West Musgrave Copper and Nickel Project

December 2020

EPA Section 38 Referral Supporting Document
Appendix C Landforms

TABLE OF CONTENTS

APPENDIX C. LANDFORMS

Appendix C1. Soil and Landform Baseline Assessment

West Musgrave Project
Baseline Soil and Landform Study

Prepared for:

OZ Minerals Limited

May 2019

Prepared by:

Martinick Bosch Sell Pty Ltd
4 Cook Street
West Perth WA 6005
Ph: (08) 9226 3166
Email: info@mbsenvironmental.com.au
Web: www.mbsenvironmental.com.au

MBS ENVIRONMENTAL

environmental and geoscience consultants

West Musgrave Project
Baseline Soil and Landform Assessment

Distribution List:

Company	Contact name	Copies	Date
OZ Minerals Limited	Justin Rowntree – Environment and Approvals Lead – West Musgrave	[01]	22 May 2019
OZ Minerals Limited	Kim Ferguson - Senior Environmental Advisor	[01]	22 May 2019

Document Control for Job Number: OZMSLA

Document Status	Prepared By	Authorised By	Date
Draft Report	David Allen / Thomas Robson	Kristy Sell	2 April 2019
Final Report	David Allen / Thomas Robson	Kristy Sell	2 May 2019
Final Report - Revision 1	David Allen / Thomas Robson	Kristy Sell	22 May 2019

EXECUTIVE SUMMARY

PROJECT BACKGROUND

OZ Minerals Limited (OZ Minerals) and Cassini Resources Limited (Cassini) propose to develop the West Musgrave Copper and Nickel Project (the West Musgrave Project (WMP)) in the West Musgrave Ranges of Western Australia (WA) as a Joint Venture. The WMP is located approximately 1,600 km north east of Perth near the border with South Australia and Northern Territory; 29 km south of Jameson and 110 km south east of Warburton (Figure 1).

The WMP consists of a number of prospective copper and nickel deposits known as Nebo, Babel, Succoth and Yappsu, with Nebo and Babel (also referred to as Nebo-Babel) being at the most advanced stage of mineral evaluation. The Joint Venture aims to develop a project that supports mine and processing plant and associated mine waste facilities, water facilities, an accommodation village and other associated industrial and non-industrial infrastructure.

OBJECTIVE AND SCOPE OF WORK

MBS Environmental (MBS) was engaged by OZ Minerals to undertake a baseline soil and landform assessment to inform project design, environmental impact assessment and closure planning. The primary objective of the study was to determine the suitability of topsoils and subsoils for use during rehabilitation of land disturbances in the Project area. The scope of work included a desktop assessment of land systems, soils and landforms, verification of desktop assessment findings through site investigation, and submission of topsoil and subsoil samples collected within the Detailed Study Area (potential locations of pits and key mining infrastructure) to ChemCentre for various physical and geochemical tests.

LANDFORMS

The Project area is characterised by generally subdued relief, comprising gently undulating aeolian sandplains and minor longitudinal dunes dissected by a broad calcrete paleochannel valley. Dominant vegetation types include spinifex (*Triodia* spp.) and other grasses, with minor mulga and mixed species shrubs.

Several major landforms (i.e. obvious landscape features) were identified within 30 km of the Project area, including Blackstone Range (12 km east of the potential Northern Borefield location), Cavenagh Range (3 km southwest of the potential Northern Borefield), Jamieson Range (5 km northeast of the potential Jameson Access Road) and Barrow Range, located immediately to the west of the potential Western Access Road route. None of these major regional landforms will be impacted by the Project.

Other notable landforms (i.e. referenced in regional scale maps) identified within 30 km of the Project area included low stony hillocks (Mulaggora Hills, Milyugal Hills, Borrows Hill, Round Hill and Hacking Range), located between 2 and 28 km east and west of the potential Southern Borefield location, and small stony hillocks located within 5 km of the Detailed Study Area (Cohn Hill, Minnie Hill and Red Rock), which includes the proposed pits and locations of potential waste landforms (waste rock dumps and tailings storage facility) and a renewable energy area. None of these notable landforms will be impacted by the Project.

The significance of the landforms mentioned above was not assessed, as discussed in the Western Australian Environmental Protection Authority *Environmental Factor Guideline for Landforms* (EPA 2018), as they are located outside of the Project area and will not be disturbed by the Project.

Within the Detailed Study Area, the subject of the field investigation component of this report, the following landforms were identified:

- Calcrete Plain: Level to undulating plains of paleo-groundwater calcrete overlain by varying depths of aeolian sand.
- Hardpan Plain and Drainage: Red clayey sand hardpan plains subject to sheet flow.
- Sand Dune: Sand dunes with fine red aeolian sand, 2 to 20 m relief.
- Sand Plain: Aeolian medium red silty sand plains, often with hardpan or underlying calcrete.
- Stony Hills: Foot slopes and outwash plains at the base of small to medium sized outcrops of grano-diorite and low hills of ironstone (magnetite).

Impacts from potential disturbance of these landforms were evaluated, accounting for the likely degree of potential disturbance, and with consideration of their significance (variety, integrity and rarity, and ecological, scientific or social importance) as discussed in EPA (2018). Whilst the Project may disturb some plain landforms (e.g. Calcrete Plain, Hardpan Plain and Drainage and Sand Plain) and low aeolian sand dunes, it is unlikely that any landform considered significant will be impacted.

SOILS

The desktop assessment and site investigations were used to identify three key soil types within the Detailed Study Area:

- Red (aeolian) deep sand, including low vegetated dunes (DAFWA Soil Group 445).
- Red (aeolian) shallow sand overlying hardpan, typically calcrete (DAFWA Soil Group 423).
- Calcareous stony soils (DAFWA Soil Group 202).

Red deep sand occurs as sandplain and dune sequences in topographically elevated areas within the Detailed Study Area, and is differentiated from the other two soil types by having a minimum of 600 mm of aeolian siliceous sand (no upper limit) as A and B1 horizons overlying calcrete or silcrete.

Red shallow sand is defined as the soil type comprising a cover of non-calcareous (siliceous) aeolian A and shallow B1 horizon of less than 600 mm in depth. The corresponding B2 horizon is defined by the presence of calcrete (or silcrete) gravels and cobbles, or as indurated calcrete sheet (or silcrete) as a distinct C horizon.

Drainage is generally rapid in these red sands, except for locations where the siliceous A and B1 horizons are shallow (<300 mm) and overlie an indurated calcareous or siliceous hardpan. Saturation of the siliceous horizon may occur following heavy rainfall events, followed by overland (sheetwash) flow.

The dominant soil type at locations in which the aeolian sand soil cover is thin (or non-existent) is a calcareous stony soil. This soil type is dominant within the potential Babel and Nebo pit footprints, and is considered to be remnants of a weathered calcrete/silcrete peneplain formed within a broad palaeodrainage feature.

The three soil types are related in that they represent varying depths of aeolian sand deposition over a calcrete/silcrete hardpan peneplain. Characteristics of the aeolian sand covers for these three soil types are:

- Variable pH, ranging from 5.3 (strongly acid) to 8.6 (strongly alkaline). Topsoil pH values typically decrease with increasing depth of the sandy B1 horizons.
- Topsoils and the red aeolian sands (Soil Groups 445 and 423) are siliceous and non-calcareous, while the surface calcareous stony soil (Soil group 202) is slightly calcareous due to presence of minor calcrete gravels.
- Very low salinity as a consequence of good drainage.
- Non-sodic.

- Soil texture grading from sand to loamy sand to sandy loam, with silt and clay contents increasing with depth.
- Very low gravel contents.
- Reasonable strength for sandy soil as a consequence of slightly elevated silt and clay contents (i.e. compared to coastal aeolian soil types in the south west of WA).
- Slight risk of clay dispersion, based on a typical Emerson Class of 3.
- Low organic carbon and total nitrogen concentrations, which are typical of sandy soils in arid and semi-arid regions of WA.
- Concentrations of bio-available nutrients within the 'Typical' range of unfertilised WA soils.

Underlying calcrete/silcrete subsoil materials are characterised by:

- Strongly alkaline pH values (8.3 to 9.1).
- Highly calcareous, particularly nodular, gravelly and indurated calcretes.
- Low salinity.
- Non-sodic.
- Soil texture grading from loamy sand to (gravelly) sandy clay loam.
- Low to slight risk of clay dispersion, based on a typical Emerson Class of 3 for siliceous aeolian subsoils and Class 4 for calcareous subsoils.

RECOMMENDATIONS

Based on the physical and chemical characteristics of soil types present within the Detailed Study Area, it is recommended that surface soil is stripped from all areas of potential disturbance.

A substantial layer of calcrete/silcrete is present beneath all major soil types within the Detailed Study Area. As this material has desirable acid neutralising properties, it is considered a potentially valuable resource for operational and rehabilitation purposes.

It is recommended that topsoils are segregated for storage prior to re-use as follows:

- Topsoils to a depth of 100 to 200 mm from all potentially disturbed areas: There is no requirement to separate acid and alkaline soils, or soil from the three major soil groups. Potential footprints of the TSF, WRD and Babel and Nebo pits will supply most of this material. Smaller stockpiles can be created from other potentially disturbed areas including haul roads, the accommodation village, process plant and airport. Topsoils should be managed in accordance with WA Department of Mines, Industrial Regulation and Safety (DMIRS 2016) guidelines and constructed to a maximum height of 2 m. Harvesting should not be undertaken during windy conditions as the soil has potential to generate significant volumes of dust.
- Sandy subsoils from dunes and red sandy soils from the footprints of the potential Babel and Nebo pits: As this soil is expected to contain very little viable seed and minimal nutrients, stockpiles may exceed the 2 metre height limit of topsoil stockpiles. Substantial volumes of sandy subsoil (supplemented by non-acid forming waste rock) may be useful for constructing covers for the TSF at closure.
- Calcareous gravels and nodular calcrete from the calcareous stony soil within the footprints of the potential Babel and Nebo pits: This material is considered the best available soil type for rehabilitation of sloping surfaces, such as waste landform embankments, at mine closure. Additional material is expected to be encountered in local deposits from soil harvesting prior to construction of potential WRDs and TSF.

All topsoil is considered suitable for rehabilitation of flat or gently sloping (less than 2°) surfaces such as the top of potential WRDs and the upper TSF surfaces. Provided the upper layer of rock in the potential WRDs is non-acid forming and non-mineralised, direct placement of harvested topsoil (indicatively 100 to 200 mm in depth) of is expected to be sufficient to encourage revegetation consistent with the post-closure land use requirements. A 100 mm layer of topsoil overlying a suitably thick layer of harvested subsoil and non-acid forming waste rock is considered appropriate for applications such as covering tailings deposited in the potential TSFs. These specifications are indicative, and the optimum layer thickness will be determined by physical properties of the rehabilitation materials and geochemical properties of tailings.

The preferred soil type for rehabilitation of mine waste landforms with sloping surfaces, such as embankments of potential WRDs and TSFs, is calcareous stony soil and nodular calcrete. It would be necessary to test the suitability of this material using trials, as indicated below, considering the numerous potential options for landform rehabilitation.

It is recommended that the final surface cover designs for sloping landform surfaces and potential TSF covers are assessed by a cover trial program prior to final mine rehabilitation and closure. Such trials may consider:

- Different topsoil thickness, ranging from 100 to 300 mm.
- Blending soil with competent, geochemically benign waste rock to improve resistance to erosion on sloping surfaces.
- Different subsoil/waste rock blends and thicknesses for cover over tailings deposited in potential TSFs.
- Different plant species, consistent with the post closure land use requirements. If native vegetation is to be replaced, consistent with suitable reference sites, it is recommended that spinifex grasses (*Triodia* spp.) are evaluated. These typically require a well-drained, moderately deep soil profile.

TABLE OF CONTENTS

TABLES

FIGURES

PLATES

APPENDICES

1. INTRODUCTION AND PROJECT BACKGROUND

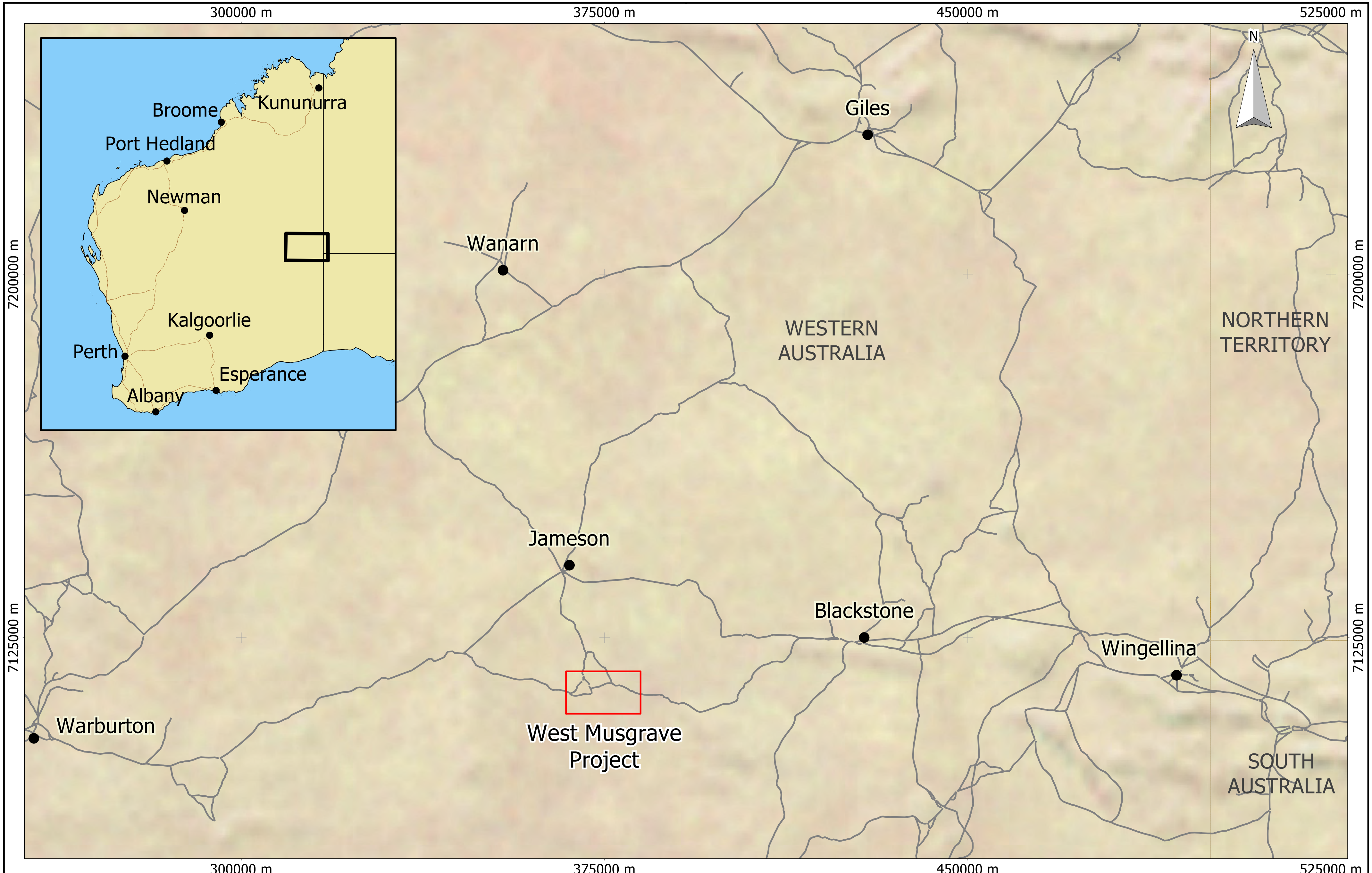
OZ Minerals Limited (OZ Minerals) and Cassini Resources Limited (Cassini) (the Joint Venture) are assessing the West Musgrave Copper and Nickel Project (the West Musgrave Project (WMP or the Project)) in the West Musgrave Ranges of Western Australia. The WMP is located approximately 1,600 km north east of Perth near the border with South Australia and Northern Territory; 30 km south of Jameson and 110 km south east of Warburton (Figure 1).

The WMP is located within the Shire of Ngaanyatjarraku. The WMP is also located within the approximate 170,000 km^2 Yarnangu Ngaanyatjarraku Parna (Aboriginal Corporation) Native Title determination, and within the 98,000 km^2 Ngaanyatjarra Indigenous Protected Area (IPA Reserve No. 17614), which forms part of the National Reserve System under the Commonwealth Department of Prime Minister and Cabinet.

The WMP area is within the Musgrave Geological Province (also known as the Musgrave Block), a relatively-recently discovered mineral district where mineralisation occurs at multiple locations. The WMP consists of a number of prospective copper and nickel deposits known as Nebo, Babel, Succoth and Yappsu, with Nebo and Babel (referred to as Nebo-Babel) being at the most advanced stage of mineral evaluation.

The Nebo-Babel copper-nickel deposits were discovered by WMC Resources in 2000. Cassini purchased the Project from BHP in April 2014 and completed a significant infill drilling campaign. A Scoping Study was announced and completed in December 2017 (OZ Minerals 2017), which concluded that the WMP presented a viable opportunity for development. OZ Minerals subsequently signed an earn-in and Joint Venture agreement with Cassini, achieving 51% ownership of the Project as of October 2018.

The Project pre-feasibility study (PFS) is underway to define the key characteristics of the Project and determine its technical and economic viability. The Project will include open pit mining, a processing plant and associated mine waste facilities, water facilities, accommodation village and other associated site industrial and non-industrial infrastructure. The PFS is scheduled for completion in 2019, hence key project characteristics such as life of mine, processing rate, waste handling and storage and water requirement will be defined as the PFS progresses.



Scale: 1:1000000
Original Size: A4
Grid: MGA94(52)

0 50 km

OZ Minerals
West Musgrave Project
Soil and Landform Report

Figure 1

Project Location

4 Cook St
West Perth WA 6005
Ph: (08) 9226 3166
Fax: (08) 9226 3177
info@mbsenvironmenta
MBS ENVIRONMENTAL

W:\OZ Minerals\Drawings\Location Map.map 10/12/2018 Location Map Layout

2. OBJECTIVES AND SCOPE OF WORK

2.1 OBJECTIVES

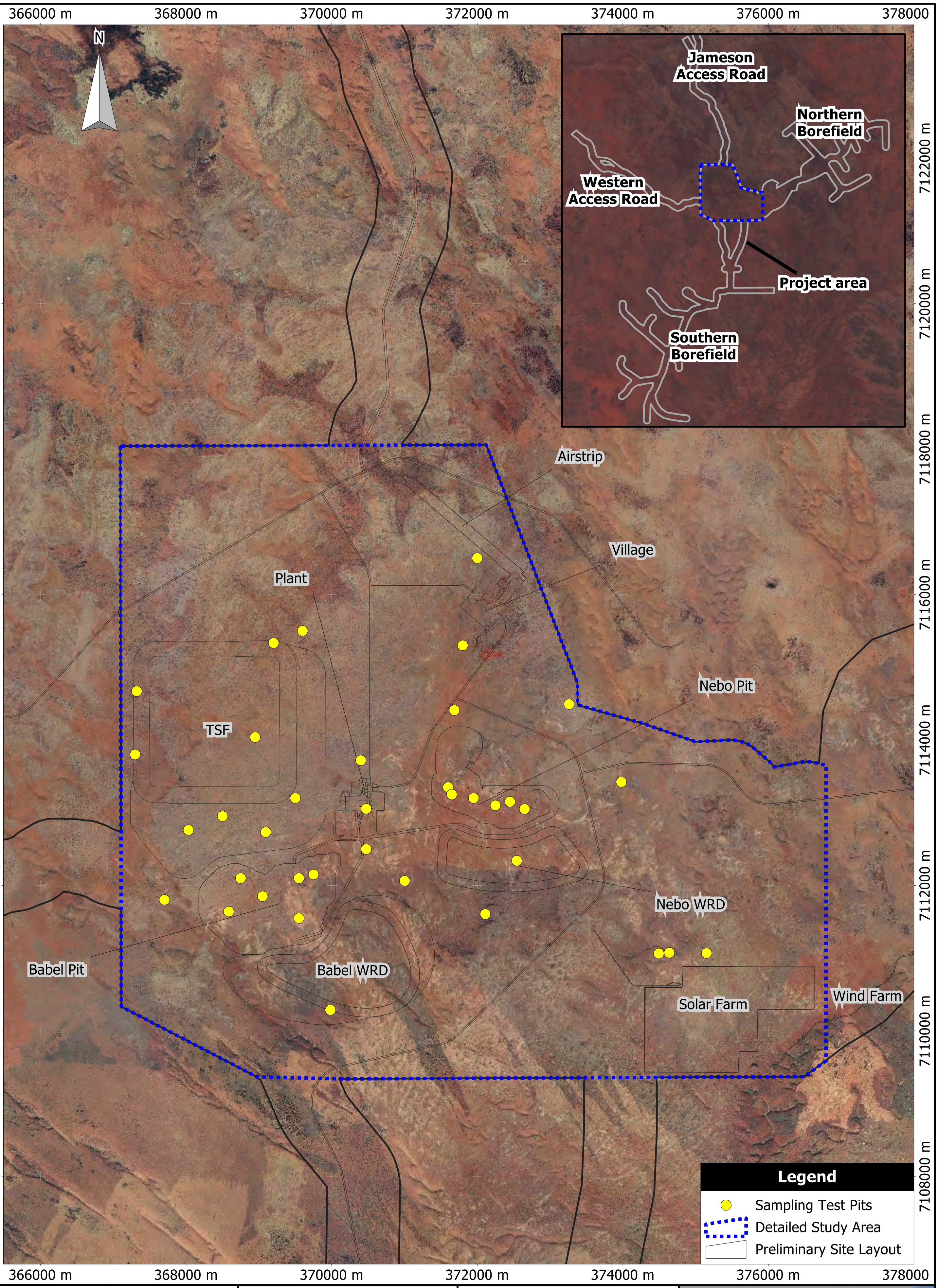
MBS Environmental (MBS) was engaged by OZ Minerals to undertake a baseline soil and landform assessment to inform project design, environmental impact assessment and closure planning. The primary objective of the study was to determine the suitability of topsoils and subsoils for use during rehabilitation of land disturbances in the Project area. For the purposes of this report, Project area is defined as the maximum potential disturbance area for the WMP (including potential access roads, borefields and renewable energy infrastructure) as shown in Figure 2.

2.2 SCOPE OF WORK

The scope of work comprised:

- Assessment of natural landforms within the Project area and surrounds (Local Assessment Unit).
- Collection of samples to provide field descriptions of topsoil and subsoil from representative sites within the footprint of the potential open pits, waste rock stockpiles, TSF and other operational areas (the Detailed Study Area, Figure 2).
- Submission of selected topsoil and subsoil samples to ChemCentre (Bentley, Western Australia) for a range of physical and geochemical tests including particle size distribution, Emerson Aggregate Class, pH, electrical conductivity (EC), organic carbon, nutrients, both plant available and total environmentally available metals and metalloids, and cation exchange properties.
- Preparation of this report, tailored to provide a set of conclusions and recommendations relating to potential suitability of topsoil and subsoil materials for use in rehabilitation of land disturbances in the Detailed Study Area.

This study does not include an assessment of the geotechnical properties of soils required for construction or engineering purposes. An assessment of the suitability of waste rock for rehabilitation purposes will be subject of a separate geochemical waste rock characterisation report.



Scale: 1:68000
Original Size: A4
Air Photo Date: 2018
Grid: Australia MGA94 (52)
0 2 km

OZ Minerals
West Musgrave Project
Soil and Landform Report

Figure 2

Soil and Landform Detailed Study Area

Martinick Bosch Sell Pty Ltd
4 Cook St
West Perth WA 6005
Australia
t: +61 8 9226 3166
info@mbsenvironmental.com.au
www.mbsenvironmental.com.au
MBS ENVIRONMENTAL

3. EXISTING ENVIRONMENT

3.1 CLIMATE

The WMP area has an arid, desert climate with distinct summer and winter rainfall patterns. The closest Bureau of Meteorology (BoM) weather stations to the Project area are Warburton Airfield Meteorological Station (13011, records from 1981) located 110 km west and Giles Meteorological Station (No. 013017, records from 1956) located approximately 130 km to the north. BoM mapping products and Scientific Information for Land Owners (SILO) data have been used to describe climate conditions that typify the WMP area (CDM Smith 2019).

The Project area experiences a broad temperature regime (Figure 3). Average daily maximum temperatures exceed 34°C between November and March. Average daily minimum temperatures range from 23.1°C to 5.7°C (BoM 2018). The SILO data identifies maximum temperatures of 46.2°C and minimums of -2.1°C.

The area receives rainfall (>1 mm) on average 27 days each year, and rainfall is influenced by tropical depressions located off the northwest coast (BoM 2018, OZ Minerals 2017). At a regional scale, the average yearly rainfall totals around 250 mm, with 80% of years having a total rainfall ranging between 100 and 400 mm. Average monthly rainfall is highest during the summer months of December, January and February and the shoulder months of March and November, ranging from 30 to 50 mm/month. The remaining months have average rainfalls ranging from 10 to 20 mm/month.

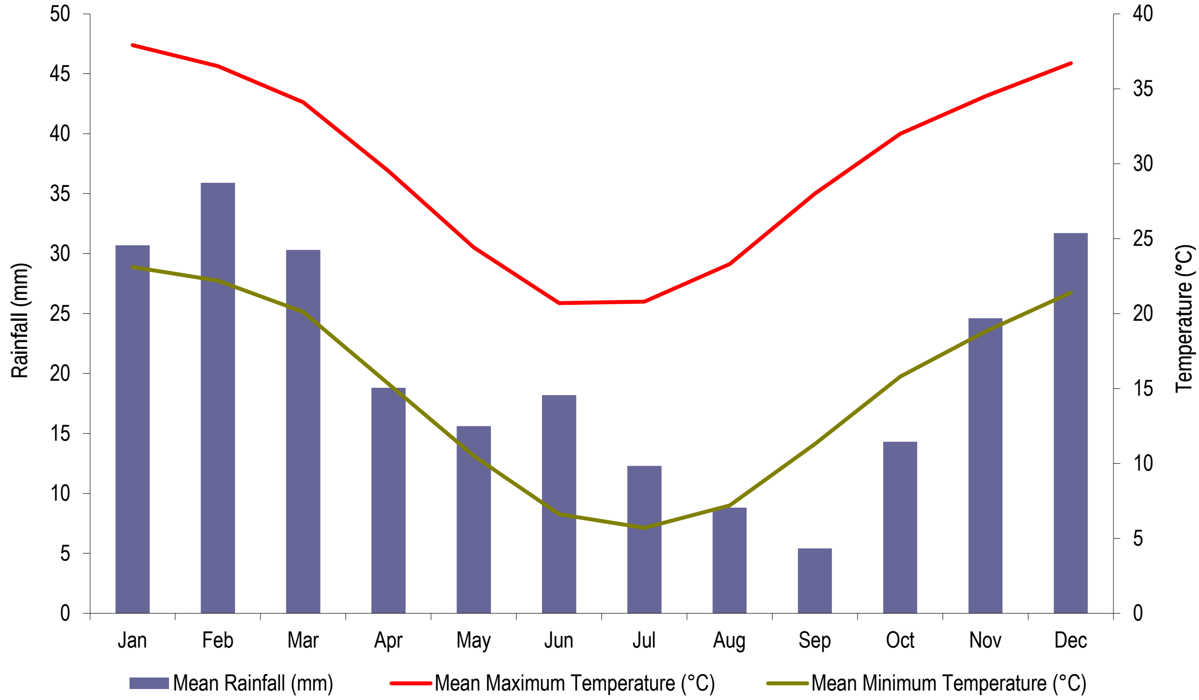


Figure 3: Climate Statistics for Warburton Airfield (BoM 2018)

Analysis of rainfall data highlights the variable nature of rainfall around the WMP area. Figure 4 shows the average annual rainfall and cumulative deviation from mean (CDFM) rainfall in the WMP area, in which the average annual rainfall at the site approximates 181 mm/yr. There appears to be multi-decadal climate/rainfall variability, with the period from 1974 to the present being significantly wetter than previous years.

Estimated annual pan evaporation and potential evapotranspiration for the area are 3,254 mm and 2,650 mm, respectively. As illustrated in Figure 5, estimated evaporation rates are greater than 20 times the mean annual rainfall.

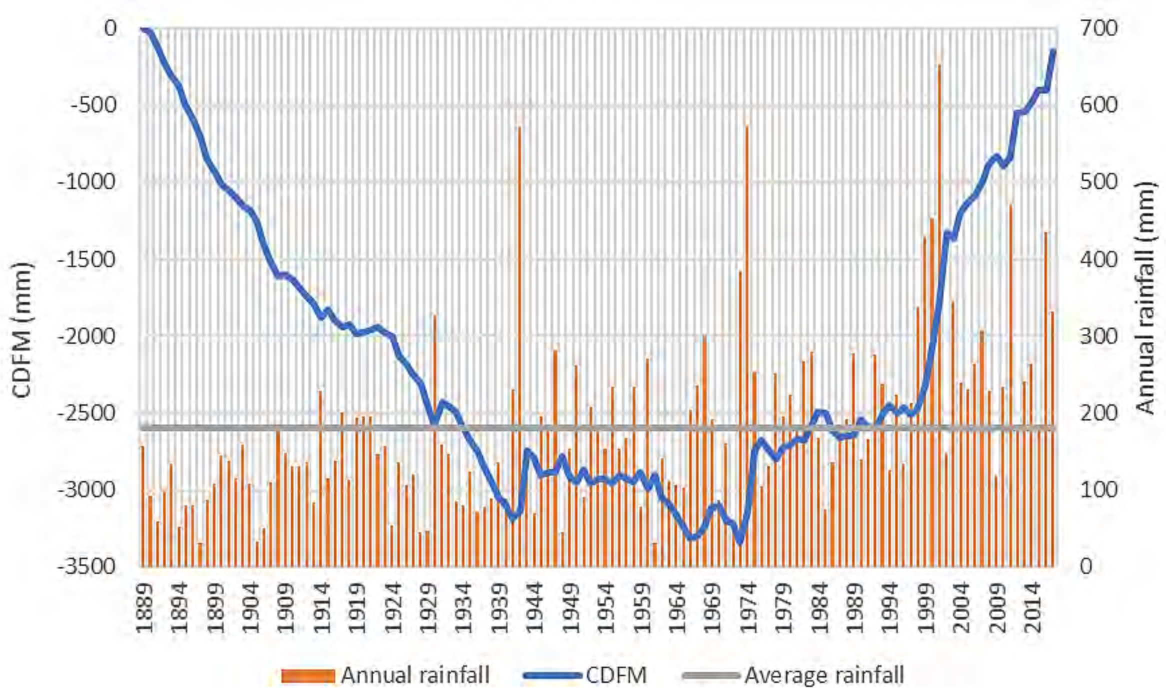


Figure 4: Annual Rainfall and CDFM at West Musgrave

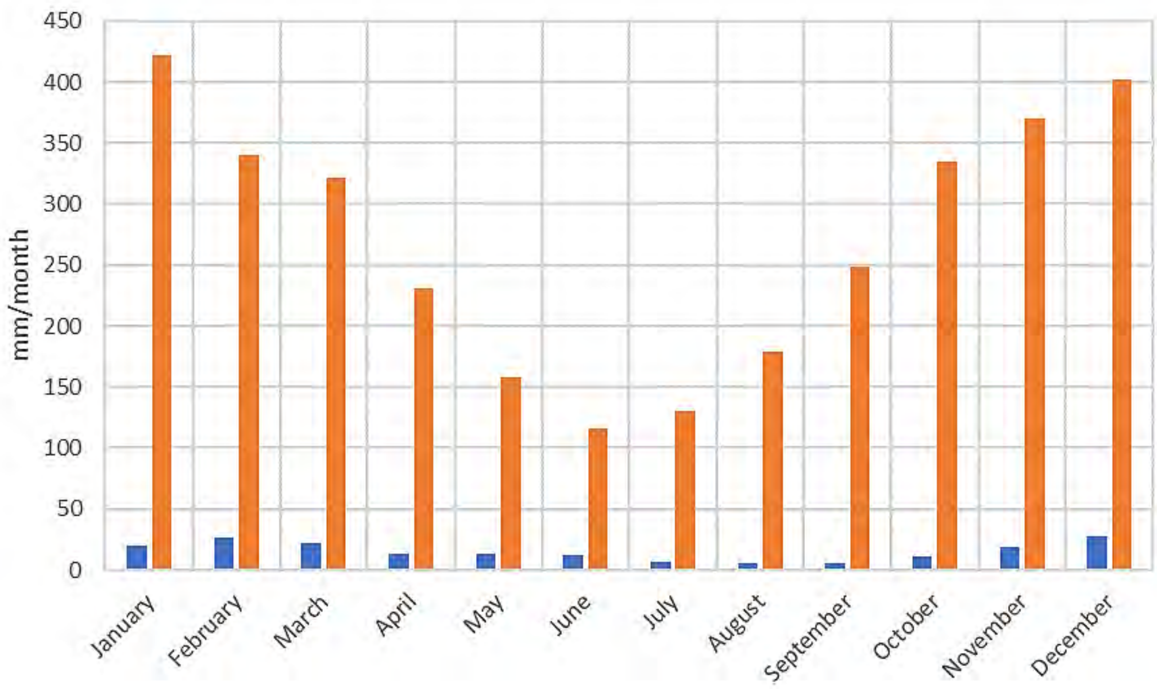


Figure 5: Average Monthly Evaporation (Orange) vs. Rainfall (Blue)

The Intensity Frequency Duration (IFD) AEP rainfall event data for the Project area that was used for hydrological modelling is presented in Table 1. An analysis of the daily rainfall data concludes high rainfall events which are greater than 100 mm are only likely to occur once every 10 years on average.

Table 1: Design Rainfall Intensity (mm/hr) Data

Duration (hours)	Annual Exceedance Probability					
	20%	10%	5%	2%	1%	0.1%
12	4.37	5.57	6.86	8.7	10.2	
24	2.79	3.57	4.41	5.59	6.57	10.3
36	2.13	2.73	3.39	4.29	5.04	
48	1.74	2.24	2.78	3.53	4.15	6.58
72	1.28	1.66	2.07	2.62	3.08	
96	1.01	1.31	1.64	2.08	2.45	4.92
120	0.83	1.08	1.35	1.72	2.02	
144	0.70	0.91	1.14	1.45	1.7	3.92
168	0.60	0.78	0.98	1.24	1.46	

Source: BoM 2016

3.2 GEOLOGY

The WMP lies within the Mann-Musgrave Block subregion (CR1) of the Central Ranges CER1 Interim Biogeographic Regionalisation for Australia (IBRA) region. This subregion is characterised by a high proportion of Proterozoic ranges including both volcanic, quartzite and derived soil plains, which are interspersed with red Quaternary sandplains with some Permian exposure (Graham and Cowan, 2001). The West Musgrave mineral district of magmatic ore deposits extends over a distance of at least 40 km and represents a relatively recently established prospective region. This district is globally significant, being one of only ten mafic-intrusion hosted nickel-copper-platinum group element deposits that have been discovered.

The Nebo-Babel deposits are hosted by a sub-horizontal, concentrically zoned, tube-shaped (chonolithic) gabbronorite intrusion. The east-west trending mafic intrusion has a known extent of 5 km, with a gentle 15 degree dip to the south, and in the case of Babel, a less than 10 degree plunge toward the southwest. Babel and Nebo are separated by the steeply-dipping, north-south trending Jameson Fault, with Babel to the west of the fault and Nebo to the east (Figure 6).

