Northern Minerals Limited

Browns Range Project

Baseline Soil and Landform Assessment

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Northern Minerals Limited - Browns Range Project

Baseline Soil and Landform Assessment

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Executive Summary

Outback Ecology was commissioned by Northern Minerals Limited to conduct a baseline soil assessment of the near surface soils within the proposed Browns Range Project Study Area (the 'Overall Study Area'). The 'Soil Survey Area' is located within the 'Overall Study Area' and encompasses an area of approximately 9606 hectares (ha). The Browns Range Project (the Project) is located adjacent to the Western Australia / Northern Territory border, approximately 150 kilometres (km) southeast of Halls Creek, on Gordon Downs Station in the Shire of Halls Creek.

The information pertaining to the surface soils and landforms presented in this report was derived from a field investigation by Outback Ecology. The aim of the soil and landform baseline survey was to develop a greater understanding of the physical and chemical properties of surface soils (to a maximum depth of 1.5 metres [m]) occurring within potential disturbance areas related to the Project, to identify potentially problematic soils, and to assist with the development of recommendations for the use of soil resources in rehabilitation activities.

Four soil-landform associations were identified within the Soil Study Area, namely; 'colluvium gravelly soils', 'deep sandy plains', 'metamorphic outcrops with rocky soils' and 'sand over gravel plains'. A total of 22 'surface' soil sampling sites were investigated within these soil-landform associations.

Characterisation of representative samples indicated a range of soil properties between, and in some instances within, the soils and soil-landform associations investigated. A summary of the physical and chemical characteristics of the surface soils within each soil-landform association follows below and is summarised in **Table ES1**.

Physical characteristics of surface soils

The surface soils surveyed were typically classed as sandy loams to sandy clay loams, reflecting some variation in the clay fraction of the soil (**Table ES1**). The surface soils exhibited varying amounts of coarse rock fragments and outcropping rock. The coarse material content (i.e. competent rock >2 millimetres [mm] in size) was highest in the 'metamorphic outcrops with rocky soil' soil-landform association, and lowest in the 'deep sandy plains'. The majority of surface soils were typically single grained in structure, occasionally with some weak to moderate soil structure in the upper soil profile.

The majority of the surface soils were identified by the Emerson Aggregate Test as non-dispersive (Emerson Class 6 and 8) or partially dispersive (Emerson Class 3a, 3b and 5). Many of the soils exhibited a tendency for clay dispersion following disturbance of the <2 mm soil fraction. Soils of the 'deep sandy plains' soil-landform association were the most dispersive particularly from deeper in the soil profile (e.g. 20 to 110 centimetres [cm]). By contrast, susceptibility to dispersion and instability decreased with depth for soils of the 'sand over gravel' and 'colluvium gravelly soils' soil-landform associations. Increased susceptibility to dispersion following disturbance indicates that some of these materials may be problematic once disturbed and re-deposited. However, the high amount of coarse material present within many of the soils sampled is likely to mitigate against erosion and provide surface stability, as reflected in the undisturbed environment. For example, soils from the 'metamorphic outcrops with rocky soils' soil-landform association were the least dispersive and characteristically had the highest amount of coarse rock fragments.

Measurement of soil strength, as modulus of rupture (MOR), indicated that the majority of soils within each soil-landform association are unlikely to hard set upon wetting and drying. However, care should be taken to minimise handling of soil materials, particularly when wet, to limit the degree of soil structural decline.

The water holding capacity of the soils was variable and dependant on soil texture and coarse material content. The majority of the representative samples analysed for water retention characteristics from the various soil-landform associations had 'moderate' water holding capacity (**Table ES1**). The plant-available water (PAW) content for the total soil material (i.e. including the <2 mm fraction and coarse fraction) ranged from 5.4% ('colluvium gravelly soils' soil-landform association, 40 to 50 cm depth) to 22.1% PAW ('sand over gravel plains' soil-landform association, 0 to 10 cm depth). The lowest PAW values were typically found for samples from deeper in the soil profile, indicating a general reduction in water holding capacity with depth.

Chemical characteristics of surface soils

Soil pH ranged between pH 4.9 to pH 8.6 (pH H_2O) with the majority of the soils classed as 'moderately acidic' to 'neutral' (**Table ES1**). Average soil pH did not change with depth within the majority of the soil profiles, except in the 'metamorphic outcrops' where the average pH decreased to 'strongly acidic' with depth. All surface soils were classed as 'non-saline' and non-sodic.

Soil nutrient analyses indicated low concentrations of plant-available nutrients ('plant-available' nitrogen [N], phosphorus [P], potassium [K] and sulphur [S]) in all surface soils. The organic carbon content was generally very low. Low levels of nutrients and organic carbon are considered typical for soils of the arid region and not problematic for supporting native plant species.

Total concentrations of arsenic (As), cadmium (Cd), zinc (Zn), and mercury (Hg) in all the surface soils tested were below the limit of reporting (LOR). Results for chromium (Cr), copper (Cu), lead (Pb) and nickel (Ni) above the limit of reporting were compared with the 'Ecological Investigation Levels' (EILs) for soils (Department of Environment and Conservation (DEC 2010). None of the soils tested exceeded the EILs for the elements assessed.

Conclusions and recommendations

None of the surface soils within the Soil Study Area are considered to be problematic from a soil handling, rehabilitation and erodibility perspective.

Little variation in the majority of soil chemical and physical characteristics was identified between the four soil-landform associations from different positions in the landscape. Based on the four soil-landform associations identified, three soil management units (SMUs) have been delineated and mapped for the Soil Study Area. The three SMUs represent a preliminary classification of potential soil resources that may be salvaged for use in future rehabilitation activities. A preliminary inventory has been developed for the SMUs including indicative topsoil stripping depths, key soil characteristics, volumes from within proposed disturbance areas and recommendations for potential use in rehabilitation applications. Further refinement of this information and calculations of potential sub-surface soil or overburden waste resource volumes can occur as the Project develops.

While none of the surface soils in the Soil Study Area are considered to be overly problematic, the different properties of the soils (primarily the amount of coarse material present) from different positions in the landscape will, in some instances influence their suitability for placement as a rehabilitation medium. The placement of salvaged soil materials on waste landforms will depend, to some degree, on the final design of the waste landforms. It may be beneficial to target specific areas of the waste landforms for selective placement of rehabilitation resources and have rehabilitation prescriptions (e.g. depth of soil and seed mixes) which are targeted for certain positions / aspects, within the constructed landforms.

Table ES1: Average physical and chemical characteristics of surface soils (grouped into soil-landform associations) within the Browns Range Project. Figures 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)	Physical properties					Chemical properties					
		Soil texture [1]	Coarse material content (%) [2]	Emerson Class [3]	Modulus Of Rupture (kPa)	Water retention (PAW%) [4]	pH (H_2O)	Salinity Class (dS/m)	Organic carbon (%)	Nutrient status	Exchangeable Sodium Percentage (%)	Total metal concentrations [5]
Colluvium gravelly soils (C S)	0 to 10	Sandy loam	40	Partially dispersive (2, 3a, 5)	Non-hardsetting (34.7)	Moderate (11.1)	Moderately acidic (5.9)	Non-saline	Low (0.5)	Low	Non-sodic	Low
	20 to 40	Sandy loam	47	Partially dispersive (3a, 5)	Non-hardsetting (51.6)	-	Neutral (6.6)	Non-saline	Low (0.1)	Low	Non-sodic	Low
	40 to 80	Sandy clay loam	77	Partially dispersive (3a, 5)	Hardsetting (69.7)	Low (5.4)	Slightly acidic (6.1)	Non-saline	Low (0.1)	Low	Non-sodic	Low
	100 to 110	Sandy clay	29	Partially dispersive (5)	Non-hardsetting (33.2)	-	Slightly acidic (6.2)	Non-saline	Low (0.2)	Low	Non-sodic	Low
Deep sandy plain (D S)	0 to 10	Sandy loam	3	Non-dispersive (8)	Non-hardsetting (32.8)	-	Slightly acidic (6.0)	Non-saline	Low (0.4)	Low	Non-sodic	Low
	20 to 40	Sandy loam	4	Variable; dispersive to non-dispersive (1, 3a, 5, 8)	Non-hardsetting (33.0)	Moderate (16.6)	Slightly acidic (6.2)	Non-saline	Low (0.2)	Low	Non-sodic	Low
	40 to 80	Sandy clay loam	7	Partially dispersive (2, 3a, 5)	Non-hardsetting (47.5)	-	Neutral (6.5)	Non-saline	Low (0.1)	Low	Non-sodic	Low
	100 to 160	Sandy loam	8	Partially dispersive (2, 3b, 5)	Non-hardsetting (33.8)	-	Neutral (6.6)	Non-saline	Low (0.1)	Low	Non-sodic	Low

Soil-landform association	Depth (cm)	Physical properties					Chemical properties					
		Soil texture [1]	Coarse material content (%) [2]	Emerson Class [3]	Modulus Of Rupture (kPa)	Water retention (PAW%) [4]	pH (H_2O)	Salinity Class (dS/m)	Organic carbon (%)	Nutrient status	Exchangeable Sodium Percentage (%)	Total metal concentrations [5]
Metamorphic outcrop with rocky soils (M O)	0 to 10	Sandy loam	56	Variable; partially dispersive to non-dispersive (5, 8)	Non-hardsetting (54.5)	Moderate (13.0)	Slightly acidic (6.0)	Non-saline	Low (0.4)	Low	Non-sodic	Low
	20 to 40	Sandy loam	64	Partially dispersive (5)	Non-hardsetting (57.1)	Moderate (10.9)	Moderately acidic (5.6)	Non-saline	Low (0.2)	Low	Non-sodic	Low
	40 to 80	Sandy clay loam	65	Partially dispersive (5)	Hardsetting (64.8)	-	Strongly acidic (5.4)	Non-saline	Low (0.2)	Low	Non-sodic	Low
Sand over gravel plain (S G)	0 to 10	Sandy loam	10	Variable; partially dispersive to non-dispersive (3a, 5, 8)	Non-hardsetting (34.5)	High (22.1)	Slightly acidic (6.3)	Non-saline	Low (0.4)	Low	Non-sodic	Low
	20 to 40	Loamy sand	14	Variable; partially dispersive to non-dispersive (3a, 5, 8)	Non-hardsetting (41.6)	-	Slightly acidic (6.2)	Non-saline	Low (0.1)	Low	Non-sodic	Low
	40 to 80	Sandy clay loam	26	Variable; partially dispersive to non-dispersive (5, 8)	Non-hardsetting (59.6)	Moderate (14.4)	Slightly acidic (6.4)	Non-saline	Low (0.1)	Low	Non-sodic	Low
	100 to 160	Sandy clay loam	46	Partially dispersive (5)	Non-hardsetting (37.6)	Low (9.1)	Slightly acid (6.4)	Non-saline	Low (0.1)	Low	Non-sodic	Low

1. Based on the <2 mm size fraction
2. Determined for all coarse fragments >2 mm in size
3. See Appendix B for Emerson Classes.
4. Plant-available water (PAW) (% vol) of total material (<2 mm fraction and coarse material)
5. 'Low' metal concentrations indicate results below Ecological Investigation Levels (EILs) (Department of Environment 2010)

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1. INTRODUCTION

1.1 Background

Northern Minerals Limited (Northern Minerals) is an ASX-listed company focused on the development of rare earth elements (REE). The Browns Range Project (the Project) consists of three granted exploration licenses E80/3547, E80/3548, E80/4393 and one tenement application E80/4479. The Project previously formed part of the Gardiner-Tanami Project, but since 2009 has become a focus for Northern Minerals' REE exploration program. The Project is located within the Kimberley region of Western Australia, adjacent to the Western Australia / Northern Territory border, approximately 150 km southeast of Halls Creek (**Figure 1**). The Project is located on Gordon Downs Station in the Shire of Halls Creek.

