



The mine closure specialists



## Mulga East Iron Ore Project

### Baseline Soil and Landform Assessment

April 2021

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## EXECUTIVE SUMMARY

Mine Earth was commissioned by Hancock Prospecting Pty Ltd to complete a baseline soil and landform assessment for the Mulga East Iron Ore project (the Project). The Project is located approximately 200 kilometres (km) north-west of Newman in the Pilbara region of Western Australia (WA). The study area for the baseline soil and landform assessment encompassed the R47/12 and E47/2117 tenements, with a combined total area of approximately 32,000 hectares (ha).

The aim of the assessment was to characterise the existing surface soil materials within the study area, to identify available soil resources and potentially problematic materials, and to develop associated recommendations for the recovery and stockpiling soil resources and for their use in rehabilitation and mine closure activities.

Five soil-landform associations were identified within the study area, namely 'Low hills / rises' 'Alluvial plains', 'Floodplains', 'Calcareous flats' and 'Clay pans'.

### ***Surface Soil Characteristics***

The physical and chemical characteristics of surface soil materials were assessed from 24 representative locations within the study area, which were sampled to a maximum depth of 1.5 m.

There was a wide range in most of the physical and chemical soil characteristics identified, reflecting the wide range of landscapes and soils across the study area (Table ES1). The major consistent differences in the soils from the various soil-landform associations were the depth of soil present over partially weathered or competent rock, soil texture and the amount of coarse rock fragments (>2 mm) present within the soil materials. As would be expected there was a general trend of deeper, finer grained (i.e. more clay rich) and fertile soils, lower in the landscape.

In general, the topsoils (0 to 0.2 m depth) from the 'Low hills / rises' have characteristics which indicate a relatively low inherent erodibility (i.e. low clay content, only partial dispersion upon severe disturbance, high coarse material content and free draining). These rocky soils will be a valuable rehabilitation resource especially on final slopes of constructing landforms including waste rock dumps.

Topsoil materials sampled from lower in the landscape typically have higher clay contents, lower percentages of coarse material, lower hydraulic conductivities and may be prone to minor clay dispersion. While the surface soils from the 'Alluvial plains', 'Floodplain' and 'Calcareous flats' soil-landform associations are likely to be more erodible than the topsoils from higher in the landscape, they are a valuable rehabilitation resource especially for flat rehabilitation areas. If placed on final slopes of constructed landforms including waste rock dumps, these soils should be ripped through a rocky substrate to enhance their erosion resistance.

Topsoils from the 'Clay pans' have a high clay fraction and low percentage of competent rock. These soils are classified as extremely saline, highly sodic, have a slow drainage class and are likely to be highly erodible.

### ***Soil Management Recommendations***

Based upon the physical, chemical and morphological characteristics of the soils in the study area, it is recommended that topsoils from disturbance areas within the 'Low hills / rises', 'Alluvial plains', 'Floodplain' and 'Calcareous flats' areas are salvaged to a depth of approximately 0.2 m and stockpiled as a rehabilitation resource. It is recommended that the saline, highly sodic, highly erodible topsoil from the 'Clay pans' is not utilised as a rehabilitation resource.

Soil stripping and placement recommendations for rehabilitation and closure activities are as follows:

- 'Topsoil' (0 to 0.2 m) within the 'Low hills / rises' is likely to be the most erosion resistant growth media and should be stockpiled for use as a surface rehabilitation medium on rehabilitated slopes of constructed landforms.
- 'Topsoil' (0 to 0.2 m) from the 'Alluvial plains', 'Floodplain' and 'Calcareous flats' soil-landform associations are less suitable for placement on rehabilitated slopes due to the higher clay content, lower coarse rock fraction and tendency for partial dispersion of the clay fraction following disturbance. It is recommended that the topsoil from disturbance areas within these areas be stockpiled separately from the 'Low hills / rises' topsoil, for preferential placement on flat rehabilitation areas, or incorporation via ripping into competent rock on rehabilitated slopes.
- The deeper subsoil materials (i.e. soils from approximately 0.2 to 1 m depth) from low in the landscape (i.e. within the 'Alluvial plains', 'Floodplain' and 'Calcareous flats' soil-landform associations) typically have a higher clay content, higher sodicity and are considered likely to be more erodible than the topsoil materials. These deeper soils may be considered as an additional rehabilitation resource, if required, but will require incorporation into competent waste rock to reduce the likely erodibility.

**Table ES1 Average physical and chemical characteristics of surface soils (grouped into soil-landform associations) within the study area. The figures / classifications represent average values with broad ratings of good, moderate and poor for each parameter relative to suitability for plant growth and/or overall material stability**

Soil-landform association	Depth (cm)	Soil Texture <sup>1.</sup>	Clay content <sup>2.</sup>	% Coarse material <sup>3.</sup>	Soil pH	Salinity class	Plant-available nutrients	ESP	Structural stability	Drainage class <sup>6.</sup>	Water retention <sup>6.</sup>	Total metals <sup>7.</sup>
Low hills / rises	Topsoils (0 to 20 cm)	Sandy loam	16	75	Slightly acidic	Non-saline	Low	Non-sodic	Emerson Class 3	Moderate	Moderate	Elevated As and Se
Alluvial plains		Sandy clay loam	28	24	Neutral	Non-saline	Low to moderate	Sodic	Emerson Class 2 or Class 3	Moderately slow	Moderate	Elevated As and Se
Floodplains		Sandy loam	18	15	Neutral	Moderately saline	Low to moderate	Highly sodic	Emerson Class 2 or Class 3	Moderately slow	Moderate	Elevated As and Se
Calcareous flats		Loam	20	25	Moderately alkaline	Slightly saline	Low to moderate	Sodic	Emerson Class 3	Moderately slow	High	Elevated As and Se
Clay pans		Sandy clay loam	30	12	Neutral	Extremely saline	Moderate to high	Highly sodic	Emerson Class 2 or Class 3	Slow	High	Elevated As and Se
Low hills / rises <sup>4.</sup>	Subsoils (20 to 150 cm)	-	-	-	-	-	-	-	-	-	-	-
Alluvial plains		Clay loam	36	20	Neutral	Very saline	Low to moderate	Highly sodic	Emerson Class 2 or Class 3	Moderately slow	Moderate	Elevated As and Se
Floodplains		Loam	32	10	Neutral	Extremely saline	Low to moderate	Highly sodic	Emerson Class 1, Class 2 or Class 3	Moderately slow	High	Elevated As and Se
Calcareous flats		Silty clay loam	33	68	Moderately alkaline	Slightly saline	Low	Sodic	Emerson Class 3 or Class 4	Moderate	High	Elevated As and Se
Clay pans		Light clay	40	5	Neutral	Extremely saline	Low to moderate	Highly sodic	Emerson Class 4 <sup>5.</sup>	Moderately slow	High	Elevated As and Se

1. Average texture of soil sized fraction (<2 mm)
2. Average % clay of soil sized fraction
3. Average % coarse rock material (>2 mm)
4. No sampling below 0.2 m in 'Low hills / rises' due to high % of competent rock
5. Dispersion of clay sized fraction may be masked by high salinity
6. Broad ratings for drainage class and Field Capacity (Upper Storage Limit) of <4.75 mm fraction of soil material
7. Elements elevated substantially above average crustal abundance

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# 1 INTRODUCTION

## 1.1 Project background

Hancock Prospecting Pty Ltd (HPPL) are the proponents of the proposed Mulga East Iron Ore project, located approximately 200 km north-west of Newman in the Central Pilbara of Western Australia (Figure 1).

The Project incorporates the former Murray's Hill project (on former tenement M47/206), which received approval for construction and operation. The scope of the Murray's Hill project was subsequently revised and expanded to form the current Mulga East Iron Ore project (the Project). The Project is currently in its conceptual phase, but is likely to include:

- A series of open cut mine pits, some of which will extend below the water table.
- An ore processing plant, waste rock dumps and a waste fine storage area (or tailings storage facility).
- Mine infrastructure including rail load out facility, workshops, access and service roads, accommodation camp and airport.
- A rail spur that is approximately 50 km in length from the existing Roy Hill Iron Ore rail line.

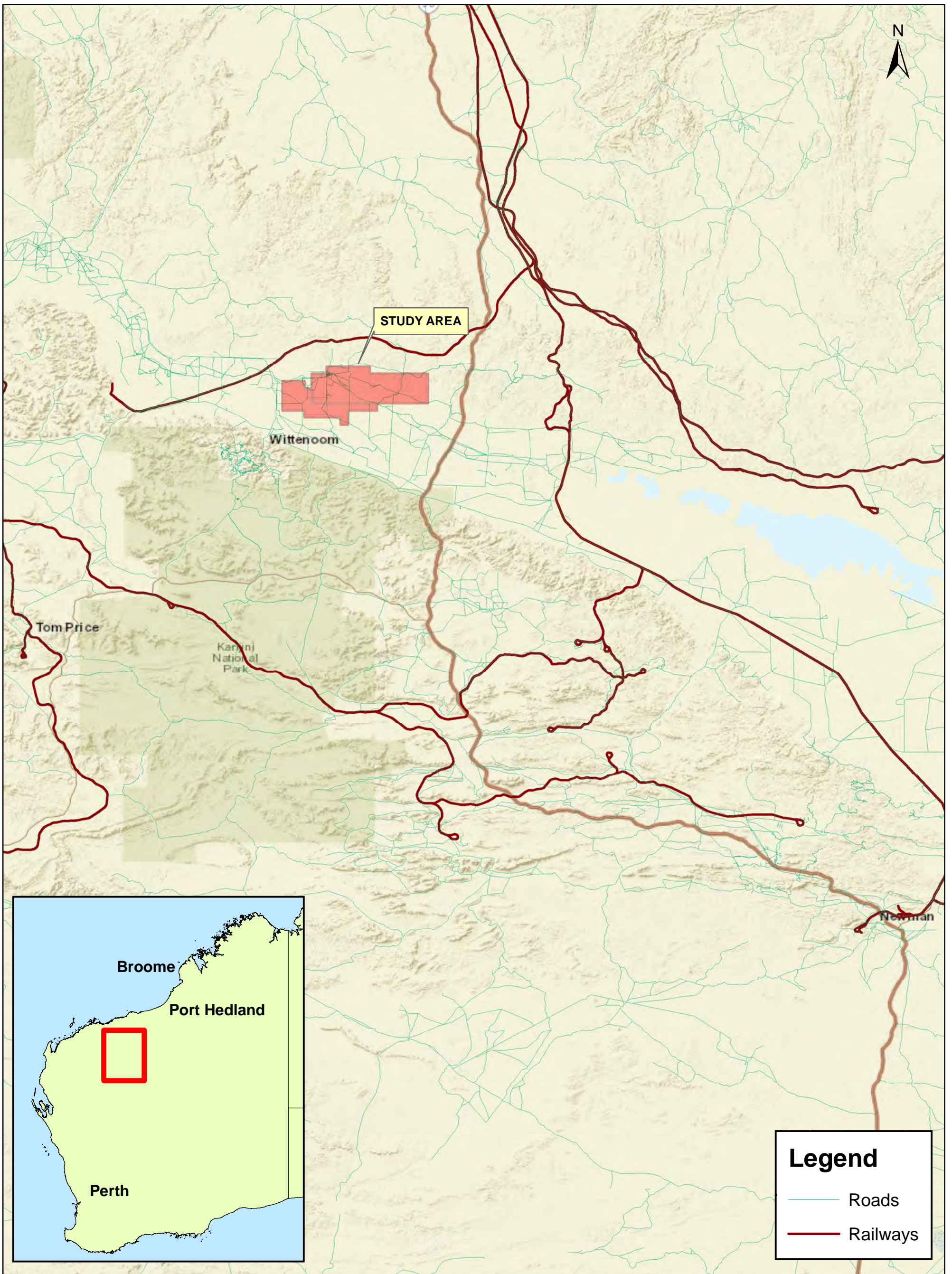
It is likely that the Project will be referred for assessment under Part IV of the *Environmental Protection Act 1986*, will be referred under the *Environmental Protection and Biodiversity Conservation Act 1999* and will require assessment under the *Mining Act 1978*.

## 1.2 Objectives

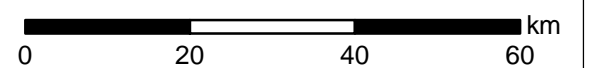
The aim of the assessment was to characterise the existing surface soil materials within the study area, to identify available soil resources and potentially problematic materials, and to develop associated recommendations for the recovery and stockpiling of soil resources and for their use in rehabilitation and mine closure activities. The study area for the baseline soil and landform assessment encompassed the R47/12 and E47/2117 tenements, with a combined total area of approximately 32,000 ha.

This report includes:

- A review of relevant site information, land system and regional soil information.
- A description of the materials and methods used for sample collection and analysis.
- Surface soil profile descriptions.
- A description of soil physical characteristics including surface soil profile morphology, soil texture, soil structure, structural stability, hydraulic conductivity and water holding capacity.
- A description of soil chemical characteristics including pH, electrical conductivity, organic matter, exchangeable cations, exchangeable sodium percentage, plant-available nutrients and total metal concentrations.
- Mapping of the soil-landform associations within the study area.
- Soil management recommendations for topsoil stripping, handling and placement as a rehabilitation resource.



Date: 12/04/2021  
 Author: J. Barrett  
 Coordinate System: GCS WGS 1984  
 Datum: WGS 1984  
 Units: Degree



**Legend**

- Roads
- Railways

Figure  
 Project Location **1**

## **2 DESCRIPTION OF STUDY AREA**

A description of the existing environment within the study area is provided in this section under the following headings: climate, geology, land systems and regional soil information.

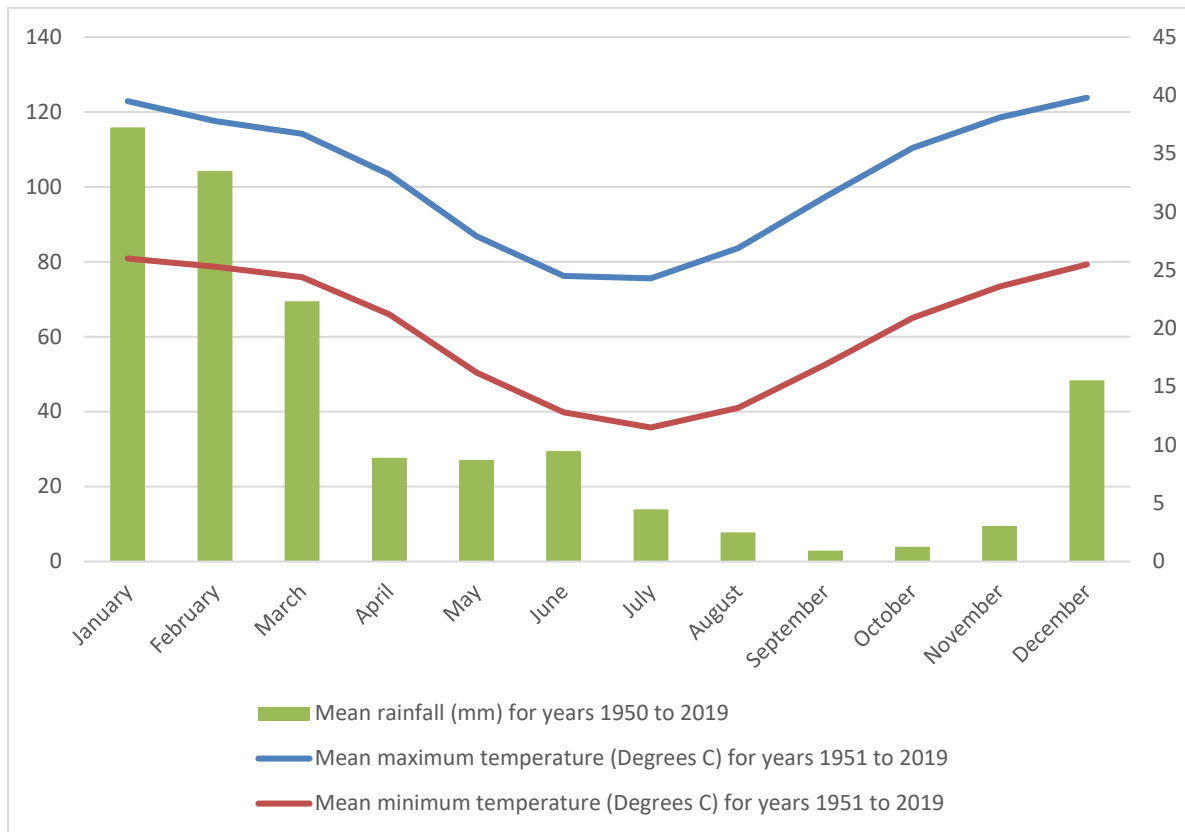
The nearest geographical features to the study area are the Karijini National Park, located approximately 75 km to the south-west and the Fortescue Marsh approximately 150 km to the east. The study area is located on the southern slopes of the Chichester Ranges, within the Fortescue subregion of the Pilbara region of the Interim Biogeographic Regionalisation for Australia (IBRA) (Thackway and Cresswell, 1995).

### **2.1 Climate**

Climate data has been collected from the nearby Wittenoom Bureau of Meteorology Station No. 5026 since 1951 (BOM, 2019) and is relevant to apply to the study area. The climate is classified as semi-arid, with two distinct seasons characterised by seasonal periodic rainfall and high evaporation rates.

Mean maximum temperature is highest in December (39.8°C) and lowest in July (24.3°C), while the mean minimum temperature is lowest in July (11.5°C) and highest in January (26.0°C) (Figure 2).

The long-term annual average rainfall for the area is 461.8 mm/year. Annual total rainfall values range from 143.2 to 1,344.6 mm, reflecting the variable nature of rainfall in the area, driven predominantly by cyclonic events and tropical lows. The largest rainfall events typically occur in January, which averages approximately 115.9 mm for the month (Figure 2). Evaporation rates are at their highest during the summer months, with December recording the highest daily average evaporation of 12.4 mm/day (BOM, 2019).



**Figure 2 Mean monthly rainfall and mean monthly maximum temperature for the Wittenoom weather station (BOM, 2019).**

## 2.2 Geology

### 2.2.1 Regional Geology

The Project is located within the Hamersley Province in the northwest of Western Australia. The Mulga East and Murray's Hill deposits are hosted by the Marra Mamba Iron Formation (MMIF) of the Proterozoic Hamersley Group, conformably overlying the Jeerinah Formation of the Fortescue Group. The Wittenoom Formation (including the West Angela Member shale) overlies the Marra Mamba Iron Formation (Hancock Prospecting, 2015).

