The mine closure specialists

MIRALGA CREEK

BASELINE SOIL ASSESSMENT

January 2020

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EXECUTIVE SUMMARY

Mine Earth was commissioned by Atlas Iron Pty Ltd to complete a baseline soil and landform assessment for the Miralga Creek project (the Project). The Project is located approximately 100 kilometres (km) south-east of Port Hedland in the Pilbara region of Western Australia (WA). The study area encompassed five parcels of land incorporating the proposed disturbance areas of the Miralga Creek East, Miralga Creek West and Sandtrax deposits, and the Stockyard A and Stockyard B infrastructure areas. The combined study area totalled approximately 2,600 hectares (ha).

The aim of the assessment was to characterise the existing surface soil materials within the study area, with a focus on the soils within disturbance areas associated with proposed mining activities, and to develop associated recommendations for soil salvaging, management, stockpiling and application of soil resources in rehabilitation and mine closure activities.

Five soil-landform associations were identified within the study area, namely ‘Ridgelines / Rocky outcrops’, ‘Low hills / Scree slopes’, ‘Stony plains’, ‘Sandy plains’ and ‘Drainage lines’

Surface Soil Characteristics

The physical and chemical characteristics of surface soil materials were assessed from 17 representative locations within the study area, which were sampled to a maximum depth of 0.25 m.

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, and the amount of coarse rock fragments (>2 mm) present within the soil materials. There was an overall, general consistency in the soil characteristics within each of the three mining areas (Miralga Ck East, Miralga Ck West and Sandtrax).

Many of the chemical and physical characteristics of the surface soils across the study area were relatively similar, with little consistent correlation with soil-landform association, or sample depth. All soils sampled were relatively coarse grained, with generally low clay contents (minor increase in clay with depth), were non-saline, partially dispersive upon severe disturbance, free draining (moderate hydraulic conductivity) and were typically low in organic carbon and plant-available nutrients.

Numerous soil samples from across the study area were considered enriched in total concentrations of As and Se (relative to the average crustal abundance), however there is no apparent correlation with soil-landform associations.

Soil Management Recommendations

Based upon the physical, chemical and morphological characteristics of the soils in the study area, it is recommended that topsoils, to a depth of approximately 20 cm from within the within the ‘Low hills / Scree slopes’ and any topsoil able to be opportunistically salvaged from the ‘Ridgelines / Rocky outcrops’ should be stockpiled together for use as a surface rehabilitation medium on rehabilitated slopes of constructed landforms. The high coarse fraction, low clay content, non-dispersive and free draining nature of these topsoils indicate a low inherent erodibility and suitability for use on rehabilitated sloped areas.

Topsoil materials from within the ‘Stony plains’ of the study area are suitable for salvage and use as a surface rehabilitation medium, particularly for flat rehabilitation areas situated low in the landscape. Topsoils from the ‘Sandy plains’ soil-landform association are considered unsuitable for placement on rehabilitated slopes due to the lower coarse rock fraction and tendency for partial dispersion of the clay fraction. These soils however, are still considered a valuable source of surface rehabilitation material for flat rehabilitation surfaces.

Soils from the ‘Drainage lines’ were not sampled as part of this investigation as there is unlikely to be major disturbance or soil salvaging from within those areas.

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

- ‘Topsoil’ (0 to 20 cm) within the ‘Low hills / Scree slopes’ and any topsoil able to be opportunistically salvaged from the ‘Ridgelines / Rocky outcrops’ should be stockpiled together for use as a surface rehabilitation medium on rehabilitated slopes of constructed landforms.
- ‘Topsoil’ (0 to 20 cm) salvaged from the ‘Stony plain’ and ‘Sandy plain’ soil-landform association are considered suitable for placement on flat rehabilitation areas.

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1 INTRODUCTION

Atlas Iron Pty Ltd (Atlas) are the proponents of the proposed Miralga Creek Iron Ore project (the Project), located approximately 100 km south-east of Port Hedland in the Pilbara region of Western Australia (WA) (Figure 1). Mine Earth was commissioned to complete a baseline soil and landform assessment for the Project. The study area encompassed five parcels of land incorporating the proposed disturbance areas of the Miralga Creek East, Miralga Creek West and Sandtrax deposits, and the proposed Stockyard A and Stockyard B infrastructure areas. The combined study area totalled approximately 2,600 ha.

An assessment of soil and landform associations within the study area was undertaken to support regulatory approvals, to identify soil management requirements and potential utilisation of soil resources in rehabilitation activities, and to facilitate mine closure planning.

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, structure, structural stability and hydraulic conductivity.
- 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.

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Project Location

Figure 1

2 DESCRIPTION OF STUDY AREA

A description of the existing environment for the Project is provided in this section under the headings: climate, land systems and soils.

2.1 Climate

The study area is located within the Chichester subregion of the Pilbara Craton bioregion, which experiences a semi-desert-tropical climate characterised by hot, dry summers and cool, dry winters (McKenzie, N.I., May, J.E. and McKenna, S., 2003).

The closest Bureau of Meteorology (BOM) weather station to the study area is located at Marble Bar (Station Number 4106), situated approximately 45 km to the south-east.

The mean maximum temperature for Marble Bar is highest in December and January at over 40° Celsius (C) and lowest in June at 28°C (Figure 2). Rainfall occurs mainly over the months of January to March (Figure 2) and is typically associated with thunderstorm and cyclonic activity. The mean average yearly rainfall is approximately 394 millimetres (mm) (BOM, 2019).

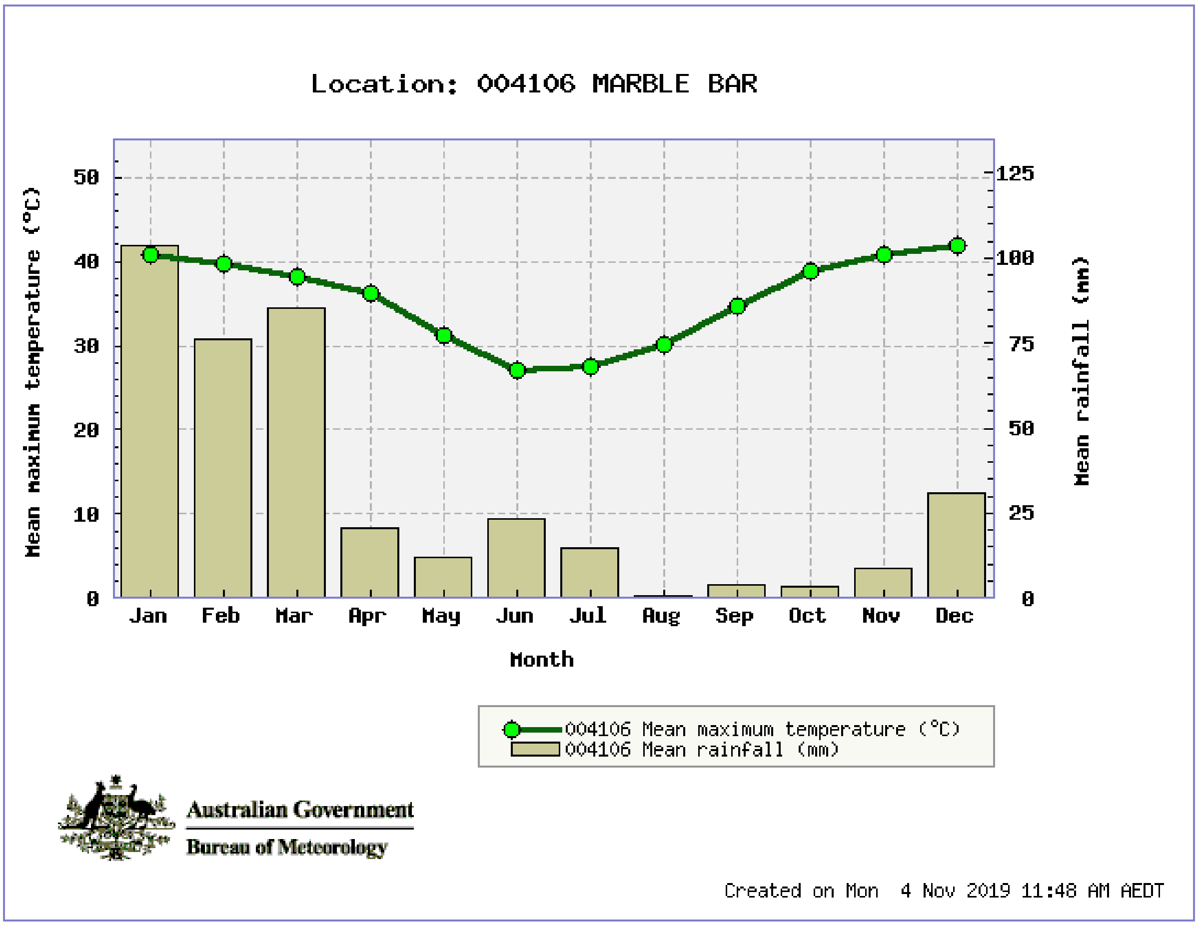


Figure 2 Mean monthly rainfall and mean monthly maximum temperature at the Marble Bar weather station

2.2 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 Agriculture and Food) 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).

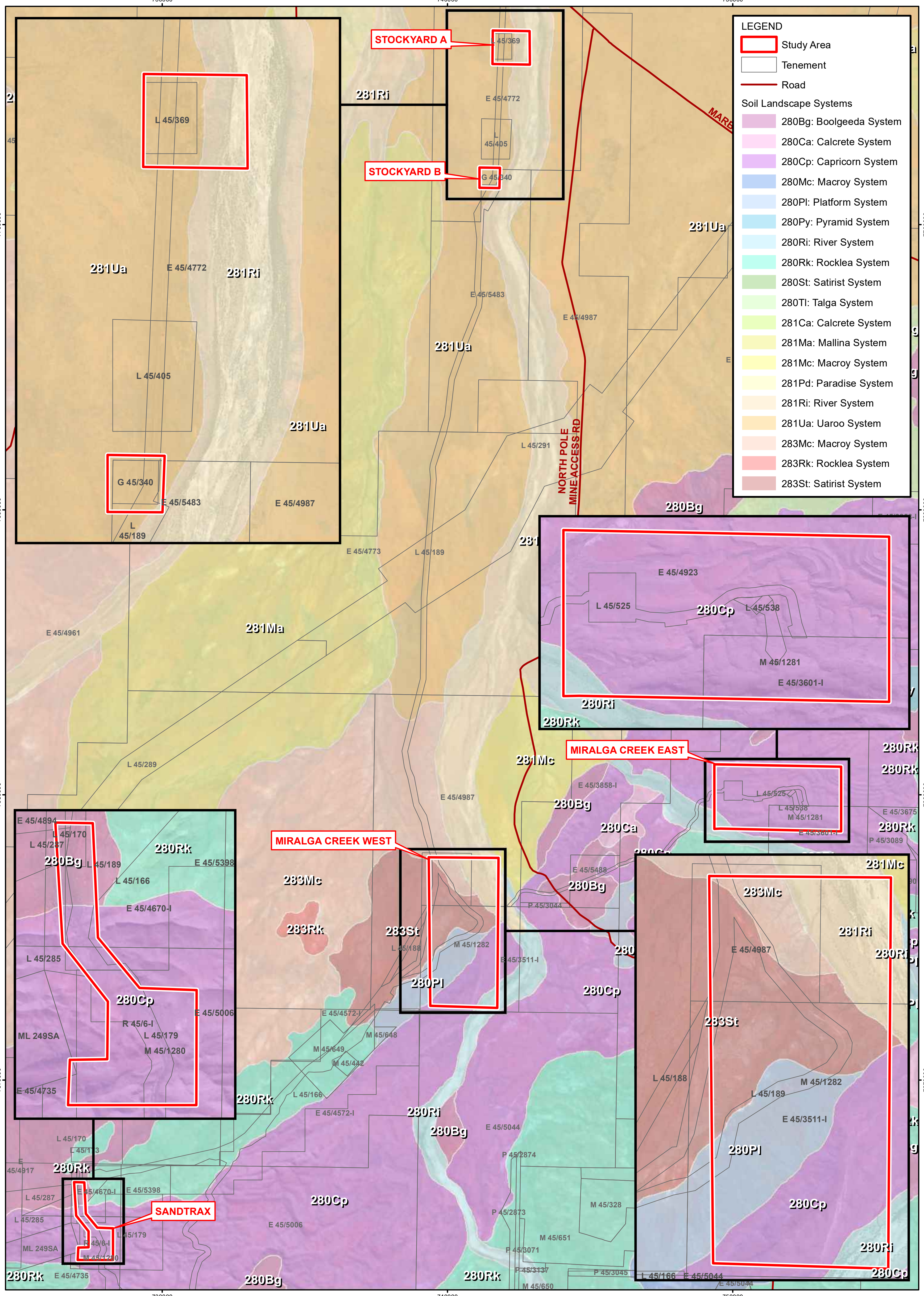
Land systems present within the study area are described in Table 2 and spatially delineated in Figure 3.