Outback Ecology was commissioned by Northern Minerals Limited to conduct a baseline soil and landform assessment of the surface soils within the area of the proposed Browns Range Project (the Study Area). The soil survey was one component of a broader study undertaken concurrently by Outback Ecology, including a Terrestrial Vertebrate Fauna survey, Terrestrial SRE Invertebrate Fauna survey, Subterranean Fauna survey and a Flora and Vegetation survey.

The baseline soil and landform field survey was conducted in August 2012. An additional assessment of surface soils and vegetation on analogue slopes was conducted in May 2013, concurrently with a flora and vegetation survey (Outback Ecology 2014).

The soil and landform baseline survey was conducted to develop a greater understanding of the physical and chemical properties of the surface soils (to a maximum depth of 1.5 metres [m]), to identify potentially problematic soil materials and to assist with the development of recommendations for the use and placement of soil resources as part of rehabilitation and mine closure activities.

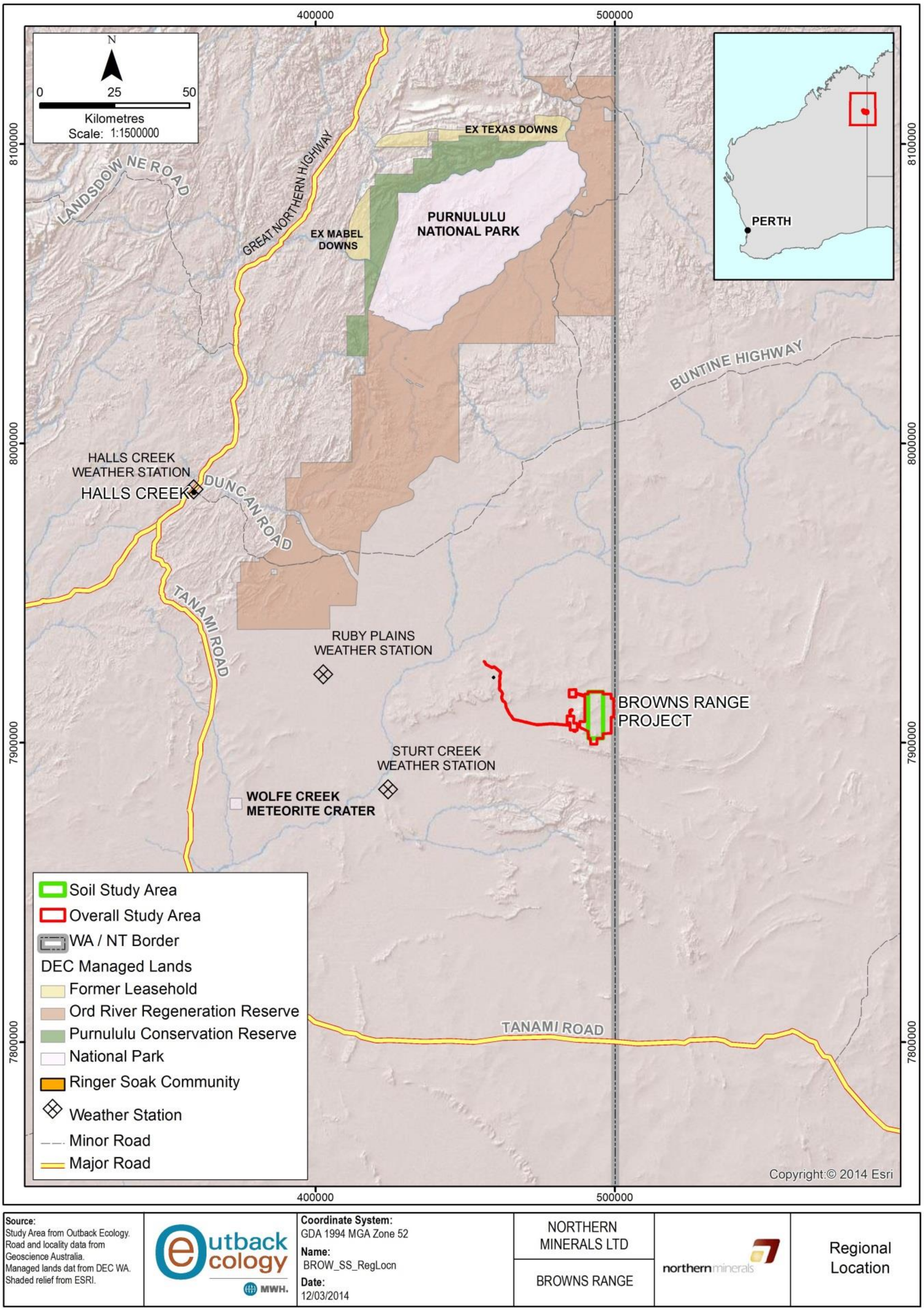


Figure 1: Regional location of the Browns Range Project

1.2 Report scope and objectives

The soil survey was conducted in accordance with the Western Australia (WA) Department of Mines and Petroleum (DMP), formerly the WA Department of Industry and Resources (DoIR), *Guidelines for Mining Proposals in Western Australia* (DoIR 2006) and the Commonwealth Department of Resources, Energy and Tourism (DRET) *Leading Practice Sustainable Development Program for the Mining Industry* (DRET 2011).

Specifically, objectives of the baseline surface soil assessment comprised:

- a brief description of the geology in and surrounding the Project area;
- a summary of land systems within the Project and surrounding areas;
- a summary of available information pertaining to soils and landforms within the Project area;
- assessment of physical and chemical surface soil characteristics, corresponding to landform attributes and vegetation community boundaries within the Project area;
- mapping of soil types derived from land systems and soil-landform associations within the Project area;
- identification of potentially-problematic materials which may influence rehabilitation practices, and ways to minimise these impacts;
- a description of the likely impacts to landforms and soils as a result of mining and construction activities;
- development of a preliminary soil resources inventory;
- the development of recommendations for soil / earthworks components of rehabilitation prescriptions (e.g. soil stripping and replacement depths); and
- recommendations for future monitoring or assessment of soil and landform attributes.

To facilitate the above objectives, this report documents the results of the baseline soil and landform assessment and provides the following:

- descriptions of surface soil profile morphology, based on Australian Soil Classification Standards (McDonald *et al.* 1998);
- assessment of soil physical parameters;
    - soil texture and particle size distribution;
    - structural stability (Emerson Aggregate Test);
    - hardsetting / strength of disturbed material (modified Modulus of Rupture (MOR) test);
    - hydraulic conductivity; and
    - water retention characteristics of representative samples.
- assessment of soil chemical characteristics;
    - pH and electrical conductivity;
    - plant-available nutrients (N, P, K, S) and soil organic matter;
    - exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) of selected samples, derivation of exchangeable sodium percentage (ESP); and
    - total metal concentrations.

2. DESCRIPTION OF THE STUDY AREA

2.1 Climate

The Study Area experiences an arid-tropical climate with mainly summer rainfall due to a monsoonal influence (Graham 2001b). The Bureau of Meteorology (BOM) weather station at Halls Creek Airport, which is located approximately 150 km northwest of the Study Area, is the closest locality with comprehensive climate data available and consequently provides climate information most relevant to the Study Area (**Figure 2**).

Mean maximum temperatures at Halls Creek Airport range from 27.2° Celcius (C) in July to 38.4°C in November, and peak temperatures are recorded from September to April (**Figure 2**). The mean minimum temperature in winter months ranges from 12.6 to 14.8°C. Halls Creek Airport has a mean annual rainfall of 635.8 mm and an average of 49 rain days per year (BOM 2012). The majority of rainfall consistently occurs between November and March (the 'wet season'), whereas very little rainfall is typically recorded in winter months (the 'dry season') (**Figure 2**). However, rainfall in the region can be highly localised and unpredictable, with substantial fluctuations occurring spatially and temporally (BOM 2012). Monthly rainfall at Halls Creek Airport was highly variable over the period 2008 to 2012. For example, for the month of March, 379.8 mm of rain was recorded in 2011, but only 69 mm was recorded in 2010 and only 11 mm was recorded in 2008 (**Figure 3**).

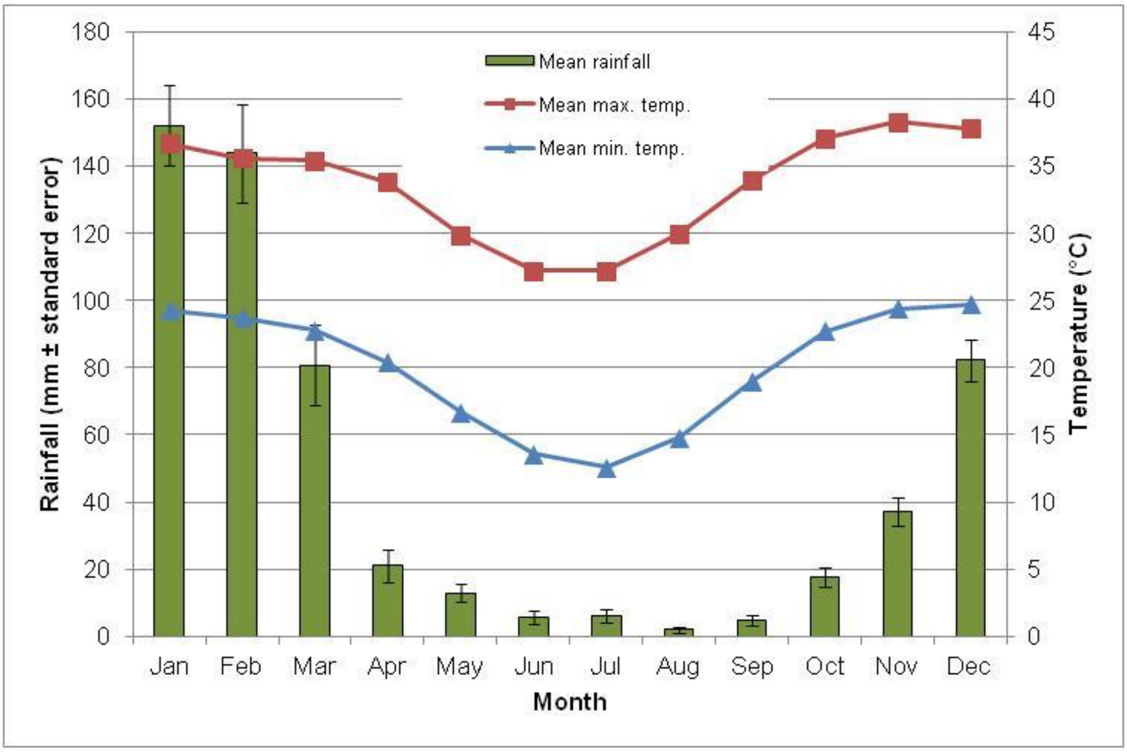


Figure 2: Climate data for Halls Creek Airport weather station (002012)