The MMIF is the basal Formation of the Hamersley Group and is characterised by sedimentary rocks including banded iron formation (BIF), chert and shale. The MMIF is subdivided into three Members:

1. Mount Newman Member which comprises BIF with thin shale intervals. It is the predominant host to iron mineralisation in the MMIF and is approximately 60m thick. These deposits are currently being mined at Orebody 29, Marandoo, West Angelas, Mining Area C and Hope Downs (Hancock Prospecting, 2009).
2. MacLeod Member consists of shale, BIF and chert as interbedded units. It has an approximate thickness of 45m. Distinct podded chert layer occurs at the base of this member (Hancock Prospecting, 2009).
3. Nammuldi Member is the lower most unit of the Hamersley Group and conformably overlies the Roy Hill Shale member of the Fortescue Group. It is approximately 60 to 100m thick and consists of banded iron formation (BIF), podded chert and shale as alternating mesobands.

The Nammuldi Member is host to the mineralisation at Mulga Downs East deposit. Other known deposits hosted by the Nammuldi Member are Roy Hill, Christmas Creek and Cloud Break deposits (Hancock Prospecting, 2015).

The Jeerinah Formation comprises volcanics and interbedded sediments including shale, sandstone and carbonaceous pelite and is exposed along the Chichester Range. The upper part of this Formation is composed of mudstone and siltstone with black carbonaceous material. Within the Project area, the Jeerinah Formation is locally pyritic and dolomitic (Hancock Prospecting, 2015).

### 2.2.2 Local Geology

Alluvial sediments occur within the Fortescue Valley to the south which consist of unconsolidated silt, sand and gravel of the ephemeral creeks and riverbeds, and clay, silt and sand of the adjacent flood plains of the Fortescue River. Calcrete horizons generally underly the alluvial deposits whilst some silcrete occurs in the deeper channel of the erosional surface, towards the Fortescue Valley (Hancock Prospecting, 2015).

Detrital material has formed as part of paleo-erosional channels which cut the MMIF. Pisolite layers, channel iron deposits and detrital scree slope deposits have been recognised at surface and from the drilling. Some of these units host secondary 'detrital' mineralisation at Mulga East (Hancock Prospecting, 2015).

The MMIF outcrops as small rounded hills in the Mulga Downs East area, with the hill slopes commonly covered with Cainozoic sediments such as alluvial-colluvial and detritals. The Roy Hill Shale Member of the Jeerinah Formation is exposed at the centre of Mulga East and at the foothill of the Chichester Range to the north. It is locally up to 40 m thick and is characterised by pyritic black shale or bleached white, dolomitic shale (Hancock Prospecting, 2015).

The Mulga East main mineralisation is hosted by the lower part of the MMIF, with secondary mineralisation identified within transported or detrital material. A weathered, hydrated horizon or hardcap is recognised at Mulga Downs East with elevated iron to above 50% in places. Localised patches of manganiferous material on outcrops of the MMIF occur at the lower central part of the Mulga Downs East lease. At Mulga Downs East, manganiferous material is closely associated with hardcap and detritals (Hancock Prospecting, 2015).

## 2.3 Land Systems

An inventory and condition survey of the Pilbara region was undertaken between 1995 and 1999 by the Department of Agriculture (now the Department of Primary Industries and Regional Development) to develop a comprehensive description of the biophysical resources and assess the vegetation composition and soil condition within the region. This information has been utilised to classify and map the land systems of the region according to similarities in landform, soil, vegetation, geology and geomorphology (Van Vreeswyk et al, 2004).

Land systems present within the study area are described in Table 1 and delineated in Figure 3.

**Table 1 Land systems within the study area (Van Vreeswyk *et al*, 2004)**

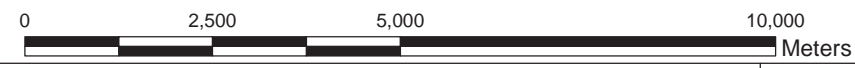
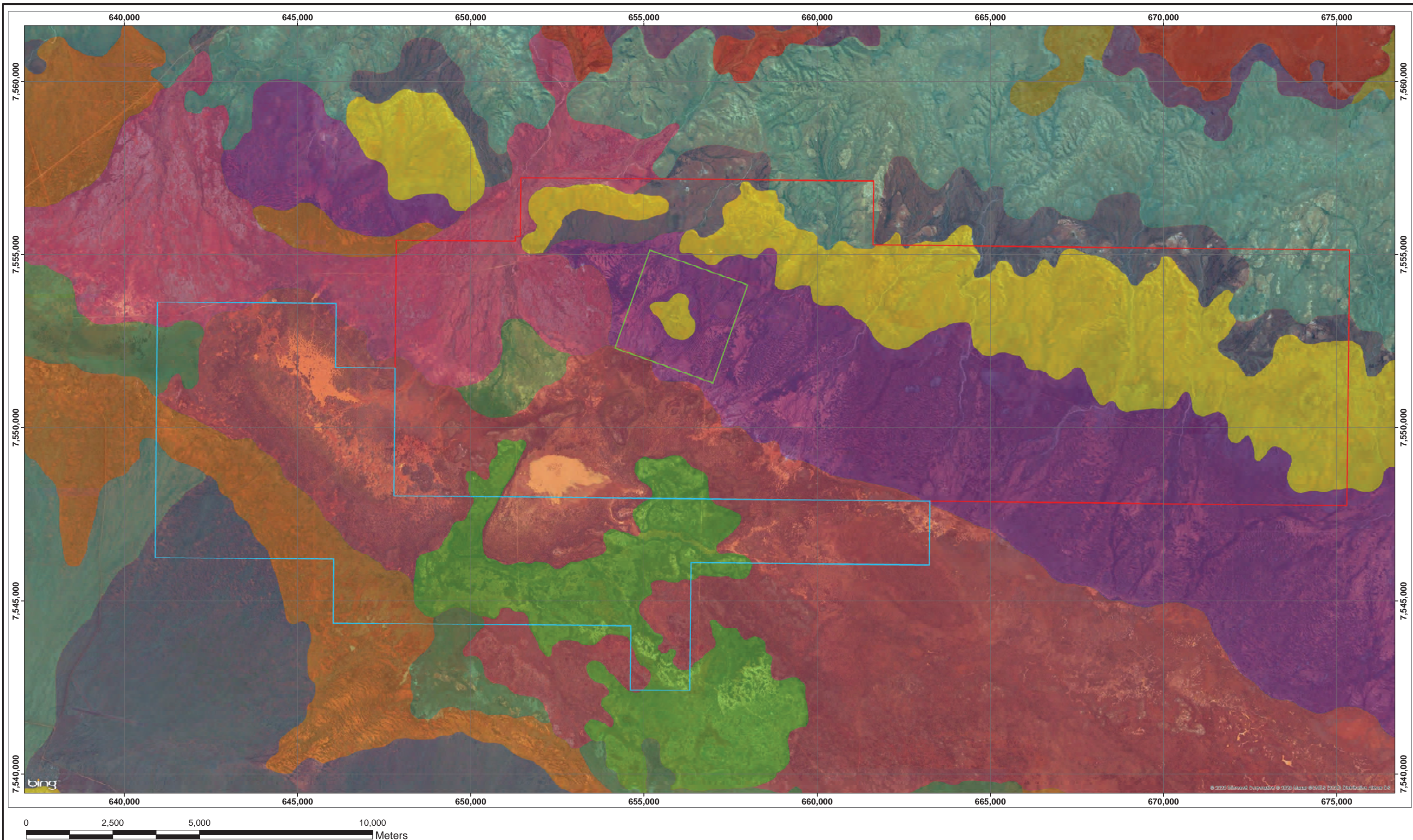
Name	Description
Boolgeeda System	Stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands and mulga shrublands.
Brockman System	Alluvial plains with cracking clay soils supporting tussock grasslands.
Calcrete System	Low calcrete platforms and plains supporting shrubby hard spinifex grasslands.
Coolibah System	Flood plains with weakly gilgaied clay soils supporting coolibah woodlands with tussock grass understorey.
Hooley System	Alluvial clay plains supporting a mosaic of snakewood shrublands and tussock grasslands.
Jamindie System	Stony hardpan plains and rises supporting groved mulga shrublands, occasionally with spinifex understorey.
Jurrawarrina System	Hardpan plains and alluvial tracts supporting mulga shrublands with tussock and spinifex grasses.
Newman System	Rugged jaspilite plateaux, ridges and mountains supporting hard spinifex grasslands.
Urandy System	Stony plains, alluvial plains and drainage lines supporting shrubby soft spinifex grasslands.

## 2.4 Soils

Regional scale soil mapping for the Pilbara region is detailed within (Van Vreeswyk *et al*, 2004). The most extensive soils within the region comprise shallow stony soils on hills and ranges and sands on sandplains. The dominant Soil Groups reported as occurring within the Land Systems in the study area include Stony soils, Red shallow loams, Red loamy earths, Calcareous shallow loams and Red-brown hardpan shallow loams.

A soil and overburden assessment of the Murray's Hill former tenement M47/206 was undertaken by Landloch in 2009 (Landloch, 2009). The assessment defined two soil associations within M47/206, namely 'upland soils' and 'lowland soils'. Soil texture was classed typically as clay loam. Surface coarse fragments were common in both upland and lowland soils. Coarse fragments were also present throughout the profile. Soil depth at each of the sites varied from very shallow (<0.10 m) to deep (>1.0 m). Shallower soils were typically found in upland soils, with lowland soil profiles tending to be deeper.

Soils typically had a neutral to mildly alkaline pH and were classed as non-saline. Soils were classified as moderately permeable and tended to be moderately well-drained with water movement being limited by underlying rock. All soils were described as likely to have moderate plant available water holding capacity. Water repellence was not observed on any soils in the Murray's Hill project area (Landloch, 2009).



**Figure 3**  
**Land systems**

Project tenements	Land system	McKay System	Brockman System
R47/12	Urandy System	Hooley System	Calcrete System
E47/2117	Rocklea System	Newman System	Jamindie System
M 47/206-I	Bonney System	Boolgeeda System	Coolibah System
	Wona System	Jurrawarrina System	

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A	4/10/19	Issued for comment

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## 3 MATERIALS AND METHODS

### 3.1 Sampling Regime

Soil samples were collected by Mine Earth personnel from 24 sites within the study area in August 2019 (Figure 4). Sampling was facilitated by a backhoe in areas where deep soil profiles were present (13 sites) or collected by hand in areas where only shallow / skeletal soils were present and/or where access was restricted (11 sites). Soil samples were taken within areas with existing Programme of Work approvals, and outside of the Wittenoom Asbestos Management Area (Figure 4).

Samples were taken from two to four depth intervals at each soil sampling site, depending upon the near-surface soil profile morphology and depth of excavation possible.

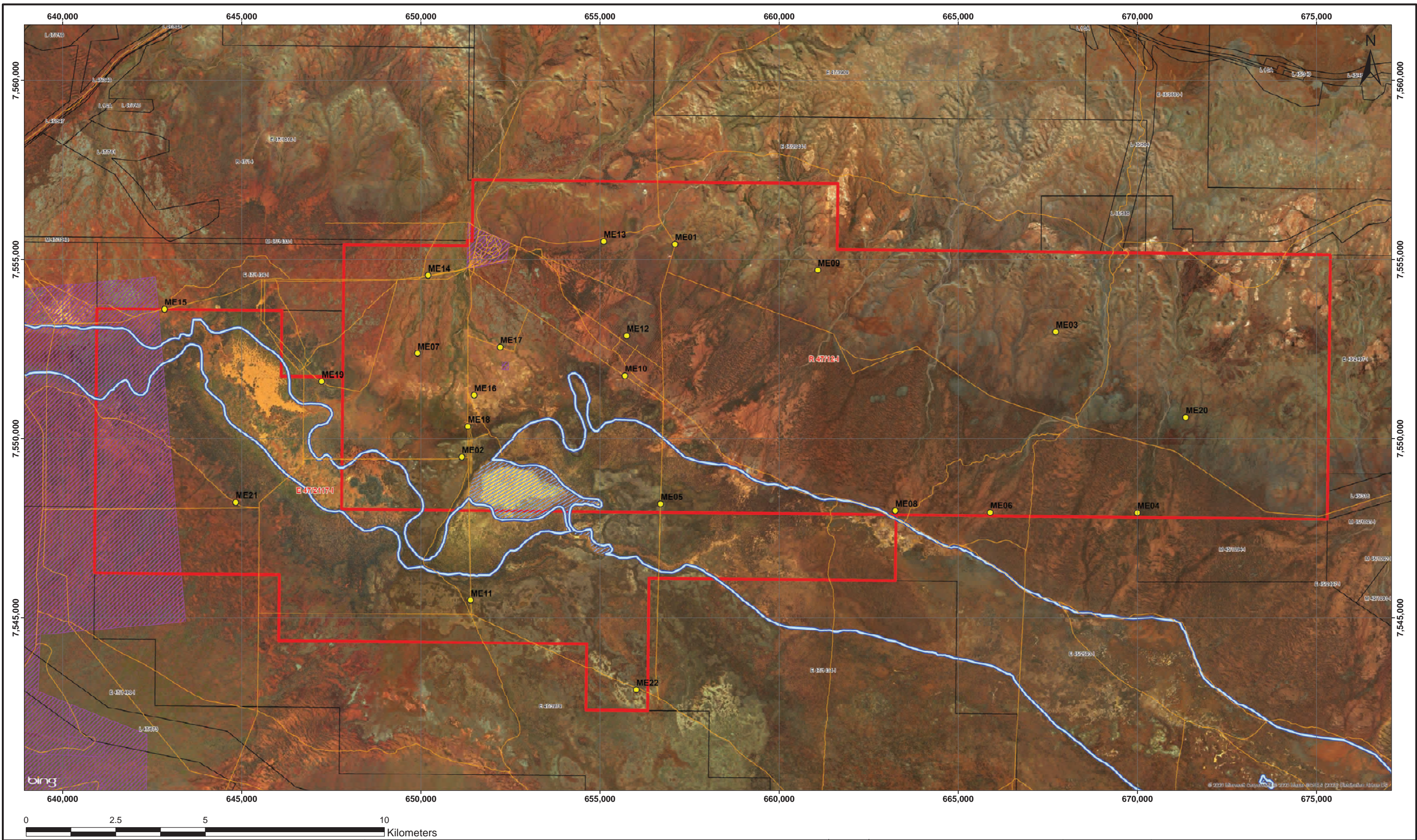
Field based observations made during the sampling program included a description of soil surface characteristics, soil profile morphology, vegetation assemblage present and the surface drainage characteristics of each soil sampling site, as per the Australian Soil and Land Survey guidelines (CSIRO, 2009).

### 3.2 Test Work and Procedures

Laboratory test work on the sampled soils was conducted at the Mine Earth laboratory for soil physical parameters and at the CSBP Soil and Plant Laboratory for analysis of chemical parameters. Laboratory based soil analyses included:

- Physical characteristics;
  - Soil texture and particle size distribution
  - Soil structural stability (Emerson Dispersion Test)
  - Saturated hydraulic conductivity ( $K_{sat}$ )
  - Water retention characteristics (field capacity)
- Chemical characteristics;
  - Soil pH
  - Electrical conductivity
  - Organic carbon
  - Exchangeable cations
  - Plant available nutrients (N, P, K and S)
  - Total metal concentrations

All soil test work procedures were conducted in accordance with standard analytical procedures to assess potential soil erodibility and soil properties related to the support of plant growth (Rayment and Lyons, 2011). Descriptions of relevant soil classification categories are detailed in Appendix A. All external laboratory results for soil samples are provided in Appendix B.



**Figure 4**  
**Soil sampling locations**

- Study Area
- Soil sample site
- Tenement
- Wittenoom Asbestos Management Area
- Roads
- Lake / clay pan
- Fortescue River floodplain

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## **4 RESULTS AND DISCUSSION**

The findings of the soil survey and laboratory test work program are presented and discussed in the following sections.

### **4.1 Sample Site and Soil Profile Descriptions**

Sampling site and surface soil profile descriptions for the 24 sites within the study area are presented below.

<b>Site Reference:</b>	Mulga East Site ME01	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Top of low rise in E-W running ridgeline	<b>Easting:</b>	657091
<b>Soil Landform Association:</b>	Low hills / Rises	<b>Northing:</b>	7555423



**Plate 1 Surface soil at Site ME01**

**Soil profile description:**

0-5 cm: Single-grained soil with approximately 90% sub-rounded to sub-angular coarse fragments, 2 to 50 mm in size.

10-20 cm: Single-grained soil with approximately 80 to 90% sub-rounded to sub-angular coarse fragments, 10 to 60 mm in size.

**Soil surface:** Weak surface crust with approximately 90% cover of angular to sub-rounded coarse fragments (ironstone) at surface, with 10 to 15% litter cover.

**Vegetation:** Spinifex, scattered Acacia and Eucalypt species.



**Plate 2 Landscape / vegetation at Site ME01**

<b>Site Reference:</b>	Mulga East Site ME02	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Flat alluvial plain	<b>Easting:</b>	651144
<b>Soil Landform Association:</b>	Calcareous flats	<b>Northing:</b>	7549479



**Soil profile description:**

0-5 cm: Weakly structured soil with polyhedral aggregates of low strength. Approximately 5 to 10% sub-rounded to sub-angular coarse fragments, 2 to 10 mm in size.

10-20 cm: Weak structured soil with polyhedral aggregates of low strength. Approximately 5 to 10% sub-rounded to sub-angular coarse fragments, 2 to 20 mm in size.

20+ cm: Calcareous nodules present.

**Plate 3 Surface soil at Site ME02**

**Soil surface:** Weak surface crust with 30 to 40% cover of sub-angular to sub-rounded coarse fragments (ironstone and calcrete) at surface, with 30% litter cover.

**Vegetation:** Acacia, scattered Eucalypts (5 to 6 m) and grasses.



**Plate 4 Landscape / vegetation at Site ME02**

<b>Site Reference:</b>	Mulga East Site ME03	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Upper slope of E-W ridge	<b>Easting:</b>	667419
<b>Soil Landform Association:</b>	Low hills / Rises	<b>Northing:</b>	7552187



**Plate 5 Surface soil at Site ME03A**

**Soil profile description:**

0-20 cm: Single-grained soil with approximately 70% sub-rounded to sub-angular coarse fragments, 2 to 50 mm in size.

**Soil surface:** Very weak surface crust with 90% cover of angular to sub-rounded 5 to 50 mm coarse fragments (ironstone) at surface, with 5 to 10% litter cover.

**Vegetation:** Spinifex, scattered Eucalypts (5 to 6 m) and Acacia (2 to 3 m).



**Plate 6 Landscape / vegetation at Site ME03A**

<b>Site Reference:</b>	Mulga East Site ME04	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Flat wooded alluvial plain	<b>Easting:</b>	669994
<b>Soil Landform Association:</b>	Alluvial plain	<b>Northing:</b>	7547876



**Soil profile description:**

0-20 cm: Well-structured soil with polyhedral aggregates of moderate strength to 100 mm. Approximately 10% sub-angular to sub-rounded coarse fragments, 2 to 30 mm in size. Plant root abundance classified as 'abundant'.