Table 1 Land systems in 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.
Capricorn System	Hills and ridges of sandstone and dolomite supporting shrubby hard and soft spinifex grasslands.
Macroy System	Stony plains and occasional tor fields based on granite supporting hard and soft spinifex grasslands.
Platform System	Dissected slopes and raised plains supporting hard spinifex grasslands.
River System	Active flood plains and major rivers supporting grassy eucalypt woodlands, tussock grasslands and soft spinifex grasslands.
Satirist System	Stony plains and low rises supporting hard spinifex grasslands, and gilgai plains supporting tussock grasslands.
Uaroo System	Broad sandy plains supporting shrubby hard and soft spinifex grasslands.

2.3 Soils

In 2019, an assessment of local soils was conducted along the Shaw River by the Department of Primary Industries and Regional Development (DPIRD unpublished data, 2019). Soils, while variable across the landscape, were described as typically neutral to alkaline in soil pH and were classed as non-saline. Red Kandosols (red sandy to loamy surface soils, grading to porous sandy clay subsoils with low fertility) were dominant, often overlying an alluvial gravel layer (in low lying areas). Soil texture was identified as typically increasing from sandy loam to light sandy clay in areas where deep soil profiles were present. All soils were typically measured as having a low plant-available nutrient status.



N

0 2.5 5 km

Scale: 1:125,000 @ A3
GDA 1994 MGA Zone 50

Figure 2

Land Systems

3 MATERIALS AND METHODS

3.1 Sampling Regime

Soil samples were collected by Mine Earth personnel from 17 sites within the study area in September 2019. Six soil sampling sites were located within the Miralga Creek East area, six sites within the Miralga Creek West area and five sites within the Sandtrax area (Figure 4). An additional sampling site was located within the Stockyard A area. Due to the dominance of shallow / skeletal soils within the proposed mining areas, sampling was conducted by hand to a maximum depth of approximately 20 cm, where possible.

Sampling sites were focussed within the proposed disturbance areas associated with the Project. Samples were taken from one or two 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, surface 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).

No soil samples were collected from the ‘Drainage lines’ as there is unlikely to be major disturbance or soil salvaging from within those areas.

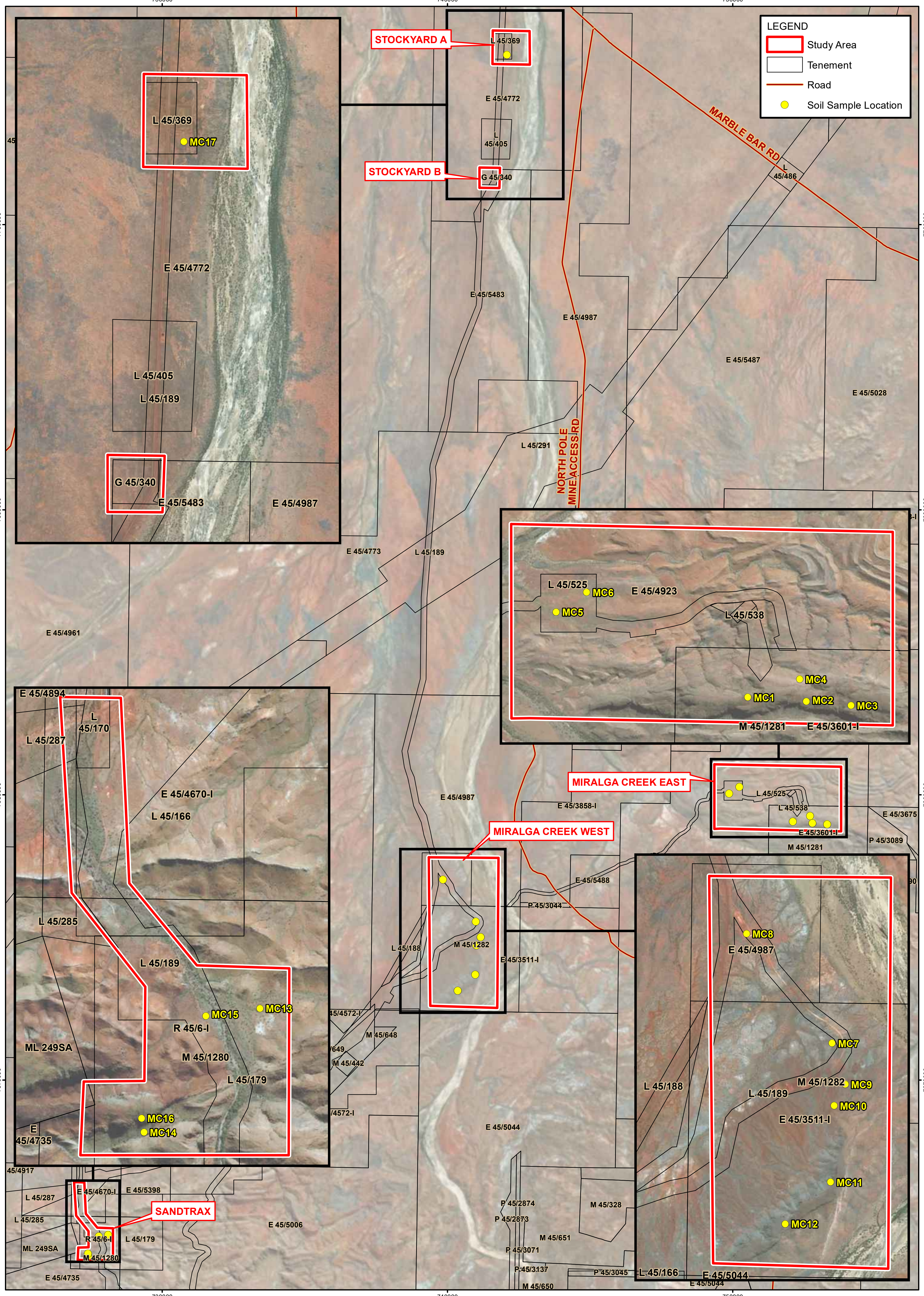
3.2 Test Work and Procedures

Laboratory test work on the sampled soils was conducted at the Mine Earth in-house laboratory for soil physical parameters and sent to the CSBP Soil and Plant Laboratory for analysis of chemical parameters.

Laboratory based soil analyses included:

- Physical characteristics:
    - Soil texture
    - Soil structural stability (Emerson Dispersion Test)
    - Saturated hydraulic conductivity
- 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, 2011). Descriptions of relevant soil classification categories are detailed in Appendix A. All external laboratory results for soil samples are provided in Appendix B.



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N

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Scale: 1:125,000 @ A3
GDA 1994 MGA Zone 50

Figure 3

Soil Sample Sites

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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 descriptions for the 17 sites within the combined study area are presented below.

Site Reference:	MC01	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Miralga Creek East Area - top of ridgeline	**Easting:**	752111
Soil Landform Association:	Ridgeline / Rocky outcrop	**Northing:**	7679061

Plate 1 Surface soil at Site MC01

Soil profile description:

0-5 cm: Skeletal single-grained soil with approximately 75% angular to sub-angular coarse fragments, 2 to 100 mm in size. Outcropping rock present over approximately 30% of surface.

Soil surface: 100% cover of angular to sub-angular coarse fragments at surface, varying in size from 2 mm to 100 mm. Approximately 10% spinifex litter cover.

Vegetation: Spinifex, low Acacia shrubs (<0.5m) and scattered Acacia and Eucalypt tree species (1-3m).

Plate 2 Landscape / vegetation at Site MC01

Site Reference:	MC02	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Miralga Creek East Area - top of ridgeline	**Easting:**	752794
Soil Landform Association:	Ridgeline / Rocky outcrop	**Northing:**	7679010

Plate 3 Surface soil at Site MC02

Soil profile description:

0-5 cm: Skeletal single-grained soil with >75% angular to sub-angular coarse fragments, 2 mm to 75 mm in size. Outcropping rock over approximately 30% of surface.

Soil surface: 100% cover of angular to sub-angular coarse fragments at surface, varying in size from 2 mm to 75 mm. Approximately 20% spinifex litter cover.

Vegetation: Spinifex, low Acacia shrubs (<0.5m) and scattered Acacia tree species (1-3m).

Plate 4 Landscape / vegetation at Site MC02

Site Reference:	MC03	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Miralga Creek East Area - top of ridgeline	**Easting:**	753313
Soil Landform Association:	Ridgeline / Rocky outcrop	**Northing:**	7678965

Plate 5 Surface soil at Site MC03

Soil profile description:

0-5 cm: Skeletal single-grained soil with >75% angular to sub-angular coarse fragments, 2 mm to 100 mm in size. Outcropping rock over approximately 40% of surface.

Soil surface: 100% cover of angular to sub-angular coarse fragments at surface, varying in size from 2 mm to 100 mm. Approximately 30% spinifex litter cover.

Vegetation: Spinifex, low Acacia shrubs (<0.5m), Senna species (1-2m), Grevillea species (1-3m) and Eucalyptus tree species (1-3m).

Plate 6 Landscape / vegetation at Site MC03

Site Reference:	MC04	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Miralga Creek East Area – Upper slope	**Easting:**	752715
Soil Landform Association:	Low hills / Scree slopes	**Northing:**	7679270

Plate 7 Surface soil at Site MC04

Soil profile description:

0-5 cm: Skeletal single-grained soil with approximately 80% angular to sub-angular coarse fragments, 2 mm to 100 mm in size. Outcropping rock over approximately 50% of surface.

Soil surface: 100% cover of angular to sub-angular coarse fragments at surface, varying in size from 2 mm to 150 mm, with 10% spinifex litter cover.

Vegetation: Predominantly Spinifex, low Acacia shrubs (<0.5m), small scattered Acacia tree species (1-3m).

Plate 8 Landscape / vegetation at Site MC04

Site Reference:	MC05	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Miralga Creek East Area – Stony plain adjacent to minor drainage line	**Easting:**	749876
Soil Landform Association:	Stony plain	**Northing:**	7680054

Plate 9 Surface soil at Site MC05

Soil profile description:

0-20 cm: Single-grained soil with 60-70% angular to sub-angular coarse fragments, 2mm to 100mm in size.

Soil surface: Weak surface crust with approximately 95% cover of angular to sub-angular coarse fragments at surface, varying in size from 2mm to 200mm, with 15% spinifex litter cover.

Vegetation: Predominantly Spinifex, low Acacia shrubs (<0.5m), occasional Solanum species and scattered Eucalyptus tree species (2-5m).