Source data: BOM (2012), 1944 to 2012

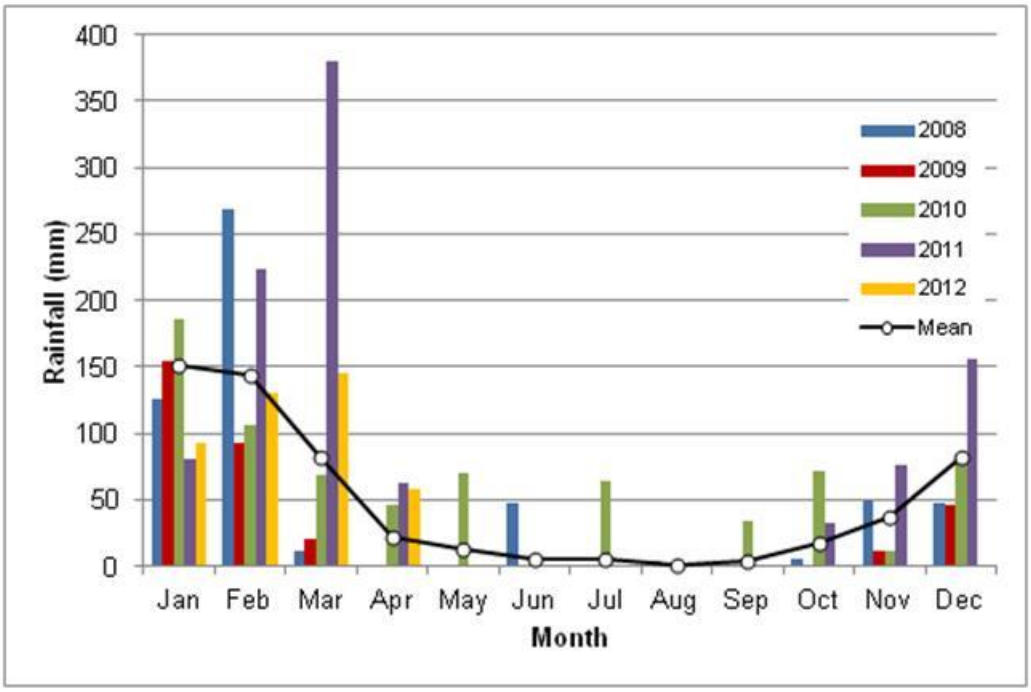


Figure 3: Monthly rainfall for Halls Creek Airport weather station for 2008-2012

Source data: BOM (2012), 1944 to 2012

2.2 Geology

The Study Area is located on the western side of the Browns Range Dome, a Palaeoproterozoic dome formed by a granitic core intruding the Palaeoproterozoic "Browns Range Metamorphics" (meta-arkoses, feldspathic metasandstones and schists) and an Archaean orthogneiss and schist unit to the south. The dome and its aureole of metamorphics are surrounded by the Palaeoproterozoic Gardiner Sandstone (Birrindudu Group). Middle-Devonian to (likely) Ordovician sandstones from the Eastern Canning Basin margin (Billiluna Shelf) of uncertain age have also been interpreted to occur over the Gardiner Sandstone to the south-west of the dome (Das 2012).

The Study Area is primarily covered with transported soil and low-lying vegetation. The dominant geological unit throughout the Project area consists of arkose and meta-arkose outcrops. Other rock types include quartz mica schists, banded iron formation / quartz pebble conglomerate, dolerite and calc-silicate rocks. Minor occurrences of quartzite, silcrete, ferricrete and ironstone have also been identified. The Gardiner Sandstone is seen to flank the western margins of the Project area and unconformably overlies the older Browns Range metamorphic rocks (Das 2012).

Mapping has identified both mineralised and non-mineralised occurrences of quartz veins and quartz breccia veins occurring as elongated discontinuous bodies, up to several metres wide and tens of metres long, and intruding along possible shear or faults trending 320° (north-west) and 270° (east-west).

2.3 Land Systems

The Study Area lies within the Kimberley land region of Western Australia. Numerous rangelands resource surveys conducted since the 1940s have contributed to a comprehensive description of biophysical resources present within the Kimberley region, including the condition of soil and vegetation (Payne and Schoknecht 2011). This information has been used to classify and map the Land Systems of the Kimberley region based on landforms, soils, vegetation, geology and geomorphology. An assessment of these Land Systems provides an indication of the occurrence and distribution of relevant natural resources present within and surrounding the Soil Study Area. The Soil Study Area contains two Land Systems: Coolindie and Winnecke (**Table 1**). The Coolindie Land System occupies the majority of the Soil Study Area (**Figure 4**). Soil and landforms typically associated with each of the Land Systems are described in **Section 2.3.1** and **2.3.2**.

Table 1: Land Systems within the Browns Range Soil Study Area

Land System	Description	Area within Soil Study Area (hectares)	Proportion of Soil Study Area (%)
Coolindie	Consists of gently undulating red desert sandplains and dunes supporting *Acacia* shrublands, *Eucalyptus* woodlands and soft spinifex (*Triodia pungens*) grasslands. These grasslands are subject to frequent fires that cause short-term changes in floristic composition and abundance. Drainage lines are shallow, widely spaced and infrequent, and erosion is minimal.	6,473	84.3
Winnecke	Consists of stony hills and lowlands associated with red desert sands that support *Acacia* and *Eucalyptus* woodlands and soft spinifex (*Triodia pungens*) grasslands. These grasslands are subject to frequent fires that cause short-term changes in floristic composition and abundance. Intensive parallel drainage lines occur on upper slopes, while widely spaced angular drainage lines occur on lower slopes and terminate at the base of hills. Erosion is generally minimal, though some drainage floors are moderately susceptible.	1,203	15.7

Source: Payne and Schoknecht (2011)

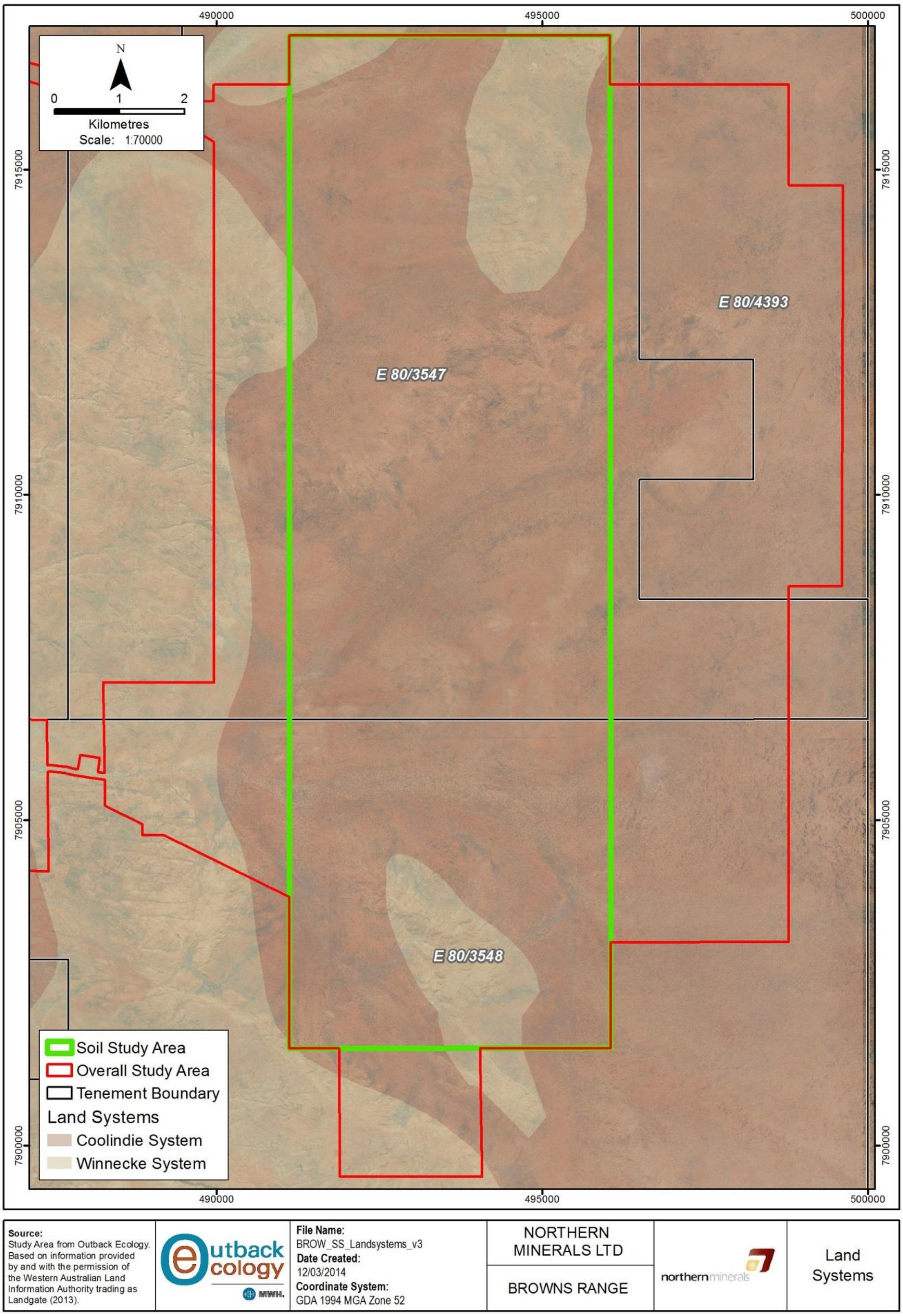


Figure 4: Land Systems within and surrounding the Browns Range Soil Study Area

2.3.1 Coolindie Land System

Plate 1: Example of the Coolindie Land System within the Browns Range Study Area

The Coolindie Land System is characterised by gently undulating red sandplains and dunes with acacia shrublands and spinifex. The soils are predominantly deep red sand with some lateritic gravel rises. The drainage floors are broad and shallow.

2.3.2 Winnecke Land System

Plate 2: Example of the Winnecke Land System within the Browns Range Study Area

The Winnecke Land System is characterised by low linear or rounded hills and lowlands with eucalypt woodlands and spinifex. The soils are deep red sand with outcrops of sandstone. The gently sloping sandplains merge into mainly unchannelled valley floors.

2.4 Surface regolith mapping

Regional surface regolith mapping was provided by Northern Minerals for the Project and surrounding areas. The surface regolith mapping provided valuable background information pertaining to soils and landforms within the Project. In addition to the Land Systems, the surface regolith mapping contributed to an understanding of the soil-landform associations present across the Study Area and aided development of the baseline soil field survey sampling regime detailed in **Section 3.1**.