20-50 cm: Well-structured soil with polyhedral aggregates of moderate strength to 40 mm. Approximately 10% sub-angular to sub-rounded coarse fragments, 2 to 30 mm in size. Plant root abundance classified as 'few', decreasing with depth.

50-100 cm: Massive soil structure with approximately 20% sub-angular to sub-rounded coarse fragments, 2 to 50 mm in size.

**Plate 7 Surface soil profile at Site ME04**

**Soil surface:** Moderate, thin platy surface crust with approximately 10% cover of angular to sub-rounded coarse fragments at surface, with approximately 75% litter cover.

**Vegetation:** Heavily wooded with Acacia (2 to 6 m), and some grasses.



**Plate 8 Landscape / vegetation at Site ME04**

<b>Site Reference:</b>	Mulga East Site ME05	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Flat spinifex plain with very minor undulation	<b>Easting:</b>	656695
<b>Soil Landform Association:</b>	Calcareous flats	<b>Northing:</b>	7548183



**Plate 9 Surface soil profile at Site ME05**

**Soil profile description:**

0-50 cm: Predominantly single grained soil with approximately 60% calcareous nodules 2 to 10 mm in size. Plant root abundance classified as 'abundant'.

50-100 cm: Calcareous nodules 2 to 30 mm in size in a calcareous, weakly consolidated single grained matrix.

**Soil surface:** Weak, thin surface crust with approximately 20% cover of angular to sub-rounded coarse calcareous fragments at surface, 2 to 100 mm in size, with approximately 50% leaf litter cover.

**Vegetation:** Predominantly spinifex with occasional Acacia trees (2 to 4 m) and shrubs (0.5 to 2 m).



**Plate 10 Landscape / vegetation at Site ME05**

<b>Site Reference:</b>	Mulga East Site ME06	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Broad flood plain with minor drainage lines	<b>Easting:</b>	665839
<b>Soil Landform Association:</b>	Alluvial plain	<b>Northing:</b>	7547904



**Plate 11 Surface soil profile at Site ME06**

**Soil profile description:**

0-50 cm: Well-structured soil with polyhedral aggregates of moderate strength, 2 to 80 mm. Approximately 15-20% sub-angular to sub-rounded coarse fragments, 2 to 30 mm in size.

50-100 cm: Massive soil structure with approximately 15-20% sub-angular to sub-rounded coarse fragments, 2-30 mm in size.

**Soil surface:** Thin platy surface crust with approximately 90% cover of angular to sub-rounded coarse ironstone fragments at surface, 2 to 60 mm in size, with approximately 5% leaf litter cover. Areas of deposition and erosion within minor channelling of surface drainage.

**Vegetation:** Predominantly bare stony surface with occasional Acacia trees (1-5m).



**Plate 12 Landscape / vegetation at Site ME06**

<b>Site Reference:</b>	Mulga East Site ME07	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Broad stony alluvial plain dissected with minor drainage channels	<b>Easting:</b>	649918
<b>Soil Landform Association:</b>	Alluvial plain	<b>Northing:</b>	7552382



**Soil profile description:**

0-40 cm: Well-structured alluvial soil with polyhedral aggregates of moderate strength, 2 to 80 mm in size. Approximately 40% sub-angular to sub-rounded coarse fragments, 2 to 30 mm in size.

40-120 cm: Weakly structured friable soil with ironstone nodules and aggregates to 70 mm. Structure decreases with depth to massive. Approximately 20% sub-angular to sub-rounded coarse fragments, 2-30 mm in size.

**Plate 13 Surface soil profile at Site ME07**

**Soil surface:** No crust present. Approximately 90% cover of angular to sub-rounded coarse ironstone fragments at surface, 2 to 80 mm in size, with approximately 15% leaf litter cover. Distinct areas of erosion and deposition from surface drainage, varying from shallow surface channels to larger scours of 30 to 40 cm depth.

**Vegetation:** Predominantly bare stony surface with occasional Acacia trees (1 to 5 m) and some spinifex.



**Plate 14 Landscape / vegetation at Site ME07**

<b>Site Reference:</b>	Mulga East Site ME08	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Broad flood plain with minor channelling	<b>Easting:</b>	663200
<b>Soil Landform Association:</b>	Floodplain	<b>Northing:</b>	7547988



**Soil profile description:**

0-5 cm: Weakly structured soil with polyhedral aggregates of weak-moderate strength, to 100 mm in size. Approximately 10 to 15% sub-angular to sub-rounded coarse fragments, 2 to 20 mm in size.

10-60 cm: Well-structured iron-rich soil with polyhedral aggregates to 30 mm in size. Approximately 25% sub-angular to sub-rounded coarse fragments, 2 to 20 mm in size.

60-100 cm: Massive soil with approximately 15 to 20% sub-angular to sub-rounded coarse ironstone fragments, 2 to 10 mm in size.

**Plate 15 Surface soil profile at Site ME08**

**Soil surface:** Weak to moderate surface crust with approximately 90% cover of angular to sub-rounded coarse ironstone fragments at surface, 2 to 50 mm in size, with approximately 5 to 10% litter cover. Minor sheet erosion evident.

**Vegetation:** Predominantly bare stony surface with scattered Acacia trees (2 to 5 m) and shrubs.



**Plate 16 Landscape / vegetation at Site ME08**

<b>Site Reference:</b>	Mulga East Site ME09	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Upper slope of E-W ridge	<b>Easting:</b>	661075
<b>Soil Landform Association:</b>	Low hills / Rises	<b>Northing:</b>	7554694



**Plate 17 Surface soil at Site ME09**

**Soil profile description:**

0-20 cm: Skeletal, single-grained soil with approximately 80% sub-rounded to sub-angular coarse fragments, 2 to 70 mm in size.

**Soil surface:** Weak surface crust with approximately 90% cover of angular to sub-rounded coarse fragments (ironstone) at surface, 2 to 100 mm in size, with 20% litter cover.

**Vegetation:** Predominantly spinifex with scattered small shrubs and Eucalypt trees (3 to 5 m).



**Plate 18 Landscape / vegetation at Site ME09**

<b>Site Reference:</b>	Mulga East Site ME10	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Flat stony alluvial plain	<b>Easting:</b>	655657
<b>Soil Landform Association:</b>	Alluvial plain	<b>Northing:</b>	7551787



**Soil profile description:**

0-20 cm: Well-structured soil with polyhedral aggregates of weak to moderate strength, up to 150 mm in size. Approximately 40 to 50% sub-angular to sub-rounded coarse fragments, 5 to 20 mm in size.

20-80 cm: Weakly structured, friable soil with polyhedral aggregates to 30 mm size. Approximately 40 to 50% sub-angular to sub-rounded coarse fragments, 5 to 10 mm in size.

80cm+: Massive soil with approximately 40 to 50% sub-angular to sub-rounded coarse fragments, 5 to 10 mm in size.

**Plate 19 Surface soil profile at Site ME10**

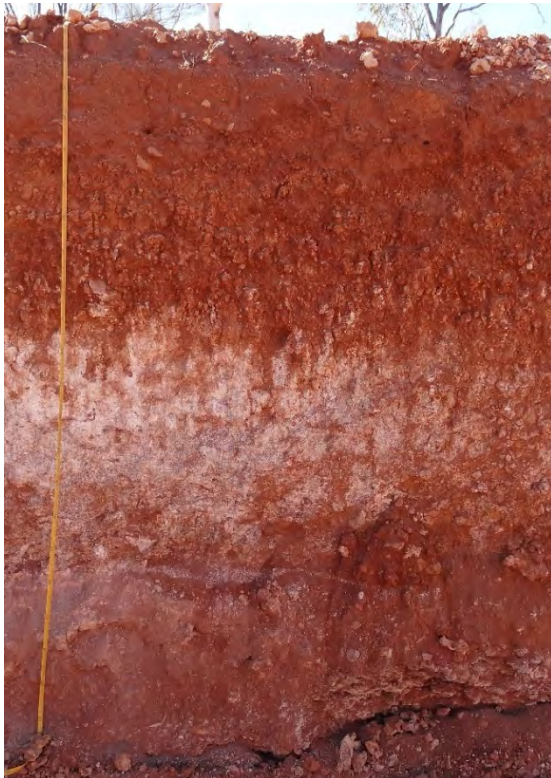
**Soil surface:** Moderate surface crust present. Approximately 90% cover of angular to sub-rounded coarse ironstone fragments at surface, 2 to 30 mm in size, with approximately 5 to 10% litter cover.

**Vegetation:** Predominantly bare stony surface with scattered Acacia trees (2 to 5 m) and shrubs.



**Plate 20 Landscape / vegetation at Site ME10**

<b>Site Reference:</b>	Mulga East Site ME11	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Flat wooded alluvial plain with outcropping calcrete	<b>Easting:</b>	651397
<b>Soil Landform Association:</b>	Calcareous flats	<b>Northing:</b>	7545489



**Soil profile description:**

0-50 cm: Well-structured soil with polyhedral aggregates of moderate strength, up to 70 mm in size. Approximately 20% sub-angular to sub-rounded coarse fragments, 2 to 30 mm in size. Plant root abundance described as 'minor'

50-110 cm: Approximately 75% calcareous nodules of, 2 to 70 mm size within a single-grained soil matrix.

110-240 cm: Single-grained, friable weakly consolidated calcareous soil.

**Plate 21 Surface soil profile at Site ME11**

**Soil surface:** Very weak thin surface crust, with approximately 40 to 50% cover of sub-angular to sub-rounded calcareous nodules, 2 to 60 mm in size, with approximately 40% litter cover.

**Vegetation:** Acacia sp. (2 to 3 m), small Eucalypts (2 to 4 m) and various other shrubs.



**Plate 22 Landscape / vegetation at Site ME11**

<b>Site Reference:</b>	Mulga East Site ME12	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Mid-slope of Murray's Hill	<b>Easting:</b>	655742
<b>Soil Landform Association:</b>	Low hills / rises	<b>Northing:</b>	7552867



**Soil profile description:**

0-20 cm: Skeletal, single-grained soil with approximately 60% sub-rounded to sub-angular coarse fragments, 2 to 20 mm in size.

**Plate 23 Surface soil at Site ME12**

**Soil surface:** Weak surface crust with approximately 90% cover of angular to sub-rounded coarse fragments (ironstone) at surface, 2 to 100 mm in size, with 10 to 15% litter cover. Some outcropping rock and large boulders 10cm to 1m in size.

**Vegetation:** Predominantly spinifex with scattered shrubs and Eucalypt trees (4 to 6 m).



**Plate 24 Landscape / vegetation at Site ME12**

<b>Site Reference:</b>	Mulga East Site ME13	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Mid-slope of Murray's Hill	<b>Easting:</b>	655131
<b>Soil Landform Association:</b>	Low hills / rises	<b>Northing:</b>	7555635



**Soil profile description:**

0-5 cm: Weakly structured single-grained soil with approximately 60% sub-rounded to sub-angular coarse fragments, 2 to 30 mm in size.

10-20 cm: Massive soil structure with approximately 75% sub-rounded to sub-angular coarse fragments, 2 to 50 mm in size

**Plate 25 Surface soil at Site ME13A**

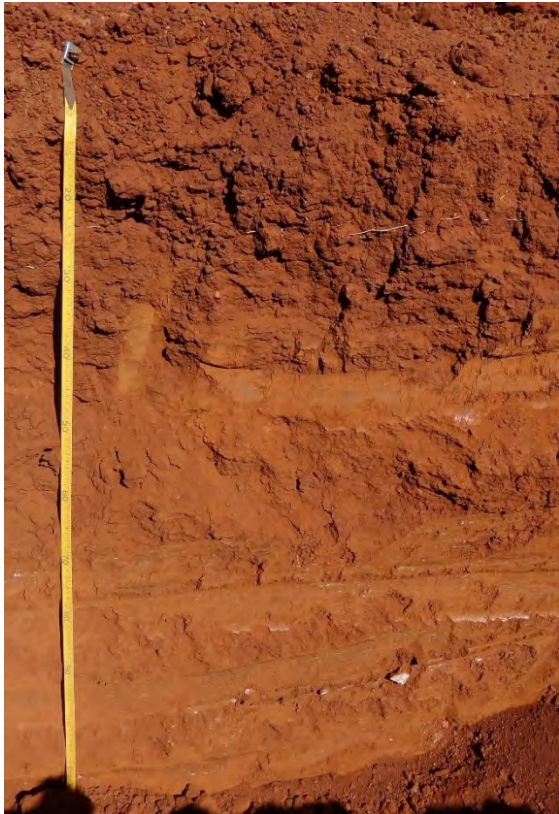
**Soil surface:** Weak surface crust with approximately 90% cover of angular to sub-rounded coarse fragments (ironstone) at surface, 2 to 60 mm in size, with 5% litter cover.

**Vegetation:** Predominantly spinifex with scattered Acacia and Eucalypt trees (4 to 6 m) and shrubs.



**Plate 26 Landscape / vegetation at Site ME13A**

<b>Site Reference:</b>	Mulga East Site ME14	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Alluvial plain adjacent of minor tributary of Fortescue River	<b>Easting:</b>	650285
<b>Soil Landform Association:</b>	Alluvial plain	<b>Northing:</b>	7554538



**Plate 27** Surface soil profile at Site ME14

**Soil surface:** Very thin platy surface crust, with approximately 20% cover of angular to rounded coarse fragments at surface, 2 to 100 mm in size, with approximately 10 to 15% litter cover.

**Vegetation:** Scattered Acacia and Eucalypt trees (4 to 6 m) with shrubs (1 to 2 m) and minor Spinifex cover.

**Soil profile description:**

0-40 cm: Well-structured soil with polyhedral aggregates of moderate strength, 5 to 50 mm in size. Approximately 5 to 10% sub-angular to sub-rounded coarse fragments, 2 to 20 mm in size. Plant root abundance described as 'minor'.

40-120 cm: Massive soil with 10% ironstone nodules, 2 to 30 mm in size.



**Plate 28** Landscape / vegetation at Site ME14

<b>Site Reference:</b>	Mulga East Site ME15	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Broad alluvial floodplain	<b>Easting:</b>	642859
<b>Soil Landform Association:</b>	Alluvial plain	<b>Northing:</b>	7553566



**Soil profile description:**

0-5 cm: Weakly structured friable soil with few small aggregates and < 10% sub-rounded to sub-angular coarse fragments, 2 to 10 mm in size.

10-20 cm: Moderately structured soil with 5 to 10 mm aggregates and < 10% sub-rounded to sub-angular coarse fragments, 2 to 10 mm in size.

**Plate 29 Surface soil at Site ME15**

**Soil surface:** Very weak surface crust with approximately 80 to 90% cover of angular to sub-rounded coarse fragments at surface, 2 to 60 mm in size, with 40 to 50% litter cover.

**Vegetation:** Predominantly bare stony ground with pockets of Eucalypt trees (4 to 6 m) and Acacia sp. (1 to 5 m).



**Plate 30 Landscape / vegetation at Site ME15**

<b>Site Reference:</b>	Mulga East Site ME16	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Broad stony plain with minor undulation	<b>Easting:</b>	651489
<b>Soil Landform Association:</b>	Clay pan	<b>Northing:</b>	7551206



**Soil profile description:**

0-5 cm: Weakly structured soil with aggregates to 50 mm in size and approximately 20% sub-rounded to sub-angular coarse fragments, 2 to 20 mm in size.

10-20 cm: Massive soil structure with 10% sub-rounded to sub-angular coarse fragments, 2 to 20 mm in size.

**Plate 31 Surface soil at Site ME16**

**Soil surface:** Moderate strength platy surface crust with approximately 80 % cover of angular to sub-rounded coarse fragments at surface, 2 to 60 mm in size, with < 5% litter cover.

**Vegetation:** Predominantly bare stony ground with sparse Acacia trees.



**Plate 32 Landscape / vegetation at Site ME16**

<b>Site Reference:</b>	Mulga East Site ME17	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Broad stony alluvial plain	<b>Easting:</b>	652219
<b>Soil Landform Association:</b>	Floodplain	<b>Northing:</b>	7552541



**Soil profile description:**

0-60 cm: Moderately structured soil with polyhedral aggregates of moderate strength, to 50 mm in size. Approximately 20% sub-angular to sub-rounded coarse fragments, 2 to 20 mm in size.

60-120 cm: Massive soil structure with 10% ironstone nodules, 2 to 30 mm size.

**Plate 33 Surface soil profile at Site ME17**

**Soil surface:** Very thin platy surface crust, with approximately 80% cover of angular to sub-rounded coarse fragments at surface, 2 to 75 mm in size, with < 2% litter cover. Minor areas of deposition and erosion from sheet flow but no obvious drainage channels.

**Vegetation:** Mostly bare stony surface with scattered Acacia trees (2 to 3 m) and patches of grasses.



**Plate 34 Landscape / vegetation at Site ME17**

<b>Site Reference:</b>	Mulga East Site ME18	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Stony clay pan	<b>Easting:</b>	651304
<b>Soil Landform Association:</b>	Clay pan	<b>Northing:</b>	7550408

**Soil profile description:**

0-110 cm: Homogenous profile of a moderately well-structured soil with increasing size of aggregates with depth. Gypsum crystals, 2-10mm in size present throughout profile. Some (approx. 5%) coarse aggregates present from 20 to 30 cm depth, 2 to 10 mm in size.

**Plate 35 Surface soil profile at Site ME18**

**Soil surface:** Clayey platy moderate surface crust, with approximately 70% cover of angular to sub-rounded coarse fragments at surface, 2 to 40 mm in size, with < 5% leaf litter cover.

**Vegetation:** Mostly bare stony surface with grassy islands of saltbush. Occasional Acacia and Eucalypt trees away from claypan edge.

**Plate 36 Landscape / vegetation at Site ME18**

<b>Site Reference:</b>	Mulga East Site ME19	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Flat wooded alluvial plain	<b>Easting:</b>	647198
<b>Soil Landform Association:</b>	Alluvial plain	<b>Northing:</b>	7551591



**Plate 37 Surface soil profile at Site ME19**

**Soil profile description:**

0-40 cm: Well-structured soil with polyhedral aggregates of moderate strength, 10 to 50 mm in size. Approximately 20 to 30% angular to sub-rounded coarse fragments, 2 to 30 mm in size. Plant root abundance described as 'abundant'.

40-90 cm: Well-structured soil with polyhedral aggregates of moderate strength, 10 to 50 mm. Approximately 5 to 10% ironstone nodules. Plant root abundance described as 'abundant'.

90-110 cm: Massive soil with 5 to 10% ironstone nodules.

**Soil surface:** Thin platy surface crust, with approximately 40 to 50% cover of angular to sub-rounded coarse fragments at surface, 2 to 50 mm in size, with approximately 20% litter cover.