Plate 10 Landscape / vegetation at Site MC05

Site Reference:	MC06	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Miralga Creek East Area – base of slope	**Easting:**	750232
Soil Landform Association:	Low hills / scree slopes	**Northing:**	7680286

Plate 11 Surface soil at Site MC06

Soil profile description:

0-20 cm: Predominantly single-grained soil with some weak aggregates up to 50 mm. Approximately 30% angular to sub-angular coarse fragments, 2 mm to 60 mm in size.

Soil surface: Weak surface crust with approximately 25% cover of cryptograms, 50% cover of angular to sub-rounded coarse fragments at surface, varying in size from 2mm to 100mm, with 30% spinifex litter cover.

Vegetation: Predominantly Spinifex with small Acacia tree species (2-3m).

Plate 12 Landscape / vegetation at Site MC06

Site Reference:	MC07	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Miralga Creek West Area – gently undulating stony plain	**Easting:**	740991
Soil Landform Association:	**Stony plain**	**Northing:**	7675562

Plate 13 Surface soil at Site MC07

Soil profile description:

0-20 cm: Single-grained soil with approximately 60-70% angular to sub-angular ironstone and calcrete coarse fragments, 2 mm to 150 mm in size.

Soil surface: Weak surface crust with approximately 75% cover of angular to sub-rounded calcareous and ironstone coarse fragments at surface, varying in size from 2 mm to 80 mm, with 5% leaf litter cover.

Vegetation: Recently burnt, emerging Spinifex, Acacia, Senna, Solanum species with occasional Eucalyptus tree species (2-4 m).

Plate 14 Landscape / vegetation at Site MC07

Site Reference:	MC08	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Miralga Creek West Area - Flat stony spinifex plain	**Easting:**	739840
Soil Landform Association:	Stony plain	**Northing:**	7677037

Plate 15 Surface soil at Site MC08

Soil profile description:

0-20 cm: Weakly structured soil with polyhedral aggregates of moderate strength, 2 to 20 mm in size. Approximately 40 to 50% angular to sub-angular coarse fragments, 2 mm to 40 mm in size.

Soil surface: Weak surface crust with approximately 75% cover of angular to sub-rounded coarse fragments at surface, varying in size from 2 mm to 60 mm, with 10% litter cover.

Vegetation: Predominantly Spinifex with Acacia shrubs to 2 m and Acacia trees to 4 m.

Plate 16 Landscape / vegetation at Site MC08

Site Reference:	MC09	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Miralga Creek West Area - Flat stony spinifex plain	**Easting:**	741215
Soil Landform Association:	Stony plain	**Northing:**	7675013

Plate 17 Surface soil at Site MC09

Soil profile description:

0-10 cm: Single-grained soil with approximately 80% angular to sub-angular coarse fragments, 2 to 40 mm in size.

10-20 cm: Weakly structured soil with weak polyhedral aggregates 2 to 20 mm in size. Approximately 80-90% angular to sub-angular coarse fragments, 2 to 40 mm in size

Soil surface: Weak surface crust with 95% cover of angular to sub-rounded coarse fragments at surface, varying in size from 2 to 70 mm, with 5-10% litter cover.

Vegetation: Predominantly Spinifex with scattered Acacia sp. (1-4 m).

Plate 18 Landscape / vegetation at Site MC09

Site Reference:	MC10	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Miralga Creek West Area – Stony plain at base of slope	**Easting:**	741017
Soil Landform Association:	Stony plains	**Northing:**	7674724

Plate 19 Surface soil at Site MC10

Soil profile description:

0-20 cm: Weakly structured soil with very weak polyhedral aggregates 2 to 30 mm in size. Approximately 60% angular to sub-angular coarse fragments, 2 to 60 mm in size.

Soil surface: Weak surface crust with > 90% cover of angular to sub-angular coarse fragments at surface, varying in size from 2 mm to 200 mm, with < 5% litter cover.

Vegetation: Recently burnt. Predominantly Spinifex with scattered Acacia trees (2-3 m in size), emerging grasses and shrubs.

Plate 20 Landscape / vegetation at Site MC10

Site Reference:	MC11	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Miralga Creek West Area – top of scree slope	**Easting:**	740971
Soil Landform Association:	Low hills / Scree slopes	**Northing:**	7673696

Plate 21 Surface soil at Site MC11

Soil profile description:

0-5 cm: Skeletal, single-grained soil with approximately 90% angular to sub-angular coarse fragments, 2 to 75 mm in size. Outcropping rock over approximately 30% of surface.

Soil surface: 100% cover of angular to sub-angular coarse fragments at surface, varying in size from 2 to 75 mm.

Vegetation: Recently burnt. Emerging grasses and shrubs and occasional small Eucalyptus sp.

Plate 22 Landscape / vegetation at Site MC11

Site Reference:	MC12	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Miralga Creek West Area – top of ridgeline	**Easting:**	740362
Soil Landform Association:	Ridgeline / rocky outcrop	**Northing:**	7673134

Plate 23 Surface soil at Site MC12

Soil profile description:

0-20 cm: Skeletal single-grained soil with approximately 75% angular to sub-angular coarse fragments, 2 to 200 mm in size.

Soil surface: 100% cover of angular to sub-angular coarse fragments at surface, varying in size from 2 to 200 mm.

Vegetation: Recently burnt. Emerging grasses, spinifex and shrubs. Occasional burnt Acacia sp. to 1 to 2 m in height.

Plate 24 Landscape / vegetation at Site MC12

Site Reference:	MC13	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Sandtrax Area – Stony plain at base of slope	**Easting:**	728095
Soil Landform Association:	Stony plain	**Northing:**	7664569

Plate 25 Surface soil at Site MC13

Soil profile description:

0-20 cm: Moderately structured soil with large polyhedral aggregates of moderate strength, 2 to 50 mm in size. Approximately 40% angular to sub-angular coarse fragments, 2 to 75 mm in size.

Soil surface: Moderate surface crust with approximately **5**0% cover of angular to sub-rounded coarse fragments at surface, varying in size from 2 to 75 mm with approximately 15% litter cover.

Vegetation: Spinifex with small Eucalyptus and Acacia sp.,1 to 3 m in size.

Plate 26 Landscape / vegetation at Site MC13

Site Reference:	MC14	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Sandtrax Area – Scree slope	**Easting:**	727404
Soil Landform Association:	Low hills / Scree slopes	**Northing:**	7663831

Plate 27 Surface soil at Site MC14

Soil profile description:

0-20 cm: Single-grained skeletal soil with approximately 75% angular to sub-angular coarse fragments, 2 to 200 mm in size. Outcropping rock over approximately 25% of surface.

Soil surface: 95% cover of angular to sub-angular coarse fragments at surface, varying in size from 2 mm to 200 mm.

Vegetation: Spinifex with occasional low Acacia shrubs, scattered Eucalyptus (3 to 4 m) and Acacia sp. (2 to 3 m).

Plate 28 Landscape / vegetation at Site MC14

Site Reference:	MC15	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Sandtrax Area – Stony plain adjacent to drainage line	**Easting:**	727773
Soil Landform Association:	Stony plain	**Northing:**	7664524

Plate 29 Surface soil at Site MC15

Soil profile description:

0-20 cm: Weakly structured soil with polyhedral aggregates of weak strength, 2 to 30 mm in size. Approximately 10% angular to sub-angular coarse fragments, 2 to 20 mm in size

Soil surface: Weak soil crust at surface. Variable (15-95%) cover of angular to sub-rounded coarse fragments at surface, varying in size from 2 to 60 mm, with 10% litter cover.

Vegetation: Spinifex with scattered Eucalyptus (3 to 4 m) and Acacia sp. (1 to 3 m).

Plate 30 Landscape / vegetation at Site MC15

Site Reference:	MC16	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Sandtrax Area – top of ridgeline	**Easting:**	727391
Soil Landform Association:	Ridgelines / rock outcrops	**Northing:**	7663915

Plate 31 Surface soil at Site MC16

Soil profile description:

0-20 cm: Predominantly single-grained skeletal soil with approximately 75% angular to sub-angular coarse fragments, 2 to 150 mm in size. Outcropping rock over approximately 25% of surface.

Soil surface: Weak surface crust with >95% cover of angular to sub-angular coarse fragments at surface, varying in size from 2 to 150 mm. Approximately 30% litter cover.

Vegetation: Spinifex with low Acacia shrubs (<0.5 m), scattered Eucalyptus (2 to 5 m) and Acacia tree sp. (1 to 3 m).

Plate 32 Landscape / vegetation at Site MC16

Site Reference:	MC17	**Datum:**	GDA 1994 MGA Zone 50
Site Description:	Stockyard A Area – undulating sandplain adjacent to drainage line	**Easting:**	742086
Soil Landform Association:	Sand plain	**Northing:**	7705953

Plate 33 Surface soil at Site MC17

Soil profile description:

0-5 cm: Predominantly single-grained soil with some weak aggregates. Less than 5% angular to sub-angular coarse fragments, 2 to 20 mm in size.

5-20 cm: Massive soil with increasing strength at depth. Less than 5% coarse fragments 2 to 20 mm in size.

Soil surface: Weak soil surface crust with 5% cover of sub-rounded to sub-angular coarse fragments at surface, varying in size from 2 to 15 mm. Approximately 10% litter cover.

Vegetation: Spinifex with sparse small burnt trees (1 to 2 m).

Plate 34 Landscape / vegetation at Site MC17

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 only minor variation in terms of morphological characteristics. The surface soils were grouped into five soil-landform associations, namely ‘Ridgelines / Rocky outcrops’, ‘Low hills / Scree slopes’, Stony plains’, ‘Sandy plains’ and ‘Drainage lines’. The landform and surface soils within these associations were typically characterised as follows:

- Ridgelines / Rocky outcrops;
  - Shallow / skeletal soils over fractured / weathered and competent rock
  - Outcropping rock present at the surface (approximately 20 to 40% cover)
  - High percentage of competent rock fragments through the surface soil profile
- Low hills / Scree slopes;
  - Low undulating hills with minor outcropping rock in some areas, and scree slopes below ridgelines
  - Shallow surface soils (variable depth) over fractured / weathered and competent rock
  - High percentage of competent rock fragments through the surface soil profile
  - Areas of outcropping competent rock present in some areas
- Stony plains;
  - Relatively flat / low relief depositional plains with surface lag of gravel / competent rock materials
  - Deeper soil profiles with well structured ‘topsoil’ layer to approx. 15-20 cm depth
  - Typically, moderate percentage of coarse material (>2 mm) through surface soil profile
- Sandy plains;
  - Flat, depositional areas at low points in local landscape
  - Deep sandy soils (comparative to surrounding soil profiles)
  - Relatively low coarse fraction (>2 mm)
- Drainage channels;
  - Large and distinct incised channels
  - Variable particle size distribution reflecting areas of erosion and deposition in drainage channel. Typically, coarse sands comprise the bulk of the surface soil sized fraction.

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 narrow range of particle size distributions exhibited throughout the study area, with surface soil textures ranging from 'loamy sand' (approximately 5% clay) to 'sandy loam' (approximately 10 to 20% clay) (Table 2).

As would be expected, samples collected from lower in the landscape (e.g. soils from the Stony and Sandy plains) were typically finer grained with a slightly higher clay content than those soils 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 relatively consistent, with the topsoil materials at most of the sampling locations recording single grained to weakly-structured soils with weak aggregation. A weak soil crust was observed at the surface of a number of sampling sites.

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 should be seen as 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 3b (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 in the case of the Class 3b soils, may exhibit dispersion following severe disturbance (e.g. earthworks). Care should be taken to minimise the handling of these soil materials where possible, particularly when wet.