The mapping was provided as GIS files, however no specific detail or information about the soil units accompanied the GIS files. As there was no indication of the relevant depth of the mapping units, it was assumed that the mapping units represent the surface expression of soil types or features only (e.g. metamorphic outcrops) and do not represent the deeper regolith profile. Surface regolith mapping units that fell within the Study Area included;

- alluvium;
    - typically occurs in low lying areas in broad drainage plains;
- Tertiary sand;
    - occurs in broad sand plains;
    - dominant surface regolith unit;
- Quaternary sand;
    - occurs in broad sand plains;
- Tertiary lime soils;
    - occurs in broad sand plains;
- iron (Fe) loams;
    - minimal occurrence within the Study Area;
- colluvium subcrop;
    - mostly occurs surrounding rocky hills or outcrops ;
    - indicates colluvial deposition of weathered rock;
- Gardiner sandstone;
    - minimal occurrence in the northern extents of the Study Area;
- ferruginised metamorphic; and
    - typically occurs in low lying areas in broad drainage plains;
- metamorphic outcrops;
    - low stony hills and rocky ridges and outcrops rising above the broad sand plains.

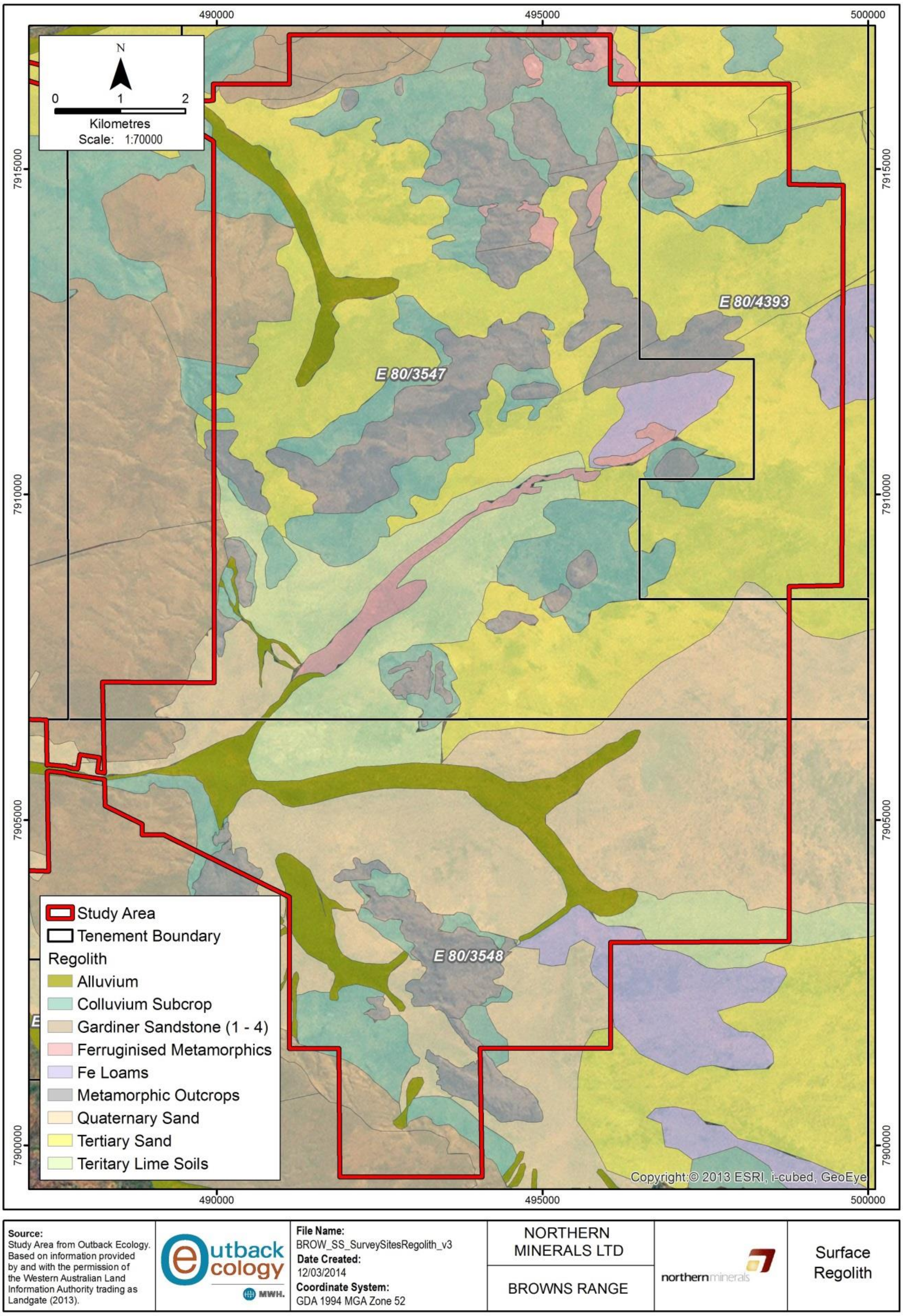


Figure 5: Surface regolith mapping within and surrounding the Browns Range Study Area

3. MATERIALS AND METHODS

3.1 Sampling regime

The baseline soil and landform field survey was conducted in August 2012. An additional assessment of surface soils and vegetation on analogue slopes was conducted in May 2013, concurrently with a flora and vegetation survey (Outback Ecology 2014).

Soil survey sites were chosen to encompass the range of landform and vegetation communities present within the Soil Study Area. The sampling locations were focussed within the areas likely to comprise the major disturbance areas associated with the Project. Soil pits were excavated at 22 sites by a backhoe as deep as possible or to a maximum depth of 1.5 metres (m), with samples collected by Outback Ecology personnel (**Table 2**, **Figure 6**). Surface soil profile morphology and soil structure were described, according to the Australian Soil and Land Survey Handbook (McDonald *et al.* 1998). Samples were generally collected from three to four depth intervals within each profile for analysis of chemical and physical parameters.

Table 2: Surface soil survey sampling sites and locations within the Browns Range Soil Study Area

Site	Disturbance area	Land System	Coordinates (Projection: UTM Zone 50K, Datum: GDA 94)		Elevation (m)
			Easting (mE)	Northing (mN)	
BRP01	Wolverine	Winnecke	493951	7914653	469
BRP02	Wolverine	Winnecke	493766	7914767	454
BRP03	Wolverine	Winnecke	493541	7914858	456
BRP04	Wolverine	Winnecke	493641	7914757	456
BRP05	Gambit	Winnecke	494092	7913764	480
BRP06	Gambit	Winnecke	494173	7913851	468
BRP07	Gambit	Coolindie	493886	7913660	453
BRP08	Area 5	Coolindie	492155	7910080	460
BRP09	Area 5	Coolindie	492067	7910148	459
BRP10	Area 5	Coolindie	492151	7909910	451
BRP11	Banshee	Winnecke	492544	7903967	451
BRP12	Mystique	Winnecke	493291	7903109	451
BR1	Broad disturbance area	Winnecke	495022	7914860	466
BR2	Broad disturbance area	Coolindie	493296	7912521	451

Site	Disturbance area	Land System	Coordinates (Projection: UTM Zone 50K, Datum: GDA 94)		Elevation (m)
			Easting (mE)	Northing (mN)	
BR3	Broad disturbance area	Coolindie	495495	7911655	461
BR4	Broad disturbance area	Coolindie	494047	7910832	449
BR5	Broad disturbance area	Coolindie	491714	7907135	435
BR6	Broad disturbance area	Winnecke	492017	7904272	436
BR7	Broad disturbance area	Coolindie	491732	7902093	442
BR8	Broad disturbance area	Coolindie	491816	7905649	423
BR9	Broad disturbance area	Coolindie	495359	7906266	441
BR10	Broad disturbance area	Coolindie	491719	7907634	432

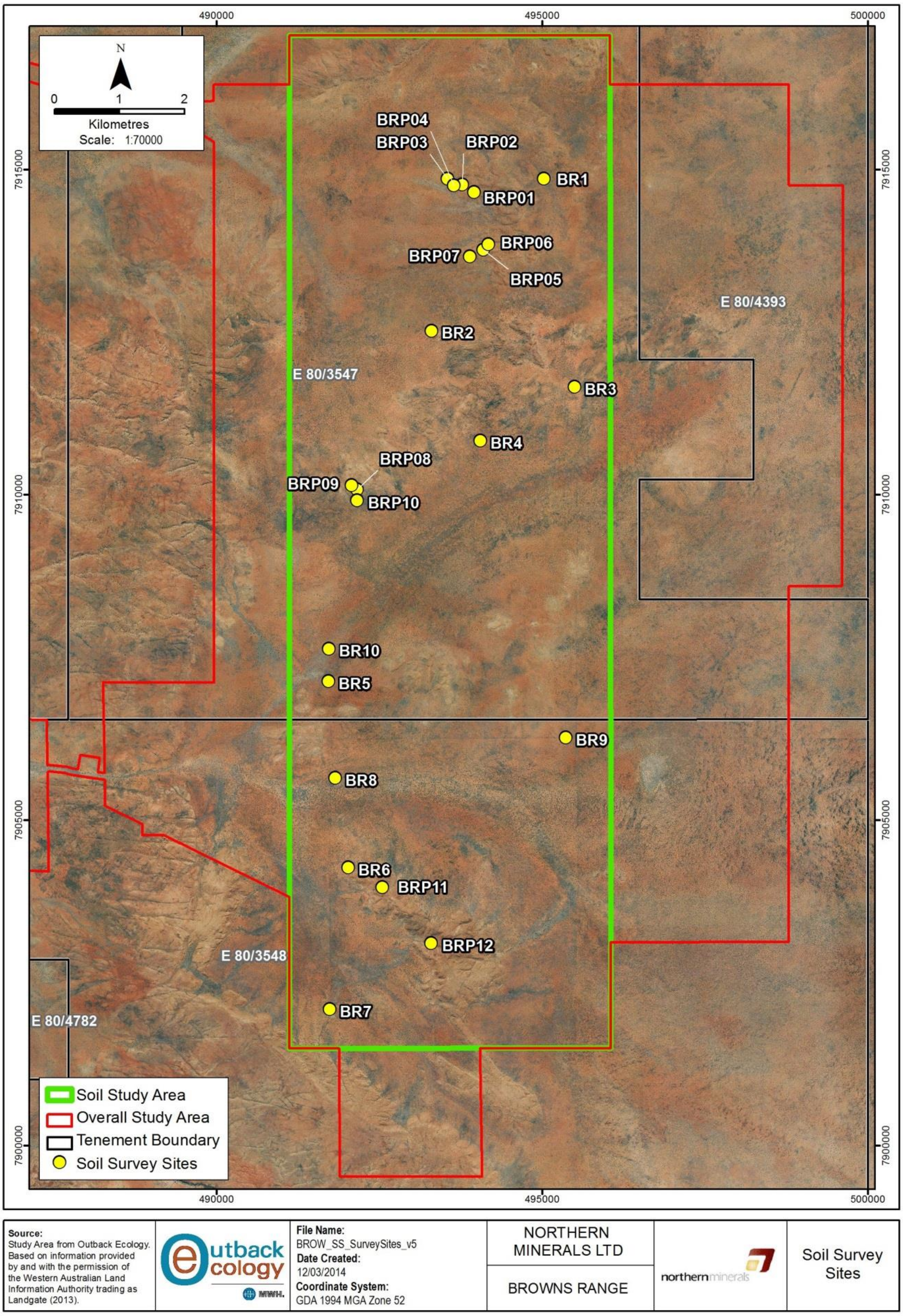


Figure 6: Location of soil sampling sites within the Soil Study Area

3.2 Test work and procedures

CSBP Soil and Plant Laboratory conducted analyses on the sampled surface soils from the 22 survey sites for ammonium and nitrate (Scarle 1984), plant-available phosphorus and potassium (Colwell 1965, Rayment and Higginson 1992), plant-available sulphur (Blair *et al.* 1991) and organic carbon (Walkley and Black 1934). Measurements of electrical conductivity (1:5 H_2O) and soil pH (H_2O and $CaCl_2$), were conducted using the methods described in Rayment and Higginson (1992). Exchangeable cations Ca^{2+}, Mg^{2+}, Na^+ and K^+ (Rayment and Higginson 1992) and particle size distribution (McKenzie *et al.* 2002) were also assessed on selected surface soil samples.

