VULCAN SOUTH

SOIL AND LAND SUITABILITY ASSESSMENT

PREPARED FOR

METSERVE PTY LTD

SEPTEMBER 2023

aarc
ENVIRONMENTAL SOLUTIONS

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List of Abbreviations

AARC	AARC Environmental Solutions Pty Ltd
Ca/Mg	Calcium/Magnesium Ratio
CEC	Cation Exchange Capacity
EC	Electrical Conductivity
ESP	Exchangeable Sodium Percentage
MLA	Mining Lease Application
NATA	National Association of Testing Authorities
PAWC	Plant Available Water Capacity
ROM	Run-of-mine
SCL	Strategic Cropping Land
SLSA	Soil and Land Suitability Assessment
SMU	Soil Management Unit
VCM	Vulcan Coal Mine
VCP	Vulcan Complex Project
VS	Vulcan South

1 Introduction

AARC Environmental Solutions Pty Ltd (AARC) was commissioned by Mining and Energy Technical Services Pty Ltd (METServe), on behalf of Vitrinite Pty. Ltd., owner of Qld Coal Aust No.1 Pty. Ltd. and Queensland Coking Coal Pty. Ltd. (Vitrinite), to conduct a Soil and Land Suitability Assessment (SLSA) for Vulcan South (VS, the Project). The Project is located north of Dysart and approximately 45 km south of Moranbah in Queensland's Bowen Basin (Figure 1). The Project is located immediately to the south of Vitrinite's initial mining project, the Vulcan Coal Mine (VCM) as well as to the west of several established mining operations including BHPs Peak Downs and Saraji mines. The closest major town to the site is Emerald, approximately 125 km south of the Project site.

As part of early Project planning and feasibility assessment, the proponent nominated a considerably larger area (the study area). The baseline data collected within this larger study area has been used in the assessment of the Project, and for context, as required.

This SLSA documents the nature and distribution of major soil types in the study area and assesses their suitability for the land uses of both cattle grazing and dryland cropping. This assessment establishes baseline environmental characteristics and values relating to land use and suitability and provides recommendations for the management of soil resources within the Project areas.

1.1 Objectives

The objectives of the SLSA are to:

- Describe the agricultural use(s) of the Project site and the surrounding area.
- Describe, map and illustrate soil types and profiles 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 2002).
- Identify soils that would require specialised management due to wetness, erosivity, depth, acidity, salinity or other features.
- Identify soils from representative samples down the soil profile, based on their physical and chemical properties that are likely to, or have potential to be subject to erosion from storm water runoff. Similarly, soils proposed to be used for rehabilitation, and particularly where agriculture is the final land use, will be assessed for their suitability for this use.
- Describe and map land suitability classes of the study area in accordance with the *Guidelines for Agricultural Land Evaluation in Queensland—2nd Edition* (DSITI and DNRM 2015), and the *Technical Guidelines for the Environmental Management of Exploration and Mining in Queensland—Land Suitability Assessment Techniques* (DME 1995).
- Assess the potential impacts of the Project on the soil and land use values of the area and provide recommended mitigation measures to minimise negative impacts.
- Include the findings in a stand-alone report suitable for inclusion in an environmental impact statement.

2 Project Background

The Project is located immediately to the south of Vitrinite's initial mining project, VCM. The Project is situated in the Bowen Basin, central Queensland, approximately 30 km north of the township of Dysart, 125 km north of Emerald, and 270 km north-west of Rockhampton (Figure 1).

The Project will operate for approximately nine years and will extract approximately 13.5 Mt of ROM coal consisting predominantly of hard coking coal (with an incidental thermal secondary product) at a rate of up to 1.95 Mtpa. The VS is defined and selected for open cut development via three (3) separate open cut pits that form the primary mining focus of the study area.

Truck and shovel mining operations will be employed to develop the pit. A mine infrastructure area (MIA) will be established along with a modular coal handling and preparation plant (CHPP), rail loop and train load-out facility (TLO) at a location between the northern and central pits. The CHPP will include tailings dewatering technologies to maximise water recycling and to produce a dry tailings waste product for permanent storage within active waste rock dumps. No wet tailings wastes are proposed and therefore no tailings dams are required.

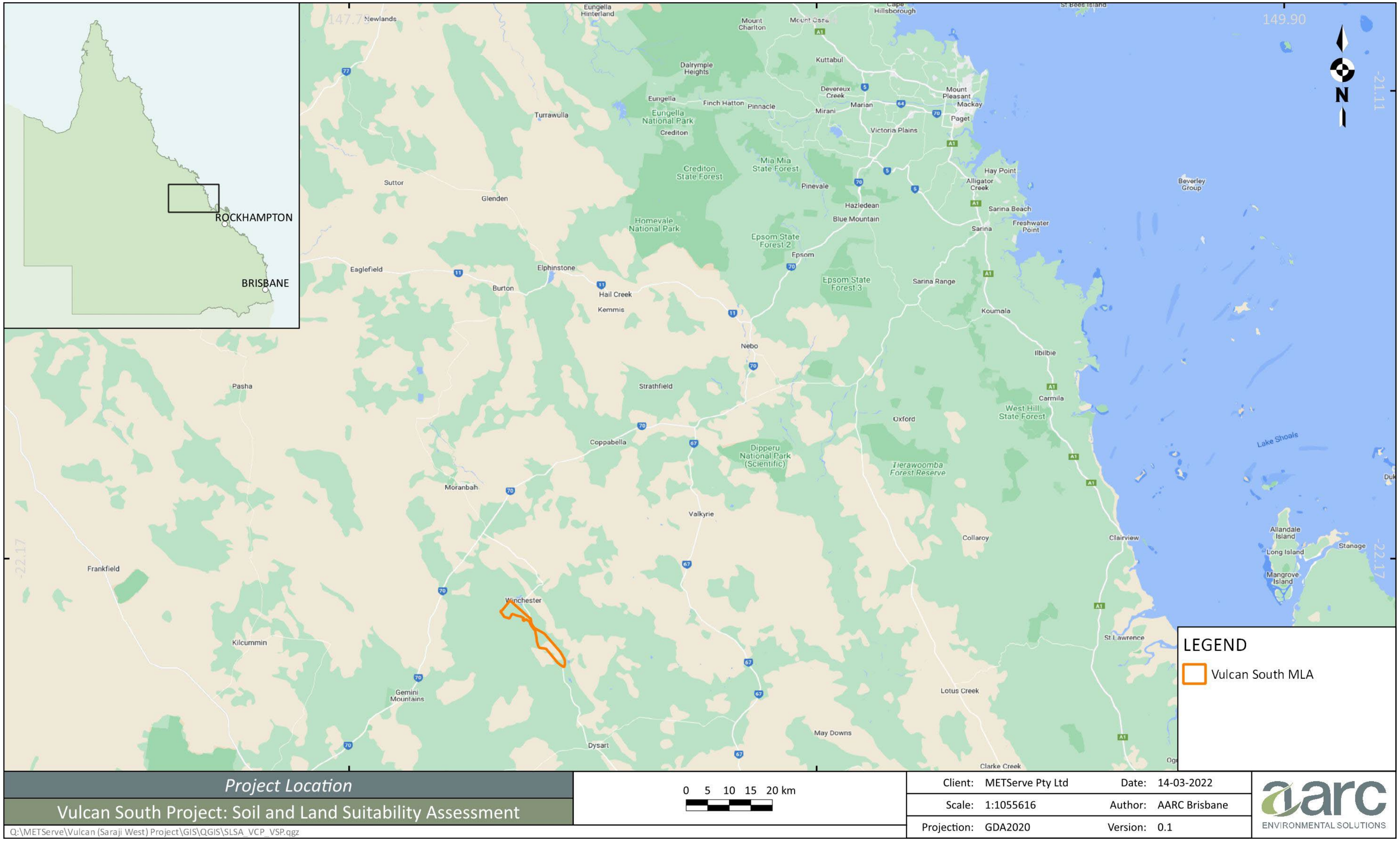


Figure 1: Project location

2.1 Local topography and landform

The Project lies within the Fitzroy River Basin. This basin encompasses an area of 142,545 km^2, and contains the Comet, Dawson, Fitzroy, Isaac, Mackenzie and Nogoa Rivers, which make up six sub-catchment areas (Department of Environment and Science 2019).

The Project exists within the Isaac River sub-catchment, which is situated in the northern region of the Fitzroy River Basin and has a total area of 22,364 km^2. The major water bodies associated with the site are the Boomerang and Hughes Creeks. Boomerang Creek dissects the study area in a north-easterly direction and flows just to the south of the Project area. Hughes Creek flows in an easterly direction across the southern region of the study area. Both creeks form within approximately 10 km beyond the western boundary of the study area, flowing east to north-east. Boomerang Creek joins Hughes Creek near the south-eastern boundary of the study area before its confluence with the Isaac River and finally the Fitzroy River; eventually flowing to the Pacific Ocean approximately 46 km north of Gladstone.

The topography within the study area varies from hilly, rocky terrain to the north to flat plains and undulating hills to the south, with elevation ranging between 200 m to 400 m above sea level. Vegetation in the region includes grassy plains, riparian vegetation and woodlands.

2.2 Regional geology

The geology of the area is influenced by its position within the Bowen Basin, one of Queensland's largest depositional zones, forming through a period of rifting and subsidence lasting from the Early Permian to the Mid-Triassic. The area surrounding the Project is dominated by clastic sedimentary rocks of marine and lacustrine origin, including sandstones, mudstones, siltstones and coal (Geoscience Australia 2019).

The coal seams found in the east-central part of the Bowen Basin are of Permian age and contain higher quality coking coal deposits, with the rank falling below the coking range farther south and west (Hutton 2009, Mutton 2003).

The solid geology of the region is described as including:

- Moranbah Coal Measures—Permian comprising of coal and interseam material composed of sandstone, shale, siltstone with minor clay stone; and
- Back Creek Group—Early to Late Permian comprising of quartzose to lithic sandstone, conglomerate, siltstone, carbonaceous shale and coal.

While surface geology includes the following:

- Qr–Qr–(QLD) (Qr) – Quaternary clay, silt, sand, gravel and soil with colluvial and residual deposits; and
- TQa–QLD (TQa)—Late Tertiary to Quaternary poorly consolidated sand, silt, clay, minor gravel and high-level alluvial deposits.

2.3 Regional climate

The regional climate is classified as semi-arid, with characteristic hot summers and mild to warm winters. Climate statistics have been sourced from the Bureau of Meteorology for the Clermont Post Office, located approximately 77 km south-west of the Project. The data indicates average rainfall for the region to be approximately 665 mm with a characteristic wet season between November and March. Long term temperature statistics demonstrate that the average maximum daily temperature in summer is 34^{o}C with overnight minimum temperatures averaging at 21^{o}C. In winter, the average maximum temperature is 24^{o}C with an average minimum temperature of 8^{o}C (Bureau of Meterology 2019).

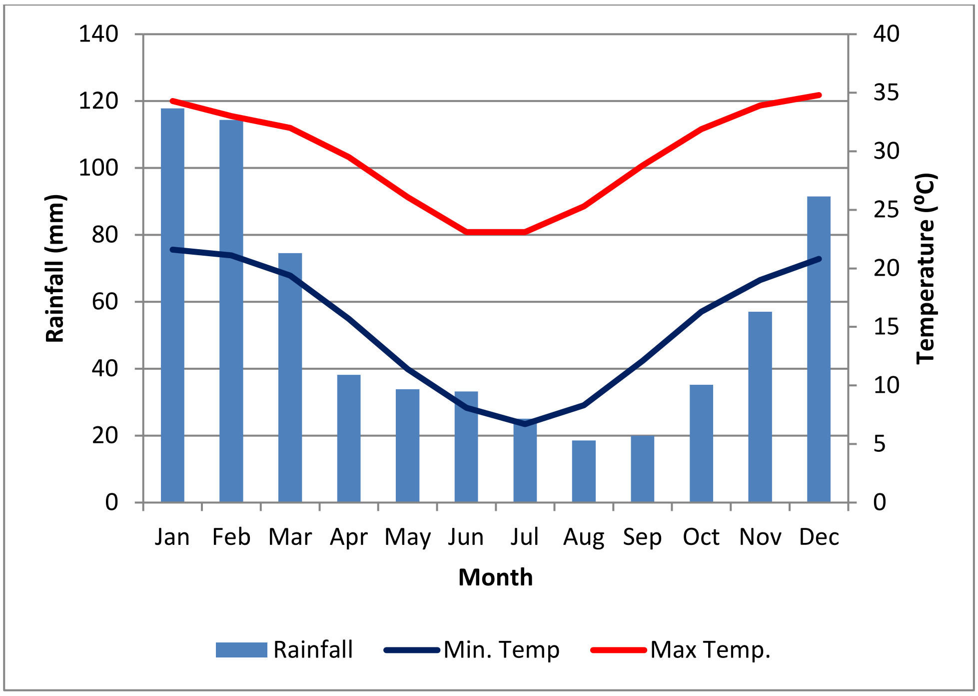


Figure 2: Climate statistics (Clermont Post Office)

2.4 Current land use

The land within the Project boundary is currently used for low intensity cattle grazing, and small commercial operations with few significant disturbances apart from small farm dams and dirt tracks.

2.5 Strategic cropping land

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

The Department of Natural Resources, Mines and Energy makes and certifies the SCL trigger map. None of the lands within the study area are included within the SCL trigger map.

2.6 Land systems

The Report on Lands of The Isaac-Comet Area (Story *et al.* 1967) mapped at a scale of 1:500,000 indicates the study area contains the land system units described in the following sections.

2.6.1 Carborough land system

The Carborough Land System is characterised by mountains and hills with broken and dissected local relief ranging between 30 m to 400 m. Structural benches and cliffs are common landforms with severe weathering occurring in some areas. This mountainous land system has formed shallow coarse-textured rocky soils with species such as bloodwood (*Corymbia erythrophloia*), lancewood (*Acacia shirleyi*) and narrow-leaved ironbark (*Eucalyptus crebra*) populating the area. A small area of the Carborough Land System is also characterised by lower slopes and hills and alluvial flats with a local relief between 10 m to 60 m. Texture-contrast soils have formed in these areas and possess a thick sandy topsoil. Savannah woodland dominated by narrow-leaved iron bark (*Eucalyptus crebra*) is established in this area.

Geology in this land system is comprised of partly weathered quartz sandstone.

2.6.2 Connors land system

The Connors Land System is characterised by alluvial plains composed of terraces and levees up to 3 km wide. Texture-contrast soils have developed in this area and are characterised by a thick sandy topsoil and neutral to strongly alkaline subsoil. Vegetation consists of savannah woodlands dominated by Poplar box (*Eucalyptus populnea*) and mixed shrub woodland.

2.6.3 Cotherstone land system

The Cotherstone Land System is characterised by hills and prominent strike ridges as well as gentler undulating terrain associated with low indefinite strike ridges and colluvial foot slopes. The more prominent strike ridges possess a local relief varying between 10 m to 30 m and have developed shallow course-textured to rocky soils that support savannah woodland consisting mostly of narrow-leaved iron bark (*Eucalyptus crebra*) and lancewood (*Acacia shirleyi*). The gentler undulating terrain has a local relief of less than 15 m and is associated with texture-contrast soils with a sandy upper-horizon. Depending on the steepness of terrain either narrow-leaved iron bark dominated savannah woodland (slopes of <10%) or mixed shrub woodland (slopes of <5%) have been established.

The geology in this land system is weathered Permian sandstone and shale.

2.6.4 Monteagle land system

The Monteagle Land System is predominantly characterised by low-lying plains and colluvial foot slopes with local relief generally below 6 m. This land system is associated with texture-contrast soils composed of a thick sandy topsoil and neutral to strongly alkaline subsoils. Savannah woodlands consisting largely of Poplar box (*Eucalyptus populnea*) and some narrow-leaved iron bark (*Eucalyptus crebra*) dominate the area.

Geology in this land system is comprised of undissected Tertiary sandstones and clays.

3 Soil Survey Methodology

3.1 Desktop analysis

A desktop analysis was conducted prior to field sampling. This analysis was comprised of 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 good foundation for understanding the soils that may be present in the study area region.
- 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.
- *Reference information for land systems: Land Systems of the Isaac-Comet Area, Queensland* (Story *et al.* 1967).
- Reference Information for regional geology: *Geology of the Bowen Basin, Queensland* (Dickins and Malone 1973).
- Reference information for land management: *Understanding and Managing Soils in the Central Highlands* (Bourne and Tuck 1993).

3.2 Survey design

Methodologies employed throughout this study followed procedures detailed in the *Australian Soil and Land Survey Field Handbook* (National Committee on Soil and Terrain 2009) and the *Guidelines for Surveying Soil and Land Resources* (McKenzie *et al.* 2008). The soil survey was based on a free-survey technique with soil profile and observation sites located to best represent all soil types present in the study area.

As part of the Project planning and feasibility assessment, the proponent commissioned environmental assessments of a considerably larger study area than the proposed MLA Project area. As a result, the SLSA study area surveyed comprises a significantly larger area of 10,150 ha which incorporates the Project area as well as lands lying predominantly to the west and south of the Project area.

Mapping scales for the study area were selected in order to satisfy the requirements of an environmental impact statement taking into consideration available resources, land access and soil complexity. For the study area, a scale between 1:25,000 to 1:100,000 was deemed most appropriate. This scale was selected based on information contained within the *Guidelines for Surveying Soil and Land Resources* (McKenzie *et al.* 2008). The final mapping scale of 1:85,000 for the study area fell within the specified range.

To achieve a mapping scale of 1:25,000 to 1:100,000, McKenzie *et al.* (2008) suggest a minimum recommended sampling density of one site per 25 ha with data collection comprising detailed soil profile descriptions (15-35% of sites), representative profile sampling for lab analysis (1-5%) and mapping observations sites (55-83%).

The number of sites surveyed for the SLSA (refer Table 1) exceeded these minimum requirements.

Table 1: Survey site numbers for SLSA 2019

Survey site	Scale	Detailed soil profiles	Representative profiles for analysis	Mapping observations	Total
Study Area (10,150 ha)	1:100,000	42	12	66	121

3.3 Field Investigations

AARC undertook field sampling at the Project from 19 to 26 July 2019, consisting of both primary sampling sites (profiles) and secondary visual assessments (observations).

Sampling site locations were determined based on the desktop analysis, land management units, landform 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 profiles were undertaken at 42 sites within the Project boundaries. A jackhammer-operated soil corer was used to excavate cores to a maximum depth of 120 cm. Soil samples were collected from profiles at standard depths of 0–10 cm, 20–30 cm, 50–60 cm, 80–90 cm and 110–120 cm where possible. Samples were sealed in clean, plastic zip-lock bags and labelled with the site number, date, depth of sampling and the initials of the sampler.

Parameters recorded included micro relief, permeability, drainage, substrate, site disturbance, landform (slope percentage, relief, elevation, morphological type, landform element and landform pattern), runoff, erosion, surface coarse fragments, rock outcrops, surface condition and dominant vegetation type. Soil profile morphology was described in the field in terms of horizon type, horizon depth, boundary, colour, mottles, texture, coarse fragments, structure, segregations, consistency and field pH.

3.4 Laboratory analysis

Samples from a total of 12 representative 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 characteristics;
- assist in the determination of land suitability classes;
- assist in the determination of topsoil and subsoil as a suitable topdressing media; and
- assist in the identification of soils that would require specialised management.

Physical and chemical parameters analysed for all samples included:

- 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 included:

- organic matter (%);
- Particle Size Analysis (PSA);
- extractable trace elements/metals (Fe, Cu, Zn, Mn);
- boron ($CaCl_2$ extractable);
- N as nitrate;
- SO_4 (water soluble S as sulphate);

- phosphorus and potassium (Colwell); and
- Emerson Class.

3.5 Characterisation of soil management units

Soil classification was undertaken using the methodologies specified in *The Australian Soil Classification* (Isbell 1996). 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 in terms of its soil profile class 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 cattle grazing and broadacre cropping. SMUs were mapped at a scale of 1:85,000 across the study area.

3.6 Interpretation of 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); and
- *Standard Soil Test Methods and Guidelines for Interpretation of Soil Results* (Government of South Australia 2013).

Broad descriptions for each soil parameter have been provided below and where applicable, a summary of the rating system used.

3.6.1 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. The soil pH ratings used are shown in Table 2. In general, a suitable soil pH ranges from 5.5 to 9.0 as at this pH all essential nutrients are available to some degree.

Table 2: Electrical conductivity ratings after interpreting soil test results (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	Moderately acid	Range most suitable for plant growth
6.0 to < 7.0	Slightly acid	
7.0	Neutral	
> 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

3.6.2 Electrical conductivity

EC provides an indication of the presence of soluble salts in the soil profile. High levels of soluble salts can interfere with the osmotic capacity of plants. This compromises the plant's ability 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 3 provides soil salinity ratings sourced from Rayment and Lyons (2011).

Table 3: Soil salinity ratings (based on EC values in dS/m)

Soil salinity rating	10– 20% clay	20– 40% clay
Very low	< 0.07	< 0.09
Low	0.07–0.15	0.09–0.19
Medium	0.15–0.34	0.19–0.45
High	0.34–0.63	0.45–0.76
Very high	0.63–0.93	0.75–1.21
Extreme	> 0.93	> 1.21

3.6.3 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 4 provides chloride ratings (Rayment and Bruce 1984).

