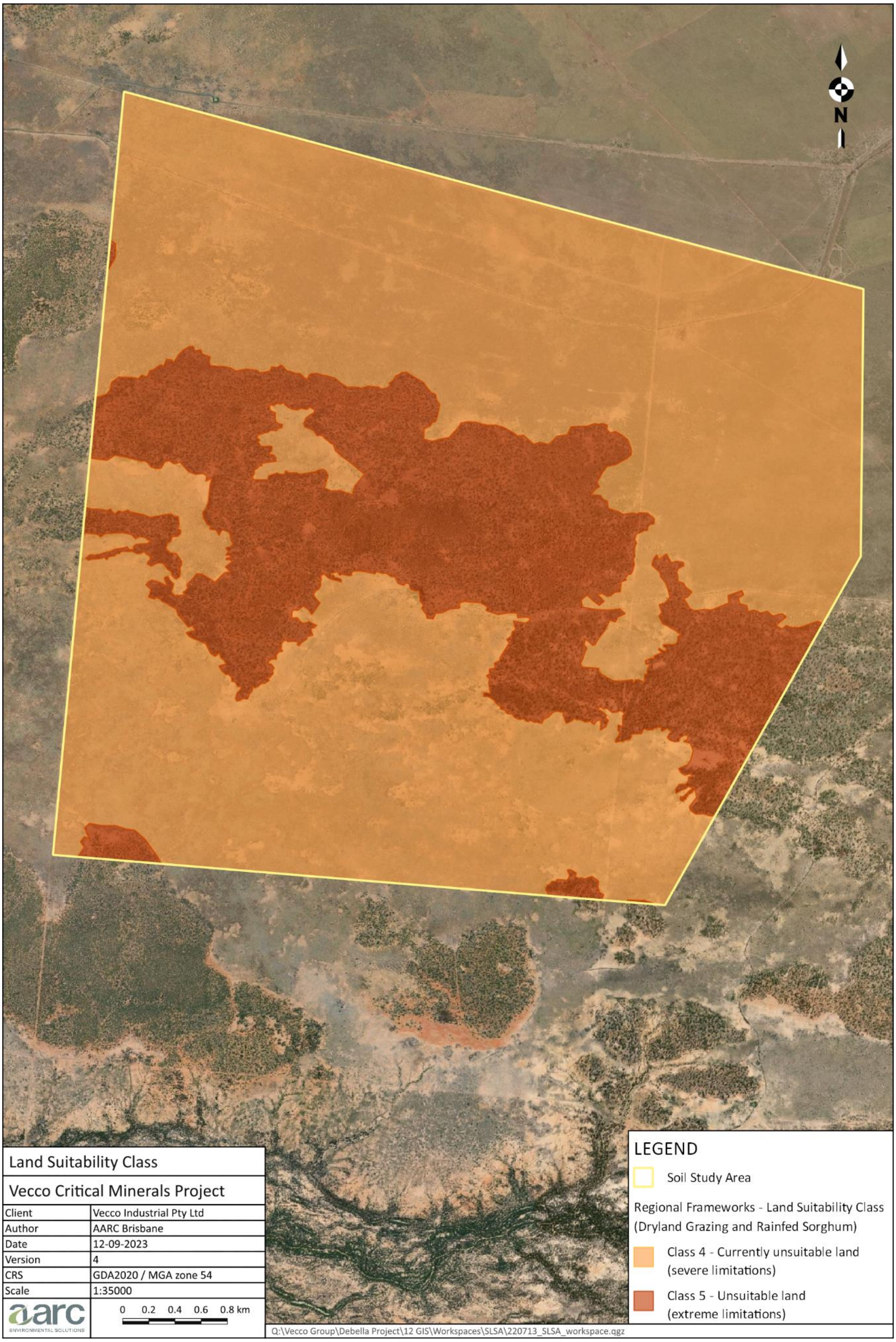


Figure 8 Land suitability classes for dryland grazing and cropping land uses for the Study Area

6 Suitability of soils for rehabilitation

The following subsections discuss soil management recommendations for rehabilitation activities for the SMUs within the Study Area. Recommendations are provided based on the characteristics of SMUs described in section 4.2.

6.1 Topsoil suitability and stripping

Topsoil stripping is required in planned mining disturbance areas to recover valuable topsoil resource for rehabilitation purposes. The identification and stripping of suitable topsoil is necessary to ensure removal of the maximum volume of viable topsoil and reduce wastage. Subsequent maintenance of topsoil viability must be supervised through employing best practices in soil stripping, stockpiling and spreading activities.

Generally, soil fertility decreases with depth in response to the variation within a number of factors including soil texture, pH, organic matter content. Chemical and physical analysis of the SMUs identified in the Study Area indicates the most valuable soil resources are mainly confined to the surface horizons, which contain seedstock, micro-organisms and nutrients necessary for plant growth. However, much of the solum to at least 0.5 m depth is usable for rehabilitation and respreading purposes, although chemical fertility declines with depth.

Where practicable, stripping should be timed to avoid periods of excessive rain or prolonged dry periods. Ideally, topsoil should be directly placed in prepared rehabilitation areas and used immediately rather than stockpiled for later use, although this is not often possible as areas of rehabilitation are not always readily available. Where topsoils have been identified as requiring amelioration, and where practicable, the areas where they have been re-spread and/or the stockpiles where they have been stored should be delineated and recorded to ensure the appropriate treatment subsequently occurs.

It is usually important to stockpile topsoils and subsoils separately. For the soils in the Project area it is recommended that the top 0.2 m of all soils be stripped and stockpiled separately to maintain the valuable vegetative organic matter, seedstock, and limited nutrients that occur in the surface layers.

Table 22 summarises the maximum stripping depth recommendation and the estimated volumes of topsoil resource per SMU within the Study Area. A detailed discussion of the recommended topsoil resource depth follows.

Table 22 Recommended topsoil stripping depth and estimated topsoil resource volumes for each SMU.

SMU	SMU area (m^2)	Topsoil stripping depth (m)	Potential topsoil volume (m^3)	Subsoil stripping depth (m)	Potential subsoil volume (m^3)
Mitchell	23,020,000	0.2	4,604,000	0.2 – 0.6	9,208,000
Soapberry*	420,000	0.2	84,000	0.2 – 0.5	126,000
Gum*	8,010,000	0.2	1,602,000	0.2 – 0.5	2,403,000
		Total topsoil = 6,290,000 m^3		**Total subsoil = 11,737,000 m3**	

SMUs with an asterisk (*) indicate soils where amelioration measures (e.g., gypsum), or actions (e.g., mixing) are considered beneficial to achieve a satisfactory grazing land use outcome.

6.1.1 Mitchell SMU stripping

The Mitchell SMU (see section 4.2.1.1) contains moderate CEC, contributing to relatively good capacity to retain nutrients on aggregate and clay mineral surfaces and the small amount of organic matter throughout the profile. The top 0.5 m of the solum does not indicate any sodicity or salinity concerns. Dispersive characteristics are observed only from 0.5 m depth. The lower solum is also limited by strongly alkaline pH limiting the availability of essential nutrient for plant growth at 0.6 m depth and deeper. Therefore, the absolute maximum stripping depth is 0.6 m for the Mitchell SMU.

A stripping depth of 0.6 m is recommended for the Mitchell SMU, with separation of the top 0.2m preferred as the replacement 'topsoil'.

6.1.2 Soapberry SMU stripping

The top 0.1 m of the Soapberry SMU is primarily composed of sand (90%) and organic matter content is low, contributing to poor structural stability of the topsoil, but it is suitable for most rehabilitation uses for topsoil, as it contains the most nutrients, seedstock and the organic matter. The soil below 0.2 m does not pose any particular restrictions for re-use but is predominantly sandy and the nutrient composition and distribution in the subsoil is generally low. Therefore, the subsoil material below 0.2 m is best used as a substrate material under the respread topsoil. The top 0.2 m can be stripped an respread, or stockpiled, as separate topsoil material

The profile is non-sodic but still presents slaking characteristics below 0.3 m and is therefore potentially susceptible to erosive conditions if exposed. This subsoil material should not be placed on slopes exceeding 3% without consideration of appropriate measures to manage stability.

Amelioration is recommended with an admix of the Mitchell SMU clay material, particularly as a replacement topsoil (A horizon) to aid soil water retention and cohesive structure and to avoid rapid drainage to the waste rock substrate, and surface erosion. A surface application of gypsum at a low rate before seeding, would serve to improve structural stability. Any application of organic matter as a mulch would benefit both erosion protection, retain soil moisture, improve topsoil organic matter and improve structural stability.