ALS Environmental Laboratory analysed 43 selected samples for total concentrations of metals including arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), zinc (Zn) and mercury (Hg). Cold Vapour / Flow Injection Mercury System (CV/FIMS) was used to analyse for Hg, while Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) was used for the other elements.

Soil texture of the surface soils was assessed by Outback Ecology staff using the procedure described in McDonald *et al.* (1998). A measure of soil slaking and dispersive properties (Emerson Aggregate Test) was conducted as described in McKenzie *et al.* (2002). Soil strength and the resulting tendency of each material to hardset was assessed by Outback Ecology staff using a modified Modulus of Rupture test (Aylmore and Sills 1982, Harper and Gilkes 1994). Soil colour was determined using a Munsell® soil colour chart. Saturated hydraulic conductivity was also measured for selected samples (Hunt and Gilkes 1992).

The water retention characteristics of nine selected samples were assessed by Outback Ecology using pressure plate apparatus, as described in McKenzie *et al.* (2002). Samples assessed were packed to a bulk density likely to be experienced once the materials are disturbed and re-deposited, approximately 75% of the maximum dry bulk density.

Table 3: Soil analyses conducted for surface soils sampled within the Soil Study Area

Soil parameter	Measurement method	Conducted by	Number of samples analysed	Sample selection criteria
Chemical properties				
Total Metals (As, Cd, Cr, Cu, Pb, Ni and Zn)	Inductively coupled plasma atomic emission spectroscopy (ICP-AES) method	ALS	43	Selected representative samples
Total Metals (Hg)	Cold vapour/ Flow injection mercury system (CV/FIMS method)	ALS	43	Selected samples
Soil pH	pH measured in 1:5 soil:water and 1:5 Soil:$CaCl_2$ (Rayment and Higginson 1992)	CSBP	71	All samples
Electrical conductivity	Measured in 1:5 soil:water (Rayment and Higginson 1992)	CSBP	71	All samples
Plant-available nitrogen (ammonium and nitrate)	Scarle (1984)	CSBP	71	All samples
Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+)	Rayment and Higginson (1992)	CSBP	42	Selected representative samples
Plant-available phosphorus and potassium	Colwell (1965); Rayment and Higginson (1992)	CSBP	71	All samples
Plant-available sulphur	Blair *et al.* (1991)	CSBP	71	All samples
Organic carbon percentage	Walkley and Black (1934)	CSBP	71	All samples
Physical properties				
Particle size distribution	Pipette method (Day 1965)	CSBP	39	Selected representative samples
Soil slaking and dispersive properties	Emerson Aggregate Test (McKenzie *et al.* 2002)	Outback Ecology	71	All samples
Saturated hydraulic conductivity (K_{sat})	Measured on materials packed to their respective field bulk densities, using a constant-head of pressure technique (Hunt and Gilkes, 1992)	Outback Ecology	12	Selected representative samples (whole sample)
Soil strength	Modified Modulus of Rupture test (Aylmore and Sills 1982; Harper and Gilkes 1994)	Outback Ecology	71	All samples

Soil parameter	Measurement method	Conducted by	Number of samples analysed	Sample selection criteria
Soil colour	Determined using a Munsell® soil colour chart	Outback Ecology	71	All samples
Water retention characteristics	Using pressure plate apparatus (McKenzie *et al.* 2002)	Outback Ecology	9	Selected samples to represent the various soil types

4. RESULTS AND DISCUSSION

4.1 Surface soil profile descriptions

A description of the soil profile morphology at each site and a summary of the measured physical, chemical and morphological parameters been documented (**Sections 4.1.1 – 4.3.6**). Individual soil characteristics are then discussed in further detail (**Sections 4.2 – 4.3**).

The sampling sites were categorised into four soil-landform associations;

- colluvium gravelly soils (C O);
- deep sandy plains (D S);
- metamorphic outcrops with rocky soils (M O); and
- sand over gravel plains (S G).

4.1.1 Site BR01

Site description: Gently sloping sand plain adjacent to rounded stony outcrop of sandstone

Soil-landform association: Deep sandy plain

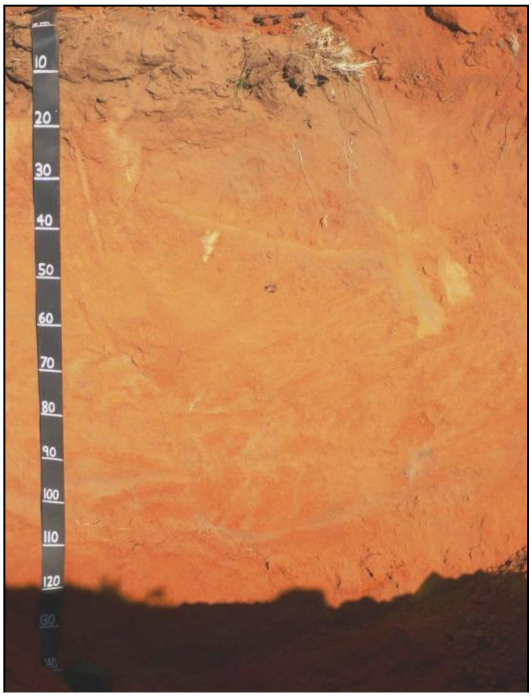


Plate 3: Soil profile at Site BR01

Soil profile description:

0 – 20 cm: Grey, platy surface crust. Predominantly single-grained sand, grey in colour with some strong, polyhedral to blocky aggregates 20 to 200 mm in size. Less than 5% coarse fragments. Root abundance classed as 'common' to 'many'.

20 – 90 cm: Massive, coherent structure, orange in colour, increasing clay content with depth. Less than 5% coarse fragments. Roots 'few' to 'common'.

90 – 130 cm: Massive, coherent structure, orange/red in colour, with clay and moisture increasing with depth. Less than 5% coarse fragments. Roots 'few' to 'common'. Excavator refusal at 130 cm.

Soil surface: Thin platy surface crust, with less than 5% cryptogam cover and 5% litter cover on soil surface. No coarse fragments.

Vegetation: Dominant understorey of grasses including *Triodia* sp. Scattered overstorey of *Eucalyptus* sp. and *Acacia* sp. trees and shrubs.

Plate 4: Vegetation at Site BR01

4.1.2 Site BR02

Site description: Gently sloping gravelly sand plain, adjacent to low rocky rises

Soil-landform association: Colluvium gravelly sand

Plate 5: Soil profile at Site BR02

Soil profile description:

0 – 10 cm: Grey, platy surface crust. Predominantly single-grained sand, grey in colour and with some weak polyhedral aggregates 5 to 10 mm in size. Approximately 40% angular and sub-angular coarse fragments, 5 to 20 mm in size. Root abundance classed as 'few'.

10 – 50 cm: Predominantly single-grained soil. Approximately 60 to 70% sub-angular and sub-rounded coarse fragments increasing in abundance with depth, 2 to 30 mm in size. Roots 'many' decreasing to 'common' with depth.

50 – 90 cm: Massive coherent structure. No coarse fragments. Red /orange mottles present, 20 mm in size, 60% abundance. Roots 'few'. Excavator refusal at 90 cm.

Soil surface: Thin platy surface crust, with approximately 10% cryptogam cover on soil surface. Approximately 30% coarse fragments, 2 to 60 mm in size and sub-angular.

Vegetation: Dominant understorey of grasses and shrubs including *Triodia* sp, and *Solanum* sp. Scattered overstorey of *Eucalyptus* sp. and *Acacia* sp trees and shrubs.

Plate 6: Vegetation at Site BR02

4.1.3 Site BR03

Site description: Gently sloping plain / broad drainage line

Soil-landform association: Sand over gravel plain

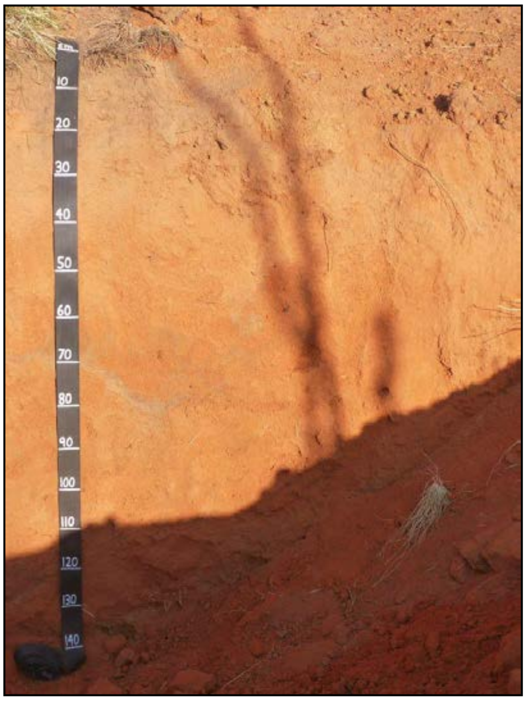


Plate 7: Soil profile at Site BR03

Soil profile description:

0 – 20 cm: Thin platy surface crust. Predominantly single-grained sand, with some weak polyhedral aggregates 2 to 150 mm in size. Less than 10% coarse fragments. Root abundance classed as ‘common’ to ‘many’.

20 – 100 cm: Predominantly single-grained sand, with some weak polyhedral aggregates 2 to 100 mm in size. No coarse fragments. Roots classed as ‘few’ to ‘common’. Increasing clay with depth.

100 – 130 cm Predominantly single-grained red iron mottles and moisture present. Approximately 60% rounded and sub-rounded coarse fragments, 2 to 20 mm in size. Excavator refusal at 130 cm.

Soil surface: Thin platy crust covering 10% of the soil surface, with 5% litter cover and less than 5% cryptogam cover. No coarse fragments.

Vegetation: Dominant understorey of grasses including *Triodia* sp. Scattered overstorey of trees and shrubs including *Acacia* sp., *Eucalyptus* sp., and *Senna* sp..