Table 4: Chloride concentration ratings

Chloride rating	Concentration (mg/kg)
Very low	< 100
Low	100–300
Medium	300–600
High	600–2,000
Very high	> 2,000

3.6.4 Cation exchange capacity and exchangeable cations

CEC is an indication of the soil's capacity 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 5 and Table 6 provide ratings for soil CEC and extractable cations sourced from the guide *Interpreting Soil Test Results* (2016).

Table 5: Soil CEC ratings

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

Table 6: Ratings for extractable cations (cmol(+)/kg)

Cation	Very low	Low	Moderate	High	Very high	Ideal range (% of CEC)
Ca	0–2	2–5	5–10	10–20	> 20	65–80
K	0–0.2	0.2–0.3	0.3–0.7	0.7–2	> 2	1–5
Mg	0–0.3	0.3–1	1–3	3–8	> 8	10–15
Na	0–0.1	0.1–0.3	0.3–0.7	0.7–2	> 2	< 1

3.6.5 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 7 provides ESP ratings sourced from the guide *Interpreting Soil Test Results* (2016).

Table 7: Soil ESP ratings

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

3.6.6 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 8 provides soil organic matter ratings sourced from the guide *Interpreting Soil Test Results* (2016).

Table 8: Soil organic matter ratings

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

3.6.7 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.

3.6.8 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 9 provides trace element/metal ratings sourced from the guide *Standard Soil Test Methods and Guidelines for Interpretation of Soil Results* (2013).

Table 9: Ideal concentration ranges for trace elements/metals

Trace element/metal	Rating	Concentration
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

3.6.9 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 10 provides soil nitrate ratings sourced from the guide *Interpreting Soil Test Results* (2016).

Table 10: Soil nitrate ratings

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

3.6.10 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 11 provides soil sulphate ratings sourced from Government of South Australia (2013).

Table 11: Soil sulphate ratings

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

3.6.11 Phosphorous and potassium

Both phosphorous and potassium are the next most essential nutrients after nitrogen and sulphate. Phosphorous 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 12 and Table 13 provide ratings for soil phosphorous and potassium levels sourced from the guide *Interpreting Soil Test Results* (2016).

Table 12: Soil phosphorous ratings

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

Table 13: Soil potassium ratings

Soil texture	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

3.6.12 Emerson class

Emerson class is a class assigned to soil that is determined on the stability of dry aggregates in water. The Emerson Class Number of a soil is assigned as an indication of the dispersion and slaking ability of a soil. Table 14 describes the Emerson Dispersion Class (Emerson 1967).

Table 14: Emerson class numbers

Emerson aggregate class	Level of dispersion
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

4 Soil Survey Results

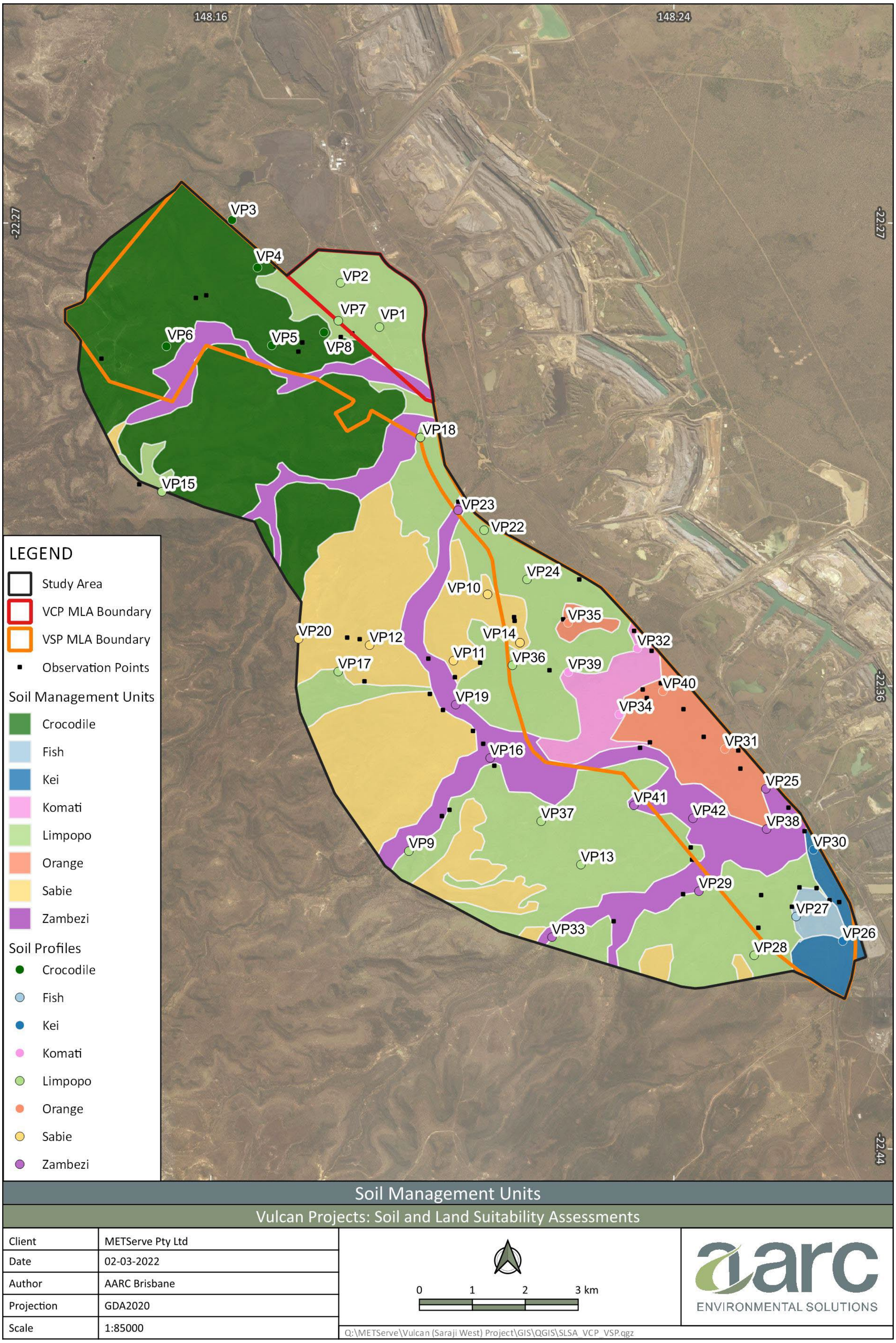
Eight SMUs have been described within the study area. Table 15 provides an overview of each SMU and its extent within the study area and Table 16 lists the SMUs present within the Project areas. The spatial distribution of the SMUs has been mapped at a scale of 1:85,000 and is illustrated in Figure 3. The coordinates for each sampling site have been provided in Appendix 4. Two small areas resulting from subsequent minor changes to the Project MLA boundary extended beyond the original study area boundary. Desktop assessment has determined that these areas constitute Kei SMU for the south adjustment area and Crocodile SMU for the northern adjustment area.

Table 15: Soil management units—Study Area

SMU	Surface area (ha)	Per cent of study area (%)
Crocodile	2,526	24.9
Fish	76	0.7
Kei	183	1.8
Komati	262	2.6
Limpopo	3,316	32.6
Orange	471	4.6
Sabie	1,865	18.4
Zambezi	1,451	14.4
Total Area	10,150	100

Table 16: Soil management units— VSP MLA Boundary

SMU	Surface area (ha)	Per cent of Project area (%)
Crocodile	1,195	31.3
Fish	76	2.0
Kei	174	4.6
Komati	262	6.9
Limpopo	1,015	26.6
Orange	472	12.4
Sabie	47	1.2
Zambezi	577	15.0
Total Area	3,818	100



Client	METServe Pty Ltd
Date	02-03-2022
Author	AARC Brisbane
Projection	GDA2020
Scale	1:85000

Figure 3: Distribution of soil management units (1:85,000)

4.1 Crocodile soil management unit

4.1.1 Soil unit description

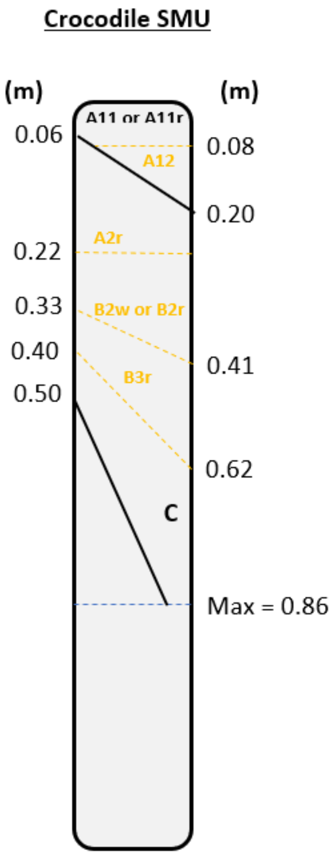
A shallow rocky soil unit associated with hill slopes and plateaus. Soil textures grade from loam at the surface, to loamy sands with depth; often containing rock material with little to no pedologic development throughout the solum. Vegetation associated with this unit includes *Eucalyptus crebra* and Bloodwood *Corymbia erythrophloia*.

Figure 4: Crocodile SMU vegetation

Table 17: Key Crocodile SMU parameters

Parameter	Soil unit description
Profile Site Numbers	VP3, VP4, VP5, VP6, VP8
Observation Site Numbers	OP1, OP3, OP6, OP8, OP10, OP14, OP15, OP16
Landform	Rises and Plateaus
Australian Soil Classification	Arenic Rudosol
Land System	Carborough Land System
Slope	1 to 10%
Geology	Back Creek Group
Vegetation	Narrow-leaved ironbark (Eucalyptus crebra), Bloodwood (Corymbia erythrophloia)
Runoff	Moderate
Permeability	Slow to moderately permeable
Drainage	Moderate to rapidly drained

Profile description—representative sites VP5 and VP8



The **surface soil** (A11/A11r/A12) is a black to very dark greyish brown (10YR2/1, 10YR3/2) sand to sandy loam with loose to weak polyhedral structure with some profiles containing moderately strong to strong sub-angular rock material. The soil unit has a field pH of 4.5–5.5, demonstrating an abrupt to clear change to;

The **lower surface soil** (A2r) is not a common horizon observed for this SMU. It is a dark brown (10YR3/3) loamy sand with an abundance (comprising 50–90% of this horizon) of moderately strong coarse fragments approximately 2–6 cm in diameter. It has loose structure and a field pH of 5.5 to 5.0. Gradual change to;

The **subsoil** (B2w/B2r) is a dark greyish to reddish brown (10YR3/2, 2.5YR2.5/4) loamy sand to clay loam with weak to moderate polyhedral structure. It can contain rounded to angular course fragments which make up < 10% of the horizon. This horizon has a field pH of 4.5 to 5.5, with a gradual change to;

The **lower profile** (C) contains either consolidated or unconsolidated partly weathered rock material that appear to have originated from underlying sandstone and siltstone with some profiles possessing an overlying transitionary horizon (B3r). Depending on the rock material present, this horizon can range from dark red to light yellow-brown colour.

Chemical and physical analysis

Table 18: Chemical properties of the Crocodile SMU

Representative site: VP5								
Depth	**pH**		**EC**		**Cl**	**ESP%**		**Moisture**
(m)	#	Rating	dS/m	Rating	(mg/kg)	%	Rating	(%)
0–0.1	5.4	Strongly Acid	0.014	Low	< 10	1.5	Non-sodic	2.9
0.2–0.3	5.4	Strongly Acid	0.007	Very low	< 10	1.3	Non-sodic	2.6
0.5–0.6	5.6	Moderately Acid	0.006	Very low	< 10	1.5	Non-sodic	1.9
Depth	**CEC**		**Exchangeable cations (meq/100g)**					**Emerson class no.**
(m)	**meq/ 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg ratio**	
0–0.1	7.3	Low	3.1	1.5	0.8	0.1	2.1	8
0.2–0.3	3.1	Very Low	0.1	1	0.2	< 0.1	< 0.1	7
0.5–0.6	2.4	Very Low	< 0.1	1	0.1	< 0.1	< 0.1	7
Nutrient Distribution in Topsoil (%)			42.5%	20.6%	10.9%	1.4%		

The Crocodile SMU is strongly acidic throughout the solum with only a minor increase in pH at depth. In the upper part of the profile (to an approximate depth of 0.3 m), this has the potential to limit the availability of essential nutrients and increase the risk of aluminium toxicity. Throughout the profile, both EC and chloride concentration remain very low with EC ranging between 0.014 dS/m in the topsoil to 0.006 dS/m at depth and chloride concentration remaining below 10 mg/kg. This indicates this SMU is not affected by issues associated with salinity and toxic chloride concentrations (Rayment and Lyons 2011).

CEC levels for this SMU are considered low (7.3 meq/100g) and decrease to 2.4 meq/100g with depth. All extractable cations except sodium (Na) fall below suitable plant concentrations according to (Hazelton and Murphy 2016). These low CEC values can be attributed to the predominantly sandy texture of this SMU. The distribution of exchangeable cations within the topsoil indicates a misbalance between nutrients with the proportion of K on the exchange lower than ideal while all other cations are higher (Hazelton and Murphy 2016). However, this is not likely to have a negative effect on soil quality due to low ESP values and Emerson class numbers.

The calcium to magnesium ratio (Ca/Mg) indicates that, relative to Mg, soil Ca concentration is considered low to deficient. This is not expected to affect plant growth in the topsoil; however, Ca concentration decreases below 0.5 meq/100g in the subsoil which may have potential to impact growth. Although the Ca:Mg ratio in the subsoil indicates that it has the potential to enhance sodicity (Ca/Mg <1), ESP values fall below 4% thus the risk of dispersion is extremely low. This is supported by the Emerson Class Number.

Table 19: Surface Soil (0–10 cm) Properties of the Crocodile SMU

Particle size analysis %					**Soil particle density (g/cm3)**		**Organic matter (%)**	
Clay	**Silt**	**Sand**	**Gravel**					
8	10	52	30		1.88		3.5	
Extractable nutrients (mg/kg)				**Extractable metals (mg/kg)**				
Phosphorous	**Potassium**	**Sulphate**	**Nitrate**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
8	617	< 10	22	< 0.2	< 1	89.6	9.81	< 1

The topsoil is dominated by sand (52%) and gravel (30%) with 10% silt and 8% clay. This particle size distribution could limit the ability of the soil to hold and store plant available water. Organic matter content is considered as high providing a buffering capacity to pH changes, as well as imparting good structural stability and enhancing the capacity of the soil to retain nutrients and water. Regardless, the sandy composition of the surface horizon is a key limitation to the water holding capacity of a soil.

According to guidelines (Hazelton and Murphy 2016), extractable nutrients measured in the SMU, with the exception of potassium (617 mg/kg), indicate poor growing conditions with phosphorous (8 mg/kg), nitrate (2.2 mg/kg) and sulphate (<10 mg/kg) considered to be outside the ideal range for plant life. In terms of extractable metals, iron (Fe) and manganese (Mn) fall within an acceptable range for plant growth with copper (Cu) and zinc (Zn) considered below plant suitable levels (Government of South Australia 2013).

4.2 Fish management unit

4.2.1 Soil unit description

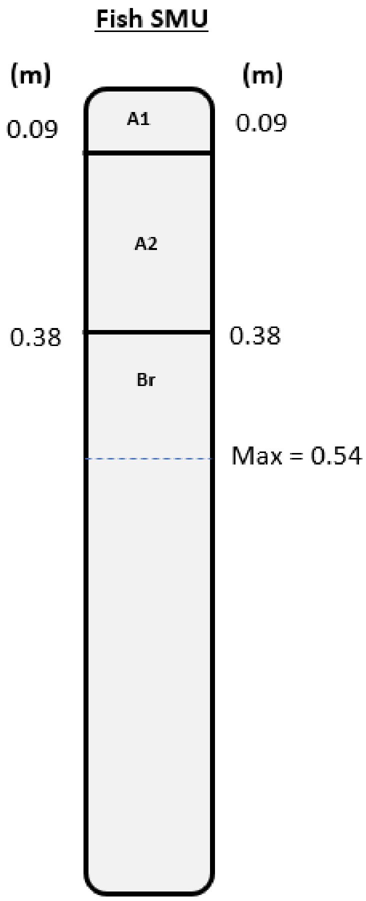
Predominantly sandy soil unit occurring on the flats of the south-eastern end of the study area. Soil textures grade from loamy sand at the surface, to clay and silty sands with depth. Vegetation associated with this unit includes largely *Acacia excelsa* and *Eucalyptus populnea*.

Figure 5: Fish SMU vegetation

Table 20: Key Fish SMU parameters

Parameter	Soil unit description
Profile Site Numbers	VP27
Observation Site Numbers	OP46, OP50, OP51, OP52
Landform	Plains
Australian Soil Classification	Grey Kurosol
Land System	Cotherstone Land System
Slope	0%
Geology	Back Creek Group
Vegetation	Rosewood (*Acacia excelsa*), Poplar Box (*Eucalyptus populnea*)
Runoff	Slow to moderate
Permeability	Moderately permeable
Drainage	Moderate to well drained

Profile description—representative sites VP27



The **surface soil** (A1) is a dark grey (10YR4/1) loamy sand with weak platy structure with the deeper horizons of the profile exhibiting diffuse red to orange mottling. It has a field pH of 5.5 to 6, demonstrating a clear change to;

The **lower surface soil** (A2) is a grey (10YR5/1) clayey loam sand. This horizon has a weak polyhedral structure and a field pH of 5.5. Abrupt change to;

The **subsoil** (Br) is a grey (10YR5/1) silty clay loam with moderate polyhedral structure. This horizon has minor occurrence of indistinct red and orange mottle with diameters of <1.5cm. This horizon has a field pH of 4.5 to 5.5.

Chemical and physical analysis

Table 21: Chemical properties of the Fish SMU

Representative site: VP27								
Depth		**pH**		**EC**	**Cl**		**ESP%**	**Moisture**
(m)	**#**	**Rating**	**dS/m**	**Rating**	**(mg/kg)**	**%**	**Rating**	**(%)**
0–0.1	5.5	Moderately Acid	0.046	Very low	40	5.2	Non-sodic	1
0.2–0.3	5.2	Strongly Acid	0.042	Very low	50	8.2	Sodic	4.3
0.5–0.6	5.3	Strongly Acid	0.059	Very low	110	8.9	Sodic	5.3
Depth		**CEC**					**Exchangeable cations (meq/100g)**	**Emerson Class No.**
(m)	**meq / 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg Ratio**	
0–0.1	2.5	Very Low	1.3	1	0.1	0.1	1.3	3
0.2–0.3	4.2	Very Low	0.6	2.4	< 0.1	0.3	0.2	3
0.5–0.6	4.9	Very Low	0.6	3.5	< 0.1	0.4	0.2	3
Nutrient distribution in topsoil (%)			52.0%	40.0%	4.0%	4.0%		

The pH of the Fish SMU is considered strongly acidic throughout the profile, becoming more severe with depth to the point of introducing a risk of aluminium toxicity (pH less than 5.5). All EC values are very low which indicate the soil will not be at risk to issues associated with salinity. Chloride values are also very low and are not expected to compromise the plant environment (Rayment and Lyons 2011).

The CEC of this soil indicates low availability of plant nutrients with all values considered below suitable levels according to guidelines (Hazelton and Murphy 2016). There is a slight increase in CEC with depth which is likely attributed to the slight increase in clay content in deeper horizons. Of the exchangeable cations, both potassium and calcium rate as very low with manganese and sodium content considered moderate in the topsoil but increasing to high levels at depth. Nutrient distribution in topsoil indicates magnesium occupies a large proportion of the exchange capacity of the soil, contributing to the low Ca/Mg ratio.

Soil ESP values increase to what is considered sodic with depth. The very low Ca/Mg ratio in conjunction with an Emerson Class Number of 3 indicate that the subsoil of this unit is at risk of dispersion.

Table 22: Surface soil (0–10 cm) properties of the Fish SMU

Particle size analysis %					**Soil particle density (g/cm³)**		**Organic matter (%)**	
Clay	**Silt**	**Sand**	**Gravel**					
15	23	60	2		2.37		2.5	
			Extractable nutrients (mg/kg)					**Extractable metals (mg/kg)**
Phosphorous	**Potassium**	**Sulphate**	**Nitrate**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
< 5	< 100	30	0.3	< 0.2	< 1	163	5.16	< 1

The surface soil is dominated by sand (60%) and silt (23%) with 15% clay and 2% gravel. Moderate organic matter content offers adequate structural stability while ESP and the Ca/Mg ratio indicate that the topsoil is at risk of becoming dispersive if physically disturbed.