**Vegetation:** Open forest of Acacia trees (2 to 6 m), Eucalypts (4 to 6 m) and sporadic ground cover.



**Plate 38 Landscape / vegetation at Site ME19**

<b>Site Reference:</b>	Mulga East Site ME20	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Mid-slope of E-W running ridgeline	<b>Easting:</b>	671324
<b>Soil Landform Association:</b>	Low hills / rises	<b>Northing:</b>	7550523



**Plate 39** Surface soil at Site ME20

**Soil surface:** Weak surface crust with approximately 90% cover of angular to sub-rounded coarse fragments at surface, 2 to 300 mm in size, with 10% litter cover.

**Vegetation:** Ground cover of spinifex with Acacia and Eucalypt sp.

**Soil profile description:**

0-5 cm: Weak-moderately structured soil with aggregates to 20 mm and approximately 75% sub-rounded to sub-angular coarse fragments, 2 to 75 mm in size.

10-20 cm: Loose, single-grained soil with 60-75% sub-rounded to sub-angular coarse fragments, 2 to 20 mm in size. Small plant roots.



**Plate 40** Landscape / vegetation at Site ME20

<b>Site Reference:</b>	Mulga East Site ME21	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Southern extent of flood plain	<b>Easting:</b>	644808
<b>Soil Landform Association:</b>	Flood plain	<b>Northing:</b>	7548262



**Soil profile description:**

0-50 cm: Well-structured soil with polyhedral aggregates of moderate strength, up to 100 mm in size. Approximately 20% angular to sub-rounded coarse fragments, 2 to 10 mm in size.

60-110 cm: Massive soil with approximately 5 to 10% coarse fragments, 2 to 5 mm in size.

**Plate 41 Surface soil profile at Site ME21**

**Soil surface:** Weak surface crust, with approximately 90% cover of sub-angular to sub-rounded coarse fragments at surface, 2 to 50 mm in size, with approximately 15% litter cover.

**Vegetation:** Open forest of Acacia trees (1 to 4 m) and small thin Eucalypts (2 to 4 m).



**Plate 42 Landscape / vegetation at Site ME21**

<b>Site Reference:</b>	Mulga East Site ME22	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Flat to gently undulating alluvial plain with outcropping calcrete	<b>Easting:</b>	656005
<b>Soil Landform Association:</b>	Calcareous flats	<b>Northing:</b>	7543001



**Plate 43 Surface soil profile at Site ME22**

**Soil surface:** Thin platy surface crust, with approximately 10 to 15% cover of angular to sub-rounded calcareous coarse fragments at surface, 5 to 150 mm in size, with approximately 70% litter cover.

**Vegetation:** Acacia sp. (2 to 3 m), occasional Eucalypt trees (5 to 6 m), variety of shrubs, spinifex and other grasses.

**Soil profile description:**

0-50 cm: Well-structured soil with polyhedral aggregates of moderate strength, up to 100 mm in size. Approximately 10% angular to sub-rounded coarse fragments, 2 to 10 mm in size. Plant root abundance described as 'moderate'.

50-130 cm: Approximately 70% ironstone and calcareous nodules, 5 to 30 mm in size, in a single-grained calcareous matrix.



**Plate 44 Landscape / vegetation at Site ME22**

<b>Site Reference:</b>	Mulga East Site ME23	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Flat stony wooded alluvial plain	<b>Easting:</b>	663609
<b>Soil Landform Association:</b>	Alluvial plain	<b>Northing:</b>	7551651



**Soil profile description:**

0-20 cm: Moderately structured soil with aggregates up to 50 mm in size and approximately 25% sub-rounded to sub-angular coarse fragments, 2 to 30 mm in size.

**Plate 45 Surface soil at Site ME23**

**Soil surface:** Platy surface crust with approximately 70% cover of angular to sub-rounded coarse fragments at surface, 2 to 70 mm in size, with 30 to 40% litter cover.

**Vegetation:** Abundant Acacia trees (2 to 6 m), some grasses.



**Plate 46 Landscape / vegetation at Site ME23**

<b>Site Reference:</b>	Mulga East Site ME24	<b>Datum:</b>	GDA 1994 MGA Zone 50
<b>Site Description:</b>	Flat stony wooded alluvial plain	<b>Easting:</b>	659652
<b>Soil Landform Association:</b>	Alluvial plain	<b>Northing:</b>	7552314



**Soil profile description:**

0-20 cm: Loosely friable, single-grained soil with approximately 40% sub-rounded to sub-angular coarse fragments, 2 to 50 mm in size.

**Plate 47 Surface soil at Site ME24**

**Soil surface:** Weak surface crust with variable surface cover, 20 to 50% of angular to sub-rounded coarse fragments, 2 to 70 mm in size, with 15 to 20% litter cover. Evidence of minor surface water flows, scouring and deposition.

**Vegetation:** Abundant Acacia trees (2 to 6 m), some grasses present.



**Plate 48 Landscape / vegetation at Site ME24**

## 4.2 Soil Physical Characteristics

The physical characteristics of the surface soils within the study area, as determined by the field investigation and laboratory analysis of collected samples, are discussed in the following sections.

### 4.2.1 Soil Profile Morphology

The surface soil profiles within the study area exhibited a substantial degree of variation in terms of morphological characteristics. The soil profiles were grouped into five soil-landform associations, namely 'low hills / rises', 'alluvial plains', 'floodplains', 'clay pans' and 'calcareous flats'. The landform and soil profiles within these soil associations were typically characterised as follows:

- Low hills / rises:
  - Low undulating hills, minor outcropping rock in some areas.
  - Shallow / skeletal soils over fractured / weathered and competent rock.
  - High percentage of competent rock fragments through the surface soil profile.
  - Hills dissected by narrow, shallow drainage channels.
- Alluvial plains:
  - Relatively flat, with gentle relief towards valley floor. Dissected by multiple minor drainage channels.
  - Relatively deep, earthy soil profiles with well-structured soils close to surface and massive soil horizons below.
  - Moderate percentage of competent rock fragments through the surface soil profile.
- Floodplains:
  - Valley floor with depositional areas and evidence of surface sheet-flow.
  - Moderate, poorly defined drainage channels.
  - Relatively deep, earthy soil profiles with well-structured soils close to surface and massive soil horizons below.
  - Relatively low coarse fraction through soil profiles.
- Clay pans:
  - Flat depositional areas within valley floor.
  - Generally homogenous, weakly structured to massive soil profiles with high clay content.
  - Low percentage of competent rock material.
- Calcareous flats:
  - Relatively flat and slightly elevated above surrounding landscape. Some outcropping calcrete present.
  - High percentage of competent rock fragments through the surface soil profile, typically increasing with depth.

#### 4.2.2 Soil Texture

Soil texture describes the proportions of sand, silt and clay (the particle size distribution) within the <2 mm fraction of a soil. The particle size distribution and resulting textural class of a soil is an important factor influencing most physical and many chemical and biological properties. Soil structure, water holding capacity, hydraulic conductivity, soil strength, fertility, erodibility and susceptibility to compaction are some of the factors closely linked to the texture of a soil material.

There were a wide range of particle size distributions exhibited throughout the study area, with soil textures ranging from 'sandy loam' (approximately 10 to 15% clay) to 'medium heavy clay' (>55% clay) (Table 2). There was typically only a minor change observed in soil texture from the surface to the maximum sampling depth at each location.

As would be expected, samples collected from low in the landscape (e.g. Floodplain / Clay pan soils) were typically finer grained with a higher clay content than those soils sampled from higher in the landscape.

#### 4.2.3 Soil Structure

Soil structure describes the arrangement of solid particles and void space in a soil. It is an important factor influencing the ability of soil to support plant growth, store and transmit water and resist erosional processes. A well-structured soil is one with a range of different sized aggregates; with component particles bound together to give a range of pore sizes facilitating root growth and the transfer of air and water.

Soil structure can be influenced by the particle size distribution, chemical composition and organic matter content of a soil. Soil structure is often affected by root growth, vehicle compaction and, with respect to reconstructed soil profiles, the methods of soil handling and deposition. When a soil material is disturbed, the breakdown of aggregates into primary particles can lead to structural decline (Moore, 1998). This can result in hard-setting and crusting at the soil surface and a 'massive' soil structure at depth, potentially reducing the ability of seeds to germinate, roots to penetrate the soil matrix and water to infiltrate to the root zone.

The structure of the surface soils within the study area was variable, reflecting the range of landform positions and soil profiles present. Soil structure ranged from skeletal, single-grained soils high in the landscape, to well-structured topsoils lower in the landscape, with a range of different sized aggregates. Soil structure typically decreased with depth through the soil profiles with massive soils common beyond 0.5 to 0.6 m depth.

#### 4.2.4 Structural Stability

The structural stability of a soil and its susceptibility to structural decline is complex and depends on the net effect of a number of properties, including the amount and type of clay present, organic matter content, soil chemistry and the nature of disturbance. Soil aggregates that slake and particularly those that disperse, indicate a weak soil structure that is easily degraded. These soils can be potentially problematic when used as a rehabilitation medium, particularly if left exposed at the surface.

The Emerson Aggregate Test identifies the potential slaking and dispersive properties of soil aggregates. The dispersion test identifies the properties of the soil materials under a worst-case scenario, where severe stress is applied to the soil material. Generally, samples allocated into Emerson Classes 1 and 2 are those most likely to exhibit dispersion of the clay sized fraction and therefore be the most problematic.

The majority of surface soils from the study area were identified as Emerson Class 3 (slaking, remoulded soil partially dispersed) (Table 2). These results indicate that the soils are not prone to dispersion of the clay fraction in their natural state but may exhibit dispersion following severe disturbance (e.g. earthworks). Care should be taken to minimise the handling of these soils where possible, particularly when wet.

Several soils sampled from sites located low in the landscape were classified as Emerson Class 2 (Table 2). One sample from 40 to 50 cm depth within the Floodplain soil-landform association (Site 21) was classified as Emerson Class 1. These samples exhibited dispersion of the clay fraction upon saturation of an undisturbed soil aggregate. Subsoil materials from the 'Calcareous flats' were classed as Emerson Class 4, indicating no dispersion and the presence of carbonate.

It should be noted that the salinity of some soils, particularly those from within the 'Clay pan' soil-landform association, may have a flocculating effect on clay particles, masking the potential dispersion in these clay-rich, highly sodic (see Section 4.3.3) soil materials.

**Table 2 Soil texture and Emerson Aggregate Test Class for selected soil samples**

Site #	Depth (cm)	Soil-landform association	Soil texture (< 2 mm soil fraction)	Clay fraction (%)	Emerson Aggregate Test	
					Test Class	Description
ME01	0-5	Low hills / rises	Sandy clay loam	19	Class 3	Remoulded aggregated slakes and disperses
ME02	0-5	Calcareous flats	Sandy clay loam	18	Class 3	Remoulded aggregated slakes and disperses
ME03	0-5	Low hills / rises	Sandy loam	15	Class 3	Remoulded aggregated slakes and disperses
ME04	0-5	Calcareous flats	Loam	25	Class 3	Remoulded aggregated slakes and disperses
	40-50		Silty clay loam	31	Class 4	No dispersion, carbonate or gypsum present
ME05	0-5	Calcareous flats	Sandy loam	15	Class 3	Remoulded aggregated slakes and disperses
	40-50		Sandy clay loam	25	Class 4	No dispersion, carbonate or gypsum present
ME06	0-5	Alluvial plain	Clay loam	28	Class 3	Remoulded aggregated slakes and disperses
	40-50		Clay	35	Class 3	Remoulded aggregated slakes and disperses
ME07	0-5	Alluvial plain	Sandy clay loam	25	Class 3	Remoulded aggregated slakes and disperses
	40-50		Clay loam	30	Class 2	Remoulded aggregated slakes and disperses
ME08	0-5	Floodplain	Sandy loam	14	Class 2	Partial dispersion of undisturbed aggregate
	40-50		Loam	17	Class 3	Remoulded aggregated slakes and disperses
ME09	0-5cm	Low hills / rises	Loam	17	Class 3	Remoulded aggregated slakes and disperses
ME10	0-5	Calcareous flats	Loam	15	Class 2	Partial dispersion of undisturbed aggregate
	40-50		Silty clay loam	25	Class 3	Remoulded aggregated slakes and disperses

Site #	Depth (cm)	Soil-landform association	Soil texture (< 2 mm soil fraction)	Clay fraction (%)	Emerson Aggregate Test	
					Test Class	Description
ME11	0-5	Calcareous flats	Loam	17	Class 3	Remoulded aggregated slakes and disperses
	40-50		Sandy clay	28	Class 3	Remoulded aggregated slakes and disperses
ME12	0-5	Low hills / rises	Loam	18	Class 3	Remoulded aggregated slakes and disperses
ME13	0-5	Low hills / rises	Sandy loam	15	Class 3	Remoulded aggregated slakes and disperses
ME14	0-5	Alluvial plain	Sandy clay	30	Class 3	Remoulded aggregated slakes and disperses
	40-50		Light clay	41	Class 3	Remoulded aggregated slakes and disperses
ME15	0-5	Alluvial plain	Silty clay loam	33	Class 3	Remoulded aggregated slakes and disperses
ME16	0-5	Clay pan	Sandy clay loam	30	Class 2	Partial dispersion of undisturbed aggregate
ME17	0-5	Floodplain	Silty loam	22	Class 3	Remoulded aggregated slakes and disperses
	40-50		Loam	25	Class 3	Remoulded aggregated slakes and disperses
ME18	0-5	Clay pan	Sandy clay loam	30	Class 3	Remoulded aggregated slakes and disperses
	40-50		Light clay	40	Class 4	No dispersion, carbonate or gypsum present
ME19	0-5	Alluvial plain	Sandy clay	31	Class 2	Partial dispersion of undisturbed aggregate
	40-50		Medium heavy clay	59	Class 2	Partial dispersion of undisturbed aggregate
ME20	0-5	Low hills / rises	Sandy loam	15	Class 3	Remoulded aggregated slakes and disperses
ME21	0-5	Floodplain	Loam	23	Class 2	Partial dispersion of undisturbed aggregate
	40-50		Light clay	40	Class 1	Complete dispersion of undisturbed aggregate
ME22	0-5	Calcareous flats	Silty clay loam	33	Class 3	Remoulded aggregated slakes and disperses
	40-50		Silty clay	46	Class 3	Remoulded aggregated slakes and disperses
ME23	0-5	Alluvial plain	Clay loam	35	Class 3	Remoulded aggregated slakes and disperses
ME24	0-5	Alluvial plain	Clay loam	36	Class 3	Remoulded aggregated slakes and disperses

#### 4.2.5 Hydraulic conductivity

Hydraulic conductivity ( $K_{sat}$ ) refers to the saturated permeability of soil, or the ability of water to infiltrate and drain through the soil matrix. The  $K_{sat}$  of a soil is dependent on soil characteristics such as texture and structure (Moore, 1998). Freely draining soils with high  $K_{sat}$  values will generally be less susceptible to surface runoff and erosion. Slow draining soils with low  $K_{sat}$  values, are more likely to experience waterlogging, increased surface runoff and erosion.

Saturated hydraulic conductivity was determined for the <4.75 mm fraction of selected, representative soil samples from the study area. Drainage classes were determined for each sample according to their  $K_{sat}$  (Hunt and Gilkes, 1992) (Table 3). The drainage class of soil samples from the study area ranged between 'slow' and 'moderately rapid'. As would be expected, the coarser textured soils sampled from high locations in the landscape recorded the highest hydraulic conductivity. Average  $K_{sat}$  values for the topsoil materials sampled from each soil-landform association are presented in Figure 5.

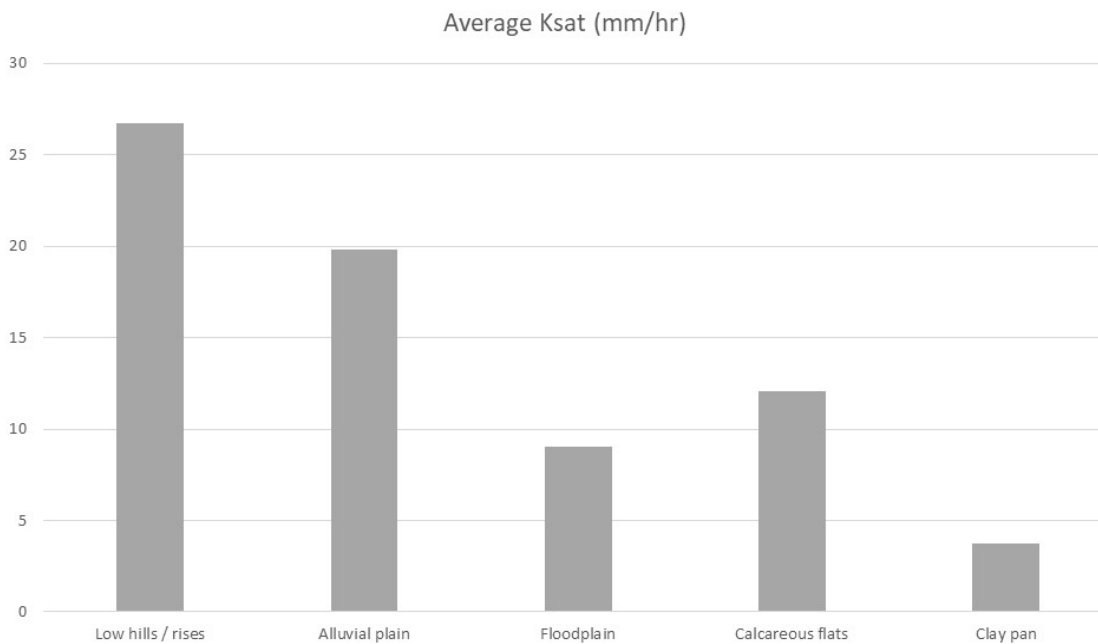
The topsoils from the 'Low hills / rises' and 'Alluvial plains' within the study area were relatively free-draining, however the  $K_{sat}$  values of salvaged soil resources may decrease if the soils are compacted during salvage, stockpiling and rehabilitation activities. The low  $K_{sat}$  values recorded for the soils sampled from lower positions within the landscape indicate a propensity for waterlogging and / or surface run-off and erosion, if placed on sloped rehabilitation areas.