Plate 8: Vegetation at Site BR03

4.1.4 Site BR04

Site description: Gently sloping sand plain

Soil-landform association: Deep sandy plain

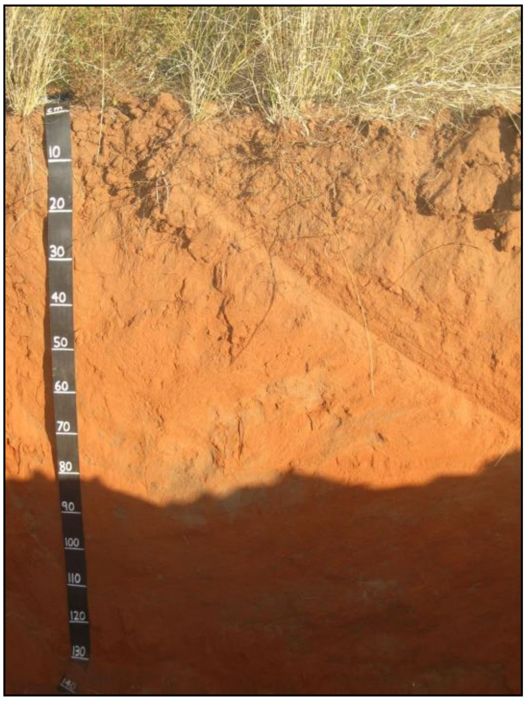


Plate 9: Soil profile at Site BR04

Soil profile description:

0 – 20 cm: Predominantly single-grained sand, grey in colour, with weak-to-medium polyhedral aggregates 5 to 150 mm in size. No coarse fragments. Roots classed as 'many'.

20 – 120 cm: Single-grained sand. No coarse fragments. Roots classed as 'common' decreasing to 'few' at depth. Increasing moisture with depth. Excavator refusal at 120 cm.

Soil surface: Thin platy surface crust, with less than 10% cryptogam cover and 5% litter cover. No coarse fragments.

Vegetation: Dominant understorey of grasses including *Triodia* sp. Scattered, sparse overstorey of *Acacia* sp. and *Grevillea* sp. shrubs.

Plate 10: Vegetation at Site BR04

4.1.5 Site BR05

Site description: Gently sloping plain

Soil-landform association: Sand over gravel plain

Plate 11: Soil profile at Site BR05

Soil profile description:

0 – 5 cm: Brown sand with medium strength, platy aggregates 5 to 50 mm in size. No coarse fragments. Root abundance classed as 'few' to none.

5 – 30 cm: Predominantly single-grained, with some blocky aggregates, 50 to 250 mm in size. No coarse fragments. Roots classed as 'common'.

30 – 140 cm: Predominantly single-grained. Red to orange in colour. Approximately 10% rounded and sub-rounded coarse fragments, 2 to 5 mm in size. Roots classed as 'few'.

140 – 190 cm: Predominantly single-grained. Increasing clay content with depth. Red/orange mottles present, approximately 10% abundance and 30 to 40 mm in size. Approximately 50% rounded coarse fragments, 2 to 20 mm in size. Excavator refusal at 190 cm.

Soil surface: A platy surface crust to 10 mm, with approximately 20% cryptogam cover and 5% litter cover. No coarse fragments.

Vegetation: Dominant understorey of grasses including *Triodia* sp. Scattered overstorey of *Eucalyptus* sp..

Plate 12: Vegetation at Site BR05

4.1.6 Site BR06

Site description: Gently sloping sand plain adjacent to rounded stony outcrop of sandstone

Soil-landform association: Sand over gravel plain

Plate 13: Soil profile at Site BR06

Soil profile description:

0 – 10 cm: Predominantly single-grained sand, grey/brown in colour with some moderate strength polyhedral to platy aggregates 20 to 150 mm in size. Approximately 10% semi-angular to semi-rounded coarse fragments 2 to 10 mm in size. Root abundance classed as 'few' to 'common'.

10 – 70 cm: Predominantly single-grained, with some medium to weak polyhedral aggregates 2 to 30 mm in size. Approximately 10% sub-angular coarse fragments, 2 to 5 mm in size. Roots classed as 'common' to 'many'.

70 – 130 cm: Predominantly single-grained. Mottles present, iron/red colour, 5 to 30 mm in size, approximately 50% abundance. Approximately 80 to 90% sub-angular coarse fragments, 2 to 80 mm in size. Excavator refusal at 130 cm.

Soil surface: Thin platy crust, covering 70% of surface, with approximately 40% cryptogam cover and 10% litter cover. Approximately 10% sub-angular coarse fragments 5 to 50 mm in size.

Vegetation: Dominant understorey of grasses including *Triodia* sp. Scattered overstorey of *Eucalyptus* sp and *Acacia* sp shrubs.

Plate 14: Vegetation at Site BR06

4.1.7 Site BR07

Site description: Gently slope away from stony outcrop

Soil-landform association: Colluvium gravelly sands

Plate 15: Soil profile at Site BR07

Soil profile description:

0 – 5 cm: Platy, moderate strength aggregates at surface, 5 to 100 mm in size. No coarse fragments. Root abundance classed as 'few'.

5 – 40 cm: Polyhedral, moderate strength aggregates, 5 to 120 mm in size. Decreasing structure with depth. Approximately 30% sub-angular coarse fragments, 2 to 10 mm in size. Roots 'few' to 'common'.

40 – 70 cm: Predominantly single-grained. Approximately 70% to 80% angular and sub-angular coarse fragments and 2 to 200 mm in size. Roots 'common'.

70 – 100 cm: Predominantly single-grained, yellow to orange in colour. Approximately 80 to 90% angular and sub-angular coarse fragments, 2 to 60 mm in size. Roots 'few' to 'common'. Excavator refusal at 100 cm.

Soil surface: Thin platy crust, with approximately 50% cryptogam cover and 20% litter cover on soil surface. Approximately 10% coarse fragments, 2 to 5 mm in size and sub-angular.

Vegetation: Dominant understorey of *Triodia* sp., with some *Acacia* sp. and other scrubs. Scattered overstorey of *Eucalyptus* sp..

Plate 16: Vegetation at Site BR07

4.1.8 Site BR08

Site description: Gently sloping plain / broad drainage line

Soil-landform association: Deep sandy plain

Plate 17: Soil profile at Site BR08

Soil profile description:

0 – 10 cm: Weak, platy to polyhedral aggregates, 5 to 100 mm in size, brown in colour. No coarse fragments. Root abundance classed as 'few' to 'common'.

10 – 30 cm: Predominantly single-grained, with some weak polyhedral aggregates 5 to 30 mm in size. No coarse fragments. Roots classed as 'common' to 'many'.

30 – 120 cm: Predominantly single-grained. Orange in colour. No coarse fragments. Roots 'common'.

120 – 150 cm: Predominantly single-grained. Red/orange in colour. No coarse fragments. Mottles present, iron-red in colour 10 to 15% abundance and 5 to 15 mm in size. Roots 'few'. Excavator refusal at 150 cm.

Soil surface: Thin platy surface crust to 5 mm, with approximately 10% cryptogam cover and 5% litter cover on soil surface.

Vegetation: Dominant understorey of grasses including *Triodia* sp. Scattered overstorey of *Eucalyptus* sp. and *Hakea* sp..

Plate 18: Vegetation at Site BR08

4.1.9 Site BR09

Site description: Gently sloping plain

Soil-landform association: Deep sandy plain

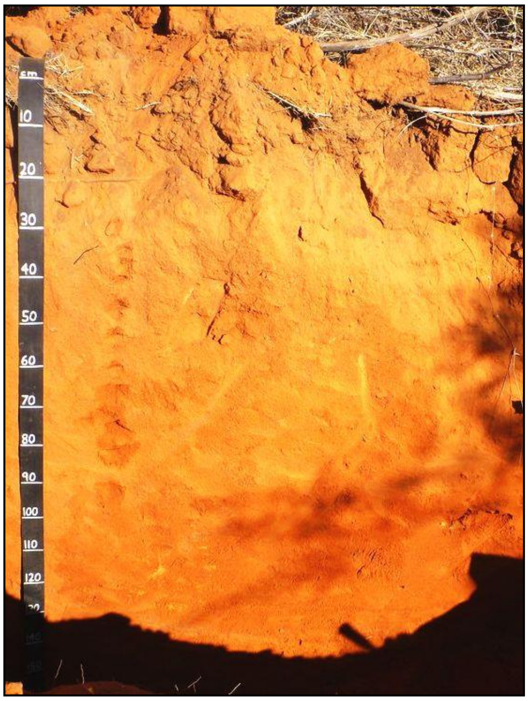


Plate 19: Soil profile at Site BR09

Soil profile description:

0 – 30 cm: Well-structured with moderate-to-strong, platy-to-blocky aggregates, 5 to 120 mm. No coarse fragments. Root abundance classed as 'common'.

30 – 150 cm: Predominantly single-grained. Less than 10% rounded coarse fragments, 2 to 10 mm in size. Roots classed as 'common' to 'many'.

150 – 175 cm: Predominantly single-grained. Yellow/orange in colour. Approximately 30% rounded coarse fragments, 2 to 15 mm in size. Mottles present, red in colour, 10% abundance and 10 mm in size. Roots classed as 'few'. Excavator refusal at 170 cm.

Soil surface: Thin platy 2 mm surface crust, with approximately 10% cryptogam cover and 10 to 15% litter cover on soil surface.

Vegetation: Dominant understorey of grasses including *Triodia* sp. and thick *Acacia* scrubs. Sparse overstorey of *Eucalyptus* sp.

Plate 20: Vegetation at Site BR09

4.1.10 Site BR10

Site description: Gently sloping plain

Soil-landform association: Deep sandy plain

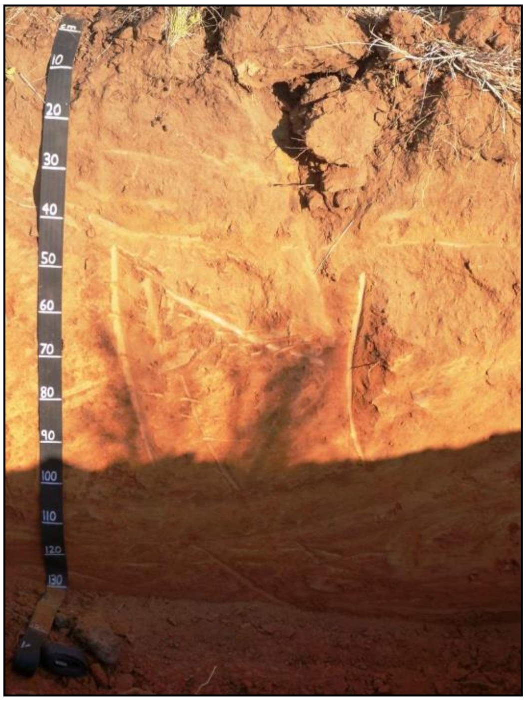


Plate 21: Soil profile at Site BR10

Soil profile description:

0 – 20 cm: Moderate-to-strong, blocky aggregates, 5 to 200 mm in size. No coarse fragments. Root abundance classed as 'common' to 'many'.

20 – 40 cm: Strong polyhedral aggregates, 10 to 60 mm in size. Colour change with depth from brown to orange. No coarse fragments. Roots classed as 'few' to 'common'.

40 – 130 cm: Massive, structureless. Orange in colour. No coarse fragments. No moisture and 'few' roots. Excavator refusal at 130 cm.