All extractable nutrients in this SMU are deficient with phosphorous, potassium and nitrate expected to be severely limiting to plant growth. The extractable metals iron, zinc and manganese are deemed adequate for plant growth, however, both copper and boron are considered deficient (Government of South Australia 2013)

4.3 Kei management unit

4.3.1 Soil unit description

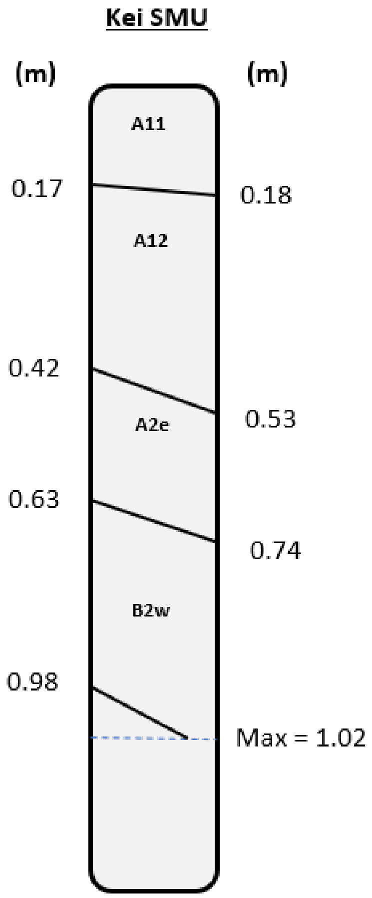
Brown coloured soil unit occurring on the flats of the south-eastern end of the study area. Soil textures grade from clayey to loamy sands at the surface, to medium clay with depth and orange to yellow mottles present in the deeper horizons. Vegetation associated with this unit largely includes *Eucalyptus populnea*.

Figure 6: Kei SMU vegetation

Table 23: Key Kei SMU parameters

Parameter	Soil unit description
Profile site numbers	VP26, VP30
Observation site numbers	OP30, OP52, OP58
Landform	Plains
Australian soil classification	Brown chromosol
Land system	Cotherstone Land System
Slope	0%
Geology	TQa–Tqa– QLD
Vegetation	Poplar Box (*Eucalyptus populnea*)
Runoff	Slow to moderate
Permeability	Moderately permeable
Drainage	Moderately well drained

Profile description—representative sites VP26 and VP30



The **surface soil** (A11/A12) is a very dark greyish brown to dark yellowish brown (7.5YR3/2, 7.5YR3/4) clayey sand to sandy loam with a loose to weak platy structure. It has a field pH of 6 to 7, demonstrating a gradual to diffuse change to;

The **lower surface soil** (A2e) is a bleached brown (10YR4/4) loamy sand. This horizon has a loose structure and a field pH of 7–7.5. Clear to gradual change to;

The **subsoil** (B2w) is a dark greyish brown (10YR4/2) silty clay loam to medium clay with moderate strength polyhedral structure. This horizon has occurrence of faint yellow and orange mottles with diameters of <1.5cm. This horizon has a field pH of 7 to 7.5.

Chemical and physical analysis

Table 24: Chemical properties of the Kei SMU

Representative site: VP30								
Depth	**pH**		**EC**		**Cl**	**ESP%**		**Moisture**
(m)	**#**	**Rating**	**dS/m**	**Rating**	**(mg/kg)**	**%**	**Rating**	**(%)**
0–0.1	6.4	Slightly Acid	0.013	Very low	< 10	1	Non-sodic	1.5
0.2–0.3	7	Neutral	0.014	Very low	< 10	1.4	Non-sodic	2.4
0.5–0.6	7.4	Slightly Alkaline	0.009	Very low	< 10	< 0.2	Non-sodic	1.7
0.8–0.9	8.6	Moderately Alkaline	0.101	Low	20	< 0.2	Non-sodic	8
Depth	**CEC**		**Exchangeable cations (meq/100g)**					**Emerson class no.**
(m)	**meq/ 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg ratio**	
0–0.1	4.5	Very Low	2.9	1.1	0.5	0.1	2.6	3
0.2–0.3	4.4	Very Low	2.8	1.1	0.5	< 0.1	2.5	3
0.5–0.6	1.5	Very Low	1.5	< 0.2	< 0.2	< 0.2	< 7.5	3
0.8–0.9	9.4	Low	8.4	0.6	0.4	< 0.2	12.9	4
Nutrient distribution in topsoil (%)			64.4%	24.4%	11.1%	2.2%		

The Kei SMU has a neutral to slightly acidic pH in the upper horizons with an increase in alkalinity with depth. The pH in the upper 0.6 m is not considered plant limiting, however, in the deeper horizons of the profile this has potential to reduce plant available nutrients. This soil unit is not likely to be affected by issues associated with salinity and chloride toxicity with EC and chloride well within appropriate bounds (Rayment and Lyons 2011). ESP values in conjunction with the Ca/Mg ratio indicate a very low risk of dispersion throughout the entire profile.

CEC values in the upper 0.6 m of the profile are all very low (CEC less than 6) indicating that the soil has a poor ability to retain nutrients (Hazelton and Murphy 2016). The CEC of soil is considered low with calcium, manganese and potassium below levels ideal for plant growth. Nutrient holding capacity and exchangeable cation content increase below this depth. The distribution of nutrients in the topsoil reflects an adequate balance of nutrients on the soil exchange with only potassium above the ideal proportion. This is not anticipated to influence the risk of dispersion of the soil (Hazelton and Murphy 2016).

Table 25: Surface soil (0–10 cm) properties of the Kei SMU

Particle size analysis %					**Soil particle density (g/cm3)**		**Organic matter (%)**	
Clay	**Silt**	**Sand**	**Gravel**					
12	25	62	1		2.31		2.4	
Extractable nutrients (mg/kg)				**Extractable metals (mg/kg)**				
Phosphorous	**Potassium**	**Sulphate**	**Nitrate**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
< 5	477	< 10	0.7	< 0.2	< 1	30.6	13.8	1.52

The surface soil of this unit is predominantly comprised of sand-sized particles (62%) with 25% silt, 12% clay and 1% gravel which is a contributing factor of the very low CEC. The topsoil is non-sodic with a Ca/Mg ratio above 2. This, along with the moderate organic matter content of 2.4%, indicates this soil is not likely to disperse.

The low phosphorous and nitrate concentration of the soil suggest deficiency in these nutrients which may be limiting to plant growth (Hazelton and Murphy 2016). Both potassium and sulphate content are within acceptable bounds for plant growth. Excluding manganese and boron, all extractable metals are sufficiently concentrated in the soil with boron likely deficient (<0.5 mg/kg) and manganese content rated high (>10 mg/kg) which has potential to induce manganese toxicity in plants (Government of South Australia 2013).

4.4 Komati management unit

4.4.1 Soil unit description

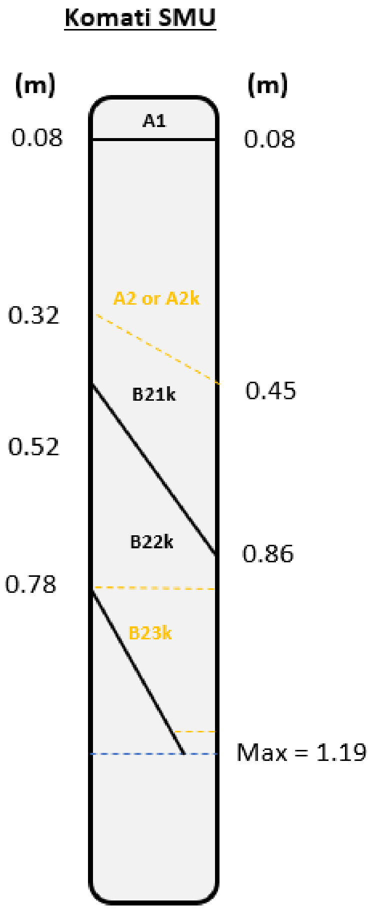
Dark brown coloured soil unit displaying vertic properties. Soil textures predominantly grade from light to medium clays with calcareous segregations occurring within the deeper horizons. Vegetation associated with this unit includes *Eucalyptus papuana* and open grassland.

Figure 7: Komati SMU vegetation

Table 26: Key Komati SMU parameters

Parameter	Soil unit description
Profile site numbers	VP32, VP34, VP39
Observation site numbers	OP23, OP24, OP25, OP42, OP43, OP65
Landform	Plains
Australian soil classification	Brown Vertosol
Land system	Monteagle land system
Slope	0%
Geology	Qr–Qr–QLD
Vegetation	Dallachy's ghost gum (Eucalyptus papuana), grasses and shrubs
Runoff	Slow
Permeability	Slowly permeable
Drainage	Imperfectly to moderately well drained

Profile description—representative sites VP32 and VP39



The **surface soil** (A1) is black to a very dark brown (7.5YR2.5/1, 7.5YR3/3) sandy clay loam to light medium clay with a polyhedral structure of moderate strength. It has a field pH of 7-8.5, demonstrating a clear to abrupt change to;

The **lower surface soil** (A2 or A2k) this horizon was not observed in all profiles of this SMU. It is a brown to very dark brown (7.5YR4/4, 10YR2/2) light medium to medium clay with a moderately strong polyhedral structure and a field pH of 8–8.5. Some profiles display a minor occurrence (< 10%) of calcareous segregations. Clear to gradual change to;

The **subsoil** (B21k, B22k, B23k) is separated into several B2 horizons depending on colour, however, all contain an abundance of calcareous segregations (20–50% of the horizon). Colours range from strong browns (7.5YR4/6, 7.5YR5/6) to browns and light browns 7.5YR4/4, 7.5YR6/4). Textures grade as medium clay with moderate strength lenticular to polyhedral structure. This horizon has a field pH of 8.5-9.

Chemical and physical analysis

Table 27: Chemical properties of the Komati SMU

Representative site: VP32								
Depth	**pH**		**EC**		**Cl**	**ESP%**		**Moisture**
(m)	**#**	**Rating**	**dS/m**	**Rating**	**(mg/kg)**	**%**	**Rating**	**(%)**
0–0.1	6.8	Neutral	0.011	Very low	< 10	2.4	Non-sodic	2.4
0.2–0.3	8.5	Moderately alkaline	0.142	Low	80	13	Sodic	7.8
0.5–0.6	9.5	Strongly alkaline	0.582	High	620	18.2	Strongly Sodic	8
0.8–0.9	9.5	Strongly alkaline	0.641	High	730	21.6	Strongly Sodic	7.6
Depth	**CEC**		**Exchangeable cations (meq/100g)**					**Emerson class no.**
(m)	**meq/ 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg ratio**	
0–0.1	7	Low	3.7	3	0.2	0.2	1.2	3
0.2–0.3	16.4	Moderate	4.3	10	< 0.2	2.1	0.4	3
0.5–0.6	15.3	Moderate	3	9.5	< 0.2	2.8	0.3	4
0.8–0.9	14.9	Moderate	2.1	9.6	< 0.2	3.2	0.2	4
Nutrient distribution in topsoil (%)			52.9%	42.9%	2.9%	2.9%		

The Komati SMU is predominantly a strongly alkaline unit with pH ranging from 6.8 (neutral) at the surface to 9.5 (very strongly alkaline) in the subsoil. The higher pH has the potential to severely reduce the availability of essential plant nutrients such as nitrogen and phosphorous (Hazelton and Murphy 2016). EC values indicate that salinity is low in the upper 0.3 m the profile. Below this depth EC increases to 0.582-0.641 dS/m which is considered high. Chloride concentration increases from an acceptable concentration in the topsoil (<80 mg/kg) to 730 mg/kg in the subsoil (Rayment and Lyons 2011). This increase in EC and chloride has the potential to induce chloride toxicity which can interfere with the osmotic capacity of plants.

CEC is regarded low in the surface soil (7 meq/100g) and increases to moderate levels (approximately 15 meq/100g) in deeper horizons (Hazelton and Murphy 2016). Only magnesium (>1.6 meq/100g) is present on the soil exchange at a suitable concentration. However, and particularly in the subsoil, magnesium concentration is disproportionately large relative to other cations. This contributes to a very low Ca/Mg ratio which increases the risk of dispersion of the soil. Both calcium (<5 meq/100g) and potassium (<0.5 meq/100g) are below ideal levels throughout the profile. The distribution of nutrients within the topsoil again, reflects the imbalance between calcium and magnesium while the presence of potassium and sodium on the exchange is considered appropriate and high respectively (Hazelton and Murphy 2016).

ESP values increase rapidly with depth indicating a high risk of dispersion from as shallow as 0.2 m below the surface. This risk of dispersion is further exacerbated by the very low Ca/Mg ratio discussed above. However, below the depth of 0.5 m, the Emerson class numbers indicate that the soil is not dispersive due to the presence of carbonate ($CaCO_3$) at this depth (Emerson 1967).

Table 28: Surface soil (0–10 cm) properties of the Komati SMU

Particle size analysis %					Soil particle density (g/cm3)		Organic matter (%)	
Clay	**Silt**	**Sand**	**Gravel**					
32	11	55	2		2.24		2.7	
Extractable nutrients (mg/kg)				**Extractable metals (mg/kg)**				
Phosphorous	**Potassium**	**Sulphate**	**Nitrate**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
< 5	146	< 10	0.2	< 0.2	< 1	26.6	6.8	< 1

The surface soil of the Komati SMU is composed of a moderately high clay content (32%), with 55% sand, 11% silt and 2% gravel. It has a moderate polyhedral structure with cracking occurring at the surface. The topsoil is non-sodic, however, the Emerson Class Number (3) in conjunction with a Ca/Mg ratio of 1.2 indicate that disturbance may give rise to dispersion. The particle size distribution and organic matter content (2.7%) suggest good stability of the surface horizon.

Extractable nutrient content for the surface soil is considered poor with nitrate (0.2 mg/kg), potassium (146 mg/kg) and phosphorous (<5 mg/kg) all below suitable levels for plant life and sulphate (<10 mg/kg) considered marginal (Hazelton and Murphy 2016). Of the extractable metals detected, only manganese (6.8 mg/kg) and iron (26.6 mg/kg) are present at adequate levels for plant life. Copper (<1 mg/kg), zinc (<1 mg/kg) and boron (<0.2 mg/kg) are all below concentrations suitable for plant growth (Government of South Australia 2013).

4.5 Limpopo management unit

4.5.1 Soil unit description

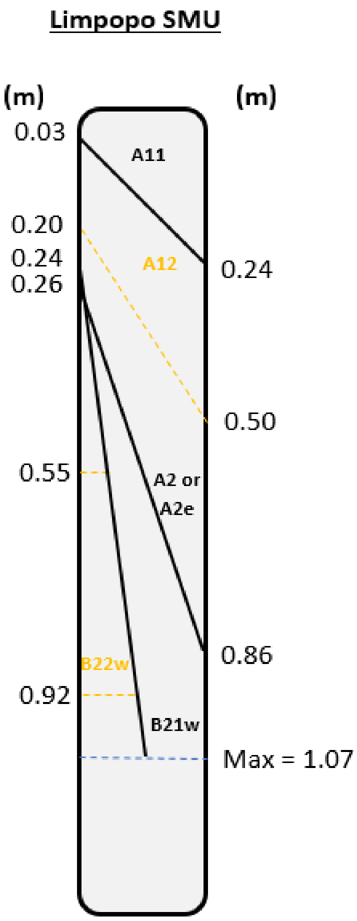
The Limpopo unit is a brown texture-contrast soil. Soil textures predominantly grade from sands to clay sands in the surface soils to light clays in deeper horizons. Vegetation associated with this unit includes *Eucalyptus populnea* and *Eucalyptus crebra*.

Figure 8: Limpopo SMU vegetation

Table 29: Key Limpopo SMU parameters

Parameter	Soil Unit Description
Profile site numbers	VP1, VP2, VP7, VP9, VP13, VP15, VP17, VP18, VP22, VP24, VP28, VP36, VP37
Observation site numbers	OP6, OP8, OP10, OP11, OP18, OP19, OP22, OP23, OP26, OP32, OP33, OP39, OP41, OP45, OP46, OP47, OP48, OP49, OP55, OP56, OP57
Landform	Low rises to plains
Australian soil classification	Brown Sodosol
Land system	Cotherstone land system
Slope	< 3%
Geology	Back Creek Group
Vegetation	Poplar box (Eucalyptus populnea), narrow-leaved ironbark (Eucalyptus crebra),
Runoff	Slow
Permeability	Slow to moderately permeable
Drainage	Well drained

Profile description—representative sites VP7, VP15, VP17, VP18, VP22



The **surface soil** (A11, A12) is brown to a dark brown (7.5YR4/4, 7.5YR3/3) sand to loamy sand with a loose structure. It has a field pH that ranges between 5 and 6, demonstrating a clear to gradual change to;

The **lower surface soil** (A2 or A2e) is a brown to greyish brown (7.5YR4/4, 10YR5/2) with some profiles within this soil unit displaying bleaching in this horizon (A2e). Predominant textures observed in this horizon range from sandy loams to sandy clay loams with a loose to weak polyhedral structure and a field pH of 6. Clear to gradual change to;

The **subsoil** (B21w, B22w) includes dark yellowish brown to a dark greyish brown (10YR4/4, 10YR4/2) clayey or sandy loams and light clays clay with weak to moderate strength polyhedral structure. Mottling was often observed in this horizon with colours ranging between red, orange and yellow. This horizon has a field pH of 5.5-7.

Chemical and physical analysis

Table 30: Chemical properties of the Limpopo SMU

Representative site: VP17								
Depth	**pH**		**EC**		**Cl**	**ESP%**		**Moisture**
(m)	**#**	**Rating**	**dS/m**	**Rating**	**(mg/kg)**	**%**	**Rating**	**(%)**
0–0.1	5.5	Moderately Acid	0.004	Very low	< 10	1	Non-sodic	1.6
0.2–0.3	5.5	Moderately Acid	0.005	Very low	< 10	2.6	Non-sodic	2.4
0.5–0.6	5.8	Moderately Acid	0.035	Very low	50	12.1	Sodic	3.8
0.8–0.9	5.6	Moderately Acid	0.154	Low	110	21.5	Strongly Sodic	8.6
Depth	**CEC**		**Exchangeable cations (meq/100g)**					**Emerson class no.**
(m)	**meq/ 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg ratio**	
0–0.1	2.3	Very Low	0.8	0.5	0.4	0.1	1.6	3
0.2–0.3	1.8	Very Low	0.1	0.6	0.3	< 0.1	0.2	4
0.5–0.6	2.7	Very Low	< 0.1	1.8	0.2	0.3	< 0.1	4
0.8–0.9	7.3	Low	< 0.1	5.4	0.2	1.5	< 0.1	4
Nutrient distribution in topsoil (%)			34.78%	21.74%	17.39%	4.35%		

The upper 0.3 m of the Limpopo SMU is strongly acidic with a pH of 5.5, increasing only slightly beyond this depth. This pH is not within the bounds best suited to plant growth (Hazelton and Murphy 2016). EC and chloride concentration across the profile indicate salinity is very low with EC values ranging from 0.004 dS/m in the topsoil to 0.154 dS/m in the subsoil. Chloride concentration reflects this ranging from <10 mg/kg in the topsoil and increasing to 110 mg/kg in the subsoil which is below the limits of toxicity (Rayment and Lyons 2011).

CEC is considered very low (CEC < 6 meq/100g) across the majority of the profile increasing only slightly with depth (Hazelton and Murphy 2016). This is likely attributed to the sandy texture of the upper horizons. Potassium and calcium are present at very low concentrations throughout the soil profile with potassium consistently below 0.5 meq/100g and calcium consistently below 5 meq/100g). Although not as severe, manganese concentration is also regarded as low in the topsoil increasing to a more appropriate range in the subsoil. The Ca/Mg ratio reflects this with the ratio ranging from 1.6 in the topsoil to <0.1 in the subsoil; indicating calcium is deficient (Hazelton and Murphy 2016).

ESP values that range between 1% to 2.6% indicate the topsoil is not likely to be at risk of dispersion; however, ESP increases with depth to 21.5% in the subsoil indicating the subsoil is susceptible to dispersion. This is further supported by the very low Ca/Mg ratio discussed above although Emerson class numbers do not support this.

Table 31: Surface soil (0–10 cm) properties of the Limpopo SMU

Particle size analysis %					Soil particle density (g/cm3)		Organic matter (%)	
Clay	Silt	Sand	Gravel					
10	8	79	3		2.48		1.8	
Extractable nutrients (mg/kg)				Extractable metals (mg/kg)				
Phosphorous	Potassium	Sulphate	Nitrate	B	Cu	Fe	Mn	Zn
< 5	335	< 10	0.2	< 0.2	< 1	82.1	4.64	< 1

The particle size distribution reveals the A11 horizon of this SMU is strongly dominated by sand (79%) with silt and clay size particles comprising 8% and 10% of this horizon respectively. Organic matter content is regarded as moderate, contributing to average structural stability and low cohesiveness and suggesting the soil unit may be at a greater risk of erosion-induced movement.

Extractable nutrients are considered poorly balanced with both phosphorus (<5 mg/kg) and nitrate (0.2 mg/kg) concentration well below appropriate bounds for plant growth (Hazelton and Murphy 2016). Sulphate (<10 mg/kg) presence in the topsoil is considered marginal and only potassium (335 mg/kg) content is considered suitable. Extractable metals were mostly found below suitable concentrations with copper and zinc detected at <1 mg/kg and boron at <0.2 mg/kg. Only iron (82.1 mg/kg) and manganese (4.64 mg/kg) were present at suitable concentrations (Hazelton and Murphy 2016).