**Table 3 Saturated hydraulic conductivity ( $K_{sat}$ ), drainage class and water retention for selected soils**

Site #	Depth (cm)	Soil-landform association	$K_{sat}$ (mm/hr) <sup>1</sup> .	Drainage Class <sup>2</sup> .	Soil-water retention (field capacity) (% vol) <sup>1</sup> .
ME01	0-5	Low hills / rises	26.2	Moderate	33
ME02	0-5	Calcareous flats	29.3	Moderate	36
ME03	0-5	Low hills / rises	9.1	Moderately slow	41
ME04	0-5	Calcareous flats	11.9	Moderately slow	48
	40-50		55.2	Moderate	45
ME05	0-5	Calcareous flats	3.9	Slow	39
	40-50		65.4	Moderately rapid	40
ME06	0-5	Alluvial plain	25.9	Moderate	42
	40-50		29.8	Moderate	39
ME07	0-5	Alluvial plain	20.0	Moderate	44
	40-50		3.2	Slow	36
ME08	0-5	Floodplain	1.9	Slow	30
	40-50		35.5	Moderate	35
ME09	0-5cm	Low hills / rises	23.1	Moderate	35
ME10	0-5	Calcareous flats	12.9	Moderately slow	45
	40-50		4.3	Slow	42
ME11	0-5	Calcareous flats	13.1	Moderately slow	37
	40-50		7.2	Moderately slow	43
ME12	0-5	Low hills / rises	37.3	Moderate	32
ME13	0-5	Low hills / rises	49.8	Moderate	33
ME14	0-5	Alluvial plain	16.6	Moderately slow	40
	40-50		5.9	Moderately slow	34
ME15	0-5	Alluvial plain	9.7	Moderately slow	38
ME16	0-5	Clay pan	4.0	Slow	40
ME17	0-5	Floodplain	13.3	Moderately slow	41
	40-50		7.7	Moderately slow	46
ME18	0-5	Clay pan	3.5	Slow	43

Site #	Depth (cm)	Soil-landform association	K <sub>sat</sub> (mm/hr) <sup>1.</sup>	Drainage Class <sup>2.</sup>	Soil-water retention (field capacity) (% vol) <sup>1.</sup>
	40-50		47.8	Moderate	43
ME19	0-5	Alluvial plain	16.5	Moderately slow	34
	40-50		8.9	Moderately slow	44
ME20	0-5	Low hills / rises	14.9	Moderately slow	40
ME21	0-5	Floodplain	12.0	Moderately slow	39
	40-50		4.1	Slow	43
ME22	0-5	Calcareous flats	18.6	Moderately slow	37
	40-50		56.9	Moderate	49
ME23	0-5	Alluvial plain	22.2	Moderate	42
ME24	0-5	Alluvial plain	27.8	Moderate	39

1. Determined for the <4.75 mm fraction of the material
2. (Hunt and Gilkes, 1992)



**Figure 5 Average K<sub>sat</sub> values (mm/hr) for topsoil materials (0-5 cm depth sample) grouped into soil-landform associations.**

#### 4.2.6 Water retention

The water retention properties of the surface soils within the study area are an important factor in determining the amount of water available for plant growth when soil materials are re-deposited and rehabilitated. In relatively low-nutrient environments, such as that of the Project, the amount of water available to plants is often the most limiting factor to vegetation establishment and growth. The water retention or water holding capacity of a soil is influenced by a number of factors including soil particle size (and pore space) distribution, soil structure and organic matter content (Moore 1998).

The field capacity (or upper storage limit) of a soil material refers to the maximum water holding capacity of a freely drained soil, or the volumetric water content after gravity induced drainage has ceased. The field capacity of the <4.75 mm fraction of the soils from the study area ranged between 30% and 49% (Table 3). These values are considered 'moderate' to 'high' for the field capacity of a soil (Hazelton and Murphy, 2007). The water retention characteristics of the soils throughout the study area were generally reflective of the soil textures present, with the finer grained soils from lower in the landscape typically having a higher field capacity water content than the coarser textured soils from the 'Low hills / rises' soil-landform association.

A major factor influencing the water retention / storage capacity of the soils is the percentage of coarse rock material present. Once the coarse fraction is considered, the water storage capacity of the total material (i.e. including coarse rock fraction) is considerably reduced for those soils with substantial coarse fractions. This is of particular relevance for the skeletal soils of the 'Low hills / rises' soil-landform association, which typically have around 75% coarse rock material.

### 4.3 Soil Chemical Characteristics

#### 4.3.1 Soil pH and Electrical Conductivity

Soil pH (H<sub>2</sub>O) measures the acidity or alkalinity of the soil in relation to suitability for plant growth. Ratings for soil pH are based on the Land Evaluation Standards for Land Resource Mapping categories (van Gool, 2005).

Soil pH (H<sub>2</sub>O) results indicated substantial variation between and within the various soil-landform associations / sampling locations within the study area, ranging from pH 5.8 (classified as 'moderately acidic') for the surface of a 'Low hills / rises' sample, to pH 9.7 ('strongly alkaline') for a sample from 90-100 cm depth within the 'Flood plain' soil-landform association (Figure 6). On average, soils from the 'Low hills / rises' were typically the most acidic, with soils from the 'Calcareous flats' being the most alkaline (Figure 6).

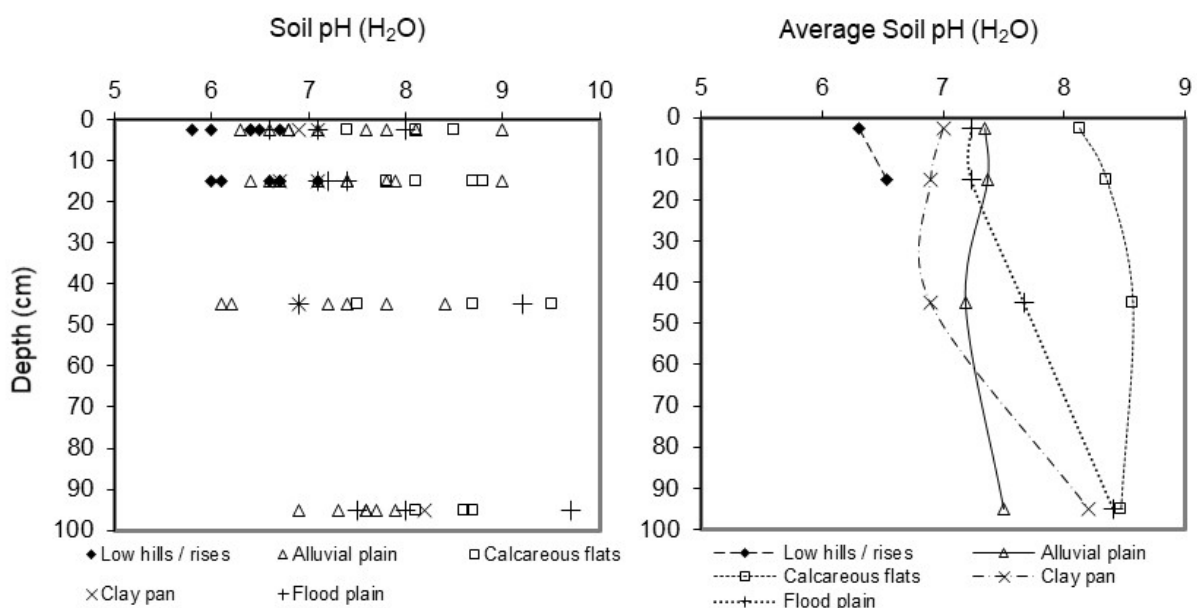
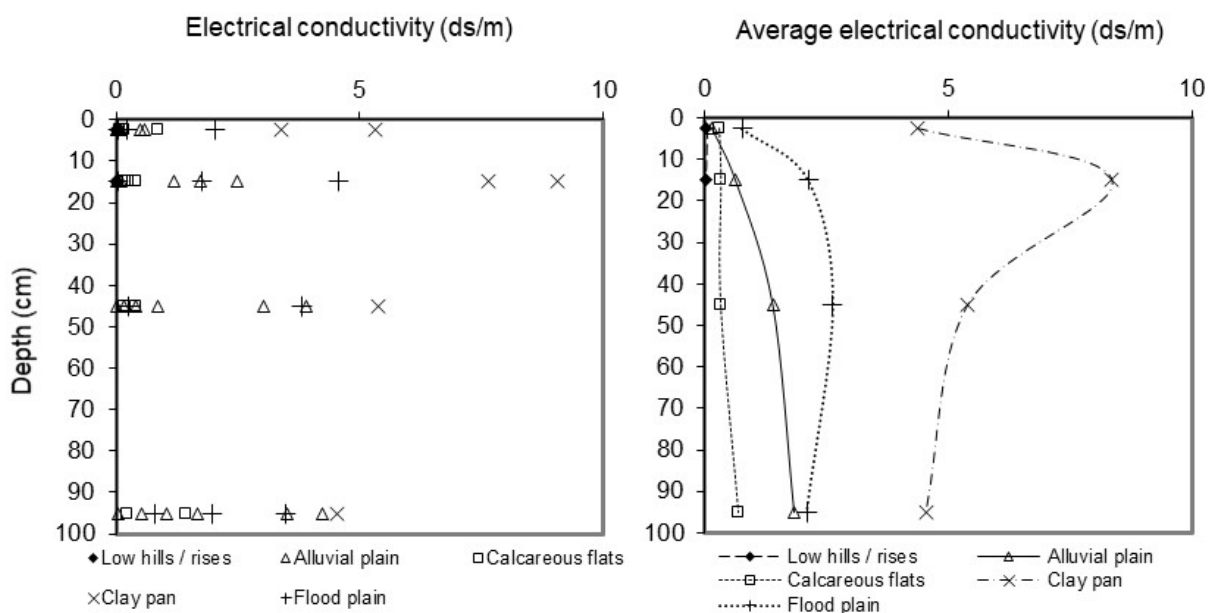


Figure 6 Individual and average pH (H<sub>2</sub>O) of soils with depth for each soil-landform association

Electrical conductivity (EC) is a measurement of the soluble salts in soils or water. Soil salinity results from natural processes of landscape evolution, hydrological processes and rainfall (Hunt and Gilkes, 1992). There was a wide range of EC values recorded for the soils within the study area, with individual values ranging between 0.010 dS/m (non-saline) and 9.05 dS/m (extremely saline) based on the standard USDA and CSIRO electrical conductivity categories (Appendix A). While there was a range of soil salinities measured across the study area, the majority of the soil samples were classed as either 'non-saline' (< 0.17 dS/m) or 'slightly saline' (0.17 to 0.33 dS/m) (Figure 7).

On average, soils from low positions within the landscape recorded the highest EC values, with the 'Floodplain' and most noticeably the 'Clay pan' soils recording the highest salinity values (Figure 7).

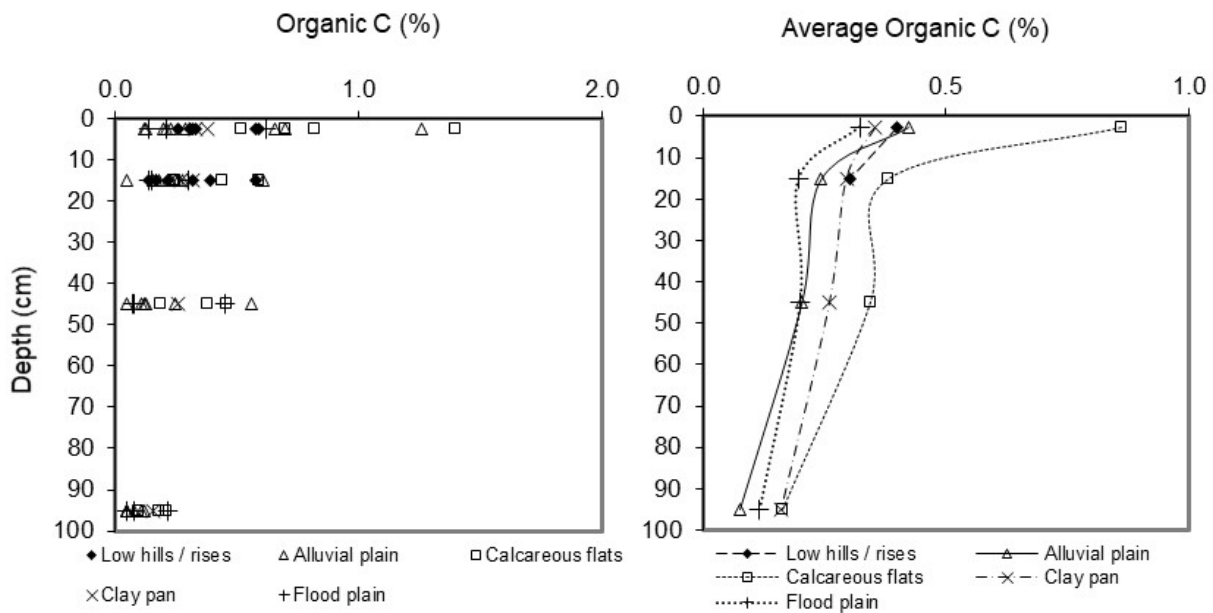


**Figure 7 Individual and average EC (dS/m) of soils with depth for each soil-landform association**

#### 4.3.2 Soil Organic Matter

The organic matter content of soil is an important factor that influences many physical, chemical and biological soil characteristics. The organic matter content is directly derived from plants and animals and its functions include supporting the micro and macro fauna and flora populations in the soil, increasing the water retention capacity, buffering pH and improving soil structure.

The organic matter content of the soils within the study area was determined as a measure of the soil organic carbon percentage (SOC%). The SOC% of the soils sampled was low, as is typical of most highly weathered soils in the Pilbara, ranging between 0.05% and 1.40% (Figure 8). Soils sampled from the 'Calcareous flats' reported the highest average SOC% at each sampling depth interval. There was typically a small decrease in SOC% with depth through the soil profiles (Figure 8).



**Figure 8 Individual and average organic C concentration (%) of soils with depth for each soil-landform association**

### 4.3.3 Exchangeable Cations and Exchangeable Sodium Percentage

Exchangeable cations, held on clay surfaces and within organic matter, are an important source of soil fertility and can influence the physical properties of soil. Generally, if cations such as  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{K}^{+}$  are dominant on the clay exchange surfaces, the soil will typically display increased physical structure and stability, leading to increased aeration, drainage and root growth (Moore, 1998). If Na cations ( $\text{Na}^{+}$ ) are dominant on exchange surfaces and the exchangeable sodium percentage (ESP) exceeds more than 6% of the total exchangeable cations, then the soil is considered to be 'sodic', which can lead to poor physical properties (i.e. dispersion, hardsetting and erosion in clay-rich soils). ESP values over 15% are classified as 'highly sodic'.

Exchangeable cation concentration, effective cation exchange capacity (eCEC) and exchangeable sodium percentage (ESP) results were highly variable across the various soil-landform associations (Table 4), reflecting the range of soils present within the study area. A number of soils sampled from low positions within the landscape were classed as highly sodic.

The exchangeable cation and ESP results should be viewed in conjunction with the Emerson Test results, the amount of clay in the soil and the salinity of the material, to identify the likely influence on the physical stability of the soil once the materials are salvaged and utilised as a rehabilitation resource.

**Table 4 Exchangeable cations and ESP of selected samples. Shading of ESP values denotes non-sodic, sodic and highly sodic classifications**

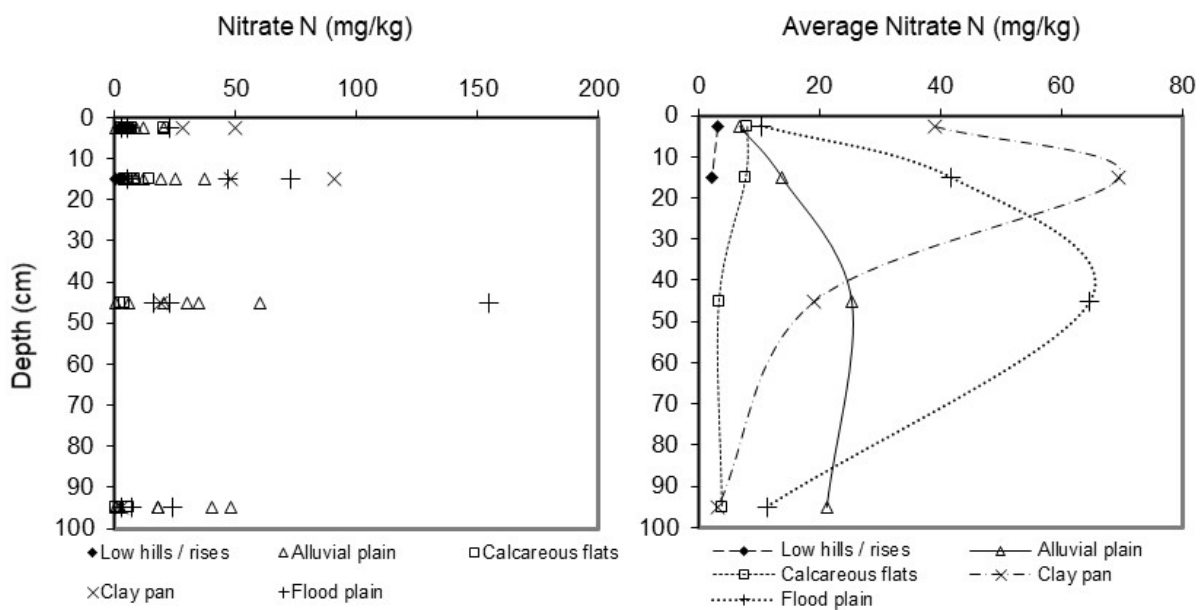
Site #	Depth (cm)	Soil-landform association	Exchangeable cations (meq/100g)				eCEC (meq/100g)	ESP (%)
			Ca	Mg	K	Na		
ME01	0-5	Low hills / rises	1.46	0.79	0.29	0.03	2.7	1.1
ME02	0-5	Calcareous flats	14.96	2.08	2.19	1.97	21.2	9.3
ME03	0-5	Low hills / rises	2.96	1.18	0.42	0.04	4.6	0.9
ME04	0-5	Calcareous flats	7.32	1.21	0.93	0.03	9.5	0.3
	40-50		4.95	1.11	0.47	0.03	6.6	0.5
ME05	0-5	Calcareous flats	13.45	1.02	1.08	0.03	15.6	0.2
	40-50		6.31	1.19	1.18	1.46	10.2	14.3
ME06	0-5	Alluvial plain	4.94	1.78	0.78	0.07	7.7	0.9
	40-50		7.00	2.79	0.71	0.40	11.0	3.6
ME07	0-5	Alluvial plain	12.09	5.51	0.71	4.24	22.6	18.8
	40-50		13.70	8.34	0.23	17.00	39.4	43.2
ME08	0-5	Floodplain	5.39	3.35	1.21	6.80	16.8	40.5
	40-50		6.85	6.69	1.46	13.79	28.9	47.8
ME09	0-5cm	Low hills / rises	2.44	0.94	0.31	0.08	3.8	2.1
ME10	0-5	Calcareous flats	4.48	1.12	1.02	2.15	8.8	24.3
	40-50		1.52	5.25	1.86	22.46	31.2	72.0
ME11	0-5	Calcareous flats	16.91	3.02	1.37	0.08	21.4	0.4
	40-50		11.19	4.58	1.77	2.65	20.3	13.1
ME12	0-5	Low hills / rises	2.53	1.28	0.40	0.05	4.3	1.2
ME13	0-5	Low hills / rises	1.88	0.82	0.35	0.07	3.3	2.1
ME14	0-5	Alluvial plain	9.63	3.77	0.82	0.73	15.0	4.9
	40-50		14.32	4.73	0.28	3.76	23.2	16.2
ME15	0-5	Alluvial plain	16.57	2.07	0.71	6.28	25.7	24.5
ME16	0-5	Clay pan	11.16	9.96	0.74	19.04	40.9	46.5
ME17	0-5	Floodplain	11.59	4.58	0.93	1.89	19.0	9.9
	40-50		18.13	8.29	0.26	13.20	39.9	33.1
ME18	0-5	Clay pan	6.16	5.62	1.34	20.67	33.8	61.1
	40-50		3.50	15.62	1.06	35.18	55.4	63.5
ME19	0-5	Alluvial plain	6.92	3.61	1.2	0.27	12.0	2.2
	40-50		8.36	6.48	1.11	2.53	18.6	13.6
ME20	0-5	Low hills / rises	2.64	0.96	0.47	0.23	4.4	5.3
ME21	0-5	Floodplain	5.1	2.07	0.74	0.2	8.1	2.5
	40-50		8.88	4.85	0.89	4.11	18.8	21.9
ME22	0-5	Calcareous flats	10.05	6.86	1.8	5.24	24.0	21.9
	40-50		15.48	5.99	1.53	0.55	23.6	2.3
ME23	0-5	Alluvial plain	5.89	1.04	0.60	0.04	7.6	0.5
ME24	0-5	Alluvial plain	4.28	0.85	0.59	0.03	5.8	0.5