Babel consist of three main lithostratigraphic units, which are variably textured leucogabbronorite (VLGN) that forms the outer shell around mineralised gabbronorite (MGN), and barren gabbronorite (BGN) in the core of the intrusion. At Nebo, the main lithostratigraphic units are VLGN that forms an outer shell of the intrusion, around BGN and oxide-apatite gabbronorite (OAGN), which occur in the core of the intrusion at the eastern end (Seat *et al*. 2007). The Nebo-Babel deposits contain two main styles of mineralisation: massive and breccia sulfides, which are a comparatively minor component of the overall sulphide inventory and disseminated gabbronorite-hosted sulphides that represent the bulk of the mineralisation. Massive and breccia sulphides at both deposits comprise, in decreasing abundance, pyrrhotite, pentlandite, chalcopyrite and trace pyrite. In most of the shallower intersections, supergene alteration has modified the primary sulphide assemblages to pyrite and violarite. The disseminated mineralisation at both deposits occurs as blebs in gabbronorites. Nickel and copper grades at Nebo and Babel are at a 1:1 ratio with higher grades occurring in the massive sulfides and marginal breccia zones. Lower nickel and copper grades occur in the disseminated sulphide zones (OZ Minerals 2017).

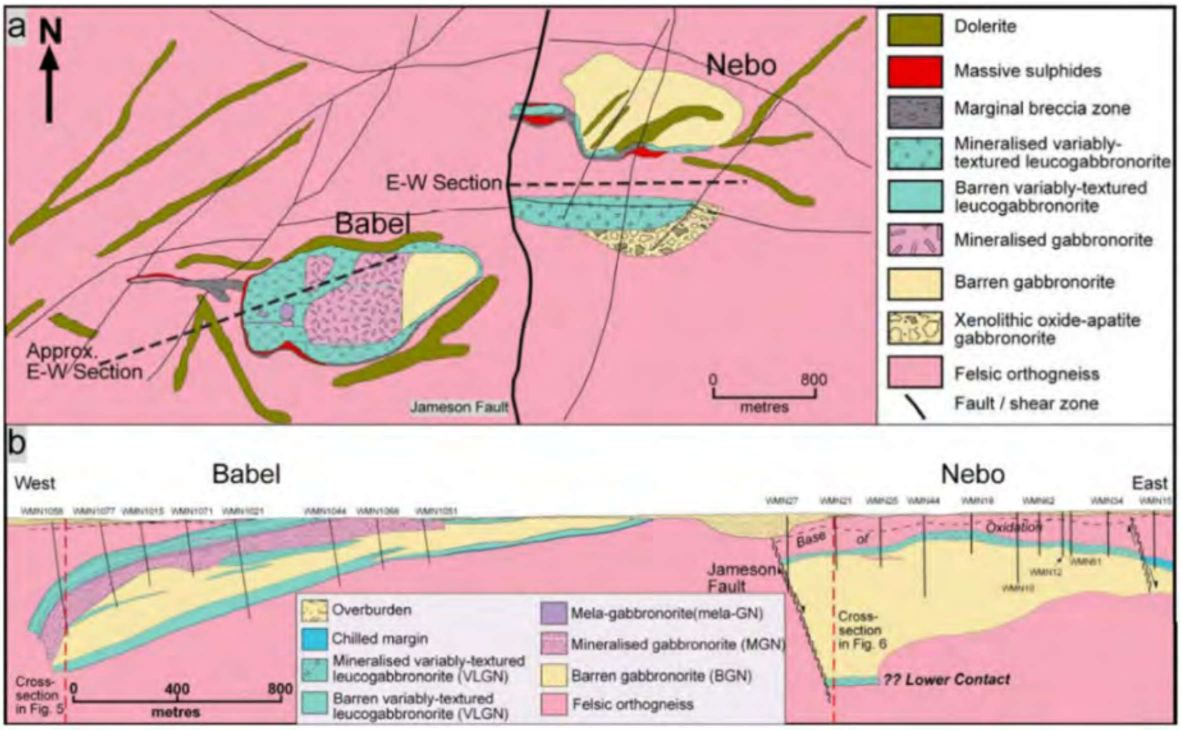


Figure 6: Plan (a) and Long Section (b) Views of the Nebo-Babel Deposits (Seat *et al.* 2007)

3.3 VEGETATION ASSOCIATIONS

The Nebo-Babel deposits are situated within Beard's Giles Botanical District, located in the Mann-Musgrave Block sub-region of the Central Ranges (CR1) Interim Biogeographic Regionalisation for Australia (IBRA) region (Thackway and Cresswell 1995, Beard 1990). The Central Ranges region extends from the Northern Territory into South Australia and Western Australia, creating a cross-over of flora species throughout the region. The regional sandplains support low open woodlands of either Desert Oak (in the east) or Mulga (in the west) over *Triodia basedowii* hummock grasslands (Graham and Cowan 2001).

The majority of the southern borefield is located within the Central subregion (GVD2) of the Great Victoria Desert IBRA region. The GVD2 subregion supports a tree steppe of *Eucalyptus gongylocarpa*, Mulga and *E. youngiana*, over hummock grassland, which is dominated by *Triodia basedowii* on aeolian sands (Barton and Cowan 2001).

Western Botanical (2018) completed a detailed flora and vegetation survey of the Project area and identified vegetation associations with five main landforms types comprising Calcrete Plain, Hardpan and Drainage, Sand Dune, Sand Plain and Stony Hills (Table 2). The Hardpan and Drainage and the Stony Hills types were divided further into sub-units for the purpose of the survey. Sub-units of the Hardpan and Drainage types were Plains and Claypans. Sub-units of the Stony Hills type were based on granodiorite and ironstone geologies. These landforms are discussed in more detail in Section 4.

Table 2: Vegetation Associations of the Project Area

Landform Type	Vegetation Association
Calcrete Plain	Calcrete *Corymbia opaca* Woodland
	Calcrete Open Grassland
	Calcrete Platform Hummock Grassland Hummock Grassland
	Calcrete Platform Hummock Grassland Hummock Grassland with *Acacia eremophila* var. Numerous-nerved variant (A.S. George 11924) (P3)
	Calcrete Platform Hummock Grassland Hummock Grassland with *Allocasuarina helmsii*
	Calcrete Platform Hummock Grassland Hummock Grassland with *Melaleuca eleuterostachya*
	Low Mallee Woodland / Calcrete Platform Hummock Grassland Complex
	Sandplains with Wattles other than Mulga / Calcrete Platform Hummock Grassland COMPLEX
Hardpan Plain & Drainage	Hardpan Mulga Woodland
	Hardpan Mulga Woodland Drainage
	Mulga Grove
	Eremophila duttonii Shrubland
	Hardpan Chenopod Shrubland
	Claypan Playa
	Claypan Grassland
Sand Dune	*Aluta maisonneuvei* subsp. *maisonneuvei* low Shrubland
	Sand Dune *Acacia* - *Grevillea* Shrubland
Sand Plain	Sandplains with Wattles other than Mulga
	Sandplain Spinifex
	Sandplain Mulga
	Mulga Wanderrie
	Low Mallee Woodland
	Low Mallee Woodland / Sandplains with Wattles other than Mulga Complex
	Melaleuca glomerata with *Acacia kempeana* Shrubland
	Melaleuca glomerata with *Acacia kempeana* Shrubland / Calcrete Platform Hummock Grassland Complex
	Acacia brachystachya over Spinifex Shrubland
	Acacia rhodophloia over Spinifex Shrubland
Stony Hills Grano-diorite Geology	Stony Mulga Shrubland
	Senna Shrubland
	Acacia kempeana Shrubland
	Acacia cuthbertsonii Shrubland

3.4 HYDROGEOLOGY AND SURFACE HYDROLOGY

The Project area is within the East Murchison Groundwater Area and the Officer Groundwater Sub-area of the Musgrave Province. The Musgrave Province is composed of igneous and metamorphic rocks, which form a regional fractured rock aquifer with minimal available water (low primary porosity inferred) (CDM Smith 2018a). Palaeovalleys are incised into the bedrock terrane of the Musgrave Province, with overlying Quaternary calcrete, aeolian sand and playa deposits (Zang and Stoian 2006). Several palaeodrainage systems originate from the Musgrave Province including the Kadgo Palaeovalley, which starts to the northwest of the Project and drains into the Officer Basin to the south (Figure 7).

Groundwater investigations conducted by CDM Smith (CDM Smith 2018a; 2018b) in 2018 indicate that the water table is relatively shallow (<5 mBGL) in low lying areas and most likely intersects calcrete in some parts of the Project area. In the surrounding ranges, depth to groundwater is estimated at 20 mBGL. Groundwater predominantly flows from topographically elevated areas to the north, east and west of the Project, through the palaeochannel towards the low-lying areas to the south.

Two sedimentary units were identified within the Kadgo palaeochannel, an upper unit comprising alluvial and colluvial sediments that have been substituted by calcrete near the surface, and an underlying basal sand aquifer. These units are separated by a confining layer of clays and the basal sand aquifer is expected to be confined, whilst the upper sediments are expected to be unconfined to semi-confined with respect to groundwater flow.

Water quality in the palaeochannel is typically brackish, with total dissolved solids (TDS) concentrations generally less than 3,000 mg/L. High evaporation rates combined with small, but highly variable rainfall suggests that groundwater recharge may be episodic, and studies have estimated groundwater recharge in the Musgrave Basin to be between 0.05% and 19% of average annual rainfall (Magee 2009).

Surface water flow in the region is severely limited by a combination of high evaporation/evapotranspiration rates and low annual rainfall (Section 3.1). The area immediately surrounding the proposed mine and supporting infrastructure is characterised by poorly defined surface water catchments and unconnected ephemeral drainage lines, with the dunefields of the Great Victoria Desert being the dominant landform.

Potential for relatively high infiltration rates exists in the Project area, which can be attributed to the predominance of sandy soils and shallow calcrete horizons. Where rainfall is sufficient to generate runoff, sheet flow is expected (CDM Smith 2018b).

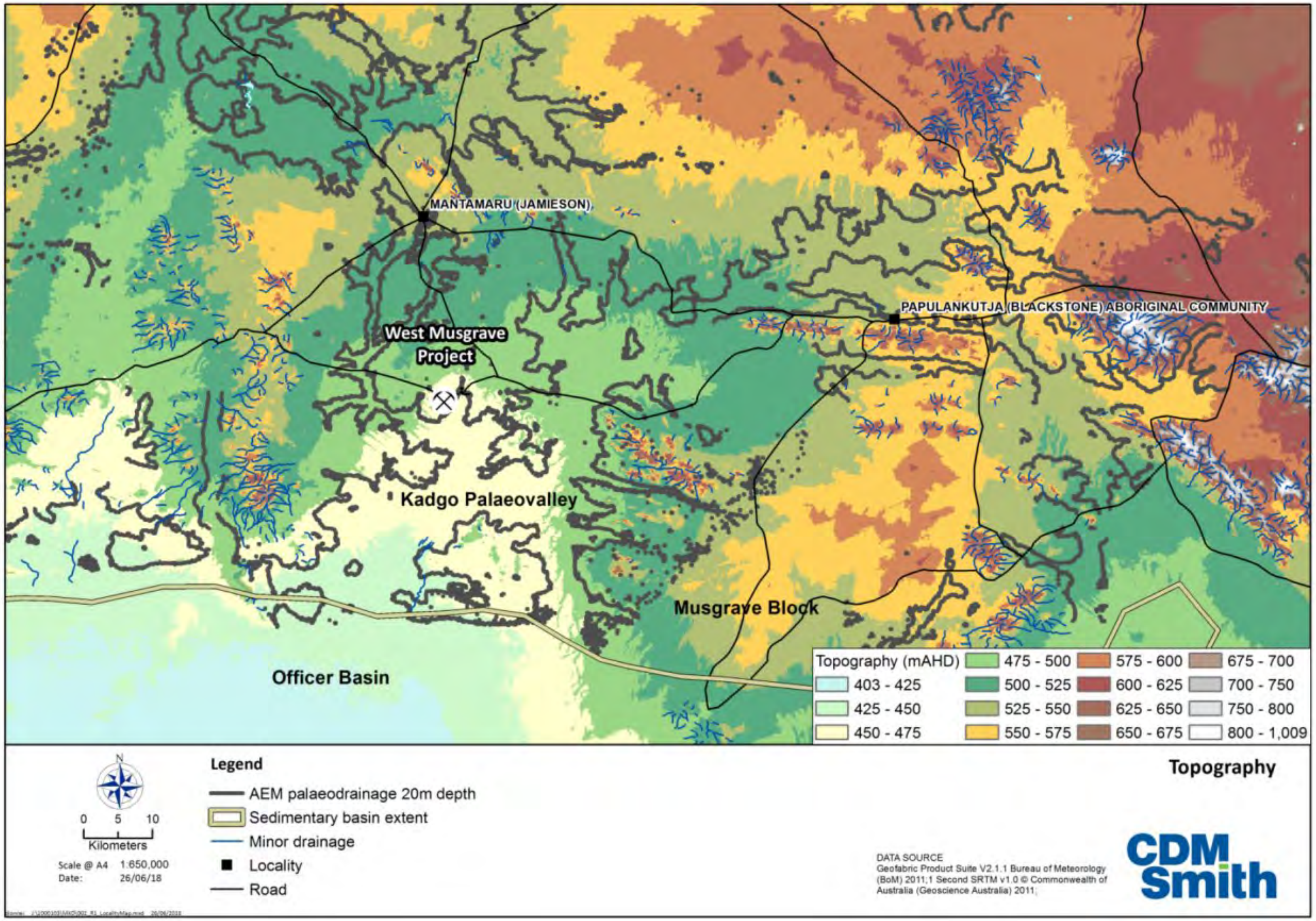


Figure 7: Regional Topography and Hydrogeological Domains (CDM Smith 2018a)

4. LAND SYSTEMS AND LANDFORMS

4.1 PROJECT AREA OVERVIEW

The Nebo-Babel deposits are situated within Western Desert Ranges Province soil-landscape region of the Western Australian Department of Industries and Regional Development (previously Department of Agriculture and Food WA) system. The Desert Ranges Province has been described at the regional level as sandplains and dunes (with hills and ranges surrounded by wash plains) on granitic and volcanic rocks of the Musgrave Complex and sedimentary rocks of the Amadeus Basin (Tille 2006). Soils typically present include red sandy earths, red deep sands and red loamy earths, with some stony soils. The province is located in the central eastern Arid Interior, extending from Warburton to the South Australian border and Lake McDonald.

The Project area is gently undulating at an elevation of approximately 470 metres Australian Height Datum (mAHD), with sand dunes providing sporadic relief up to 15 metres relative height (discussed further in this Section). Landforms of the Project area are dominated by sand sheets, low sand dunes, low calcrete outcrops and clayey hardpan plains. Internally draining claypans are common in low lying areas and gilgai (calcareous) soils are expected to be widely occurring in these low lying areas. Colluvial slopes and outwashes occur adjacent to elevated areas where they occur.

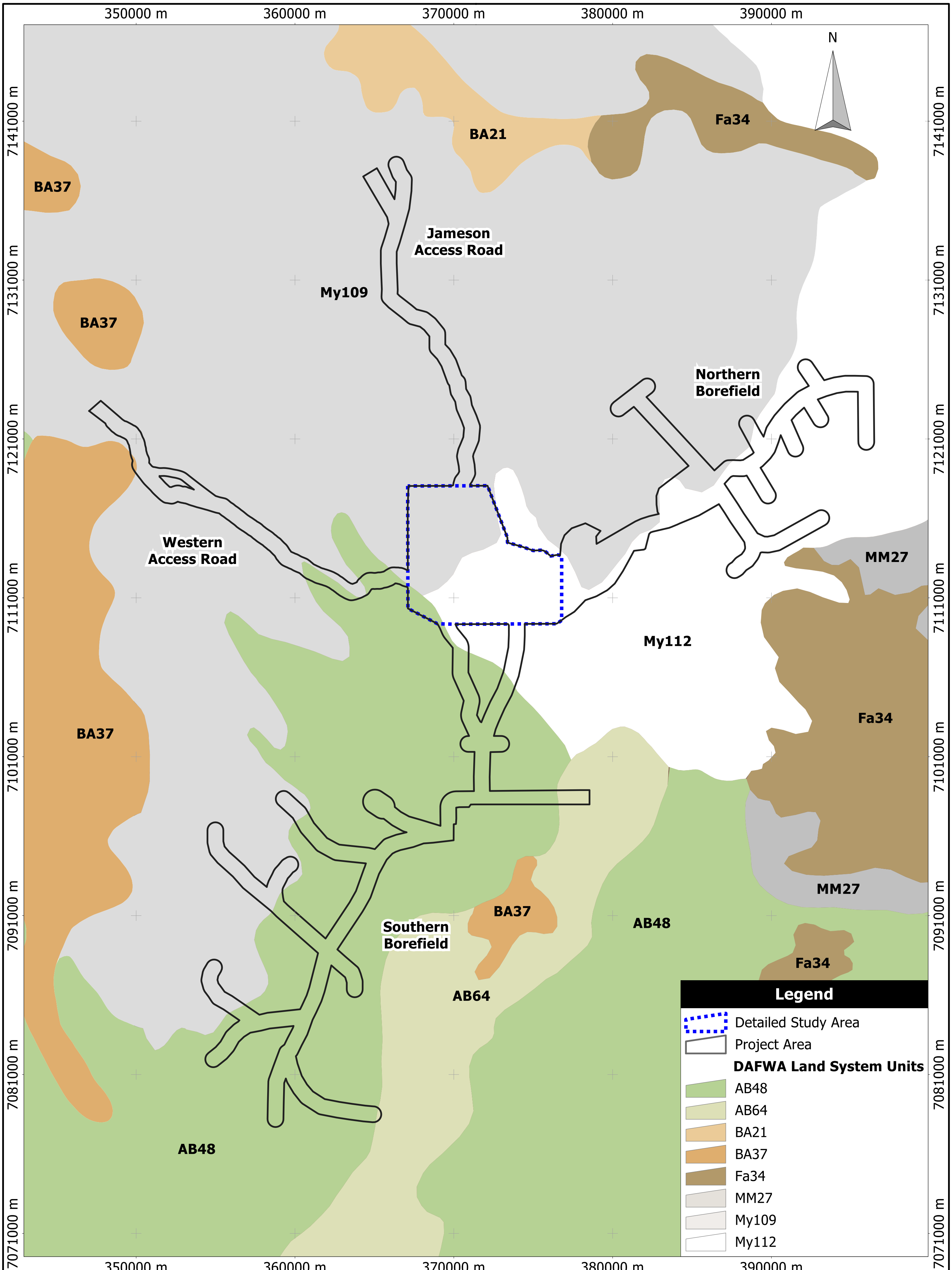
4.2 LAND SYSTEMS AND SOILS

Eight land system units (DAFWA 2017) occur in the Project area and immediate surrounds, five of which (My109, My112, AB48, AB64 and BA37) occur within the Project area (Table 3 and Figure 8).

The Detailed Study Area, which includes likely locations of potential pits, waste landforms (e.g. waste rock dumps and tailings storage facility) and potential renewable energy area, occurs predominantly within the My112 and My109 land system units. The Detailed Study Area was the focus of the soils investigation in this study (Figure 2), as discussed in Sections 5 through 7.

Table 3: Land System Units and Soils of the WMP Region

Unit	Description	Project Area	Detailed Study Area	Project Component
My109	Outwash plains and dissected fan and terrace formations flanking ranges of sedimentary and some metamorphic, volcanic, and granitic rocks. Main soil types are expected to be red loamy earth (40%), red sandy earth (25%) and red-brown shallow hardpan loam (15%).	11,893.4 ha (40.16%)	2,989.9 ha (44.3%)	Key mining infrastructure, Jameson Access Road, Western Access Road, Southern Borefield
My112	Extensive plains with numerous dunes which are often short and of irregular shape and orientation. Main soil types are expected to be red sandy earth (40%), red loamy earth (35%) and red deep sand (25%).	8,976.3 ha (30.31%)	3,509.6 ha (52.01%)	Key mining infrastructure, Northern Borefield
AB48	Very gently undulating plain traversed by longitudinal dunes. Main soil types are expected to be red sandy earth (50%) and deep red sand (40%).	8,527.3 ha (23.79%)	247.8 ha (3.67%)	Key mining infrastructure, Western Access Road, Southern Borefield
AB64	Plains with occasional short dunes and hilly areas with rock outcrops. Main soil types are expected to be deep red sand (40%), red sandy earth (40%), red loamy earth (10%) and red shallow sandy duplex (10%).	197.3 ha (0.67%)	-	Southern Borefield
BA37	Ranges and hills mainly on granitic rocks; rock outcrop is extensive. Main soil types are stony soil / bare rock (50%), red shallow loam (15%), red shallow sand (15%) and deep red sand (10%).	23 ha (0.08%)	-	Western Access Road
BA21	Steep hills and ranges on sedimentary and some metamorphic, volcanic, and granitic rocks; bare rock outcrop is common; some gorges. Main soil types are stony soil (30%), bare rock (20%), red shallow sand (15%), red shallow loam (10%) and red deep sand (10%).	-	-	None.
Fa34	Steep hills and ranges on basic rocks; rock outcrop common; some gorges; small pediments and plains. Main soils types are red loamy earth (40%), stony soil / bare rock (30%) and red sandy earth, shallow loam / sand (25%).	-	-	None
MM27	Outwash plains subjacent to ranges of basic igneous rocks; some low hills of basic rocks occur in the unit; occasional dunes. Main soil types are self-mulching cracking clays (25%), hard cracking clays (20%), red/brown non-cracking clays (20%), red deep sand (10%), red sandy earth (10%) and calcareous loamy earths/shallow loam (15%).	-	-	None



Scale: 1:310000
Original Size: A4
Grid: Australia MGA94 (52)

0 5 km

OZ Minerals
West Musgrave Project
Soil and Landform Report

Figure 8

Regional Distribution of Land Systems

Martinick Bosch Sell Pty Ltd
4 Cook St
West Perth WA 6005
Australia
t: +61 8 9226 3166
info@mbsenvironmental.com.au
www.mbsenvironmental.com.au

MBS ENVIRONMENTAL

4.3 LANDFORMS

The Western Australian Environmental Protection Authority (EPA 2018) defines landforms as:

The distinctive, recognisable physical features of the earth's surface having a characteristic shape produced by natural processes. A landform is defined by the combination of its geology (composition) and morphology (form).

Landforms are considered a component of the landscape, which is considered to be:

All the features of an area that can be seen in a single view, which distinguish one part of the earth's surface from another part.

The EPA's environmental objective for the factor, Landforms, is:

To maintain the variety and integrity of significant physical landforms so that environmental values are protected.

The following criteria may be used in determining whether a landform is significant:

- Variety: The landform is a particularly good or important example of its type. The landform is not well represented over the local, regional or national scale or differs from other examples at these scales, either naturally or as a result of cumulative impacts from existing and reasonably foreseeable activities, developments and land uses.
- Integrity: The landform is intact, being largely complete or whole and in good condition.
- Ecological importance: The landform has a distinctive or exclusive role in maintaining existing ecological and physical processes; for example, by providing a unique microclimate, source of water flow, or shade. The landform supports endemic or highly restricted plants or animals.
- Scientific importance: The landform provides evidence of past ecological processes or is an important geomorphological or geological site. The landform is of recognised scientific interest as a reference site or an example of where important natural processes are operating.
- Rarity: The landform is rare or relatively rare, being one of the few of its type at a national, regional or local level.
- Social importance: The landform supports significant amenity, cultural or heritage values linked to its defining physical features.

4.3.1 Regional Landform Context

A local assessment unit (LAU) was defined in order to capture the regional landform context for the WMP. The LAU extends from the maximum Project area extent by between 25 and 37 km. At the LAU scale, landforms were identified using a digital elevation model (DEM with 2 m resolution) as shown in Figure 9.

The major landforms (i.e. obvious landscape features) within the LAU are Blackstone Range 12 km east of the potential Northern Borefield location (elevation up to 700 mAHD), Cavenagh Range 3 km southwest of the potential Northern Borefield (≤ 700 mAHD), Jamieson Range (up to 700 mAHD) 5 km northeast of the potential Jameson Access Road route, and the sparsely grouped Barrow Range (up to 680 mAHD) immediately to the west of the potential Western Access Road route. None of these major landforms will be impacted by the Project.

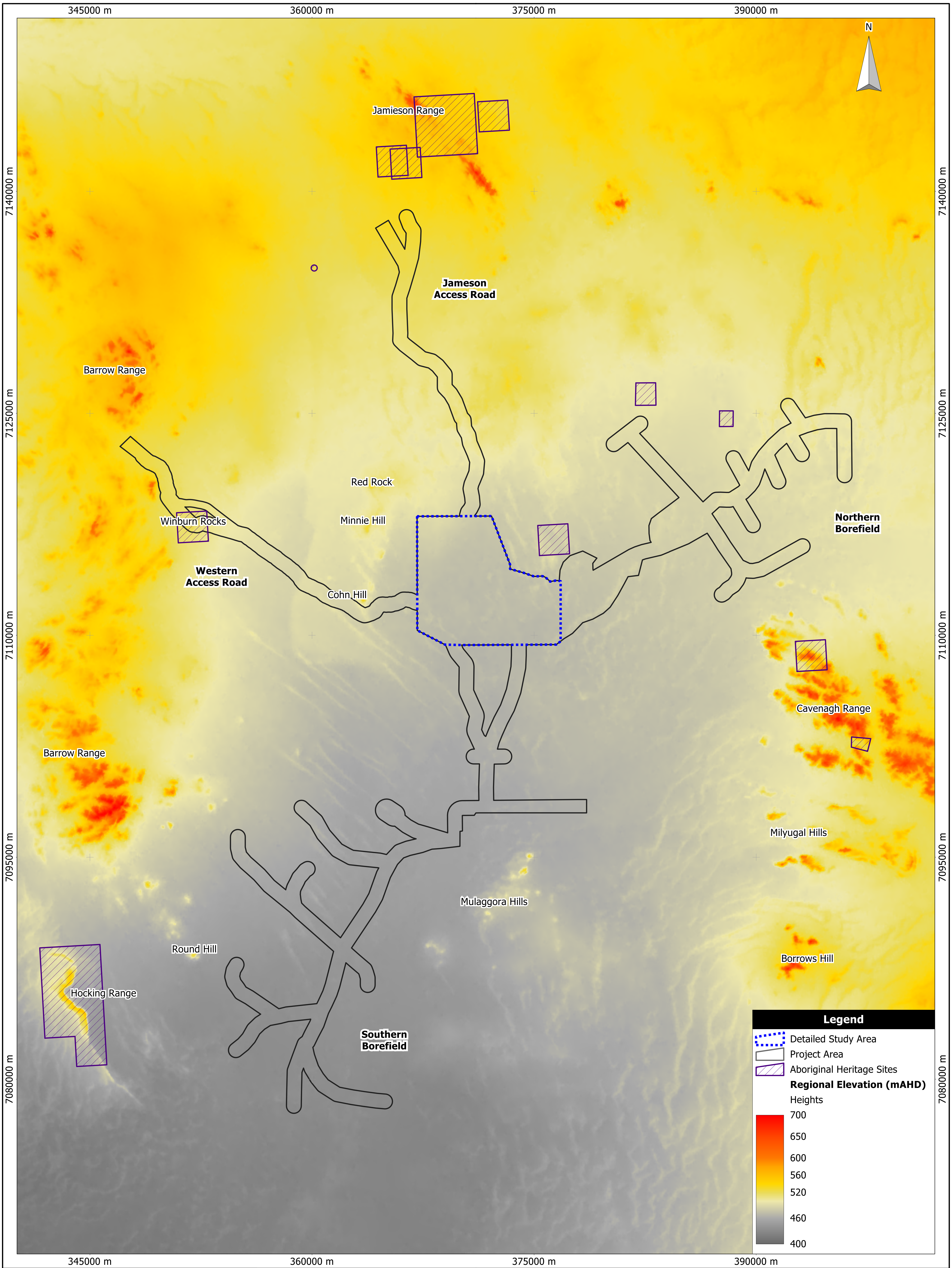
Other notable landforms (i.e. referenced in regional scale maps) include low stony hillocks such as the Mulaggora Hills, Milyugal Hills and Borrows Hill, which are respectively located 7, 18 and 28 km east of the potential Southern Borefield location. To the west of the Southern Borefield are Round Hill (2 km) and Hacking Range (10 km). Small stony hillocks located closer to the potential Nebo-Babel pits and potential locations of the key mining infrastructure (within 5 km) include Cohn Hill, Minnie Hill and Red Rock. None of these notable landforms will be impacted by the Project.

The significance of the landforms discussed above has not been assessed as they are located outside of the Project area.

4.3.2 Landforms in the Project Area

The Project area lies on the Kadgo Palaeovalley plain with elevation typically varying between 465 and 485 mAHD. This area comprises flat or gently undulating sandplains, featuring sequences of low linear aeolian dunes that are typically between five and ten metres above the level of the interdune planes. Some of these low linear dunes may be impacted by the Project.

Western Botanical (2018) identified five main landform types within the Project area, as well as respective vegetation associations and regional occurrence (Table 4 and Figure 10). These were Calcrete Plain (Plate 1), Hardpan Plain and Drainage (Plate 2), Sand Dune (Plate 3), Sand Plain (Plate 4) and Stony Hills (Plate 5).



Scale: 1:230000
Original Size: A3
DEM: SRTM 2000
Grid: MGA94(52)

0 10 km

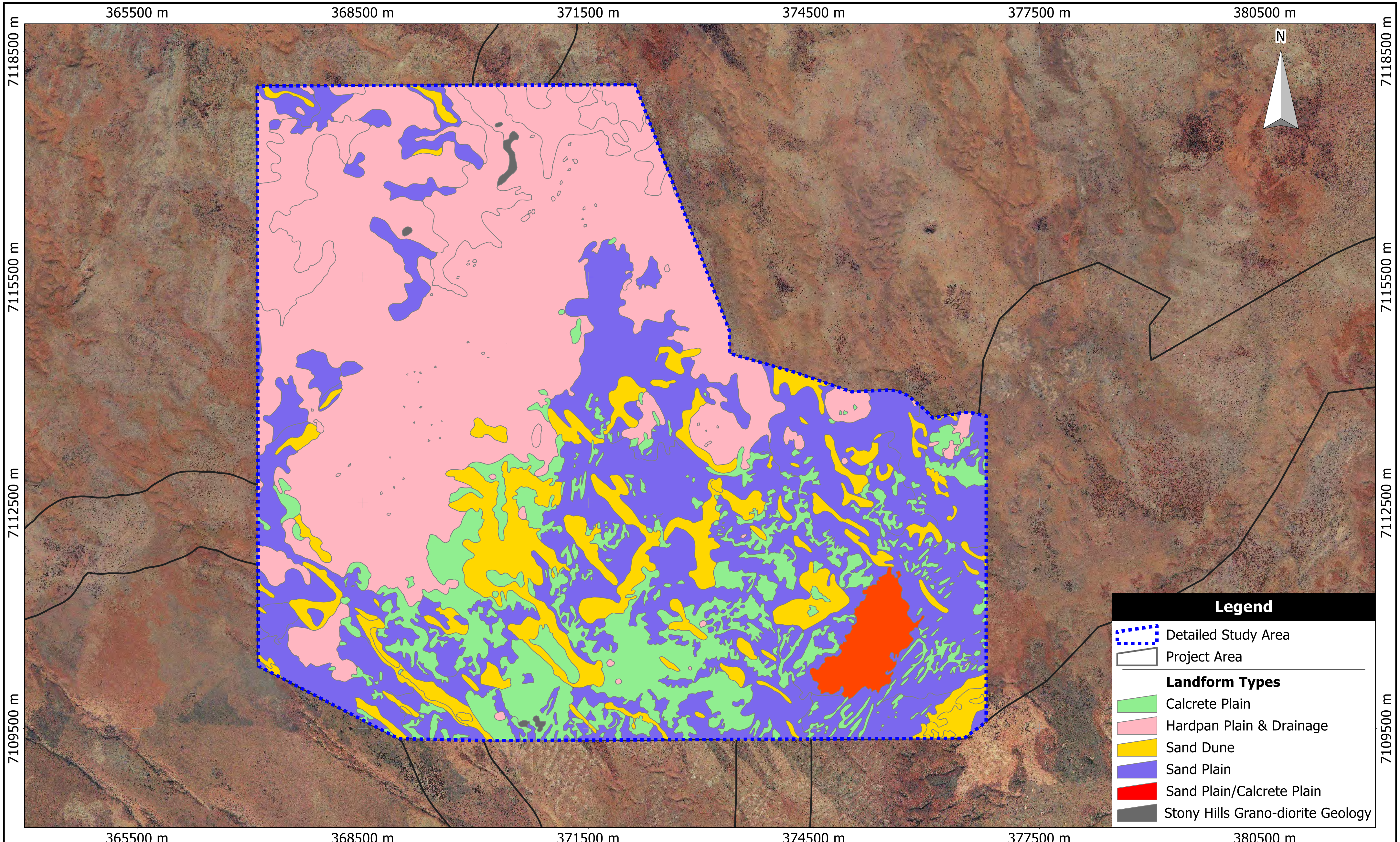
OZ Minerals
West Musgrave Project
Soil and Landform Assessment

Figure 9

Regional Landform Context

Martinick Bosch Sell Pty Ltd
4 Cook St
West Perth WA 6005
Australia
t: +61 8 9226 3166
info@mbsenvironmental.com.au
www.mbsenvironmental.com.au

MBS ENVIRONMENTAL



Scale: 1:65000
Original Size: A4
Air Photo Date: 2018
Grid: Australia MGA94 (52)

0 1 km

OZ Minerals
West Musgrave Project
Soil and Landform Report

Figure 10

Landforms within Detailed Study Area

Martinick Bosch Sell Pty Ltd
4 Cook St West Perth WA 6005
Australia
t:+61 8 9226 3166
info@mbsenvironmental.com.au
www.mbsenvironmental.com.au
MBS ENVIRONMENTAL

Table 4: Landform Systems and Vegetation of the WMP

Landform	Subclass	Description	Regional Occurrence
Calcrete Plain		Level to undulating plains of paleo-groundwater Calcrete overlain by varying depths of aeolian sand, supporting *Corymbia* Woodlands, *Eucalyptus* Mallee Shrublands, *Acacia* or *Allocasuarina* Shrublands over *Triodia scariosa* Hummock Grasslands.	Extensive across the Project area
Hardpan Plain and Drainage	Plains	Red clayey sand hardpan plains subject to sheet flow, supporting Mulga Woodlands with Shrub mid storey and Grass and Forb dominated understorey.	Extensive in the region
	Clay Pans	(a) Small ephemerally inundated clay pans with hard setting clay soils supporting annual grasses and herbaceous vegetation; or (b) Extensive clay pans with medium to heavy clay soils supporting perennial grasses.	Limited areas in the region
Sand Dune		Sand dunes with fine red aeolian sand, 2 to 20 m relief supporting *Acacia*, *Grevillea*, *Dodonaea* and *Aluta* Shrublands.	Extensive in the region
Sand Plain		Aeolian medium red silty sand plains, often with hardpan or underlying calcrete, supporting extensive Spinifex (*Triodia basedowii, T. schinzii*) hummock grasslands with emergent *Acacia*, *Eremophila* and *Grevillea* shrubs.	Extensive in the region
Stony Hills	Grano-diorite	Foot slopes and outwash plains at the base of small to medium sized outcrops of grano-diorite, supporting *Acacia* and *Senna* Shrublands and *Eriachne* hummock grasslands.	Extensive in the region
	Ironstone	Low hills of ironstone (magnetite) supporting Mulga and / or Low Chenopod Shrublands.	Limited areas in the region

Plate 1: Typical Calcrete Plain

Plate 2: Typical Hardpan Plain and Drainage

Plate 3: Typical Sand Dune (Western Botanical 2018)

Plate 4: Typical Sand Plain

Plate 5: Typical Interdune Plain and Distant Stony Hills

The EPA Environmental Factor for landforms provides criteria to determine whether landforms are significant. The landforms within the Project area are considered in the following sub sections against these criteria.