6.1.3 Gum SMU stripping

The Gum SMU is suitable for rehabilitation purposes to a depth of 0.5 m as the topsoil does not indicate concerns with pH, salinity or sodicity. Although the subsoil below 0.2 m is considered non-sodic, minor dispersion may be expected to occur upon wetting (evidenced by Emerson aggregate stability test), causing possible issues with erosion and soil stability. Therefore topsoil stripping is recommended to 0.2 m depth for the Gum SMU soil with subsoil stripping and separation to 0.5 m.

The composition of the surface 0.1 m soil is predominantly sand (81%) with poor structural stability and low organic matter content. It is recommended that this topsoil material is not placed on slopes exceeding 3% without appropriate measures to manage stability.

Like the Soapberry SMU amelioration is recommended with an admix of the Mitchell SMU clay material, particularly as a replacement topsoil (A horizon) to aid soil water retention and cohesive structure and to avoid rapid drainage to rock substrate, and erosion. A surface application of gypsum at a low rate before seeding, would serve to improve structural stability. Any application of organic matter as a mulch would benefit both erosion protection, retain soil moisture, improve topsoil organic matter and improve structural stability.

6.2 Topsoil stockpiling

Where possible, topsoil should be directly placed in prepared rehabilitation areas, rather than stockpiled, to assist in maintaining a viable seedbank and promote timely revegetation. Stockpiling of topsoil for extended periods can lead to physiochemical and biological deterioration in the soil and affect the viability of the soil seed bank.

It is often important to stockpile topsoils and subsoils separately. For the soils in the Project area it is recommended that the top 0.2 m of all soils be stripped and stockpiled separately to maintain the valuable vegetative organic matter, seedstock, and limited nutrients that occur in the surface layers.

Where stockpiling of topsoil is required, the following recommendations for soil management will reduce the risk of soil degradation and improve the chances of rehabilitation success (IECA 2008):

- Stockpiles should be located in areas outside of mining activities and well away from any existing drainage courses or zones of overland flow that may pose and erosion threat;
- Locations should be protected from wind erosion where possible and be restricted from stock, vehicles or other mechanical disturbances;
- Stockpiles should generally be less than 3 m high with a batter no steeper than 1:4 and be constructed and positioned in a manner that encourages water drainage and discourages erosion. The surface of the stockpile should be flat;
- If stockpiles are to remain for six weeks or more without addition, then appropriate erosion and sediment controls need to be put in place (refer IECA 2008);
- If stockpiles are to remain for substantial periods, then revegetation with appropriate grass seeding should be undertaken. This is to minimise erosion, encourage increases in organic matter, microbial activity and nutrient levels whilst minimising weed growth and encouraging native vegetation regrowth;
- If there is a risk of a grass cover not establishing voluntarily, stockpiles will need to be ripped and seeded with a quick establishment pasture. Topsoil should ideally be stockpiled for the minimum time. Studies in the Hunter Valley have shown that most deterioration occurs within the first year (Keipert *et al*. 2005);
- Stockpiles should be monitored for erosion and weeds and control measures implemented as appropriate as required, or at least every three months;
- Where soil has been stockpiled for extended periods (more than 12 months), soil testing is recommended before use for rehabilitation purposes. If required, fertilisers and soil ameliorants should be applied.

6.3 Topsoil placement

The estimated topsoil volumes suggests that the topsoil resource will be sourced predominantly from the Mitchell SMU, as well as material to mix with the sandier soil materials from the other two SMUs. The Mitchell SMU is characterised as having relatively low organic matter content and extractable nutrients. To create a favourable environment for vegetation growth, it is recommended to apply organic matter to the respread topsoil in the form of a degrading mulch.

The use of Soapberry and Gum topsoil resource must be carefully managed as both SMUs are described as having very low organic matter content, low extractable nutrients, and poor structural stability, therefore at a greater risk of erosion-induced movement. It is recommended that soil material from the Mitchell SMU be mixed with these sandy soils prior to or at the time of respreading of topsoil.

It is important to establish a sufficient vegetative cover to mitigate erosion risk, particularly as rehabilitated slopes increase. To promote revegetation success, topsoil from both SMUs will require application of one or more of the amelioration measures outlined in the following sub-sections, particularly the application of an organic (hay/straw) mulch.

Where possible, placement of topsoil at a minimum thickness of 0.2 m is recommended for rehabilitation areas to create a growth medium of sufficient depth to hold water and support revegetation (Australian Government 2016). For all rehabilitated areas, deep ripping to a depth of at least 0.5 m of the landform after topsoil placement should be undertaken to key the topsoil and subsoil layers / waste rock material together, and to improve seed germination conditions (Corbett 1999, Australian Government 2016).

6.3.1 Topsoil amelioration

6.3.1.1 Organic matter application

The soil characteristics described within the Study Area are generally characterised by poor soil structure, low moisture retention and low available nutrient concentrations due to the predominantly sandy composition. Where possible, topsoil should be stripped with its existing ground cover vegetation and, if subject to stockpiling, relocated with its cover crop vegetation

The addition of organic matter of any form to such soils goes to improving soil structure by creating a binding effect. Clay-humus compounds not only bind soil particles into aggregates which are more resistant to physical breakdown, therefore minimising erosion-induced movement, but also improve nutrient availability to plants.

The incorporation of organic material also provides a source of nitrogen, phosphorus, and sulphur. Significant improvement to revegetation response was observed through increased phosphorus and nitrogen uptake in sandy soils (Fierro et al. 1999). Vegetation establishment was attributed to improvement of limiting conditions and re-initiation of carbon and nutrient cycling, providing more exchange sites for necessary cations and increased water-holding capacity.

Depending on availability, additional organic matter such as mulches should be or laid as a surface cover and incorporated into the topsoil. Application rates will vary depending on mulch type. Straw mulch is recommended to be applied at a rate of 8 t/ha. Note that fresh mulch should not be used in acidic soils.

6.3.1.2 Fertiliser use and application

If required, the low concentration and imbalanced distribution of nutrients in soils can be ameliorated through fertiliser application.

The natural Australian landscape is low in available phosphorus, causing native species to be adapted to low soil phosphorus concentrations. Therefore, phosphorus application rates should be considered carefully. Application rates of 10–50 kg P/ha have been suggested for grazing pastures (Corbett 1999) and mine restoration (Daws *et al.* 2013). Single superphosphate (8.8% P) may be applied, which satisfies the phosphorus requirements as well as supplying sulphate to aid rapid emergence and vegetative cover growth. It should be noted that this fertiliser should not be blended with urea.

Application of fertilizers is not expected to be necessary to re-establish native grassland species but may be considered where alternate species are desirable. If applying fertilisers it is important to incorporate them into the soil, preferably to a depth of approximately 0.3 m (using a scarifier or ripper tines) prior mulching. The mulch can also be incorporated at the same time as the fertiliser. This is to prevent loss of nutrients through wind erosion or water erosion. Following vegetation establishment (6 to 12 months after sowing), it is recommended to analyse the chemical and physical properties of topsoil to determine the nutrient status and the requirement for any further ameliorative actions.

Natural methods of increasing soil nitrogen levels may be applied through the incorporation of native leguminous forbs such as Barrel Medic (*Medicago truncatula),* Spineless Burr Medic *(Medicago polymorpha var. brevispina) and* Disc Medic *(Medicago tornata)* to the seed mix at 2 – 3 kg/ha. It is best sown at the end of the dry season or early in the wet season. The legume species are capable of fixing nitrogen, as well as establishing a natural nitrogen cycle within the topsoil resulting in long-term improvements in soil fertility and self-sustaining vegetation.

6.3.2 Gypsum application

The poor structural stability of the Soapberry and Gum SMU is attributed to the low organic matter content and soil texture. Structural stability issues may be enhanced through addition of a low-grade, coarse granular gypsum (hydrated calcium sulphate), with the admixture of the clay loam soils materials of the Mitchell SMU, allowing clay particles to form stable aggregates. Soil aeration and water retention rates should be improved, minimising runoff and formation of rill erosion in the absence of adequate vegetative cover.

Lower quality gypsum is not highly soluble, and its significant effects on soil properties may be slow. Therefore, it is recommended for gypsum to be applied before initial stripping to allow soil to be mixed by the stripping process. This allows a longer period in which the ameliorant may dissolve and interact with the soil. In low-rainfall areas, gypsum could take a decade or more to move. Repeated applications of 2.5 – 5 t/ha broadcasted every few years is recommended to be economical and provides long term improvement to soil structure (Abbott and McKenzie 1996, GRDC 2021).