### 4.3.4 Soil Nutrients

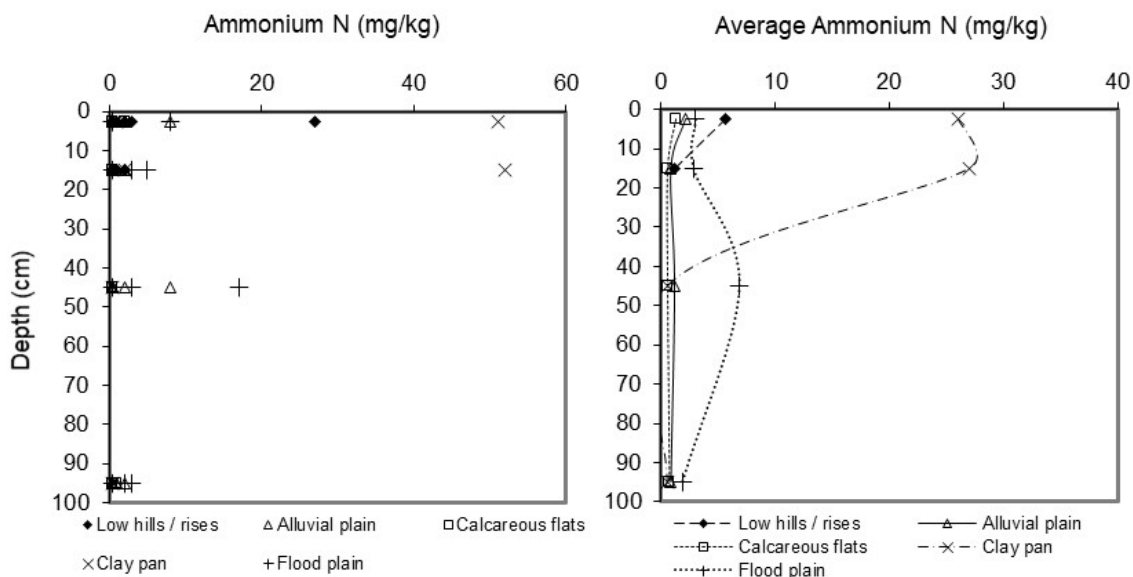
The most important macro-nutrients for plant growth are nitrogen (N), phosphorus (P), potassium (K), and sulphur (S). These nutrients are largely derived from the soil mineral component and organic matter. Native plant species have several physiological adaptations that enable them to be productive in areas where the supply of macronutrients is limited. There is limited information available which details the specific nutritional requirements for native plant species in the semiarid zone of WA. Therefore, the use of analogue sites is an effective way to baseline the soil nutritional requirements of native plant species within the study area.

#### 4.3.4.1 Nitrogen

The plant-available nitrogen concentrations of the soils from the study area were variable but generally low and ranged from <1 (below detection limit) to 155 mg/kg nitrate (Figure 9) and from <1 (below detection limit) to 52 mg/kg ammonium (Figure 10). There was little apparent relationship between plant-available nitrogen concentrations and soil-landform association, or sample depth.



**Figure 9 Individual and average Nitrate-N concentration (mg/kg) of soils with depth for each soil-landform association**

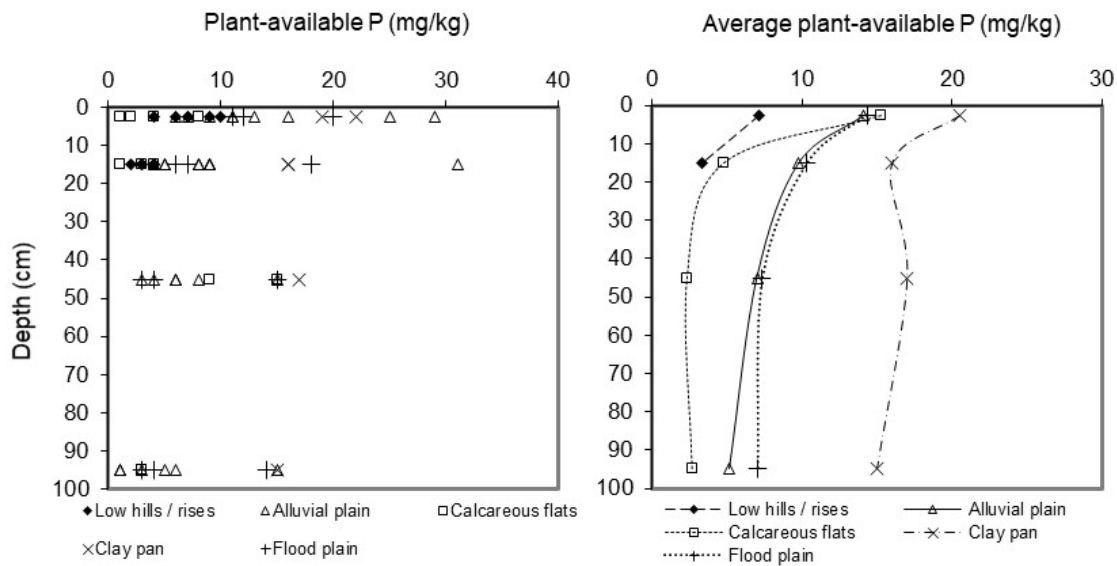


**Figure 10 Individual and average Ammonium-N concentration (mg/kg) of soils with depth for each soil-landform association**

#### 4.3.4.2 Phosphorus

Phosphorus (P) is essential for the growth of vegetation as it plays a key role in the formulation of energy producing organic compounds. Adequate phosphorus nutrition enhances many aspects of plant physiology, including the fundamental processes of photosynthesis, nitrogen fixation, flowering, fruiting (including seed production) and maturation (Brady and Weil., 2002).

The plant-available P concentrations of the majority of soils from the study area were classed as low (<10 mg/kg) to moderate (10 to 30 mg/kg) (Moore, 1998) (Figure 11). On average, soils from low positions within the landscape recorded the highest plant-available P values, with the 'Clay pan' soils recording the highest concentrations at all sample intervals (Figure 11). On average, there was generally a slight decrease in plant-available K concentration with sample depth.

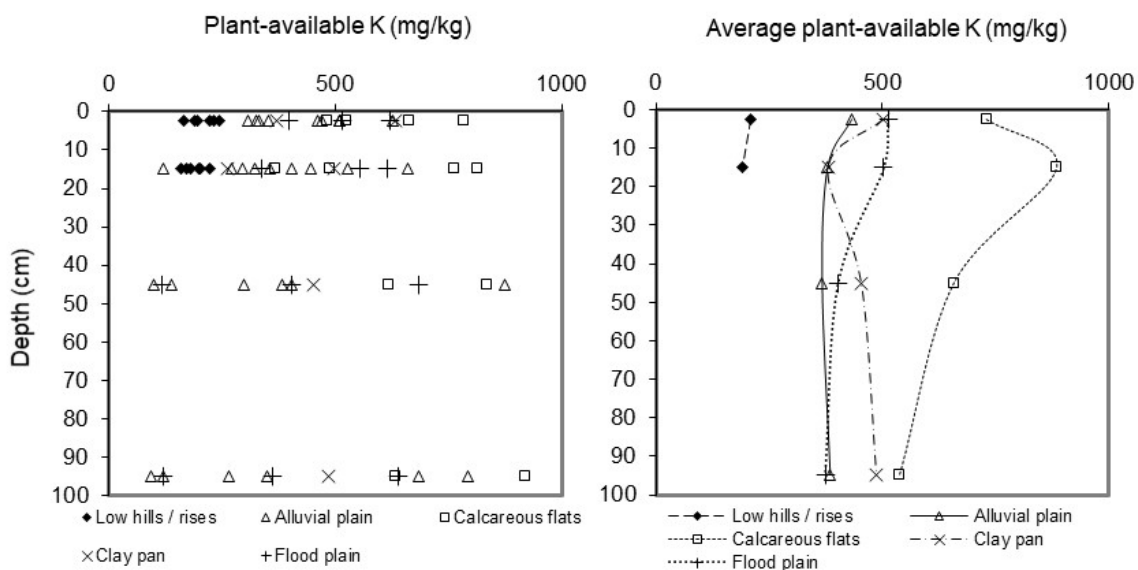


**Figure 11 Individual and average plant-available phosphorus concentration (mg/kg) of soils with depth for each soil-landform association**

#### 4.3.4.3 Potassium

Potassium (K) plays a critical role in a number of plant physiological processes. Adequate amounts of K have been linked to improved drought tolerance, better resistance to certain fungal diseases and greater tolerance to insect pests (Brady and Weil., 2002).

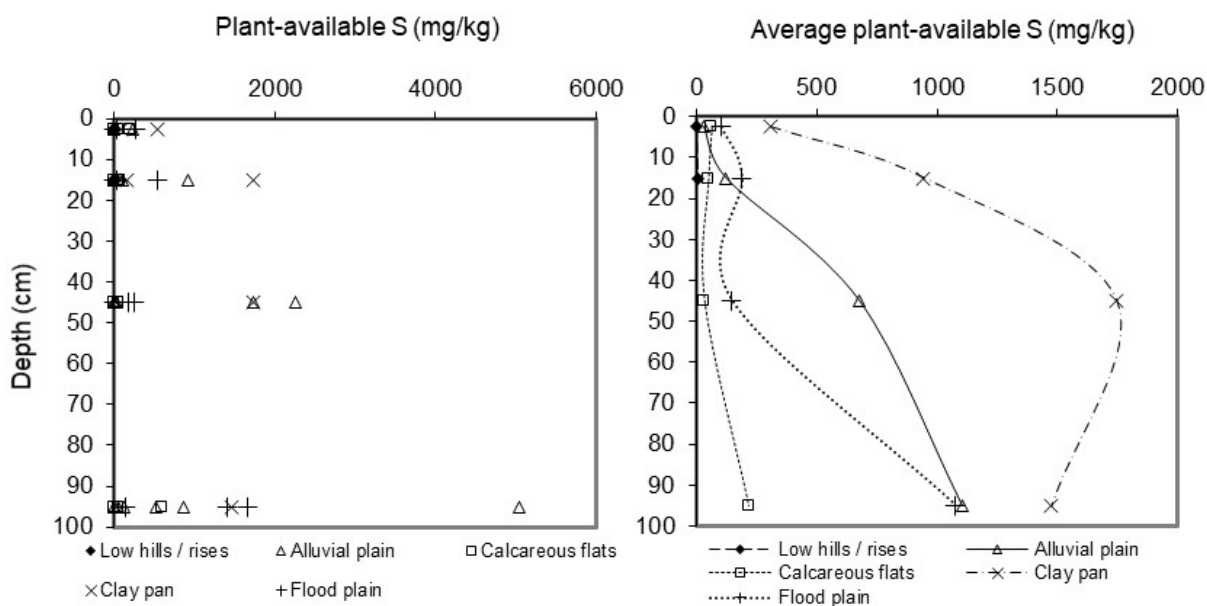
The plant-available K concentrations of the soils from the study area were classed as moderate to high (high rating: >200 mg/kg) (Moore, 1998) for most samples. Soils sampled from the 'Low hills / rises' typically reported the lowest plant-available K concentrations, with samples from the 'Calcareous flats' recording on average the highest concentrations at all sample intervals (Figure 12). There was generally a slight decrease in plant-available K concentration observed with sample depth.



**Figure 12 Individual and average plant-available potassium concentration (mg/kg) of soils with depth for each soil-landform association**

#### 4.3.4.4 Sulphur

There was a wide range of plant-available sulphur (S) concentrations measured for soils from the study area, with individual values ranging from 1.2 mg/kg (classed as low) to 5,041 mg/kg (classed as very high) (Moore, 1998). On average, soils from low positions within the landscape recorded the highest plant-available P values, with the 'Clay pan' soils recording the highest concentrations at all sample intervals (Figure 13). Gypsum crystals (CaSO<sub>4</sub>) were evident within some of the soil profiles for which high concentrations of plant-available S were recorded.



**Figure 13 Individual and average plant-available sulphur concentration (mg/kg) of soils with depth for each soil-landform association**

#### 4.3.5 Total metal concentrations

The total concentration of selected metals was measured for selected samples that were representative of the soils and associated landscape positions. The results are presented in Table 5. As a point of comparison, the average crustal abundance (Reimann and de Caritat, 1998) for each metal is also provided in Table 5.

Of note are the high baseline concentrations of As and Se in many of the analogue soils relative to the average crustal abundance. There is no apparent correlation in total metal concentration between the soils from the various soil-landform associations, or any apparent trend with sample depth.

**Table 5 Total metal concentration for selected samples**

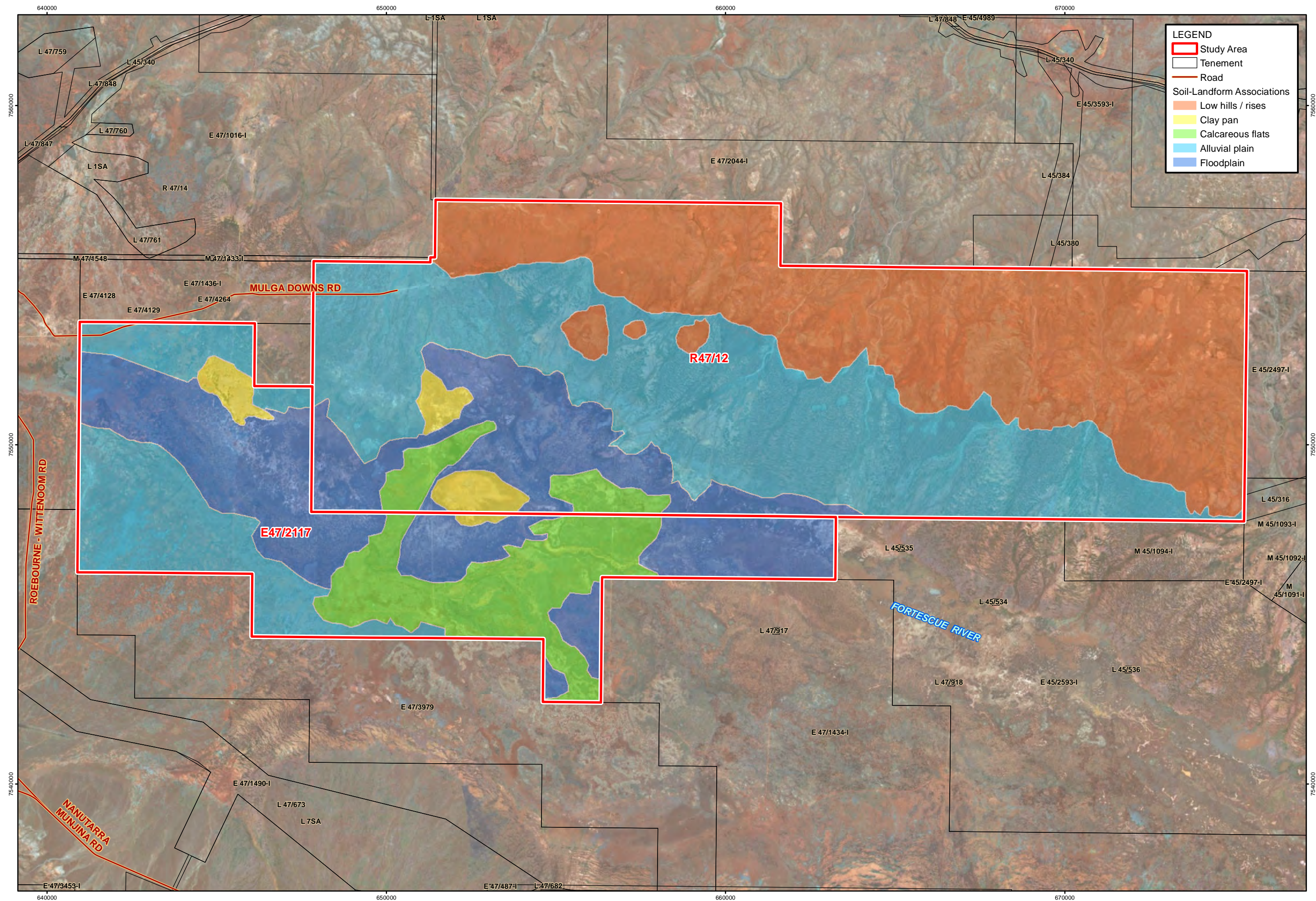
Site	Sample depth (cm)	Land System	Soil-landform association	Total metal concentration (ug/kg)						
				As	Cd	Cr	Co	Pb	Mo	Se
ME01	0-5	Newman	Low hills / rises	27,707	41.3	203,950	11,562	17,759	1,527	1,481
ME02	0-5	Boolgeeda	Alluvial plain	18,369	99.7	100,708	16,666	18,231	524	905
ME03	0-5	Newman	Low hills / rises	16,578	37.8	108,932	14,369	16,995	1,041	986
ME04	0-5	Jamindie	Alluvial plain	22,562	135.1	100,480	24,509	24,781	1,332	1,392
	40-50			26,894	145.1	129,425	27,781	28,640	1,654	1,293