4.3.2.1 Variety, Rarity and Integrity of Impacted Landforms

From a review of aerial photography and use of DMIRS GeoVIEW database (DMIRS 2019), none of the landforms present within the Project area appear to have been previously disturbed or fragmented, other than by mineral exploration activities. The region is not actively grazed (Graham and Cowan 2001) and minimal disturbance to vegetation communities is expected to have occurred. Whilst the dunes are essentially ephemeral, their integrity is not considered to have been impacted in a permanent or significant way.

Apart from Clay Pans (Hardpan Plain and Drainage landform type) and Ironstone (Stony Hills landform type), all landform types within the Project area are considered to be extensively represented within the region. Although Clay Pans are considered to be present in limited areas within the region, these are likely to avoided for siting project infrastructure and therefore it is unlikely that they will be significantly impacted. Likewise, Ironstone Stony Hills are generally unsuitable for construction and are unlikely to be significantly disturbed by project infrastructure. The red sandplains and dunefields that may potentially be impacted by the Project are widely represented in the local and broader region.

Using the EPA criteria for determining whether a landform is significant, the landforms within the Project area are not considered to be significant as:

- Landforms that may potentially be impacted are well represented over the local and regional scale and are not considered to be rare at either scale.
- No landforms have been identified that could be considered to be an important example of their type.
- While the landforms within the Project area are intact and in good condition due to the previous and current land use and land tenure, this is also true of the landforms within the region.

4.3.2.2 Ecological Functions of Impacted Landforms

Detailed flora and vegetation (Western Botanical 2018) and vertebrate fauna (Western Wildlife 2019) baseline surveys are being undertaken for the WMP. Results of these have been considered in relation to species and communities identified being associated with landforms discussed in this report.

It is noted that the landforms identified within the Project area are well represented overall at the regional level and therefore ecological impacts from landform disturbance are not expected to be significant (Table 4).

Using the EPA criteria for determining whether a landform is significant, the landforms within the Project area are not considered to be significant as:

- The landforms within the Project area do not have a distinctive or exclusive role in maintaining existing ecological and physical processes; for example, by providing a unique microclimate, source of water flow, or shade.
- The landforms within the Project area do not support endemic or highly restricted plants or animals that are not known to be also present outside of the Project area.

4.3.2.3 Scientific or Evolutionary Values of Impacted Landforms

Landforms with significant scientific or evolutionary values in WA are identified as geoheritage sites or reserves. A State register of all geoheritage sites and reserves is managed by the Executive Director of the Geological Survey of Western Australia (GSWA) to assist in managing, preserving and protecting exceptional geological features. Geoheritage focuses on the diversity of minerals, rocks, fossils, and features that indicate the origin and/or alteration of minerals, rocks and fossils. It also includes landforms and other geomorphological features that illustrate the effects of present and past effects of climate and earth forces (McBriar 1995 as cited in Brocx and Semeniuk 2007).

There are no known scientific or evolutionary values associated with the landforms within the Project area. The closest geoheritage site to the Project area, Connolly Basin, is 400 km to the northwest within the Gibson Desert. It is unlikely that landforms within the Project area or the LAU would be considered to be geoheritage sites, given they are not unique or restricted to this area.

Using the EPA criteria for determining whether a landform is significant, the landforms within the Project area are not considered to be significant as:

- The landforms within the Project area do not specifically provide evidence of past ecological processes.

- The landforms within the Project area are not known to be important geomorphological or geological sites.
- The landforms within the Project area are not of recognised scientific interest as reference sites or examples of where important natural processes are operating.

4.3.2.4 Social Importance of Impacted Landforms

Landforms may be of social importance if they support significant amenity, cultural or heritage values linked to their defining physical features (EPA 2018).

A review of registered Aboriginal Heritage Places (GeoVIEW WA, DMIRS 2019) indicated that many of the landforms discussed in Section 4.3.1 (e.g. the Cavenagh and Jamieson Ranges) are of cultural importance (Figure 9), with many located in exclusion zones agreed with Traditional Owners (People on the Ngaanyatjarra lands). MBS understands that OZ Minerals does not intend to pursue development of the potential Western Access Road due to the cultural and heritage significance of potentially impacted sites in that area. This means that Winburn Rocks (Plate 6), a registered Aboriginal Heritage Place located adjacent to the potential Western Access Road route, will not be impacted. An additional three heritage sites have been identified in proximity to the potential Northern Borefield location; however, these are not associated with a particular landform type and will not be directly impacted by the Project.

Using the EPA criteria for determining whether a landform is significant, the landforms within the Project area are not considered to be significant as:

- The landforms within the Project area do not support significant amenity, cultural or heritage values linked to its defining physical features. Those landforms present regionally that are of potential social significance will not be impacted by the Project as a result of specific agreements with Traditional Owners.

Plate 6: Winburn Rocks – Registered Heritage Site

5. DETAILED FIELD INVESTIGATIONS

5.1 SOIL PROFILE ASSESSMENT AND SAMPLING

Soil samples were collected from excavated test pits and surface samples within the Detailed Study Area. Samples were collected by OZ Minerals staff in accordance with a Sampling and Analysis Plan prepared by MBS Environmental (Appendix 1). The corresponding sample locations are shown in Figure 11.

Soil profile characteristics were described and assessed using methodologies described in the Australian Soil and Land Survey Handbook (McDonald and Isbell 2009) and Department of Agriculture and Food, Resource Management Technical Report 280 (DAFWA 2004). Soil attributes described include:

- Depth of soil horizons, including ‘hardpan‘ layers.
- Soil colour.
- Soil texture.
- Soil fabric, including level of compaction.
- Moisture content.
- Presence or absence of plant roots at depth.
- Presence of distinctive soil genesis features such as mottling, gleying, calcrete and ferruginous pisoliths.

Relevant landscape features including topography (slope), vegetation and surface conditions (leaf litter, woody debris, rock fragments, cryptogamic crusts, surface cracking) were also recorded.

5.2 TEST PIT LOCATIONS

Test pits were located in areas that may be disturbed by potential mining activities, consistent with potential locations of two pits and key mining infrastructure, as well as four ‘reference’ locations that are unlikely to be disturbed.

A total of 37 samples of topsoil (to a maximum depth of 500 mm) and 32 samples of subsoil (B1 or B2 horizons) were collected from 37 test pit locations within the Detailed Study Area. As shown in Figure 11, the sample locations reflect the dominant landform types identified within the Detailed Study Area including Hardpan Plain and Drainage, Calcrete Plain, Sand Plain, Sand Dune and Sand Plain/Calcrete Plain. Sample locations were also selected to achieve coverage of the potential project infrastructure locations (i.e. to reflect maximum disturbance). Details of the soil sample locations and basic characteristics are presented in Table A4-1 (Appendix 4). The following comments relate to the selection of sample locations relative to potential project infrastructure:

- Six pits (Pits BP01 to BP06 and NP01 to NP06) were excavated to refusal or a maximum depth of 1.5 m within the potential footprint of the Babel and Nebo pits, respectively.
- Three pits (Pits TSF1 to TSF3) were excavated from an area to the north of the potential Babel deposit, which is considered suitable for construction of a potential TSF (subject to further site assessment).
- Three pits (Pits WRD1 to WRD3) were excavated from potential locations for waste rock dumps for each deposit. These included one pit (WRD1) to the north of potential Babel deposit and two pits (WRD2 and WRD3) south of potential Nebo deposit.
- Twelve pits (Pits PD1 to PD12) were excavated at various locations around the Detailed Study Area to reflect soil conditions at other potential disturbance areas including possible locations for process plant, access roads, wastewater and landfill facilities.

- Four shallow pits (REF1 to REF4) were excavated at locations just outside the perimeter of areas of potential disturbance to reflect baseline soil conditions.
- Three shallow pits (SF3) were excavated at locations within the potential renewable energy area footprint covered by aeolian sand.

5.3 LABORATORY TESTS

A program of laboratory testing was undertaken to characterise physical and chemical properties of the soils, and to assess their suitability for use as cover materials during site rehabilitation. For these reasons, the test program focused on parameters relating to physical stability and plant nutrition characteristics.

The following tests were undertaken by ChemCentre (Bentley, Western Australia), generally using NATA accredited, in-house modifications of standard soil tests described by Rayment and Lyons (2011):

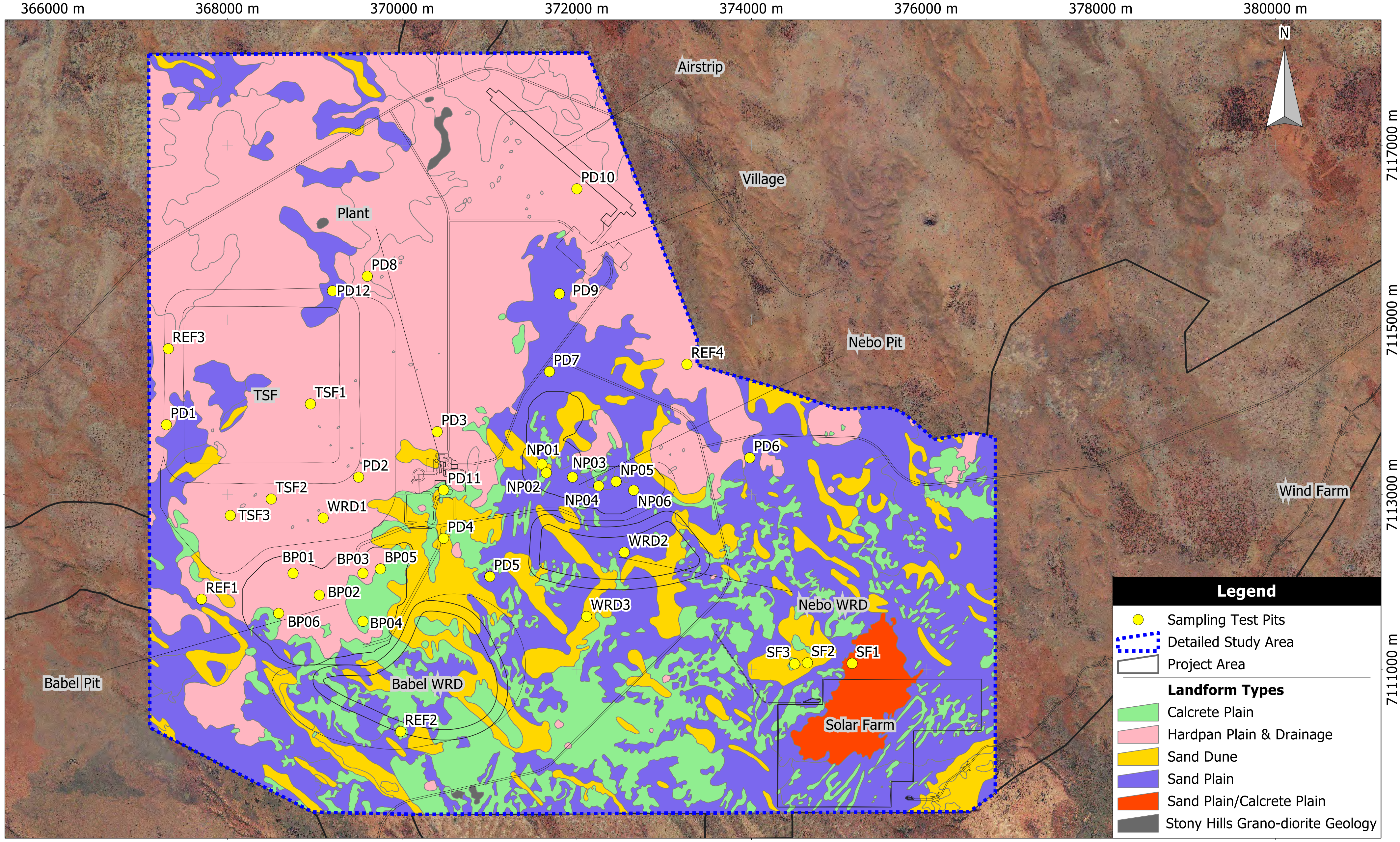
- Soil pH and electrical conductivity (EC) in water extracts (1:5 solids to liquids ratio).
- Exchangeable cations (calcium, sodium, potassium and magnesium) and sodicity. Exchangeable acidic cations (aluminium and manganese) were also measured on soils with pH values below 5.
- Organic carbon and total nitrogen.
- Gravel content and texture (sand, silt, clay and gravel contents).
- Potential for dispersion (Emerson Class, AS 1289 C8.1, Standards Australia 1980).
- Plant-available nutrients and potentially phytotoxic metals (Mehlich extract, Mehlich 1984).
- Total environmentally-available concentrations of an eight element suite of metals and metalloids designed to calculate site-specific Ecological Investigation Levels (EILs) in accordance with NEPM (NEPC 2013) guidelines.
- Acid Neutralising Capacity (ANC) using the Sobek method as described by AMIRA International (2002).

5.4 INTERPRETATION OF RESULTS

The following sources of information were used to assess the significance of laboratory test results:

- Soil Analysis: An Interpretation Manual (Peverill *et al*. 1999).
- Interpreting Soil Test Results. What do all the numbers mean? (Hazelton and Murphy 2007).
- Soil Guide. A handbook for understanding and managing agricultural soils. DAFWA Bulletin 4343 (DAFWA 1998).
- Soil-Landscape Mapping in South-Western Australia, Overview of methodology and outputs. Resource Management Technical Report 280 (DAFWA 2004).
- The author's (David Allen) experience from coordinating chemical analysis for DAFWA soil surveys conducted between 1988 and 1998.

A summary of the information sources and ratings tables used for this assessment is presented in Appendix 2.



Scale: 1:57000
Original Size: A4
Air Photo Date: 2018
Grid: Australia MGA94 (52)

OZ Minerals
West Musgrave Project
Soil and Landform Report

Figure 11

Test Pit and Surface Soil Sampling Locations

Martinick Bosch Sell Pty Ltd
4 Cook St West Perth WA 6005
Australia
t:+61 8 9226 3166
info@mbsenvironmental.com.au
www.mbsenvironmental.com.au

MBS ENVIRONMENTAL

6. DESCRIPTIONS AND SOIL PROFILES

6.1 SOIL AND LANDFORM MAPPING UNITS

A review of aerial imagery, results of project specific vegetation surveys (Western Botanical 2018) and site observations allowed for identification of the following soil types within the Detailed Study Area:

- Deep aeolian sand, typically associated with low vegetated dunes.
- Shallow aeolian sand overlying hardpan, typically calcrete.
- Shallow gravelly calcareous soils.

These soil types are further described in Section 6.2 and their distribution within the Detailed Study Area is shown in Figure 12. The dominant soil types and descriptions are presented in Table 5, using the classifications presented in Schoknecht and Pathan (2013), as well as the surface area and proportion of the Detailed Study Area attributed to each.

Table 5: Soil Type Descriptions

Soil Types	Dominant Soil Group	Area
Deep aeolian sand dune fields	Red deep sand (Soil Group 445)	3,602 ha (53.4%)
Shallow aeolian sand over hardpan	Red shallow sand (Soil Group 423)	2,327 ha (34.5%)
Shallow gravelly calcareous soils	Calcareous stony soil (Soil Group 202)	817 ha (12.1%)

6.2 SOIL PROFILE DESCRIPTIONS

Descriptions of profile characteristics of the three key soil types within the Detailed Study Area are presented in the following Sections. Additionally, full profile descriptions for each test pit are presented in Appendix 3.

The three soil types are related in that they represent varying depths of aeolian sand deposition over a calcrete/silcrete hardpan peneplain.

6.2.1 Red Deep Sand

Red deep sand occurs as sandplain and dune sequences in topographically elevated areas within the Detailed Study Area. Deep sand is differentiated from the other two soil types by possessing a minimum of 600 mm aeolian siliceous sand as A and B1 horizons (Plate 7) overlying calcrete or silcrete.

Deep red sand is widely distributed to the north of the proposed Babel and Nebo pits (within the My109 land system unit), but also occurs as low dunes overlying the calcrete plain within the My112 land system unit (Figure 8).

Characteristics of red deep sand profiles within the Detailed Study Area include:

- Little evidence of significant accumulation of humified organic matter in the surface (A-horizon) profile.
- Little to no gravel lag at the surface.
- A partly bleached surface, resulting in an orange-brown colour compared to a deeper red-brown (especially when deep or moist) colour of underlying sand, as evident in Plate 7.

- Spinifex (*Triodia* spp.) and grasses as the dominant vegetation types, with minor leaf litter and very little woody debris.
- The A-horizon material is typically a non-calcareous (siliceous) loamy sand, grading into a deep (>500 mm) sandy loam B1 horizon.
- Soil fabric consistent with very good vertical drainage (infiltration).

Plate 7: Red Deep Sand Profile

6.2.2 Red Shallow Sand

Red shallow sand is defined as the soil type comprising a cover of non-calcareous (siliceous) aeolian A and shallow B1 horizon of less than 600 mm in depth. The corresponding B2 horizon is defined by the presence of calcrete (or silcrete) gravels and cobbles, or as indurated calcrete sheet (or silcrete) as a distinct C horizon. Plate 8 shows an example of red shallow sand comprising 300 mm of A and B1 horizons of siliceous sandy loam overlying a gravelly calcareous B2 horizon.

Drainage is generally rapid, except for locations where the siliceous A and B1 are shallow (<300 mm) and overlie an indurated calcareous or siliceous hardpan. Saturation of the siliceous horizon may occur following heavy rainfall events, followed by overland (sheetwash) flow.

Characteristics of red shallow sand profiles within the Detailed Study Area include:

- Little evidence of significant accumulation of humified organic matter in the surface (A-horizon) profile.
- Occasional calcareous or siliceous rounded to sub-angular gravel lag at the surface.
- Mixed vegetation types with variable amounts of leaf litter and woody debris. Spinifex is dominant at locations with good drainage, while Mulga, grasses and mixed shrubs also occur, particularly on shallow sandy profiles overlying indurated hardpan.
- The A-horizon material is typically a non-calcareous (siliceous) loamy sand, grading into a shallow (<300 mm) sandy loam B1 horizon.
- A calcareous B2 horizon containing nodular, gravelly or laminar calcrete.

Plate 8: Red Shallow Sand Profile

6.2.3 Calcareous Stony Soil

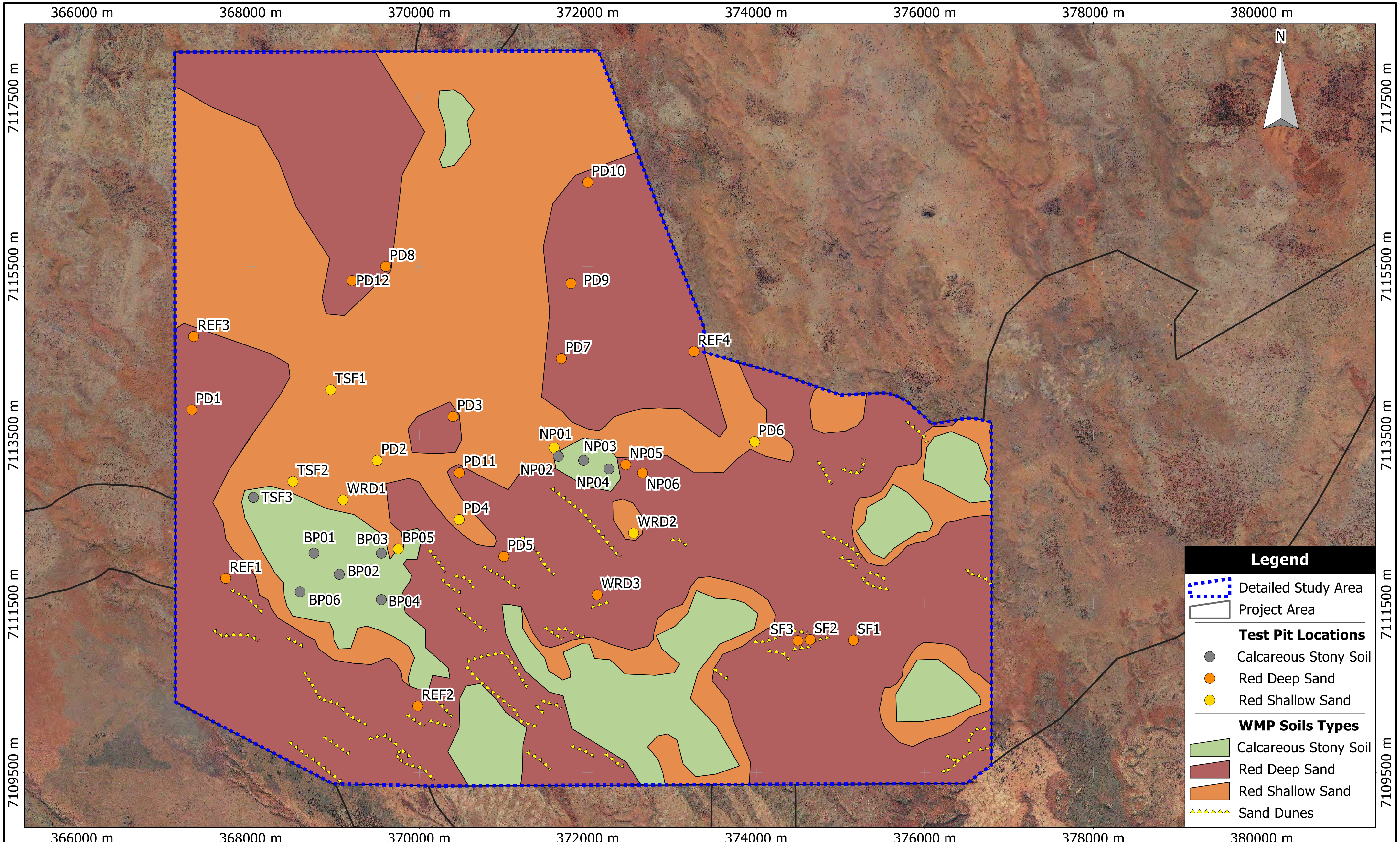
The dominant soil type at locations in which the aeolian sand soil cover is thin (or non-existent) is a calcareous stony soil (Plate 9), corresponding to Soil Group 202 as defined by Schoknecht and Pathan (2013). This soil type is considered to be remnants of a weathered calcrete/silcrete peneplain formed within a broad palaeodrainage feature. This soil type is dominant within the proposed Babel and Nebo pit footprints.

Defining characteristics of calcareous stony profiles within the Detailed Study Area include:

- Little evidence of significant accumulation of humified organic matter in the surface (A-horizon) profile.
- A very thin (<200 mm) yellowish-brown cover of aeolian sand with minor rounded, friable calcrete gravels.
- A B1 horizon comprising rounded to sub-angular, friable calcrete gravels in a yellow-brown sandy loam matrix.

- A B2 horizon comprising weakly cemented calcrete gravels in a grey calcareous sandy clay matrix.
- Root penetration limited mainly to the A and B1 horizons.

Plate 9: Calcareous Stony Soil Profile



Scale: 1:58000
Original Size: A4
Air Photo Date: 2018
Grid: MGA94(52)

0 1 km

OZ Minerals
West Musgrave Project
Soil and Landform Report

Figure 12

Distribution of Soil Types within Detailed Study Area

Martinick Bosch Sell Pty Ltd
4 Cook St West Perth WA 6005
Australia
t:+61 8 9226 3166
info@mbsenvironmental.com.au
www.mbsenvironmental.com.au
MBS ENVIRONMENTAL

7. PHYSICAL AND CHEMICAL SOIL PROPERTIES

Results of physical and chemical analyses of soils are tabulated in Appendix 4 and the original laboratory report is presented in Appendix 5.

7.1 PHYSICAL PROPERTIES

7.1.1 Gravel Content and Texture

Results of analysis of all samples for stones content (material retained by sieving gently crushed material through a 2 mm sieve) are presented in Table A4-1 of Appendix 4, whereas more detailed particle size distributions of selected samples are presented in Table A4-3 of Appendix 4.

Consistent with field observations discussed in Section 6.2, many profiles were found to contain low (<10%) gravel contents in the aeolian A1 horizon (all soil types) and the B1 horizons of deep and shallow red sandy soils. In contrast, high gravel contents (exceeding 65%) were associated with the calcareous stony soil, increasing with soil depth. Massive calcrete was also observed at several locations, in association with calcareous stony soil.

Despite their aeolian character, clay contents were relatively elevated in topsoils and subsoils of the red deep sands, ranging from 4.0% to 18% (Table A4-3 of Appendix 4). Silt contents were lower, ranging from 1% to 13%. Consequently, the soil textures were classified as loamy sands to sandy loams and generally indicated greater coherence than many aeolian sands from the south west of Western Australia.

7.1.2 Emerson Class

Results for analysis of samples for Emerson Class are presented in Table A4-4 of Appendix 4.

Emerson Class values of surface samples were variable, ranging from 1 (highly dispersive) to 4 (relatively stable as a consequence of calcium carbonate cementation). Most topsoil samples (35 of 37) were determined to be Emerson Class 3, which do not disperse in their natural state, but are prone to dispersion when inherent soil structure is compromised by either ploughing or excavation. This observation indicates the silt and clay contents are sufficiently high to provide reasonable soil strength (for sandy soils) in the dry state, but this stability is readily disrupted by input of mechanical energy (including raindrop impact) to saturated soil.

Subsoil samples were classified as Class 1 (usually in red deep sand profiles), Class 3 or Class 4 (usually in calcareous stony soil profiles).

7.2 CHEMICAL PROPERTIES

7.2.1 Salinity and pH

Results for soil pH and salinity, as measured by pH and electrical conductivity of 1:5 soil water extracts respectively, are presented in Table A4-2 of Appendix 4.

A summary of pH results by soil type and sampling depth (i.e. topsoil vs. subsoils and massive calcrete) is presented in Table 6. The following trends were evident:

- Most of the soils were alkaline, with only six samples (all red deep sands) recording pH values below 7.0.
- For the three identified soil types, pH values of topsoils were lower than those of subsoils (Table 6). The difference between average (mean) topsoil pH and subsoil pH decreased in order red shallow sand (Soil Group 423) > red deep sand (Soil Group 445) > calcareous stony soil (Soil Group 202).

- The lowest topsoil pH values were recorded for red deep sand, which had pH values varying widely between 5.3 and 8.6 (average pH 7.2). These soils were rated as strongly acid to strongly alkaline as defined by Table A2-5 of Appendix 2.
- Average pH values of topsoils increased in the order red deep sand (pH 7.2) < red shallow sand (pH 7.7) < calcareous stony soil (pH 8.6). These results are consistent with increasing contributions of alkalinity from underlying calcrete as the depth of siliceous aeolian sand decreases.
- All subsoils across the three soil types (and massive calcrete) were typically alkaline, with average pH values increasing in the order red deep sand (pH 7.8) < red shallow sand (pH 8.5) < calcareous stony soil (pH 8.8) < calcrete (pH 9.0).

Three samples of massive calcrete (from locations PD02, PD06 and TSF3) were analysed for ANC as a measure of calcium carbonate contents. Values ranged from 400 to 810 kg H_2SO_4/t, corresponding to calcium carbonate contents of between 41% and 83% by weight.

Table 6: Summary of pH by Soil Type and Depth

Soil Type	Topsoil/Subsoil	Minimum	Maximum	Average (Mean)
Red deep sand (Soil Group 445)	Topsoil	5.3	8.5	7.2
	Subsoil	6.8	7.6	7.8
Red shallow sand (Soil Group 423)	Topsoil	7.2	8.3	7.7
	Subsoil	8.3	8.8	8.5
Calcareous stony soil (Soil Group 202)	Topsoil	7.9	8.8	8.6
	Subsoil	8.7	8.8	8.8
Calcrete	Subsoil	8.9	9.1	9.0

A summary of EC (1:5 water extracts) results by soil type and sampling depth (topsoils and subsoils) is presented in Table 7. The following trends were evident:

- EC results were low, ranging from <1 to 10 mS/m. The corresponding salinity rating, based on criteria listed in Table A2-6 of Appendix 2, is 'Nil' for all samples (i.e. all soil types and depths).
- The lowest topsoil EC values were recorded for red deep sand (minimum <1 mS/m, average 1.5 mS/m) and red shallow sand (minimum <1 mS/m, average 1.8 mS/m). The corresponding topsoil EC values for the calcareous stony soil were slightly higher (minimum 5 mS/m, average 6 mS/m).
- EC values of subsoils for each soil type were also low, but generally slightly higher than those of the corresponding topsoils.
- Three samples of crushed calcrete, which all recorded the EC values of 10 mS/m, were the highest of the soil materials assessed, but also attained a salinity rating of 'Nil'.

Table 7: Electrical Conductivity (mS/cm) Summary by Soil Type

Soil Type	Topsoil/Subsoil	Minimum	Maximum	Average
Red deep sand (Soil Group 445)	Topsoil	<1	7	1.5
	Subsoil	1	9	4.0
Red shallow sand (Soil Group 423)	Topsoil	<1	4	1.8
	Subsoil	4	9	7.0
Calcareous stony soil (Soil Group 202)	Topsoil	5	8	6.0
	Subsoil	8	8	8.0
Calcrete	Subsoil	10	10	10

7.2.2 Cation Exchange Characteristics

Results for exchangeable cations (calcium, magnesium, sodium and potassium) are presented in Table A4-5 of Appendix 4. Also included are calculated values for Effective Cation Exchange Capacity (ECEC), Base Saturation Percentage (BS%) and Exchangeable Sodium Percentage (ESP) (Appendix 2).

Summaries of ECEC results by soil type and sampling depth (topsoils and subsoils, excluding calcrete) are presented in Table 8. The following trends relating to exchangeable cation characteristics were evident:

- ECEC values were variable, ranging from 0.8 centimoles of positive charge per kilogram of soil (cmol (+)/kg) (very low) to 11.6 cmol (+)/kg (medium).
- The lowest ECEC values were associated with topsoils of the red deep sand (Soil Group 445), which is consistent with their sandy and siliceous character.
- The low ECEC values for soils with loamy sand to sandy loam textures indicate that cation exchange is mainly associated with low activity clays (LAC) such as kaolinite.
- ECEC values of subsoils were higher than those of the corresponding topsoils for all three soil types. This was attributed to the greater alkalinity of subsoils, noting that the method used for alkaline calcareous soils (1 M ammonium chloride in 60% ethanol solution, pH 8.5) was different to that use for circum-neutral to slightly alkaline soils (1 M ammonium chloride, pH 7.0) and for acidic soils (unbuffered 0.1 M barium chloride). This observation indicates a substantial proportion of soil ECEC is considered 'variably charged' (as a consequence of extended weathering of LAC materials), with the exchange sites attaining increasing net negative charge density with increasing pH.
- Calcium was the dominant exchangeable cation in all soils, but particularly calcareous subsoils of red shallow sands (Soil Group 423) and calcareous stony soils (Soil Group 202).
- Soil sodicity was rated as low, as indicated by ESP values ranging from <1% to 8%. This observation is consistent with a dominance of Emerson Class 3 and 4 samples (Section 7.1.2). The potential for clay dispersion only after remoulding the test samples (Class 3) is related to low salinity (Section 7.2.1) rather than sodicity.
- Three acidic topsoils (from locations NP04, BP02 and BP03) were analysed for acidic exchangeable cations (Al^{3+} and Mn^{2+}) using the barium chloride extraction method. Concentrations of these potentially phytotoxic cations (refer Section 3.3 of Appendix 2) were rated as low to medium, and therefore BS% values were considered high (66% to 94%). Consequently, the potential for adverse impacts to plants growing on these acidic soil types (topsoils of deep red sands) is considered low.

Table 8: ECEC (cmol(+)/kg) Summary by Soil Type and Depth

Soil Type	Topsoil/Subsoil	Minimum	Maximum	Average
Red deep sand (Soil Group 445)	Topsoil	0.8	9.0	2.7
	Subsoil	1.8	9.2	4.5
Red shallow sand (Soil Group 423)	Topsoil	1.8	9.1	4.2
	Subsoil	4.1	11.6	8.0
Calcareous stony soil (Soil Group 202)	Topsoil	3.3	9.2	5.4
	Subsoil	4.1	10.2	6.2

7.2.3 Organic Carbon, Nitrogen and Extractable Nutrients

Results for organic carbon, total nitrogen and extractable nutrients (Mehlich 3 method) are presented in Table A4-6 of Appendix 4. Also included are results for extractable metals and metalloids (Al, Cd, Co, Mo, Ni, As, Pb and Se in Table A4-7 of Appendix 4).

The following observations were noted:

- Organic carbon contents of topsoils were typically low, ranging from 0.14% to 0.55%. These values indicate an organic carbon rating of low according to Table A2-8 of Appendix 2. These values are consistent with field observations that indicated relatively little humified organic matter enrichment at the soil surface.
- Organic carbon to total nitrogen ratios (C/N) were variable, ranging from 8.5 at location TSF2 to 21.3 at location NP01. Variable C/N ratios indicate different contributions of both bacterial and fungal degradation of leaf litter and woody debris, which are sourced from different plant species including spinifex, grasses and mulga shrubs. Soils with low to medium C/N ratios (as indicated by Table A2-8 of Appendix 2) are considered capable of releasing mineralised nitrogen nutrients via degradation of soil organic matter.
- Extractable phosphorus concentrations of topsoils, ranging from <1 to 32 mg/kg, are mainly rated as 'Typical' to 'Elevated' according to Table A2-9 of Appendix 2. Phosphorus is typically the limiting macronutrient in soils in Western Australia, noting that many native plants are adapted to low-phosphorus soils. The phosphorus levels are considered sufficient for establishing local native plants for revegetation of disturbed areas without application of fertiliser.
- Extractable sulfur concentrations ranged from 1 to 6 mg/kg in surface samples and correspond to a rating of 'Low' according to Table A2-9 of Appendix 2. Low sulfur concentrations are often associated with well-drained sandy soils, in which most of the sulfur requirement by native plants is satisfied by sulfur released by mineralisation of soil organic matter. Supplementation with fertiliser sulfur is not recommended.
- Extractable potassium concentrations were variable, ranging from 52 to 330 mg/kg, and were generally higher in calcareous stony soils. Measured concentrations were generally within the 'Typical' to 'Elevated' ratings according Table A2-9 of Appendix 2.
- Extractable calcium and magnesium concentrations were substantially higher in samples of calcareous stony soil (BP01, BP04, NP02 and TSF3) compared to those from the red deep and shallow (aeolian) sands.
- Extractable boron concentrations were variable, ranging from 0.1 to 1.2 mg/kg, with higher concentrations present in calcareous stony soils. Concentrations were within the 'Typical' range of WA soils (Table A2-9 of Appendix 2) and are unlikely to result in either deficiency or toxicity to native plants.
- Concentrations of micro-nutrients (Cu, Fe, Mn and Zn) were generally within the 'Typical' range for WA soil types according to Table A2-9 of Appendix 2. Samples containing 'Elevated' concentrations of

manganese, such as from TSF1 (120 mg/kg) and TSF2 (110 mg/kg), are unlikely to be phytotoxic to native plants because of the alkalinity (and therefore reduced bioavailability) of these soils.

7.2.4 Metals and Metalloids

Concentrations of eight environmentally significant metals and metalloids for selected samples are presented in Table A4-7 (estimated bioavailable concentrations) and Table A4-8 (total environmentally available concentrations) of Appendix 4. A statistical summary of total environmentally available concentration results is presented in Table 9.

These results indicate the selected metals and metalloids are typically present at concentrations less than the corresponding average crustal abundances, including copper and nickel which are geochemically enriched in Nebo and Babel lithologies. The low concentrations and lack of geochemical enrichment with respect to average crustal concentrations, are consistent with the dominance of aeolian sands as topsoil across the Project area.