6.3.3 Cover crops

Topsoil loss to erosive processes may be minimised through the establishment of ground cover vegetation. A fast-establishing sterile annual cover crop is often recommended to be included in the seed mix applied to sloped landforms. This approach will also supress weeds and assist in reviving biological processes in the soil, creating a favourable micro-environment for the germination and emergence of the native seeds. Considering the sandy nature of Soapberry and Gum SMU topsoil resource, it is recommended that a cover crop is included in the mix at a high seed density, of approximately 30 kg/ha, even if the soil is mixed with that of the Mitchell SMU. This should provide a rapid ground cover and assist in achieving soil stabilisation. *Echinochloa esculenta* (Japanese Millet) could be used for summer applications and *Avena strigose* (Saia Oats) for cooler season applications. In the transition between cool and warm-hot seasons, a combination of both species can be used.

6.4 Subsoil management

The Study Area consists of low ESP subsoil (e.g. Mitchell SMU), with a mild risk of dispersion and slaking due to low Ca:Mg ratios and high sand/silt particle size content. Use of subsoil as a resource is recommended with an element of caution. SMUs with subsoils that display poor structural stability (Soapberry and Gum SMU) still represent an opportunity for use as a soil resource, given their non-sodic nature throughout the solum, but consideration should be given to incorporate Mitchell SMU soil material and ameliorants to improve their stability.

6.5 Erosion modelling (WEPP)

Disturbance of vegetation and the topsoil layer can lead to soil mobilisation through erosion: water erosion from heavy rainfall or overland flow and wind erosion on the dry sandier soils and the self-mulching clays. The following activities will increase the risk of erosion at the Project:

- clearing of vegetation;
- topsoil stripping and stockpiling;
- construction of infrastructure; and
- exposure of slopes.

Given the activities listed above, erosion modelling through WEPP (Watershed Erosion Prediction Project) was conducted to ensure slope stability and land suitability of the proposed final material and landform. WEPP modelling considers four key data points: climate information, soil profile, land use management and slope design. Climate parameters were modelled from the area using CLIGEN 5.3, with input data sourced from SILO (daily rainfall, maximum and minimum temperature, solar radiation and maximum relative humidity) and BOM (pluviograph data). Six soil samples were included for modelling, two from each SMU unit (see Section 4 for details). The samples included are as follows:

- Mitchell SMU:
  - VP10
  - VP12
- Soapberry SMU
  - VP14
  - VP2
- Gum SMU
  - VP7
  - VP9

In creating the land use management parameters for WEPP modelling, cover classes were established at 5% intervals ranging from 0% to 100%. Vegetation cover was fixed at these percentages throughout the WEPP simulations, such that consistent cover was maintained across the 100-year simulation period without growth or decay. Slope design specifications were sourced from the proposed final landform design, with the selected slope sampled from the proposed waste rock dump (WRD). The western slope was selected as it represents the maximum allowed slope design present on the site. The top of the slope is approximately 142 m RL (AHD), with the bottom of the slope approximately 130 m RL, giving a maximum slope height of 12 m. The slope is separated into two sections, with an initial 25 m decline gradually increasing to 1:10 gradient, followed by a short plateau approximately 25 m along the slope, then a second 1:10 gradient slope approximately 103 m long (see Figure 9).

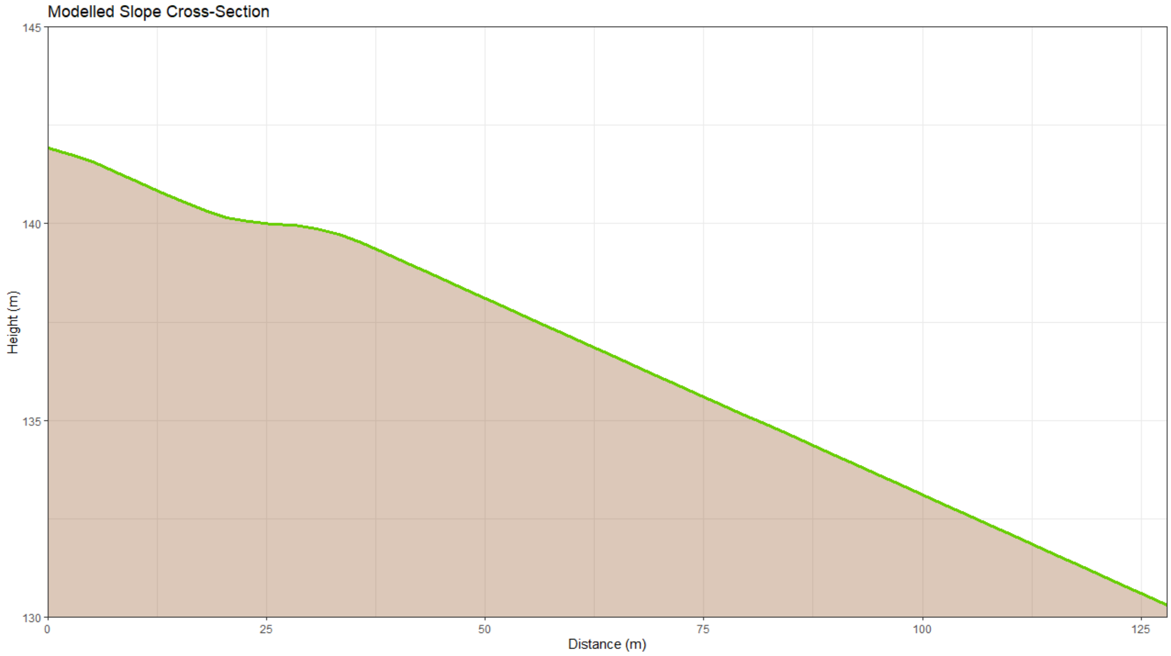


Figure 9: Slope cross-section incorporated into WEPP modelling.

In all, 126 100-year WEPP iterations were run, covering the range of soil samples and land use management profiles identified above. To determine the maximum potential erosivity of the slope, the average annual soil loss, expressed in tonnes per hectare per year (t/ha/yr), for each iteration was calculated and assessed against a target and maximum erosion rate. A target (or 'tolerable') erosion rate of 5 t/ha was adopted for assessing land suitability and erosivity risk (Landloch 2013; Howard and Loch 2019). Additionally, a maximum tolerable erosion rate of 10 t/ha was adopted, as the rate was considered acceptable for mining rehabilitation purposes (Lu 2001). The results of this analysis can be found in Figure 10: Average annual soil loss rates (t/ha/year) as vegetation cover increases..

The average base erosion (no vegetation cover) modelled for the slope is 48.98 t/h/yr, with a maximum base erosion rate of 64.03 t/ha/yr (soil VP12).

At 35% vegetation cover, erosion on the slope is modelled to be within the maximum tolerable erosion threshold for all soil samples, with VP7, VP9 and VP14 meeting the maximum tolerable erosion threshold at 25% vegetation cover. 60% vegetation cover is required for all soil samples to meet the target tolerable erosion rate of 5 t/ha, with VP7, VP9 and VP14 meeting the target tolerable erosion threshold at 45% vegetation cover (Table 23).

Table 23 Summary of modelled vegetation covers at tolerable erosion thresholds

Erosion rate thresholds	Vegetation cover (%)	
	Soil samples VP7; VP9; VP 14	**All Soils**
Target tolerable erosion rate (5 t/ha)	45	60
Maximum tolerable erosion rate (10 t/ha)	25	35

Given these results, the slopes of the proposed WRD should remain stable and non-erosive irrespective of topsoil properties, where 60% vegetation cover is maintained based on the target erosion rate. However, vegetation cover can decrease to 35% while maintaining structural integrity on the slope when considering a maximum tolerable erosion rate of 10 t/ha.