Site	Sample depth (cm)	Land System	Soil-landform association	Total metal concentration (ug/kg)						
				As	Cd	Cr	Co	Pb	Mo	Se
ME05	0-5	Calcrete	Calcareous flats	13,393	72.9	90,155	11,968	14,014	445	1,050
	40-50			14,635	77.9	66,146	7,489	7,518	236	897
ME06	0-5	Jamindie	Alluvial plain	18,711	93.2	126,380	27,992	21,100	1,252	1,272
	40-50			20,579	102.0	132,354	32,092	23,894	1,352	919
ME07	0-5	Urandy	Alluvial plain	9,842	46.2	104,325	25,929	16,393	565	963
	40-50			10,378	59.3	91,963	23,341	15,230	834	731
ME08	0-5	Jamindie	Floodplain	14,051	50.2	114,288	26,619	17,536	949	1,066
	40-50			19,237	81.4	125,244	25,583	21,792	1,303	672
ME09	0-5	Newman	Low hills / rises	55,758	33.4	171,033	8,170	16,993	1,436	1,721
ME10	0-5	Jamindie	Alluvial plain	23,059	35.8	164,755	16,572	22,644	1,285	687
	40-50			24,105	58.5	164,260	15,338	19,477	1,188	1,269
ME11	0-5	Calcrete	Calcareous flats	25,653	105.0	96,576	15,319	18,717	507	1,391
	40-50			25,940	57.1	84,911	10,252	15,673	355	694
ME12	0-5	Newman	Low hills / rises	40,641	32.0	128,738	12,094	15,779	1,197	1,590
ME13	0-5	Boolgeeda	Low hills / rises	19,606	35.3	163,813	10,814	16,383	1,445	1,081
ME14	0-5	Hooley	Alluvial plain	8,726	79.5	74,531	24,928	14,181	642	789
	40-50			8,462	57.7	75,609	25,794	14,101	623	384
ME15	0-5	Hooley	Alluvial plain	11,230	54.9	95,537	23,286	15,351	523	713
ME16	0-5	Brockman	Clay pan	8,856	109.1	79,810	28,918	37,291	645	280
ME17	0-5	Hooley	Floodplain	9,252	72.1	82,161	24,841	15,674	563	611
	40-50			9,844	72.8	76,078	25,609	15,473	744	456
ME18	0-5	Coolibah	Clay pan	11,510	58.5	86,773	31,419	20,459	625	655
	40-50			11,897	70.5	93,486	28,046	17,838	638	440
ME19	0-5	Coolibah	Alluvial plain	14,772	101.6	110,870	24,460	17,875	899	781
	40-50			16,722	88.7	112,270	26,616	19,343	1,054	216
ME20	0-5	Newman	Low hills / rises	22,023	48.7	138,074	13,198	17,191	1,333	1,172
ME21	0-5	Jurrawarrina	Floodplain	21,747	97.4	135,023	15,072	15,779	860	635
	40-50			23,046	85.6	118,260	15,919	17,498	721	614
ME22	0-5	Calcrete	Calcareous flats	21,526	99.8	113,164	17,692	18,943	709	893
	40-50			22,851	97.1	117,846	19,854	20,345	632	873
ME23	0-5	Jamindie	Alluvial plain	17,769	80.4	122,150	23,201	20,343	1,355	851
ME24	0-5	Jamindie	Alluvial plain	31,595	90.5	181,547	19,629	26,882	1,525	1,235
<b>Average crustal abundance<sup>1</sup></b>				<b>1,700</b>	<b>100</b>	<b>126,000</b>	<b>24,000</b>	<b>14,800</b>	<b>1,100</b>	<b>120</b>

1. (Reimann and de Caritat, 1998)

## **5 SOIL LANDFORM ASSOCIATION MAPPING**

Five soil-landform associations were identified within the Study area namely 'Low hills / rises', 'Alluvial plains', 'Floodplains', 'Clay pans' and 'Calcareous flats'. Identification of the soil-landform associations was based on field observations of morphological differences between the soil profiles, position within the landscape and analysis of physical and chemical soil characteristics. Approximate boundaries of the soil-landform associations within the study area are detailed in Figure 14.



## 6 CONCLUSIONS AND RECOMMENDATIONS

The aim of the assessment was to characterise the existing surface soil materials within the study area, to identify available soil resources and potentially problematic materials, and to develop associated recommendations for the recovery and stockpiling of soil resources and for their use in rehabilitation and mine closure activities.

Five soil-landform associations were identified within the study area namely 'Low hills / rises', 'Alluvial plains', 'Floodplains', 'Clay pans' and 'Calcareous flats'. There was a wide range in most of the physical and chemical soil characteristics within the study area, reflecting the wide range of landscapes and soil types. The major consistent differences in the soils from the various soil-landform associations were the depth of soil present over partially weathered or competent rock, soil texture and the amount of coarse rock fragments (>2 mm) present within the soil materials. As would be expected there was a general trend of deeper, finer grained (i.e. more clay rich) and fertile soils, lower in the landscape.

Various soil samples from across the study area were naturally enriched in total concentrations of As and Se (relative to the average crustal abundance), however there was no apparent correlation between metal enrichment and soil-landform associations.

The soils present within the various soil-landform associations are summarised as follows:

- Low hills / rises:
  - Shallow, skeletal soils over fractured / weathered and competent rock.
  - High percentage of competent rock fragments through the surface soil profile.
  - Non-saline, non-sodic, not dispersive (in natural state), low nutrient status, moderately slow drainage class and low to moderate water holding capacity.
- Alluvial plains:
  - Deep alluvial soils, well structured topsoils over massive subsoil horizons.
  - Moderate percentage of competent rock fragments through the surface soil profile.
  - Non-saline, topsoils classified as sodic, with highly sodic subsoils, minor dispersion of clay fraction upon saturation of some samples, low to moderate nutrient status, moderate drainage class and low to moderate water holding capacity.
- Floodplains:
  - Deep alluvial soils, well structured topsoils over massive subsoil horizons.
  - Relatively low percentage of competent rock fragments through the surface soil profile.
  - Moderately saline, topsoil and subsoils classified as highly sodic, with minor dispersion of clay fraction upon saturation of some samples, low to moderate nutrient status, moderately slow drainage class and moderate water holding capacity.
- Clay pans:
  - Flat depositional areas at low points in the landscape.
  - Relatively low percentage of competent rock fragments through the surface soil profile.
  - High clay content, highly sodic, extremely saline, with minor dispersion of clay fraction upon saturation of some samples. Slow drainage class and high water holding capacity.

- Calcareous flats:
  - Moderate percentage of competent rock fragments through the surface soil profile, increasing with depth. Some outcropping calcrete present in some areas.
  - Classed as alkaline and slightly saline, topsoil and subsoils classified as sodic, however soil in natural state is not dispersive, with only minor dispersion of clay fraction upon severe disturbance of some samples, low to moderate nutrient status, moderately slow drainage class and high water holding capacity.

In general, the topsoils (0 to 0.2 m depth) from the 'Low hills / rises' have characteristics which indicate a relatively low inherent erodibility (i.e. low clay content, only partial dispersion upon severe disturbance, high coarse material content and free draining). These rocky soils will be a valuable rehabilitation resource especially on final slopes of constructed landforms including waste rock dumps.

Topsoil materials sampled from lower in the landscape typically have higher clay contents, lower percentages of coarse material, lower hydraulic conductivities and may be prone to minor clay dispersion. While the surface soils from the 'Alluvial plains', 'Floodplain' and 'Calcareous flats' soil-landform associations are likely to be more erodible than the topsoils from higher in the landscape, they are a valuable rehabilitation resource especially for flat rehabilitation areas. If placed on final slopes of constructed landforms including waste rock dumps, these soils should be ripped through a rocky substrate to enhance their erosion resistance.

Topsoils from the 'Clay pans' have a high clay fraction and low percentage of competent rock. These soils are classified as extremely saline, highly sodic, have a slow drainage class and are likely to be highly erodible.

## 6.1 Soil Management Recommendations

It is recommended that topsoil material from disturbance areas within the 'Low hills / rises' soil-landform association are salvaged to a depth of approximately 0.2 m and stockpiled as a rehabilitation resource. The relatively coarse textured, rocky, free draining nature of these soil indicate a low inherent erodibility and suitability for placement as a surface rehabilitation medium on the slopes of constructed waste landforms.

Topsoils from the 'Alluvial plains', 'Floodplain' and 'Calcareous flats' soil-landform associations are suitable for salvage and use as a rehabilitation medium, particularly for flat rehabilitation areas. Due to their higher potential erodibility, if placed on final slopes of constructed waste landforms these soils should be ripped through a rocky substrate to enhance their erosion resistance. It is recommended that the topsoil from the 'Alluvial plains', 'Floodplain' and 'Calcareous flats' are salvaged and stockpiled separately to the topsoils from the 'Low hills / rises'.

It is recommended that the saline, highly sodic, highly erodible topsoil from the 'Clay pans' is not salvaged and utilised as a rehabilitation resource.

The deeper subsoil materials (i.e. soils from approximately 0.2 to 1 m depth) from low in the landscape (i.e. within the 'Alluvial plains', 'Floodplain' and 'Calcareous flats' soil-landform associations) typically have a higher clay content, higher sodicity and are considered likely to be more erodible than the topsoil materials. These deeper soils may be considered as an additional rehabilitation resource, if required, but will require ripping into rocky substrate to enhance their erosion resistance.

It is recommended that once disturbance footprints for the Project are finalised, a topsoil inventory is developed to identify the volume of topsoil likely to be available for salvage from disturbance areas and the amount of soil material required for rehabilitation of Project disturbance areas.

Specific topsoil management and handling recommendations which can optimise the success of future rehabilitation are as follows:

- It is recommended that the upper 0.2 m (topsoil) of the soil profiles within the disturbance areas is stripped and placed in stockpiles.
- Any rock fragments and surface litter present within the soil profiles should be collected and stockpiled with the topsoil.
- Machinery operators should minimise the frequency and intensity of disturbance, to minimise the impact to the structural integrity of the soil material.
- Soil stripping should occur as close as possible to the time when the proposed disturbance is scheduled to commence.
- Where possible, all stripped soil should be paddock-dumped into piles no greater than two metres in height. The piles should have adequate distance between them to create a series of mounds and troughs.
- Additional disturbance of the soil stockpiles should be avoided to minimise erosion and degradation of soil structure. Care should be taken to minimise the handling of the soils where possible, particularly when wet.

## 7 REFERENCES

- BOM. (2019, June 10). *Climate Statistics for Australian locations*. Retrieved from BOM.
- Brady, N. and Weil, R. (2002). *The Nature and Properties of Soils - Thirteenth Edition*. New Jersey: Prentice Hall.
- CSIRO. (2009). *Australian Soil and Land Survey Field Handbook*. CSIRO Publishing.
- Hancock Prospecting. (2009). *Murray's Hill Mining Proposal*. Perth.
- Hancock Prospecting. (2015). *E47/1244 Mulga Downs East: August 2015 Modelling Report*. Perth.
- Hazelton, P. and Murphy, B. (2007). *Interpreting soil test results, what do all the numbers mean?* Victoria: CSIRO Publishing.
- Hunt, N and Gilkes, R. (1992). *Farm monitoring handbook, a practical down-to-earth manual for farmers and other land users*. Perth: The University of Western Australia.
- Landloch. (2009). *Soil and overburden assessment of Murrays Hill*. Perth.
- McKenzie, N.I., May, J.E. and McKenna, S. (2003). *Bioregional Summary of the 2002 Biodiversity Audit for Western Australia*. Department of Conservation and Land Management.
- Moore, G. (1998). *Soilguide. A handbook for understanding and managing agricultural soils. Bulletin No. 4343*. Perth: Agriculture Western Australia.
- Payne, A L, van Vreeswyk, A M, Leighton, K A, Pringle, H J, and Hennig, P. (1998). *An inventory and condition survey of the Sandstone-Yalgoo-Paynes Find area, Western Australia. Technical Bulletin 90*. Perth, Western Australia: Department of Agriculture and Food.
- Rayment, G. and Lyons, P. (2011). *Soil Chemical Methods*. CSIRO Publishing.
- Reimann, C. and de Caritat, P. (1998). *Chemical Elements in the Environment*. Berlin: Springer.
- Thackway, R. and Cresswell, D. (1995). *An Interim Biogeographic Regionalisation for Australia: a framework for establishing the national system of reserves, Version 4.0*. Canberra: Australian Nature Conservation Agency.
- van Gool, D. T. (2005). *Land evaluation standards for land resource mapping*. Agriculture Western Australia.
- Van Vreeswyk, A., Payne, A., Leighton, K and Hennig, P. (2004). *An inventory and condition survey of the Pilbara Region of WA*. Perth: Department of Agriculture.

## **Appendix A**

### **Soil analysis classifications**

**Emerson Dispersion Test Classes (Moore 1998)**

Class	Description
Class 1	Dry aggregate slakes and completely disperses
Class 2	Dry aggregate slakes and partly disperses
Class 3a	Dry aggregate slakes but does not disperse; remoulded soil disperses completely
Class 3b	Dry aggregate slakes but does not disperse; remoulded soil partly disperses
Class 4	Dry aggregate slakes but does not disperse; remoulded soil does not disperse; carbonates and gypsum are present
Class 5	Dry aggregate slakes but does not disperse; remoulded soil does not disperse; carbonates and gypsum are absent; 1:5 suspension remains dispersed
Class 6	Dry aggregate slakes but does not disperse; remoulded soil does not disperse; carbonates and gypsum are absent; 1:5 suspension remains flocculated
Class 7	Dry aggregate does not slake; aggregate swells
Class 8	Dry aggregate does not slake; aggregate does not swell

**Soil Electrical conductivity classes (based on standard USDA and CSIRO categories)**

EC (1:5) (dS/m)						
Salinity class	Sand	Sandy loam	Loam	Clay loam	Light / medium clay	Heavy clay
Non-saline	<0.13	<0.17	<0.20	<0.22	<0.25	<0.33
Slightly saline	0.13-0.26	0.17-0.33	0.20-0.40	0.22-0.44	0.25-0.50	0.33-0.67
Moderately saline	0.26-0.52	0.33-0.67	0.40-0.80	0.44-0.89	0.50-1.00	0.67-1.33
Very saline	0.52-1.06	0.67-1.33	0.80-1.60	0.89-1.78	1.00-2.00	1.33-2.67
Extremely saline	>1.06	>1.33	>1.60	>1.78	>2.00	>2.67

**Soil pH classes**

	Soil pH rating						
	Very strongly acid (V <sub>sac</sub> )	Strongly acid (S <sub>ac</sub> )	Moderately acid (M <sub>ac</sub> )	Slightly acid (Sl <sub>ac</sub> )	Neutral (N)	Moderately alkaline (M <sub>alk</sub> )	Strongly alkaline (S <sub>alk</sub> )
pH <sub>w</sub>	< 5.3	5.3 - 5.6	5.6 - 6.0	6.0 - 6.5	6.5 - 8.0	8.0 - 9.0	> 9.0
pH <sub>ca</sub>	< 4.2	4.2 - 4.5	4.5 - 5.0	5.0 - 5.5	5.5 - 7.0	7.0 - 8.0	> 8.0

**Appendix B**  
**CSBP Laboratory Analysis Certificates**

# Analysis Results

CSBP Soil and Plant Laboratory



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Lab No		6IS19071	6IS19072	6IS19073	6IS19074	6IS19075	6IS19076	6IS19077	6IS19078
Name		ME01	ME02	ME03	ME04	ME04	ME05	ME05	ME06
Customer		MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH
Depth		10-20	10-20	10-20	10-20	90-100	10-20	90-100	10-20
Colour		BR	LTBR	BR	LTBR	BR	BRYW	BRWH	DKBR
Gravel	%	0	0	0	0	0	0	0	0
Texture		3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Ammonium Nitrogen	mg/kg	< 1	< 1	1	2	1	< 1	< 1	< 1
Nitrate Nitrogen	mg/kg	2	14	2	19	2	4	< 1	8
Phosphorus Colwell	mg/kg	3	12	4	5	5	< 2	< 2	9
Potassium Colwell	mg/kg	161	1165	224	405	265	816	489	448
Sulfur	mg/kg	4.6	69.4	3.1	2.8	2.7	3.4	593.2	4.9
Organic Carbon	%	0.17	0.59	0.14	0.61	0.12	0.25	0.10	0.18
Conductivity	dS/m	0.015	0.411	0.013	0.044	0.037	0.128	1.438	0.058
pH Level (CaCl2)		5.1	7.6	5.6	5.5	6.3	7.7	8.2	5.9
pH Level (H2O)		6.1	8.1	7.1	6.4	6.9	8.8	8.7	6.6

# Analysis Results

CSBP Soil and Plant Laboratory



Lab No		6IS19079	6IS19080	6IS19081	6IS19082	6IS19083	6IS19084	6IS19085	6IS19086
Name		ME06	ME07	ME07	ME08	ME08	ME09	ME10	ME10
Customer		MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH
Depth		90-100	10-20	90-100	10-20	90-100	10-20	10-20	90-100
Colour		DKBR	BRRD	DKBR	BRGR	BRRD	BRGR	DKBR	BRRD
Gravel	%	0	0	0	0	0	0	0	0
Texture		2.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Ammonium Nitrogen	mg/kg	< 1	< 1	2	5	< 1	< 1	1	< 1
Nitrate Nitrogen	mg/kg	18	25	48	47	7	< 1	12	18
Phosphorus Colwell	mg/kg	< 2	8	3	6	3	2	5	< 2
Potassium Colwell	mg/kg	349	120	120	616	639	172	661	794
Sulfur	mg/kg	62.0	110.0	530.1	534.0	1662.0	4.2	920.5	5041.0
Organic Carbon	%	< 0.05	0.17	0.08	0.14	< 0.05	0.58	0.05	< 0.05
Conductivity	dS/m	1.029	2.474	3.521	4.563	1.986	0.020	1.745	4.227
pH Level (CaCl2)		6.8	7.4	6.8	6.7	7.1	5.4	6.6	7.4
pH Level (H2O)		7.6	7.8	7.3	7.1	7.5	6.6	6.7	7.9

# Analysis Results

CSBP Soil and Plant Laboratory



Lab No		6IS19087	6IS19088	6IS19089	6IS19090	6IS19091	6IS19092	6IS19093	6IS19094
Name		ME11	ME11	ME12	ME13A	ME14	ME14	ME15	ME16
Customer		MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH
Depth		10-20	90-100	10-20	10-20	10-20	90-100	10-20	10-20
Colour		LTBR	LTBR	BR	BR	DKBR	BR	DKBR	DKBR
Gravel	%	0	0	0	0	0	0	0	0
Texture		3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Ammonium Nitrogen	mg/kg	< 1	1	2	1	< 1	< 1	< 1	52
Nitrate Nitrogen	mg/kg	5	5	2	3	6	40	37	91
Phosphorus Colwell	mg/kg	3	4	3	4	4	6	9	16
Potassium Colwell	mg/kg	635	763	200	202	324	93	272	264
Sulfur	mg/kg	74.6	51.2	6.9	4.5	7.2	862.1	48.0	157.3
Organic Carbon	%	0.24	0.18	0.32	0.22	0.16	< 0.05	0.25	0.32
Conductivity	dS/m	0.546	0.434	0.021	0.015	0.100	1.679	1.195	9.051
pH Level (CaCl2)		7.8	7.8	5.4	4.8	6.5	7.3	8.2	6.3
pH Level (H2O)		8.7	8.6	6.7	6.0	7.4	7.6	9.0	6.7