The 80th percentile values presented in Table 9 are considered suitable as “Ambient Background Concentrations” (ABCs) from which site-specific Ecological Investigation Levels (EILs) can be derived as baseline comparators for assessing potential site contamination from mining activities. Site specific EIL values for As, Cu, Cr, Ni, Pb and Zn may be calculated from these ABC values using guidelines documented in the National Environment Protection (Assessment of Site Contamination) Measure published by the National Environment Protection Council (NEPC 2013).

Table 9: Metal and Metalloid Concentrations Summary (mg/kg)

Element	As	Cd	Cr	Cu	Mn	Ni	Pb	Zn
Minimum	0.6	<0.05	7	3.8	23	5.5	0.9	9
Maximum	2.2	0.22	57	71	330	95	8.3	70
Average	1.3	0.05	34	13	158	16	3.0	20
80th Percentile	1.9	0.05	39	14	274	15	4.0	21
Crustal Average	25	0.11	100	50	950	80	14	75

8. CONCLUSIONS

8.1 LANDFORMS

Several major landforms were identified within the LAU for the Project, including:

- Blackstone Range, located 12 km east of the potential Northern Borefield.
- Cavenagh Range, located 3 km southwest of the potential Northern Borefield.
- Jamieson Range, located 5 km northeast of the potential Jameson Access Road route.
- Barrow Range, located immediately to the west of the potential Western Access Road route.

Other notable landforms identified within the LAU included:

- Low stony hillocks such as the Mulaggora Hills, Milyugal Hills and Borrows Hill, which are respectively located 7, 18 and 28 km east of the potential Southern Borefield.
- Low stony hillocks located west of the potential Southern Borefield, including Round Hill (2 km) and Hacking Range (10 km).
- Small stony hillocks located closer to the potential locations of key mining infrastructure and two pits (within 5 km), including Cohn Hill, Minnie Hill and Red Rock

The significance of the landforms mentioned above was not assessed, as discussed in the Western Australian Environmental Protection Authority *Environmental Factor Guideline for Landforms* (EPA 2018), as they are located outside of the Project area and will not be impacted by the Project.

The following landforms were identified within the Detailed Study Area:

- Calcrete Plain: Level to undulating plains of paleo-groundwater calcrete overlain by varying depths of aeolian sand.
- Hardpan Plain and Drainage: Red clayey sand hardpan plains subject to sheet flow.
- Sand Dune: Sand dunes with fine red aeolian sand, 2 to 20 m relief.
- Sand Plain: Aeolian medium red silty sand plains, often with hardpan or underlying calcrete.
- Stony Hills: Foot slopes and outwash plains at the base of small to medium sized outcrops of grano-diorite and low hills of ironstone (magnetite).

Impacts from potential disturbance of these landforms were evaluated, accounting for the likely degree of potential disturbance, and with consideration of their significance (variety, integrity and rarity, and ecological, scientific or social importance) as discussed in EPA (2018). The key findings in relation to landform disturbance were:

- There are no significant landforms, as defined by the Western Australian Environmental Protection Authority, within the Project area.
- Whilst the Project may impact some of plain landforms (e.g. Calcrete Plain, Hardpan Plain and Drainage and Sand Plain) and low aeolian sand dunes, these are well represented at a regional level and are not considered unique or rare.
- Landform disturbance is not considered likely to represent significant impacts in terms of ecological function, scientific interest, cultural importance or social values (Section 4.3.2).

8.2 PHYSICAL AND CHEMICAL SOIL PROPERTIES

Three physically and chemically distinct soil types were identified in the Project area:

- Red deep sand (DAFWA Soil Group 445).
- Red shallow sand (DAFWA Soil Group 423).
- Calcareous stony soil (DAFWA Soil Group 202).

These soil types are related to each other by variable depths of cover of red-brown aeolian sand over a calcrete/silcrete peneplain. The deep phase (Soil Group 445) is indicated by a sandy subsoil layer of at least 600 mm (and considerably more within dunes) over nodular, gravelly or massive calcrete/silcrete. The shallow phase (Soil Group 423) is indicated by a subsoil sandy layer of 300 to 600 mm. The calcareous stony soil (Soil Group 202), which is the dominant soil type within the footprints of the potential Babel and Nebo pits, has a thin (0 to 200 mm) A1 sandy horizon over weathered, gravelly calcrete.

Characteristics of the aeolian sand covers for these three soil types are summarised as follows:

- Variable pH, ranging from 5.3 (strongly acid) to 8.6 (strongly alkaline). Topsoil pH values typically decrease with increasing depth of the sandy B1 horizons.
- Topsoils and the red aeolian sands (Soil Groups 445 and 423) are siliceous and non-calcareous, while the surface calcareous stony soil (Soil group 202) is slightly calcareous due to presence of calcrete gravels.
- Very low salinity as a consequence of good drainage.
- Non-sodic.
- Soil texture grading from sand to loamy sand to sandy loam, with silt and clay contents increasing with depth.
- Very low gravel contents.
- Reasonable strength for sandy soil as a consequence of slightly elevated silt and clay contents (i.e. compared to coastal aeolian soil types in the south west of WA).
- Slight risk of clay dispersion, based on a typical Emerson Class of 3.
- Low organic carbon and total nitrogen concentrations, which are typical of sandy soils in arid and semi-arid regions of WA.
- Concentrations of bioavailable nutrients generally within the ‘Typical’ range of unfertilised WA soils.

Underlying calcrete/silcrete subsoil materials are characterised by:

- Strongly alkaline pH values (8.3 to 9.1).
- Highly calcareous, particularly nodular, gravelly and indurated calcretes.
- Low salinity.
- Non-sodic.
- Soil texture grading from loamy sand to (gravelly) sandy clay loam.
- Low to slight risk of clay dispersion, based on a typical Emerson Class of 3 for siliceous aeolian subsoils and Class 4 for calcareous subsoils.

8.3 IMPLICATIONS FOR SOIL MANAGEMENT

8.3.1 Soil Harvesting

The purpose of soil harvesting from potentially disturbed areas, particularly open pit and waste landform footprints, is to ensure that there are sufficient volumes of topsoils and subsoils of suitable quality for rehabilitating disturbed areas at mine closure.

Based on the physical and chemical characteristics of soil types present within the Detailed Study Area, it is recommended that topsoil is stripped from all areas of potential disturbance. As the expected volume of sandy subsoils is substantial, especially within areas covered by dunes and deep red sand (i.e. likely to exceed rehabilitation requirements), it is recommended that harvesting of sandy subsoil is restricted to the potential footprints of the Babel and Nebo pits.

A substantial layer of calcrete/silcrete is present beneath all major soil types within the potential disturbance areas. As this material has desirable acid neutralising properties, it is considered a potentially valuable resource for operational and rehabilitation purposes.

It is recommended that any topsoils harvested should be segregated for storage prior to re-use as follows:

- Topsoils to a depth of 100 to 200 mm from all potentially disturbed areas: There is no requirement to separate acid and alkaline soils, or soil from the three major soil groups. Potential footprints of the TSF, WRD and Babel and Nebo pits (Figure 11) will supply most of this material. Smaller stockpiles can be created from other disturbed areas including roads, borefields, the accommodation village, process plant and airport. Topsoils should be managed in accordance with DMIRS guidelines (DMIRS 2016) and constructed to a maximum height of 2 m. Harvesting should not be undertaken during windy conditions as the soil has potential to generate significant volumes of dust.
- Sandy subsoils from dunes and red sandy soils from the footprints of the potential Babel and Nebo pits: As this soil is expected to contain very little viable seed and minimal nutrients, stockpiles may exceed the 2 metre height limit of topsoil stockpiles. Substantial volumes of sandy subsoil (supplemented by non-acid forming waste rock) are anticipated to be useful for constructing covers such as store and release covers (e.g. on the potential TSF) at closure.
- Calcareous gravels and nodular calcrete from the calcareous stony soil within the footprints of the proposed Babel and Nebo pits: This material is considered the best available soil type for rehabilitation of sloping surfaces, such as waste landform embankments, at mine closure. Additional material is expected to be encountered in local deposits from soil harvesting prior to construction of WRDs and TSF.

8.3.2 Waste Landform Rehabilitation and Mine Closure

All topsoil is considered suitable for rehabilitation of flat or gently sloping (less than 2°) surfaces such as the top of potential WRDs and upper TSF surfaces. Provided the upper layer of rock in the potential WRDs is non-acid forming and non-mineralised, direct placement of harvested topsoil (indicatively 100 to 200 mm in depth) of is expected to be sufficient to encourage revegetation consistent with the post-closure land use requirements. A 100 mm layer of topsoil overlying a suitably thick layer of harvested subsoil and non-acid forming waste rock is considered appropriate for applications such as covering tailings deposited in the potential TSFs. These specifications are indicative, and the optimum layer thickness will be determined by physical properties of the rehabilitation materials and geochemical properties of tailings.

The preferred soil type for rehabilitation of mine waste landforms with sloping surfaces, such as embankments of potential WRDs and TSFs, is calcareous stony soil and nodular calcrete. It would be necessary to test the suitability of this material using trials, as indicated below, considering the numerous potential options for landform rehabilitation.

It is recommended that the final surface cover designs for sloping landform surfaces and potential TSF covers are assessed by a cover trial program prior to final mine rehabilitation and closure. Such trials may consider:

- Different topsoil thickness, ranging from 100 to 300 mm.
- Blending soil with competent, geochemically benign waste rock to improve resistance to erosion on sloping surfaces.
- Different subsoil/waste rock blends and thicknesses for cover over tailings deposited in potential TSFs.
- Different plant species, consistent with the post closure land use requirements. If native vegetation is to be replaced, consistent with suitable reference sites, it is recommended that spinifex grasses (*Triodia* spp.) are evaluated. These typically require a well-drained, moderately deep soil profile.

9. REFERENCES

AMIRA International. 2002. ARD Test Handbook: Project 387A Prediction and Kinetic Control of Acid Mine Drainage. Prepared for AMIRA International by Ian Wark Research Institute and Environmental Geochemistry International Pty Ltd. http://www.amira.com.au/documents/downloads/P387AProtocolBooklet.pdf (accessed 18 January 2019).

Australian National Herbarium. 2011. *Botanical Districts of Australia*. Centre for Australian National Biodiversity Research, Canberra. https://www.anbg.gov.au/cpbr/anhsir/anhsir-manual/botanical-districts.html (accessed 3 November 2017).

Barton, B. and Cowan, M. 2001. Great Victoria Desert 2 (GVD2 - Great Victoria Desert Central subregion). https://www.dpaw.wa.gov.au/images/documents/about/science/projects/waaudit/great_victoria_desert02_p351-357.pdf (accessed 31 January 2019).

Beard, J.S. 1990. *Plant life of Western Australia*. Kangaroo Press. Kenthurst, Australia.

Beard, J. S., Beeston, G. R., Harvey, J. M., Hopkins, A. J. M. and Shepherd, D. P. 2013. *The vegetation of Western Australia at the 1:3,000,000 scale*. Explanatory memoir. Second edition. *Conservation Science Western Australia* 9: 1-152.

Beecham, B. and Danks, A. 2001. Mallee 2 (MAL2 – Western Mallee subregion). In *A Biodiversity Audit of Western Australia's 53 Biogeographical Subregions in 2002*. Department of Conservation and Land Management, Western Australia.

BoM (Commonwealth Bureau of Meteorology). 2016. *Intensity – Frequency – Duration.* http://www.bom.gov.au/water/designRainfalls/ifd/.

BoM (Commonwealth Bureau of Meteorology). 2018. *Climate Statistics for Australian Locations - Warburton*. http://www.bom.gov.au/climate/averages/tables/cw_013011_All.shtml#rainfall (accessed 21 November 2018).

Brocx, M, and Semeniuk, V. 2007. Geoheritage and geoconservation – history, definition, scope and scale. *Journal of the Royal Society of Western Australia* 90: 53-87.

CDM Smith. 2018a. West Musgrave Project Pre-Feasibility Study – Desktop study of the water supply potential of the Officer Basin. Unpublished report prepared for OZ Minerals Pty Ltd.

CDM Smith. 2018b. West Musgrave Project Mine Water Supply – Preliminary Groundwater Flow Modelling of the Kadgo Palaeochannel. Unpublished report prepared for OZ Minerals Pty Ltd. August 2018.

CDM Smith. 2019. West Musgrave Project Pre-feasibility Study – Surface Water Baseline and Impact Assessments Report DRAFT. Unpublished report prepared for OZ Minerals Pty Ltd. January 2019.

CSIRO. 1991. *Australian Soil Resource Information System*. http://www.asris.csiro.au/themes/Atlas.html#Atlas_Digital (accessed 28 November 2018).

Department of Agriculture and Food Western Australia (DAFWA). 1998. *Soil Guide - A Handbook for Understanding and Managing Agricultural Soils.* Bulletin No. 4343. Ed. G. Moore. Western Australia.

Department of Agriculture and Food Western Australia (DAFWA). 2004. *Soil-Landscape Mapping in South-Western Australia, Overview of Methodology and Outputs. Resource Management Technical Report 280.* Western Australia.

Department of Agriculture and Food Western Australia (DAFWA). 2017. *Soil Landscape Mapping – Best Available (DPRID-027).* https://catalogue.data.wa.gov.au/dataset/soil-landscape-mapping-best-available (accessed 15 February 2019).

Department of Mines, Industry Regulation and Safety (DMIRS). 2016. Guidelines for Mining Proposals in Western Australia. April 2016.

EPA. 2018. Environmental Factor Guideline: Landforms. Government of Western Australia Environmental Protection Authority (EPA). http://www.epa.wa.gov.au/sites/default/files/Policies_and_Guidance/Guideline-Landforms-29062018.pdf (accessed 27 March 2019).

Department of Mines, Industry Regulation and Safety (DMIRS). 2019. *GeoVIEW WA Interactive Geological Map*. https://geoview.dmp.wa.gov.au/GeoViews/?Viewer=GeoVIEW (accessed 28 March 2019).

Graham, D. and Cowan, M. 2001. *Bioregional Summary of the 2002 Biodiversity Audit for Western Australia – Central Ranges Bioregion: Mann-Musgrave Block Sub-region (CR1)*. Perth: DBCA. http://www.dpaw.wa.gov.au/images/documents/about/science/projects/waaudit/central_ranges01_p127-136.pdf.

Hazelton, P. and Murphy, B. 2007. *Interpreting Soil Test Results, What Do All the Numbers Mean?* CSIRO Publishing, Collingwood.

Isbell, RF. 2002. *The Australian Soil Classification.* Revised. CSIRO Publishing, Collingwood.

Magee, J. W. 2009. *Palaeovalley Groundwater Resources in Arid and Semi-Arid Australia*. Canberra ACT: Geoscience Australia.

McDonald, R.C. and Isbell, R.F. 2009. Soil Profile. In *Australian Soil and Land Survey Handbook*, 3rd ed. CSIRO Publishing, Collingwood.

Mehlich, A. 1984. Mehlich 3 Soil Test Extractant: A Modification of Mehlich 2. *Communications of Soil Science and Plant Analysis* 15: 1409-1416.

Murphy-White, S. 2007. *Farm water for the north-eastern and eastern wheatbelt of Western Australia (Zones 2 and 5).* Report 318. Perth: Department of Agriculture and Food..

National Environment Protection Council (NEPC). 2013. Schedule B1 - Guideline on Investigation Levels for Soil and Groundwater. In *National Environment Protection (Assessment of Site Contamination) Measure.* Canberra: NEPC.

OZ Minerals. 2017. West Musgrave Project: Stage One Study Update - November 2017. Adelaide SA: OZ Minerals Limited.

Peverill, K.I., Sparrow, L.A. and Reuter, D.J. 1999. *Soil Analysis: An Interpretation Manual.* CSIRO Publishing, Melbourne.

Purdie, B. R., Tille, P. J. and Schoknecht, N. R. 2004. Soil-landscape mapping in south-Western Australia: an overview of methodology and outputs. Resource Management Technical Report 280. Perth: DAFWA.

Rayment, G. and Lyons, D. 2011. *Soil Chemical Methods – Australasia.* CSIRO Publishing, Collingwood.

Seat, Z., Beresford, S. W., Grguric, B. A., Waugh, R. S., Hronsky, J. M. A., Gee, M. A., Groves, D. I. and Mathison, C. I. 2007. Architecture and Emplacement of the Nebo-Babel Gabbronorite-hosted Magmatic Ni-Cu-PGE Sulphide Deposit, West Musgrave, Western Australia. *Mineralium Deposita:* 42:551.

Schoknecht, N. and Pathan, S. 2013. Soil Groups of Western Australia. In *Resource Management Technical Report 380, Soil Physical Measurement and Interpretation for Land Evaluation, Australian Soil and Land Survey Handbooks Series 5,* 4th ed. Perth: DAFWA.

Standards Australia. 1980. *AS 1289 C8.1: Determination of Emerson Class Number of a Soil.* Strathfield.

Thackway R. and Cresswell, I. D. 1995. An Interim Biogeographic Regionalisation for Australia: A Framework for Setting Priorities in the National Reserves System Cooperative Program. Version 4.0. Canberra: Australian Nature Conservancy Agency.

Tille, P. 2006. Soil-landscapes of Western Australia's Rangelands and Arid Interior. Resource Management Technical Report 313. Perth: DAFWA.

Western Botanical. 2018. Detailed Flora and Vegetation Survey, West Musgrave Project – December 2018. Unpublished report prepared for OZ Minerals Limited.

Western Wildlife. 2019. West Musgrave Copper and Nickel Project: Level 2 Vertebrate Fauna Survey 2018 – Draft Final Report. January 2019. Unpublished report prepared by Western Wildlife.

Zang, W. L. and Stoian, L. 2006. Tertiary-Quaternary Land Evolution of the Northwestern South Australia. In *Proceedings of the CRC LEME Regolith Symposium, November 2006, Hahndorf Resort, South Australia*. http://crcleme.org.au/Pubs/Monographs/Regolith2006.html (accessed 28 January 2019).

APPENDICES

APPENDIX 1: SAMPLING AND ANALYSIS PLAN

WEST MUSGRAVE PROJECT
BASELINE SOIL AND LANDFORM ASSESSMENT
SAMPLING AND ANALYSIS PLAN

PREPARED FOR:

OZ MINERALS LIMITED

NOVEMBER 2018

PREPARED BY:

Martinick Bosch Sell Pty Ltd
4 Cook Street
West Perth WA 6005
Ph: (08) 9226 3166
Fax: (08) 9226 3177
Email: info@mbsenvironmental.com.au
Web: www.mbsenvironmental.com.au

NEBO-BABEL SOIL AND LANDFORM ASSESSMENT SAMPLING AND ANALYSIS PLAN

Distribution List:

Company	Contact name	Copies	Date
OZ Minerals Limited	Justin Rowntree Environmental and Approvals Lead	[01]	2 November 2018
Cassini Resources Limited	Exploration Manager	[02]	2 November 2018

Document Control for Job Number: OZMSLA

Document Status	Prepared By	Authorised By	Date
Draft Report	David Allen	Michael North	2 November 2018
Final Report	David Allen	Michael North	2 November 2018

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

1. INTRODUCTION

OZ Minerals Limited (OZ Minerals) and their joint venture partner Cassini Resources Limited are looking to develop the Nebo-Babel Copper and Nickel Project in order to mine copper and nickel ore from the Nebo and Babel deposits, concentrate it and transport the concentrate for both domestic use and export to international customers. The project is currently at a Pre-Feasibility Study (PFS) stage which is scheduled for completion in March 2019 after which a Definitive Feasibility Study (DFS) is expected to be completed by March 2020. Following this a decision to mine will be made. This aggressive schedule means environmental studies and approvals need to be completed and in place within the next two years.

As part of approvals requirements, a baseline soil assessment is required for the project to indicate the types, extent and properties of soil and subsoil materials that will be encountered to inform management and mine closure practices of the project. An assessment of project landforms is to be included as part of this assessment.

2. BASELINE SOIL AND LANDFORM ASSESSMENT

2.1 SCOPE OF WORK

MBS Environmental (MBS) will provide OZ Minerals with a soil and landform assessment to support approval applications for the West Musgrave (Nebo-Babel deposit) Project. The scope of work for the project is as follows:

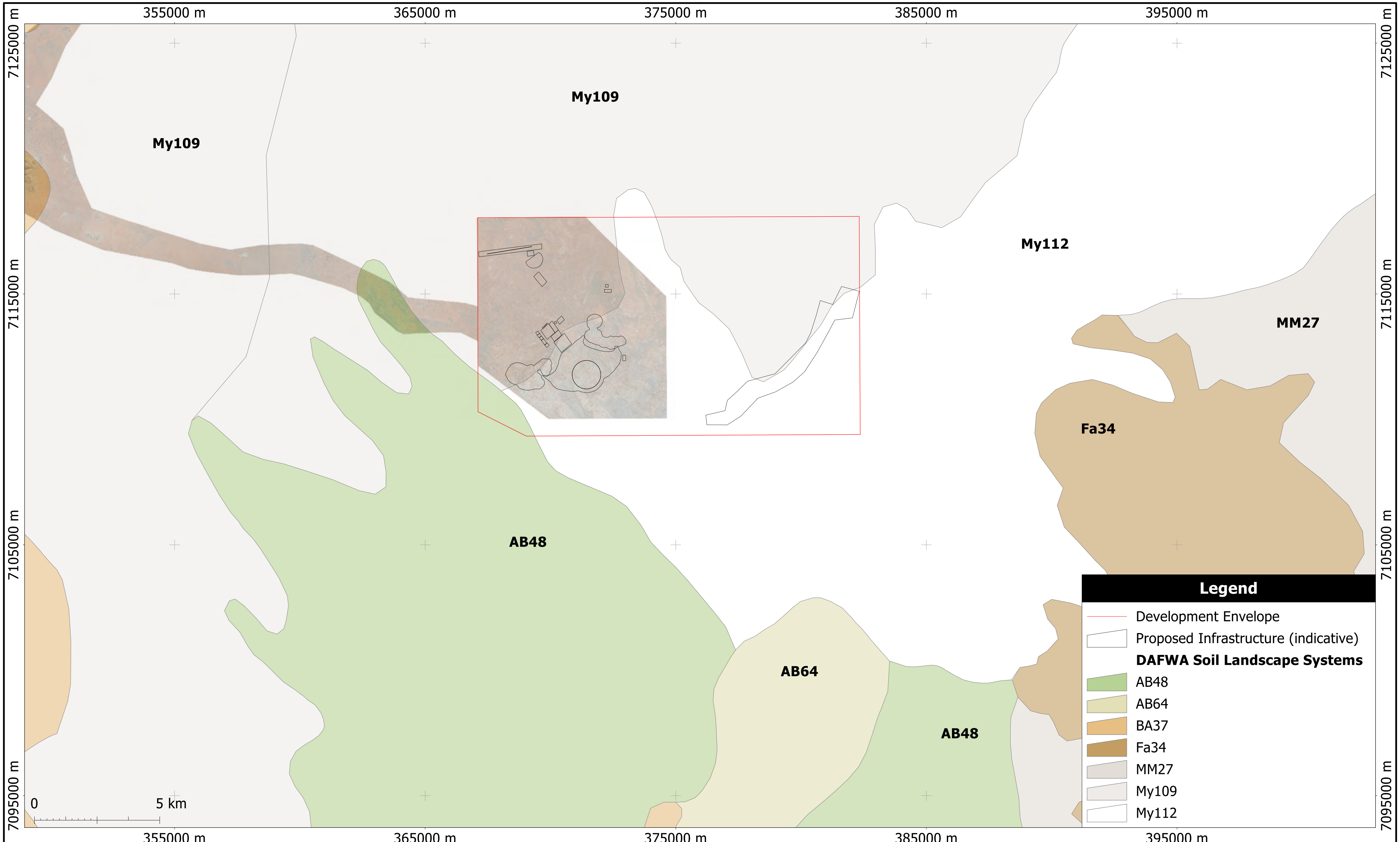
- Desktop review and gap analysis of any existing soil and landform information for the project area.
- Based on the above review, prepare a sample and analysis plan (SAP) for soil samples and locations to be collected from the project area. This is based on site layout information available for areas of significant disturbance and the desktop information on soils and landforms.
- Collate site observations/photographs and data to describe landforms and soil profiles at the project site.
- Liaise with OZ Minerals and Cassini geologists to arrange collection of samples of soil (surface and subsoil) from soil test pits for laboratory analysis and logging of soil profiles. Samples can be collected from drilling sump pits only if they have not been used (as this results in contamination from groundwater salts). As time permits, used pit sumps can however be logged for profile (without sample collection) to inform better resolution of harvestable depth/volumes of growth media in the report.
- Arrange analysis of these samples after delivery to MBS by a NATA accredited laboratory.
- Prepare a baseline soil and landform assessment report that includes interpretation of all data. The report will include:
  - A map of project soils with a focus on areas of potential disturbance.
  - Indications of the suitability of each soil type for use in rehabilitation based on its type and properties.
  - An estimated materials balance of harvestable soils/subsoils for use in rehabilitation for use in mine planning to ensure appropriate harvesting and storage of material for later closure planning.

2.2 DESKTOP REVIEW

A desktop review of soil and landform mapping units was undertaken using the Australian Soil Resources Information System (ASRIS). Figure 1 shows the regional soil and landform mapping units in relation to the indicative project disturbance envelope. Note that the disturbance envelope in Figure 1 and others in this SAP are subject to change and final project layout decisions being made. Hence although the pit shells are essentially known, other locations are estimated only.

Three of these soil and mapping units are present within the disturbance envelope. Characteristics of the units are summarised as follows:

- My109 (indicated by gray shading in Figure 1) - Outwash plains and dissected fan and terrace formations flanking ranges of sedimentary and some metamorphic, volcanic, and granitic rocks. Main soil types are expected to be red loamy earth (40%), red sandy earth (25%) and red-brown shallow hardpan loam (15%).
- My112 (indicated by white shading in Figure 1) - Extensive plains with numerous dunes which are often short and of irregular shape and orientation. Main soil types are expected to be red sandy earth (40%), red loamy earth (35%) and deep red sand (25%).
- AB48 (indicated by green shading in Figure 1) - Very gently undulating plain traversed by longitudinal dunes. Main soil types are expected to be red sandy earth (50%) and deep red sand (40%). This soil and mapping unit forms only a very minor portion in the southwest corner of the lease and may not be disturbed by project activities.



Scale: 1:200000
Original Size: A4
Air Photo Date
Grid: Australia MGA94 (52)

0 5 km

Oz Minerals
Nebo-Babel Project
Sampling and Analysis Plan

Figure 1

Regional Soil and Landform Mapping

4 Cook St
West Perth WA 6005
Ph: (08) 9226 3166
Fax: (08) 9226 3177
info@mbsenvironmental.com.au
www.mbsenvironmental.com.au

W:\OZ Minerals\Baseline Studies\Soils\Drawings\Nebo-Babel Soils Working 2.0.map 25/10/2018 F1 Regional Soil and Landform Mapping

3. SAMPLING AND ANALYSIS PLAN

3.1 SAMPLING LOCATIONS

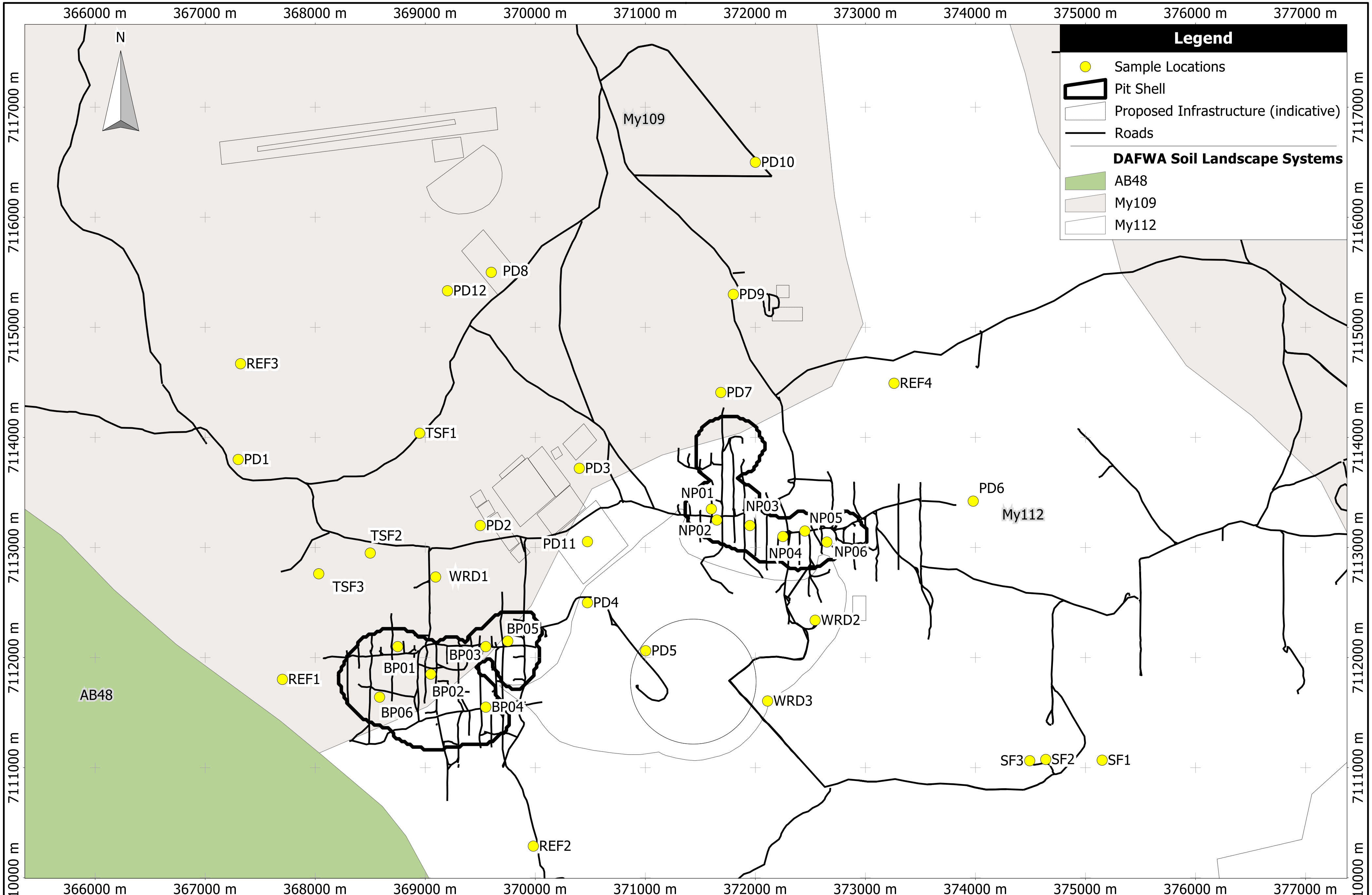
Sampling locations are usually approximately determined prior to the site visit for field sampling. Available soil and landform data are reviewed in conjunction with the proposed site infrastructure layout and available vehicle access to determine the sampling locations. Once locations have been determined, inspection trenches are organised to be prepared ahead of the site visit. Freshly constructed, uncontaminated exploration drill pad sumps are ideal for describing soil profiles and collecting samples within the proposed open pit footprints. If excavators or backhoes are unavailable, manual digging or augering will have to be done.

Based on the regional soil and landform information (Figure 1) and proposed site layout (as of 24 October 2018), a total of 34 sampling locations have been identified. Details of these proposed locations are presented in Table 1 and shown in Figure 2 (in relation to soil and landform units, and pit locations) and Figure 3 (in relation to vegetation mapping units). The actual final locations of test pits may be moved (up to 100 metres) upon consideration of site conditions including access, vegetation and landforms.