Soils sampled from the surface of the Stockyard A area were classified at Emerson Class 2 (Table 2), indicating partial clay dispersion of the undisturbed soil aggregates. This indicates that the surface soils are prone to dispersion of the clay sized fraction in their natural state.

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

Site #	Depth (cm)	Soil-landform association	Soil texture (< 2 mm soil fraction)	Approximate clay content (%)	Emerson Test Class
MC01	0-5	Ridgelines / rocky outcrops	Loamy sand	5%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
MC02	0-5	Ridgelines / rocky outcrops	Loamy sand	5%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
	10-20		Loamy sand	5%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
MC03	0-5	Ridgelines / rocky outcrops	Clayey sand	5 to 10%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
MC04	0-5	Low Hills / Scree slopes	Loamy sand	5%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
MC05	0-5	Stony plains	Clayey sand	5 to 10%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
	10-20		Sandy loam	10 to 20%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
MC06	0-5	Low Hills / Scree slopes	Clayey sand	5 to 10%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
	10-20		Clayey sand	5 to 10%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
MC07	0-5	Stony plains	Clayey sand	5 to 10%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
	10-20		Sandy loam	10 to 20%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
MC08	0-5	Stony plains	Clayey sand	5 to 10%	5 (aggregate slakes but does not disperse, no dispersion of remoulded soil, soil:water suspension remains dispersed)
	10-20		Clayey sand	5 to 10%	5 (aggregate slakes but does not disperse, no dispersion of remoulded soil, soil:water suspension remains dispersed)
MC09	0-5	Stony plains	Clayey sand	5 to 10%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
	10-20		Sandy loam	10 to 20%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
MC10	0-5	Stony plains	Clayey sand	5 to 10%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)

Site #	Depth (cm)	Soil-landform association	Soil texture (< 2 mm soil fraction)	Approximate clay content (%)	Emerson Test Class
	10-20		Sandy loam	10 to 20%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
MC11	0-5	Low Hills / Scree slopes	Loamy sand	5%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
MC12	0-5	Ridgelines / rocky outcrop	Loamy sand	5%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
	10-20		Loamy sand	5%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
MC13	0-5	Stony plains	Sandy loam	10 to 20%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
	10-20		Sandy loam	10 to 20%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
MC14	0-5	Low Hills / Scree slopes	Loamy sand	5%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
	10-20		Clayey sand	5 to 10%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
MC15	0-5	Stony plains	Clayey sand	5 to 10%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
	10-20		Clayey sand	5 to 10%	3a (aggregate slakes but does not disperse, complete dispersion of remoulded soil)
MC16	0-5	Ridgelines / rocky outcrop	Loamy sand	5%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
	10-20		Clayey sand	5 to 10%	3b (aggregate slakes but does not disperse, partial dispersion of remoulded soil)
MC17	0-5	Sandy plains	Clayey sand	5 to 10%	2 (aggregate slakes with partial dispersion)
	10-20		Sandy loam	10 to 20%	2 (aggregate slakes with partial dispersion)

4.2.5 Hydraulic conductivity

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

Saturated hydraulic conductivity was determined for selected soil samples from the study area. Drainage classes were determined for each sample according to their Ksat (Hunt, N and Gilkes, R, 1992) (Table 3). Average Ksat values for each soil-landform association are presented in Figure 7.

The drainage class of the samples tested ranged between 'moderately slow' and 'moderately rapid' (Table 3 and Figure 7), with the majority of soils classified as having a 'moderate' drainage class. As would be expected, the finer textured soils from lower in the landscape (Sandy plains) recorded the lowest hydraulic conductivity.

The soils from the study area are considered to be relatively free-draining, however the Ksat values may decrease if the soils are compacted during salvage and rehabilitation operations.

Table 3 Saturated hydraulic conductivity (Ksat) for selected soils

Site #	Depth (cm)	Soil-landform association	Ksat (mm/hr)	Drainage Class [1.]
MC01	0-5	Ridgelines / rocky outcrops	20.5	Moderate
MC04	0-5	Low Hills / Scree slopes	36.6	Moderate
MC05	0-5	Stony plains	44.4	Moderate
MC07	0-5	Stony plains	64.1	Moderately rapid
MC10	0-5	Stony plains	25.4	Moderate
MC11	0-5	Low Hills / Scree slopes	52.9	Moderate
MC12	0-5	Ridgelines / rocky outcrop	21.6	Moderate
MC14	0-5	Low Hills / Scree slopes	45.1	Moderate
MC15	0-5	Stony plains	20.6	Moderate
MC16	0-5	Ridgelines / rocky outcrop	35.2	Moderate
MC17	0-5	Sandy plains	7.3	Moderately slow

1. (Hunt, N and Gilkes, R, 1992)

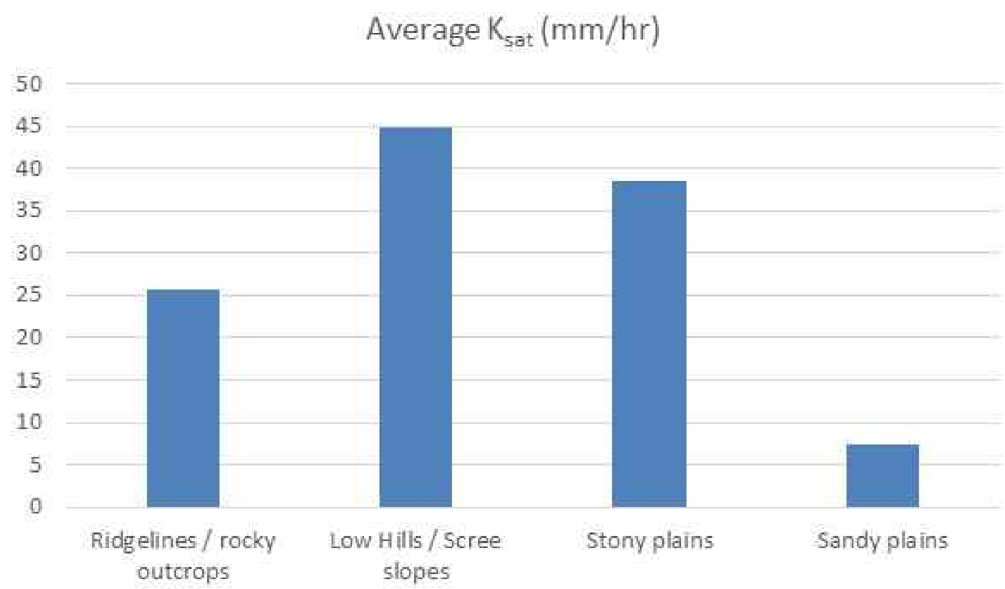


Figure 5 Average Ksat values (mm/hr) for topsoil materials (0-5cm sample) grouped into soil-landform associations.

4.3 Soil Chemical Characteristics

4.3.1 Soil pH and Electrical Conductivity

Soil pH (H_2O) 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_2O) showed substantial variation between and within the various soil-landform associations / sampling locations within the study area, ranging from 6.0 (classified as 'slightly acidic') to 8.6 ('strongly alkaline') with little consistency relating to position in the landscape (Figure 6). On average, the soils were typically pH neutral, with a relative consistency in pH through the surface soil profile (Figure 6).

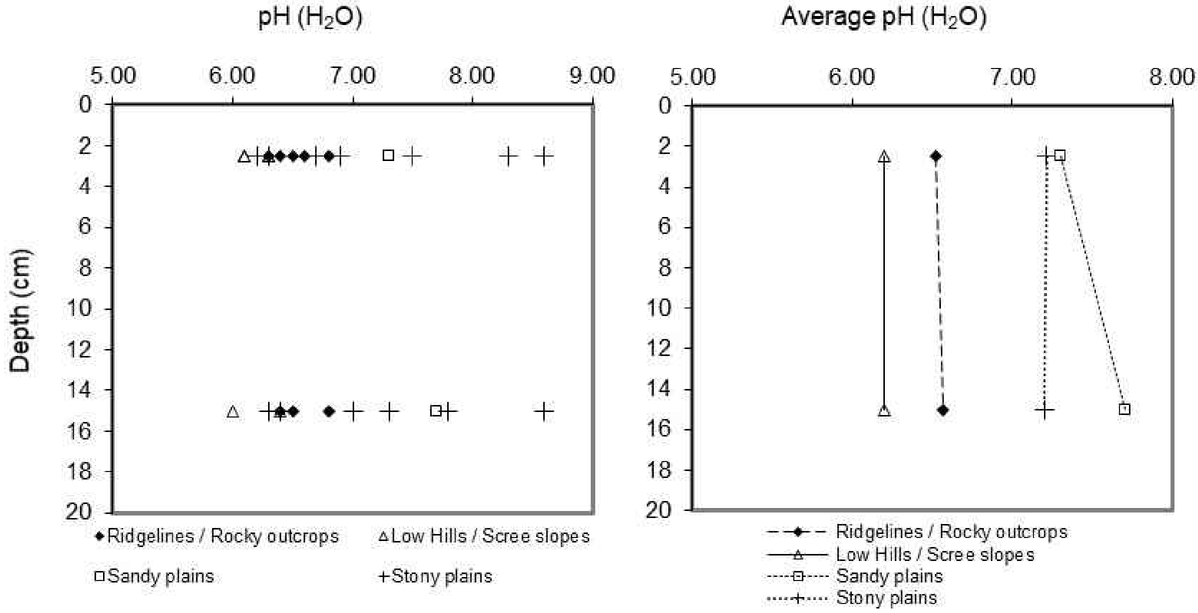


Figure 6 Individual and average pH (H_2O) of soils with depth for each soil-landform association

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, N and Gilkes, R, 1992). The EC of the soils from the study area were all classed as non-saline, based on the standard USDA and CSIRO electrical conductivity categories (Appendix A). Individual EC values ranged between 0.010 dS/m and 0.077 (Figure 7).

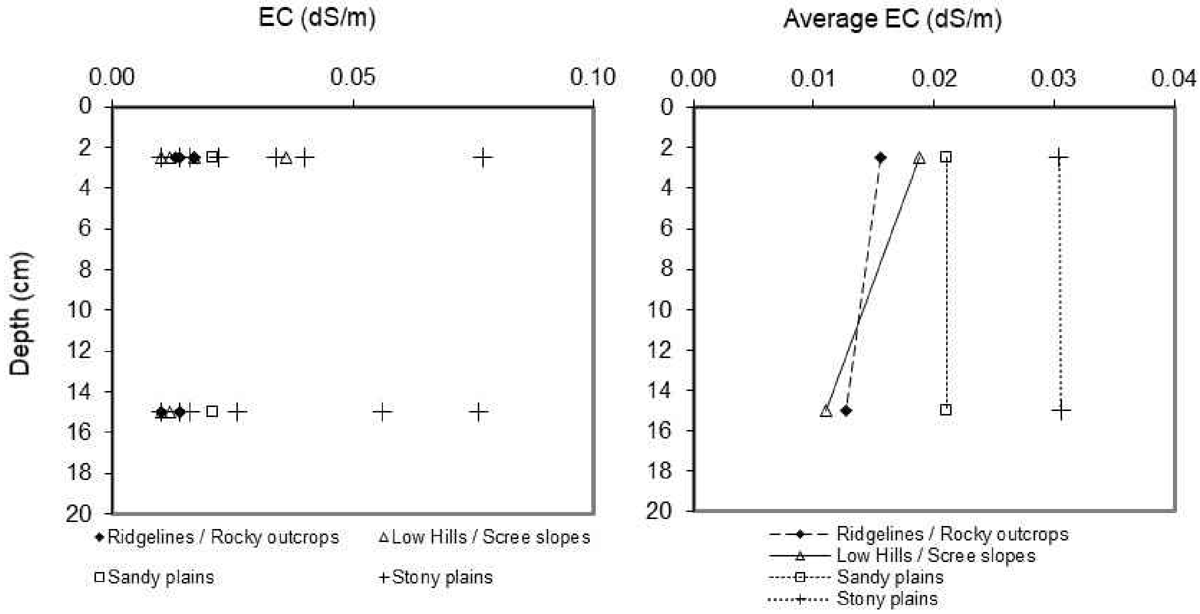


Figure 7 Individual and average EC (dS/m) of soils with depth for each soil-landform association

4.3.2 Soil Organic Matter

The organic matter content of soil is an important factor influencing many physical, chemical and biological soil characteristics. Directly derived from plants and animals, its functions in soil include supporting the micro and macro fauna and flora populations, 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 soil samples was low, as is typical of most highly weathered soils in the Pilbara, ranging between 0.08% and 1.4% (Figure 8).