4.6 Orange management unit

4.6.1 Soil unit description

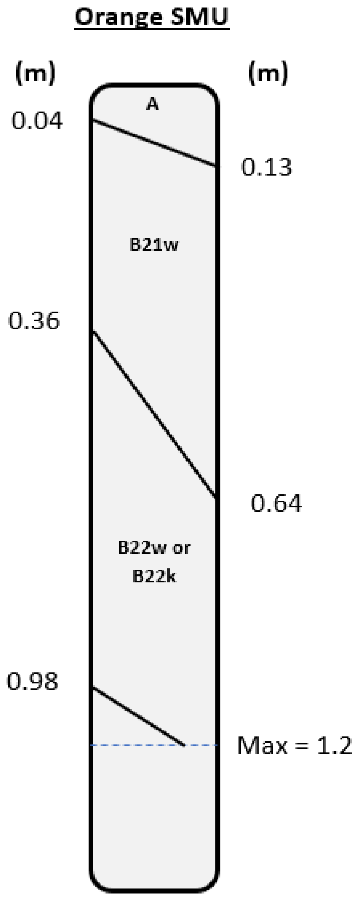
Dark cracking clays associated with the flat grassy plains of the mid-eastern edge of the study area. The predominant textures of soils within this unit range from light clays in surface soils to light medium clays in deeper horizons. Vegetation associated with this unit is predominantly open grassland.

Figure 9: Orange SMU vegetation

Table 32: Key Orange SMU parameters

Parameter	Soil unit description
Profile site numbers	VP31, VP35, VP40
Observation site numbers	OP21, OP24, OP25, OP44, OP60, OP61, OP62, OP65,
Landform	Plains
Australian soil classification	Grey Vertosol
Land system	Monteagle land system
Slope	0%
Geology	Qr–Qr–QLD
Vegetation	Open grassland
Runoff	Slow
Permeability	Slowly permeable
Drainage	Imperfectly to moderately well drained

Profile description—representative sites VP31, VP35, VP40



The **surface soil** (A) is black (10YR2/1, 2.5Y2.5/1) light clay with moderate lenticular structure. It has a field pH of 6–7, demonstrating an abrupt change to;

The **upper subsoil** (B21w) is a black to a very dark grey (10YR2.5/1, 2.5Y3/1) light medium clay with strong lenticular structure and a field pH of 7.5–8.5. Clear to diffuse change to;

The **lower subsoil** (B22w/B22k) is a very dark grey (10YR3/1, 2.5Y3/1) light medium to medium clay with strong lenticular structure. This horizon has a field pH of 8.5–9.

Chemical and physical analysis

Table 33: Chemical properties of the Orange SMU

Representative site: VP31								
Depth	**pH**		**EC**		**Cl**	**ESP%**		**Moisture**
(m)	**#**	**Rating**	**dS/m**	**Rating**	**(mg/kg)**	**%**	**Rating**	**(%)**
0–0.1	8.1	Moderately alkaline	0.135	Low	10	1.4	Non-sodic	5.5
0.2–0.3	8.4	Moderately alkaline	0.054	Very low	40	7	Sodic	12.2
0.5–0.6	9.5	Strongly alkaline	0.321	Medium	180	16.9	Strongly Sodic	13.1
0.8–0.9	9.6	Strongly alkaline	0.575	High	540	20.8	Strongly Sodic	12.9
Depth	**CEC**		**Exchangeable Cations (meq/100g)**					**Emerson class no.**
(m)	**meq/ 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg ratio**	
0–0.1	15.5	Moderate	8.8	6.2	0.3	0.2	1.4	4
0.2–0.3	21	Moderate	9.4	10.1	<0.2	1.5	0.9	3
0.5–0.6	26.6	High	5.7	16.4	<0.2	4.5	0.3	3
0.8–0.9	27.7	High	4.3	17.7	<0.2	5.8	0.2	4
Nutrient distribution in topsoil (%)			56.8%	40.0%	1.9%	1.3%		

The Orange SMU is characterised by high pH ranging from 8.1 in the topsoil to 9.6 in the subsoil, this is beyond the pH range at which all plant nutrients are available and thus not ideal for plant growth. EC values indicate low salinity in the upper 0.3 m of the profile and increases from what is considered medium to high at depth. This has potential to compromise the health of sensitive and moderately tolerant plant species. Chloride concentrations increase from 10 mg/kg in the topsoil to 540 mg/kg in the subsoil which is considered within acceptable limits (Rayment and Lyons 2011).

CEC increases with depth, ranging from moderate (15.5 meq/100g) in the topsoil, to high (27.7 meq/100g) in the subsoil layer. Calcium is present in the topsoil layer at a concentration of 8.8 meq/100g and decreases to 4.3 meq/100g. Magnesium concentration increases with depth from 6.2 meq/100g at the surface to 17.7 meq/100g. While the absolute concentration of calcium and magnesium are at suitable levels for plant growth, magnesium concentration is considered disproportionately high relative to calcium. This is reflected in the Ca/Mg ratio that decreases from 1.4 (calcium low) in the topsoil to 0.2 (calcium deficient) in the subsoil. In the topsoil potassium content is below the ideal concentration (0.3 meq/100mg), this decreases further with depth to <0.2 meq/100g in the subsoil. The distribution of nutrients within the topsoil shows magnesium occupying a large proportion of the exchange while the proportion of calcium on the exchange is considered lower than ideal. Both potassium and sodium are at appropriate levels (Hazelton and Murphy 2016).

ESP values indicate the upper 0.1 m is non-sodic (1.4%), however, ESP increases beyond this depth to 20.8% in the subsoil. These ESP values in conjunction with the Ca/Mg ratio (discussed above) suggest that soil below 0.2 m in depth is prone to dispersion. In the deeper horizons (below 0.8 m), Emerson class numbers indicate this soil is not likely to disperse due to the presence of carbonate (Emerson 1967).

Table 34: Surface soil (0–10cm) properties of the Orange SMU

Particle size analysis %					Soil particle density (g/cm3)		Organic matter (%)	
Clay	Silt	Sand	Gravel					
28	19	51	2		2.13		3.6	
Extractable nutrients (mg/kg)				Extractable metals (mg/kg)				
Phosphorous	Potassium	Sulphate	Nitrate	B	Cu	Fe	Mn	Zn
< 5	182	< 10	0.2	< 0.2	< 1	27	24.5	<1

The surface soil of the Orange SMU is composed of 51% sand, 28% clay, 19% silt and 2% gravel. It has a moderate lenticular structure with a cracking, self-mulching surface. This particle size distribution in conjunction with a high organic matter content (3.5%) will contribute to good structural stability of the topsoil. ESP values suggest the topsoil is not considered to be at risk of dispersion which is supported by the Emerson Class Number of 4.

Extractable nutrients are mostly considered to be low with phosphorous (<5 mg/kg), sulphate (<10 mg/kg) and nitrate (0.2 mg/kg) all below suitable concentrations for plant life and only potassium (182 mg/kg) above the critical concentration (Hazelton and Murphy 2016). The majority of extractable metals are present at low concentrations with boron <0.2 mg/kg and both copper and zinc at <1 mg/kg. Iron (27 mg/kg) is considered adequate; however, manganese (24.5 mg/kg) is regarded as high potentially inducing manganese toxicity in plants.

4.7 Sabie management unit

4.7.1 Soil unit description

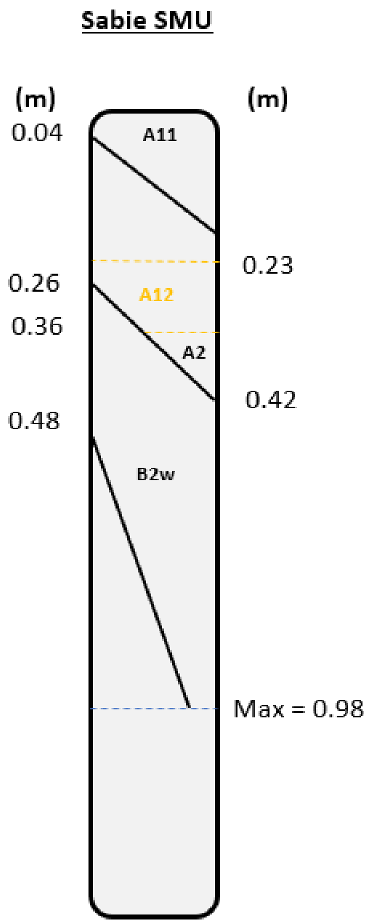
A dark-coloured texture-contrast soil with surface soils consisting of sands, increasing in clay content in deeper horizons. Lower horizons display red to orange mottles. Vegetation associated with this unit is dominated by *Eucalyptus crebra.*

Figure 10: Sabie SMU vegetation

Table 35: Key Sabie SMU parameters

Parameter	Soil unit description
Profile site numbers	VP10, VP11, VP12, VP14, VP20, VP21,
Observation site numbers	OP10, OP19, OP27, OP30, OP32, OP33, OP35, OP41
Landform	Rises and Plains
Australian soil classification	Red Sodosol
Land system	Carborough land system
Slope	<10%
Geology	Back creek group
Vegetation	Narrow-leaved ironbark (Eucalyptus crebra), Bloodwood (Corymbia erythrophloia)
Runoff	Slow to moderate
Permeability	Moderately permeable
Drainage	Moderate to well drained

Profile description—representative sites VP10, VP11, VP12, VP20



The **surface soil** (A11/A12) is black to very dark brown (2.5YR2.5/1, 7.5YR2.3/3) sand to loamy sand with loose to very weak platy structure. It has a field pH of 5–7, demonstrating a clear to abrupt change to;

The **lower surface soil** (A2) is a brown to a dark reddish brown (7.5YR4/4, 5YR3/3) clayey sand to sandy clay loam with loose or very weak polyhedral structure and a field pH of 5–6. Clear to gradual change to;

The **lower subsoil** (B2w) is a dark reddish brown to dusky red (5YR3/3, 2.5Y3/2) clayey loam to medium clay with moderate polyhedral structure. This horizon has a field pH of 5–6.

Chemical and physical analysis

Table 36: Chemical properties of the Sabie SMU

Representative site: VP10								
Depth	**pH**		**EC**		**Cl**	**ESP%**		**Moisture**
(m)	**#**	**Rating**	**dS/m**	**Rating**	**(mg/kg)**	**%**	**Rating**	**(%)**
0–0.1	4.6	Strongly acid	0.128	Low	50	3.2	Non-sodic	2
0.2–0.3	4.9	Strongly acid	0.025	Very low	10	9.2	Sodic	5
0.5–0.6	5.9	Moderately acid	0.02	Very low	20	8.4	Sodic	11.6
0.8–0.9	6	Slightly acid	0.108	Low	140	15.4	Strongly sodic	9.9
Depth	**CEC**		**Exchangeable cations (meq/100g)**					**Emerson class no.**
(m)	**meq/ 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg ratio**	
0–0.1	3.7	Very Low	1.3	0.6	0.5	0.1	2.2	3
0.2–0.3	3.5	Very Low	0.1	0.5	0.3	0.1	0.2	3
0.5–0.6	8.1	Low	< 0.1	5.6	0.6	0.6	< 0.1	3
0.8–0.9	9.6	Low	< 0.1	7.4	0.4	1.4	< 0.1	2
Nutrient distribution in topsoil (%)			35.1%	16.2%	13.5%	2.7%		

The surface soil of the Sabie SMU is strongly acidic (pH < 5) to a depth of 0.3 m which has potential to reduce plant available nutrients and induce aluminium toxicity. Beyond this depth pH increases to 6 which is suitable for plant life. EC is low throughout the profile, with EC values varying between 0.02 dS/m to 0.128 dS/m with no obvious trend associated with depth. The chloride concentration reflects the low EC with chloride consistently below 300 mg/kg.

CEC values are considered very low in the topsoil (3.7 meq/100g) and increase with depth to 9.6 meq/100g in the subsoil. Throughout the profile calcium is below ideal levels and decreases from 1.3 meq/100g to <0.1 meq/100g in the subsoil. Topsoil magnesium concentration is also below ideal levels at 0.6 meq/100g, however, with depth this increases to an acceptable concentration. Overall potassium concentration is sufficient for plant life as it varies within close-proximity of the critical concentration of 0.5 meq/100g. Nutrients in the topsoil are poorly distributed with the proportion of the exchange occupied by calcium considered below ideal while both sodium and potassium in particular are considered high (Hazelton and Murphy 2016).

ESP increases from 3.2% in the topsoil to 15.4% in the subsoil. This information in conjunction with the Ca/Mg ratio indicates the risk of dispersion increases substantially below 0.2m. The Emerson class numbers of 3 and 2 support this (Emerson 1967).

Table 37: Surface soil (0–10cm) properties of the Sabie SMU

Particle size analysis %					Soil particle density (g/cm3)		Organic matter (%)	
Clay	Silt	Sand	Gravel					
12	10	75	3		2.29		4.1	
Extractable nutrients (mg/kg)				Extractable metals (mg/kg)				
Phosphorous	Potassium	Sulphate	Nitrate	B	Cu	Fe	Mn	Zn
< 5	446	30	35.8	0.3	< 1	226	8	< 1

The A11/A12 horizon of this SMU is dominated by sand-sized particles (75%) with 12% clay, 10% silt and 3% gravel. It has a loose single grain to weak platy structure with high organic matter content (4.1%). This information in conjunction with the ESP and Ca/Mg ratio of this topsoil layer suggest the topsoil is not prone to dispersion if undisturbed.

Apart from phosphorous (<5 mg/kg), all extractable nutrients are present in the topsoil at concentrations suitable for plant life (Hazelton and Murphy 2016). Of the extractable metals, only manganese (8 mg/kg) is detected at a suitable concentration. Both copper (<1 mg/kg) and zinc (<1 mg/kg) are low for plant growth and iron concentration is found to be very high with the capacity to induce iron toxicity in plants.

4.8 Zambezi management unit

4.8.1 Soil unit description

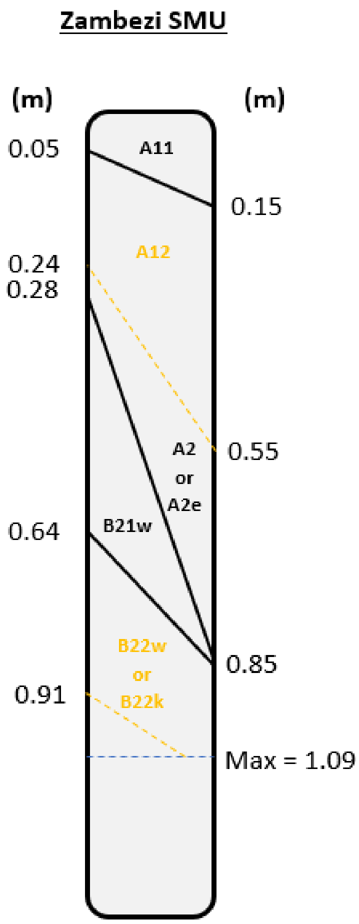
A predominantly grey coloured texture-contrast soil with surface soils consisting of sands, increasing in clay content in deeper horizons. Lower horizons display diffuse orange to yellow mottles. Vegetation associated with this unit is dominated by *Eucalyptus populnea.*

Figure 11: Zambezi SMU vegetation

Table 38: Key Zambezi SMU parameters

Parameter	Soil unit description
Profile site numbers	VP16, VP19, VP23, VP25, VP29, VP33, VP38, VP41. VP42
Observation site numbers	OP18, OP28, OP29, OP32, OP34, OP35, OP37, OP39, OP40, OP41, OP43, OP45, OP47, OP55, OP56, OP57, OP58
Landform	Plains
Australian soil classification	Grey Sodosol
Land system	Cotherstone land system
Slope	<3%
Geology	TQa–Tqa–QLD
Vegetation	Poplar-box (*Eucalyptus populnea*), Narrow-leaved ironbark (*Eucalyptus crebra*)
Runoff	Slow
Permeability	Moderately permeable
Drainage	Moderately well drained

Profile description—representative sites VP25, VP29



The **surface soil** (A11/A12) is dark brown to a very dark greyish brown (7.5YR2.2.5/5, 10YR3/2) coarse grained loamy sand with loose to very weak platy structure. It has a field pH of 5.5–7, demonstrating a clear to abrupt change to;

The **lower surface soil** (A2/A2e) is a brown to greyish brown (7.5YR5/4, 10YR5/2) loamy sand with some profiles displaying this as a bleached horizon with loose single-grained structure and a field pH of 6–7.5. Clear to abrupt change to;

The **lower subsoil** (B2w) is a light grey to grey (10YR7/2, 7.5YR6/1) clayey loam sand to silty clay loam with moderate polyhedral structure. This horizon has a field pH of 7–9.

Chemical and physical analysis

Table 39: Chemical properties of the Zambezi SMU

Representative site: VP25								
Depth	**pH**		**EC**		**Cl**	**ESP%**		**Moisture**
(m)	**#**	**Rating**	**dS/m**	**Rating**	**(mg/kg)**	**%**	**Rating**	**(%)**
0–0.1	6.4	Slightly acid	0.018	Very low	< 10	0.6	Non-sodic	1.8
0.2–0.3	6.7	Slightly acid	0.005	Very low	< 10	0.1	Non-sodic	2.8
0.5–0.6	7.8	Slightly alkaline	0.059	Very low	40	18.5	Strongly sodic	7.2
0.8–0.9	9	Strongly alkaline	0.174	Low	160	23.3	Strongly sodic	9.1
Depth	**CEC**		**Exchangeable cations (meq/100g)**					**Emerson class no.**
(m)	**meq/ 100g**	**Rating**	**Ca**	**Mg**	**K**	**Na**	**Ca/Mg ratio**	
0–0.1	3.4	Very low	2.3	0.8	0.4	0.1	2.9	3
0.2–0.3	1.8	Very low	1.3	0.4	0.1	0.1	3.2	4
0.5–0.6	5.1	Very low	1.1	3.1	< 0.2	0.9	0.4	2
0.8–0.9	10	Low	1.7	5.7	< 0.2	2.3	0.3	2
Nutrient distribution in topsoil (%)			67.7%	23.5%	11.8%	2.9%		

The Zambezi SMU has a slightly acidic (6.4–6.7) pH in the upper 0.3 m of the profile which is not considered plant limiting. However, beyond this depth pH rises to very strongly alkaline (9), which is beyond the suitable pH range for plants (Hazelton and Murphy 2016). EC values and chloride concentration are both well below appropriate limits. EC values range from 0.0018 dS/m in the topsoil to 0.174 dS/m in the subsoil. The chloride concentration is consistently below 300 mg/kg throughout the profile.

CEC is predominantly regarded as very low (<6 meq/100g) with a slight increase in the deepest observed horizon. This is reflected in the low concentrations of extractable cations with calcium and potassium consistently below 5 meq/100g and 0.5 meq/100g respectively. Topsoil magnesium concentrations are considered low (<1.6 meq/100g) but increase to concentrations suitable for plant life with depth. Within the topsoil, the proportion of the exchange occupied by calcium is considered appropriate, however the presence of magnesium, potassium and sodium on the exchange is above ideal (Hazelton and Murphy 2016).

The upper 0.3 m of the profile is non-sodic with ESP values well below 6%. Below this point ESP values increase to 23.2% indicating high potential for dispersion. This is supported by the very low Ca/Mg ratios and an Emerson Class Number of 2 in the subsoil (Emerson 1967).

Table 40: Surface soil (0–10cm) properties of the Zambezi SMU

Particle size analysis %					Soil particle density (g/cm3)		Organic matter (%)	
Clay	Silt	Coarse sand	Gravel					
9	14	77	< 1		2.43		2	
Extractable nutrients (mg/kg)				Extractable metals (mg/kg)				
Phosphorous	Potassium	Sulphate	Nitrate	B	Cu	Fe	Mn	Zn
< 5	311	< 10	2.6	< 2	< 1	60.7	8.92	<1

The surface horizon (A11) of the Zambezi SMU is dominated by sand (77%) with 14% silt, 9% clay and <1% gravel and has a loose to weak platy structure. This, in conjunction with the low organic matter content (2%) suggests poor structural stability of topsoil layer. The topsoil is non-sodic with very low Ca/Mg ratio indicating the topsoil is not dispersive if undisturbed.

Nutrient levels in the topsoil layer are generally poor, with nitrate (2.6 mg/kg), sulphate (<10 mg/kg) and phosphorous (<5 mg/kg) below suitable levels and potassium (311 mg/kg) above the critical concentration indicating potassium is not deficient. Extractable metals vary in suitability with iron (60.7 mg/kg), manganese (8.92 mg/kg), and boron (<2 mg/kg) present in suitable concentrations and both copper (<1 mg/kg) and zinc (<1 mg/kg) at lower than preferred levels for plant growth (Hazelton and Murphy 2016).

5 Strategic Cropping Land Assessment

The RPI Act aims to identify areas of Queensland that are of regional interest because they contribute, or are likely to contribute, to Queensland's economic, social and environmental prosperity. The RPI Act also aims to give effect to the policies about matters of State interest stated in regional plans, and to effectively manage the impact of resource activities on the areas of regional interest.