Table 1: Proposed Test Pit and Sampling Locations

Location ID	Domain	Drill Hole	MGA 94 (Zone 52)		Sampling Requirements
			Easting	Northing	
NP01	Nebo Pit footprint	NE3004	371600	7113350	Top soil, subsoil
NP02	Nebo Pit footprint	NE3009	371650	7113250	Top soil, subsoil
NP03	Nebo Pit footprint	NE3023	371950	7113200	Top soil, subsoil
NP04	Nebo Pit footprint	NE3032	372250	7113100	Top soil, subsoil
NP05	Nebo Pit footprint	NE3039	372450	7113150	Top soil, subsoil
NP06	Nebo Pit footprint	NE3052	372650	7113050	Top soil, subsoil
BP01	Babel Pit footprint	BA3007	368750	7112100	Top soil, subsoil
BP02	Babel Pit footprint	BA3019	369050	7111850	Top soil, subsoil
BP03	Babel Pit footprint	BA3054	369550	7112100	Top soil, subsoil
BP04	Babel Pit footprint	BA3056	369550	7111550	Top soil, subsoil
BP05	Babel Pit footprint	BA3075	369750	7112150	Top soil, subsoil
BP06	Babel Pit footprint		368585	7111641	Top soil, subsoil
TSF1	TSF footprint		368949	7114038	Top soil, subsoil
TSF2	TSF footprint		368500	7112950	Top soil, subsoil
TSF3	TSF footprint		368032	7112762	Top soil, subsoil
WRD1	WRD footprint		369094	7112732	Top soil, subsoil
WRD2	WRD footprint		372543	7112340	Top soil, subsoil
WRD3	WRD footprint		372111	7111606	Top soil, subsoil
PD1	Potential disturbance		367300	7113800	Top soil
PD2	Potential disturbance		369500	7113200	Top soil
PD3	Potential disturbance		370400	7113720	Top soil
PD4	Potential disturbance		370474	7112499	Top soil

Location ID	Domain	Drill Hole	MGA 94 (Zone 52)		Sampling Requirements
			Easting	Northing	
PD5	Potential disturbance		371003	7112062	Top soil
PD6	Potential disturbance		373980	7113422	Top soil
PD7	Potential disturbance		371686	7114409	Top soil
PD8	Potential disturbance		369600	7115500	Top soil
PD9	Potential disturbance		371800	7115300	Top soil
PD10	Potential disturbance		372000	7116500	Top soil
PD11	Potential disturbance		370474	7113054	Top soil
PD12	Potential disturbance		369202	7115332	Top soil
REF1	Baseline reference		367702	7111802	Top soil
REF2	Baseline reference		369982	7110288	Top soil
REF3	Baseline reference		367322	7114670	Top soil
REF4	Baseline reference		373260	7114492	Top soil
SF1	Solar Farm reference		375152	7111068	Top soil
SF2	Solar Farm reference		374639	7111075	Top soil
SF3	Solar Farm reference		374493	7111063	Top soil



Scale: 1:45000
Original Size: A4
Air Photo Date: N/A

0 1000 m

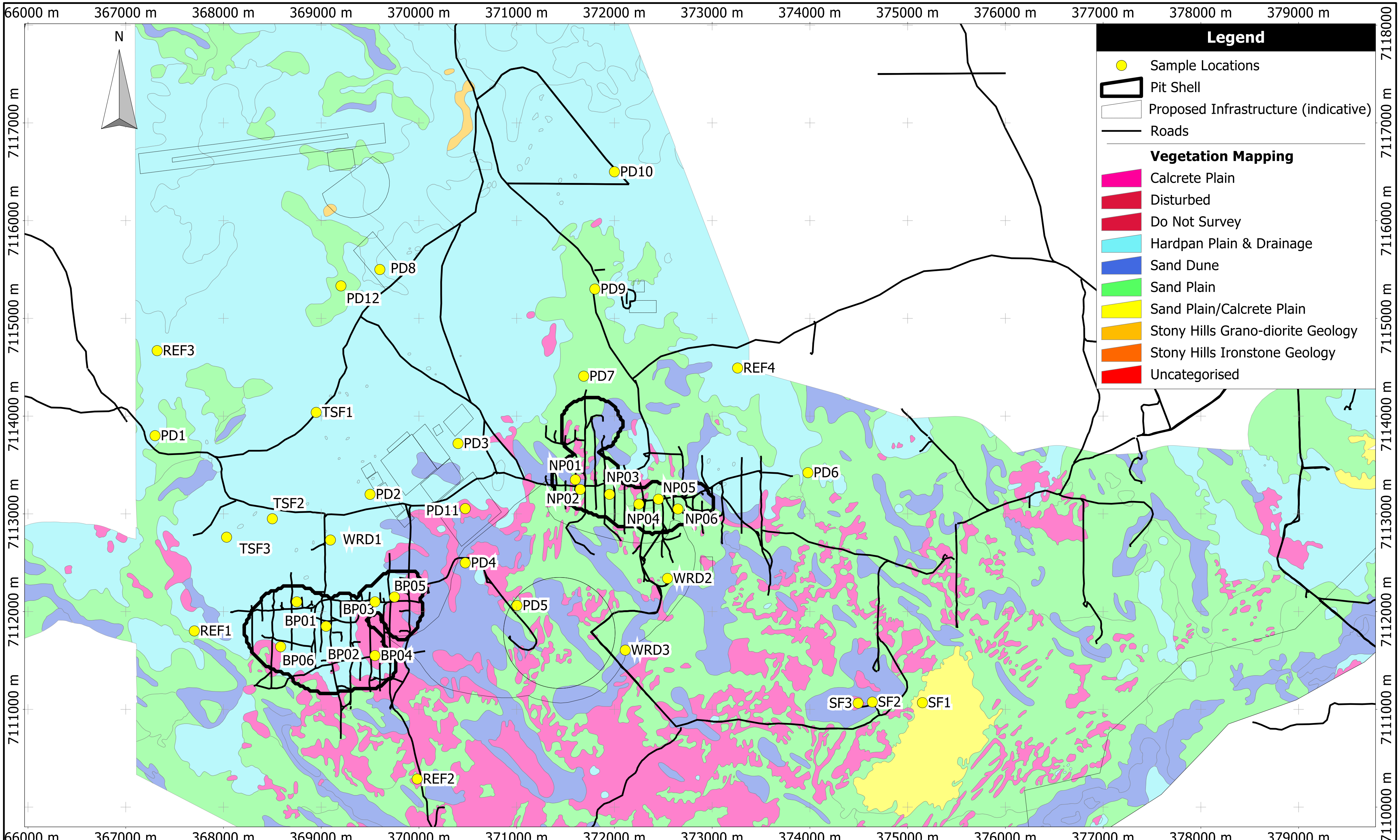
OZ Minerals
Nebo-Babel Project
Sampling and Analysis Plan

Figure 2

Proposed Sampling Locations in Relation to Soil and Landform Units

4 Cook St
West Perth WA 6005
Ph: (08) 9226 3166
Fax: (08) 9226 3177
info@mbsenvironmental.com.au
MBS ENVIRONMENTAL

W:\OZ Minerals\Baseline Studies\Soils\Drawings\Soil and Landform SurveyTR.map 2/11/2018 F2 Sampling Locations with Soil and Landform Units



Scale: 1:50000
Original Size: A4
Air Photo Date: N/A
Grid: Australia MGA94 (52)

0 1000 m

OZ Minerals
Nebo-Babel Project
Sampling and Analysis Plan

Figure 3

Proposed Sampling Locations in Relation to Vegetation Mapping Units

4 Cook St
West Perth WA 6005
Ph: (08) 9226 3166
Fax: (08) 9226 3177
info@mbsenvironmental.com.au
www.mbsenvironmental.com.au

W:\OZ Minerals\Baseline Studies\Soils\Drawings\Soil and Landform SurveyTR.map 2/11/2018 F3 Sampling Locations with Vegetation Mapping

3.2 SOIL PROFILE DESCRIPTIONS

Logging of the soil profile requires sufficient available area to observe soil characteristics. Excavators are typically used to dig trenches or test pits from which soil logging and sampling can be done (also see Section 3.3.2.2). The trenches may already be present at the time of sampling or an excavator / bobcat will be digging and each location logged and sampled. For purpose dug test pits, excavator operators should be instructed to remove approximately 200 to 250 mm portions of the profile at a time and place in successive piles adjacent to the pit. This will allow examination and sampling of subsoils in relation to depth without needing to enter the test pits (similar to standard practice for drilling bags adjacent to holes but using a smaller interval).

Profile logging provides information on the different soil layers from the topsoil and down into the subsoil. The depth required to log and sample depends on the type of excavator available and also on the terrain where the digging is required. Large excavators can account for up to approximately 5 m to be excavated whereas smaller bobcats only account for up to approximately 2 m. It should be noted that personnel should not enter trenches of more than 1 m depth unless there is a suitable exit ramp and observer (a second person for safety considerations). The type of terrain also dictates on the ease of excavation, for example, hard surfaces are tougher to dig into and soft, muddy soil will restrict the mode of excavation. In these cases, refusal can be noted and the team moves on to the next location. A soil profile log template that is used by MBS Environmental is provided in Appendix 1. It may be preferred to use a field log book to record soil profile logs and other observations during the field trip and the information transferred to the soil log template at a later stage, before report preparation. A Globally Positioning System (GPS) device should also be used to record coordinates of actual test pits/trenches as these might differ from pre-selected locations.

For each trench or test pit that is evaluated, the profile by depth needs to be classified and paired with a description of the type of soil. Layers of soil are referred to as horizons and different horizons comprise of the following:

- 'O Horizons'. Partly decomposed organic matter accumulated at the surface of the topsoil and overlies the A horizon. O-horizons are noted but not generally sampled
- 'A Horizons': topsoil or first horizon. Can also be sub-classified (A1, A2, etc.) if multiple types of different soils occur within the same horizon. Soils in the A horizon are typically enriched in organic matter content (plant debris and humus) and more coarse texture (less clay) compared to underlying horizons.
- 'B Horizons': second horizon (subsoil). Clay, soluble salts, gravel and/or iron staining are commonly found in this horizon as a result of illuviation. It is common for more than one B horizon to be present – these are sequentially identified as B1, B2, etc. when present.
- 'C Horizons': third horizon (substratum). Underlies horizon B before fresh bedrock is found. Typically characteristic of weathered bedrock (saprock). Depth to C horizon if found should be noted but does not require sampling.
- 'E Horizons'. If present, this is a distinctive layer (usually pale/white) formed between A and B horizons as a result of heavy leaching, leaving only resistant minerals behind (i.e. quartz).
- 'R Layer'. Hard bedrock.

Along with the soil profile classification and description, photographs must be included in the log. One photograph should be taken of the soil profile and at least one of the surrounding landscape and vegetation. When photographing a pit or trench soil profile, it is recommended that the wall be scaped to provide a clean surface and a tape measure (ideally to allow later confirmation of depths) or shovel be included to provide a sense of scale. The profile side should be the one exposed to direct sunlight. In some situations, additional detail may be provided by wetting the soil profile with water.

All samples taken from the particular trench or test pit should also be recorded on the soil profile log and labelled in the format number/horizon/depth (i.e. BP A 0-0.05 m, BP A 0.05-0.1 m, BP B 0.5-1 m, etc.).

Site and field profile descriptions should follow procedures documented in the Australian Soil and Land Survey Handbook. Record soil attributes on the field data sheet (Appendix 1). Key characteristics to be recorded include:

- Horizon depth and boundary type (transitional or clear-cut).
- Soil colour (grey, grey-brown, dark brown, red-brown, yellow-brown, yellow, etc.).
- Field texture description (e.g. sand, light clay, gravelly loam, silty gravel). Confirmation of field texture (including bolus testing) will be conducted by MBS staff after sample collection for this project.
- Moisture content (dry, damp, moist or saturated).
- Soil structure (loose, uniform, massive, heterogeneous, platy, blocky, and prismatic).
- Presence, depth and types of plant roots (fine, medium, coarse).
- Presence and characteristics of coarse fragments such as pisolitic gravels, rock fragments, and charcoal (proportions of total matrix, rounded or angular, composition/possible source of fragments).
- Presence or absence of pedogenic features (terrace gravels, mottles, hardpans – silcrete, calcrete, ferricrete, nodular calcrete, ferruginous pisoliths, etc).
- Underlying bedrock or saprock geology.

3.3 SAMPLE MANAGEMENT

3.3.1 Sampling Equipment

A list of soil sampling equipment is provided in Table 2.

Table 2: Soil Sampling Equipment

Equipment Type	List of Equipment
Data Recording	Soil profile field data sheet.
	Chain of Custody form.
	Permanent marker, biro pens.
	Water (for field texturing).
	GPS.
	Camera.
	Measuring tape.
Sampling	Shovel.
	Trowel.
	Clean plastic bucket.
	Hand auger (if required).
Sample Containers	Calico bags or plastic zip-lock bags.
Storage and Transport	Sturdy large green plastic bags (RC bags), maximum capacity 20 kg.
Safety equipment	PPE (long sleeved clothing, safety shoes/boots, sunscreen, field hat, safety glasses, gloves, dust mask, gators).
	First aid kit (including snake bite compression bandages)

3.3.2 Sampling Methodology

3.3.2.1 Preparation

Prior to commencement of sampling:

- Ensure appropriate field documents are at hand including log sheets, sample locations and SAP.
- Ensure sufficient sampling bags (calico or zip-lock plastic) are available for use.
- Check all field sampling equipment is in good condition and has been cleaned.
- Arrange for storage and transport of collected samples as soon as possible after completion of sample collection.

3.3.2.2 Sampling

Samples of topsoil are usually collected to a depth of 100 mm (mixed using trowel) from a location that has not been impacted by site activities such as traffic, compaction or contamination. When sampling near exploration drill sumps, select a location 2 to 3 m from the trench and preferably close (1 m) to standing vegetation.

Subsoil samples will only be collected from exposed walls of uncontaminated exploration drill sumps or spoil from a backhoe trench. Subsoil sampling should be restricted to a single soil horizon (usually the B1 horizon, Section 3.2). If there is a distinct lower (B2 horizon) within 1 m of the natural soil surface, a second subsoil sample may be collected.

- When handling soil, hands should be clean to avoid cross-contamination from other sites.
- Sample location details and site conditions must be recorded on the soil field data sheet provided in Appendix 1:
  - Northing/easting and elevation.
  - Topography (slope).
  - Vegetation type (spinifex, mulga, eucalypts, mixed shrubs, etc.) and density (dense, groves, scattered, sparse or bare).
  - Surface conditions (leaf litter, cracking, woody debris, rock fragments, cryptogamic crusts, termite mounds, animal burrows, etc.).
- Remove surface debris (coarse gravel lag and woody debris) at the sampling location.
- Excavate top soil material with a shovel or trowel to a depth of approximately 100 mm. A pick and crowbar may be required to excavate highly compacted or gravelly soil profiles. Place approximately 5 kg of soil into a clean plastic bucket and mix thoroughly with a trowel.
- Place approximately 500 g to 1 kg of sandy soil types (or up to 2 kg for clays and gravelly soil types) into a labelled sample bag.
- Each sample bag should record the following information using a black permanent marker pen:
  - Location ID (as listed in Table 1).
  - A sample suffix to indicate if the sample is topsoil (suffix ‘A’) or subsoil (suffix ‘B’, or ‘C’ if more than one subsoil sample is collected).
  - Sampling depth range (e.g. 200 - 300 mm).
- Take a photograph of the collection of sample bags from each location, clearly showing the sample identification details.

3.3.2.3 *Post-sampling Requirements*

On completion of sampling:

- Record all samples taken on the Chain of Custody form (Appendix 2). MBS will determine analysis requirements and sample submission to laboratory after receipt of the samples.
- Place all samples in a cool, dry, clean area prior to packing in sturdy bags for transport to MBS Environmental in West Perth (i.e. labelled green plastic bags). Place no more than 15 kg of samples into each bag.
- Arrange transport of samples including the Chain of Custody form to MBS Environmental at 4 Cook St WEST PERTH. Email an electronic version of the Chain of Custody form to MBS Environmental (dallen@mbsenvironmental.com.au, mnorth@mbsenvironmental.com.au)
- Scan or transfer information from the completed field data sheet (Appendix 1) to an appropriate file (Word or Excel).
- Back-fill all trenches (other than exploration drilling sumps).

3.4 SAMPLE ANALYSIS

3.4.1 Field Texturing

The samples will be delivered to the MBS Environmental office in West Perth so that additional observations and field tests will be undertaken by an experienced soil scientist.

3.4.2 Laboratory Analysis

Soil samples (topsoil and/or any subsoils potentially suitable as regrowth material) will be analysed by a NATA accredited soil testing laboratory for the following parameters:

- pH and EC (1:5 water extract).
- Exchangeable cations (calcium, sodium, potassium and sodium) and sodicity. Exchangeable aluminium and manganese will be determined on moderately acidic soil types (pH less than 5.0).
- Potential for dispersion (Emerson Class).
- Organic carbon and total nitrogen.
- Nutrients and bio-available heavy metals.
- Particle size distribution (less than 0.002 mm to greater than 16 mm).
- Twelve element heavy metals (including arsenic, cobalt, copper, nickel and zinc) and metalloids screen to establish site specific Ecological Investigation Levels (EILs).
- Phosphorus Retention Index and total phosphorus at locations intended for wastewater irrigation/disposal to inform required approvals for this.

MBS Environmental will identify analysis requirements for each sample and complete a laboratory Chain of Custody form/sample submission form. MBS Environmental will then arrange delivery of the samples to the laboratory.

APPENDICES

APPENDIX 1: SOIL PROFILE LOGSHEET

Site		**GPS Coordinates**		mE mN	Page x of y
Locality		**Date**		**Time**	

Vegetation and Landscape	
Slope:	
Vegetation:	
Landscape:	

Pit Notes	
Horizon	*Description*
Sample Register	

Photo 1: Soil Profile	**Photo 2: Landscape**

APPENDIX 2: CHAIN OF CUSTODY FORM

Chain of Custody Documentation

MBS Environmental	Project: OZ Minerals Nebo-Babel
4 Cook Street, West Perth, WA 6005	Project Code: OZMSLA
Send Report to: dallen@mbsenvironmental.com.au	**Analyses Required**
Send Invoice to: accounts@mbsenvironmental.com.au	
Turnaround Time: Standard	

Lab ID	**Sample ID**	**Matrix**	**Date**	**Sampled By**	pH/EC (1:5 water)	Particle Size	Emerson Class	Exch. Cations	Organic Carbon	Total P	P retention	Metals	Nutrient suite			**Comments**

Relinquished By:		Received By:		**Lab Use**
Date:		Date:		Cooler Seal:
Time:		Time:		Cooler Temperature:

APPENDIX 2: SOIL ASSESSMENT METHODOLOGY

1. INTRODUCTION

1.1 SOIL TEST METHODOLOGY

Understanding the physical, chemical and biological properties of soils is dependent on the ability of scientists and land managers to critically evaluate and assess data provided by meaningful soil tests. A multitude of different soil tests, often intended to measure the same soil quality parameter, have been developed over many years for various reasons, including:

- Characterisation of the diversity of soil types around the world with widely different physical and chemical properties.
- Cost - market forces by land managers, especially farmers, have driven development of soil tests that are simple, rapid and cheap to form, even though technically superior procedures exist.
- Speed of assessment: Rapid advances in laboratory automation, technical capabilities of modern instruments and data management systems.
- Increasing demands to deal with emerging issues of natural resource management including sustainability issues, environmental protection, soil health and food safety.

Unlike water and geological analysis, total elemental composition of soils generally provides little predictive capacity for assessing the ability of soil to provide necessary levels of nutrients for good plant growth. For this reason, different soil tests for specific nutrients have been developed using extracting solutions that mimic the role of plant roots for taking up nutrients from soil.

In recent times, there have been attempts by various organisations to standardise laboratory methods throughout Australia. Most government and commercial soil testing laboratories in Australia now use standard methods, or validated variations derived from the following sources:

- Chemical analysis for agriculture and land management: Soil Chemical Methods – Australian (Rayment and Lyons 2011).
- Environmental assessment: NEPM. 2013. National Environment Protection (Assessment of Site Contamination) Measure. Guideline on Laboratory Analysis of Potentially Contaminated Soil. Schedule B3. National Environment Protection Council.
- Physical and engineering properties of soil: Australian Standard AS 1289.0-2000.

MBS Environmental provides soil characterisation assessments, mainly for the mining industry in WA and other Australian states, to inform pre-feasibility studies, mining proposals and closure planning to meet regulators' requirements. Soil test data and interpretation is provided to meet the following objectives:

- Properties of regional and project areas soils in terms of:
  - Physicochemical attributes including acidity, alkalinity, salinity, sodicity, texture, fertility and structural stability.
  - An indication of the volumes of suitable topsoils and subsoils that can be harvested and stockpiled for rehabilitation activities.
  - Ability to assimilate potential environmental contaminants such as hydrocarbons, metals, metalloids, nutrients, salts, acidity and pathogens.
- Achieving acceptable mine closure outcomes to provide a land surface that is:
  - Structurally stable and safe.
  - Non-polluting (surface water run-off, groundwater and air quality).
  - Compatible with post-mineral land use requirements.

Note that MBS Environmental does not offer geophysical and geotechnical soil assessment for engineering purposes such as constructions of roads, structures and water storages.

1.2 INFORMATION SOURCES

Interpretation of laboratory and field soil testing results and observations requires not only accurate data, but also a "Decision Support System" that provides meaningful predictions of soil properties and behaviour. A reliable Decision Support System needs to be:

- Developed and validated for local conditions including soil types, climate and land use.
- Able to predict soil constraints that may limit productivity and health of vegetation including:
  - Crop plants for agricultural land use on different soil types and environmental settings.
  - Pasture and feed value for pastoral land use.
  - Native plants for rehabilitation of degraded or disturbed areas, especially for WA plant species that are specially adapted to low nutrient and poorly structured soils.
- Able to quantify the risk of ecological and human health impacts for a specific location relating to:
  - Heavy metals and metalloids.
  - Nutrient runoff and leaching.
  - Petroleum hydrocarbons.
  - Agro-chemicals including insecticides and herbicides.

There is an enormous volume of interpretative soil test information available in response to the diversity of soil test methods and differences in soil types throughout the world. However, it is important that the information used be validated against local conditions and for this reason, much of the information published by reputable authorities in overseas countries is not applicable to Australian conditions.

The following sources of information are used by MBS Environmental to assess the significance of laboratory test results:

- Soil Analysis: An Interpretation Manual (Peverill *et al.* 1999). This reference was compiled by specialists from CSIRO and State Government agricultural research agencies. It is biased towards agricultural production, mainly in the eastern states, although it does reference large volumes of research provided by WA researchers between 1960 and 1998.
- Interpreting Soil Test Results. What do all the numbers mean? (Hazelton and Murphy 2007). This document was written specifically for officers in the former Soil Conservation Service of NSW, but is now used widely by soil professionals in other Australian States.
- Soil Guide. A handbook for understanding and managing agricultural soils. DAFWA Bulletin 4343 (DAFWA 2001). This document was prepared specifically for WA agricultural land use.
- Land Evaluation Standards for Land Resource Mapping (assessing land qualities and determining land capability in south-western Australia). DAFWA Resource Management Technical Report 298 (DAFWA 2006). This report describes the standard method for attributing and evaluating conventional land resource survey maps in the south-west agriculture region of Western Australia so that strategic decisions about the management, development and conservation of land resources can be based on the best information available.
- Soilquality.org.au website, with contributions from the University of Western Australia, DAFWA, Wheatbelt Natural Resource Management, Grains Research & Development Corporation, South Coast Natural Resource Management and the Grower Group Alliance.

MBS Environmental also draws upon the author's experience from coordinating physical and chemical laboratory analysis for DAFWA and DPaw soil and biological surveys conducted between 1988 and 2008. These include:

- Reference soils of south-western Australia (McArthur 1991). This publication presents soil profile descriptions and laboratory analysis of samples from the O, A and B soil horizons from 161 locations between Geraldton and Esperance in south-western Australia.
- Laboratory soil test results for about 10,000 soil samples from soil surveys of WA conducted by DAFWA between 1989 and 2007. Details of these surveys are presented in DAFWA Resource Management Technical Report 280, Soil-Landscape Mapping in South-Western Australia, Overview of methodology and outputs (DAFWA 2004).
- Soil analysis data to support the following biological surveys conducted by the Department of Parks and Wildlife (DPaW):
    - Pilbara region biological survey, 2002-2007 (George *et al*. 2009).
    - Floristic surveys of the banded iron formation ranges of the Yilgarn, 2005 to 2008 (Meissner and Caruso, 2008).
    - Wetland flora and vegetation of the WA wheatbelt, 2004.

2. PHYSICAL PROPERTIES

2.1 PARTICLE SIZE AND TEXTURE

2.1.1 Field Measurements

Soil texture describes the proportions of sand, silt and clay particles; the particle size distribution. Sands are mineral particles with an effective diameter between 0.02 and 2 mm, silt from 0.002 to 0.02 mm and clay less than 0.002 mm.

The field (or hand texture) of soil can be assigned by describing the behaviour of a sample of field sieved (<2 mm) soil when moistened to field capacity and kneaded into a ball or bolus and then pressed out between the thumb and forefinger to form a ribbon (bolus) (McDonald *et al.* 1990). The behaviour of the soil during bolus formation and the length of the ribbon define the field texture grade, as summarised in Table A2-1.

Table A2-1: Field Texture Grades

Texture Grade	Behaviour of Moist Bolus	Approximate Clay Content
Sand	Nil to very slight coherence; cannot be moulded; single sand grains adhere to fingers	<5%
Loamy sand	Slight coherence; can be sheared between thumb and forefinger to give a small ribbon (~5 mm)	About 5%
Clayey sand	Slight coherence; sticky when wet; many sand grains stick to fingers, discolours fingers with stain; ribbon 5 to 15 mm	5-10%
Sandy loam	Coherent bolus but very gritty; dominant sand grains of medium size and readily visible; ribbon of 15 to 25 mm	10-20%
Loam	Bolus coherent and spongy; no obvious grittiness or silkiness; ribbon about 25 mm	About 25%
Sandy clay loam	Strongly coherent bolus; sandy to touch; ribbon of 25 to 40 mm	20-30%
Clay loam	Coherent plastic bolus; smooth to manipulate; ribbon of 40 to 50 mm	30-35%
Clay loam, sandy	Coherent plastic bolus; sand grains visible in finer matrix; ribbon of 40 to 50 mm	30-35%
Light clay	Plastic bolus; smooth to touch; slight resistance to shearing; ribbon of 50 to 75 mm	35-40%
Light medium clay	Ribbon of about 75 mm; slight to moderate resistance to ribboning shear	40-45%
Medium clay	Smooth plastic bolus; can be moulded into rods without fracture; moderate resistance to ribboning shear; ribbons 75 mm of longer	45-55%
Medium heavy clay	Ribbons of 75 mm or longer; moderate to firm resistance to ribboning shear	≥50%
Heavy clay	Extremely plastic; firm resistance to ribboning shear; ribbons of 75 mm or longer	≥50%

2.1.2 Laboratory Measurements

Soil texture assessment can be undertaken by two distinct laboratory methodologies:

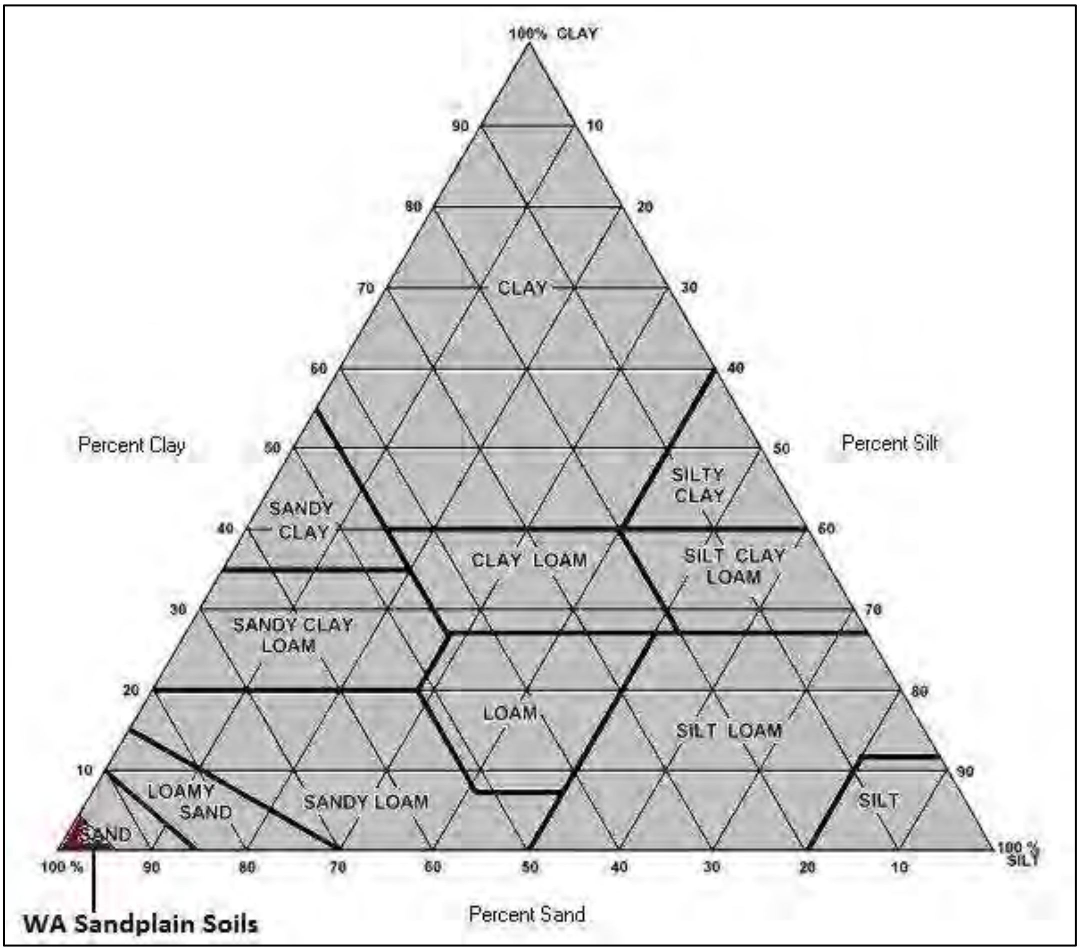
- Particle size determination. This method involves determination of the relative proportions of and, silt and clay sized particles, usually by a combination of sedimentation (hydrometer measurements) and sieving, and classifying the sol texture using the "soil texture triangle" (Figure 1). The method is preferred by land capability and land management professionals.
- Atterberg limits. This methodology, favoured by engineers, classifies soil on the basis of measurements for:
  - Plastic limit, defined as the amount of water added to dry soil to reach a plastic state.
  - Liquid limit, defined as the amount of water added to dry soil to reach a fluid state.
  - Plasticity Index, defined as the difference between the liquid limit (% by weight, dry soil basis) and plastic limit ((% by weight, dry soil basis).

In most cases, field texture grades align well with laboratory based classifications. Poor correlation is occasionally observed for unusual soil types, especially highly saline soils and compacted ferruginous soils (plinthites).

Soil texture information based on laboratory particle size measurements is often used to predict other soil physical characteristics such as hydraulic permeability and water holding capacity (DAFWA 2004). Although laboratory tests are available for direct measurement of these properties, the methodology is comparatively expensive and requires specific sample collection and preservation techniques.

The southwest and arid interior of WA is represented by vast tracts of sandplain, especially dune fields in the Great Sandy and Great Victoria Deserts and coastal plains between Geraldton and Esperance. The sandy nature of these soils in indicated in Figure 1.

Figure 1: Soil Texture Triangle



2.2 DISPERSION POTENTIAL

The structural stability of loams and clay soils can be assessed by a simple field test referred to as the Emerson aggregate test (AS 1289 C8.1 1980). The test involves observation of the behaviour of natural soil aggregates (peds) and subsamples of soil remoulded at field capacity when placed in deionised water. Poorly structured soils, often containing sodic clays (Section 3.3), exhibit low strength when wet, resulting in rapid slaking of aggregates and dispersion of fine clays, resulting in a cloudy halo when placed in deionised water.

The Emerson Aggregate Test provides an Emerson class number ranging from 1 to 8, with Emerson class number 1 indicating soils with weak structure and high potential for clay dispersion, while Emerson class number 8 indicating soils that do not slake, swell or disperse when placed in water. Soil aggregates that slake and disperse readily (Emerson class numbers 1, 2 and 3) indicate weak structure that is easily disrupted by raindrop impact or mechanical disturbance and therefore prone to water erosion, especially on sloping landforms.

The Emerson aggregate test requires submission of a field sample in which natural aggregates have been preserved and not destroyed by crushing and grinding. For this reason, samples provided by reverse circulation drilling are not suitable.

Description of Emersion class numbers are presented in Table A2:2.

Table A2:2: Emerson Aggregate Test Class Numbers

Class Number	Description
Class 1	Dry aggregates slake and completely disperse within several hours.
Class 2	Dry aggregates slake and partly disperse after 24 hours.
Class 3a	Dry aggregates slake but do not disperse. Remoulded soil disperses completely.
Class 3b	Dry aggregates slake but do not disperse. Remoulded soil partly disperses.
Class 4	Dry aggregates slake but do not disperse. Remoulded soil does not disperse. Soil contains free carbonate minerals and / or gypsum.
Class 5	Dry aggregates slake but do not disperse. Remoulded soil does not disperse. No carbonates or gypsum present. 1:5 suspension in water remains dispersed
Class 6	Dry aggregates slake but do not disperse. Remoulded soil does not disperse. No carbonates or gypsum present. 1:5 suspension in water flocculates.
Class 7	Dry aggregates do not slake. Aggregates swell.
Class 8	Dry aggregates do not slake. Aggregates do not swell.

2.3 SOIL WATER RELATIONSHIPS

Physical characteristics of soil, especially drainage and water storage, play critically important roles in the ability of soils to support sustainable plant growth. Well drained soils with low water holding capacity, such as those with deep sandy profiles, retain relatively little water from rainfall, and therefore require a deep profile to support plant growth. Conversely, poorly drained clay soils are subject to water-logging as a consequence of very slow infiltration rates. Many plant species perform poorly in water-logged soils as a consequence of low oxygen availability, or high risk of fungal disease (especially *Phytophora*).

Providing meaningful laboratory results for hydraulic conductivity and water holding capacity in the laboratory is complicated by the nature of the sample submitted for analysis. These tests require an undisturbed core sample to reflect physical characteristics of soil in its natural environment. Other physical and chemical soil tests are usually conducted on a homogenised sample that has been crushed and sieved to break down natural structure and allow removal of coarse fragments. The inherent structure of undisturbed soil, which comprises various micro, meso and macropores determines drainage and water storage characteristics. During a mining project, soil required for waste landform rehabilitation is disturbed at regular intervals by processes including compaction, vegetation clearing, soil harvesting, stockpiling, re-spreading, blending with waste rock and contour ripping – all of which changes these physical soil characteristics.

MBS Environmental does not recommend laboratory testing for these soil properties for reason discussed above (and high costs). Useful information relating to assessment of these soil properties is better provided by field observations by an experienced soil scientist, and by correlation with more easily measured soil properties such as particle size distribution.

2.3.1 Hydraulic Permeability

The rate at which the water moves through a soil profile depends on the soil's permeability (the ease with which water can be transmitted). The permeability of a soil to water is described by its hydraulic conductivity (K), which is usually measured on an intact soil core sample to reflect field conditions. Darcy's Law combines the effects of gradient and hydraulic conductivity to calculate the quantity of water (flux) flowing in a saturated system:

$$\text{Flux rate in a saturated system (mm/h)} = -K_s * (\Delta\psi/\Delta z)$$

where K_s is the saturated hydraulic conductivity,
$\Delta\psi$ is the change in matric potential, and
Δz is the change in distance.

Hydraulic conductivity is highest in soils with a porous structure and where the pores are interconnected (i.e. coarse sands, gravels and structured loam and clay soils). Common values for K_s for soils of different texture are presented in Table A2-3. In general, K_s values greater than 1 x 10^{-6} m/sec (0.1 m/day) represent freely draining conditions, while soils where K_s is less than 1 x 10^{-9} (0.0001 m/day) are almost impermeable.

Table A2-3: K_s Values of Soils of Different Texture Classes

Texture / Soil Type	K_s (m/sec)
Gravel	10^{-2} to 10^{-3}
Coarse sand	10^{-3}
Medium sand	10^{-4}
Fine sand	10^{-5}
Loam	10^{-5} to 10^{-6}
Clay soils	10^{-6} to 10^{-7}
Compacted clays	10^{-7} to 10^{-12}

Provided soils are well graded, contain mainly spherical particles and Low Activity Clays (LAC) clay minerals, it is possible to estimate the K_s of compacted soil using Hazen's formula, which states that K_s (m/s) is related to the 10th percentile particle diameter (d_{10} expressed as mm) by the equation:

$$K_s = C\,(d_{10})^2$$, where C is a constant between 0.4 and 1.2 (typically 1.0).

2.3.2 Water Holding Capacity

Pore space is that fraction of the soil with potential to be occupied by air and/or water. The *matric potential* (ψ) is the
potential produced by capillary and surface forces, or alternatively, the suction pressure by which water is held by the soil. Most soil water is stored in capillaries (or pores) of varying diameter and connectivity. Water stored in very fine (micro) capillaries requires a very high suction force to drain the water. For this reason, water stored in these pores may not be available for plant uptake. On the other hand, water stored in large diameter pores may drain from the soil profile by gravitational forces, and therefore drains beyond the root zone before it can be accessed by plant roots. The amount of water stored in "mesopores", i.e. water that is not tightly by bound in soil, but does not drain rapidly, is termed "Available Water capacity" (AWC).

AWC is defined as the difference between the upper storage limit (USL) and lower storage limit (LSL) per unit depth (v/v) or mass (w/w). AWC is a capacity measure (e.g. 200 mm/m) while *available water* (or available water storage) is a mass or volume measure related to water extraction by plants or to a specified depth (e.g. 75 mm to a depth of 0.5 m). Values of AWC range from 20 mm/m in very coarse sands to more than 250 mm/m in finer textured soils, with the typical range being 50 to 150 mm/m for WA soils. Typical values for soils of different texture classes are presented in Table A2-4 (adapted from DAFWA 2001).

Table A2-4: AWC Values of Soils of Different Texture Classes

Texture / Soil Type	Clay Content (%)	Sand Size Fraction	AWC (mm/m)
Sand	<5	Coarse	~20
		Medium	30-50
		Fine	50-70
Loamy/clayey sands	5-10	Coarse	50-60
		Medium	60-90
		Fine	80-100
Sandy loam	15-20	Coarse	50-220
		Medium	60-170
		Fine	140-220
Light sandy clay loam	15-20	Coarse	50-150
		Medium	90-220
		Fine	100-180
Loam	25	-	100-240
Sandy clay loam	20-30	-	100-190
Clay loam	30-35	-	100-210
Sandy clay	35-40	-	80-150
Clay (non-cracking)	>35	-	90-140
Clay (cracking)	>35	-	~210

3. CHEMICAL PROPERTIES

3.1 PH

As with many measurements on soil, pH values vary with the procedure used. Being a solution measurement, pH of dry soil is effectively meaningless. Soil pH estimates are undertaken in the laboratory by shaking a sample of dry, sieved soil with a standard volume of either deionised water or a dilute salt solution, followed by pH measurement with a calibrated pH meter. pH measurements using deionised water at a sample : solution ratio of 1:5 are widely used for land capability assessment, while use of 0.01 M calcium chloride as the equilibrating solution is preferred for agricultural purposes as this method has been shown by researchers as a superior indicator of phytotoxicity of soil.