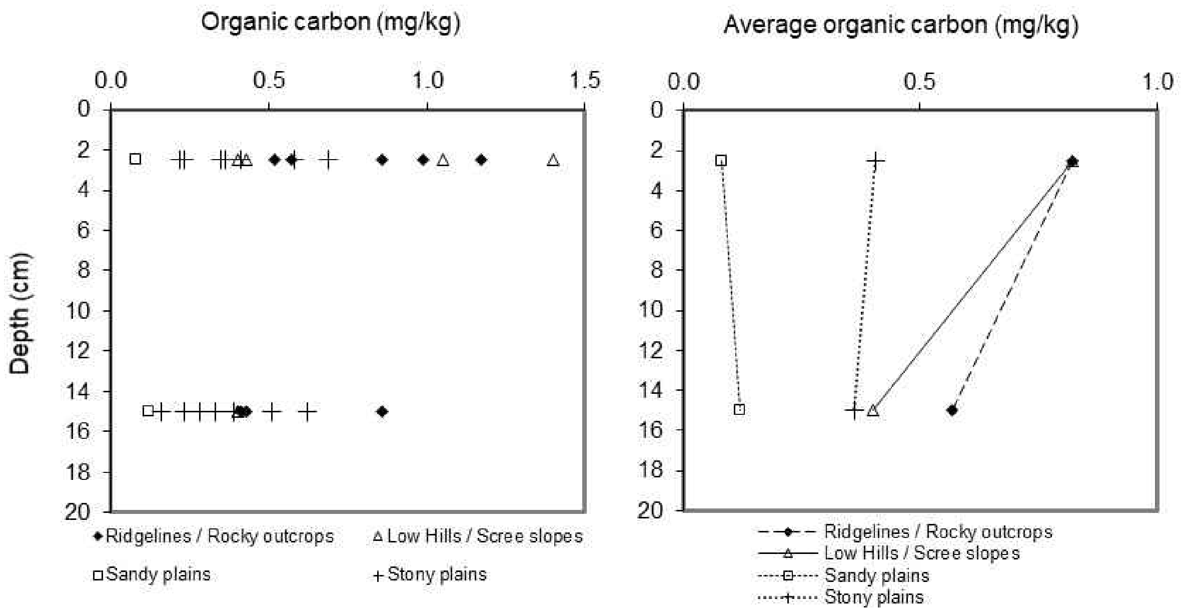


Figure 8 Individual and average Organic C concentration (%) of soils with depth for each soil-landform association

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 Ca^{2+}, Mg^{2+} and 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 (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 ESP results were relatively consistent across the various soil-landform associations (Table 4), with most soils identified as 'non-sodic'. The exchangeable cations and eCEC were generally very low, reflecting the highly weathered and typically coarse textured (i.e. low clay contents) nature of the soils present. The ESP results indicate that there is generally a low risk of clay dispersion. Soils sampled from the Sandy plain soil-landform association within the Stockyard A area (Site 17) recorded ESP values classed as 'sodic'. The propensity for these soils to experience clay dispersion upon saturation is identified in Section 4.2.4.

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 (%)
			Al	Ca	Mg	K	Na		
MC01	0-5	Ridgelines / rocky outcrops	0.09	2.94	0.94	0.21	0.04	4.22	0.95
MC02	0-5	Ridgelines / rocky outcrops	0.13	2.53	0.98	0.24	0.03	3.91	0.77
	10-20		0.14	3.03	1.13	0.28	0.03	4.61	0.65
MC03	0-5	Ridgelines / rocky outcrops	0.19	2.59	0.77	0.32	0.02	3.89	0.51
MC04	0-5	Low Hills / Scree slopes	0.34	2.57	0.83	0.28	0.03	4.05	0.74
MC05	0-5	Stony plains	0.2	1.35	0.76	0.25	0.02	2.58	0.78
	10-20		0.22	1.57	0.9	0.29	0.03	3.01	1.00
MC06	0-5	Low Hills / Scree slopes	0.24	1.2	0.46	0.17	0.03	2.1	1.43
	10-20		0.17	1.53	0.59	0.21	0.03	2.53	1.19
MC07	0-5	Stony plains	0.05	10.11	2.16	0.31	0.03	12.66	0.24
	10-20		0.10	10.43	2.09	0.28	0.03	12.93	0.23
MC08	0-5	Stony plains	0.17	2.5	2.48	0.33	0.15	5.63	2.66
	10-20		0.15	2.81	2.50	0.33	0.20	5.99	3.34
MC09	0-5	Stony plains	0.11	3.19	2.82	0.26	0.03	6.41	0.47
	10-20		0.19	5.36	3.30	0.20	0.04	9.09	0.44
MC10	0-5	Stony plains	0.26	1.49	1.39	0.34	0.04	3.52	1.14
	10-20		0.22	1.78	1.64	0.32	0.04	4	1.00
MC11	0-5	Low Hills / Scree slopes	0.07	4.19	1.01	0.37	0.03	5.67	0.53
MC12	0-5	Ridgelines / rocky outcrop	0.08	2.51	0.96	0.30	0.03	3.88	0.77
	10-20		0.14	2.5	1.04	0.28	0.03	3.99	0.75
MC13	0-5	Stony plains	0.05	3.85	1.61	0.27	0.02	5.8	0.34
	10-20		0.07	3.54	1.64	0.26	0.02	5.53	0.36
MC14	0-5	Low Hills / Scree slopes	0.15	0.79	0.26	0.10	0.01	1.31	0.76
	10-20		0.16	0.78	0.29	0.09	0.01	1.33	0.75
MC15	0-5	Stony plains	0.08	3.51	2.17	0.42	0.03	6.21	0.48
	10-20		0.08	4.45	2.92	0.51	0.03	7.99	0.38
MC16	0-5	Ridgelines / rocky outcrop	0.13	3.99	0.93	0.35	0.02	5.42	0.37
	10-20		0.13	4.41	0.95	0.35	0.03	5.87	0.51
MC17	0-5	Sandy plains	0.04	1.28	1.65	0.23	0.25	3.45	7.25
	10-20		0.07	1.22	2.48	0.22	0.53	4.52	11.73

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 a number of 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.

The plant-available nitrogen concentrations of the soils from the study area were variable, but generally very low ranging from 1 mg/kg to 17 mg/kg nitrate (Figure 9) and from 0.5 mg/kg to 14 mg/kg ammonium (Figure 9). There was no apparent relationship between plant-available nitrogen concentrations and soil-landform association, with a slight decrease in concentration with sample depth.

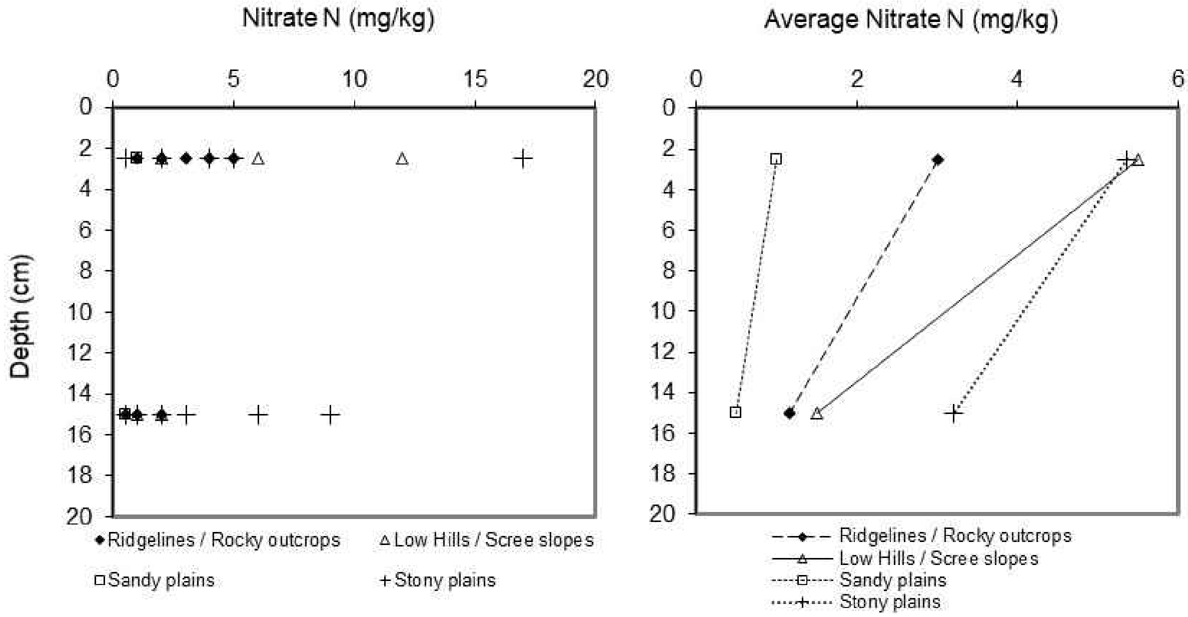


Figure 9 Individual and average Nitrate-N concentration (mg/kg) of soils with depth for each soil-landform association

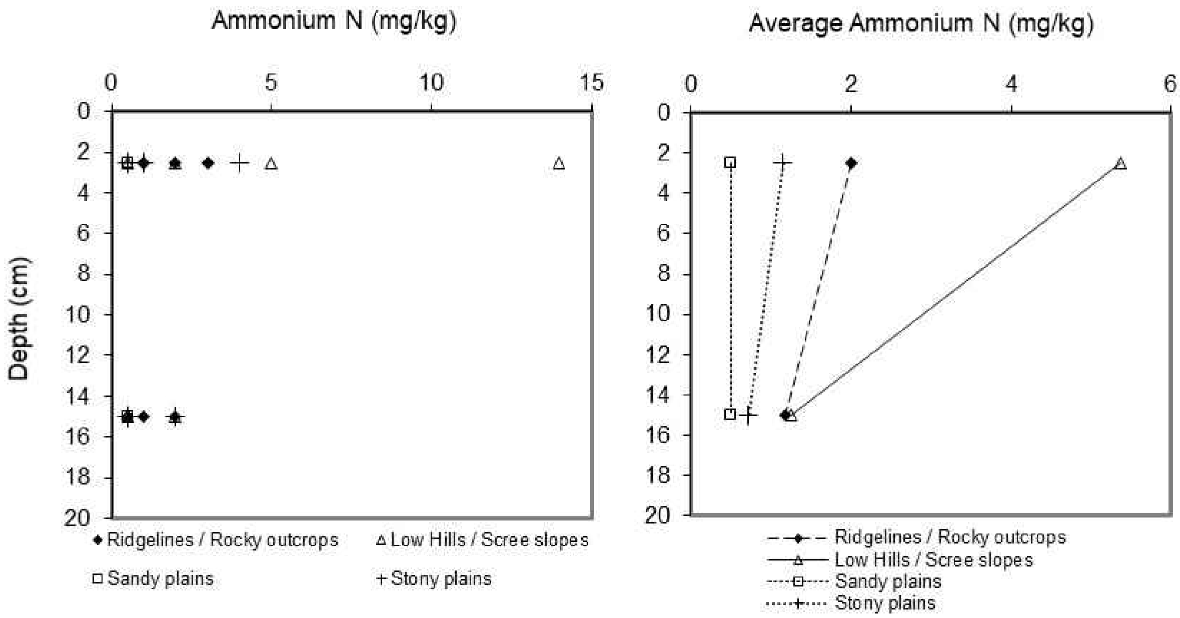


Figure 10 Individual and average Ammonium-N concentration (mg/kg) of soils with depth for each soil-landform association

Phosphorus 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, N. and Weil, R., 2002).