Areas of regional interest that the RPI Act aims to protect are classified as:

- living areas in regional communities (Priority Living Areas);
- high-quality agricultural areas from dislocation (Priority Agricultural Areas);
- strategic cropping areas; and
- regionally important environmental areas (Strategic Environmental Areas).

Detailed descriptions of what constitutes each type of area of regional interest are provided in Sections 8 to 11 of the RPI Act as well as the Regional Planning Interests Regulation 2014 (RPI regulation). The RPI Act and RPI Regulation seek to strike an appropriate balance between protecting priority land uses and delivering a diverse and prosperous economic future for our regions.

There are no areas of regional interest within the study area. The nearest mapped strategic cropping areas are located between 13–15 km to the north-west, south-west and south-east of the study area.

6 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 Project area for agricultural land uses including cattle grazing and dryland cropping, prior to the development of the mine.

The assessment for land suitability (cattle grazing and rainfed broadacre cropping) has been carried out in accordance with the methodologies described in:

- DSITI and DNRM (2015). *Guidelines for Agricultural Land Evaluation in Queensland* (2nd edition); and
- DME (1995). *Technical Guidelines for the Environmental Management of Exploration and Mining in Queensland—Land Suitability Assessment Techniques*.

The five land suitability classes used for assessing land are defined in Table 41. 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 41: Agricultural and conservation land classes

Class	Agricultural description	Conservation description
Class 1	**Suitable land with negligible limitations**—this is highly productive land requiring only simple management practices to maintain economic production.	Areas well suited for conservation uses must possess significant conservation benefits in the pre-mining environment and be capable of being returned to that use post-mining.
Class 2	**Suitable land with minor limitations** which either reduce production or require more than the simple management practices of class 1 land to maintain economic production.	Areas suited to conservation use in that a significant component of the pre-mining conservation values can be restored post-mining. There will however be some loss in conservation values where soil terrain or hydrological post-mining conditions may inhibit the full replication of the pre-mining values.
Class 3	**Suitable land with moderate limitations** which either further lower production or require more than those management practices of class 2 land to maintain economic production.	These lands contain significant conservation values pre-mining, however restoration of all of these values may not be feasible. These areas could, however, be restored to a form of conservation use which provides alternative conservation benefits.
Class 4	**Marginal land**, which is presently considered unsuitable due to severe limitations. The long-term significance of these limitations on the proposed land use is unknown or not quantified. The use of this land is dependent upon undertaking additional studies to determine whether the effect of the limitation(s) can be reduced to achieve sustained economic production.	These lands contain limited conservation value pre-mining and/or are incapable of being effectively restored post-mining to any alternative conservation use which provides similar benefits. The area could however be restored to provide a stable form of use which does not impact on surrounding conservation values.

Class	Agricultural description	Conservation description
Class 5	**Unsuitable land** with extreme limitations that preclude its use.	These lands contain no significant conservation values.

6.1 Cattle grazing

Limitations for the assessment of grazing land suitability on improved pastures as outlined in the Land Suitability Assessment Technique (QDME 1995) Guidelines (Table 2.2) are:

- water availability;
- nutrient deficiency;
- soil physical factors;
- salinity;
- rockiness;
- micro relief;
- pH;
- ESP;
- wetness;
- topography;
- water erosion;
- flooding; and
- vegetation.

Numerous parameters outlined in this assessment require determination of the 'rootzone'. The rootzone is the depth to hard or weathered rock, or the depth to a significant salt bulge within the soil profile. Where these limitations are not encountered within the sampling depth, a value of 0.6 m can be assumed as the rootzone as described in the QDME guidelines (1995).

For cattle grazing, **Class 1** and **Class 2** land is considered suitable for grazing improved pastures with maximum grazing productivity achieved in most seasons. **Class 3** land is considered suitable for grazing improved pastures however, it is less productive than **Classes 1** and **2**. **Class 4** land is categorised as marginal for grazing improved pastures although it is largely considered suitable for grazing native pastures of variable quality. **Class 5** land is unsuitable for any form of pasture improvement and is limited to low productivity grazing of native pastures. Due to the poor soil quality **Class 5** land may require destocking in poor seasons.

Each of the limitations listed above is assessed in the following subsections on the basis of Table 2.2 of the QDME guidelines (1995).

6.1.1 Water availability

The availability of water in soils is vital for both plants and soil organisms as they require water to survive. The PAWC cut-off levels for each of the land suitability classes for beef cattle grazing are as follows:

- **Class 1:** > 125 mm
- **Class 2:** 100–125 mm
- **Class 3:** 75–100 mm
- **Class 4:** 50–75 mm
- **Class 5:** < 50 mm

These cut-off levels are not based on a specific species of pasture, but on pasture as a general land use. The soils are assessed on the depth to weathered rock, or other root inhibiting factors such as a salt bulge or significant sodicity. Table 42 provides the outcomes of the land suitability class assessment on the basis of plant available water capacity.

Table 42: Land suitability for cattle grazing based on PAWC

Soil management unit	Limiting features	PAWC (mm)	Land suitability class
Crocodile	Shallow sands and sandy loams ≤ 45 cm deep	≤ 50 mm	5
Fish	Sands and sandy loams 45–90 cm deep	50–75 mm	4
Kei	Sands and sandy loams > 90 cm deep	75–100 mm	3
Komati	Cracking clays: alkaline to neutral pH throughout and 60– 90 cm depth to ESP ≥ 15	100–125 mm	2
Limpopo	Duplex soils with subsoil becoming sodic (ESP 6–14) within 60 cm of the surface but not strongly sodic (ESP ≥ 15) within 90 cm	75–100 mm	3
Orange	Cracking clays: alkaline to neutral pH throughout and 60–90 cm depth to ESP ≥ 15	100–125 mm	2
Sabie	Duplex soils with subsoil becoming sodic (ESP 6–14) within 60 cm of the surface but not strongly sodic (ESP ≥ 15) within 90 cm	75–100 mm	3
Zambezi	Duplex soils with a sodic subsoil (ESP 6–14) becoming strongly sodic (ESP ≥ 15) within 60 cm of surface	50–75 mm	4

6.1.2 Nutrient deficiency

The nutrient status of each SMU identified has been assessed and the results are presented in Table 43. Note that bicarbonate phosphorus was only analysed within the topsoil layer (0–10 cm). Soil nutrients are vital for plant and animal growth and metabolism.

Table 43: Land suitability for cattle grazing based on nutrient status

Soil management unit	Limiting features	Land suitability class
Crocodile	Sands and loams at least 75 cm deep or overlying rock at shallow depth, with bicarbonate P 5–10 ppm,	4
Fish	Sands and loams at least 75 cm deep or overlying rock at shallow depth, with bicarbonate P ≤ 4 ppm	4
Kei	Sands and loams at least 75 cm deep or overlying rock at shallow depth, with bicarbonate P ≤ 4 ppm	4
Komati	Other soils with bicarbonate P 5–10 ppm	3
Limpopo	Sands and loams at least 75 cm deep or overlying rock at shallow depth, with bicarbonate P ≤ 4 ppm	4
Orange	Other soils with bicarbonate P 5–10 ppm	3
Sabie	Sands and loams at least 75 cm deep or overlying rock at shallow depth, with bicarbonate P ≤ 4 ppm	4
Zambezi	Sands and loams at least 75 cm deep or overlying rock at shallow depth, with bicarbonate P ≤ 4 ppm	4

6.1.3 Soil physical factors

Soil physical factors for each SMU identified have been assessed with results presented in Table 44. The physical condition of soils plays a direct role with seed germination and emergence. Adverse conditions such as hard-setting or crusting of surface soils reduces plant establishment through creating a barrier, reducing seed soil contact.

Table 44: Land suitability for cattle grazing based on soil physical factors

Soil management unit	Limiting features	Land suitability class
Crocodile	Rigid soils with a loose, soft or firm surface when dry	1
Fish	Rigid soils with a loose, soft or firm surface when dry	1
Kei	Rigid soils with a loose, soft or firm surface when dry	1
Komati	Cracking clays with fine self-mulch (peds 2–10 mm)	2
Limpopo	Rigid soils with a loose, soft or firm surface when dry	1
Orange	Cracking clays with fine self-mulch (peds 2–10 mm)	2
Sabie	Rigid soils with a hard-setting surface when dry	3
Zambezi	Rigid soils with a loose, soft or firm surface when dry	1

6.1.4 Salinity

Land suitability class for each SMU based on salinity has been assessed with the results provided in Table 45. Given salinity can inhibit plant growth, the highest EC recorded is considered the most limiting factor and dictates the rating given to each SMU. Significant levels of salinity present in the rootzone can negatively impact plant growth and production.

Table 45: Land suitability for cattle grazing based on salinity

Soil management unit	Limiting features	Land suitability class
Crocodile	Rootzone EC < 0.15 mS/cm	1
Fish	Rootzone EC < 0.15 mS/cm	1
Kei	Rootzone EC < 0.15 mS/cm	1
Komati	Rootzone EC 0.3–0.9 mS/cm	3
Limpopo	Rootzone EC < 0.15 mS/cm	1
Orange	Rootzone EC 0.15–0.3 mS/cm	2
Sabie	Rootzone EC < 0.15 mS/cm	1
Zambezi	Rootzone EC < 0.15 mS/cm	1

Notes: The 0.5–0.6m Orange horizon marginally exceeds the 0.3 threshold but given the EC values for adjacent upper horizons it is considered sufficiently close to the threshold to warrant the classification provided.

6.1.5 Rockiness

The land suitability for each SMU based on rockiness was assessed with results presented in Table 46. The impacts of rockiness are more extreme for cropping than for grazing. With respect to grazing, rock outcrops reduce the area available to grow pasture, indirectly impacting the carrying capacity of the land.

Table 46: Land suitability cattle grazing based on rockiness

Soil management unit	Limiting features	Land suitability class
Crocodile	20–50% surface cobble (6–20 cm diameter) and rock outcrop	3
Fish	< 10 course surface gravel (> 6 cm diameter)	1
Kei	< 10 course surface gravel (> 6 cm diameter)	1
Komati	< 10 course surface gravel (> 6 cm diameter)	1
Limpopo	< 10 course surface gravel (> 6 cm diameter)	1
Orange	< 10 course surface gravel (> 6 cm diameter)	1
Sabie	< 10 course surface gravel (> 6 cm diameter)	1
Zambezi	< 10 course surface gravel (> 6 cm diameter)	1

6.1.6 Microrelief

The microrelief for each SMU identified has been assessed with results presented in Table 47. 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 cattle grazing are only experienced when soil is severely melonholed. Ponding of water in the depressions can reduce pasture yield, indirectly impacting the land's carrying capacity.

Table 47: Land suitability for cattle grazing based on microrelief

Soil management unit	Limiting features	Land suitability class
Crocodile	Melonholes cover <20% surface area	1
Fish	Melonholes cover <20% surface area	1
Kei	Melonholes cover <20% surface area	1
Komati	Melonholes cover <20% surface area	1
Limpopo	Melonholes cover <20% surface area	1
Orange	Melonholes cover <20% surface area	1
Sabie	Melonholes cover <20% surface area	1
Zambezi	Melonholes cover <20% surface area	1

6.1.7 pH

The land suitability class for pH has been assessed with results presented in Table 48. Soil pH determines the availability of nutrients for plant intake. Where a soil material is strongly acidic, aluminium and manganese toxicity may limit root growth and plant productivity. Were an improved pasture post-mining land use to be targeted, there may be a need to for ameliorants to correct soil pH and increase nutrient availability.

Table 48: Land suitability for cattle grazing based on pH

Soil management unit	Limiting features	Land suitability class
Crocodile	pH 5.0–5.6	2
Fish	pH 5.0–5.6	2
Kei	pH 6.6–8.0	2
Komati	pH 6.6–8.0	2
Limpopo	pH 5.0–5.6	2
Orange	pH 8.0–9.0	3
Sabie	pH 4.5–5.0	3
Zambezi	pH 6.6–8.0	2

6.1.8 Exchangeable sodium percentage (ESP)

The ESP of each SMU identified has been assessed with results presented in Table 49. ESP is used to determine the erosion potential of soils. The land suitability class identified for each SMU based on ESP in the upper 100 mm of soil.

Table 49: Land suitability for cattle grazing based on ESP

Soil management unit	Limiting features	Land suitability class
Crocodile	ESP < 5%	1
Fish	ESP 5–10%	2
Kei	ESP < 5%	1
Komati	ESP < 5%	1
Limpopo	ESP < 5%	1
Orange	ESP < 5%	1
Sabie	ESP < 5%	1
Zambezi	ESP < 5%	1

6.1.9 Wetness

The land suitability class identified for each SMU based on wetness has been assessed with results presented in Table 50. 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 50: Land suitability for cattle grazing based on wetness

Soil management unit	Limiting features	Land suitability class
Crocodile	Undulating terrain or elevated plains	1
Fish	Non-sodic rigid soils with coarse pale grey and yellow mottles within 50 cm of the surface	2
Kei	Low-lying level plains	2
Komati	Rigid soils with strongly sodic subsoil (ESP≥15) within 60 cm of the surface	2
Limpopo	Non-sodic rigid soils with coarse pale grey and yellow mottles within 50 cm of the surface	2
Orange	Low-lying level plains	2
Sabie	Undulating terrain or elevated plains	1
Zambezi	Rigid soils with strongly sodic subsoil (ESP≥15) within 60 cm of the surface	2

6.1.10 Water erosion

The land suitability class identified for each SMU based on water erosion has been assessed with the results presented in Table 51. Erosion of topsoil reduces the productivity of the land through the loss of key nutrients in the soil’s upper horizons.

Table 51: Land suitability for cattle grazing based on water erosion

Soil management unit	Limiting features	Land suitability class
Crocodile	Slopes 3–12% on non-sodic rigid soils	2
Fish	Slopes < 3% on non-sodic soils	1
Kei	Slopes < 3% on non-sodic soils	1
Komati	Slopes < 3% on non-sodic soils	1
Limpopo	Slopes < 3% on non-sodic soils	1
Orange	Slopes < 3% on non-sodic soils	1
Sabie	Slopes < 3% on non-sodic soils	1
Zambezi	Slopes < 3% on non-sodic soils	1

6.1.11 Flooding

The land suitability class identified for each SMU based on flooding risk has been assessed with results presented in Table 52. Flooding may result in plant death or reduced growth. In severe cases where land is inundated for a prolonged period stock loss and loss of grazing production may also occur.

Table 52: Land suitability for cattle grazing based on flooding

Soil management unit	Limiting features	Land suitability class
Crocodile	No flooding	1
Fish	No flooding	1
Kei	No flooding	1
Komati	Periodic flooding	2
Limpopo	No flooding	1
Orange	Periodic flooding	2
Sabie	No flooding	1
Zambezi	Periodic flooding	2

6.1.12 Vegetation regrowth (management limitation)

The land suitability class identified for each SMU based on vegetation regrowth has been assessed with results presented in Table 53. Vegetation communities may contain poisonous species or woody weeds that will limit the productivity of grazing pastures to varying degrees and increase the need for land management. The density of tree species and presence of a woody shrub layer may also limit the carrying capacity of the land.

Table 53: Land suitability for cattle grazing based on vegetation

Soil management unit	Limiting features	Land suitability class
Crocodile	Bloodwood and ironbark open woodland	1
Fish	Acacia scrub without melonholes	1
Kei	Acacia scrub without melonholes	1
Komati	Box woodlands without wattle understorey	2
Limpopo	Box and ironbark woodlands without wattle understorey	2
Orange	Grasslands	1
Sabie	Bloodwood and ironbark open woodlands	1
Zambezi	Box and ironbark woodlands without wattle understorey	2

6.1.13 Summary of land suitability for cattle grazing

Table 54 provides a summary of the assessed land suitability limitations for a beef cattle grazing land use.

In the study area, the suitability of land for cattle grazing is mostly limited by pH controlled nutrient deficiency and water availability.

Unsuitable pH conditions can greatly reduce nutrient levels in the soil. This has potential to impact livestock production through a reduction in pasture growth and the nutrient value of pasture species. Additionally, water availability can also compromise pasture growth by inducing water stress in pasture species and preventing the mobilisation of nutrients in the root zone.

While no Class 1 or Class 2 land was identified for the study area, examination of the land suitability limitations for cattle grazing (Table 54) indicates that 734 ha is suitable for cattle grazing with moderate limitations (Class 3). The majority of the study area (6,892 ha) is considered marginal land with the remaining area (2,524 ha) comprised of Class 5 land.

It is important to note that although the SMUs present in the Project areas are classified as Class 4 (marginally suitable) and Class 5 (unsuitable); given this is the current land use of the area, the land is considered suitable for grazing. The land suitability framework is used as a guide to determine potential land suitability and should be considered alongside historical land use. One of the two limiting factors which produced a land suitability class of 4 is limited soil phosphorous (< 10 mg/kg), which is able to be overcome with the addition of phosphorous to topsoil before re-spreading.

Figure 12 shows the distribution of land suitability classes for cattle grazing across the study area.

Table 54: Summary of land suitability limitations for cattle grazing

Limitation	Crocodile	Fish	Kei	Komati	Limpopo	Orange	Sabie	Zambezi
Water availability	5	4	3	2	3	2	3	4
Nutrient deficiency	4	4	4	3	4	3	4	4
Soil physical factors	1	1	1	2	1	2	3	1
Salinity	1	1	1	3	1	2	1	1
Rockiness	3	1	1	1	1	1	1	1
Microrelief	1	1	1	1	1	1	1	1
pH	2	2	2	2	2	3	3	2
ESP (10cm) %	1	2	1	1	1	1	1	1
Wetness	1	2	2	2	2	2	1	2
Water erosion	2	1	1	1	1	1	1	1
Flooding	1	1	1	2	1	2	1	2
Vegetation Regrowth	1	1	1	2	2	1	1	2
Overall Suitability Rating	5	4	4	3	4	3	4	4

Notes: Green shading = suitable, red shading = unsuitable.

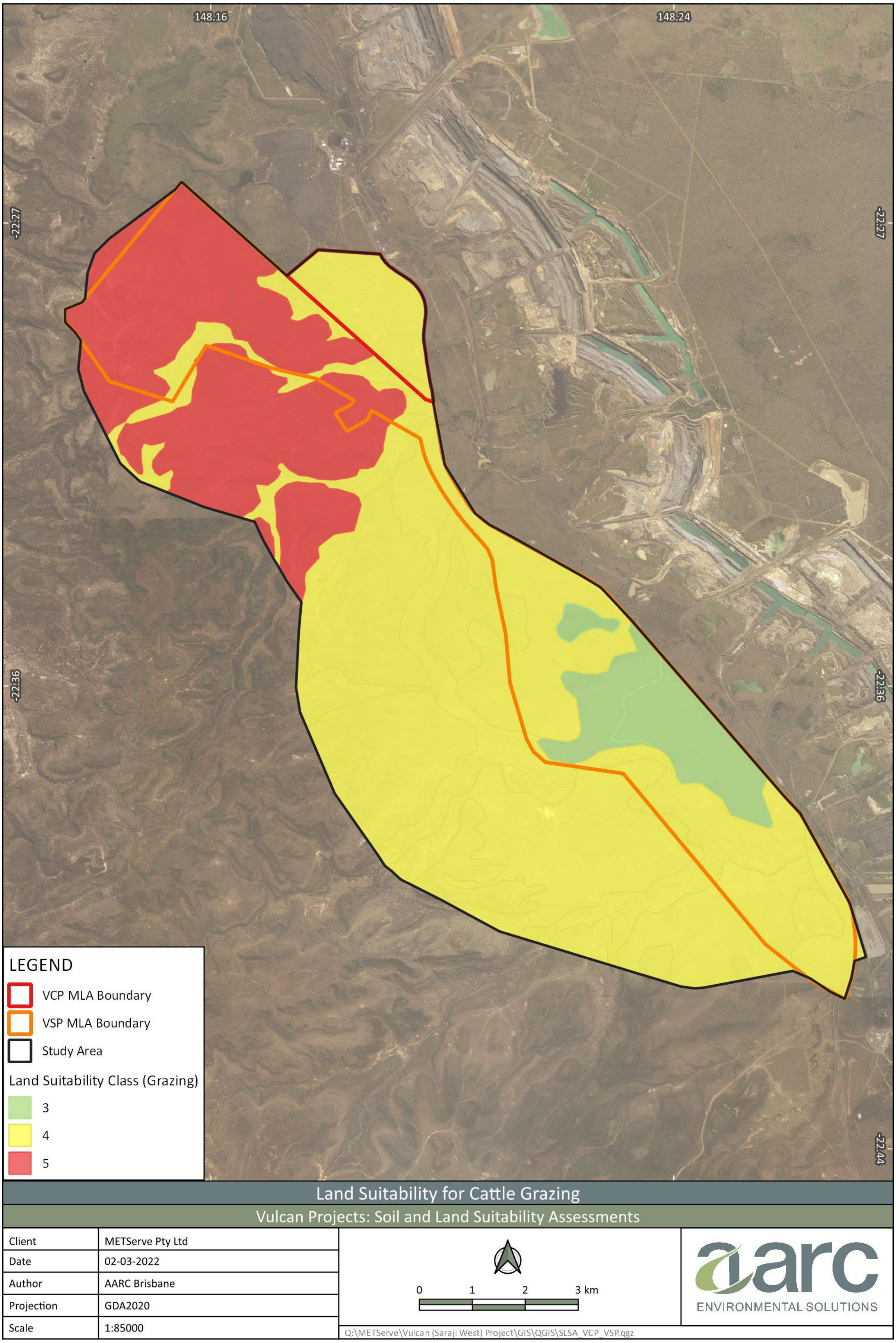


Figure 12: Cattle grazing land suitability classes

6.2 Rainfed broadacre cropping

Limitations for the assessment of rainfed broadacre cropping as outlined in the Land Suitability Assessment Technique (QDME 1995) Guidelines (Table 2.1) are:

- water availability;
- nutrient deficiency;
- soil physical factors;
- soil workability
- salinity;
- rockiness;
- micro relief;
- wetness;
- topography;
- water erosion; and
- flooding.