The soil pH rating Table adopted for use by MBS Environmental is presented in Table A2-5. The rating table applies to measurements using the 1:5 deionised water extraction method.

Table A2-5: Soil pH Rating Table

pH Range	Rating
1.8 - 3.4	Ultra acid
3.5 - 4.4	Extremely acid
4.5 - 5.0	Very strongly acid
5.1 - 5.5	Strongly acid
5.6 - 6.0	Moderately acid
6.1 - 6.5	Slightly acid
6.6 - 7.3	Circum-neutral
7.4 - 7.8	Slightly alkaline
7.9 - 8.4	Moderately alkaline
8.5 - 9.0	Strongly alkaline
9.1 - 10	Very strongly alkaline
>10	Ultra alkaline

From Rayment and Lyons (2011), adapted from Bruce and Rayment 1982 and USDA 2004.

3.2 ELECTRICAL CONDUCTIVITY AND SALINITY

Measurement of electrical conductivity (EC) of recovered soil porewater, or more commonly either porewater recovered after wetting the sample to saturation or using the 1:5 soil:water extract from pH measurement. EC of the saturation extract is referred to as ECe, while EC of the 1:5 soil:water extract is referred to as EC (1:5).

ECe is considered to be the superior indication of salinity; values of <200 mS/m indicate very low salinity, while values >1,600 indicate high salinity, regardless of the soil type. However, measurement of ECe involves a labour intensive test method and therefore not commonly requested. Salinity risk assessment based on EC (1:5) measurements need to consider the soil type. Table A2-6 presents soil salinity rating classes used by MBS Environmental for sand, loam and clay soil types.

Table A2-6: Salinity Rating Table

Soil Type	Salinity Rating Based on EC (1:5) (mS/m)				
	Nil	Slight	Moderate	High	Extreme
Sand	0 – 15	15 - 25	25 – 50	50 – 100	>100
Loam	0 – 20	20 – 35	35 – 70	70 – 150	>150
Clay	0 - 25	25 - 50	50 - 100	100 - 200	>200

3.3 EXCHANGEABLE CATIONS

The ability of soil to behave as a cation exchange material has been known for more than a century. The major soil cations fall into two distinct groups:

- Basic soil cations comprising Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}.
- Acidic cations comprising H^{+}, Al^{3+} and Mn^{2+}. The sum of these cations is referred to as either "exchangeable" or "titratable" acidity.

At a fixed pH, the sum of all soil cations (when expressed in units of centimoles of positive charge per kilogram, cmol(+)/kg) is constant. This value is referred to as the Cation Exchange Capacity (CEC), which is measured at either pH 7 for circum-neutral soils or pH 8.5 for soils containing free calcium carbonate.

The main soil components contributing to CEC are organic matter and clay minerals. CEC values typically range from <2 cmol(+)/kg) for highly weathered siliceous sands, to 10 cmol(+)/kg) for clay loam soils containing kaolinite as the dominant clay mineral, to greater than 50 cmol(+)/kg) for soils containing clay minerals belonging to the smectite (montmorillonite) or illite group. CEC is an important property for productive agricultural soils as it plays a major role in retention of essential plant nutrients and influencing the physical structure of clay rich soil types.

While most laboratories provide cost-effective methods for measuring soil CEC, it is more common to measure the individual soil cations after extraction with ammonium chloride solution (at either pH 7 or pH 8.5). These procedures are effective at extracting the basic soil cations, but the acidic soil cations are not extracted. For circum-neutral and alkaline soil types, the sum of the concentrations of basic soil cations is very close to the measured CEC. In such cases, the sum of the basic soil cations (expressed in units of cmol(+)/kg)) is referred to as Effective CEC (ECEC).

For acidic soils, the contribution of the acidic soil cations becomes increasingly significant. In such cases, ECEC calculation requires inclusion of the 'exchangeable acidity" component. Alternatively, use of unbuffered 0.1 M barium chloride as the cation displacing extractant allows for measurement of extraction aluminium and manganese, in addition to the basic soil cations. Although exchangeable hydrogen has not been measured, this sum of the basic cations plus exchangeable aluminium and manganese provides an acceptable estimate of ECEC.

The relative proportions of the four basic cations play a major role on the structure of clay rich soil type. Calcium, magnesium and potassium are essential plant nutrients and contribute to good soil structure by allowing effective exchange of air and water into the soil matrix during both wetting and drying cycles. Exchangeable sodium, however, is not conducive to good soil structure and sodium rich (sodic) clays are prone to spontaneous dispersion (Section 2.2), resulting in hard-setting soils when dry and highly erodible soils when saturated.

The acidic soil cations are also undesirable components of a healthy soil, particularly the aluminium component as soluble aluminium is phytotoxic to plants. Elevated concentrations of soluble manganese, which is associated with high concentrations of exchangeable manganese in acidic soils, may also be phytotoxic.

Two important derived parameters from exchangeable cation soil measurements are Base Saturation Percentage (BS%) and Exchangeable Sodium Percentage (ESP). BS% is the sum of the basic soil cations divided by the measured CEC (or ECEC if exchangeable acidity has been measured) and expressed as a percentage. Circum-neutral and alkaline soils have very high BS% values, while acidic soils may have much lower BS% values. BS% provides a better indication of potential soil acidity problems than pH measurements. For example, a soil with a pH of 4.5 and BS% of 30% is likely to be toxic to plants, while a soil with pH of 4.5 and BS% of 80% may not be toxic.

ESP is the exchangeable sodium concentration divided by the measured CEC (or ECEC for circum-neutral and alkaline soils) and expressed as a percentage. ESP values as low as 6% can be responsible for poor structure. ESP values greater than 6% identify sodic soils (Northcote and Skene 1972), which are highly susceptible to structural degradation and erosion.

Table A2-7: Ratings for Exchangeable Cations and Related Parameters

Parameter	Units	Rating		
		Low	Medium	High
CEC	cmol(+)/kg	<5	5 - 15	>15
Calcium	cmol(+)/kg	<5	5 - 10	>10
Magnesium	cmol(+)/kg	<1	1 - 5	>5
Sodium	cmol(+)/kg	<0.3	0.3 – 1.0	>1.0
Potassium	cmol(+)/kg	<0.5	0.5 -2.0	>2.0
Aluminium	cmol(+)/kg	<0.1	0.1 – 1.0	>1.0
Manganese	cmol(+)/kg	<0.02	0.02 – 1.0	>1.0
BS%	%	<20	20 - 60	>60
ESP	%	<6 (non-sodic)	6 – 15 (moderately sodic)	>15 (highly sodic)

Adapted from DAFWA 2004.

3.4 ORGANIC CARBON AND SOIL NITROGEN

Soil organic matter is a critical component of a healthy soil. It plays a major role in maintaining good soil structure, retaining moisture and nutrients and a source of food and energy for soil microbial activity.

Soil organic matter contains 45% to 55% carbon, with most of the balance being oxygen, hydrogen and nitrogen, with lower but still important concentrations of phosphorus and sulfur. There are two reliable laboratory methods for measuring soil organic carbon, which is a very good indicator of soil organic matter content:

- Wet oxidation, with the Walkley and Black method (Walkley and Black 1934) being the most common variation.
- Combustion, occasionally referred to as LECO® Total Organic Carbon.

By international standards, WA soils contain low concentrations of organic carbon. Organic carbon content is dependent upon soil texture and climate, with sandy soils and soil from tropical northern WA and arid central WA containing lower carbon contents (typically <1% in topsoil) compared to clay and loam soils from the temperature southwest corner of WA.

Soil organic matter is also responsible for most of the total nitrogen content of soil, with the remainder (typically <5% of total nitrogen) being in the mineral ammonium (NH_4^+) and nitrate (NO_3^-) forms. Mineralisation of soil organic matter by microbial activity can convert some of this organic nitrogen into mineral nitrogen, which is then available for uptake by plants. However, the amount of nitrogen that can be released by mineralisation is variable and determined largely by the ratio of organic carbon to nitrogen (C/N ratio). For soils with low C/N ratios, mineralisation of soil organic matter releases substantial amounts of mineral nitrogen. Alternatively, microbes breaking down carbon rich soil organic matter require more nitrogen than is available from organic matter, resulting in removal of mineral forms of nitrogen naturally present in soil. This is known as "nitrogen drawdown" and is common when carbon rich woody mulch or leaf litter is added to soil as a soil conditioner or water retentive mulch. Ratings descriptions for organic carbon, total nitrogen and C/N ratio are presented in Table A2-8.

Table A2-8: Ratings Table for Organic Carbon, Total Nitrogen and C/N Ratio

Parameter	Rating		
	Low	Medium	High
Organic carbon, A1 horizon, northern and eastern WA	<0.5%	0.5 – 1.5%	>1.5%
Organic carbon, A2 and B horizon, northern and eastern WA	<0.05%	0.05 – 0.3%	>0.3%
Organic carbon, A1 horizon, southwest WA	<1%	1 – 2%	>2%
Organic carbon, A2 and B horizon, southwest WA	<0.1%	0.1 – 0.5%	>0.5%
Total nitrogen, A1 horizon, northern and eastern WA	<0.05%	0.05 – 0.3%	>0.3%
Total nitrogen, A1 horizon, southwest WA	<0.1	0.1 – 0.5%	>0.5%
Total nitrogen, A2 and B horizons	Generally not measured		
C/N ratio	<10	10 - 16	>16

Adapted from DAFWA 2004.

3.5 BIOAVAILABLE NUTRIENTS

Soil testing is widely used for diagnosing potential nutrient deficiencies and imbalances in soils used for agriculture. Large fertiliser companies often provide cost-effective soil testing packages that provide fertiliser recommendations based on soil test results.

The decision support systems required for provision of reliable fertiliser recommendations based on soil test require a large volume of calibration data based on field trials conducted over many years for different crop plants and on different soil types. The soil tests used also vary for different nutrients as summarised below:

- Phosphorus and potassium use 0.5 M sodium bicarbonate.
- Sulfur uses 0.25 M potassium chloride.
- Boron uses extraction with hot 0.01 M calcium chloride solution.
- Multi-element test for micro-nutrients (Cu, Fe, Mn and Zn) uses 0.005 M DTPA solution.

With the exception of phosphorus (Handreck 1997a and 1997b), there is very little published information available that relates nutrient soil test results with the health of Australian native plants. Also, native plant establishment on disturbed WA soil types is considered to be limited mainly of constraints such as low water holding capacity, salinity or elevated acidity/alkalinity rather than nutrient deficiencies or imbalances. Even in circumstances where nutrient deficiency has been identified as a potential limitation for rehabilitating disturbed sites with WA native plants, land managers are often reluctant to apply additional nutrients in the form of organic or chemical fertilisers on the potential for promoting weed establishment.

MBS Environmental has adopted the Mehlich 3 multi-element soil test methodology (Mehlich 1984) as a cost-effective alternative method to the suite of nutrient soil tests listed above to assess mine site soils for potential nutrient deficiencies, toxicity or imbalance that may affect revegetation outcomes. Concentrations assigned to low, typical and elevated ranges presented in Table A2-9 were derived from the following information:

- Correlations between calibrated single nutrient soil test values (specific for each nutrient) and plant response, typically crop plants under glasshouse or controlled field experiments (Peverill et al. 1999).
- Correlations between Mehlich 3 and calibrated single nutrient soil test results (Walton and Allen 2004). Most of the single nutrient tests correlate well the Mehlich 3 test for acidic, neutral and slightly alkaline (but non-calcareous) WA soil types.
- Results for surface samples analysed from DAFWA and DPaW soil surveys (Section 1.2) and previous mine site surveys conducted by MBS Environmental.

The "Low" rating corresponds approximately to the lowest fifth percentile of unfertilised WA surface soil types and indicates conditions that may result in deficiency to plants not adapted to very low nutrient concentrations in soils. These soil types are often highly weathered siliceous sands in moderate to high rainfall areas in the southwest of WA.

The "Elevated" rating corresponds approximately to the 95th percentile of unfertilised WA surface soil types and may indicate conditions resulting in either nutrient imbalances or toxicities to plant not adapted to high nutrient (especially micronutrients such as boron) concentrations.

Table A2-9: Ratings Table for Bio-available Nutrients (mg/kg), Mehlich 3 Test

Nutrient	Rating		
	Low	Typical Range	Elevated
Phosphorus	<2	2 - 10	>10
Potassium	<10	10 - 300	>300
Calcium	<50	50 – 5,000	>5,000
Magnesium	<20	20 – 2,000	>2,000
Sulfur	<5	5 - 200	>200
Boron	<0.1	0.1 - 2	>2
Copper	<0.1	0.1 - 5	>5
Iron	<10	10 – 200	>200
Manganese	<5	5 - 100	>100
Molybdenum	<0.01	0.01 – 0.05	>0.05
Zinc	<0.2	0.2 - 5	>5

4. REFERENCES

Australian and New Zealand Environment and Conservation Council (ANZECC). 2000. *National Water Quality Management Strategy, Australian and New Zealand Guidelines for Fresh and Marine Water Quality.* ANZECC.

Bruce, R. C. and Rayment, G. E. 1982. *Analytical methods and interpretations used by the Agricultural Chemistry Branch for soil and land use surveys. Bulletin QB 82004.* Brisbane: Queensland Department of Primary Industries.

George, A. S., McKenzie, N. L. and Doughty, P. 2009. *A Biodiversity Survey of the Pilbara Region of Western Australia, 2002-2007. Records of the Western Australian Museum, Supplement No 78.* Perth: Western Australian Museum.

Gunn, R. H., Beattie, J. A., Riddler, A. M. H. and Lawrie, R. A. 1988. *Australian Soil and Land Survey Handbook: Guidelines for Conducting Surveys*. Melbourne: Inkata Press.

Handreck, K. A. 1997a. Phosphorus requirements of Australian native plants. *Australian Journal of Soil Research* 35(2): 241 – 290.

Handreck, K. 1997b. Phosphorus needs of some Australian native plants. *Society for growing Australian Plants Journal* 14: 8-14.

Hazelton, P. and Murphy, B. 2007. *Interpreting Soil Test Results, What Do All the Numbers Mean?* Collingwood: CSIRO Publishing.

McArthur, W. M. 1991. *Reference soils of south-western Australia*. Perth: WA Department of Agriculture on behalf of the Australian Society of Soil Science Incorporated (WA Branch).

McDonald, R. C., Isbell, R. F., Speight, J. G., Walker, J. and Hopkins, M. S. 1990. *Australian soil and land survey field handbook*, 2nd ed. Melbourne: Inkata Press.

Mehlich, A. 1984. Mehlich 3 Soil Test Extractant: A Modification of Mehlich 2. *Communications of Soil Science and Plant Analysis* 15: 1409-1416.

Meissner, R and Caruso, Y. 2008. Flora and vegetation of banded iron formations of the Yilgarn Craton: Koolanooka and Perenjori Hills. *Conservation Science W. Aust.* 7(1): 73-88.

National Environment Protection Council (NEPC). 2013. *National Environment Protection (Assessment of Site Contamination) Measure*. *Guideline on Laboratory Analysis of Potentially Contaminated Soil. Schedule B3.* Canberra: NEPC.

Northcote, K. H. and Skene, J. K. M. 1972. *Australian soils with saline and sodic properties. CSIRO Australia Soil Publication No. 27*. Melbourne: CSIRO.

Peverill, K.I., Sparrow, L.A. and Reuter, D.J. 1999. *Soil Analysis: An Interpretation Manual.* Melbourne: CSIRO Publishing.

Rayment, G. and Lyons, D. 2011. *Soil Chemical Methods – Australasia.* Collingwood: CSIRO Publishing.

Soilquality. 2016. http://www.soilquality.org.au/ (accessed 10 June 2015).

Standards Australia. 1980. *AS 1289 C8.1: Determination of Emerson Class Number of a Soil.* Strathfield: Standards Australia International.

Standards Australia. 2000. *AS 1289.0-2000: Methods for testing soils for engineering purposes*. 2nd ed. Strathfield: Standards Australia International.

US Department of Agriculture (USDA). 2004. Reaction, Soil (pH) (618.47). In *Soil survey Investigations Report No 42, Soil Survey Methods Manual,* Version 4.0. Lincoln: USDA.

Walton, K and Allen, D. 2004. *Mehlich No. 3 Soil Test - The Western Australian Experience*. SuperSoil 2004: 3rd Australian New Zealand Soils Conference, 5 – 9 December 2004, University of Sydney, Australia.

Western Australia. Department of Agriculture and Food Western Australia (DAFWA). 1998. *Soil Guide - A Handbook for Understanding and Managing Agricultural Soils.* Bulletin No. 4343. Ed. G. Moore. Perth: DAFWA

Western Australia. Department of Agriculture and Food Western Australia (DAFWA). 2004. *Soil-Landscape Mapping in South-Western Australia, Overview of Methodology and Outputs. Resource Management Technical Report 280.* Perth: DAFWA.

Western Australia. Department of Agriculture and Food Western Australia (DAFWA). 2008. *Understanding Soil Analysis. Resource Management Technical Report 327.* Perth: DAFWA.

APPENDIX 3: SOIL PROFILE DESCRIPTIONS

Site	NP01	**GPS Coordinates**	52J	371616 7113362	mE mS	
Locality	Nebo Pit footprint	**Date**	17-Nov-18		**Time**	

Vegetation and Landscape

Slope:	Elevation 482 mAHD.
Vegetation:	Spinifex and mallee sand plain adjacent to sand dune
Landscape:	My112 - extensive plains with occasional dunes

Pit Notes

Horizon	*Description*
Surface	Bare orange/brown sand between clumps of grasses and mulga groves
A 0 - 100 mm	Red/brown loamy sand. Some moisture.
B1 100 - 300 mm	Red/brown loamy sand. Some moisture.
B2 300 - 600 mm	Red/brown sandy loam with nodular calcrete gravels.
≥ 600 mm	
Sample Register	A 0 - 100 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	NP02	**GPS Coordinates**	52J	371640 mE 7113253 mS	Page 2 of 37
Locality	Nebo Pit footprint	**Date**	17-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 481 mAHD.
Vegetation:	Spinifex and mallee sand plain
Landscape:	My112 - extensive plains with occasional dunes

Pit Notes

Horizon	*Description*
Surface	Red/brown loamy sandy with extensive grasses and sparse mulga shrubs
A 0 - 100 mm	Red/brown loamy sand
B 200 - 500 mm	Light brown loamy sand with calcrete gravels.
≥500 mm	Calcrete hardpan
Sample Register	A 0 - 100 mm B 200 - 500 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	NP03	**GPS Coordinates**	52J	371940 7113205	mE mS	
Locality	Nebo Pit footprint	**Date**	17-Nov-18		**Time**	

Vegetation and Landscape

Slope:	Elevation 479 mAHD.
Vegetation:	Spinifex and mallee sand plain
Landscape:	My112 - extensive plains with occasional dunes

Pit Notes

Horizon	*Description*
Surface	Bare red/brown loamy sandy with extensive grasses and sparse mulga shrubs
A1 0 - 150 mm	Red/brown loamy sand.
B 150 - 500 mm	Light brown, loamy sand with calcrete cobbles.
≥500 mm	Calcrete hardpan.
Sample Register	A 0 - 150 mm B 200 - 500 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	NP04	**GPS Coordinates**	52J	372248 7113099	mE mS	
Locality	Nebo Pit footprint	**Date**	15-Nov-18		**Time**	

Vegetation and Landscape

Slope:	Elevation 480 mAHD.
Vegetation:	Spinifex and mallee sand plain
Landscape:	Disturbed site in preparation for drilling

Pit Notes

Horizon	*Description*
Surface	Bare red/brown loamy sandy with extensive grasses and sparse mulga shrubs
A 0 - 100 mm	Red/brown loamy sand
B 250 mm	Calcrete with red/brown loamy sand. Plant roots present.
Sample Register	A 0 - 500 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	NP05	**GPS Coordinates**	52J 372444 mE 7113152 mS		
Locality	Nebo Pit footprint	**Date**	15-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 479 mAHD.
Vegetation:	Spinifex and mallee sand plain
Landscape:	Disturbed site in preparation for drilling

Pit Notes

Horizon	*Description*
Surface	Bare red/brown sand (no gravel), extensive grasses.
A 0 - 100 mm	Red/brown sand.
B 100 - 500 mm	Red/brown sand. Plant roots present. Uniform profile, with no significant change with depth.
Sample Register	A 0 - 500 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	NP06	**GPS Coordinates**	52J	372643 7113054	mE mS	
Locality	Nebo Pit footprint	**Date**	15-Nov-18		**Time**	

Vegetation and Landscape	
Slope:	Elevation 478 mAHD.
Vegetation:	Spinifex and mallee sand plain.
Landscape:	Disturbed site in preparation for drilling.

Pit Notes

Horizon	*Description*
Surface	Bare red/brown sand (no gravel), extensive grasses.
A 0 - 200 mm	Red/brown coarse sand. Plant roots present.
B 200 - 500	Deep red/brown coarse sand. Uniform profile with no significant change with depth.
Sample Register	A 0 - 500 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	BP01	**GPS Coordinates**	52J	368739 7112099	mE mS	
Locality	Babel Pit footprint	**Date**	17-Nov-18		**Time**	

Vegetation and Landscape

Slope:	Elevation 475 mAHD.
Vegetation:	Open mulga woodland over grassland
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Bare orange/brown sand with minor calcaerous gravel between grass clumps and scattered mulga trees.
A 0 - 100 mm	Medium brown, loamy sand with friable fragments. Some moisture and roots present.
≥100 mm	Calcrete hardpan.
Sample Register	A 0 - 100 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	BP02	**GPS Coordinates**	52J	369042 7111850	mE mS	
Locality	Babel Pit footprint	**Date**	17-Nov-18		**Time**	

Vegetation and Landscape

Slope:	Elevation 473 mAHD.
Vegetation:	Open mulga scrublands with sparse low grass
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Bare orange/brown sand with minor calcaerous gravel between grass clumps and scattered mulga trees.
A 0 - 100 mm	Medium brown loamy sand, minor proportion of small rounded calcrete gravels.
B 100 - 500	Predominantly calcrete fragments. Light brown sandy loam fines.
≥ 500	Calcrete in weathered basement (gabbronorite)
Sample Register	A 0-100 mm B 200-500 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	BP03	**GPS Coordinates**	52J	369544 7112100	mE mN	
Locality	Babel Pit footprint	**Date**	17-Nov-18	**Time**		

Vegetation and Landscape

Slope:	Elevation 479 mAHD.
Vegetation:	Open mulga scrublands with sparse low grass
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Bare orange/brown sand with minor calcaerous gravel between grass clumps and scattered mulga trees.
A 0 - 100 mm	Medium brown loam sand.
B 100 - 300	Medium brown loam sand with calcrete fragments.
≥ 300	Calcrete in weathered basement (gabbronorite).
Sample Register	A 0 - 300 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	BP04	**GPS Coordinates**	52J	369539 7111549	mE mS	
Locality	Babel Pit footprint	**Date**	17-Nov-18	**Time**		

Vegetation and Landscape

Slope:	Elevation 484 mAHD.
Vegetation:	Spinifex-covered calcrete plain
Landscape:	My112 - extensive plains with occasional dunes

Pit Notes

Horizon	*Description*
Surface	Bare orange/brown sand with minor calcaerous gravel between extensive grass clumps.
A 0 - 300 mm	Light brown sandy loam with calcrete fragments.
≥ 500 mm	Calcrete hardpan.
Sample Register	A 0 - 300 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	BP05	GPS Coordinates	52J	369797 mE 7112151 mS	Page 11 of 37
Locality	Babel Pit footprint	**Date**	17-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 482 mAHD.
Vegetation:	Sand plain with sparse low grass adjacent to mulga scrublands
Landscape:	My112 - extensive plains with occasional dunes

Pit Notes

Horizon	*Description*
Surface	Bare red/brown sand (no gravel) between clumps of grasses and extensive mulga shrub groves.
A 0 - 100 mm	Medium brown loamy sand.
B1 100 - 700 mm	Medium brown loamy sand with friable fragments. Plant roots present.
B2 700 - 1,200 mm	Red brown loamy sand with calcrete. Gritty/coarse fines.
≥ 1,200 mm	Calcrete in weathered basement (gabbronorite).
Sample Register	A 0 - 300 mm B 700 - 1000 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	BP06	**GPS Coordinates**	52J	368583 7111598	mE mS	Page 12 of 37
Locality	Babel Pit footprint	**Date**	17-Nov-18	**Time**		

Vegetation and Landscape

Slope:	Elevation 482 mAHD.
Vegetation:	Calcrete plain with spinifex and low scrub
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Bare orange/brown sand with minor calcareous gravel between clumps of grasses and mulga shrubs.
A 0 - 100 mm	Brown loamy sand with friable fragments. Calcrete fragments throughout. Plant roots present.
B 100 - 300 mm	Light to medium brown loamy sand with calcrete gravel.
Sample Register	A 0 - 100 mm B 100 - 300 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	TSF1	**GPS Coordinates**	52J	368931 7114047	mE mS	
Locality	TSF footprint	**Date**	16-Nov-18		**Time**	

Vegetation and Landscape

Slope:	Elevation 484 mAHD.
Vegetation:	Plain with sparse grass and mulga
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Bare orange/brown sand between grass clumps and scattered mulga shrubs
A1 0 - 100 mm	Red/brown loamy sand.
B1 100 - 300 mm	Red/brown loamy sand with friable fragments.
B2 300 - 700 mm	Calcrete with red/brown loamy sand, predominantly cemented with minimal fines.
Sample Register	A 0 - 300 mm B 400 - 700 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	TSF2	**GPS Coordinates**	52J	368498 7112947	mE mS	Page 14 of 37	
Locality	TSF footprint	**Date**	16-Nov-18		**Time**		

Vegetation and Landscape

Slope:	Elevation 481 mAHD.
Vegetation:	Sand plain with low scrubby grass.
Landscape:	My109 - Outwash plains and dissected fan and terrace formations. Outcropping rock ~5m WSW

Pit Notes

Horizon	*Description*
Surface	Bare orange/brown sand (no gravel) between grass clumps.
A 0 - 150 mm	Red/brown loamy sand. Predominantly fines with scattered calcrete and small gravels.
B 150 - 500 mm	Calcrete fragments with red/brown sandy loam.
Sample Register	A 0 - 200 mm B 200 - 500 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	TSF3	GPS Coordinates	52J	368029 mE 7112796 mS	Page 15 of 37
Locality	TSF footprint	**Date**	16-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 478 mAHD.
Vegetation:	Sand plain with low scrubby grass
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Bare orange/brown sand with minor calcareous gravels between grass clumps.
A1 0 - 150 mm	Light brown loamy sand with calcrete gravels,
B1 150 - 450 mm	Light brown, clayey sand with calcrete. Minimal fines, predominantly coarse calcrete cobbles.
Sample Register	A 0 - 150 mm B 150 - 450 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	WRD1	GPS Coordinates	52J	369084 mE 7112725 mS	Page 16 of 37
Locality	WRD footprint	**Date**	16-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 472 mAHD.
Vegetation:	Sand plain with low scrubby grass
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Bare red/brown sound (no gravel) between clumps of grasses.
A 0 - 300 mm	Red/brown loamy sand with friable fragments.
B1 300 - 700 mm	
B2 700 - 1,000 mm	Red/brown sandy loam with calcrete fragements.
Sample Register	A 0 - 300 mm B2 700 - 1,000 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	WRD2	GPS Coordinates	52J	372556 mE 7112222 mS	
Locality	WRD footprint	**Date**	15-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 479 mAHD.
Vegetation:	Spinifex and mallee sandplain
Landscape:	Area of minimal slope surrounded by calcrete and sand dunes

Pit Notes

Horizon	*Description*
Surface	Bare orange/brownsand with parse calcaerous gravel between clumps of grasses.
A 0 - 300 mm	Medium brown loamy sand.
B 300 - 600 mm	Red/brown loamy sand with calcrete cobbles. Predominantly smaller coarse fragements and fines.
Sample Register	A 0 - 300 mm B 300 - 600 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	WRD3	**GPS Coordinates** 52J	372111 mE 7111606 mS		
Locality	WRD footprint	**Date**	20-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Flat to very gentle slope.
Vegetation:	Sparse spinifex clumps with scaterred mix shrub
Landscape:	My112 - extensive plains with occasional dunes

Pit Notes

Horizon	*Description*
Surface	Bare orange brown sand (no gravel) between spinfex clumps.
A 0 - 100 mm	Red/brown sand, predominantly fines with some friable fragements.
B 100- 500 mm	Uniform soil profile with minimal change with depth. Red/brown sand, predominantly fines with some friable fragements.
Sample Register	

Photo 1: Soil Profile

Photo 2: Landscape

Site	PD01	GPS Coordinates	52J	367307 7113761	mE mS	
Locality	Potential disturbance	**Date**	16-Nov-18		**Time**	

Vegetation and Landscape

Slope:	Elevation 483 mAHD.
Vegetation:	Plain with low scrub and sparse mulga
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Bare orange brown loam with minor silt crusting, no gravel, between clumps of grasses and sparse mulga shrubs/woodlands
A 0 - 100 mm	Medium red/brown clayey sand.
B1 100 - 600 mm	Weakly cemented medium red/brown clayey sand.
B2 600 - 1,100	Medium brown, loamy sand with variable sized calcrete fragments throughout.
Sample Register	B1 100 - 400 mm B2 800 - 1,100 mm

Photo 1: Soil Profile

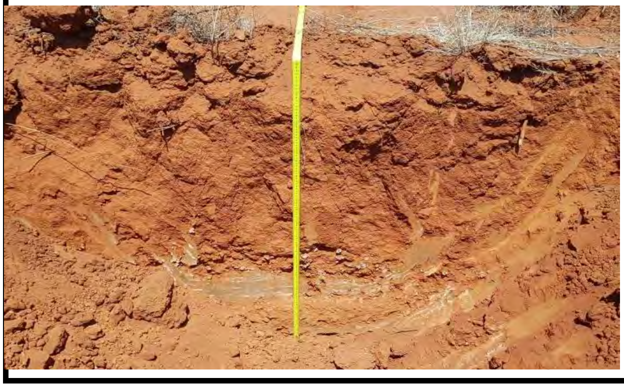


Photo 2: Landscape

Site	PD02	**GPS Coordinates**	52J	369477 mE 7113173 mS	Page 20 of 37
Locality	Potential disturbance	**Date**	15-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 493 mAHD.
Vegetation:	Sandy area surrounded by calcrete.
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Bare orange brown loam with minor silt crusting, no gravel, between sparse clumps of grasses and sparse mulga shrubs/woodlands
A 0 - 300 mm	Red/brown loamy sand.
B1 300 - 600 mm	Red/brown loamy sand with large proportion of small gravels.
B2 600 -800 mm	Predominantly calcrete with some red/brown loamy sand fines.
Sample Register	A 0 - 300 mm B1 500 - 600 mm B2 600 - 800 mm

Photo 1: Soil Profile

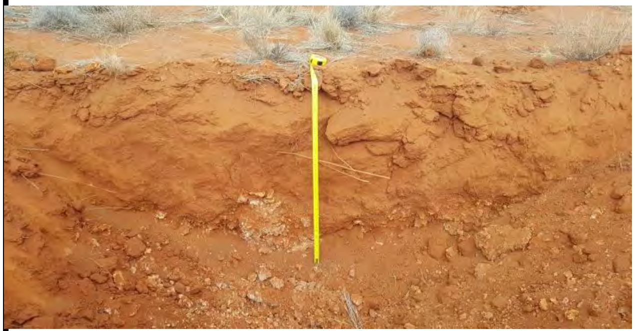


Photo 2: Landscape

Site	PD03	**GPS Coordinates**	52J	370475 7113740	mE mS	
Locality	Potential disturbance	**Date**	15-Nov-18	**Time**		

Vegetation and Landscape

Slope:	Elevation 481 mAHD.
Vegetation:	Flat area downslope surrounded on three sides by low calcrete ridges
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Bare orange/brown sand, no gravel, between sparse clumps and grass and mulga woodland/shrubs.
A 0 - 300 mm	Medium brown loamy sand.
B1 300 - 600 mm	Medium brown loamy sand.
B2 600 - 900 mm	Calcrete and red/brown sandy loam.
Sample Register	A 0 - 300 mm B2 600 - 900 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	PD04	**GPS Coordinates**	52J	370576 7112473	mE mS	
Locality	Potential disturbance	**Date**	15-Nov-18	**Time**		

Vegetation and Landscape

Slope:	Elevation 485 mAHD.
Vegetation:	Sandy area surrounded by calcrete.
Landscape:	My112 - extensive plains with occasional dunes

Pit Notes

Horizon	*Description*
Surface	Bare red/brown loose sand (no gravel) between clumps of spinifex.
A 0 - 250 mm	Red/brown loamy sand.
B1 250 - 600 mm	Red/brown loamy sand with calcrete fragments.
Sample Register	A 0 - 250 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	PD05	**GPS Coordinates**	52J	371018 mE 7112066 mS	Page 23 of 37
Locality	Potential disturbance	**Date**	16-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 484 mAHD.
Vegetation:	Spinifex sandplain
Landscape:	Sandy area surrounded by calcrete.

Pit Notes

Horizon	*Description*
Surface	Bare orange/brown sand (no gravel) between clumps of spinifex.
A 0 - 100 mm	Red/brown sand
B1 100 - 700 mm	Red/brown clayey sand. Uniform soil profile with minimal change over depth.
Sample Register	A 0 - 200 mm B1 200 - 500 mm B2 500 - 700 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	PD06	**GPS Coordinates**	52J	373897 mE 7113440 mS	Page 24 of 37
Locality	Potential disturbance	**Date**	15-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 483 mAHD. Very gentle slope to the west.
Vegetation:	Shrubland with sparse spinifex grasses.
Landscape:	My112 - extensive plains with occasional dunes

Pit Notes

Horizon	*Description*
Surface	Bare red/brown sand (no gravel) between sparse clumps of spinifex.
A 0 - 100 mm	Red/brown coarse sand with friable fragments.
B1 100 - 600 mm	Red/brown coarse sand. Uniform soil profile with minimal change over depth.
B2 ≥ 600 mm	Calcrete hardpan.
Sample Register	A 0 - 300 mm B2 600 - 800 mm

Photo 1: Soil Profile

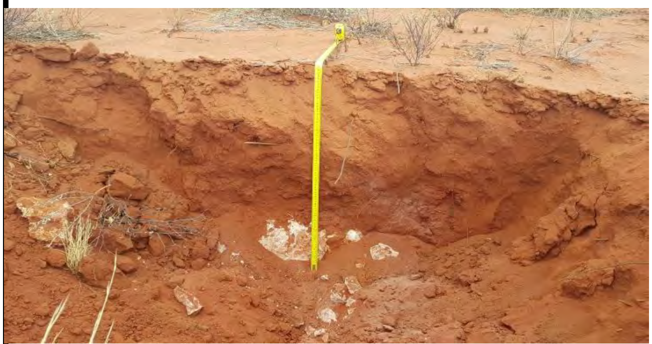


Photo 2: Landscape

Site	PD07	GPS Coordinates	52J	371643 mE 7114326 mS	Page 25 of 37
Locality	Potential disturbance	**Date**	15-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 479 mAHD. Very gentle slope to the south.
Vegetation:	Sandplain with sparse grass.
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Bare orange/brown sand (no gravel) between sparse clumps of spinifex.
A 0 - 300 mm	Red/brown loamy sand fines with some friable aggregates.
B ≥ 300 mm	Red/brown loamy sand. Uniform soil profile with minimal change with depth.
Sample Register	A 0 - 300 mm B 1,500 - 1,800 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	PD08	**GPS Coordinates**	52J	369613 mE 7115500 mS	
Locality	Potential disturbance	**Date**	16-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 487 mAHD.
Vegetation:	Sandplain with sparse grass and mulga.
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Bare orange/brown sand (no gravel) between sparse clumps of grasses and mulga shrubs.
A 0 - 100 mm	Fine red/brown loamy sand with minimal coarse material.
B1 100 - 500 mm	Red/brown loamy sand. Plant roots present.
B2 500 - 1,100 mm	Ferruginous red/brown loamy sand with mixed rounded gravels. Conglomerate of friable fragments and gravels.
Sample Register	A 0 - 300 mm B2 800 - 1,100 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	PD09	**GPS Coordinates**	52J 371791 mE 7115336 mS		Page 27 of 37
Locality	Potential disturbance	**Date**	16-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 485 mAHD.
Vegetation:	Spinifex sand plain.
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Red/brown sand (no gravel) among relatively dense spinifex.
A 0 - 300 mm	Medium brown loamy sand.
B ≥ 300 mm	Red/brown loamy sand. Uniform soil profile with minimal change with depth.
Sample Register	A 0 - 300 mm B 900 - 1,200 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	PD10	**GPS Coordinates**	52J	371996 mE 7116502 mS	Page 28 of 37
Locality	Potential disturbance	**Date**	16-Nov-18	**Time**	

Vegetation and Landscape	
Slope:	Elevation 487 mAHD.
Vegetation:	Plain with low scrub and sparse mulga
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Bare range/brown sand (no gravel) between sparse clumps of grasses.
A 0 - 300 mm	Red/brown loamy sand.
B1 300 - 900 mm	Red/brown loamy sand with a large proportion of ironstone gravels.
B2 900 - 1,500 mm	Red/brown loamy sand with friable rock. Moderate gravels and larger cobbles present.
Sample Register	A 0 - 300 mm B1 900 - 1,200 mm B2 1,200 - 1,500 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	PD11	**GPS Coordinates**	52J	370492 7113070	mE mS	
Locality	Potential disturbance	**Date**	15-Nov-18		**Time**	

Vegetation and Landscape

Slope:	Elevation 483 mAHD.
Vegetation:	Hummock grassland.
Landscape:	Sandy depression in calcrete platform.