The plant-available phosphorus concentrations of the majority of soils from the study area were classed as low for most samples (<10 mg/kg) (Figure 11). Although there was little consistent correlation with soil-landform association, there was a general reduction in plant-available P concentration with sample depth.

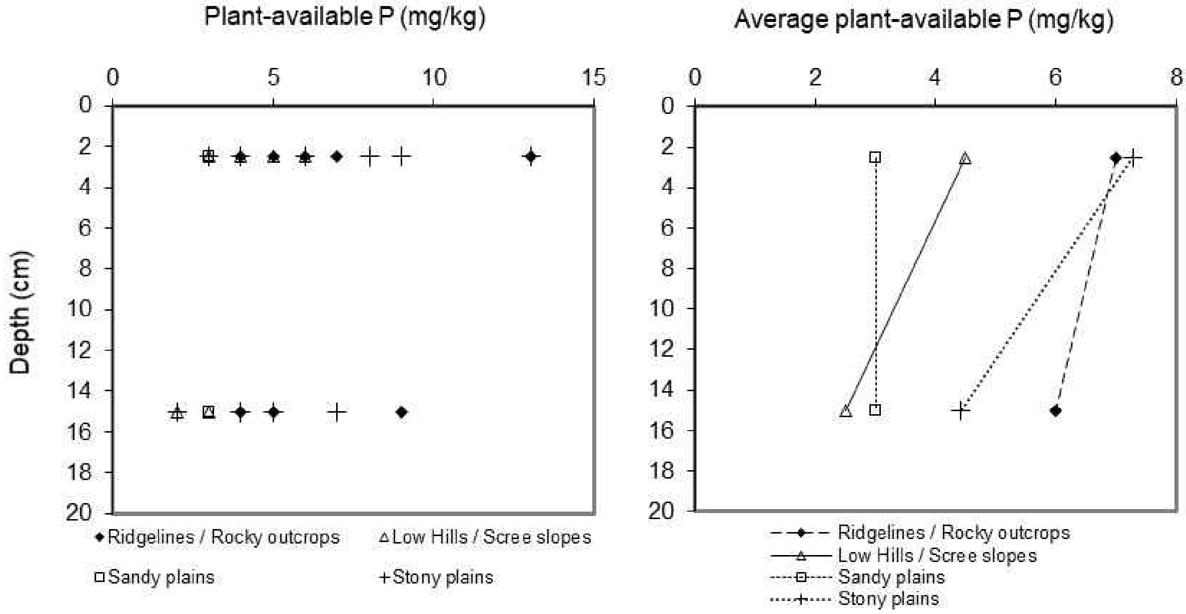


Figure 11 Individual and average plant-available phosphorus concentration (mg/kg) of soils with depth for each soil-landform association

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, N. and Weil, R., 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, with little consistent correlation between the soils from the various soil-landform associations (Figure 12). On average, there was a slight decrease in plant-available K concentration with sample depth.

There was a narrow range of plant-available sulphur (S) concentrations measured for soils from the study area, with individual values ranging from 0.7 mg/kg to 2.6 mg/kg, classed as very low (Moore, 1998). Generally speaking, there was little consistent correlation in plant-available S between the soils from the various soil-landform associations, with only a slight decrease in plant-available S concentration with sample depth (Figure 13).

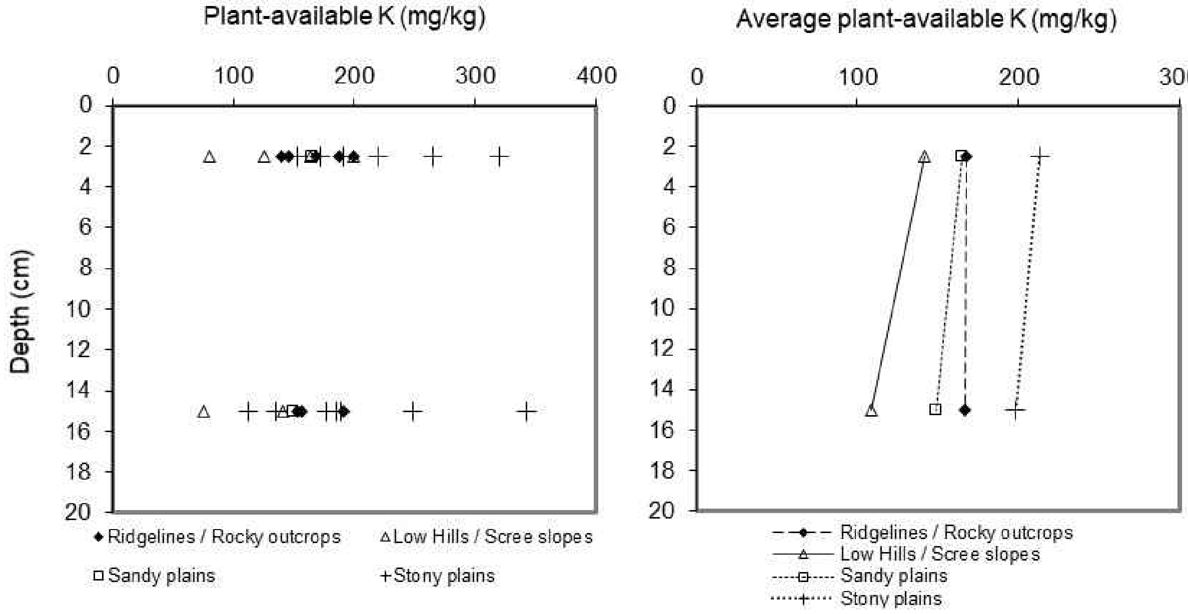


Figure 12 Individual and average plant-available potassium concentration (mg/kg) of soils with depth for each soil-landform association

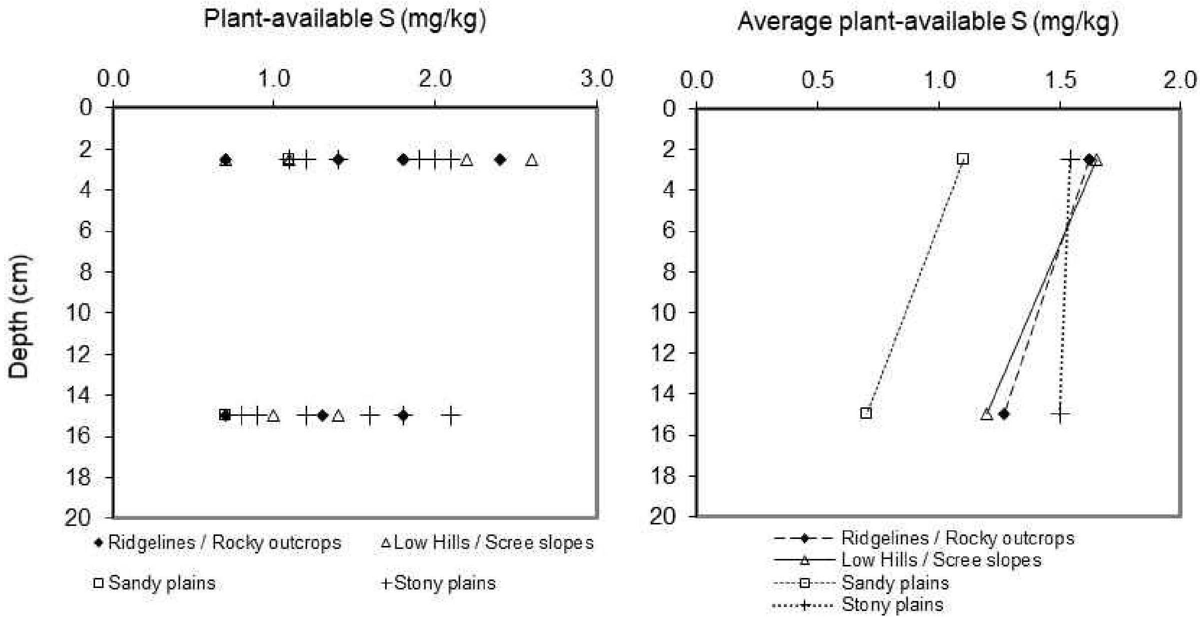


Figure 13 Individual and average plant-available sulphur concentration (mg/kg) of soils with depth for each soil-landform association

4.3.5 Total metal concentrations

The total concentration of selected metals was measured for all samples, with the results presented in Table 5. As a point of comparison, the average crustal abundance (Reimann, C. and de Caritat, P, 1998) for each metal is also provided in Table 5.

Of particular note are the very high baseline concentrations of As and Se in many of the analogue soils tested, 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 trend with sample depth.

Table 5 Total metal concentration for selected samples

Site #	Depth (cm)	Soil-landform association	Total metal concentrations (ug/kg)						
			As	Cd	Cr	Co	Pb	Mo	Se
MC1	0-5	Ridgelines / rocky outcrops	10,837	29	99,603	11,203	12,045	820	794
MC2	0-5	Ridgelines / rocky outcrops	13,065	36	129,505	10,665	11,481	869	2,175
	10-20		11,691	22	112,400	12,507	12,231	879	2,264
MC3	0-5	Ridgelines / rocky outcrops	12,578	40	103,660	10,622	10,895	736	1,827
MC4	0-5	Low hills / Scree slopes	5,566	37	79,255	11,351	10,618	652	655
MC5	0-5	Stony plains	5,587	17	59,926	9,441	10,044	661	467
	10-20		5,618	18	59,070	9,072	10,286	662	418
MC6	0-5	Low hills / Scree slopes	5,113	13	39,634	4,313	9,862	514	391
	10-20		6,145	6	38,138	6,659	11,223	573	430
MC7	0-5	Stony plains	3,805	36	145,430	12,281	7,236	244	201
	10-20		4,589	36	149,178	12,588	6,482	218	188
MC8	0-5	Stony plains	5,908	27	79,786	10,494	10,316	520	345
	10-20		5,848	26	78,571	10,232	9,921	513	717
MC9	0-5	Stony plains	5,885	36	111,401	14,543	8,736	410	818
	10-20		6,421	26	137,777	15,474	9,508	432	866
MC10	0-5	Stony plains	8,324	10	152,912	11,295	9,123	1,211	513
	10-20		7,245	13	142,085	11,596	8,815	1,011	442
MC11	0-5	Low Hills / Scree slopes	6,837	33	74,792	10,094	9,214	656	651
MC12	0-5	Ridgelines / rocky outcrops	6,584	38	94,122	10,645	10,747	598	311
	10-20		8,249	53	96,458	12,930	10,597	807	646
MC13	0-5	Stony plains	18,123	65	130,829	18,645	9,399	942	208
	10-20		18,697	60	143,001	19,564	10,489	872	214
MC14	0-5	Low hills / Scree slopes	35,502	19	85,751	3,796	17,084	1,878	373
	10-20		42,282	17	92,539	4,352	20,269	2,305	525
MC15	0-5	Stony plains	14,686	87	140,932	17,772	10,302	578	106
	10-20		20,030	58	160,232	18,650	10,621	545	973
MC16	0-5	Ridgelines / rocky outcrops	16,525	38	262,998	11,499	16,393	1,413	1,391
	10-20		24,274	50	330,355	12,266	21,020	1,568	1,627
	0-5	Sandy plains	2,998	23	70,999	10,931	7,200	298	373