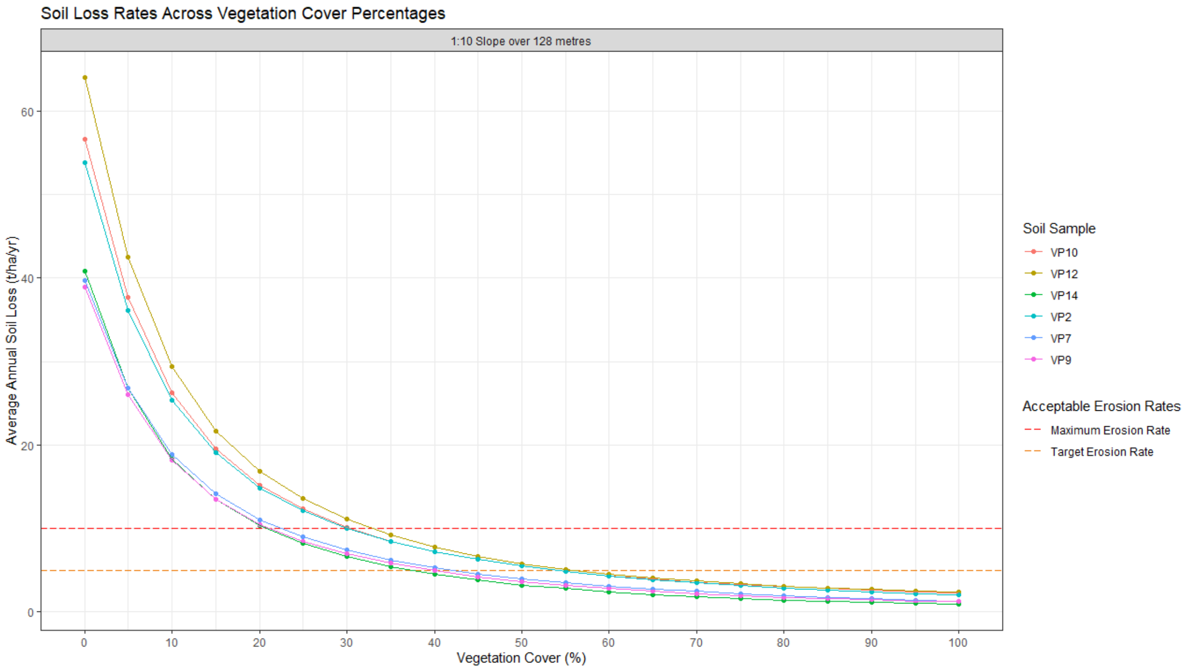


Figure 10: Average annual soil loss rates (t/ha/year) as vegetation cover increases.

7 Potential impacts and management

The Project is anticipated to be developed with land disturbance potentially impacting the existing land suitability of the area. To mitigate potential impacts to land suitability several measures have been proposed and are detailed within this section.

The existing land suitability classes are detailed in section 5 and summarised in Table 24.

Table 24 Summary of land suitability classes and area of SMUs in the study area

SMU	Land Suitability Class (Grazing)	Area (ha)	Land Suitability Class (Cropping)	Area (ha)
Mitchell	4*	2302	4	2302
Soapberry	5*	42	5	42
Gum	5*	801	5	801

* *considered suitable based on current land use type of extensive, low-intensity grazing management in the sub-tropical savanna region.*

The outcomes of the land suitability assessment indicate the Study Area is capable of supporting low-intensity cattle grazing, which is the pre-mining land use of the Study Area and the surrounding areas. It is also potentially suitable for dryland cropping (sorghum), although profitable, sustainable dryland cropping faces significant limitations and would need to be assessed for suitable soils and management regimes at a more detailed scale for specific cropping LUTs.

Post-mine land conditions may be restored to productive and profitable conditions by incorporating 3P (perennial, persistent, and palatable) species (e.g., native Mitchell grass (*Astrebla spp*.)), increasing basal area and seed production of individual plants. Legume species such as *Medic spp.* varieties may also be incorporated in the seed mix for long-term improvements in soil fertility and self-sustaining vegetation (see section 6.3.3).

Mining activities, especially stripping, stockpiling and handling of soil, have the potential to impact the physical, chemical and biological properties of land. Therefore, the land suitability outcome for both dryland cropping and cattle grazing need to be reproduced or improved for rehabilitated landforms by appropriate management.

The impact of mining activities on soils can be mitigated through:

- good topsoil management practices (see sections 6.2 and 6.3);
- the addition of fertilisers and soil ameliorants (see section 6.3.1);
- timely seeding with suitable species (see section 6.3.3); and
- post-establishment management of rehabilitated areas.

These management strategies form improved pastures that benefit land conditions by maintaining a high density of perennial grasses, consequently improving and maintaining soil organic matter, stimulating soil organisms, promoting soil structure, and thereby enhancing soil moisture retention and mitigating both wind and water erosion.

7.1 Topsoil and subsoil stripping impacts and mitigation

Stripping activities (section 6.1) may lead to negative impacts on the chemical and physical attributes of soil, and subsequently the land suitability classification. Impacts associated with topsoil stripping have been described in section 6. Namely,

- exposure of potentially unstable subsoil during soil stripping;
- loss of soil physical structure due to excavation and handling;
- loss of soil seedbank and vegetative matter; and
- impacts on soil fertility due to mixing of infertile subsoils and resulting changes in soil chemistry.

Mitigation measures recommended to monitor topsoil stripping procedures include development of a Topsoil Management Plan that includes the following management aspects:

- minimising the handling of topsoil;
- supervision of stripping to determine consistent recovery depths for specific soil types;
- delineation of areas to be stripped and date of stripping;
- delineation of planned areas for direct return of topsoil (as required);
- delineation of suitable stockpile areas (as required);
- ensuring stockpiles are generally less than 2 m high and contours encourage water drainage;
- if topsoil resources are to be stockpiled for a period in excess of six months, testing of soil properties prior to use in rehabilitation should be carried out. Conducting soil physiochemical analysis of stockpiled topsoil resources could be considered to assess for changes in topsoil quality (changes to soil chemistry and biological activity as a result of being stockpiled, e.g., pH, ESP, CEC (major cations), organic matter content and other essential nutrients such as nitrate, phosphorus and sulphur); and
- the application of fertilisers, soil ameliorants and an appropriate seed mix to increase the likelihood of rehabilitation success (See section 6.3).

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Appendix A. Laboratory Data Interpretation

The characteristics and chemical data for each SMU have been described in section 4. Broad descriptions for each soil parameter have been provided below and where applicable, a summary of the rating system used.

Physical and chemical parameters analysed for all samples were:

- pH;
- electrical conductivity (EC);
- moisture content;
- chloride (soluble);
- exchangeable cations (Ca, Mg, Na, K);
- cation exchange capacity (CEC); and
- exchangeable sodium percentage (ESP).

Additional physical and chemical parameters analysed for topsoil samples were:

- organic matter (%);
- particle size analysis (PSA);
- extractable trace elements/metals (Fe, Cu, Zn, Mn);
- boron ($CaCl_2$ extractable);
- nitrogen as nitrate;
- sulphate (water-soluble S as sulphate);
- phosphorus and potassium (Colwell); and
- Emerson aggregate stability class.

A1.1 pH

Soil pH influences the availability of plant available nutrients and toxic elements by controlling the solubility of these elements. At extreme pH, the availability of essential plant nutrients can be severely reduced while toxic elements can become mobile within the soil solution in acidic environments. The soil pH ratings used are shown in Table 25. In general, a suitable soil pH ranges from 5.5–9.0 as at this pH all essential nutrients are available to some degree.

Table 25 Interpretation of pH measured in water (1:5 soil/water ratio) (Hazelton and Murphy 2016)

pH_{water}	Rating	Soil chemistry indications
< 4.0	Very strongly acid	Typical of disturbed acid sulphate soils
4.0 to < 5.0	Strongly acid	Acidified soils
5.0 to < 6.0 6.0 to < 7.0 7.0	Moderately acid Slightly acid Neutral	Range most suitable for plant growth
> 7.0 to < 8.0	Slightly alkaline	
8.0 to < 9.0	Moderately alkaline	
9.0 to 10.0	Strongly alkaline	Some nutrients becoming unavailable, indication of sodicity
> 10.0	Very strongly alkaline	Extreme pH, high sodicity and carbonates

A1.2 Electrical conductivity

Soil salinity is determined by measuring the electrical conductivity of soil:water suspensions in soil. This provides an indication of the presence of water-soluble salts, including sodium, calcium and magnesium, which can be chlorides, sulphates or carbonates, in the soil profile.

Electrical conductivity is determined by converting the $EC_{(1:5)}$ (soil:water suspension) to saturated extract (EC_{SAT}) (dS/m), which based on soil texture and estimated water holding capacity of the soil. To convert $EC_{(1:5)}$ to EC_{SAT}, the following formula is used:

EC_{SAT} (dS/m) = $EC_{(1:5)}$ (dS/m) x multiplier factor (Hazelton and Murphy 2016)

High soil salinity can increase soil erosion, severely effecting plant growth and land use. Highly saline conditions compromise the ability of a plant to take up water as needed, resulting in water stress regardless of the water content in the soil. The texture of soil needs to be considered when interpreting EC as the clay content determines the amount of salt present that will affect plant growth. Table 26 provides the multiplier factors to be applied to the formula for converting $EC_{(1:5)}$ (dS/m) to EC_{SAT} (dS/m), as described in Hazelton and Murphy (2016).