Pit Notes

Horizon	*Description*
Surface	Orange/brown sand (no gravel) within hummock grasslands.
A 0 - 300 mm	Red/brown loamy sand with plant roots present.
B1 300 - 1,300 mm	Red/brown loamy sand. Uniform soil profile with minimal changes from A horizon to B1.
B2 1,300 - 1,800 mm	Red/brown loamy sand with calcrete cobbles.
Sample Register	A 0 - 300 mm B1 1,000 - 1,300 mm B2 1,500 - 1,800 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	PD12	**GPS Coordinates**	52J 369183 mE 7115341 mS		
Locality	Potential disturbance	**Date**	16-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 480 mAHD.
Vegetation:	Plain with sparse grass and mulga.
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Bare orange/brown sand (no gravel) between sparse grass clumps.
A 0 - 200 mm	Red/brown loamy sand with friable fragments.
B1 200 - 1,000 mm	Red/brown loamy sand with friable fragments and minor small gravels throughout.
B2 ≥ 1,000 mm	Platey calcrete with red/brown loamy sand.
Sample Register	A 100 - 400 mm B1 700 - 1,000 mm B2 1,400 - 1,700 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	REF1	GPS Coordinates	52J	367716 mE 7111814 mS	Page 31 of 37
Locality	Baseline reference	**Date**	20-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 479 mAHD.
Vegetation:	Plain to east of sand dune adjacent to mulga scrubland
Landscape:	My109 - Outwash plains and dissected fan and terrace formations, gently undulating.

Pit Notes

Horizon	*Description*
Surface	Loose, bare orange/brown sand among sparse clumps of grasses.
A 0 - 200 mm	Brown loamy sand with friable fragments. Predominantly fines.
B 200 - 500 mm	Brown loamy sand. Uniform soil profile with minimal changes with depth, with the exception of increased soil moisture.
Sample Register	A 0 - 200 mm B - 200 - 500 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	REF2	GPS Coordinates	52J	369980 mE 7110261 mS	Page 32 of 37
Locality	Baseline reference	**Date**	20-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 479 mAHD. Northfacing gentle slope of sand dune.
Vegetation:	Low scrub and spinifex.
Landscape:	My112 - extensive plains with occasional dunes, gently undulating,

Pit Notes

Horizon	*Description*
Surface	Bare, loose red/brown sand (no gravel) between dense clumps of spinifex.
A 0 - 100 mm	Red/brown loamy sand.
B1 100 - 500 mm	Deep red loamy sand with friable fragments.
Sample Register	A 0 - 500 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	REF3	**GPS Coordinates**	52J	367310 mE 7114669 mS	Page 33 of 37
Locality	Baseline reference	**Date**	20-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 483 mAHD.
Vegetation:	Open mulga scrublands with sparse low grass
Landscape:	My109 - Outwash plains and dissected fan and terrace formations

Pit Notes

Horizon	*Description*
Surface	Bare red/brown sand between sparse clumps of grasses and mulga shrubs.
A 0 - 100 mm	Medium brown loam. Predominantly fines with friable fragments.
B 100 - 500 mm	Uniform soil profile with depth. Medium brown loam. Predominantly fines with friable fragments.
Sample Register	A 0 - 500 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	REF4	GPS Coordinates	52J	373278 mE 7114494 mS	Page 34 of 37
Locality	Baseline reference	**Date**	20-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 485 mAHD.
Vegetation:	Sand plain with sparse low grass adjacent to mulga scrublands
Landscape:	My112 - extensive plains with occasional dunes

Pit Notes

Horizon	*Description*
Surface	Bare orange/brown sand between clumps of grasses.
A 0 - 100 mm	Red/brown loamy sand. Majority fines with some roots.
B1 100 - 500 mm	Uniform soil profile with depth. Red/brown loamy sand.
Sample Register	A 0 - 500 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	SF1	GPS Coordinates	52J 375176 mE 7111090 mS	Page 35 of 37
Locality	Solar Farm reference	Date	20-Nov-18	Time

Vegetation and Landscape

Slope:	Elevation 483 mAHD.
Vegetation:	Sand plain with sparse spinifex adjacent to calcrete/silcrete rises
Landscape:	My112 - extensive plains with occasional dunes

Pit Notes

Horizon	*Description*
Surface	Loose red/brown sand (no gravel) between sparse spinifex clumps.
A 0 - 400 mm	Medium brown loam with friable larger fragments.
Sample Register	A 0 - 400 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	SF2	**GPS Coordinates**	52J 374829 mE 7111083 mS		
Locality	Solar Farm reference	**Date**	20-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 485 mAHD.
Vegetation:	Northwest side of sand dune. Sparse spinifex
Landscape:	My112 - extensive plains with occasional dunes

Pit Notes

Horizon	*Description*
Surface	Bare red/brown sand (no gravel) between spinifex clumps.
A 0 - 100 mm	Red/brown sand with predominantly fines.
B1 100 - 500 mm	Uniform soil profile with depth. Red/brown sand with predominantly fines.
Sample Register	A 0 - 500 mm

Photo 1: Soil Profile

Photo 2: Landscape

Site	SF3	**GPS Coordinates**	52J 374490 mE 7111053 mS		
Locality	Solar Farm reference	**Date**	20-Nov-18	**Time**	

Vegetation and Landscape

Slope:	Elevation 481 mAHD.
Vegetation:	Hummock grassland.
Landscape:	Flat area surrounded by calcrete rises amongst sand dunes

Pit Notes

Horizon	*Description*
Surface	Bare, loose red/brown sand (no gravel) between clumps of spinifex. Surface calcareous gravels on calcrete rises.
A 0 - 100 mm	Red/brown loamy sand.
B1 100 - 450 mm	Uniform soil profile with depth. Red/brown loamy sand.
Sample Register	A 0 - 450 mm

Photo 1: Soil Profile

Photo 2: Landscape

APPENDIX 4: DATA TABLES

LIST OF APPENDIX TABLES

Table A4-1: Soil Sample Descriptions

Sample	Location	Depth (mm)	Description	Soil Group[1]	Stones (%)
PD01 (0.1 -0.4m)	PD01	100 – 400	Red deep sand	445	5.2
PD01 (0.8 - 1.1m)	PD01	800 – 1,100	Red deep sand	445	29.7
PD02 (0 - 0.3m)	PD02	0 – 300	Red shallow sand	423	5.1
PD02 (0.5 - 0.6m)	PD02	500 – 600	Red shallow sand	423	57.2
PD02 (0.6 - 0.8m)	PD02	600 – 800	Red shallow sand	Calcrete	-
PD03 (0 - 0.3m)	PD03	0 – 300	Red deep sand	445	1.0
PD03 (0.6 - 0.9m)	PD03	600 – 900	Red deep sand	445	48.8
PD04 (0 - 0.25m)	PD04	0 – 250	Red shallow sand	423	0.8
PD05 (0 - 0.2m)	PD05	0 – 200	Red deep sand	445	0.3
PD05 (0.2 - 0.5m)	PD05	200 – 500	Red deep sand	445	0.6
PD05 (0.5 - 0.7m)	PD05	500 – 700	Red deep sand	445	28.8
PD06 (0 - 0.3m)	PD06	0 – 300	Red shallow sand	423	0.2
PD06 (0.6 - 0.8m)	PD06	600 – 800	Red shallow sand	Calcrete	-
PD07 (0 - 0.3m)	PD07	0 – 300	Red deep sand	445	0.2
PD07 (1.5 - 1.8m)	PD07	1,500 – 1,800	Red deep sand	445	0.5
PD08 (0 – 0.3m)	PD08	0 – 300	Red deep sand	445	5.3
PD08 (0.8 – 1.1m)	PD08	800 – 1,100	Red deep sand	445	50.6
PD09 (0 - 0.3m)	PD09	0 – 300	Red deep sand	445	0.6
PD09 (0.9 - 1.2m)	PD09	900 – 1,200	Red deep sand	445	2.5
PD10 (0 - 0.3m)	PD10	0 – 300	Red deep sand	445	1.9
PD10 (0.9 - 1.2m)	PD10	900 – 1,200	Red deep sand	445	54.6
PD10 (1.2 - 1.5m)	PD10	1,200 – 1,500	Red deep sand	445	55.7
PD11 (0 - 0.3m)	PD11	0 - 300	Red deep sand	423	0.4

Sample	Location	Depth (mm)	Description	Soil Group[1]	Stones (%)
PD11 (1.0 - 1.3m)	PD11	1,000 – 1,300	Red deep sand	445	1.1
PD11 (1.5 - 1.8m)	PD12	1,500 – 1,800	Red deep sand	445	52.3
PD12 (0.1 - 0.4m)	PD12	100 – 400	Red deep sand	445	5.0
PD12 (0.7 - 1.0m)	PD12	700 – 1,000	Red deep sand	445	14.2
PD12 (1.4 - 1.7m)	PD12	1,400 – 1,700	Red deep sand	445	16.5
NP01 (0 - 0.1m)	NP01	0 – 100	Red shallow sand	423	0.3
NP02 (0 - 0.1m)	NP02	0 – 100	Calcareous stony soil	202	6.3
NP02 (0.2 - 0.5m)	NP02	200 – 500	Calcareous stony soil	202	63.3
NP03 (0 - 0.15m)	NP03	0 – 150	Calcareous stony soil	202	2.1
NP03 (0.2 - 0.5m)	NP03	200 – 500	Calcareous stony soil	202	77.9
NP04 (0 - 0.5m)	NP04	0 - 500	Calcareous stony soil	202	17.1
NP05 (0 - 0.5m)	NP05	0 – 500	Red deep sand	445	0.4
NP06 (0 - 0.5m)	NP06	0 – 500	Red deep sand	445	0.2
BP01 (0 - 0.1m)	BP01	0 – 100	Calcareous stony soil	202	10.3
BP02 (0 - 0.1m)	BP02	0 – 100	Calcareous stony soil	202	6.3
BP02 (0.2 - 0.5m)	BP02	200 – 500	Calcareous stony soil	202	84.5
BP03 (0 - 0.3m)	BP03	0 – 300	Calcareous stony soil	202	52.4
BP04 (0 - 0.3m)	BP04	0 – 300	Calcareous stony soil	202	53.9
BP05 (0 - 0.3m)	BP05	0 – 300	Red shallow sand	423	0.7
BP05 (0.7 - 1.0m)	BP05	700 – 1,000	Red shallow sand	423	65.3
BP06 (0 - 0.1m)	BP06	0 – 100	Calcareous stony soil	202	10.3
BP06 (0.1 - 0.3m)	BP06	100 – 300	Calcareous stony soil	202	59.2
WRD1 (0 -0.3m)	WRD1	0 – 300	Red shallow sand	423	9.5
WRD1 (0.7 - 1.0m)	WRD1	700 – 1,000	Red shallow sand	423	41.8
WRD2 (0 - 0.3m)	WRD2	0 - 300	Red shallow sand	423	0.8

Sample	Location	Depth (mm)	Description	Soil Group[1]	Stones (%)
WRD2 (0.3 - 0.6m)	WRD2	300 – 600	Red shallow sand	423	49.4
WRD3 (0 - 0.5m)	WRD3	0 – 500	Red deep sand	445	<0.1
TSF1 (0 - 0.3m)	TSF1	0 - 300	Red shallow sand	423	3.5
TSF1 (0.4 - 0.7m)	TSF1	400 – 700	Red shallow sand	423	67.1
TSF2 (0 - 0.2m)	TSF2	0 – 200	Red shallow sand	423	7.2
TSF2 (0.2 - 0.5m)	TSF2	200 – 500	Red shallow sand	423	69.7
TSF3 (0 - 0.15m)	TSF3	0 – 150	Calcareous stony soil	202	11.5
TSF3 (0.15 - 0.45m)	TSF3	150 – 450	Calcareous stony soil	Calcrete	-
SF1 (0 - 0.4m)	SF1	0 – 400	Red deep sand	445	4.1
SF2 (0 - 0.5m)	SF 2	0 – 500	Red deep sand	445	0.1
SF3 (0 - 0.4m)	SF3	0 – 400	Red deep sand	445	0.3
REF1 (0 - 0.2m)	REF1	0 – 200	Red deep sand	445	1.2
REF1 (0.2 - 0.5m)	REF1	200 – 500	Red deep sand	445	1.2
REF2 (0 - 0.5m)	REF2	0 – 500	Red deep sand	445	0.7
REF3 (0 - 0.5m)	REF3	0 – 500	Red deep sand	445	3.6
REF4 (0 – 0.5m)	REF4	0 - 500	Red deep sand	445	5.0

Table A4-2: pH and EC, 1:5 Water Extracts

Sample	pH (H_2O)	EC
	pH units	mS/m
PD01 (0.1 -0.4m)	7.7	1
PD01 (0.8 - 1.1m)	8.3	6
PD02 (0 - 0.3m)	7.8	1
PD02 (0.5 - 0.6m)	8.3	4
PD02 (0.6 - 0.8m)	9.0	10
PD03 (0 - 0.3m)	7.9	2
PD03 (0.6 - 0.9m)	8.6	6
PD04 (0 - 0.25m)	7.7	1
PD05 (0 - 0.2m)	7.6	1
PD05 (0.2 - 0.5m)	7.7	1
PD05 (0.5 - 0.7m)	7.9	2
PD06 (0 - 0.3m)	7.5	<1
PD06 (0.6 - 0.8m)	9.1	10
PD07 (0 - 0.3m)	7.7	<1
PD07 (1.5 - 1.8m)	7.8	1
PD08 (0 – 0.3m)	5.7	1
PD08 (0.8 – 1.1m)	7.0	5
PD09 (0 - 0.3m)	7.3	1
PD09 (0.9 - 1.2m)	7.5	1
PD10 (0 - 0.3m)	6.6	1
PD10 (0.9 - 1.2m)	7.2	1
PD10 (1.2 - 1.5m)	7.3	4
PD11 (0 - 0.3m)	7.2	1
PD11 (1.0 - 1.3m)	7.9	2
PD11 (1.5 - 1.8m)	8.6	7
PD12 (0.1 - 0.4m)	5.3	<1
PD12 (0.7 - 1.0m)	6.8	1
PD12 (1.4 - 1.7m)	8.6	9
NP01 (0 - 0.1m)	7.4	1
NP02 (0 - 0.1m)	8.7	5
NP02 (0.2 - 0.5m)	8.8	8
NP03 (0 - 0.15m)	8.8	5
NP03 (0.2 - 0.5m)	8.8	8
NP04 (0 - 0.5m)	7.9	5
NP05 (0 - 0.5m)	7.6	2
NP06 (0 - 0.5m)	6.2	<1

Sample	pH (H_2O)	EC
	pH units	mS/m
BP01 (0 - 0.1m)	8.5	7
BP02 (0 - 0.1m)	8.7	5
BP02 (0.2 - 0.5m)	8.7	8
BP03 (0 - 0.3m)	8.8	6
BP04 (0 - 0.3m)	8.8	8
BP05 (0 - 0.3m)	7.7	3
BP05 (0.7 - 1.0m)	8.6	7
BP06 (0 - 0.1m)	8.5	7
BP06 (0.1 - 0.3m)	8.7	8
WRD1 (0 -0.3m)	7.7	2
WRD1 (0.7 - 1.0m)	8.5	7
WRD2 (0 - 0.3m)	8.3	3
WRD2 (0.3 - 0.6m)	8.8	7
WRD3 (0 - 0.5m)	7.2	<1
TSF1 (0 - 0.3m)	7.6	2
TSF1 (0.4 - 0.7m)	8.5	9
TSF2 (0 - 0.2m)	8.1	4
TSF2 (0.2 - 0.5m)	8.4	8
TSF3 (0 - 0.15m)	8.7	6
TSF3 (0.15 - 0.45m)	8.9	10
SF1 (0 - 0.4m)	7.4	2
SF2 (0 - 0.5m)	7.6	1
SF3 (0 - 0.4m)	7.1	<1
REF1 (0 - 0.2m)	8.5	7
REF1 (0.2 - 0.5m)	8.5	3
REF2 (0 - 0.5m)	7.7	1
REF3 (0 - 0.5m)	6.6	2
REF4 (0 – 0.5m)	7.0	5

Table A4-3: Particle Size Distribution

Sample	Less than 2 mm Fraction			Stones (% of Whole Sample)	Soil Texture Class
	Sand (>20 µm)	Silt (2 to 20 µm)	Clay (<2 µm)	(>2 mm)	
PD03 (0 – 0.3m)	86.0	3.0	11.0	1.0	Loamy sand
PD05 (0 – 0.2m)	89.0	2.0	9.0	0.3	Loamy sand
PD06 (0 – 0.3m)	92.0	1.0	7.0	0.2	Sand
PD08 (0 – 0.3m)	83.5	2.0	14.5	5.3	Loamy sand
PD08 (0.8 – 1.1m)	76.0	3.0	21.0	50.6	Sandy clay loam (gravelly)
NP02 (0 – 0.1m)	94.0	2.0	4.0	6.3	Sand
NP02 (0.2 – 0.5m)	82.0	7.0	11.0	63.3	Loamy sand (gravelly)
NP03 (0 – 0.15m)	94.0	1.0	5.0	2.1	Sand
BP01 (0 – 0.1m)	91.5	2.5	6.0	10.3	Sand
BP04 (0 – 0.3m)	72.0	13.0	15.0	53.9	Sandy loam (gravelly)
BP06 (0 – 0.1m)	89.0	3.0	8.0	10.3	Sand
BP06 (0.1 – 0.3m)	85.0	4.5	10.5	59.2	Loamy sand (gravelly)
WRD1 (0 – 0.3m)	86.5	3.5	10.0	9.5	Loamy sand
TSF2 (0 - 0.2m)	74.0	8.0	18.0	7.2	Sandy loam
TSF3 (0 – 0.15m)	84.5	6.5	9.0	11.5	Loamy sand

Table A4-4: Emerson Aggregate Class

Sample	Emerson Class
PD01 (0.1 -0.4m)	3
PD01 (0.8 - 1.1m)	1
PD02 (0 - 0.3m)	1
PD02 (0.5 - 0.6m)	3
PD02 (0.6 - 0.8m)	(Calcrete)
PD03 (0 - 0.3m)	3
PD03 (0.6 - 0.9m)	1
PD04 (0 - 0.25m)	3
PD05 (0 - 0.2m)	3
PD05 (0.2 - 0.5m)	1
PD05 (0.5 - 0.7m)	1
PD06 (0 - 0.3m)	3
PD06 (0.6 - 0.8m)	(Calcrete)
PD07 (0 - 0.3m)	3
PD07 (1.5 - 1.8m)	3
PD08 (0 – 0.3m)	3
PD08 (0.8 – 1.1m)	3
PD09 (0 - 0.3m)	3
PD09 (0.9 - 1.2m)	3
PD10 (0 - 0.3m)	3
PD10 (0.9 - 1.2m)	3
PD10 (1.2 - 1.5m)	1
PD11 (0 - 0.3m)	3
PD11 (1.0 - 1.3m)	3
PD11 (1.5 - 1.8m)	3
PD12 (0.1 - 0.4m)	3
PD12 (0.7 - 1.0m)	3
PD12 (1.4 - 1.7m)	3
NP01 (0 - 0.1m)	3
NP02 (0 - 0.1m)	3
NP02 (0.2 - 0.5m)	4
NP03 (0 - 0.15m)	3
NP03 (0.2 - 0.5m)	4
NP04 (0 - 0.5m)	3
NP05 (0 - 0.5m)	3
NP06 (0 - 0.5m)	3
BP01 (0 - 0.1m)	3

Sample	Emerson Class
BP02 (0 - 0.1m)	3
BP02 (0.2 - 0.5m)	4
BP03 (0 - 0.3m)	4
BP04 (0 - 0.3m)	4
BP05 (0 - 0.3m)	3
BP05 (0.7 - 1.0m)	4
BP06 (0 - 0.1m)	3
BP06 (0.1 - 0.3m)	4
WRD1 (0 -0.3m)	3
WRD1 (0.7 - 1.0m)	3
WRD2 (0 - 0.3m)	3
WRD2 (0.3 - 0.6m)	4
WRD3 (0 - 0.5m)	3
TSF1 (0 - 0.3m)	3
TSF1 (0.4 - 0.7m)	3
TSF2 (0 - 0.2m)	3
TSF2 (0.2 - 0.5m)	3
TSF3 (0 - 0.15m)	3
TSF3 (0.15 - 0.45m)	(Calcrete)
SF1 (0 - 0.4m)	3
SF2 (0 - 0.5m)	3
SF3 (0 - 0.4m)	3
REF1 (0 - 0.2m)	3
REF1 (0.2 - 0.5m)	3
REF2 (0 - 0.5m)	3
REF3 (0 - 0.5m)	1
REF4 (0 – 0.5m)	3

Table A4-5: Exchangeable Cations

Sample	Ca	Mg	Na	K	Al	Mn	ECEC	ESP	BS%
	cmol (+)/kg							%	
PD01 (0.1 -0.4m)	3.8	0.51	0.10	0.44			4.9	2	100
PD01 (0.8 - 1.1m)	8.1	0.63	0.14	0.34			9.2	2	100
PD02 (0 - 0.3m)	3.3	0.78	0.02	0.52			4.6	0	100
PD02 (0.5 - 0.6m)	5.5	0.73	<0.02	0.61			6.8	0	100
PD02 (0.6 - 0.8m)	Calcrete								
PD03 (0 - 0.3m)	2.7	0.9	0.02	0.51			4.1	0	100
PD03 (0.6 - 0.9m)	4.8	1.1	<0.02	0.54			6.4	0	100
PD04 (0 - 0.25m)	2.1	0.62	0.03	0.28			3.0	1	100
PD05 (0 - 0.2m)	2.4	1.4	0.02	0.28			4.1	0	100
PD05 (0.2 - 0.5m)	3.7	2.1	0.03	0.39			6.2	0	100
PD05 (0.5 - 0.7m)	4.7	2.2	0.04	0.37			7.3	1	100
PD06 (0 - 0.3m)	1.3	0.52	<0.02	0.17			2.0	0	100
PD06 (0.6 - 0.8m)	Calcrete								
PD07 (0 - 0.3m)	1.0	0.39	<0.02	0.15			1.5	0	100
PD07 (1.5 - 1.8m)	1.5	0.48	0.02	0.15			2.2	1	100
PD08 (0 – 0.3m)	0.70	0.21	<0.02	0.32	0.13	0.02	1.4	0	89
PD08 (0.8 – 1.1m)	2.1	0.90	0.18	0.43			3.6	5	100
PD09 (0 - 0.3m)	1.7	0.52	0.02	0.27			2.5	1	100
PD09 (0.9 - 1.2m)	2.3	0.62	0.04	0.32			3.3	1	100
PD10 (0 - 0.3m)	1.1	0.28	0.02	0.26			1.7	1	100
PD10 (0.9 - 1.2m)	1.4	0.40	0.04	0.26			2.1	2	100
PD10 (1.2 - 1.5m)	1.8	0.76	0.27	0.42			3.3	8	100
PD11 (0 - 0.3m)	1.8	0.6	<0.02	0.36			2.8	0	100
PD11 (1.0 - 1.3m)	2.5	0.64	0.02	0.61			3.8	1	100
PD11 (1.5 - 1.8m)	4.5	1.1	0.13	0.35			6.1	2	100
PD12 (0.1 - 0.4m)	0.34	0.13	<0.02	0.11	0.30	<0.02	0.9	0	66
PD12 (0.7 - 1.0m)	1.3	0.25	0.04	0.24			1.8	2	100
PD12 (1.4 - 1.7m)	3.2	0.86	0.21	0.47			4.7	4	100
NP01 (0 - 0.1m)	1.1	0.53	0.03	0.15			1.8	2	100
NP02 (0 - 0.1m)	2.4	0.82	<0.02	0.17			3.4	0!	100
NP02 (0.2 - 0.5m)	2.7	1.2	<0.02	0.15			4.1	0	100
NP03 (0 - 0.15m)	2.5	0.59	<0.02	0.18			3.3	0	100
NP03 (0.2 - 0.5m)	3.3	1.2	<0.02	0.18			4.7	0	100
NP04 (0 - 0.5m)	2.9	0.95	<0.02	0.19			4.0	0	100
NP05 (0 - 0.5m)	1.3	0.39	<0.02	0.21			1.9	0	100

Sample	Ca	Mg	Na	K	Al	Mn	ECEC	ESP	BS%
	cmol (+)/kg							%	
NP06 (0 - 0.5m)	0.49	0.18	<0.02	0.06	0.05	<0.02	0.8	0!	94
BP01 (0 - 0.1m)	4.0	0.69	0.02	0.66			5.4	0	100
BP02 (0 - 0.1m)	5.8	0.88	<0.02	0.63			7.3	0	100
BP02 (0.2 - 0.5m)	8.6	1.4	0.06	0.18			10.2	1	100
BP03 (0 - 0.3m)	4.3	0.61	<0.02	0.32			5.2	0	100
BP04 (0 - 0.3m)	4.4	1.8	0.04	0.16			6.4	1	100
BP05 (0 - 0.3m)	2.8	0.69	0.03	0.36			3.9	1	100
BP05 (0.7 - 1.0m)	5.8	0.75	0.06	0.34			7.0	1	100
BP06 (0 - 0.1m)	4.9	0.45	0.03	0.33			5.7	1	100
BP06 (0.1 - 0.3m)	5.0	0.50	<0.02	0.51			6.0	0	100
WRD1 (0 -0.3m)	2.8	0.64	0.03	0.41			3.9	1	100
WRD1 (0.7 - 1.0m)	5.6	0.61	0.06	0.51			6.8	1	100
WRD2 (0 - 0.3m)	2.6	1.0	<0.02	0.21			3.8	0	100
WRD2 (0.3 - 0.6m)	2.7	1.1	0.04	0.22			4.1	1	100
WRD3 (0 - 0.5m)	0.99	0.17	<0.02	0.09			1.3	0	100
TSF1 (0 - 0.3m)	4.1	0.76	0.03	0.73			5.6	1	100
TSF1 (0.4 - 0.7m)	9.7	0.98	<0.02	0.84			11.5	0	100
TSF2 (0 - 0.2m)	7.4	0.78	<0.02	0.87			9.1	0	100
TSF2 (0.2 - 0.5m)	9.9	0.9	0.09	0.70			11.6	1	100
TSF3 (0 - 0.15m)	6.2	0.98	<0.02	0.91			8.1	0	100
TSF3 (0.15 - 0.45m)	Calcrete								
SF1 (0 - 0.4m)	5.4	3.1	0.04	0.42			9.0	0	100
SF2 (0 - 0.5m)	1.2	0.26	<0.02	0.12			1.6	0!	100
SF3 (0 - 0.4m)	1.3	0.34	<0.02	0.15			1.8	0	100
REF1 (0 - 0.2m)	2.7	0.21	0.03	0.30			3.2	1	100
REF1 (0.2 - 0.5m)	2.5	0.18	<0.02	0.25			2.9	0	100
REF2 (0 - 0.5m)	1.9	0.57	<0.02	0.11			2.6	0	100
REF3 (0 - 0.5m)	2.1	0.37	0.05	0.44			3.0	2	100
REF4 (0 – 0.5m)	1.1	0.36	0.18	0.42			2.1	9	100

Table A4-6: Extractable Nutrients and Metals (Mehlich)

Sample	Organic C	Total N	C/N ratio	Extr. P	Extr. K	Extr. Ca	Extr. Mg	Extr. S	Extr. B	Extr. Cu	Extr. Fe	Extr. Mn	Extr. Zn
	%	%		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
PD03 (0 – 0.3m)	0.16	0.016	10.0	6	190	600	130	2	0.8	0.9	32	77	0.3
BP01 (0 – 0.1m)	0.23	0.021	11.0	12	250	1,600	170	5	1.0	4.2	29	55	0.5
BP04 (0 – 0.3m)	0.55	0.053	10.4	3	68	>5,500	890	6	0.1	1.6	<1	2	0.4
BP05 (0 – 0.3m)	0.28	0.020	14.0	7	130	650	99	2	0.7	12	26	64	0.5
WRD1 (0 – 0.3m)	0.21	0.013	16.2	15	150	630	92	2	0.6	0.8	32	84	0.1
WRD2 (0 – 0.3m)	0.24	0.020	12.0	2	73	610	230	2	0.8	0.7	24	31	0.2
TSF1 (0 – 0.3m)	0.30	0.017	17.6	32	260	860	110	2	0.7	1.3	44	120	0.5
PD09 (0 – 0.3m)	0.14	0.013	10.8	2	92	380	70	1	1.2	0.7	14	35	<0.1
PD11 (0 – 0.3m)	0.18	0.015	12.0	7	130	400	84	1	1.1	0.8	23	69	0.2
NP01 (0 – 0.1m)	0.17	0.008	21.3	<1	52	240	71	3	1.2	0.2	7	13	<0.1
NP02 (0 – 0.1m)	0.27	0.026	10.4	6	62	1,300	420	3	1.2	0.5	35	26	0.5
TSF2 (0 – 0.2m)	0.23	0.027	8.5	12	320	1,700	150	2	0.8	1.8	41	110	0.4
TSF3 (0 – 0.15m)	-	-	-	23	330	2,000	240	4	0.8	1.5	31	72	0.7

Table A4-7: Extractable Nutrients and Metals, continued

Sample	Extr. Al	Extr. Cd	Extr. Co	Extr. Mo	Extr. Ni	Extr. As	Extr. Pb	Extr.Se
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
PD03 (0 – 0.3m)	310	<0.01	1.4	0.03	0.5	<0.1	0.7	<0.1
BP01 (0 – 0.1m)	350	<0.01	1.1	0.02	1.2	<0.1	0.7	<0.1
BP04 (0 – 0.3m)	24	<0.01	0.06	0.03	0.3	0.1	0.3	0.1
BP05 (0 – 0.3m)	310	<0.01	2.5	0.01	5.0	<0.1	0.6	<0.1
WRD1 (0 – 0.3m)	360	<0.01	1.5	0.01	0.5	<0.1	0.8	<0.1
WRD2 (0 – 0.3m)	270	<0.01	0.8	0.01	0.4	<0.1	0.4	<0.1
TSF1 (0 – 0.3m)	400	<0.01	2.4	0.01	0.7	0.1	1.0	<0.1
PD09 (0 – 0.3m)	300	<0.01	0.82	0.02	0.2	<0.1	0.4	<0.1
PD11 (0 – 0.3m)	320	<0.01	1.2	0.02	0.4	<0.1	0.7	<0.1
NP01 (0 – 0.1m)	290	<0.01	0.62	0.01	0.2	<0.1	0.3	<0.1
NP02 (0 – 0.1m)	310	<0.01	0.41	0.01	0.3	0.1	0.4	<0.1
TSF2 (0 – 0.2m)	550	<0.01	2.3	<0.01	0.8	<0.1	1.0	<0.1
TSF3 (0 – 0.15m)	450	<0.01	1.5	0.02	0.5	<0.1	0.8	<0.1

Table A4-7: Total (Environmentally Available) Metals and Metalloids of Environmental Concern

Sample	As	Cd	Cr	Cu	Co	Mn	Ni	Pb	Se	Zn
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
PD02 (0.6 – 0.8m)	2.2	0.22	15	16	6.5	320	6.6	2.8	0.17	70
PD03 (0 – 0.3m)	1.3	<0.05	37	6.7	7.8	140	9.8	4.4	<0.05	17
PD06 (0.6 – 0.8m)	2.1	0.06	7	9.8	4.1	23	5.5	0.9	0.11	17
BP04 (0 – 0.3m)	1.9	<0.05	29	19	5.0	75	20	1.3	0.10	12
BP05 90 – 0.3 m)	0.8	<0.05	36	71	8.1	120	95	2.0	0.09	14
WRD1 (0 – 0.3m)	1.4	<0.05	37	6.7	7.8	310	10	3.6	<0.05	21
NP02 (0 – 0.1m)	0.6	0.11	35	4.7	4.0	87	7.7	1.3	<0.05	14
NP04 (0 – 0.m)	0.6	<0.05	34	8.6	6.1	82	12	1.2	<0.05	11
TSF2 (0 – 0.2m)	1.9	<0.05	42	11	8.8	250	15	6.2	<0.05	25
TSF3 (0 – 0.15m)	1.4	<0.05	40	7.7	5.7	160	10	3.8	<0.05	22
REF1 (0.2 – 0.5m)	0.8	<0.05	31	3.8	4.8	100	6.3	1.8	<0.05	11
REF2 (0 – 0.5m)	0.8	<0.05	32	4.2	5.8	70	7.2	1.6	<0.05	9
REF3 (0 – 0.5m)	1.6	<0.05	57	13	8.6	330	16	8.3	0.07	17
REF4 (0 – 0.5m)	1.2	<0.05	39	4.7	5.6	140	7.4	3.1	<0.05	13

APPENDIX 5: LABORATORY REPORT

ChemCentre

Inorganic Chemistry Section

Report of Examination

PO Box 1250, Bentley Delivery Centre
Bentley WA 6983
T +61 8 9422 9800
F +61 8 9422 9801
www.chemcentre.wa.gov.au
ABN 40 991 885 705