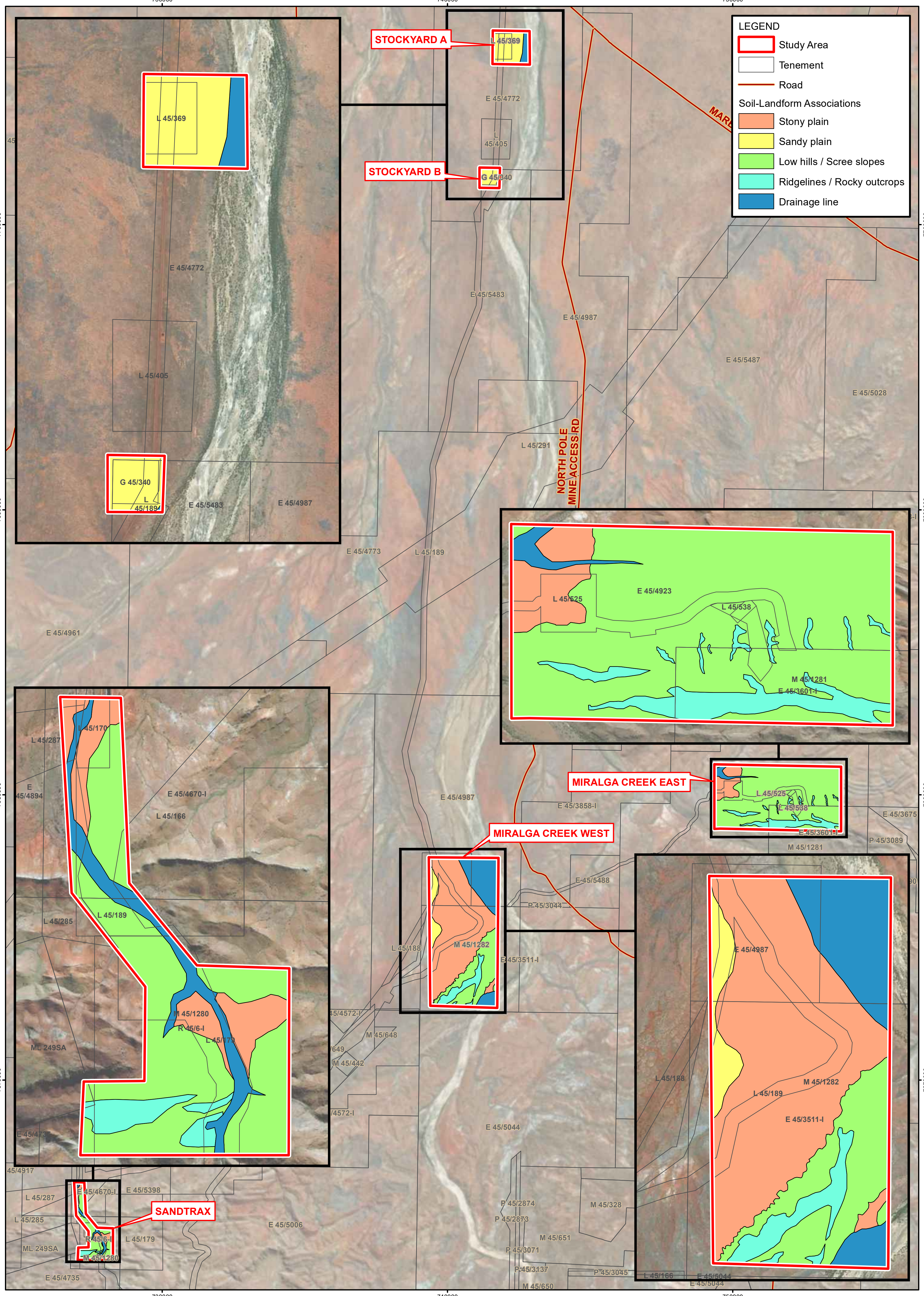
Site #	Depth (cm)	Soil-landform association	Total metal concentrations (ug/kg)						
			As	Cd	Cr	Co	Pb	Mo	Se
MC17	10-20		3,103	20	92,619	11,745	8,500	332	292
Average crustal abundance[1.]			**1,700**	**100**	**126,000**	**24,000**	**14,800**	**1,100**	**120**

1. (Reimann, C. and de Caritat, P, 1998)

5 SOIL LANDFORM ASSOCIATION MAPPING

Five soil-landform associations were identified within the study area namely; 'Ridgelines / Rocky outcrops', 'Low hills / Scree slopes', Stony plains', 'Sandy plains' and 'Drainage lines'. 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 16.

The classification of these soil-landform units provides a means of identifying soils and that may be considered for salvage, storage and use in future rehabilitation activities associated with the Project. When identifying the potential salvage of soils from these units, the potential areas of disturbance and practicalities of soil stripping should be considered.



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Scale: 1:125,000 @ A3
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Figure 4

Soil-Landform Associations

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6 CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this investigation was to characterise the surface soils within the study area, to identify any potentially problematic soil materials that may cause issues during the proposed mining activities, and to identify the optimal use of the soils as a rehabilitation resource. Information detailed within this report can be used to assist in planning and adoption of appropriate soil management and rehabilitation prescriptions for the Project.

Five soil-landform associations were identified within the study area namely; 'Ridgelines / Rocky outcrops', 'Low hills / Scree slopes', 'Stony plains', 'Sandy plains' and 'Drainage lines'. 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 and the amount of coarse rock fragments (>2 mm) present within the soil materials. There was an overall, general consistency in the soil characteristics within each of the three mining areas (Miralga Ck East, Miralga Ck West and Sandtrax).

Many of the chemical and physical characteristics of the surface soils across the study area were relatively similar, with little consistent correlation with soil-landform association, or sample depth. All soils sampled were relatively coarse grained, with generally low clay contents (minor increase in clay with depth), were non-saline, partially dispersive upon severe disturbance, free draining (moderate hydraulic conductivity) and typically low in organic carbon and plant-available nutrients.

Numerous 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 is no apparent correlation with soil-landform associations.

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

- Ridgelines / Rocky outcrops:
    - Shallow / skeletal soils over fractured / weathered and competent rock
    - Outcropping rock present at the surface (approx. 20 to 40% cover)
    - Coarse texture with low clay contents
    - High percentage of competent rock fragments through the surface soil profile
    - Non-saline, non-sodic, low plant-available nutrient concentration
    - Moderate hydraulic conductivity
- Low hills / Scree slopes:
    - Low undulating hills with minor outcropping rock in some areas, and scree slopes below ridgelines
    - Shallow surface soils (variable depth) over fractured / weathered and competent rock
    - High percentage of competent rock fragments through the surface soil profile
    - Coarse texture with low clay contents
    - Non-saline, non-sodic, low plant-available nutrient concentration
    - Low plant-available nutrient concentration
    - Moderate hydraulic conductivity
- Stony plains:
    - Relatively flat / low relief depositional plains with surface lag of gravel / competent rock materials

  - Deeper soil profiles than higher in the landscape
  - Moderate percentage of competent rock fragments through the surface soil profile
  - Non-saline, non-sodic, low plant-available nutrient concentration
  - Moderate hydraulic conductivity
- Sandy plains:
  - Flat, depositional areas at low points in local landscape
  - Deep sandy soils (comparative to surrounding soil profiles)
  - Relatively low coarse fraction (>2 mm)
  - Non-saline, low plant-available nutrient concentration
  - Sodic and partially dispersive
  - Moderately slow hydraulic conductivity
- Drainage channels;
  - Large and distinct incised channels.
  - Variable particle size distribution reflecting areas of erosion and deposition in drainage channel. Typically, coarse sands comprise the bulk of the surface soil sized fraction.

In general, the topsoil materials (0 to 20 cm depth) across the 'Ridgelines / Rocky outcrops', 'Low hills / Scree slopes' and 'Stony plains' soil-landform associations have characteristics which indicate a relatively low inherent erodibility (i.e. low clay content, only partially dispersive, high coarse material content and free draining. The topsoils sampled from the 'Sandy plain' contained relatively low amounts of coarse material (i.e. rock >2 mm) and may be prone to partial clay dispersion. While these soils are considered likely to be more prone to erosion than the soils from higher in the landscape, they are still considered a potential resource for use in rehabilitation activities on flat disturbance areas.

6.1 Soil Management Recommendations

It is recommended that topsoil materials, to a depth of approximately 20 cm from within the 'Stony plain' and 'Low hills / Scree slopes' soil-landform associations are salvaged from disturbance areas, for potential use as a rehabilitation resource. Topsoils from the 'Ridgelines / Rocky outcrops' are also physically and chemically suitable for salvage and use as a rehabilitation medium, however, due to accessibility and the prevalence of outcropping rock, the salvage of these topsoils is likely to be opportunistic.

Ideally, topsoils salvaged from disturbance areas within the 'Low hills / Scree slopes' and any topsoil able to be opportunistically salvaged from the 'Ridgelines / Rocky outcrops' should be stockpiled together for use as a surface rehabilitation medium on rehabilitated slopes of constructed landforms. The high coarse fraction, low clay content, non-dispersive and free draining nature of these topsoils indicate a low inherent erodibility and suitability for use on rehabilitated sloped areas.

Topsoil materials from within the 'Stony plains' of the study area are suitable for salvage and use as a surface rehabilitation medium, particularly for flat rehabilitation areas situated low in the landscape.

Topsoils from the 'Sandy plain' soil-landform association are less suitable for placement on rehabilitated slopes due to the lower coarse rock fraction and tendency for partial dispersion of the clay fraction. These soils however, are still considered a valuable source of surface rehabilitation material for flat surfaces.

Soil materials from within the ‘Drainage channels’ should not be disturbed or salvaged as part of soil stripping operations.

It is recommended that, once disturbance footprints for the Project are finalised, that 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 and closure of waste landforms and other rehabilitation 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 proposed disturbance areas is stripped (where possible) 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, so they do not compromise the structural integrity of the 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.
- Excessive traffic and disturbance of the stockpiles should be minimised to minimise erosion and degradation of soil structure. Care should be taken to minimise the handling of the soils where possible, particularly when wet.
- As a rule topsoil rehabilitation materials should not be placed at depths greater than 0.2 m on rehabilitated areas. This is particularly the case for slope areas of rehabilitation.

Although the majority of soils within the study area, and particularly those from the ‘Low hills / Scree slopes’ and ‘Ridgelines / Rocky outcrops’ soil-landform associations, have a high percentage of competent rock and low inherent erodibility, it is recommended that consideration is given to incorporation of additional competent, benign waste rock (via contour ripping of the rehabilitated surface following topsoil application) to further armour against surface erosion. This is particularly the case for constructed slopes of waste landforms.