Table 26 Multiplier factors for converting $EC_{1:5}$ to EC_{SAT} (Hazelton and Murphy 2016)

Soil texture	Multiplier factors
Sand, loamy sand, clayey sand	23
Sandy loam, fine sandy loam, light sandy clay loam	14
Loam, fine sandy loam, silty loam, sandy clay loam	9.5
Clay loam, silty clay loam, fine sandy clay loam, sandy clay, silty clay, light clay	8.6
Light medium clay	8.6
Medium clay	7.5
Heavy clay	5.8

Saline soils are defined as having an EC_{SAT} >4 dS/m (Table 27).

Table 27 Salinity ratings for soil based on EC_{SAT} (Hazelton and Murphy 2016)

Rating	EC_{SAT} dS/m	Effect on plants
Non-saline	< 2	Salinity effects are mostly negligible
Slightly saline	2 – 4	Yields of sensitive crops are affected
Moderately saline	4 – 8	Yields of many crops are affected
Highly saline	8 – 16	Only tolerant crops yield satisfactorily
Extremely saline	> 16	Only very tolerant crops yield satisfactorily

A1.3 Chloride

Chloride is associated with EC as soluble salts contain chloride, thus the presence of soluble salts in soils is directly proportional to chloride in soil. A high chloride concentration can induce chloride toxicity and interfere with the osmotic capacity of plants. Table 28 below provides chloride ratings (Rayment and Bruce 1984).

Table 28 Chloride concentration ratings (Rayment and Bruce 1984).

Chloride rating	Cl concentration (mg/kg)
Very Low	< 100
Low	100 – 300
Medium	300 – 600
High	600 – 2000
Very High	> 2000

A1.4 Cation exchange capacity and exchangeable cations

Cation Exchange Capacity (CEC) is an indication of the capacity of a soil to adsorb cationic nutrients to the surface of soil particles. This process of adsorption prevents nutrients leaching from the soil and buffers the concentration of plant available nutrients in the soil solution. A high CEC of the soil contributes to larger quantities of exchangeable cations (Ca, K, Mg, Na) available. The ratio of cations on the exchange is also an important consideration as cations that dominate the exchange can interfere with the availability of other cations. Table 29 and Table 30 provide ratings for soil CEC and extractable cations sourced from Hazelton and Murphy (2016).

Table 29 Soil CEC ratings (Hazelton and Murphy 2016)

CEC rating	CEC (cmol(+)/kg)
Very Low	< 6
Low	6–12
Medium	12–25
High	25–40
Very High	> 40

Table 30 Desired proportions of CEC of different cations (Hazelton and Murphy 2016)

Cation	Ideal range (% of CEC)
Ca	65–80
K	3–8
Mg	10–20
Na	< 1

A1.5 Exchangeable sodium percentage

Exchangeable sodium percentage (ESP) is defined as the amount of exchangeable sodium as a percentage of the total CEC of the soil. It provides a measure of how much of the CEC of the soil is dominated by sodium. Due to the chemical characteristics of sodium ions, an increasing ESP indicates increasing sodicity thus increasing the risk of dispersion. Table 31 provides ESP ratings sourced from Hazelton and Murphy (2016).

Table 31 Soil ESP ratings (Hazelton and Murphy 2016)

ESP rating	ESP (%)
Non-sodic	< 6
Sodic	6–15
Strongly sodic	> 15

A1.6 Organic matter

Organic matter is an essential constituent of soil. It is an important component of microbial processes and nutrient cycling. Furthermore, it contributes to the ability of a soil to buffer changes to pH and nutrient content and supports the aggregation of soils thereby improving the structural stability of the soil. Table 32 provides soil organic matter ratings sourced from Hazelton and Murphy (2016).

Table 32 Soil organic matter ratings (Hazelton and Murphy 2016)

Organic matter rating	Organic matter content (g/100 g)
Extremely low	< 0.7
Very low	0.7–1
Low	1–1.7
Moderate	1.7–3
High	3–5.15
Very High	> 5.15

A1.7 Particle size analysis

Particle size analysis determines the percentage composition of sand, silt and clay sized particles which controls the soil texture. Soil texture influences the structural stability and water holding characteristics of a soil as the particle size distribution influences the porosity and permeability of soil. Differences in soil texture allows characterisation of soil types and possible limitations.

The field texture of a soil reflects the dominant particle sizes in the soil. The approximate relationship between particle size distribution and field texture is illustrated in Figure 11.

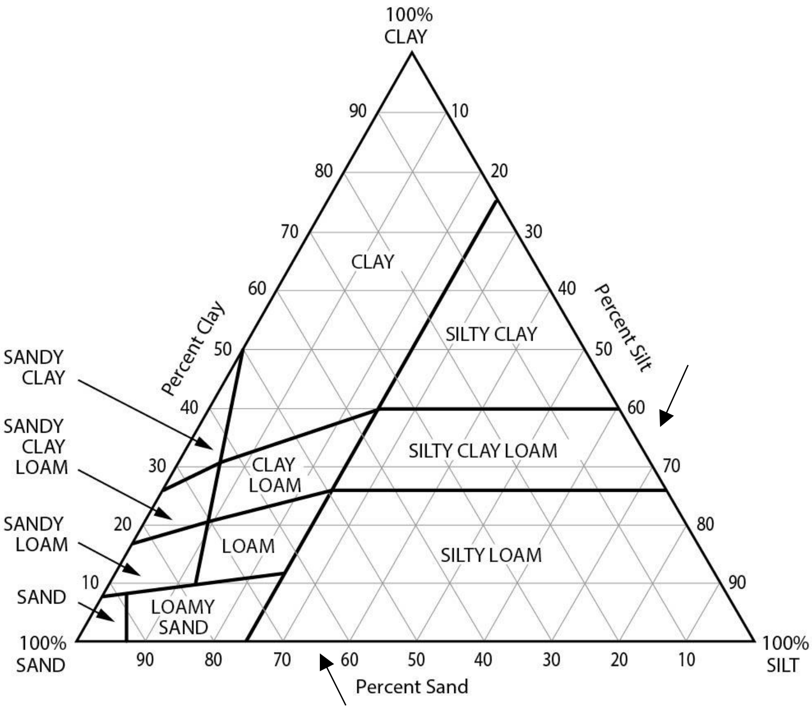

Figure 11 Ternary soil texture diagram from particle size analysis (McDonald and Isbell 2009)

A1.8 Extractable trace elements/metals

Trace elements such as copper, iron, manganese, zinc and boron are essential nutrients required for plant growth, although needed in much smaller quantities than exchangeable cations. Table 33 provides trace element/metal ratings sourced from Government of South Australia (2013).

Table 33 Ideal concentration ranges for trace elements/metals (Government of South Australia 2013)

Trace element/metal	Rating	Concentration (mg/kg)
Boron	Low	< 0.5
	High	> 15
Copper	Low	< 0.3
	High	> 1
Iron	Low	< 10
	High	> 70
Manganese	Low	< 1
	High	> 10
Zinc	Low	< 0.5
	High	> 1

A1.9 Nitrate

Nitrate is a plant available form of nitrogen. It is an essential nutrient and is often the most limiting to plant growth. It is also susceptible to nitrification and leaching which reduces nitrate concentration in soil. Table 34 provides soil nitrate ratings sourced from Hazelton and Murphy (2016).

Table 34 Soil nitrate ratings (Hazelton and Murphy 2016)

Rating	Nitrate concentration (mg/kg)
Very low	0–6
Low	7–15
Moderate	16–22
High	23–30
Very High	> 30

A1.10 Sulphate

Sulphate is another essential plant nutrient and has a similar behaviour to nitrate in that it is susceptible to leaching and is important in microbial processes. Table 35 provides soil sulphate ratings sourced from Government of South Australia (2013).

Table 35 Soil sulphate ratings (Government of South Australia 2013)

Rating	Sulphate concentration (mg/kg)
Low	< 5
Marginal	5–10
High	> 10

A1.11 Phosphorus and potassium

Both phosphorus and potassium are the next most essential nutrients after nitrogen and sulphate. Phosphorus and potassium are involved in several chemically- and microbially-driven processes within the soil with most forms of these nutrients being unavailable for plant uptake. Table 36 and Table 37 provide ratings for soil phosphorus and potassium levels sourced from Hazelton and Murphy (2016).

Table 36 Soil phosphorus ratings (Hazelton and Murphy 2016)

Rating	Phosphorus concentration (mg/kg)
Very low	< 5
Low	5–10
Moderate	10–17
High	17–25
Very High	> 25

Table 37 Soil potassium ratings (Hazelton and Murphy 2016)

Soil Texture	Potassium critical concentration (mg/kg)*
Sand	126
Sandy loam	129
Sandy clay loam	143
Clay loam	161

* Critical concentration is that concentration where 95% of maximum yield is achieved

A1.12 Emerson class

The Emerson aggregate test class is a class assigned to soil that is determined on the stability of dry aggregates in water. The Emerson class of a soil is assigned as an indication of the dispersion and slaking ability of a soil. Table 38 below describes the Emerson Dispersion Class (Emerson 1967).