Purchase Order: None
Your Reference:
ChemCentre Reference: 18S2546 R0

MBS Environmental
4 Cook Street
West Perth WA 6005

Attention: David Allen

Final Report on 64 samples of soil received on 02/01/2019

LAB ID	Client ID and Description
18S2546 / 001	PD01 (0.1-0.4m)
18S2546 / 002	PD01 (0.8-1.1m)
18S2546 / 003	PD02 (0-0.3m)
18S2546 / 004	PD02 (0.5-0.6m)
18S2546 / 005	PD02 (0.6-0.8m) Mainly Calcrete
18S2546 / 006	PD03 (0-0.3m)
18S2546 / 007	PD03 (0.6-0.9m)
18S2546 / 008	PD04 (0-0.25m)
18S2546 / 009	PD05 (0 - 0.2m)
18S2546 / 010	PD05 (0.2 - 0.5m)
18S2546 / 011	PD05 (0.5 - 0.7m)
18S2546 / 012	PD06 (0 - 0.3m)
18S2546 / 013	PD06 (0.6 - 0.8m) Solid Calcrete
18S2546 / 014	PD07 (0 - 0.3m)
18S2546 / 015	PD07 (1.5 - 1.8m)
18S2546 / 016	PD08 (0 - 0.3m)
18S2546 / 017	PD08 (0.8 - 1.1m)
18S2546 / 018	PD09 (0 - 0.3m)
18S2546 / 019	PD09 (0.9 - 1.2m)
18S2546 / 020	PD10 (0 - 0.3m)
18S2546 / 021	PD10 (0.9 - 1.2m)
18S2546 / 022	PD10 (1.2 - 1.5m)
18S2546 / 023	PD11 (0 - 0.3m)
18S2546 / 024	PD11 (1.0 - 1.3m)
18S2546 / 025	PD11 (1.5 - 1.8m)
18S2546 / 026	PD12 (0.1 - 0.4m)
18S2546 / 027	PD12 (0.7 - 1.0m)
18S2546 / 028	PD12 (1.4 - 1.7m)
18S2546 / 029	NP01 (0 - 0.1m)
18S2546 / 030	NP02 (0 - 0.1m)
18S2546 / 031	NP02 (0.2 - 0.5m)
18S2546 / 032	NP03 (0 - 0.15m)
18S2546 / 033	NP03 (0.2 - 0.5m)
18S2546 / 034	NP04 (0 - 0.5m)
18S2546 / 035	NP05 (0 - 0.5m)
18S2546 / 036	NP06 (0 - 0.5m)

LAB ID	Client ID and Description
18S2546 / 037	BP01 (0 - 0.1m)
18S2546 / 038	BP02 (0 - 0.1m)
18S2546 / 039	BP02 (0.2 - 0.5m)
18S2546 / 040	BP03 (0 - 0.3m)
18S2546 / 041	BP04 (0 - 0.3m)
18S2546 / 042	BP05 (0 - 0.3m)
18S2546 / 043	BP05 (0.7 - 1.0m)
18S2546 / 044	BP06 (0 - 0.1m)
18S2546 / 045	BP06 (0.1 - 0.3m)
18S2546 / 046	WRD1 (0 -0.3m)
18S2546 / 047	WRD1 (0.7 - 1.0m)
18S2546 / 048	WRD2 (0 - 0.3m)
18S2546 / 049	WRD2 (0.3 - 0.6m)
18S2546 / 050	WRD3 (0 - 0.5m)
18S2546 / 051	TSF1 (0 - 0.3m)
18S2546 / 052	TSF1 (0.4 - 0.7m)
18S2546 / 053	TSF2 (0 - 0.2m)
18S2546 / 054	TSF2 (0.2 - 0.5m)
18S2546 / 055	TSF3 (0 - 0.15m)
18S2546 / 056	TSF3 (0.15 - 0.45m) Mainly Calcrete
18S2546 / 057	SF1 (0 - 0.4m)
18S2546 / 058	SF2 (0 - 0.5m)
18S2546 / 059	SF3 (0 - 0.4m)
18S2546 / 060	REF1 (0 - 0.2m)
18S2546 / 061	REF1 (0.2 - 0.5m)
18S2546 / 062	REF2 (0 - 0.5m)
18S2546 / 063	REF3 (0 - 0.5m)
18S2546 / 064	REF4 (0 - 0.5m)

Analyte		As	Cd	Co	Cr	Cu	Cu
Method		iMET2SAMS	iMET2SAMS	iMET2SAMS	iMET2SAICP	iMET2SAICP	iMET2SAMS
Unit		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Lab ID	Client ID						
18S2546/005	PD02 (0.6-0.8m)	2.2	0.22	6.5	15		16
18S2546/006	PD03 (0-0.3m)	1.3	<0.05	7.8	37		6.7
18S2546/013	PD06 (0.6 - 0.8m)	2.1	0.06	4.1	7.0		9.8
18S2546/030	NP02 (0 - 0.1m)	0.6	0.11	4.0	35		4.7
18S2546/034	NP04 (0 - 0.5m)	0.6	<0.05	6.1	34		8.6
18S2546/041	BP04 (0 - 0.3m)	1.9	<0.05	5.0	29		19
18S2546/042	BP05 (0 - 0.3m)	0.8	<0.05	8.1	36	71	
18S2546/046	WRD1 (0 -0.3m)	1.4	<0.05	7.8	37		6.7
18S2546/053	TSF2 (0 - 0.2m)	1.9	<0.05	8.8	42		11
18S2546/055	TSF3 (0 - 0.15m)	1.4	<0.05	5.7	40		7.7
18S2546/061	REF1 (0.2 - 0.5m)	0.8	<0.05	4.8	31		3.8
18S2546/062	REF2 (0 - 0.5m)	0.8	<0.05	5.8	32		4.2
18S2546/063	REF3 (0 - 0.5m)	1.6	<0.05	8.6	57		13
18S2546/064	REF4 (0 - 0.5m)	1.2	<0.05	5.6	39		4.7

Analyte		Mn	Ni	Ni	Pb	Se	Zn
Method		iMET2SAICP	iMET2SAICP	iMET2SAMS	iMET2SAMS	iMET2SAMS	iMET2SAICP
Unit		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Lab ID	Client ID						
18S2546/005	PD02 (0.6-0.8m)	320		6.6	2.8	0.17	70
18S2546/006	PD03 (0-0.3m)	140		9.8	4.4	<0.05	
18S2546/013	PD06 (0.6 - 0.8m)	23		5.5	0.9	0.11	
18S2546/030	NP02 (0 - 0.1m)	87		7.7	1.3	<0.05	
18S2546/034	NP04 (0 - 0.5m)	82		12	1.2	<0.05	
18S2546/041	BP04 (0 - 0.3m)	75		20	1.3	0.10	
18S2546/042	BP05 (0 - 0.3m)	120	95		2.0	0.09	
18S2546/046	WRD1 (0 -0.3m)	310		10	3.6	<0.05	
18S2546/053	TSF2 (0 - 0.2m)	250		15	6.2	<0.05	
18S2546/055	TSF3 (0 - 0.15m)	160		10	3.8	<0.05	
18S2546/061	REF1 (0.2 - 0.5m)	100		6.3	1.8	<0.05	
18S2546/062	REF2 (0 - 0.5m)	70		7.2	1.6	<0.05	
18S2546/063	REF3 (0 - 0.5m)	330		16	8.3	0.07	
18S2546/064	REF4 (0 - 0.5m)	140		7.4	3.1	<0.05	

Analyte		Zn	ANC	Stones	EC	pH	Sand.
Method		iMET2SAMS	ARD	(>2mm)	(1:5)	(H2O)	fraction
Unit		mg/kg	kg H2SO4/t	%	mS/m		%
Lab ID	Client ID						
18S2546/001	PD01 (0.1-0.4m)			5.2	1	7.7	
18S2546/002	PD01 (0.8-1.1m)			29.7	6	8.3	
18S2546/003	PD02 (0-0.3m)			5.1	1	7.8	
18S2546/004	PD02 (0.5-0.6m)			57.2	4	8.3	
18S2546/005	PD02 (0.6-0.8m)		400		10	9.0	
18S2546/006	PD03 (0-0.3m)	17		1.0	2	7.9	86.0
18S2546/007	PD03 (0.6-0.9m)			48.8	6	8.6	
18S2546/008	PD04 (0-0.25m)			0.8	1	7.7	
18S2546/009	PD05 (0 - 0.2m)			0.3	1	7.6	89.0
18S2546/010	PD05 (0.2 - 0.5m)			0.6	1	7.7	
18S2546/011	PD05 (0.5 - 0.7m)			28.8	2	7.9	

Analyte		Zn	ANC	Stones	EC	pH	Sand.
Method		iMET2SAMS	ARD	(>2mm)	(1:5)	(H2O)	fraction
Unit		mg/kg	kg H2SO4/t	%	mS/m		%
Lab ID	Client ID						
18S2546/012	PD06 (0 - 0.3m)			0.2	<1	7.5	92.0
18S2546/013	PD06 (0.6 - 0.8m)	17	810		10	9.1	
18S2546/014	PD07 (0 - 0.3m)			0.2	<1	7.7	
18S2546/015	PD07 (1.5 - 1.8m)			0.5	1	7.8	
18S2546/016	PD08 (0 - 0.3m)			5.3	1	5.7	83.5
18S2546/017	PD08 (0.8 - 1.1m)			50.6	5	7.0	76.0
18S2546/018	PD09 (0 - 0.3m)			0.6	1	7.3	
18S2546/019	PD09 (0.9 - 1.2m)			2.5	1	7.5	
18S2546/020	PD10 (0 - 0.3m)			1.9	1	6.6	
18S2546/021	PD10 (0.9 - 1.2m)			54.6	1	7.2	
18S2546/022	PD10 (1.2 - 1.5m)			55.7	4	7.3	
18S2546/023	PD11 (0 - 0.3m)			0.4	1	7.2	
18S2546/024	PD11 (1.0 - 1.3m)			1.1	2	7.9	
18S2546/025	PD11 (1.5 - 1.8m)			52.3	7	8.6	
18S2546/026	PD12 (0.1 - 0.4m)			5.0	<1	5.3	
18S2546/027	PD12 (0.7 - 1.0m)			14.5	1	6.8	
18S2546/028	PD12 (1.4 - 1.7m)			64.2	9	8.6	
18S2546/029	NP01 (0 - 0.1m)			0.3	1	7.4	
18S2546/030	NP02 (0 - 0.1m)	14		6.3	5	8.7	94.0
18S2546/031	NP02 (0.2 - 0.5m)			63.3	8	8.8	82.0
18S2546/032	NP03 (0 - 0.15m)			2.1	5	8.8	94.0
18S2546/033	NP03 (0.2 - 0.5m)			77.9	8	8.8	
18S2546/034	NP04 (0 - 0.5m)	11		17.1	5	7.9	
18S2546/035	NP05 (0 - 0.5m)			0.4	2	7.6	
18S2546/036	NP06 (0 - 0.5m)			0.2	<1	6.2	
18S2546/037	BP01 (0 - 0.1m)			10.3	7	8.5	91.5
18S2546/038	BP02 (0 - 0.1m)			6.3	5	8.7	
18S2546/039	BP02 (0.2 - 0.5m)			84.5	8	8.7	
18S2546/040	BP03 (0 - 0.3m)			52.4	6	8.8	
18S2546/041	BP04 (0 - 0.3m)	12		53.9	8	8.8	72.0
18S2546/042	BP05 (0 - 0.3m)	14		0.7	3	7.7	
18S2546/043	BP05 (0.7 - 1.0m)			65.3	7	8.6	
18S2546/044	BP06 (0 - 0.1m)			10.3	7	8.5	89.0
18S2546/045	BP06 (0.1 - 0.3m)			59.2	8	8.7	85.0
18S2546/046	WRD1 (0 -0.3m)	21		9.5	2	7.7	86.5
18S2546/047	WRD1 (0.7 - 1.0m)			41.8	7	8.5	
18S2546/048	WRD2 (0 - 0.3m)			0.8	3	8.3	
18S2546/049	WRD2 (0.3 - 0.6m)			49.4	7	8.8	
18S2546/050	WRD3 (0 - 0.5m)			<0.1	<1	7.2	
18S2546/051	TSF1 (0 - 0.3m)			3.5	2	7.6	
18S2546/052	TSF1 (0.4 - 0.7m)			67.1	9	8.5	
18S2546/053	TSF2 (0 - 0.2m)	25		7.2	4	8.1	74.0
18S2546/054	TSF2 (0.2 - 0.5m)			69.7	8	8.4	
18S2546/055	TSF3 (0 - 0.15m)	22		11.5	6	8.7	84.5
18S2546/056	TSF3 (0.15 - 0.45m)		490		10	8.9	
18S2546/057	SF1 (0 - 0.4m)			4.1	2	7.4	
18S2546/058	SF2 (0 - 0.5m)			0.1	1	7.6	
18S2546/059	SF3 (0 - 0.4m)			0.3	<1	7.1	

Analyte		Zn	ANC	Stones	EC	pH	Sand.
Method		iMET2SAMS	ARD	(>2mm)	(1:5)	(H2O)	fraction
Unit		mg/kg	kg H2SO4/t	%	mS/m		%
Lab ID	Client ID						
18S2546/060	REF1 (0 - 0.2m)			1.2	7	8.5	
18S2546/061	REF1 (0.2 - 0.5m)	11		1.2	3	8.5	
18S2546/062	REF2 (0 - 0.5m)	9.0		0.7	1	7.7	
18S2546/063	REF3 (0 - 0.5m)	17		3.6	2	6.6	
18S2546/064	REF4 (0 - 0.5m)	13		5.0	5	7.0	

Analyte		Silt.	Clay.	OrgC	Emerson	N	P
Method		fraction	fraction	(W/B)	Class	(total)	PRI
Unit		%	%	%		%	mL/g
Lab ID	Client ID						
18S2546/001	PD01 (0.1-0.4m)				3		
18S2546/002	PD01 (0.8-1.1m)				1		
18S2546/003	PD02 (0-0.3m)				1		
18S2546/004	PD02 (0.5-0.6m)				3		
18S2546/006	PD03 (0-0.3m)	3.0	11.0	0.16	3	0.016	
18S2546/007	PD03 (0.6-0.9m)				1		
18S2546/008	PD04 (0-0.25m)				3		
18S2546/009	PD05 (0 - 0.2m)	2.0	9.0		3		
18S2546/010	PD05 (0.2 - 0.5m)				1		
18S2546/011	PD05 (0.5 - 0.7m)				1		
18S2546/012	PD06 (0 - 0.3m)	1.0	7.0		3		4.0
18S2546/014	PD07 (0 - 0.3m)				3		
18S2546/015	PD07 (1.5 - 1.8m)				3		
18S2546/016	PD08 (0 - 0.3m)	2.0	14.5		3		11
18S2546/017	PD08 (0.8 - 1.1m)	3.0	21.0		3		
18S2546/018	PD09 (0 - 0.3m)			0.14	3	0.013	4.1
18S2546/019	PD09 (0.9 - 1.2m)				3		
18S2546/020	PD10 (0 - 0.3m)				3		
18S2546/021	PD10 (0.9 - 1.2m)				3		
18S2546/022	PD10 (1.2 - 1.5m)				1		
18S2546/023	PD11 (0 - 0.3m)			0.18	3	0.015	
18S2546/024	PD11 (1.0 - 1.3m)				3		
18S2546/025	PD11 (1.5 - 1.8m)				3		
18S2546/026	PD12 (0.1 - 0.4m)				3		11
18S2546/027	PD12 (0.7 - 1.0m)				3		
18S2546/028	PD12 (1.4 - 1.7m)				3		
18S2546/029	NP01 (0 - 0.1m)			0.17	3	0.008	
18S2546/030	NP02 (0 - 0.1m)	2.0	4.0	0.27	3	0.026	
18S2546/031	NP02 (0.2 - 0.5m)	7.0	11.0		4		
18S2546/032	NP03 (0 - 0.15m)	1.0	5.0		3		
18S2546/033	NP03 (0.2 - 0.5m)				4		
18S2546/034	NP04 (0 - 0.5m)				3		
18S2546/035	NP05 (0 - 0.5m)				3		
18S2546/036	NP06 (0 - 0.5m)				3		
18S2546/037	BP01 (0 - 0.1m)	2.5	6.0	0.23	3	0.021	
18S2546/038	BP02 (0 - 0.1m)				3		
18S2546/039	BP02 (0.2 - 0.5m)				4		
18S2546/040	BP03 (0 - 0.3m)				4		
18S2546/041	BP04 (0 - 0.3m)	13.0	15.0	0.55	4	0.053	

Analyte Method Unit Lab ID	Client ID	Silt. fraction %	Clay. fraction %	OrgC (W/B) %	Emerson Class	N (total) %	P PRI mL/g
18S2546/042	BP05 (0 - 0.3m)			0.28	3	0.020	
18S2546/043	BP05 (0.7 - 1.0m)				4		
18S2546/044	BP06 (0 - 0.1m)	3.0	8.0		3		
18S2546/045	BP06 (0.1 - 0.3m)	4.5	10.5		4		
18S2546/046	WRD1 (0 -0.3m)	3.5	10.0	0.21	3	0.013	
18S2546/047	WRD1 (0.7 - 1.0m)				3		
18S2546/048	WRD2 (0 - 0.3m)			0.24	3	0.020	
18S2546/049	WRD2 (0.3 - 0.6m)				4		
18S2546/050	WRD3 (0 - 0.5m)				3		
18S2546/051	TSF1 (0 - 0.3m)			0.30	3	0.017	
18S2546/052	TSF1 (0.4 - 0.7m)				3		
18S2546/053	TSF2 (0 - 0.2m)	8.0	18.0	0.23	3	0.027	
18S2546/054	TSF2 (0.2 - 0.5m)				3		
18S2546/055	TSF3 (0 - 0.15m)	6.5	9.0		3		
18S2546/057	SF1 (0 - 0.4m)				3		
18S2546/058	SF2 (0 - 0.5m)				3		
18S2546/059	SF3 (0 - 0.4m)				3		
18S2546/060	REF1 (0 - 0.2m)				3		
18S2546/061	REF1 (0.2 - 0.5m)				3		
18S2546/062	REF2 (0 - 0.5m)				3		
18S2546/063	REF3 (0 - 0.5m)				1		
18S2546/064	REF4 (0 - 0.5m)				3		

Analyte Method Unit Lab ID	Client ID	P (totals) mg/kg	Ca (exch) cmol(+)/kg	K (exch) cmol(+)/kg	Mg (exch) cmol(+)/kg	Na (exch) cmol(+)/kg	Al (exch) cmol(+)/kg
18S2546/001	PD01 (0.1-0.4m)		3.8	0.44	0.51	0.10	
18S2546/002	PD01 (0.8-1.1m)		8.1	0.34	0.63	0.14	
18S2546/003	PD02 (0-0.3m)		3.3	0.52	0.78	0.02	
18S2546/004	PD02 (0.5-0.6m)		5.5	0.61	0.73	<0.02	
18S2546/006A	PD03 (0-0.3m)		2.7	0.51	0.90	0.02	
18S2546/007	PD03 (0.6-0.9m)		4.8	0.54	1.1	<0.02	
18S2546/008	PD04 (0-0.25m)		2.1	0.28	0.62	0.03	
18S2546/009	PD05 (0 - 0.2m)		2.4	0.28	1.4	0.02	
18S2546/010	PD05 (0.2 - 0.5m)		3.7	0.39	2.1	0.03	
18S2546/011	PD05 (0.5 - 0.7m)		4.7	0.37	2.2	0.04	
18S2546/012	PD06 (0 - 0.3m)	62	1.3	0.17	0.52	<0.02	
18S2546/014	PD07 (0 - 0.3m)		1.0	0.15	0.39	<0.02	
18S2546/015	PD07 (1.5 - 1.8m)		1.5	0.15	0.48	0.02	
18S2546/016	PD08 (0 - 0.3m)	140	0.70	0.32	0.21	<0.02	0.13
18S2546/017	PD08 (0.8 - 1.1m)		2.1	0.43	0.90	0.18	
18S2546/018	PD09 (0 - 0.3m)	69	1.7	0.27	0.52	0.02	
18S2546/019	PD09 (0.9 - 1.2m)		2.3	0.32	0.62	0.04	
18S2546/020	PD10 (0 - 0.3m)		1.1	0.26	0.28	0.02	
18S2546/021	PD10 (0.9 - 1.2m)		1.4	0.26	0.40	0.04	
18S2546/022	PD10 (1.2 - 1.5m)		1.8	0.42	0.76	0.27	
18S2546/023	PD11 (0 - 0.3m)		1.8	0.36	0.60	<0.02	
18S2546/024	PD11 (1.0 - 1.3m)		2.5	0.61	0.64	0.02	

Analyte Method Unit Lab ID	 Client ID	P (totals) mg/kg	Ca (exch) cmol(+)/kg	K (exch) cmol(+)/kg	Mg (exch) cmol(+)/kg	Na (exch) cmol(+)/kg	Al (exch) cmol(+)/kg
18S2546/025	PD11 (1.5 - 1.8m)		4.5	0.35	1.1	0.13	
18S2546/026	PD12 (0.1 - 0.4m)	120	0.34	0.11	0.13	<0.02	0.30
18S2546/027	PD12 (0.7 - 1.0m)		1.3	0.24	0.25	0.04	
18S2546/028	PD12 (1.4 - 1.7m)		3.2	0.47	0.86	0.21	
18S2546/029	NP01 (0 - 0.1m)		1.1	0.15	0.53	0.03	
18S2546/030	NP02 (0 - 0.1m)		2.4	0.17	0.82	<0.02	
18S2546/031	NP02 (0.2 - 0.5m)		2.7	0.15	1.2	<0.02	
18S2546/032	NP03 (0 - 0.15m)		2.5	0.18	0.59	<0.02	
18S2546/033	NP03 (0.2 - 0.5m)		3.3	0.18	1.2	<0.02	
18S2546/034	NP04 (0 - 0.5m)		2.9	0.19	0.95	<0.02	
18S2546/035	NP05 (0 - 0.5m)		1.3	0.21	0.39	<0.02	
18S2546/036	NP06 (0 - 0.5m)		0.49	0.06	0.18	<0.02	0.05
18S2546/037	BP01 (0 - 0.1m)		4.0	0.66	0.69	0.02	
18S2546/038	BP02 (0 - 0.1m)		5.8	0.63	0.88	<0.02	
18S2546/039	BP02 (0.2 - 0.5m)		8.6	0.18	1.4	0.06	
18S2546/040	BP03 (0 - 0.3m)		4.3	0.32	0.61	<0.02	
18S2546/041	BP04 (0 - 0.3m)		4.4	0.16	1.8	0.04	
18S2546/042	BP05 (0 - 0.3m)		2.8	0.36	0.69	0.03	
18S2546/043	BP05 (0.7 - 1.0m)		5.8	0.34	0.75	0.06	
18S2546/044	BP06 (0 - 0.1m)		4.9	0.33	0.45	0.03	
18S2546/045	BP06 (0.1 - 0.3m)		5.0	0.51	0.50	<0.02	
18S2546/046	WRD1 (0 -0.3m)		2.8	0.41	0.64	0.03	
18S2546/047	WRD1 (0.7 - 1.0m)		5.6	0.51	0.61	0.06	
18S2546/048	WRD2 (0 - 0.3m)		2.6	0.21	1.0	<0.02	
18S2546/049	WRD2 (0.3 - 0.6m)		2.7	0.22	1.1	0.04	
18S2546/050	WRD3 (0 - 0.5m)		0.99	0.09	0.17	<0.02	
18S2546/051	TSF1 (0 - 0.3m)		4.1	0.73	0.76	0.03	
18S2546/052	TSF1 (0.4 - 0.7m)		9.7	0.84	0.98	<0.02	
18S2546/053	TSF2 (0 - 0.2m)		7.4	0.87	0.78	<0.02	
18S2546/054	TSF2 (0.2 - 0.5m)		9.9	0.70	0.90	0.09	
18S2546/055	TSF3 (0 - 0.15m)		6.2	0.91	0.98	<0.02	
18S2546/057	SF1 (0 - 0.4m)		5.4	0.42	3.1	0.04	
18S2546/058	SF2 (0 - 0.5m)		1.2	0.12	0.26	<0.02	
18S2546/059	SF3 (0 - 0.4m)		1.3	0.15	0.34	<0.02	
18S2546/060	REF1 (0 - 0.2m)		2.7	0.30	0.21	0.03	
18S2546/061	REF1 (0.2 - 0.5m)		2.5	0.25	0.18	<0.02	
18S2546/062	REF2 (0 - 0.5m)		1.9	0.11	0.57	<0.02	
18S2546/063	REF3 (0 - 0.5m)		2.1	0.44	0.37	0.05	
18S2546/064	REF4 (0 - 0.5m)		1.1	0.42	0.36	0.18	

Analyte Method Unit Lab ID	 Client ID	Mn (exch) cmol(+)/kg	Al (M3) mg/kg	B (M3) mg/kg	Ca (M3) mg/kg	Cd (M3) mg/kg	Co (M3) mg/kg
18S2546/006A	PD03 (0-0.3m)		310	0.8	600	<0.01	1.4
18S2546/016	PD08 (0 - 0.3m)	0.02					
18S2546/018	PD09 (0 - 0.3m)		300	1.2	380	<0.01	0.82
18S2546/023	PD11 (0 - 0.3m)		320	1.1	400	<0.01	1.2
18S2546/026	PD12 (0.1 - 0.4m)	<0.02					

Analyte		Mn	Al	B	Ca	Cd	Co
Method		(exch)	(M3)	(M3)	(M3)	(M3)	(M3)
Unit		cmol(+)/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Lab ID	Client ID						
18S2546/029	NP01 (0 - 0.1m)		290	1.2	240	<0.01	0.62
18S2546/030	NP02 (0 - 0.1m)		310	1.2	1300	<0.01	0.41
18S2546/036	NP06 (0 - 0.5m)	<0.02					
18S2546/037A	BP01 (0 - 0.1m)		350	1.0	1600	<0.01	1.1
18S2546/041	BP04 (0 - 0.3m)		24	0.1	>5500	<0.01	0.06
18S2546/042	BP05 (0 - 0.3m)		310	0.7	650	<0.01	2.5
18S2546/046	WRD1 (0 -0.3m)		360	0.6	630	<0.01	1.5
18S2546/048	WRD2 (0 - 0.3m)		270	0.8	610	<0.01	0.80
18S2546/051	TSF1 (0 - 0.3m)		400	0.7	860	<0.01	2.4
18S2546/053	TSF2 (0 - 0.2m)		550	0.8	1700	<0.01	2.3
18S2546/055A	TSF3 (0 - 0.15m)		450	0.8	2000	<0.01	1.5

Analyte		Cu	Fe	K	Mg	Mn	Mo
Method		(M3)	(M3)	(M3)	(M3)	(M3)	(M3)
Unit		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Lab ID	Client ID						
18S2546/006A	PD03 (0-0.3m)	0.9	32	190	130	77	0.03
18S2546/018	PD09 (0 - 0.3m)	0.7	14	92	70	35	0.02
18S2546/023	PD11 (0 - 0.3m)	0.8	23	130	84	69	0.02
18S2546/029	NP01 (0 - 0.1m)	0.2	7	52	71	13	0.01
18S2546/030	NP02 (0 - 0.1m)	0.5	35	62	420	26	0.01
18S2546/037A	BP01 (0 - 0.1m)	4.2	29	250	170	55	0.02
18S2546/041	BP04 (0 - 0.3m)	1.6	<1	68	890	2.0	0.03
18S2546/042	BP05 (0 - 0.3m)	12	26	130	99	64	0.01
18S2546/046	WRD1 (0 -0.3m)	0.8	32	150	92	84	0.01
18S2546/048	WRD2 (0 - 0.3m)	0.7	24	73	230	31	0.01
18S2546/051	TSF1 (0 - 0.3m)	1.3	44	260	110	120	0.01
18S2546/053	TSF2 (0 - 0.2m)	1.8	41	320	150	110	<0.01
18S2546/055A	TSF3 (0 - 0.15m)	1.5	31	330	240	72	0.02

Analyte		Na	Ni	P	S	Zn	As
Method		(M3)	(M3)	(M3)	(M3)	(M3)	(M3)
Unit		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Lab ID	Client ID						
18S2546/006A	PD03 (0-0.3m)	<1	0.5	6	2	0.3	<0.1
18S2546/018	PD09 (0 - 0.3m)	3	0.2	2	1	<0.1	<0.1
18S2546/023	PD11 (0 - 0.3m)	<1	0.4	7	1	0.2	<0.1
18S2546/029	NP01 (0 - 0.1m)	2	0.2	<1	3	<0.1	<0.1
18S2546/030	NP02 (0 - 0.1m)	1	0.3	6	3	0.5	0.1
18S2546/037A	BP01 (0 - 0.1m)	2	1.2	12	5	0.5	<0.1
18S2546/041	BP04 (0 - 0.3m)	15	0.3	3	6	0.4	0.1
18S2546/042	BP05 (0 - 0.3m)	1	5.0	7	2	0.5	<0.1
18S2546/046	WRD1 (0 -0.3m)	<1	0.5	15	2	0.1	<0.1
18S2546/048	WRD2 (0 - 0.3m)	<1	0.4	2	2	0.2	<0.1
18S2546/051	TSF1 (0 - 0.3m)	1	0.7	32	2	0.5	0.1
18S2546/053	TSF2 (0 - 0.2m)	3	0.8	12	2	0.4	<0.1
18S2546/055A	TSF3 (0 - 0.15m)	3	0.5	23	4	0.7	<0.1

Analyte		Pb	Se
Method		(M3)	(M3)
Unit		mg/kg	mg/kg
Lab ID	Client ID		
18S2546/006A	PD03 (0-0.3m)	0.7	<0.1
18S2546/018	PD09 (0 - 0.3m)	0.4	<0.1
18S2546/023	PD11 (0 - 0.3m)	0.7	<0.1
18S2546/029	NP01 (0 - 0.1m)	0.3	<0.1
18S2546/030	NP02 (0 - 0.1m)	0.4	<0.1
18S2546/037A	BP01 (0 - 0.1m)	0.7	<0.1
18S2546/041	BP04 (0 - 0.3m)	0.3	0.1
18S2546/042	BP05 (0 - 0.3m)	0.6	<0.1
18S2546/046	WRD1 (0 -0.3m)	0.8	<0.1
18S2546/048	WRD2 (0 - 0.3m)	0.4	<0.1
18S2546/051	TSF1 (0 - 0.3m)	1.0	<0.1
18S2546/053	TSF2 (0 - 0.2m)	1.0	<0.1
18S2546/055A	TSF3 (0 - 0.15m)	0.8	<0.1

Analyte	Method	Description
Stones	(>2mm)	Stones - sieved particles greater than 2 mm (sample preparation method manual 3.3.2)
EC	(1:5)	Electrical conductivity of 1:5 soil extract at 25 C by in-house method S02
Al	(exch)	Aluminium, Al exchangeable (ref. Rayment & Lyons 2011)
Ca	(exch)	Calcium, Ca exchangeable (ref. Rayment & Lyons 2011)
K	(exch)	Potassium, K exchangeable (ref. Rayment & Lyons 2011)
Mg	(exch)	Magnesium, Mg exchangeable (ref. Rayment & Lyons 2011)
Mn	(exch)	Manganese, Mn exchangeable (ref. Rayment & Lyons 2011)
Na	(exch)	Sodium, Na exchangeable (ref. Rayment & Lyons 2011)
pH	(H2O)	pH of 1:5 soil extract in water by in-house method S01
S	(M3)	Sulphur, S extracted by Mehlich No 3 - method S42
Pb	(M3)	Lead, Pb extracted by Mehlich No 3 - method S42
Se	(M3)	Selenium, Se extracted by Mehlich No 3 - method S42
Zn	(M3)	Zinc, Zn extracted by Mehlich No 3 - method S42
Na	(M3)	Sodium, Na extracted by Mehlich No 3 - method S42
Ni	(M3)	Nickel, Ni extracted by Mehlich No 3 - method S42
Mo	(M3)	Molybdenum, Mo extracted by Mehlich No 3 - method S42
P	(M3)	Phosphorus, P extracted by Mehlich No 3 - method S42
Mn	(M3)	Manganese, Mn extracted by Mehlich No 3 - method S42
Mg	(M3)	Magnesium, Mg extracted by Mehlich No 3 - method S42
K	(M3)	Potassium, K extracted by Mehlich No 3 - method S42
Fe	(M3)	Iron, Fe extracted by Mehlich No 3 - method S42
Ca	(M3)	Calcium,Ca extracted by Mehlich No 3 - method S42
Cd	(M3)	Cadmium,Cd extracted by Mehlich No 3 - method S42
Al	(M3)	Aluminium,Al extracted by Mehlich No 3 - method S42
As	(M3)	Arsenic, As extracted by Mehlich No 3 - method S42
Cu	(M3)	Copper,Cu extracted by Mehlich No 3 - method S42
B	(M3)	Boron,B extracted by Mehlich No 3 - method S42
Co	(M3)	Cobalt,Co extracted by Mehlich No 3 - method S42
N	(total)	Nitrogen N, total by method S10
P	(totals)	Phosphorus,P Total by method S14
OrgC	(W/B)	Organic Carbon C, Walkley and Black method S09.
ANC	ARD	Acid Neutralisation Capacity
Emerson	Class	Emerson class number by AS 1289 C.8.1
Clay.	fraction	Clay, less than 0.002mm by method S06. ref. Australian Standard AS1289.C6.3
Silt.	fraction	Silt, 0.02 to 0.002mm by method S06. ref. Australian Standard AS1289.C6.3
Sand.	fraction	Sand, 0.02 to 2.0mm by method S06. ref. Australian Standard AS1289.C6.3
Zn	iMET2SAICP	Zinc, dry basis
Cu	iMET2SAICP	Copper, dry basis
Ni	iMET2SAICP	Nickel, dry basis
Cr	iMET2SAICP	Chromium, dry basis
Mn	iMET2SAICP	Manganese, dry basis
Ni	iMET2SAMS	Nickel, dry basis
Cu	iMET2SAMS	Copper, dry basis
Co	iMET2SAMS	Cobalt, dry basis
As	iMET2SAMS	Arsenic, dry basis
Cd	iMET2SAMS	Cadmium, dry basis
Zn	iMET2SAMS	Zn, dry basis Zinc has not been validated HB 28.12
Pb	iMET2SAMS	Lead, dry basis
Se	iMET2SAMS	Selenium, dry basis
P	PRI	Phosphorus Retention Index by method S15

The results apply only to samples as received. This report may only be reproduced in full.

Unless otherwise advised, the samples in this job will be disposed of after a holding period of 30 days from the report date shown below.Multi-Element Soil Extraction Universal Extractants (Mehlich No.3)

The Mehlich No.3 Test is an alternate soil test using universal extractants for multi-elemental analysis. Results obtained using the Mehlich 3 extractant are highly correlated with the standard "single element" soil tests currently used for a wide range of Western Australian soil types.   The test provides information on the amount of plant-available nutrients including phosphorus, potassium, sulphur, calcium, magnesium, sodium, boron, copper, iron, manganese and zinc, in the soil . It can be used as a "screening*" tool (see note below) to measure concentrations of cobalt, aluminium, molybdenum and toxic metals such as cadmium, lead, arsenic, selenium and nickel in soil. It is ideally suited to acid and neutral soils, the amounts of nutrients extracted being similar to those of other soil tests used in WA .

*Results that are reported as ">" are outside the linear range of the calibration and outside the scope of the method. This results should only be used as a guide and consideration should be given to a more specific test method if the actual "value" need to be determined, hence these results should only be used as a guide.
Bolland, Allen & Walton. Aust J Soil Research 2002.
Soil Chemical Methods, Australasia (Rayment & Lyons) 2010

Results for soil analysis are reported on an air-dry (40C) less than 2 mm basis, whereby stones are removed (material >2mm) by sieving. When stone content is deemed significant the result is recorded and reported. Unless otherwise specified, all analytes (except Stones) are reported in the listed concentrations and on a dry, less than 2 mm basis. Stones are reported on a dry, whole sample basis.

Barry Price
Team Leader
Scientific Services Division
15-Feb-2019

OZ MINERALS