Numerous parameters outlined in this assessment require determination of the 'rootzone'. The rootzone is the depth to hard or weathered rock, or the depth to a significant salt bulge within the soil profile. Where these limitations are not encountered within the sampling depth, a rootzone value of 0.6 m can be assumed as described in the QDME guidelines (1995).

Class 1 and **Class 2** land is considered suitable for rainfed broadacre cropping with negligible or minor limitations and limited management requirements to sustain this use. **Class 3** land is considered suitable however, it is likely to be less productive than lands of Class **1 or 2**. **Class 4** land is categorised as marginally suitable for rainfed broadacre cropping or would require significant inputs to ensure land use sustainability. **Class 5** land is unsuitable having extreme limitations and cannot be sustainably used for the rainfed broadacre cropping.

Each of the limitations listed above are assessed below on the basis of Table 2.1 of the QDME guidelines (1995).

6.2.1 Water availability

The PAWC cut-off levels for each of the land suitability classes are as follows:

Class 1: > 150 mm

Class 2: 125–150 mm

Class 3: 100–125 mm

Class 4: 75 –100 mm

Class 5: < 75 mm

These cut-off levels are not based on a specific crop-type, but on rainfed broadacre cropping as a general land use. The soils are assessed on the depth to weathered rock, or other root inhibiting factors such as a salt bulge or significant sodicity. The availability of water in soils is vital for both plants and soil organisms as they require water to survive. Table 55 provides the outcomes of the land suitability class assessment on the basis of plant available water capacity.

Table 55: Land suitability for rainfed broadacre cropping based on PAWC

Soil management unit	Limiting features	PAWC (mm)	Land suitability class
Crocodile	Shallow sands and sandy loams ≤45 cm deep	< 75 mm	5
Fish	Sands and sandy loams 45–90 cm deep	< 75 mm	5
Kei	Sands and sandy loams >90 cm deep	75–100 mm	4
Komati	Cracking clays: alkaline to neutral pH throughout and 60–90 cm depth to ESP ≥ 15	100–125 mm	3
Limpopo	Duplex soils with subsoil becoming sodic (ESP 614) within 60 cm of the surface but not strongly sodic (ESP ≥ 15) within 90 cm	75–100 mm	4
Orange	Cracking clays: alkaline to neutral pH throughout and 60–90 cm depth to ESP ≥ 15	100–125 mm	3
Sabie	Duplex soils with subsoil becoming sodic (ESP 6–14) within 60 cm of the surface but not strongly sodic (ESP ≥ 15) within 90 cm	75–100 mm	4
Zambezi	Duplex soils with a sodic subsoil (ESP 6–14) becoming strongly sodic (ESP ≥ 15) within 60 cm of surface	< 75 mm	5

6.2.2 Nutrient deficiency

The nutrient status of each SMU identified has been assessed and the results are presented in Table 56. Note that bicarbonate phosphorus was only analysed within the topsoil layer (0–10 cm). Soil nutrients are vital for plant growth and metabolism.

Table 56: Land suitability for rainfed broadacre cropping based on nutrient status

Soil management unit	Limiting features	Land suitability class
Crocodile	Bicarbonate P 5–10 ppm and exchangeable K ≤ 0.3 meq %	3
Fish	Bicarbonate P < 10 ppm and exchangeable K ≤ 0.3 meq % and exchangeable Ca < 3 meq %	4
Kei	Bicarbonate P < 10 ppm and exchangeable K ≤ 0.3 meq % and exchangeable Ca < 3 meq	4
Komati	Bicarbonate P < 10 ppm and exchangeable K ≤ 0.3 meq % and exchangeable Ca < 3 meq %	4
Limpopo	Bicarbonate P < 10 ppm and exchangeable K ≤ 0.3 meq % and exchangeable Ca < 3 meq %	4
Orange	Bicarbonate P 5–10 ppm and exchangeable K ≤ 0.3 meq %	3
Sabie	pH < 5 within 30 cm of the surface	5
Zambezi	Bicarbonate P < 10 ppm and exchangeable K ≤ 0.3 meq % and exchangeable Ca < 3 meq %	4

6.2.3 Soil physical factors

Soil physical factors for each SMU identified have been assessed with results presented in Table 57. The physical condition of soils plays a direct role with seed germination and emergence. Adverse conditions such as hard-setting or crusting of surface soils reduces plant establishment through creating a barrier, reducing seed soil contact.

Table 57: Land suitability for rainfed broadacre cropping based on soil physical factors

Soil management unit	Limiting features	Land suitability class
Crocodile	Rigid soils with a hard-setting surface when dry	3
Fish	Rigid soils with a loose, soft or firm surface when dry	1
Kei	Rigid soils with a loose, soft or firm surface when dry	1
Komati	Cracking clays with fine self-mulch (peds 2–10 mm)	2
Limpopo	Rigid soils with a loose, soft or firm surface when dry	1
Orange	Cracking clays with fine self-mulch (peds 2–10 mm)	2
Sabie	Rigid soils with a hard-setting surface when dry	3
Zambezi	Rigid soils with a loose, soft or firm surface when dry	1

6.2.4 Soil workability

Soil physical factors for each SMU identified have been assessed with results presented in Table 58. The workability of soils refers to the capacity of the soil to support machinery during management practices such as tillage.

Table 58: Land suitability for rainfed broadacre cropping based on soil workability

Soil management unit	Limiting features	Land suitability class
Crocodile	Rigid soils with a hard-setting surface when dry	2
Fish	Rigid soils with a loose, soft or firm surface when dry	1
Kei	Rigid soils with a loose, soft or firm surface when dry	1
Komati	Firm cracking clays	2
Limpopo	Rigid soils with a loose, soft or firm surface when dry	1
Orange	Firm cracking clays	2
Sabie	Rigid soils with a loose, soft or firm surface when dry	1
Zambezi	Rigid soils with a loose, soft or firm surface when dry	1

6.2.5 Salinity

Land suitability class for each SMU based on salinity has been assessed with the results provided in Table 59. Given salinity can inhibit plant growth, the highest EC recorded is considered the most limiting factor and dictates the rating given to each SMU. Significant levels of salinity present in the rootzone can negatively impact plant growth and production.

Table 59: Land suitability for rainfed broadacre cropping based on salinity

Soil management unit	Limiting features	Land suitability class
Crocodile	Rootzone EC < 0.15 mS/cm	1
Fish	Rootzone EC < 0.15 mS/cm	1
Kei	Rootzone EC < 0.15 mS/cm	1
Komati	Rootzone EC 0.3–0.9 mS/cm	3
Limpopo	Rootzone EC < 0.15 mS/cm	1
Orange	Rootzone EC 0.3–0.9 mS/cm	3
Sabie	Rootzone EC < 0.15 mS/cm	1
Zambezi	Rootzone EC < 0.15 mS/cm	1

6.2.6 Rockiness

The land suitability for each SMU based on rockiness was assessed with results presented in Table 60. The impacts of rockiness are more extreme for cropping than for grazing. In regard to cropping, rock outcrops reduce the area available to grow crops, as land cannot be easily traversed or mechanised.

Table 60: Land suitability for rainfed broadacre cropping based on rockiness

Soil management unit	Limiting features	Land suitability class
Crocodile	20–50% surface cobble (6–20 cm diameter) and rock outcrop	3
Fish	<10 course surface gravel (>6 cm diameter)	1
Kei	<10 course surface gravel (>6 cm diameter)	1
Komati	<10 course surface gravel (>6 cm diameter)	1
Limpopo	<10 course surface gravel (>6 cm diameter)	1
Orange	<10 course surface gravel (>6 cm diameter)	1
Sabie	<10 course surface gravel (>6 cm diameter)	1
Zambezi	<10 course surface gravel (>6 cm diameter)	1

6.2.7 Microrelief

The microrelief for each SMU identified has been assessed with results presented in Table 61. 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 rainfed broadacre cropping are only experienced when soil is severely melonholed. Ponding of water in the depressions can compromise growing conditions directly impacting on crop growth and yield.

Table 61: Land suitability for rainfed broadacre cropping based on microrelief

Soil management unit	Limiting features	Land suitability class
Crocodile	No melonholes (semi-circular depressions <30 cm deep and usually surrounded by mounds)	1
Fish	No melonholes (semi-circular depressions <30 cm deep and usually surrounded by mounds)	1
Kei	No melonholes (semi-circular depressions <30 cm deep and usually surrounded by mounds)	1
Komati	Melonholes cover <20% surface area	2
Limpopo	No melonholes (semi-circular depressions <30 cm deep and usually surrounded by mounds)	1
Orange	Melonholes cover <20% surface area	2
Sabie	No melonholes (semi-circular depressions <30 cm deep and usually surrounded by mounds)	1
Zambezi	No melonholes (semi-circular depressions <30 cm deep and usually surrounded by mounds)	1

6.2.8 Wetness

The land suitability class identified for each SMU based on wetness has been assessed with results presented in Table 62. 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 62: Land suitability for rainfed broadacre cropping based on wetness

Soil management unit	Limiting features	Land suitability class
Crocodile	Undulating terrain or elevated plains	1
Fish	Non-sodic rigid soils with coarse pale grey and yellow mottles within 50 cm of the surface	3
Kei	Low-lying level plains with melonholes covering <25 % surface area	2
Komati	Rigid soils with strongly sodic subsoil (ESP≥15) within 60 cm of the surface	3
Limpopo	Rigid soils with sodic subsoil (ESP 6–14) within 60 cm of the surface	2
Orange	Rigid soils with strongly sodic subsoil (ESP≥15) within 60 cm of the surface	3
Sabie	Rigid soils with sodic subsoil (ESP 6–14) within 60 cm of the surface	2
Zambezi	Rigid soils with strongly sodic subsoil (ESP≥15) within 60 cm of the surface	3

6.2.9 Topography

The land suitability class identified for each SMU based on wetness has been assessed with results presented in Table 63. The topography limitation refers to the surface features of the land. Substantial variation in slope and elevation of an area can introduce limitations for cropping by reducing the area of land on which cropping is viable.

Table 63: Land suitability for rainfed broadacre cropping based on topography

Soil management unit	Limiting features	Land suitability class
Crocodile	Many deep gullies make the arable areas too small to cultivate	4
Fish	No gully dissection	1
Kei	No gully dissection	1
Komati	No gully dissection	1
Limpopo	No gully dissection	1
Orange	No gully dissection	1
Sabie	Occasional deep gullies impede cultivation slightly	2
Zambezi	Occasional deep gullies impede cultivation slightly	2

6.2.10 Water erosion

The land suitability class identified for each SMU based on water erosion has been assessed with the results presented in Table 64. Erosion of topsoil reduces the productivity of the land through the loss of key nutrients in the upper horizons of the soil.

Table 64: Land suitability for rainfed broadacre cropping based on water erosion

Soil management unit	Limiting features	Land suitability class
Crocodile	Slopes >6% on non-sodic rigid soils	5
Fish	Slopes 1–2 % on non-sodic soils	2
Kei	Slopes 1–2 % on non-sodic soils	2
Komati	Slopes <1% on non-sodic rigid soils	1
Limpopo	Slopes 1–2 % on non-sodic soils	2
Orange	Slopes <1% on non-sodic rigid soils	1
Sabie	Slopes 1–2 % on non-sodic soils	2
Zambezi	Slopes 1–2 % on non-sodic soils	2

6.2.11 Flooding

The land suitability class identified for each SMU based on flooding risk has been assessed with results presented in Table 65. Flooding may result in plant death or reduced growth. In severe cases where land is inundated for a prolonged period crop failure may occur.

Table 65: Land suitability for rainfed broadacre cropping based on flooding

Soil management unit	Limiting features	Land suitability class
Crocodile	No flooding	1
Fish	No flooding	1
Kei	No flooding	1
Komati	Rare flooding	2
Limpopo	No flooding	1
Orange	Rare flooding	2
Sabie	No flooding	1
Zambezi	Infrequent flooding	3

6.2.12 Summary of Land suitability for Rainfed Broadacre Cropping

Table 66 provides a summary of the assessed land suitability limitations for a rainfed broadacre cropping land use.

In the study area, the suitability of land for rainfed broadacre cropping is primarily limited by nutrient deficiency and water availability. Unsuitable nutrient availability in the soil has potential to impact crop health and yield. Fertiliser application is thus required to overcome this limitation, which is an additional expense to agricultural systems, subsequently reducing profitability of a farm. Additionally, water availability can also compromise crop growth by inducing water stress in crops and preventing the mobilisation of nutrients in the root zone.

No Class 1 or Class 2 land were identified within the study area. Examination of the land suitability limitations for rainfed broadacre cropping (Table 66) indicates that 471 ha of the study area is considered suitable land (Class 3), 3,760 ha of the Project area is considered marginal land (Class 4) with the remainder of the study area (5,919 ha) comprised of Class 5 land.

Figure 13 shows the distribution of land suitability classes for cattle grazing across the study area.

Table 66: Summary of land suitability limitations for rainfed broadacre cropping

Limitation	Crocodile	Fish	Kei	Komati	Limpopo	Orange	Sabie	Zambezi
Water availability	5	5	4	3	4	3	4	5
Nutrient deficiency	3	4	4	4	4	3	5	4
Soil physical factors	3	1	1	2	1	2	3	1
Soil workability	2	1	1	2	1	2	1	1
Salinity	1	1	1	3	1	3	1	1
Rockiness	3	1	1	1	1	1	1	1
Microrelief	1	1	1	2	1	2	1	1
Wetness	1	3	2	3	2	3	2	3
Topography	4	1	1	1	1	1	2	2
Water erosion	5	2	2	1	2	1	2	2
Flooding	1	1	1	2	1	2	1	3
Overall Suitability Rating	5	5	4	4	4	3	5	5

Notes: Green shading = suitable, red shading = unsuitable.

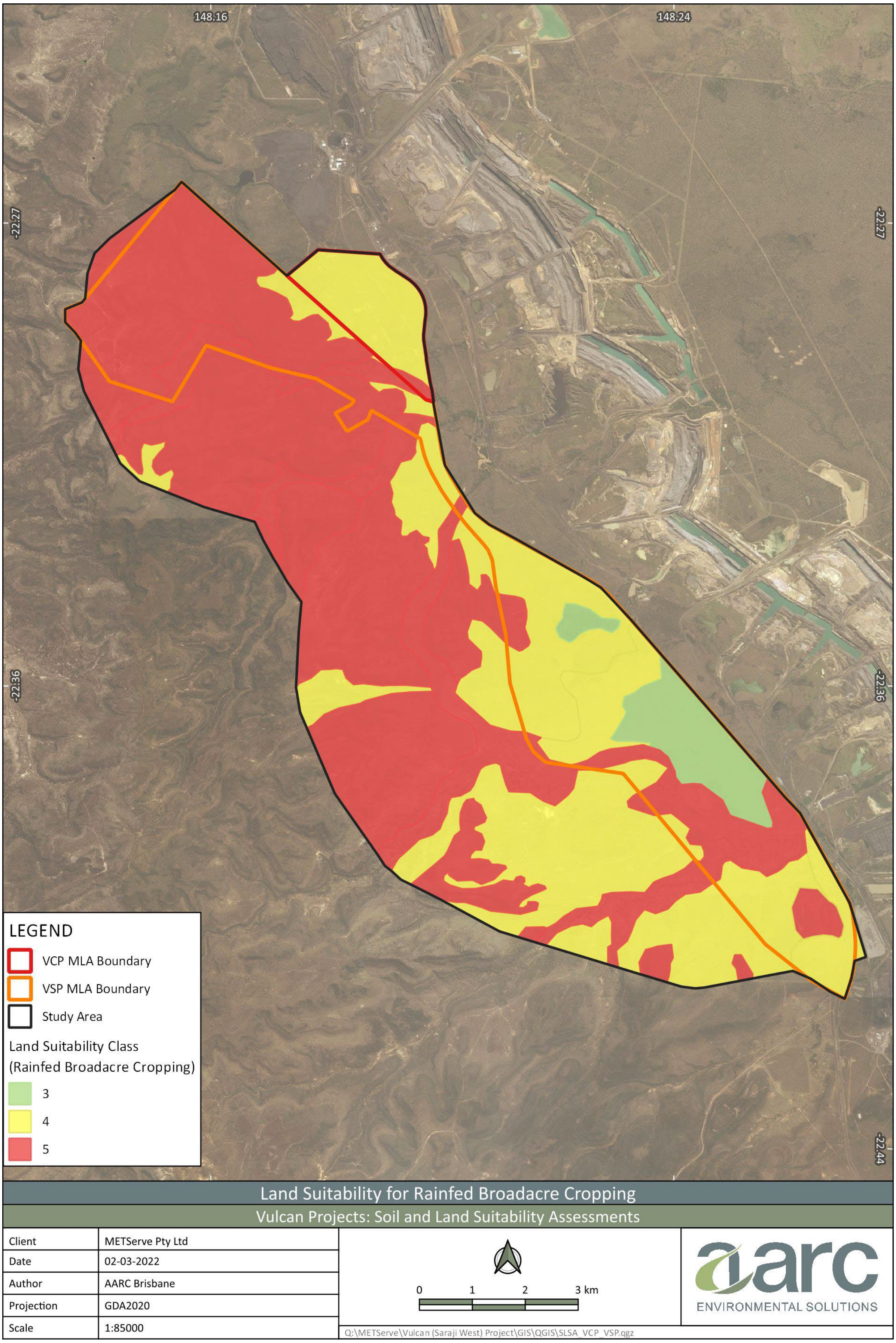


Figure 13: Rainfed broadacre cropping land suitability classes

7 Agricultural Land Assessment

Agricultural land class classification follows a hierarchical scheme in order to identify land that can be used sustainably for a particular land use to limit land degradation. There are three broad classes of agricultural land, namely Class A, Class B and Class C with one non-agricultural land class (Class D). Descriptions of agricultural land classes relevant to this agricultural assessment are provided in Table 67 (DSITI and DNRM 2015).

Table 67: Description of agricultural land classes

Class	Description
A	Cropping land—land that is suitable for a wide range of crops with nil to moderate limitations.
B	Limited cropping land—land that is suitable for a narrow range of crop types.
C1	Pasture land—land suitable for grazing on native pastures on higher fertility soils.
C2	Pasture land—land suitable for grazing on native pastures on lower fertility soils.
C3	Pasture land—Land suitable for light grazing on native pastures in accessible areas, and includes steep land.
D	Non-agricultural land—land not suitable for agricultural use.

Based on the outcome of the land suitability assessment, study area SMUs have been assigned the agricultural land classes as per Table 68.

Table 68: Summary of agricultural land classes

Agricultural land class assessment		
Soil management unit	Class	Area (ha)
Crocodile	C3	2,524
Fish	C3	77
Kei	C2	140
Komati	C2	263
Limpopo	C2	3,328
Orange	C2	474
Sabie	C3	1,869
Zambezi	C3	1,445

8 Soil Handling Recommendations

8.1 Topsoil suitability and stripping

In general, fertility decreases with depth in response to the variation with depth of the various parameters impacting on soil fertility. For the study area, usable soil resources are mainly confined to the surface horizons, which contain the seedstock, micro-organisms and nutrients necessary for plant growth. This section lists the SMUs and the maximum depth to which suitable material may be stripped for stockpiling and future rehabilitation. Stripping recommendations have been determined based on the SMU characteristics detailed in Section 4.

Where practicable, stripping should be timed to avoid periods of excessive rain or prolonged dry periods. Where practicable, topsoil should be directly placed in prepared rehabilitation areas and used immediately rather than stockpiled for later use. 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.

Table 69 summarises the maximum depths to which each SMU should be stripped, a detailed discussion of each SMUs topsoil resource is outlined in the following sections.

Table 69: Maximum topsoil stripping depths for all soil management units

SMU	Topsoil stripping depth (m)
Crocodile[2]	0.1
Fish[2]	0.1
Kei[2]	0.6
Komati[2]	0.1
Limpopo[1,2]	0.3
Orange[2]	0.1
Sabie	0.1
Zambezi[1,2]	0.3

Notes: 1 = SMUs present within the VCP area
2 = SMUs present within VS area

8.1.1 Crocodile soil management unit (stripping depth 0.1 m)

The Crocodile SMU is limited in its suitability as a topsoil medium where an improved pasture post-mining land use is to be implemented. The land within this SMU has uneven, rocky terrain which may introduce accessibility challenges for earth-moving machinery. Given this, the total volume of topsoil able to be sourced from this SMU may be reduced. The soil is very strongly acidic at the surface (pH 5.4) remaining so with depth. pH values such as these have potential to limit soil nutrient content and thus plant growth. Furthermore, this soil unit is very shallow often containing large quantities of unweathered rock material.