Table 38 Emerson aggregate test classes (Emerson 1967)

Emerson test class	Level of dispersion and or slaking
1	Slaking and complete dispersion
2	Slaking and some dispersion
3	Slaking and no dispersion
4	$CaCO_3$/$CaSO_4$ present. No dispersion at field capacity
5	No $CaCO_3$/$CaSO_4$ present. No dispersion at field capacity, however, dispersion in an aggregate-water suspension
6	No $CaCO_3$/$CaSO_4$ present. No dispersion at field capacity, however, flocculation in an aggregate-water suspension
7	No slaking and swelling
8	No slaking and no swelling

Appendix B. Regional Land Suitability Frameworks for Queensland – Land Suitability Assessment Criteria

The reference *Regional Land Suitability Frameworks for Queensland* (State of Queensland 2013) was developed for appropriate land uses based on specific regional study areas. Soil and land attributes are selected to assess limitations of the Study Area and ranked as suitability subclasses for specific local land uses (land utilization types – LUTs: FAO, 1976). The LUTs assessed here are for rain-fed sorghum (as an example of common local dryland cropping) and dryland extensive grazing for the Gulf Plains region.

The land suitability framework is essentially a matrix for each limitation, showing suitability subclass for each land use against each limitation category. The following sections discuss the definitions, attribute assessment and subclass determination of each limitation for both LUTs.

B1.1. Climate, precipitation (Cp)

Adequate rainfall is required for dryland cropping (rainfed sorghum) and pasture growth to avoid water stress. The high variability in frequency and amount of rainfall, combined with high evapotranspiration creates unfavourable conditions for vegetation growth in dryland conditions. The suitability for rainfed, wet season grain/pulse crops and perennial tree crops were determined in the guidelines and relevant criteria listed in Table 39.

The criteria of Group B were applied to determine the suitability subclass of precipitation for dryland grazing pastures. Native grasses are well adapted to severe drought and low rainfall conditions, as well as developed a variety of mechanisms for drought avoidance. These include, prolonged dormancy, deep root systems or through having a below-ground crown which is capable of surviving drought and grazing (Wang and Bughrara 2008, McWilliam 1968). Hence, it is understood that native grasses will be more tolerant in conditions of low rainfall.

Group B consists of criteria for land uses with greater capacity to tolerate low annual rainfall conditions, e.g. severe limitations (subclass 4) as opposed to extreme limitations (subclass 5) in areas with annual rainfall <500 mm.

Table 39 Climate, precipitation limitation description and suitability subclass

Description	Suitability subclasses applied for LUTs (Framework	
Mean annual rainfall	**Dryland grazing LUT (B)**	**Dryland sorghum LUT (B)**
Annual rainfall >1000 mm	1	1
Annual rainfall 800 – 1000 mm	1	1
Annual rainfall 600 – 800 mm	2	2
Annual rainfall 500 – 600 mm	3	3
Annual rainfall <500 mm	4	4

B1.2. Climate, heat stress (Cs)

Heat stress often occurs during period of significant water shortages where there is a build-up of temperature associated with little rainfall, which causes significant stress on crops. The Gulf Plains region is noted for its exceptionally hot temperatures that occur over a long period. The intense solar radiation associated with high temperatures and wind may cause damage to leaves and fruits of certain crops, particularly horticultural crops. The relevant suitability of heat stress conditions is listed in Table 40.

The criteria of group A were applied to determine the suitability subclass of heat stress of dryland grazing pastures. Native pastures are expected to have adapted a suite of tolerant traits to sustain growth in adverse climate conditions.

Group A consists of criteria for land uses with greater tolerance to heat stress, e.g., minor limitations (subclass 2) as opposed to moderate limitations (subclass 3) where there is severe heat stress.

Table 40 Climate, heat stress limitation description and suitability subclass

	Suitability subclasses applied for LUTs (Framework Group)	
Description	**Dryland grazing LUT (A)**	**Dryland sorghum LUT (A)**
Low heat stress (<5 40°days)	1	1
Moderate heat stress (5-20 40°days)	1	1
Severe heat stress (≥20 40°days)	2	2

B1.3. Climate, frost (Cf)

Frost may damage some crops by periods of a few hours of extremely low temperatures (0°C), while others do not suffer damage when subjected to longer periods and/or lower temperatures. The suitability of frost conditions on various land uses are listed in Table 41.

The suitability criteria of Group A were applied to determine the suitability subclass of frost for dryland grazing pastures.

Table 41 Climate, frost limitation description and suitability subclass

	Suitability subclasses applied for LUTs (Framework Group)	
Description	**Dryland grazing LUT (A)**	**Dryland sorghum LUT (A)**
Frost free	1	1
Occasional frost (<2 days)	1	1
Regular light frosts (≥2 days)	2	2

B1.4. Climate, temperature variation (Ct)

Temperature variations affect the growth potential of certain crops, leading to reduced yield potential. For the purposes of this assessment, dryland grazing pastures are not expected to be impacted by temperature variations. The criteria of group A were applied to determine the suitability subclass of temperature variation.

Table 42 Climate, temperature variation limitation description and suitability subclass

Description	Suitability subclasses applied for LUTs (Framework Group)	
	Dryland grazing LUT (A)	Dryland sorghum LUT (A)
Mean min. monthly temperature <15◦ for 4 months or more	1	1
Mean min. monthly temperature <15◦ for 3 months or less	1	1

B1.5. Wind erosion (A)

Periods of dry and windy conditions may lead to soil loss due to wind erosion, which is associated with areas of sparse vegetation and loose soils. Disturbance of the soil surface during these conditions can exacerbate the process.

Wind erosion is influenced by both climatic and soil factors. Climatic factors include mean annual rainfall, potential evapotranspiration and the frequency of strong winds, especially on bare soils. Soil factors include texture, structure (specifically aggregate size) and roughness of the soil surface.

The land uses in group B included rainfed crops which reflects the conditions of dryland grazing pastures, while group A only consist of irrigated crops. Hence, the criteria of group B were applied to determine the suitability subclass of wind erosion for dryland grazing pastures.

Table 43 Wind erosion limitation and suitability subclass

Description	Suitability subclasses applied for LUTs (Framework Group)	
	Dryland grazing LUT (B)	Dryland sorghum LUT (B)
No restriction: annual rainfall >= 500 mm OR surface texture not sandy	1	1
Annual rainfall <500 mm AND surface texture class 1 (sandy)	3	3
Annual rainfall <500 mm AND surface texture class 1 (sandy) AND Soil Gen Grp 8 (Sodosols)	4	4

B1.6. Moisture availability (M)

All plants require adequate moisture to achieve optimum production. Soil water availability is assessed in terms of the capacity of the soil to retain and supply water for plant use, while recognising that different species will differ in their ability to extract soil water. Plant available water capacity (PAWC) provides the best estimate of a soil's moisture storage capacity.

It should be noted that the criteria are listed for rainfed agricultural crops that require more moisture to achieve optimum yields. Native grasses are well adapted to severe drought and low rainfall conditions and developed a variety of mechanisms for drought avoidance. These include prolonged dormancy, deep root systems or through having a below-ground crown which is capable of surviving drought and grazing (Wang and Bughrara 2008, McWilliam 1968). Hence, it is understood that native pastures will be more tolerant in conditions of low rainfall and PAWC.

The Project is located within the < 500 mm rainfall zone, criteria E1 were applied to determine the land suitability class of moisture availability for dryland grazing pastures.

Table 44 Moisture availability limitation description and suitability subclass

Description	Suitability subclasses applied for LUTs (Framework Group)	
	E. Rainfall <500 mm	
	Dryland grazing LUT (E1)	Dryland sorghum LUT (E1)
PAWC > 150 mm	4	4
PAWC 125 – 150 mm	5	5
PAWC 100 – 125 mm	5	5
PAWC 75 – 100 mm	5	5
PAWC 50 – 75 mm	5	5
PAWC ≤ 50 mm	5	5

B1.7. Nutrient balance, pH (Nr)

Nutrient availability can be dependent on pH, where it may lead to certain nutrient deficiencies and/or toxicities. For example, toxic concentrations of elements may be associated with strongly acidic conditions. Suitable soil pH ranges between 5.5–9.0, where all essential nutrients are available to come degree (Hazelton and Murphy 2016). The criteria of group A were applied to determine the suitability subclass of pH for dryland grazing pastures.