7 REFERENCES

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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 (Vsac)	**Strongly acid (Sac)**	**Moderately acid (Mac)**	**Slightly acid (Slac)**	**Neutral (N)**	**Moderately alkaline (Malk)**	**Strongly alkaline (Salk)**
pH_w	< 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_{Ca}	< 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

90423
Mine Earth Pty Ltd

Lab No		6LS19075	6LS19076	6LS19077	6LS19078	6LS19079	6LS19080	6LS19081	6LS19082
Name		MC1	MC2	MC2	MC3	MC4	MC5	MC5	MC6
Customer		MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH
Depth		0-5	0-5	10-20	0-5	0-5	0-5	10-20	0-5
Colour		BR	BR	BR	BRGR	BRGR	BR	BR	BRGR
Gravel	%	0	5	5	0	0	5	5	5
Texture		2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.0
Ammonium Nitrogen	mg/kg	2	1	1	3	5	1	< 1	2
Nitrate Nitrogen	mg/kg	4	3	1	2	6	2	3	2
Phosphorus Colwell	mg/kg	4	7	5	5	4	4	4	3
Potassium Colwell	mg/kg	140	146	153	188	164	172	189	125
Sulfur	mg/kg	1.8	1.8	1.8	2.4	2.2	1.4	1.6	1.1
Organic Carbon	%	0.86	0.99	0.86	1.17	1.40	0.35	0.33	0.43
Conductivity	dS/m	0.017	0.013	< 0.010	0.017	0.017	0.010	< 0.010	0.012
pH Level (CaCl2)		5.1	5.3	5.3	5.1	5.0	5.0	5.1	5.3
pH Level (H2O)		6.3	6.5	6.4	6.4	6.1	6.3	6.3	6.3
Exc. Aluminium	meq/100g	0.090	0.130	0.140	0.190	0.340	0.200	0.220	0.240
Exc. Calcium	meq/100g	2.94	2.53	3.03	2.59	2.57	1.35	1.57	1.20
Exc. Magnesium	meq/100g	0.94	0.98	1.13	0.77	0.83	0.76	0.90	0.46
Exc. Potassium	meq/100g	0.21	0.24	0.28	0.32	0.28	0.25	0.29	0.17
Exc. Sodium	meq/100g	0.04	0.03	0.03	0.02	0.03	0.02	0.03	0.03
Arsenic	ug/kg	10837.35	13064.78	11691.10	12577.55	5566.33	5586.95	5618.30	5113.12
Cadmium	ug/kg	28.99	35.85	21.82	40.04	36.80	16.81	17.61	12.82
Chromium	ug/kg	99602.69	129504.72	112399.98	103660.46	79254.87	59925.71	59069.93	39633.70
Cobalt	ug/kg	11203.33	10664.66	12507.06	10622.48	11350.77	9440.76	9071.63	4313.36

CSBP Lab. Extract Value.

Analysis Results

CSBP Soil and Plant Laboratory

Lab No		6LS19083	6LS19084	6LS19085	6LS19086	6LS19087	6LS19088	6LS19089	6LS19090
Name		MC6	MC7	MC7	MC8	MC8	MC9	MC9	MC10
Customer		MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH
Depth		10-20	0-5	10-20	0-5	10-20	0-5	10-20	0-5
Colour		BRGR	BRGR	BRGR	BRRD	BRRD	BRRD	BRRD	BR
Gravel	%	5	5	5	5	5	5	5	5
Texture		2.0	2.5	2.5	3.0	3.0	3.0	3.0	3.0
Ammonium Nitrogen	mg/kg	2	1	< 1	< 1	< 1	< 1	< 1	4
Nitrate Nitrogen	mg/kg	2	5	2	5	6	4	1	17
Phosphorus Colwell	mg/kg	2	6	5	13	7	8	4	3
Potassium Colwell	mg/kg	141	153	135	220	185	172	112	191
Sulfur	mg/kg	1.4	2.0	1.8	2.1	2.1	1.2	1.2	1.9
Organic Carbon	%	0.40	0.58	0.51	0.22	0.16	0.36	0.28	0.69
Conductivity	dS/m	0.012	0.077	0.076	0.034	0.056	0.014	0.014	0.040
pH Level (CaCl2)		5.1	7.8	7.8	7.0	6.3	6.2	6.1	5.0
pH Level (H2O)		6.4	8.6	8.6	8.3	7.8	7.5	7.3	6.2
Exc. Aluminium	meq/100g	0.170	0.050	0.100	0.170	0.150	0.110	0.190	0.260
Exc. Calcium	meq/100g	1.53	10.11	10.43	2.50	2.81	3.19	5.36	1.49
Exc. Magnesium	meq/100g	0.59	2.16	2.09	2.48	2.50	2.82	3.30	1.39
Exc. Potassium	meq/100g	0.21	0.31	0.28	0.33	0.33	0.26	0.20	0.34
Exc. Sodium	meq/100g	0.03	0.03	0.03	0.15	0.20	0.03	0.04	0.04
Arsenic	ug/kg	6144.77	3805.44	4588.97	5907.68	5847.66	5884.76	6420.82	8324.30
Cadmium	ug/kg	6.28	35.77	35.61	26.78	26.20	35.64	25.89	10.23
Chromium	ug/kg	38138.32	145430.11	149177.69	79785.76	78571.11	111400.55	137777.15	152911.91
Cobalt	ug/kg	6659.19	12280.90	12587.84	10494.22	10231.93	14543.31	15473.72	11294.97

CSBP Lab. Extract Value.

Analysis Results

CSBP Soil and Plant Laboratory

CSBP

	Lab No	6LS19091	6LS19092	6LS19093	6LS19094	6LS19095	6LS19096	6LS19103	6LS19104
	Name	MC10	MC11	MC12	MC12	MC13	MC13	MC14	MC14
	Customer	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH
	Depth	10-20	0-5	0-5	10-20	0-5	10-20	0-5	10-20
Colour		BR	BRGR	BRGR	BRGR	BRGR	BRGR	BRGR	BRGR
Gravel	%	5	0	0	5	5	5	5	5
Texture		3.0	2.5	2.5	2.5	2.0	2.0	1.5	1.5
Ammonium Nitrogen	mg/kg	2	14	3	2	< 1	< 1	< 1	< 1
Nitrate Nitrogen	mg/kg	9	12	5	2	< 1	< 1	2	1
Phosphorus Colwell	mg/kg	2	6	6	4	8	5	5	3
Potassium Colwell	mg/kg	177	199	168	157	265	248	80	76
Sulfur	mg/kg	2.1	2.6	1.4	1.3	1.1	0.8	0.7	1.0
Organic Carbon	%	0.62	1.05	0.57	0.43	0.41	0.39	0.40	0.40
Conductivity	dS/m	0.026	0.036	0.017	0.014	0.016	0.016	< 0.010	< 0.010
pH Level (CaCl2)		5.3	5.6	5.5	5.5	6.1	6.2	4.9	4.9
pH Level (H2O)		6.4	6.3	6.6	6.5	6.9	7.0	6.1	6.0
Exc. Aluminium	meq/100g	0.220	0.070	0.080	0.140	0.050	0.070	0.150	0.160
Exc. Calcium	meq/100g	1.78	4.19	2.51	2.50	3.85	3.54	0.79	0.78
Exc. Magnesium	meq/100g	1.64	1.01	0.96	1.04	1.61	1.64	0.26	0.29
Exc. Potassium	meq/100g	0.32	0.37	0.30	0.28	0.27	0.26	0.10	0.09
Exc. Sodium	meq/100g	0.04	0.03	0.03	0.03	0.02	0.02	< 0.01	0.01
Arsenic	ug/kg	7245.00	6837.28	6583.84	8248.55	18122.90	18697.23	35502.12	42282.11
Cadmium	ug/kg	12.66	33.20	37.99	53.07	65.32	59.71	18.67	17.26
Chromium	ug/kg	142084.93	74791.52	94121.96	96457.64	130828.87	143001.43	85751.42	92538.93
Cobalt	ug/kg	11596.00	10094.05	10645.19	12929.91	18644.62	19563.91	3796.38	4351.64

CSBP Lab. Extract Value.

Analysis Results

CSBP Soil and Plant Laboratory

		6LS19105	6LS19106	6LS19107	6LS19108	6LS19109	6LS19110
Lab No		6LS19105	6LS19106	6LS19107	6LS19108	6LS19109	6LS19110
Name		MC15	MC15	MC16	MC16	MC17	MC17
Customer		MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH	MINE EARTH
Depth		0-5	10-20	0-5	10-20	0-5	10-20
Colour		DKBR	DKBR	DKBR	DKBR	BR	BR
Gravel	%	0	5	5	5	0	5
Texture		2.5	2.5	2.5	2.5	2.0	2.5
Ammonium Nitrogen	mg/kg	< 1	< 1	1	< 1	< 1	< 1
Nitrate Nitrogen	mg/kg	4	1	1	< 1	1	< 1
Phosphorus Colwell	mg/kg	9	4	13	9	3	3
Potassium Colwell	mg/kg	320	343	199	191	165	149
Sulfur	mg/kg	1.1	0.9	0.7	0.7	1.1	0.7
Organic Carbon	%	0.23	0.23	0.52	0.41	0.08	0.12
Conductivity	dS/m	0.022	0.016	0.014	0.014	0.021	0.021
pH Level (CaCl2)		6.0	6.2	5.8	6.1	6.2	6.1
pH Level (H2O)		6.7	7.0	6.8	6.8	7.3	7.7
Exc. Aluminium	meq/100g	0.080	0.080	0.130	0.130	0.040	0.070
Exc. Calcium	meq/100g	3.51	4.45	3.99	4.41	1.28	1.22
Exc. Magnesium	meq/100g	2.17	2.92	0.93	0.95	1.65	2.48
Exc. Potassium	meq/100g	0.42	0.51	0.35	0.35	0.23	0.22
Exc. Sodium	meq/100g	0.03	0.03	0.02	0.03	0.25	0.53
Arsenic	ug/kg	14686.47	20030.08	16525.00	24273.78	2998.46	3102.56
Cadmium	ug/kg	87.08	58.25	37.96	49.98	22.94	20.36
Chromium	ug/kg	140932.07	160232.46	262998.45	330354.62	70999.09	92619.12
Cobalt	ug/kg	17772.36	18650.28	11498.76	12266.09	10930.56	11744.70

CSBP Lab. Extract Value.

Analysis Results

CSBP Soil and Plant Laboratory

	Lab No	6LS19075	6LS19076	6LS19077	6LS19078	6LS19079	6LS19080	6LS19081	6LS19082
Lead	ug/kg	12044.84	11480.94	12230.99	10895.07	10618.04	10044.25	10286.42	9861.63
Molybdenum	ug/kg	820.3	868.5	878.5	736.2	652.1	661.2	662.2	513.9
Selenium	ug/kg	793.95	2174.51	2263.60	1826.90	654.79	466.85	417.83	391.48

Analysis Results

CSBP Soil and Plant Laboratory

	Lab No	6LS19083	6LS19084	6LS19085	6LS19086	6LS19087	6LS19088	6LS19089	6LS19090
Lead	ug/kg	11223.39	7235.66	6481.60	10316.18	9920.70	8736.26	9508.10	9122.55
Molybdenum	ug/kg	573.1	244.1	218.4	519.9	512.8	410.0	432.1	1211.2
Selenium	ug/kg	429.77	201.09	187.73	344.63	716.56	818.32	865.90	512.88

Analysis Results

CSBP Soil and Plant Laboratory

	Lab No	6LS19091	6LS19092	6LS19093	6LS19094	6LS19095	6LS19096	6LS19103	6LS19104
Lead	ug/kg	8814.64	9213.87	10747.14	10597.00	9399.28	10489.43	17083.77	20269.36
Molybdenum	ug/kg	1011.4	655.8	597.5	807.0	942.1	872.3	1877.8	2305.4
Selenium	ug/kg	441.78	650.87	310.51	646.36	207.63	214.44	373.39	524.95

Analysis Results

CSBP Soil and Plant Laboratory

	Lab No	6LS19105	6LS19106	6LS19107	6LS19108	6LS19109	6LS19110
Lead	ug/kg	10302.09	10620.64	16393.35	21019.83	7200.07	8500.09
Molybdenum	ug/kg	578.3	545.3	1413.1	1567.6	298.1	332.4
Selenium	ug/kg	105.80	972.63	1391.42	1627.06	372.77	291.81