The Crocodile SMU may be better suited to use where a native ecosystem post-mining land use similar to that existing on this SMU is to be re-instated. In these circumstances, this material could be stripped to 0.1 to 0.2 m depth but should be segregated to ensure its use in an appropriate post-mining land use.

8.1.2 Fish soil management unit (stripping depth 0.1 m)

The topsoil to 0.1 m of the Fish SMU is suitable for rehabilitation purposes. Although acidic with a pH of 5.5, the topsoil of this unit is within the range suitable for plant growth. Due to a very low nutrient holding capacity (CEC 2.5 meq/100g), its use in an improved pasture post-mining land use would benefit from fertiliser additions. Below the depth of 0.1 m, the Fish SMU becomes sodic and thus dispersive. Therefore, a stripping depth of 0.1 m is recommended.

8.1.3 Kei soil management unit (stripping depth 0.6 m)

The upper 0.6 m of the Kei SMU is suitable for most rehabilitation end-uses as this soil has suitable pH and low ESP and salinity. Below this depth, the soil becomes moderately alkaline (pH 8.6), which can affect plant productivity by reducing plant-available nutrients. The Kei SMU has low nutrient content (CEC > 4.5 meq/100g) and would therefore benefit from fertiliser addition when revegetating. A stripping depth of 0.6 m is recommended.

8.1.4 Komati soil management unit (stripping depth 0.1 m)

Soil to a depth of 0.1 m in the Komati SMU is considered suitable for most rehabilitation purposes. Below this depth, the soil is severely limited by its chemical characteristics with pH increasing to 8.5 and continuing to become more alkaline with depth. This pH level will limit plant available nutrients compromising plant growth and health. Furthermore, the soil becomes more susceptible to dispersion with ESP values of 13% also increasing with depth. A stripping depth of 0.1 m is recommended.

8.1.5 Limpopo soil management unit (stripping depth 0.3 m)

The Limpopo SMU is suitable for most rehabilitation end-uses in the top 0.3 m of the profile. Below this depth, sodicity increases to strongly sodic levels, increasing the risk of dispersion and susceptibility to erosion. The nutrient holding capacity of this soil is very low with CEC at 2.3 meq/100g. The addition of fertiliser would enhance revegetation success. Importantly, the topsoil associated with this SMU is predominantly composed of sand (79%) and should therefore not be placed on slopes exceeding 3% without appropriate measures to manage stability.

8.1.6 Orange soil management unit (stripping depth 0.1 m)

The topsoil of the Orange SMU to 0.1 m is suitable for most rehabilitation end-uses. This soil possesses adequate plant nutrients and is not saline. However, surface soil in this unit is moderately alkaline (pH 8.1) which is towards the top of the suitable pH range for plant growth. Depending on the desired rehabilitation outcome, pH adjustment may be desirable. Below a depth of 0.1 m, pH becomes moderately to strongly alkaline and may be limiting for plant growth. In addition, ESP values increase to 7% and continue to increase with depth. Therefore, below 0.1 m this SMU is at risk of dispersion and will be limited in its potential to be used as a topsoil /growth medium.

8.1.7 Sabie soil management unit (stripping depth 0.1 m)

Due to several constraining factors, the Sabie SMU is not considered suitable for rehabilitation use except where a native ecosystem outcome similar to the pre-mining situation is intended. The surface soil of this unit is very strongly acidic (pH 4.6) limiting the availability of essential plant nutrients. The risk of aluminium toxicity is also high. The additional constraint of sodicity becomes apparent below the depth of 0.1 m with ESP values of 9% which increase throughout the profile.

8.1.8 Zambezi soil management unit (stripping depth 0.3 m)

The Zambezi SMU is suitable for most rehabilitation purposes to a depth of 0.3 m. This surface layer has suitable pH, low salinity and is not sodic. Below this depth, the soil becomes strongly sodic with an ESP of 18.5% and is therefore at high risk of dispersion and subsequent erosion. Stripping is therefore only recommended to a depth of 0.3 m. To assist initial revegetation success, it may be beneficial to supplement this surface soil with fertiliser to improve the inherent low nutrient value of soil. The surface soil of this unit is predominantly composed of sand-sized particles (77% sand) and it is therefore recommended that the use of this soil on rehabilitated surfaces exceeding a 3% slope should be limited.

8.2 Topsoil stockpiling

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. 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.

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:

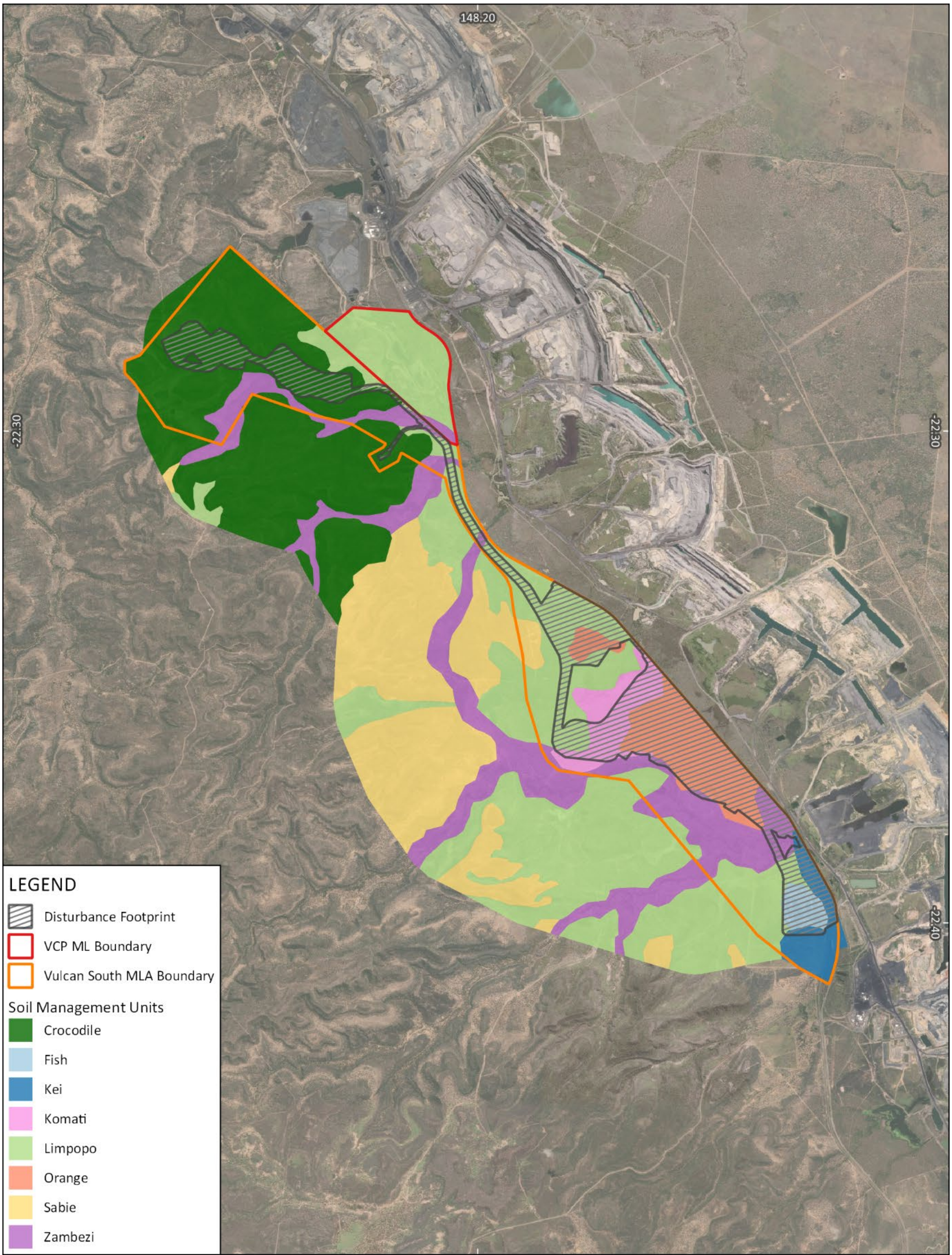
- Where practicable, stockpiles should be less than 2m high and be constructed and positioned in a manner that encourages water drainage and discourages erosion, and with appropriate erosion and sediment controls in place.
- If there is a risk of a grass cover not establishing voluntarily, stockpiles 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.
- Where soil has been stockpiled for extended periods, soil testing is recommended before use for rehabilitation purposes. If required, fertilisers and soil ameliorants should be applied.

Table 70 shows the estimated volumes of topsoil resource per SMU within the Project disturbance area, given the stripping depths outlined in section 8.1. The proposed disturbance area for the Project is shown in Figure 14.

Table 70: Estimated soil volumes—VS disturbance footprint

SMU	Topsoil Stripping Depth (m)	SMU area (m^2)	Potential Soil Volume (m^3)
Crocodile*	0.1	2,826,491	282,649
Fish*	0.1	751,423	75,142
Kei*	0.6	711,271	426,763
Komati*	0.1	1,553,106	155,311
Limpopo*	0.3	3,512,036	1,053,611
Orange*	0.1	4,457,088	445,709
Zambezi*	0.3	922,952	276,886
			Total topsoil = 2,716,070 m^3

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



Vulcan Project Disturbance Areas

Vulcan projects: Soil and Land Suitability Assessments

Client	METServe Pty Ltd
Date	29-09-2023
Author	AARC Brisbane
Projection	GDA2020 / MGA zone 55
Scale	1:100000

0 1 2 3 km

Q:\METServe\Vulcan (Saraji West) Project\GIS\Workspaces\230928_SLSA_SMU_EM.qgz

Figure 14: VS disturbance area

8.3 Topsoil placement

The proposed disturbance area (Figure 14) within the Project area suggests that topsoil material will be sourced predominantly from the Limpopo SMU. The Limpopo SMU is characterised as having moderate organic matter content and a high sand content and may therefore be at a greater risk of erosion-induced movement (Section 1.1). For this SMU, establishing a sufficient vegetative cover to mitigate erosion risk is important, particularly as rehabilitated slopes increase. To create a favourable environment for vegetation growth, topsoil from the Limpopo SMU will require application of one or more of the amelioration measures outlined in the following sub-sections.

Where possible, placement of topsoil at a minimum thickness of 0.2m is recommended for rehabilitation areas to create a growth medium of sufficient depth to hold water and support revegetation. For all rehabilitated areas, contour ripping and/or ploughing of the landform after topsoil placement should be undertaken to key the topsoil and subsoil layers together, and to improve seed germination conditions. Placement of armour rock or mulch cover to assist in stabilising the landform and reducing topsoil loss should be considered for slopes above 10%.

8.3.1 Topsoil amelioration

8.3.1.1 Organic matter application

Sandy soils such as the Limpopo SMU, usually have poor soil structure, low moisture retention and low available nutrient concentrations. The addition of organic matter to such soils helps to bind soil aggregates together and resist physical breakdown, improving soil structure; in turn increasing soil moisture retention and re-incorporating nutrients back into the soil. Where possible, topsoil should be stripped with its existing ground cover vegetation and, if subject to stockpiling, relocated with its cover crop vegetation.

Depending on availability, additional organic matter (such as mulches, manures, or compost), could be incorporated into the topsoil. Organic materials incorporated into the topsoil will increase organic carbon levels, providing more exchange sites for necessary cations, increase water holding capacity, and ensure less organic matter is oxidised into carbon dioxide and nitrous oxide or reduced into methane (Smith *et. al*. 2018). Application rates will vary depending on mulch type. Straw mulch should be applied at a rate of 5 t/ha (NSW Government 2015). Note that fresh mulch should not be used in acidic soils. Manure should be incorporated at rates of 5–30 t/ha (depending on the type of manure) (MLA n.d.). If available, compost can be applied at 70-150 t/ha (Kelly 2006).

8.3.1.2 Fertiliser application

Fertilisers can be utilised to increase nutrient concentrations in soil. As the Limpopo SMU is moderately acidic (pH of 5.5) care must be taken when fertilising, as some fertilisers (such as ammonium-based fertilisers) can have an acidifying effect on the soil. Were this to occur, lime applications would be required to mitigate the fertiliser's acidifying effects.

A calcium nitrate-based fertiliser such as calcium ammonium nitrate (15 to 27% N) is suitable for this application as it has near neutral effect on soil pH and can be used to increase both nitrogen and calcium levels in the soil. An application rate of 25–50 kg N/ha should be sufficient for successful vegetation establishment (CRDC 2020). This could be complemented with an application of sulphate of potash (41% K) to increase potassium levels in the soil. This fertiliser would also increase sulphur and can be applied with seeds (unlike other potassium fertilisers such as muriate of potash which can damage seed germination). Typical application rates of potassium for pastures in light soils are typically about 20 kg K/ha (Department of Primary Industries n.d.).

Alternatively, urea (46.7% N) could be applied as a nitrogen fertiliser (usually the most economical nitrogen fertiliser), but this would need to be applied in combination with lime (calcium carbonate), to overcome the acidifying effects of urea. A rate of 150 kg/ha of urea is recommended for soils in low rainfall areas where soil nitrate content is below 3 mg/kg. Limestone application rates should be around 1 t/ha of lime. It is expected that 1 t/ha of lime (incorporated in the first 10 cm of soil) can increase the pH of sandy soils by 0.6 units

(Department of Primary Industries n.d.). It is important to do follow up pH testing to evaluate the need to add more lime. Lime should be added initially at small doses and then at gradually increasing application rates as necessary.

Phosphorus application rates should be carefully determined, as many Australian native species are adapted to low phosphorus concentrations in the soil. Application rates of 10–20 kg P/ha have been suggested for grazing pastures (Victoria Government 2013) and mine restoration (Daws *et al.* 2013). To achieve this, single superphosphate (8.8% P) could be applied, which would also supply sulphate. (Note this fertiliser should not be blended with urea).

It is important that after application, soil ameliorants are incorporated into the soil to preferably a depth of about 0.3 m (for example by using a scarifier or ripper tynes) so they are not lost by wind or washed away by rainfall. After vegetation establishment (after 6 to 12 months since sowing), soils should be re-tested to determine if any follow-up application of ameliorants is required.

Besides using fertilisers, incorporating native leguminous forbs such as *Rhynchosia minima (*Rhynchosia) and *Glycine tabacina* (Variable Glycine) to the seed mix is a more natural method of increasing soil nitrogen levels due to the nitrogen fixing capabilities of legume species. This could establish natural nitrogen cycling within the topsoil resulting in long-term improvements in soil fertility and self-sustaining vegetation.

8.3.2 Cover crops

A fast-establishing sterile annual cover crop is recommended to be included in the seed mix. This will help to rapidly establish ground cover and minimise topsoil loss. This approach will also help to supress weeds and assist in restarting biological processes in the soil, creating a favourable micro-environment for the germination and emergence of the native seeds. Considering the sandy nature of the Limpopo topsoil, it is recommended that a cover crop is sown at a high seed density, of approximately 30 kg/ha. This should provide a rapid ground cover and assist in achieving soil stabilisation. *Echinochloa esculenta* (Japanese Millet) could be used for summer applications and *Lolium sp*. (Rye Grass) for winter applications. In the transition between cold and warm seasons, a combination of both species should be used.

8.3.3 Hydromulching

The use of hydromulching as an alternative to direct seeding is a further option that can be considered in zones at higher risk of erosion. Hydromulch consists of a semi-liquid water-based mixture composed of seed, water, mulch and other components (such as fertiliser, coir and tackifiers) which can be added depending on the site's amelioration requirements. The seed mix is included in the hydromulch slurry, which is sprayed onto the revegetation site as a thin layer (approximately 10 mm) to the soil surface, usually at a rate of approximately 50 m^3/ha for topsoil applications. The aim of using hydromulch is to cover and protect the soil, together with providing a suitable germination environment for seeds. The use of hydromulch can be effective at controlling erosion and stabilising the soil, by providing an erosion resistant layer for the period of time it takes for vegetation to become established.

8.4 Subsoil management

Excluding the Crocodile and Kei units, the subsoil layers (soil located below the recommended stripping depth of each SMU) of all other SMUs are severely constrained by elevated ESP values which place these materials at a high risk of dispersion. These constraints suggest that consideration of the use of these subsoils needs to be weighed against the geochemical and physical qualities of the waste rock materials being excavated. In particular, the requirements for separate handling, storage, placement and amelioration for these subsoils, may not provide sufficient benefit over their non-use.

Outside of the Project area, the subsoil characteristics of the Crocodile and Kei units do represent an opportunity for use as a soil resource, given their non-sodic nature throughout the depth profile. If used as a soil resource, consideration should be given to incorporating ameliorants to address the pH limitations of these materials and improve their potential to support a rapid and successful rehabilitation outcome.

Sodic subsoils left exposed after topsoil stripping has occurred will represent an erosion and potential downstream sedimentation risk. Appropriate erosion and sediment control methods should be incorporated into stripping plans for these areas.

8.4.1 Subsoil amelioration

Where dispersive materials are to be used as subsoil, they should be treated with gypsum (calcium sulphate) prior to sowing/planting. Dispersive soils generally have low porosity, low air movement and therefore low oxygen availability for plants. They also have slow water infiltration which can lead to waterlogging. Gypsum application rates for moderate to severe dispersive soils usually range from 2.5 to 5 t/ha depending on site-specific characteristics (DPIRD 2020). Given the high exchangeable sodium percentage (21.5 %) and low pH present in the Limpopo subsoil, an application of 5 t/ha of gypsum is recommended. Gypsum causes soil particles to flocculate, therefore improving soil structure, increasing water and plant root penetration into the soil. Irrigation is also important; these soils should be well irrigated so that sodium is leached down the soil profile. In contrast, low amounts of water in the soil can result in sodium move up the soil profile by evaporation.

9 Potential Impacts and Management

9.1 Land suitability

The development of the Project will disturb land through the construction of infrastructure and operation of the mine. This disturbance will impact the land suitability of the Project areas throughout the life of the mine and potentially after its closure. Pre-mining land suitability classes are outlined in Section 6 and are summarised in Table 71.

Table 71: Summary of the size and suitability classes for Project area SMUs

SMU	Land suitability class (Grazing)	Land suitability class (Cropping)	Area (ha)
Crocodile	5*	5	1,195
Fish	4*	5	76
Kei	4*	4	174
Komati	3	4	262
Limpopo	4*	4	1,015
Orange	3	3	472
Sabie	4*	5	47
Zambezi	4*	5	577

Notes: Green = suitable, red = unsuitable. Items displayed with an asterisk (*) are considered suitable based on current land use of low intensity grazing.

Based on the pre-mining land use and the results of this SLSA, it is anticipated that rehabilitated landforms will be able to support a post-mining land use of cattle grazing, on the basis that current land use is low intensity cattle grazing and that appropriate soil amelioration strategies are implemented.

The economic viability of using rehabilitated land for grazing will be considered based on post-mine land suitability, as well as the total area available for cattle grazing. If developed, improved pastures will likely incorporate species such as Buffel, Rhodes and other grasses that perform well in local conditions. The areas classed as suitable for low intensity cattle grazing are extensive and are considered to offer a land use value equivalent to that existing pre-mining.

It should be noted that mining activities, including the stripping, stockpiling and handling, of soil, have the potential to impact its physical, chemical and biological properties. Therefore, the pre-mining land suitability for cattle grazing may be reduced for some rehabilitated landforms. These potential adverse impacts can be mitigated through:

- good topsoil management practices (See Section 8);
- the addition of fertilisers and soil ameliorants;
- timely seeding with suitable species; and
- post-establishment management of rehabilitated areas.

Where final landforms represent a relatively flat landscape (e.g. slopes less than 5%) it is envisaged that the post-mining land suitability for cattle grazing will reflect that of the pre-mining landscape.

Other areas, such as steeper outer slopes of spoil (e.g. slopes of > 10%) may be subject to increased risk of erosion. These areas will require management to ensure they remain safe, non-polluting, stable and able to sustain an agreed post-mining land use.

9.2 Erosion

Disturbance of vegetation and the topsoil layer can lead to the mobilisation of soil through the process of erosion, particularly water erosion through heavy rainfall or overland flow. The risk of erosion at the Project will be increased by the following activities:

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

Management recommendations to be considered, as required, to reduce the risk and impacts of erosion include:

- Limiting land clearing to the minimum amount of land required for safe operation of the Project.
- Diversion of overland flow/runoff around disturbed areas.
- Amelioration of sodic soils through the addition of gypsum, or addition of rock for stability if used in rehabilitation.
- Progressive rehabilitation of landforms and direct placement of topsoil to help preserve the seed bank and reduce erosion.
- Seeding of topsoil as soon as possible after placement onto rehabilitated areas, to ensure root masses assist in mitigating erosion.
- Topsoil stockpiles placed away from drainage areas, roads, machinery, transport corridors, and stock grazing areas.
- Topsoil stockpiles seeded or covered with a water-shedding lining to prevent unnecessary erosion of soil.
- The use of sediment control structures such as retention ponds, to minimise the release of water and suspended sediments into the receiving environment.