# Analysis Results

CSBP Soil and Plant Laboratory



Lab No		6IS19095	6IS19096	6IS19103	6IS19104	6IS19105	6IS19106	6IS19107	6IS19108
Name		ME17	ME17	ME18	ME18	ME19	ME19	ME20	ME21
Customer		MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH
Depth		10-20	90-100	10-20	90-100	10-20	90-100	10-20	10-20
Colour		DKBR	DKBR	DKBR	DKBR	LTBR	BR	BROR	DKBR
Gravel	%	0	0	0	0	0	0	0	0
Texture		3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Ammonium Nitrogen	mg/kg	3	3	2	< 1	1	< 1	2	< 1
Nitrate Nitrogen	mg/kg	73	24	48	3	4	< 1	3	5
Phosphorus Colwell	mg/kg	18	14	16	15	31	15	4	7
Potassium Colwell	mg/kg	339	120	499	487	527	686	182	555
Sulfur	mg/kg	28.9	1411.1	1731.4	1473.1	2.2	120.4	6.2	1.6
Organic Carbon	%	0.30	0.22	0.27	0.16	0.23	0.11	0.39	0.15
Conductivity	dS/m	1.772	3.472	7.646	4.535	0.035	0.538	0.022	0.030
pH Level (CaCl2)		6.8	7.9	6.7	7.9	5.9	6.8	5.6	6.5
pH Level (H2O)		7.2	8.0	7.1	8.2	7.4	7.7	6.7	7.4

# Analysis Results

CSBP Soil and Plant Laboratory



Lab No		6IS19109	6IS19110	6IS19111	6IS19112	6IS19113
Name		ME21	ME22	ME22	ME23	ME24
Customer		MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH
Depth		90-100	10-20	90-100	10-20	10-20
Colour		DKBR	DKBR	BR	BR	BR
Gravel	%	0	0	0	0	0
Texture		3.0	3.0	3.0	3.0	3.0
Ammonium Nitrogen	mg/kg	2	< 1	< 1	< 1	1
Nitrate Nitrogen	mg/kg	3	8	6	9	4
Phosphorus Colwell	mg/kg	4	3	3	9	8
Potassium Colwell	mg/kg	363	920	367	356	295
Sulfur	mg/kg	153.5	58.4	7.6	2.0	2.5
Organic Carbon	%	0.08	0.44	0.21	0.26	0.28
Conductivity	dS/m	0.810	0.250	0.217	0.041	0.015
pH Level (CaCl2)		8.6	6.9	7.6	6.9	5.5
pH Level (H2O)		9.7	7.8	8.1	7.9	7.1

# Analysis Results

CSBP Soil and Plant Laboratory



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Lab No		6IS19114	6IS19115	6IS19116	6IS19117	6IS19118	6IS19119	6IS19120	6IS19121
Name		ME03A	ME05	ME05	ME07	ME07	ME10	ME10	ME13A
Customer		MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH
Depth		0-5	0-5	40-50	0-5	40-50	0-5	40-50	0-5
Colour		BR	LTBR	LTBR	DKBR	BRRD	BR	BRRD	DKBR
Gravel	%	0	0	0	0	0	0	0	0
Texture		3.0	2.5	3.0	3.0	3.0	3.0	3.0	3.0
Ammonium Nitrogen	mg/kg	< 1	2	< 1	8	2	< 1	< 1	3
Nitrate Nitrogen	mg/kg	2	2	2	3	60	6	20	3
Phosphorus Colwell	mg/kg	7	8	< 2	6	8	16	3	7
Potassium Colwell	mg/kg	232	483	526	332	99	510	874	198
Sulfur	mg/kg	2.4	2.8	2.3	8.2	2259.8	235.6	1736.5	3.4
Organic Carbon	%	0.31	0.52	0.19	0.12	0.12	0.13	< 0.05	0.33
Conductivity	dS/m	0.022	0.078	0.151	0.064	3.900	0.499	3.025	0.014
pH Level (CaCl2)		6.0	8.0	8.3	6.9	7.2	6.7	7.9	4.6
pH Level (H2O)		6.7	8.5	9.5	8.1	7.8	7.6	8.4	5.8
Exc. Aluminium	meq/100g	0.040	0.020	0.040	0.020	0.080	0.060	0.090	0.190
Exc. Calcium	meq/100g	2.96	13.45	6.31	12.09	13.70	4.48	1.52	1.88
Exc. Magnesium	meq/100g	1.18	1.02	1.19	5.51	8.34	1.12	5.25	0.82
Exc. Potassium	meq/100g	0.42	1.08	1.18	0.71	0.23	1.02	1.86	0.35
Exc. Sodium	meq/100g	0.04	0.03	1.46	4.24	17.00	2.15	22.46	0.07
Arsenic	ug/kg	16578.33	13393.08	14634.76	9842.37	10378.41	23059.07	24105.05	19606.06
Cadmium	ug/kg	37.75	72.88	77.90	46.21	59.25	35.81	58.50	35.31
Chromium	ug/kg	108931.71	90155.36	66146.21	104325.24	91962.78	164754.85	164260.33	163812.99
Cobalt	ug/kg	14368.57	11968.38	7489.27	25929.23	23340.74	16572.15	15338.37	10814.20

CSBP Lab. Extract Value.

# Analysis Results

CSBP Soil and Plant Laboratory



Lab No		6IS19122	6IS19123	6IS19124	6IS19125	6IS19126	6IS19127
Name		ME16	ME17	ME18	ME18	ME20	ME23
Customer		MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH
Depth		0-5	40-50	0-5	40-50	0-5	0-5
Colour		DKBR	DKBR	BRYW	DKBR	BR	BR
Gravel	%	0	0	0	0	0	0
Texture		3.0	3.0	3.0	3.0	3.0	3.0
Ammonium Nitrogen	mg/kg	51	17	1	< 1	27	1
Nitrate Nitrogen	mg/kg	50	155	28	19	7	9
Phosphorus Colwell	mg/kg	22	15	19	17	10	25
Potassium Colwell	mg/kg	370	118	634	454	244	326
Sulfur	mg/kg	81.9	173.2	534.0	1744.1	8.0	2.5
Organic Carbon	%	0.38	0.45	0.33	0.26	0.58	0.70
Conductivity	dS/m	5.334	3.815	3.403	5.393	0.044	0.030
pH Level (CaCl2)		6.8	6.7	6.8	6.6	5.2	6.1
pH Level (H2O)		6.9	6.9	7.1	6.9	6.4	6.8
Exc. Aluminium	meq/100g	0.020	0.030	0.020	0.050	0.080	0.040
Exc. Calcium	meq/100g	11.16	18.13	6.16	3.50	2.64	5.89
Exc. Magnesium	meq/100g	9.96	8.29	5.62	15.62	0.96	1.04
Exc. Potassium	meq/100g	0.74	0.26	1.34	1.06	0.47	0.60
Exc. Sodium	meq/100g	19.04	13.20	20.67	35.18	0.23	0.04
Arsenic	ug/kg	8856.06	9843.67	11510.17	11896.75	22023.49	17768.90
Cadmium	ug/kg	109.14	72.77	58.52	70.45	48.69	80.41
Chromium	ug/kg	79809.61	76078.04	86772.79	93485.71	138074.41	122150.06
Cobalt	ug/kg	28918.01	25608.52	31418.57	28046.06	13198.44	23201.18

CSBP Lab. Extract Value.

# Analysis Results

CSBP Soil and Plant Laboratory



	Lab No	6IS19114	6IS19115	6IS19116	6IS19117	6IS19118	6IS19119	6IS19120	6IS19121
Lead	ug/kg	16995.13	14013.90	7517.93	16393.34	15229.89	22644.44	19477.07	16383.31
Molybdenum	ug/kg	1041.3	445.0	235.5	565.0	833.8	1284.9	1187.6	1445.3
Selenium	ug/kg	986.30	1049.63	897.38	962.92	731.18	686.69	1268.52	1080.92

# Analysis Results

CSBP Soil and Plant Laboratory



	Lab No	6IS19122	6IS19123	6IS19124	6IS19125	6IS19126	6IS19127
Lead	ug/kg	37290.86	15473.02	20458.71	17838.26	17191.36	20342.68
Molybdenum	ug/kg	644.6	744.0	624.8	637.7	1332.6	1355.4
Selenium	ug/kg	280.07	455.59	654.51	439.81	1171.97	850.95

# Analysis Results

CSBP Soil and Plant Laboratory



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Lab No		6IS19047	6IS19048	6IS19049	6IS19050	6IS19051	6IS19052	6IS19053	6IS19054
Name		ME01	ME02	ME04	ME04	ME06	ME06	ME08	ME08
Customer		MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH
Depth		0-5	0-5	0-5	40-50	0-5	40-50	0-5	40-50
Colour		BROR	BR	BR	BR	DKBR	BRRD	BR	BRRD
Gravel	%	5	0	0	0	0	0	0	0
Texture		3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Ammonium Nitrogen	mg/kg	2	< 1	2	< 1	< 1	< 1	8	3
Nitrate Nitrogen	mg/kg	2	7	20	6	< 1	35	23	23
Phosphorus Colwell	mg/kg	6	29	7	6	13	6	11	4
Potassium Colwell	mg/kg	166	983	509	299	461	383	623	684
Sulfur	mg/kg	3.2	58.2	6.7	4.2	1.2	17.9	273.2	261.0
Organic Carbon	%	0.26	0.82	1.26	0.56	0.21	0.11	0.14	0.07
Conductivity	dS/m	0.012	0.165	0.048	0.021	0.016	0.413	2.029	3.807
pH Level (CaCl2)		5.0	8.0	5.5	5.0	5.9	5.8	6.1	6.4
pH Level (H2O)		6.0	8.5	6.3	6.1	6.8	6.2	6.6	6.9
Exc. Aluminium	meq/100g	0.140	0.020	0.020	0.070	0.090	0.130	0.030	0.080
Exc. Calcium	meq/100g	1.46	14.96	7.32	4.95	4.94	7.00	5.39	6.85
Exc. Magnesium	meq/100g	0.79	2.08	1.21	1.11	1.78	2.79	3.35	6.69
Exc. Potassium	meq/100g	0.29	2.19	0.93	0.47	0.78	0.71	1.21	1.46
Exc. Sodium	meq/100g	0.03	1.97	0.03	0.03	0.07	0.40	6.80	13.79
% Clay	%	19.02	18.44	24.68	31.11	28.62	35.30	13.87	17.01
% Course Sand	%	38.48	25.59	5.46	9.20	19.08	12.37	21.73	10.99
% Fine Sand	%	33.46	39.43	45.13	34.37	28.57	28.41	43.51	51.15
% Sand	%	71.94	65.02	50.59	43.57	47.65	40.78	65.24	62.14

CSBP Lab. Extract Value.

# Analysis Results

CSBP Soil and Plant Laboratory



Lab No		6IS19055	6IS19056	6IS19057	6IS19058	6IS19059	6IS19060	6IS19061	6IS19062
Name		ME09	ME11	ME11	ME12	ME14	ME14	ME15	ME17
Customer		MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH
Depth		0-5	0-5	40-50	0-5	0-5	40-50	0-5	0-5
Colour		DKBR	DKBR	BR	BR	DKBR	BRRD	DKBR	BR
Gravel	%	0	0	0	0	0	0	0	0
Texture		3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Ammonium Nitrogen	mg/kg	< 1	< 1	< 1	1	2	3	< 1	< 1
Nitrate Nitrogen	mg/kg	2	3	4	2	3	30	12	5
Phosphorus Colwell	mg/kg	4	9	4	9	11	4	11	12
Potassium Colwell	mg/kg	192	618	785	225	470	138	354	517
Sulfur	mg/kg	3.0	5.8	54.2	2.0	5.6	30.3	6.2	31.8
Organic Carbon	%	0.59	1.40	0.38	0.32	0.20	0.25	0.23	0.21
Conductivity	dS/m	0.022	0.081	0.432	0.012	0.090	0.862	0.588	0.236
pH Level (CaCl2)		5.2	7.4	7.8	5.3	6.8	7.0	8.1	6.9
pH Level (H2O)		6.5	8.1	8.7	6.4	7.8	7.4	9.0	8.0
Exc. Aluminium	meq/100g	0.060	0.010	0.070	0.060	0.040	0.070	0.020	0.020
Exc. Calcium	meq/100g	2.44	16.91	11.19	2.53	9.63	14.32	16.57	11.59
Exc. Magnesium	meq/100g	0.94	3.02	4.58	1.28	3.77	4.73	2.07	4.58
Exc. Potassium	meq/100g	0.31	1.37	1.77	0.40	0.82	0.28	0.71	0.93
Exc. Sodium	meq/100g	0.08	0.08	2.65	0.05	0.73	3.76	6.28	1.89
% Clay	%	16.54	17.50	28.07	17.57	30.33	41.03	33.19	22.13
% Course Sand	%	35.43	24.63	15.07	18.04	22.17	15.60	15.06	10.28
% Fine Sand	%	37.28	42.28	41.87	48.73	29.86	25.77	23.55	35.33
% Sand	%	72.71	66.91	56.94	66.77	52.03	41.37	38.61	45.61

CSBP Lab. Extract Value.

# Analysis Results

CSBP Soil and Plant Laboratory



Lab No		6IS19063	6IS19064	6IS19065	6IS19066	6IS19068	6IS19069	6IS19070
Name		ME19	ME19	ME21	ME21	ME22	ME22	ME24
Customer		MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH
Depth		0-5	40-50	0-5	40-50	0-5	40-50	0-5
Colour		LTBR	BRGR	DKBR	BRRD	DKBR	BRRD	BR
Gravel	%	0	0	0	0	0	0	0
Texture		3.0	3.0	3.0	3.0	3.0	3.0	3.0
Ammonium Nitrogen	mg/kg	4	< 1	< 1	< 1	2	< 1	1
Nitrate Nitrogen	mg/kg	5	< 1	3	16	20	4	2
Phosphorus Colwell	mg/kg	29	15	20	3	15	2	9
Potassium Colwell	mg/kg	627	405	398	405	835	665	309
Sulfur	mg/kg	2.4	6.4	3.3	8.6	191.8	46.6	1.8
Organic Carbon	%	0.66	0.13	0.62	0.08	0.70	0.46	0.29
Conductivity	dS/m	0.039	0.178	0.033	0.256	0.863	0.394	0.012
pH Level (CaCl2)		5.9	6.0	6.2	8.0	6.8	7.0	5.2
pH Level (H2O)		7.1	7.2	7.1	9.2	7.4	7.5	6.6
Exc. Aluminium	meq/100g	0.020	0.080	0.030	0.070	0.020	0.070	0.080
Exc. Calcium	meq/100g	6.92	8.36	5.10	8.88	10.05	15.48	4.28
Exc. Magnesium	meq/100g	3.61	6.48	2.07	4.85	6.86	5.99	0.85
Exc. Potassium	meq/100g	1.20	1.11	0.74	0.89	1.80	1.53	0.59
Exc. Sodium	meq/100g	0.27	2.53	0.20	4.11	5.24	0.55	0.03
% Clay	%	31.35	59.84	23.24	39.91	33.23	46.04	36.82
% Course Sand	%	22.42	11.49	33.03	17.79	9.86	6.14	20.03
% Fine Sand	%	28.57	12.96	26.27	19.89	29.34	23.81	22.77
% Sand	%	50.99	24.45	59.30	37.68	39.20	29.95	42.80

CSBP Lab. Extract Value.

# Analysis Results

CSBP Soil and Plant Laboratory



	Lab No	6IS19047	6IS19048	6IS19049	6IS19050	6IS19051	6IS19052	6IS19053	6IS19054
% Silt	%	9.03	16.54	24.73	25.32	23.73	23.91	20.89	20.85
Arsenic	ug/kg	27707.11	18368.85	22562.39	26894.02	18710.63	20579.22	14050.68	19236.87
Cadmium	ug/kg	41.30	99.71	135.10	145.05	93.18	102.03	50.17	81.39
Chromium	ug/kg	203949.82	100707.73	100480.09	129425.08	126379.94	132354.08	114288.13	125243.70
Cobalt	ug/kg	11561.55	16666.16	24509.31	27780.95	27991.89	32092.32	26619.14	25583.20
Lead	ug/kg	17758.53	18231.24	24780.75	28639.72	21100.08	23894.33	17535.98	21791.81
Molybdenum	ug/kg	1527.1	523.8	1332.2	1653.8	1251.5	1352.4	949.1	1302.9
Selenium	ug/kg	1481.02	904.96	1392.41	1292.90	1271.98	919.09	1066.13	672.44

# Analysis Results

CSBP Soil and Plant Laboratory



	Lab No	6IS19055	6IS19056	6IS19057	6IS19058	6IS19059	6IS19060	6IS19061	6IS19062
<b>% Silt</b>	%	10.74	15.59	15.00	15.66	17.64	17.60	28.20	32.26
<b>Arsenic</b>	ug/kg	55758.39	25652.57	25940.36	40641.08	8726.07	8461.85	11229.54	9251.70
<b>Cadmium</b>	ug/kg	33.40	105.04	57.13	32.00	79.53	57.67	54.90	72.06
<b>Chromium</b>	ug/kg	171032.69	96575.54	84911.01	128737.79	74530.63	75609.02	95537.11	82161.06
<b>Cobalt</b>	ug/kg	8169.96	15319.07	10252.08	12093.57	24928.32	25794.33	23285.84	24841.42
<b>Lead</b>	ug/kg	16992.62	18716.86	15673.28	15779.29	14181.47	14101.43	15351.32	15673.67
<b>Molybdenum</b>	ug/kg	1435.6	507.4	355.2	1196.9	642.0	622.9	522.6	563.0
<b>Selenium</b>	ug/kg	1721.31	1391.43	694.06	1589.63	789.40	383.95	712.55	611.39

# Analysis Results

CSBP Soil and Plant Laboratory



Lab No		6IS19063	6IS19064	6IS19065	6IS19066	6IS19068	6IS19069	6IS19070
<b>% Silt</b>	%	17.66	15.71	17.46	22.42	27.57	24.00	20.37
<b>Arsenic</b>	ug/kg	14771.85	16721.68	21746.77	23046.48	21525.77	22850.61	31595.33
<b>Cadmium</b>	ug/kg	101.61	88.73	97.38	85.60	99.77	97.09	90.52
<b>Chromium</b>	ug/kg	110870.32	112270.35	135023.22	118259.82	113164.49	117845.61	181547.44
<b>Cobalt</b>	ug/kg	24460.09	26615.90	15072.32	15918.88	17692.00	19853.77	19628.64
<b>Lead</b>	ug/kg	17875.41	19342.85	15779.21	17498.01	18943.06	20345.46	26882.07
<b>Molybdenum</b>	ug/kg	899.1	1053.7	859.9	721.2	708.9	631.7	1525.1
<b>Selenium</b>	ug/kg	780.68	215.61	634.63	614.19	893.14	873.19	1234.52