Soil surface: Thin platy surface crust (5 mm), covering 10 to 20% of the surface with approximately 10% cryptogam cover and 30% litter cover.

Vegetation: Dominant understorey of grasses including *Triodia* sp. and shrubs. Sparse overstorey of *Eucalyptus* sp. and *Hakea* sp.

Plate 22: Vegetation at Site BR10

4.1.11 Site BRP01

Site description: Rocky outcrop / low rounded hills

Soil-landform association: Metamorphic outcrop with rocky soil

Plate 23: Soil profile at Site BRP01

Soil profile description:

0 – 10 cm: Moderate strength polyhedral aggregates, 2 to 80 mm in size. Approximately 60% sub-rounded, rounded and angular coarse fragments, 2 to 80 mm in size. Root abundance classed as 'common' to 'many'.

10 – 40 cm: Predominantly single-grained, with some weak polyhedral aggregates, 5 to 20 mm in size. Approximately 70% sub-rounded, rounded and angular coarse fragments, 2 to 80 mm in size. Roots were ''many' to 'abundant'.

40 – 100 cm: Predominantly single-grained tending to 'massive' with depth. Approximately 70% angular and sub-angular coarse fragments, 2 to 15 mm in size (fractured, weathered rock). Mottles present, red and <5% abundance and 2 to 5 mm in size. Roots 'few'. Excavator refusal at 100 cm.

Soil surface: Thin platy surface crust (2 mm), with approximately 10% cryptogam cover and 5% litter cover on soil surface. Approximately 80% coarse fragments and boulders on surface, 2 to 200 mm in size, sub-angular.

Vegetation: Dominant understorey of *Triodia* sp. Sparse overstorey of scattered *Eucalyptus* sp.

Plate 24: Vegetation at Site BRP01

4.1.12 Site BRP02

Site description: Gently sloping, broad, unchannelled sandy drainage line

Soil-landform association: Sand over gravel plain

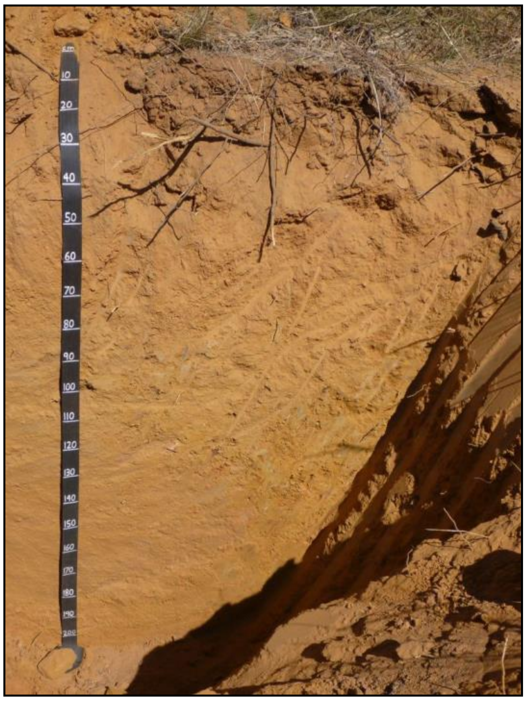


Plate 25: Soil profile at Site BRP02

Soil profile description:

0 – 10 cm: Platy-to-polyhedral, moderate strength aggregates, 20 to 200 mm in size, grey in colour. Less than 5% coarse fragments, 2 to 15 mm in size. Root abundance classed as 'many' to 'abundant'.

10 – 40 cm: Moderate-to-strong, blocky-to-polyhedral aggregates, 25 to 250 mm in size. Less than 10% angular coarse fragments, 2 to 50 mm in size. Roots classed as 'common' decreasing to 'few'.

40 – 80 cm: Predominantly single-grained, with some medium-to-strong polyhedral aggregates 10 to 60 mm in size. Approximately 10 to 20% sub-angular and sub-rounded coarse fragments, 2 to 15 mm. Mottles present, yellow/red in colour, 5 to 10 mm in size, less than 10%. Roots classed as 'few'.

80 – 200 cm: Massive, structureless. Mottles present, yellow, <10% abundance and 5 to 10 mm in size. Approximately 20% sub-angular and sub-rounded coarse fragments, 2 to 20 mm in size. Roots classed as 'few'. Excavator refusal at 200 cm.

Soil surface: Thin platy surface crust covering 20%, with approximately 10% cryptogam cover and 5% litter cover on soil surface. Approximately 5% coarse fragments, 10 to 20 mm, sub-angular to sub-rounded.

Vegetation: Dominant understorey of grasses and *Triodia* sp. with *Acacia* sp. shrubs. Sparse overstorey of *Eucalyptus* sp. and *Acacia* sp.

Plate 26: Vegetation at Site BRP02

4.1.13 Site BRP03

Site description: Upper slope of low rounded hills below rocky outcrop.

Soil-landform association: Metamorphic outcrop with rocky soils

Plate 27: Soil profile at Site BRP03

Soil profile description:

0 – 15 cm: Predominantly single-grained, with weak, platy-to-polyhedral aggregates 2 to 80 mm in size. Approximately 70 to 80% sub-angular and sub-rounded coarse fragments, 2 to 15 mm. Root abundance classed as 'many' to 'abundant'.

15 – 60 cm: Predominantly single-grained. Approximately 75% rounded and sub-rounded coarse fragments, 2 to 15 mm in size. Roots classed as 'many'.

60 – 120 cm: Predominantly single-grained between weathered, fractured rock. Approximately 70% rounded and sub-rounded coarse fragments, 2 to 15 mm. Roots classed as 'common', mainly between cracks. Excavator refusal at 120 cm.

Soil surface: Thin platy crust, covering 20% of soil surface with approximately 20% cryptogam cover and 5% litter cover. Approximately 60% sub-angular coarse fragments, 2 to 15 mm in size.

Vegetation: Dominant understorey of *Triodia* sp. with *Acacia* sp. Sparse overstorey of *Eucalyptus* sp.

Plate 28: Vegetation at Site BRP03

4.1.14 Site BRP04

Site description: Gently sloping sandy plain

Soil-landform association: Sand over gravel plain

Plate 29: Soil profile at Site BRP04

Soil profile description:

0 – 15 cm: Predominantly single-grained, grey sand, with some weak, platy to polyhedral aggregates 10 to 80 mm in size. No coarse fragments. Root abundance classed as 'abundant'.

15 – 50 cm: Predominantly single-grained, grey to brown sand. Some weak, polyhedral aggregates 10 to 20 mm in size. No coarse fragments. Roots classed as 'many'.

50 – 80 cm: Predominantly single-grained sand. Approximately 10% rounded and sub-rounded coarse fragments, 2 to 10 mm. Roots classed as 'common'.

80 – 170 cm: Massive, structureless. Mottles present, yellow/red, 5 to 10 mm in size, 10% abundance. Approximately 30% angular coarse fragments, 2 to 15 mm. Roots classed as 'few'. Excavator refusal at 170 cm.

Soil surface: Thin platy crust, covering 40% of the soil surface with approximately 5% cryptogam and 20% litter cover. No coarse fragments.

Vegetation: Dominant understorey of grasses with some *Acacia* sp. shrubs. Sparse upperstorey of *Eucalyptus* sp.

Plate 30: Vegetation at Site BRP04

4.1.15 Site BRP05

Site description: Top of rounded hill with rocky outcrop.

Soil-landform association: Metamorphic outcrop with rocky soils

Plate 31: Soil profile at Site BRP05

Soil profile description:

0 – 50 cm: Predominantly single-grained. Approximately 80% rounded, sub-rounded and sub-angular coarse fragments, 5 to 200 mm in size. Root abundance classed as 'common'.

70 – 90 cm: Predominantly single-grained. Approximately 90% rounded and sub-rounded coarse fragments, 2 to 10 mm in size (fractured, weathered rock). Mottles present, ironstone red, approximately 50% abundance. Roots classed as 'common', generally occurring between rock fractures. Excavator refusal at 90 cm.

Soil surface: No crust, with less than 5% cryptogam cover and little litter cover on soil surface. Approximately 90% sub-angular coarse fragments of 2 to 200 mm in size.

Vegetation: Dominant understorey of *Triodia* sp. Sparse upperstorey of Eucalyptus sp.

Plate 32: Vegetation at Site BRP05

4.1.16 Site BRP06

Site description: Just above drainage line and on slope between rounded hills

Soil-landform association: Metamorphic outcrops with rocky soils

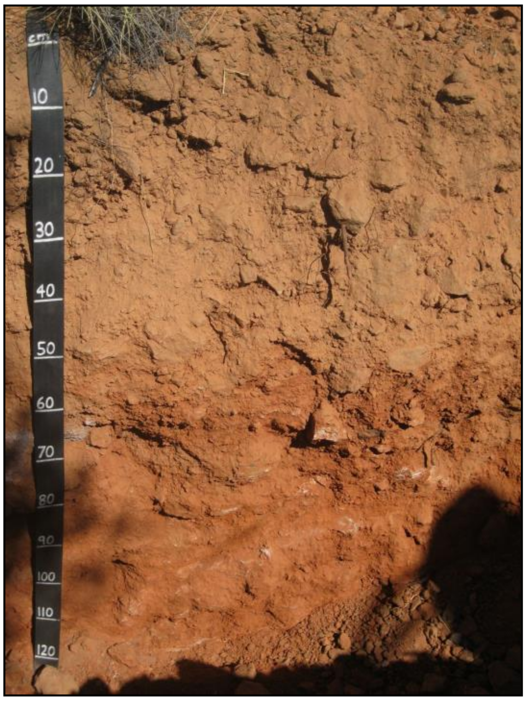


Plate 33: Soil profile at Site BRP06

Soil profile description:

0 – 5 cm: Predominantly single-grained with some moderate strength, polyhedral aggregates, 20 to 100 mm in size. Approximately 60% rounded, sub-rounded and sub-angular coarse fragments, 2 to 70 mm in size. Root abundance classed as 'few'.

5 – 50 cm: Predominantly single-grained, with some weak, polyhedral aggregates 10 mm in size. Approximately 70% sub-rounded and angular coarse fragments, 10 to 20 mm in size. Roots classed as 'common'.

50 – 120 cm: Predominantly single-grained. Approximately 70% angular and sub-angular coarse fragments (fractured weathered rock), 10 to 200 mm in size. Roots classed as 'common'. Excavator refusal at 120 cm.

Soil surface: Approximately 10% cryptogam cover on soil surface, though little litter cover. Approximately 95% sub-angular coarse fragments from 2 to 200 mm in size.

Vegetation: Dominant understorey of *Triodia* sp. Sparse upperstorey of *Eucalyptus* sp.

Plate 34: Vegetation at Site BRP06

4.1.17 Site BRP07

Site description: Gently sloping plain adjacent to low stony rise

Soil-landform association: Sand over gravel plain

Plate 35: Soil profile at Site BRP07

Soil profile description:

0 – 10 cm: Moderate-to-weak, polyhedral aggregates, 2 to 100 mm in size. Approximately 10% sub-angular coarse fragments, 2 to 10 mm in size. Root abundance classed as 'abundant'.