Table 45 Soil water availability limitation description and suitability subclass

Description	Suitability subclasses applied for LUTs (Framework Group)	
	Dryland grazing LUT (A)	Dryland sorghum LUT (A)
pH 5.5-7.0	1	1
pH 7.0-8.5	1	1
pH <5.5	2	2
pH >8.5	2	2

B1.8. Physical restrictions (P)

Soil surface conditions may adversely affect the establishment and emergence of seedlings, which includes hard setting, crusting, coarse self-mulching, hydrophobic or tough clay conditions. This limitation is used to downgrade suitability where poor surface conditions affect production, or where increased management inputs are required to manage those soils. The relevant suitability classes of physical restrictions are shown in Table 46.

The suitability criteria of Group I were applied as it included rainfed crops, while other groups consisted of irrigated crops.

Table 46 Physical restrictions limitation description and suitability subclass

Description	Suitability subclasses applied for LUTs (Framework Group)	
	Dryland grazing LUT (I)	Dryland sorghum LUT (I)
No restriction: surface condition loose	1	1
Surface condition firm/hardsetting and light textures of sands and loams	1	1
Surface condition firm/hardsetting and heavy texture of clay	2	2
Cracking clay soils with fine structure	2	2
Cracking clay soils with coarse structure	3	3
ESP ≥ 6 or surface condition firm/hardsetting and silty surface texture	4	4
Depth of A horizon <= 0.2 m AND the Soil Generic Group – "sand or loam over intractable clay subsoils"	4	4

B1.9. Soil depth (Pd)

Soil depth refers to the depth of a physical root barrier (hard rock, continuous cemented hardpan or continuous gravel layer). Where the underlying hard material is highly weathered or fractured, plants may have a rooting depth that is greater than the depth of soil.

Native grass species within the Study Area (e.g. *Astrebla spp.*) possess a dual root system whereby the shallow root system can utilise smaller falls of rain (40 – 50 mm) and a deep (>200 cm) root system which can access moisture in the subsoil (Orr and Phelps 2008). Therefore, the suitability criteria of Group A were applied for dryland grazing, as the most lenient criteria for soil depth.

Table 47 Soil depth limitation description and suitability subclass

Description	Suitability subclasses applied for LUTs (Framework Group)	
	Dryland grazing LUT (A)	Dryland sorghum LUT (F)
Very deep (≥ 1.5 m)	1	1
Deep (1.0 – 1.5 m)	1	1
Moderate (0.5 - <1.0 m)	1	2
Shallow (0.25 - <0.5 m)	2	4
Very shallow (< 0.25 m)	4	5

B1.10. Water erosion (E)

The water erosion limitation considers the potential impact of accelerated erosion of the land surface caused by various human activities. Most agricultural land uses (including pastures) increase the potential for soil loss from water erosion due to an increased volume of runoff, increased velocity of water flow, and decreased protection of the soil surface when devoid of surface cover. The rate of soil loss will increase above natural levels in many localities where surface water is concentrated, such as at water outlets and cross drains, particularly where these are located in flood-prone areas.

Subclasses are described in terms of the slope ranges permitted for each land use and soil type. The relevant subclasses are shown in Table 48, where criteria of group F included rainfed crops and were applied to determine the suitability for dryland grazing pastures.

The methodology for determining K factor of SMUs is described in Appendix G.

Table 48 Water erosion limitation description and suitability subclass

Description	Suitability subclasses applied for LUTs (Framework Group)	
	Dryland grazing LUT (F)	**Dryland sorghum LUT (F)**
Stable soils		
K factor 0.02-0.04 and slope < 0.5%	1	1
K factor 0.02-0.04 and slope 0.5-1.0%	2	2
K factor 0.02-0.04 and slope 1-2%	3	3
K factor 0.02-0.04 and slope 2-3%	3	3
K factor 0.02-0.04 and slope 3-5%	3	3
K factor 0.02-0.04 and slope 5-8%	4	4
K factor 0.02-0.04 and slope 8-12%	4	4
K factor 0.02-0.04 and slope 12-15%	5	5
K factor 0.02-0.04 and slope 15-20%	5	5
K factor 0.02-0.04 and slope > 20%	5	5
Unstable soils		
K factor 0.04-0.06 and slope < 0.5%	2	2
K factor 0.04-0.06 and slope 0.5-1.0%	3	3
K factor 0.04-0.06 and slope 1-2%	3	3
K factor 0.04-0.06 and slope 2-3%	3	3

Description	Suitability subclasses applied for LUTs (Framework Group)	
	Dryland grazing LUT (F)	Dryland sorghum LUT (F)
K factor 0.04-0.06 and slope 3-5%	4	4
K factor 0.04-0.06 and slope 5-8%	4	4
K factor 0.04-0.06 and slope 8-12%	5	5
K factor 0.04-0.06 and slope 12-15%	5	5
K factor 0.04-0.06 and slope 15-20%	5	5
K factor 0.04-0.06 and slope > 20%	5	5
Very unstable soils		
K factor > 0.06 and slope < 0.5%	2	2
K factor > 0.06 and slope 0.5-1.0%	3	3
K factor > 0.06 and slope 1-2%	3	3
K factor > 0.06 and slope 2-3%	3	3
K factor > 0.06 and slope 3-5%	4	4
K factor > 0.06 and slope 5-8%	5	5
K factor > 0.06 and slope 8-12%	5	5
K factor > 0.06 and slope 12-15%	5	5
K factor > 0.06 and slope 15-20%	5	5
K factor > 0.06 and slope > 20%	5	5

B1.11. Wetness (W)

The wetness limitation is an assessment of site drainage; determined by considering both internal (soil profile permeability) and external (landscape) factors (Table 49).

Soil permeability is the potential of the soil to transmit water internally. It is controlled by the saturated hydraulic conductivity of the least permeable layer in the soil. This can be inferred from soil attributes such as structure, the presence of hardpans, colour, texture and cracking. The supply and removal of water from the site is a function of slope, topographic position and depth to the water table.

Subclasses are established by relating site drainage attribute levels to yield reduction caused by poor aeration. Forage grass species can develop flood tolerant roots, hence, better adapted to unfavourable drainage or permeability conditions (Baruch and Merida 1995).

The criteria outlined for rainfed crops (Group C) were applied to determine the suitability subclass of wetness for dryland grazing pasture.

Table 49 Wetness limitation description and suitability subclass

Description	Suitability subclasses applied for LUTs (Framework Group)	
	Dryland grazing LUT (C)	**Dryland sorghum LUT (B)**
Rapidly drained – Drainage class 6	1	1
Well drained – Drainage class 5, permeability class 4	1	1
Well drained – Drainage class 5, permeability class 3	1	1
Well drained – Drainage class 5, permeability class 2	1	1
Well drained – Drainage class 5, permeability class 1	2	2
Moderately well-drained – Drainage class 4, permeability class 4	1	1
Moderately well-drained – Drainage class 4, permeability class 3	2	1
Moderately well-drained – Drainage class 4, permeability class 2	3	2
Moderately well-drained – Drainage class 4, permeability class 1	3	3
Imperfectly drained – Drainage class 3, permeability class 4	3	2
Imperfectly drained – Drainage class 3, permeability class 3	3	3
Imperfectly drained – Drainage class 3, permeability class 2	4	4
Imperfectly drained – Drainage class 3, permeability class 1	4	4
Poorly drained – Drainage class 2, permeability class 3 or 4	5	4
Poorly drained – Drainage class 2, permeability class 1 or 2	5	5
Very poorly drained – Drainage class 1	5	5

B1.12. Rockiness (R)

Rockiness refers to rock outcrop and coarse fragments at the soil surface. Subclasses for pastures are based on the decreased productivity associated with large amounts of surface stones and rock outcrop and possibly the potential impacts on mustering and other operations.

Table 50 Rockiness limitation and suitability subclass

Description	Suitability subclass for both LUTs
Not rocky or significantly rocky	1
Rocky	4

B1.13. Gilgai microrelief (Tm)

This limitation includes the overall slope of the land surface as well as an uneven land surface due to microrelief. Suitability subclasses are based on the amount of earthworks required to level the land or create a required slope to an extent sufficient for pasture growth.

Table 51 Microrelief limitation description and suitability subclass

Description	Suitability subclass for both LUTs
No gilgai or vertical interval <0.3 m	1
Vertical interval >0.3 m	4

Appendix C. Sampling specifications and planning

The specification of the cartographic scale is important in land resource mapping as it guides the publication scale, and in turn guides the intensity and type of information collected (Schoknecht et al. 2008).

For the Study Area, a cartographic scale of 1:50,000 falls within a medium survey intensity. Table 52 presents examples of recommended uses of information collected from a medium intensity survey.