9.3 Topsoil erodibility and erosion risk

The topsoil of the Limpopo SMU has been identified as having a high sand composition making it susceptible to erosion, particularly if used on rehabilitated landforms with steep gradients. A soil erosion assessment was undertaken to determine potential erosion rates for the use of the Limpopo SMU in rehabilitation. The Limpopo SMU was utilised being the SMU most susceptible to erosion and of most importance as a topsoil resource.

The Revised Universal Soil Loss Equation (RUSLE) is a calculation used to estimate average annual soil loss caused by hillslope and rill erosion. The equation is limited to making predictions for long-term annual soil loss. The RUSLE equation is:

$$A = R \times K \times LS \times C \times P$$

Where:

- A is the predicted rate of soil loss in tonnes per hectare per year;
- R is the rainfall erosivity factor based on the total erosive power of storms during an average year and is dependent on local weather conditions;
- K is the soil erodibility factor, which has been specifically derived for the Project area SMUs;
- LS is the slope length-gradient factor which describes the combined effect of slope length and gradient on soil loss. The LS factor is a ratio that corresponds to soil loss per unit area of an experimental plot of known length and gradient;
- C is referred to as the cover and management factor which compares cropping practices, residue management, and soil cover to a standard clean fallow plot. C-factors for different agricultural uses and management practices are developed based on their observed deviation from the standard clean fallow plot; and
- P is the conservation or support practice factor and reflects the impact of support practices on the average annual erosion rate. It is the ratio of soil loss with contouring and/or strip cropping to that with straight row farming up-and-down slope.

The K factor was determined according to methodology described in the *Prediction of Sheet and Rill Erosion over the Australian Continent, Incorporating Monthly Soil Loss Distribution* (Lu et al 2001) using the equation:

$$K = 2.77(100\ P_{125})^{1.14}(10^{-7})\ (12\text{-}2OC) + (3.29\times10^{-3})\ (PP\text{-}3)$$

Where:

- K is the RUSLE soil erodibility factor, SI Units of t ha h ha^{-1} MJ^{-1} mm^{-1}
- P_{125} is the percentage of soil clay, silt and sand particles less than 0.125mm diameter
- OC is the Organic Carbon content; and
- PP is the soil profile permeability class.

Table 72 displays all the parameters relevant to the determination of the soil K factor and the resultant K factor for topsoil of the Limpopo SMU.

Table 72: Soil RUSLE K factors

P_{125} (%)	OC (%)	PP	K (t.ha.h)/(ha.MJ.mm)
38	1	3	0.033

The R factor for the Limpopo SMU soil type within the VS boundary has been derived from the *Queensland Spatial Catalogue* (Queensland Government 2020) which contains input R factor datasets available for use in the RUSLE. An average R value of 1,729.45 MJ/mm per ha/hr/yr for land within the Project area was determined using a vector analysis GIS tool to extract the available factor data. Although, grid cells that occupy less than 10% of the Project area were excluded from the analysis.

A P-factor of 0.9 has been adopted for this assessment based on ripping along the contour of the rehabilitated landform that is assumed to be undertaken after the placement of topsoil.

For the assessment of soil erosion on the rehabilitated landform, slope length and steepness (L and S factor) and the cover management factor (C-factor) are the principal variables impacting the assessment results. These factors have been manipulated independently to predict how changes to these factors influence the erosion potential of the landform.

Slope analysis

An investigation regarding how gradient influences erosion potential was included in this assessment to quantify the erosion risk associated with the design of the rehabilitated landform.

Gradient values used in the analysis vary from 1%, 5%, 10%, and 15% as these are reflective of the slopes proposed across the rehabilitated landform. An assumed conservative uninterrupted slope length of 100 m between contour banks has been used.

Cover-type analysis

For each slope type, a range of C-factors representative of various land management practices were incorporated to identify the practices that are likely most effective at reducing erosion potential. Land management practices include the application of biodegradable ground cover products, hydromulch and grass cover. It should be noted that this prediction of erosion rates for the Project is assumption based. Therefore, results should be used for comparative purposes as opposed to being considered as absolute values.

Using remote sensing technology, national averages for erosion have been determined (Lu et. al 2001) and are presented for comparison; these include:

- that the average Australian erosion rate is 6.3 tonnes per hectare per year;
- that a low rate of erosion is defined as less than 0.5 tonnes per hectare per year; and
- that a high erosion rate is defined as greater than 10 tonnes per hectare per year.

The output from the erosion analysis is presented in Table 73.

As expected, results suggest erosion is most effectively controlled through the establishment of grass cover across the land surface as vegetation protects the soil surface and slows surface run-off whilst root systems stabilise the sub-surface. On newly constructed landforms where vegetation is not yet established, the spreading of mulch is likely the most effective intermediate management practice as it offers protection comparable to that of hydromulching.

Results suggest that both slope and management practices greatly influence the erosion potential of the landform. Slopes across the rehabilitated landform have been designed to a maximum gradient of 15%. Erosion potential should, therefore, be able to be controlled through a combination of management practices.

Table 73: Predicted soil loss as a factor of slope and management practice

Management type	C	Gradient (%)	A (tonnes/ha.yr)
Jute Mesh	0.4	1	3
Jute Mesh	0.4	5	24
Jute Mesh	0.4	10	57
Jute Mesh	0.4	15	104
50% grass cover on recently disturbed soils	0.15	1	1
50% grass cover on recently disturbed soils	0.15	5	9

Management type	C	Gradient (%)	A (tonnes/ha.yr)
50% grass cover on recently disturbed soils	0.15	10	21
50% grass cover on recently disturbed soils	0.15	15	39
Wood Mulch	0.08	1	1
Wood Mulch	0.08	5	5
Wood Mulch	0.08	10	11
Wood Mulch	0.08	15	21
Hydromulch	0.07	1	1
Hydromulch	0.07	5	4
Hydromulch	0.07	10	10
Hydromulch	0.07	15	18
70% grass cover on recently disturbed soils	0.05	1	1
70% grass cover on recently disturbed soils	0.05	5	3
70% grass cover on recently disturbed soils	0.05	10	8
70% grass cover on recently disturbed soils	0.05	15	15

9.4 Erosion of rehabilitated landforms

Erosion of rehabilitated landforms reduces the likelihood of revegetation success, and in extreme cases can compromise the structural integrity of the landform, making it unstable and unsafe. In addition, if not managed correctly, erosion can result in the release of suspended sediments and potential contaminants into the receiving environment.

The topsoil of the SMUs within the Project area largely composed of sand whilst subsoils have dispersive characteristics. Soil is likely at high risk of erosion, particularly if this risk is not considered during the design of rehabilitated landforms. The rehabilitated landform design for the Project should consider implementing controls to manage surface runoff on final landform slopes. Such controls may include:

- Limiting side slopes of spoil to a maximum slope of 1V:6H (approximately 16%) or less.
- Construction of contour banks on slopes at a recommended spacing of 80 m for slopes of 1V:6H (MCA 1998). Larger contour drains are generally more stable and longer lasting. It is recommended that drains/berms are a minimum of 5 m wide and a minimum of 500 mm in height. Berms should be constructed of compacted material (IE Aust Erosion and Sediment Control Guidelines).
- Contour banks should convey water to engineered rock-lined spine drains on steep slopes. A competent basalt or alternative rock source is recommended. The use of geofabric in construction of rock-lined spine drains is also recommended.
- To reduce the need for engineered drains on steep slopes, landform modelling can be centred around gentle concave slopes or terraced profiles, or in accordance with geomorphic principles. For materials prone to erosion, designs such as these can significantly reduce runoff velocity and erosion by a magnitude of two or three times, however, this approach can be difficult to implement where space is a limiting factor.

- Maintaining a high vegetative ground cover across the rehabilitation landform, particularly where the gradient exceeds 10% (Section 9.3).
- The incorporation of rock into the topsoil medium can also assist in reducing erodibility, as well as increasing infiltration (Commonwealth of Australia 2016).
- Rehabilitated areas should be ripped to reduce compaction from heavy machinery, encourage infiltration of water and prevent erosion. If engineered waterways are included in the landform, areas should be ripped on a grade (e.g. 0.5%). Otherwise, areas should be ripped on the contour. Ripping depths will vary depending on the type of spoil material, depth of topsoil and equipment used for rehabilitation operations. Typical ripping depths for this Project would be about 400–500 mm.
- Avoiding the use of any sodic subsoil material for use as a subsoil medium (see section 6.4).

9.5 Soil degradation

Stripping, stockpiling and handling of topsoil can potentially have a negative impact on the chemical and physical attributes of the soil. Impacts associated with mining activities include the following:

- exposure of sodic subsoils during soil stripping. This is applicable to all SMUs within the Project areas excluding Crocodile and Sabie;
- loss of soil physical structure due to excavation and handling;
- loss of the soil seedbank; and
- impacts on soil fertility due to mixing with subsoils and resulting changes in soil chemistry as subsoils are exposed to oxygen.

Physiochemical changes to the soil may impact on the viability of the soil seed bank and reduce the likelihood of successful rehabilitation if not well managed. Management recommendations to reduce the risk of soil degradation and improve the chances of rehabilitation success include:

- Segregation of saline or sodic soils and clear demarcation and labelling/recording of stockpiles to ensure appropriate use of the resource;
- Minimising the handling of topsoil;
- Ensuring that when required, stockpiles are generally less than 2 m high and contoured to encourage water to drain;
- 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. The proponent could consider conducting soil physiochemical analysis of stockpiled topsoil resources to assess for changes in topsoil quality (changes to soil chemistry and biological activity as a result of being stockpiled). Key parameters that should be considered during this additional testing, if undertaken, include pH, ESP, CEC (major cations), organic matter content and other essential nutrients such as nitrate, phosphorous and sulphate; and
- The application of fertilisers, soil ameliorants and an appropriate seed mix are recommended for some SMUs to increase the likelihood of rehabilitation success. Recommendations relevant to SMUs requiring amendments are discussed in Section 6.1.

9.6 Erosion monitoring on rehabilitated landforms

Erosion monitoring across the landform will be integral to the early detection of erosion and will allow for early intervention. Erosion monitoring can be undertaken using physical observation in the field or remotely with the use of aerial photography and lidar imagery. A brief description of suitable methodologies is provided below.

9.6.1 Field assessment methodologies

In-field erosion monitoring is based on visual assessments taken over time. Permanent monitoring transects, 50 m in length should be established across the landform to provide a basis for temporal assessments. Visual observations should be taken whilst traversing the 50 m transects on foot and recording the number and average depth of any erosion features, rill lines or gullies. It should be noted that the placement of the permanent transects may not be a true reflection of erosion across the rehabilitated landforms. General observations should therefore also be undertaken during the monitoring event. Visual assessments should identify any evidence of excessive sediment movement, including the formation of rills, removal of soil around the base of plants and accumulation of loose sediment at the base of slopes. In-field erosion monitoring should also include an assessment of the water quality of run-off water released from the catchment of a given rehabilitation area.

Table 74 records and classifies the severity of erosion observations. The overall classification of the erosion on each transect was based on the most severe characteristic of the erosion observed, i.e. either the number of rills/gullies or the average depth. For example, a transect may present only one or two rills, however, if an average depth of 25 cm is recorded, the transect will be classified as having moderate erosion.

Table 74: Erosion classifications

Erosion classification	Minor	Moderate	Major	Extensive
No. of rill(s)/gully(ies)*	< 15	15–30	31–50	> 50
Average depth (cm)	< 10	10–30	30–60	> 60

*Gully: highly visible form of soil erosion, with steep-sided, incised, drainage lines greater than 30 cm deep

9.6.2 Remote sensing methodologies

The advent of remote sensing technologies, the increasing availability of satellite imagery and the development of accurate, near-field, point-cloud surveying capability (e.g. LiDAR) creates a number of options for monitoring indicators relevant to the assessment of rehabilitated areas and sheet, rill and/ or gully erosion development more specifically. For rehabilitation assessments, there needs to be a good understanding of how such technologies work, as they bring their own specific requirements which must be addressed (e.g. coordinate reference systems, datum points, object interference etc.).

Various remote sensing technologies are now able to be used for the assessment of rehabilitated areas. They can be used for assessing the same area over time which can be useful to assess sheet erosion and or the development of rill and gully erosion over time, as well as detection of existing rill and gully erosion. It is generally recommended that such technologies be used in conjunction with the in-field monitoring technologies discussed above to provide a calibration for what is being measured.

10 References

Bourne GF and Tuck GA (1993). Resource Information, in RN Thwaites and JM Maher (eds.) Understanding and Managing Soils in the Central Highlands, Department of Primary Industries Training Series QE93002, Brisbane.

Brooks JD and Smith JW (1969). The diagenesis of plant lipids during the formation of coal, petroleum and natural gas—II. Coalification and the formation of oil and gas in the Gippsland Basin, Geochimica et Cosmochimica Acta, 33(10), pp. 1183–1194

Bureau of Meteorology (2018) Queensland River Basins. Available from: <http://www.bom.gov.au/qld/flood/brochures/qld/map.pdf>

Bureau of Rural Science (1991). Digital Atlas of Australian Soils. Department of Agriculture, Fisheries and Forestry. Commonwealth of Australia. Available from: http://www.asris.csiro.au/themes/Atlas.html#Atlas_Digital (Accessed 06.08.10)

Connolly EL and Guerinot ML (2002). Iron stress in plants. Genome Biology, 3(8), reviews1024.1–reviews1024.4.

CRDC (2020). Best Management Practices for Nitrogen (N) Fertilizer Use on Dairy Pastures–More Profit from Nitrogen Program. Retrieved from: https://www.crdc.com.au/more-profit-nitrogen (Viewed on 17th August 2020).

Daws MI, Standish J, Koch JM and Morald TK (2013). Nitrogen and phosphorus fertilizer regime affect jarrah forest restoration after bauxite mining in Western Australia. Applied Vegetation Science, 16 (4): pp. 610–618.

Department of Environment and Heritage Protection (2011) Mackenzie River Sub-basin Environmental Values and Water Quality Objectives Basin No. 130 (part), including all waters of the Mackenzie River Sub-basin. Available from: https://www.ehp.qld.gov.au/water/policy/pdf/plans/fitzroy_mackenzie_river_wqo_290911.pdf

Department of Environment and Science (2018) Fitzroy Drainage Basin—Facts and Maps. Available from: https://wetlandinfo.des.qld.gov.au/wetlands/facts-maps/basin-fitzroy/

Department of Environment and Science (2019). Isaac River drainage sub-basin—facts and maps. [Online] available at: https://wetlandinfo.des.qld.gov.au/wetlands/facts-maps/sub-basin-isaac-river/

Department of Minerals and Energy (1995). Technical Guidelines for Environmental Management of Exploration and Mining in Queensland—Land Suitability Assessment Techniques. Queensland Government. Brisbane, Queensland.

Department of Primary Industries Victoria (n.d.). Fertilizing Pastures. Retrieved from: http://www.ccmaknowledgebase.vic.gov.au/shkb/brown_book/documents/15_Sulphur/Greener_pastures_Chapter5.pdf (viewed 17th August 2020).

Dickins JM and Malone EJ (1973). Geology of the Bowen Basin, Queensland. Bureau of Mineral Resources, Geology and Geophysics Bulletin No. 130. Australian Government Publishing Service, Canberra.

DPIRD (2020). Department of Primary Industries and Regional Development. Agriculture and Food. Managing dispersive (sodic) soils. Retrieved from: https://www.agric.wa.gov.au/dispersive-and-sodic-soils/managing-dispersive-sodic-soils. (Viewed 17th August 2020).

DSITI and DNRM (2013). Regional Land Suitability Frameworks for Queensland. Queensland Government (Department of Science, Information Technology and Innovation and Department of Natural Resources and Mines), Brisbane Queensland. Chapter 10—Suitability Framework for the Inland Fitzroy and Southern Burdekin area.

DSITI and DNRM (2015). Guidelines for Agricultural Land Evaluation in Queensland (2nd edition). Queensland Government (Department of Science, Information Technology and Innovation and Department of Natural Resources and Mines), Brisbane Queensland.

Emerson WW (1967). A classification of soil aggregates based on their coherence in water, *Australian Journal of Soil Research,* 5, pp. 47-57

Geoscience Australia (2019) Province and Sedimentary Basin Geology–Bowen Basin. Available from: http://www.ga.gov.au/scientific-topics/energy/province-sedimentary-basin-geology/petroleum/onshore-australia/bowen-basin

Government of South Australia (2013) Standard Soil Test Methods and Guidelines for Interpretation of Soil Results. Retrieved from: <https://www.naturalresources.sa.gov.au/southeast/land/soil-management/Soil-testing-andobservation?BestBetMatch=standard%20soil%20est%20methods|b7dc1d2c-0a3f-428b-b83a90df9be8fdaa|02988d82-57e4-44c1-9647-a32500af070b|en-AU>

Hazelton P and Murphy B (2016) Interpreting Soil Test Results—What do all the Numbers Mean? Third Edition. CSIRO Publishing, Melbourne.

Hutton AC (2009) Geological Setting of Australasian Coal Deposits, *Australasian Coal Mining Practice* (pp. 40–84)

Isbell RF (1996). The Australian Soil Classification. Australian Soil and Land Survey Handbook Series. CSIRO Publishing, Melbourne.

Kabata-Pendias A and Pendias H (2001). Trace Elements in Soils and Plants (3rd Edition) CRC Press, New York.

Keipert NL (2005). Effect of different stockpiling procedures in open cut coal mine rehabilitation in the Hunter Valley, NSW, Australia, PhD thesis, University of New England.

Kelly (2006). Recycled organics in mine site rehabilitation. Report prepared for the Department of Environment and Conservation NSW.

Lu H, Gallant J, Prosser IP, Moran C, Priestly G (2001). *The prediction of Sheet and Rill Erosion Over the Australian Continent, Incorporating Monthly Soil Loss Distribution*, Technical Report 13/01, CSIRO Land and Water, Canberra, Australia.

McKenzie NJ, Grundy MJ, Webster R and Ringrose-Voase (2008). Guidelines for Surveying Soil and Land Resources. Australian Soil and Land Survey Handbook Series. CSIRO Publishing, Melbourne.

MLA (n.d.) Meat and Livestock Australia. Beef Cattle feedlots: waste management and utilization. Retrieved from: https://www.mla.com.au/globalassets/mla-corporate/research-and-development/program-areas/feeding-finishing-and-nutrition/manure-handbook/section-5-utilisation-of-manure-and-effluent-2016_07_28.pdf (viewed 17 August 2020).

Mutton AJ (2003) Queensland Coals–Physical and Chemical Properties, Colliery and Company Information. Department of Natural Resources and Mines. Available from: https://www.dnrm.qld.gov.au/?a=267497

National Committee on Soil and Terrain (2009). Australian Soil and Land Survey Field Handbook, Third Edition. Australian Soil and Land Survey Handbook Series. CSIRO Publishing, Melbourne.

NSW Government (2015), Transport Roads & Maritime Services. Guidelines for batter surface stabilisation.

Queensland Spatial Catalogue–QSpatial (2020). Interactive Web Resource. Available from: http://qldspatial.information.qld.gov.au/catalogue/, Queensland Government.

Rayment GE and Bruce RC (1984). *Soil testing and some soil test interpretations used by the Queensland DPI*. Queensland Department of Primary Industries Information Series QI 84029, Brisbane.

Rayment GE and Lyons D (2011). Soil Chemical Methods—Australasia. Australian Soil and Land Survey Handbook Series. CSIRO Publishing, Melbourne.

Smith KA, Ball T, Conen F, Dobbie KE, Massheder A and Rey A (2018) Exchange of greenhouse gases between soil and atmosphere: interactions of soil physical factors and biological processes. *European Journal of Soil Science, 69*(1), pp. 10–20

Story R, Galloway RW, Gunn RH and Fitzpatrick EA (1967), *Lands of the Isaac-Comet Area, Queensland. Land Research Series No 19.* CSIRO, Melbourne.

Thwaites RN and Maher JM (eds.) (1993). *Understanding and Managing Soils in the Central Highlands*, Department of Primary Industries Training Series, Brisbane.

Victoria Government (2013). Corangamite Region 'Brown Book'—How to optimise your soils to enhance productivity, retrieved from: https://www.ccmaknowledgebase.vic.gov.au/brown_book/12_Superphosphate.htm (viewed 18 August 2020)2

Withnall IW (1989). Precambrian and Palaeozoic geology of the south eastern Georgetown Inlier, north Queensland. Queensland Department of Mines, Report 2, pp. 102

Withnall IW and Cranfield LC (2012). Queensland Geological framework. Department of Natural Resources and Mines, Queensland Minerals. Retrieved from https://www.dnrm.qld.gov.au/__data/assets/pdf_file/0007/197647/geology-of-queensland.pdf

Appendix 1 Lab Results

Appendix 2 Soil Profile Data

Appendix 3 Soil Observation Data

Appendix 4 Sampling Site Locations