Table 52 Examples of recommended uses for medium intensity survey (Schoknecht et al. 2008)

Cartographic scale, survey intensity and approximate resolution	Examples of recommended uses
1: 25,000 – 1: 100,000 Medium intensity 6 – 100 ha	• General suitability for various forms of land use • Planning for low intensity land uses such as dry land agriculture • Strategic planning for more intensive land uses such as urban and horticulture • Shire planning for the development of rural land in shires experiencing moderate land use pressure (i.e. shires with larger rural towns that are experiencing some development pressure or have major development opportunities) • Regional planning in areas with high development pressure • Management for medium catchments • General planning of forests

The scale and purpose of the survey determines the sampling scheme and determines the minimum type and density of sampling for qualitative surveys. The recommended percentages of ground observation classes for general purpose surveys are described in Schoknecht et al. (2008), presented in Table 53.

Table 53 Recommended percentages of ground observation classes for general purpose surveys (Schoknecht et al. 2008)

Survey intensity and cartographic scale	Observation class			
	I Detailed profile descriptions	II Deep borings	III Profiles for sampling	IV Mapping observations
Very high intensity (> 1:10,000)	10 – 30%	1 – 5%	1 – 5%	60 – 88%
High intensity (1:10,000 to 1:50,000)	10 – 30%	1 – 5%	1 – 5%	60 – 88%
Medium intensity (1:25,000 to 1:100,000)	15 – 35%	1 – 5%	1 – 5%	55 – 83%
Low intensity (1:100,000 to 1:250,000)	15 – 40%	1 – 5%	1 – 5%	50 – 83%
Reconnaissance/overview (> 1:250,000)	30 – 90%	1 – 5%	1 – 5%	< 60%

Appendix D. Laboratory results

See attached

Appendix E. Soil profile field sheets

See attached

Appendix F. Mapping observation field sheets

See attached

VO	Date	Site ID	Vegetation	Soil description/unit	Notes
1	6/5/2022	VP2	Cattlebush, Tussock grass	Sandy, yellowish red, loose, soft	
2	7/05/2022	VP4	Tussock grassland	Sandy, red	Cracking, hardsetting
3	7/05/2022	VP8	*Corymbia* woodland, tussock grass	Sandy, pale grey, soft	
4	7/05/2022	VP4	Tussock grassland	Sandy, grey	Cracking, hardsetting, melonholes
5	7/05/2022	VP4	Tussock grassland	Sandy, grey	Cracking, hardsetting, melonholes
6	7/05/2022	VP7	*Corymbia* woodland, tussock grassland	Sandy, reddish grey	
7	7/05/2022	VP7	*Corymbia* woodland, tussock grass	Sandy, red	
8	7/05/2022	VP8	*Corymbia* woodland, tussock grass	Sandy, red	
9	7/05/2022	VP8	*Corymbia* woodland, tussock grass	Sandy, red	Hardsetting

VO	Date	Site ID	Vegetation	Soil description/unit	Notes
10	7/05/2022	VP8	Corymbia woodland, tussock grass	Sandy, red	Hardsetting
11	7/05/2022	VP12	Tussock grassland	Sandy, grey	Melonhole, cracking
12	7/05/2022	VP12	Tussock grassland	Sandy, grey	Melonhole, cracking
13	7/05/2022	VP9	Corymbia woodland, tussock grass	Sandy, red	
14	7/05/2022	VP12	Tussock grassland	Sandy, grey	Melonhole, cracking
15	7/05/2022	VP12	Tussock grassland	Sandy, grey	Melonhole, cracking
16	7/05/2022	VP12	Tussock grassland	Sandy, grey	Melonhole, cracking
17	7/05/2022	VP12	Tussock grassland	Sandy, grey	Melonhole, cracking
18	8/05/2022	VP14	Cattlebush, tussock grass	Sandy, red	

VO	Date	Site ID	Vegetation	Soil description/unit	Notes
19	8/05/2022	VP15	Tussock grassland	Sandy, grey	Melonhole, cracking
20	8/05/2022	VP15	Tussock grassland	Sandy, reddish grey	Melonhole, cracking
21	8/05/2022	VP15	Tussock grassland	Sandy, reddish grey	
22	8/05/2022	VP12	Tussock grassland	Sandy, grey	
23	8/05/2022	VP12	Tussock grassland	Sandy, grey	
24	8/05/2022	VP9	Corymbia woodland, tussock grass	Sandy, red	
25	8/05/2022	VP12	Tussock grassland	Sandy, grey	
26	8/05/2022	VP9	Corymbia woodland, tussock grass	Sandy, red	Melonholes, ant hills
27	8/05/2022	VP10	Tussock grassland	Sandy, grey	Denser grassland to northeast

VO	Date	Site ID	Vegetation	Soil description/unit	Notes
28	8/05/2022	VP10	Tussock grassland	Sandy, grey	Melonhole, cracking
29	8/05/2022	VP10	Tussock grassland	Sandy, grey	Melonhole, cracking
30	3/08/2022	VP7	*Corymbia* woodland, tussock grass	Sandy, dark red	Cracking, hardsetting
31	3/08/2022	VP7	*Corymbia* woodland, tussock grass	Sandy, red	No cracking, hardsetting
32	3/08/2022	VP4	Tussock grassland	Sandy, Reddish grey	Slight cracking, hardsetting
33	3/08/2022	VP4	Tussock grassland	Sandy, Reddish grey	Slight cracking, hardsetting
34	3/08/2022	VP12	Tussock grassland	Sandy, Reddish grey	Slight cracking, hardsetting
35	3/08/2022	VP12	Tussock grassland	Sandy, Dark grey	Melonhole, cracking
36	3/08/2022	VP13	Cattlebush, tussock grassland	Sandy, red	Flat, no gilgai

VO	Date	Site ID	Vegetation	Soil description/unit	Notes
37	3/08/2022	VP9	Corymbia woodland, tussock grass	Sandy, reddish brown	Less cracking, hardsetting
38	3/08/2022	VP10	Tussock grassland	Sandy, dark brown	Cracking, slight give
39	3/08/2022	VP10	Tussock grassland	Sandy, reddish dark brown	

Appendix G. Soil Erodibility Factor (K factor) calculations

Soil erodibility factor (*K*) is a measure of the susceptibility of the soil to erosion. For this Project, the calculation of the K-factor was done using the following pedotransfer function elaborated for Australian soils (Lu *et al.* 2001):

$$K = 2.77\ (100\ P_{125})^{1.14}\ (10^{-7})\ (12 - 2\ O_c) + 3.29\ (10^{-3})(Pr - 3)$$

Where:

P_{125} = *Percentage of particles with diameter less than 0.125mm*

O_c = *Percentage of organic carbon*

Pr = Soil permeability rating

The P_{125} and Oc values where directly obtained from the laboratory results. The soil permeability rating was estimated from the SMUs and according to the following scale (Rosewell 1993):

6 = very slow (<1 mm per hour)

5 = slow (1 to 5 mm per hour)

4 = slow to moderate (5 to 20 mm per hour)

3 = moderate (20 to 60 mm per hour)

2 = moderate to rapid (60 to 130 mm per hour)

1 = rapid (> 130 mm per hour)

Typically, Queensland soil K factors range between <0.01 (very low) to >0.06 (very high). The following table provides typical *K* factors for different soil groups in Queensland.

Table 54 Soil erodibility classes (Hazelton & Murphy 2016)

Rating	*K* value	Expected soil erodibility of soil groups
Very low	0.00 - 0.01	Red Chromosol
Low	0.01 - 0.02	Dermosol
Moderate	0.02 - 0.04	Red Chromosol, Red Ferrosol, Red Dermosol
High	0.04 - 0.06	Vertosols, Dermosols, Red Chromosol
Very High	> 0.06	Exposed sodic soils

The outcomes of the soil analysis for identified SMUs are shown in Table A2. Results show that soils from the Mitchell SMU are moderately to highly erodible as a consequence of low organic matter content and moderate permeability rating. Both Soapberry and Gum SMU have low erodibility with higher organic matter content and high permeability soils.

Table 55 K values for identified SMUs within the Study Area

SMU	Sample	P_{125} (%)	O_c (%)	Permeability Rating	*K* value
Mitchell	VP10 0 – 10	49.68	0.7	4	0.051
	VP12 0 – 10	43.84	0.7	4	0.045
Soapberry	VP2 0 – 10	13.02	0.9	1	0.003
	VP14 0 – 10	23.58	0.5	1	0.015
Gum	VP7 0 – 10	29.51	1.4	1	0.016
	VP9 0 – 10	20.71	0.9	1	0.010