10 – 50 cm: Predominantly single-grained. No coarse fragments. Colour change from brown to orange with depth. Roots classed as 'common' to 'many'.

50 – 90 cm: Massive, structureless. Mottles present red/orange, 2 to 15 mm in size, 20% abundance. Approximately 60% rounded coarse fragments from 2 to 15 mm in size. Roots classed as 'few'.

90 – 120 cm: Predominantly single-grained. Mottles present, red/orange, 10 to 20 mm in size, 50% abundance. Approximately 80% rounded coarse fragments, 2 to 100 mm in size (fractured rock). Roots classed as 'few'. Excavator refusal at 120 cm.

Soil surface: Thin platy surface crust covering 70%, with approximately 10% cryptogam cover and no litter cover on soil surface. Approximately 10% sub-angular coarse fragments, 2 to 20 mm in size.

Vegetation: Dominant understorey of *Triodia* sp. Sparse overstorey of Eucalyptus sp.

Plate 36: Vegetation at Site BRP07

4.1.18 Site BRP08

Site description: Upper slope of rocky outcrops

Soil-landform association: Metamorphic outcrop with rocky soil

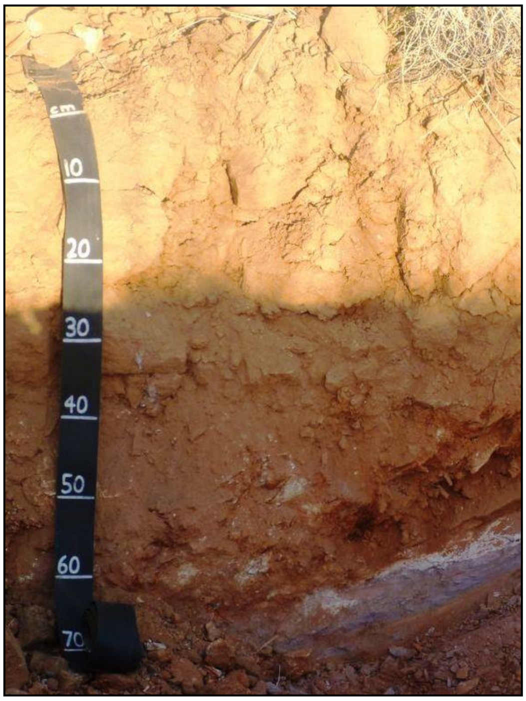


Plate 37: Soil profile at Site BRP08

Soil profile description:

0 – 5 cm: Weak, platy aggregates, 2 to 100 mm in size. Approximately 50% sub-angular coarse fragments, 2 to 80 mm in size. Root abundance classed as 'few'.

5 – 60 cm: Predominantly single-grained. Approximately 90% sub-angular coarse fragments, 2 to 200 mm in size (fractured rock at variable depth across the profile). Roots classed as 'many' to 'abundant'. Excavator refusal at 60 cm.

Soil surface: Thin platy surface crust (2 to 5 mm) covering 5% of soil surface, with approximately 10% cryptogam cover and 5% litter cover. Approximately 80% sub-angular coarse fragments, 2 to 200 mm in size.

Vegetation: Dominant understorey of *Triodia* sp. Sparse overstorey of *Eucalyptus* sp.

Plate 38: Vegetation at Site BRP08

4.1.19 Site BRP09

Site description: Plateau on rocky soils among metamorphic rocky outcrops

Soil-landform association: Colluvium gravelly sand

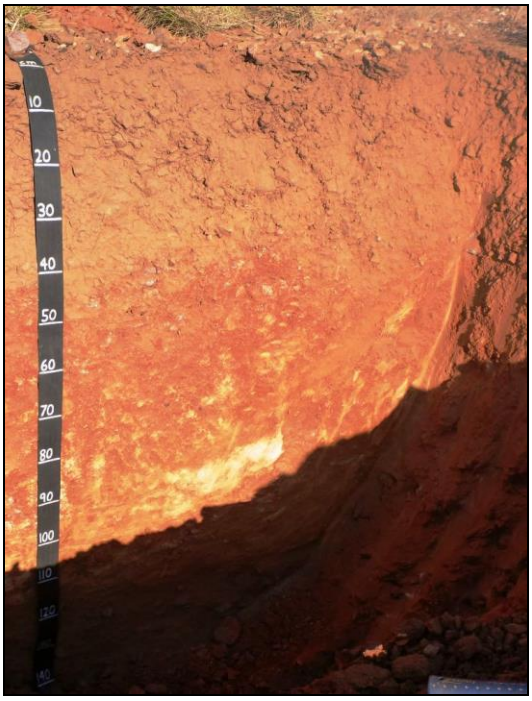


Plate 39: Soil profile at Site BRP09

Soil profile description:

0 – 5 cm: Weak, platy aggregates, 2 to 100 mm in size. Approximately 40 to 60% sub-angular to sub-rounded coarse fragments, 2 to 40 mm in size. Root abundance classed as 'few'.

5 – 30 cm: Predominantly single-grained. Approximately 60% sub-angular and sub-rounded coarse fragments, 2 to 80 mm in size. Roots classed as 'common'.

30 – 100 cm: Predominantly single-grained, though strong, dense consistence. Approximately 80% sub-angular and sub-rounded coarse fragments, 2 to 60 mm in size. Roots classed as 'few'.

100 – 140 cm: Massive, structureless, with an increase in clay content with depth. Approximately 50% sub-angular and sub-rounded coarse fragments, 2 to 25 mm in size. No roots. Excavator refusal at 140 cm.

Soil surface: Thin platy surface crust covering 20%, with less than 5% cryptogam cover and no litter cover on soil surface. Approximately 80% sub-angular coarse fragments 2 to 120 mm.

Vegetation: Dominant understorey of *Trodia* sp. Sparse overstorey of *Eucalyptus* sp .and *Acacia* sp.

Plate 40: Vegetation at Site BRP09

4.1.20 Site BRP10

Site description: Gently sloping on the edge of the sand plain

Soil-landform association: Colluvium gravelly sand

Plate 41: Soil profile at Site BRP10

Soil profile description:

0 – 10 cm: Weak, platy-to-polyhedral aggregates, 2 to 80 mm in size. Approximately 50% sub-angular and sub-rounded coarse fragments, 2 to 50 mm in size. Root abundance classed as 'common' to 'many'.

10 – 25 cm: Predominantly single-grained, with some moderate-to-strong, polyhedral aggregates, 2 to 60 mm in size. Approximately 60% sub-angular, sub-rounded and rounded coarse fragments, 2 to 80 mm in size. Roots classed as 'common'.

25 – 50 cm: Predominantly single-grained. Orange in colour. Approximately 75% sub-rounded coarse fragments, 2 to 70 mm in size. Roots classed as 'common'.

50 – 90 cm: Predominantly single-grained. Orange in colour. Mottles present, red/orange, 5 to 10 mm in size, 30% abundance. Approximately 80% sub-rounded and sub-angular coarse fragments 2 to 70 mm in size. Roots classed as 'common'. Excavator refusal at 90 cm.

Soil surface: Thin platy surface crust, covering 60% of soil surface, with approximately 20% cryptogam cover and no litter cover. Approximately 20% sub-angular coarse fragments 2 to 15 mm.

Vegetation: Dominant understorey of grasses including *Triodia* sp. with *Acacia* sp. Sparse overstorey of *Eucalyptus* sp.

.

Plate 42: Vegetation at Site BRP10

4.1.21 Site BRP11

Site description: Slope at base of stony outcrop

Soil-landform association: Metamorphic outcrop with rocky soil

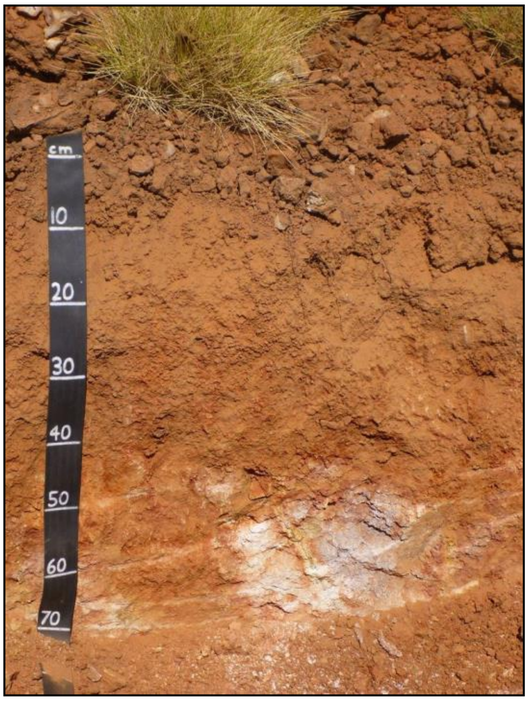


Plate 43: Soil profile at Site BRP11

Soil profile description:

0 – 5 cm: Moderate-to-strong, platy aggregates, 100 to 250 mm in size, grey in colour. Approximately 50% platy coarse fragments, 2 to 10 mm. Root abundance classed as 'few'.

5 – 40 cm: Predominantly single-grained, with some moderate aggregates, 10 to 15 mm in size. Red/orange in colour. Approximately 70 to 80% sub-angular and sub-rounded coarse fragments, 2 to 60 mm in size. Roots classed as 'few' to 'common'.

40 – 70 cm: Predominantly single-grained. Approximately 95% sub-angular coarse fragments, 2 to 70 mm in size (fractured, weathered rock). Roots classed as 'few'. Excavator refusal at 70 cm.

Soil surface: Thin platy surface crust over 50%, with approximately 10% cryptogam cover and no litter cover on soil surface. Approximately 60% sub-angular coarse fragments 5 to 200 mm in size.

Vegetation: Dominant understorey of *Triodia* sp. Sparse overstorey of *Eucalyptus* sp.

Plate 44: Vegetation at Site BRP11

4.1.22 Site BRP12

Site description: Edge of stony outcrop

Soil-landform association: Metamorphic outcrop with rocky soils

Plate 45: Soil profile at Site BRP12

Soil profile description:

0 – 10 cm: Moderate strength, platy-to-polyhedral aggregates, 5 to 130 mm in size, brown in colour. Approximately 60% sub-rounded and sub-angular coarse fragments, 2 to 30 mm. Root abundance classed as 'many'.

10 – 80 cm: Predominantly single-grained soil. Approximately 80% angular coarse fragments, 2 to 40 mm in size. Coarse fragments (weathered, fractured rock) increasing in abundance with depth. Roots classed as 'common'. Excavator refusal at 80 cm.

Soil surface: Thin platy surface crust, with approximately 10% cryptogam cover and no litter cover on soil surface. Approximately 90% coarse fragments, 2 to 200 mm in size, sub-angular.

Vegetation: Dominant understorey of *Triodia* sp. Sparse overstorey of *Eucalyptus* sp.

Plate 46: Vegetation at Site BRP12

4.2 Soil physical properties

4.2.1 Soil profile morphology

The surface soil profiles within the Soil Study Area exhibited a large degree of variation in terms of morphological characteristics. Four soil-landform associations were identified, based primarily on the morphological differences between the soil profiles and their position in the landscape.

The characteristics of the four soil-landform associations present within the Soil Study Area are summarised as follows;

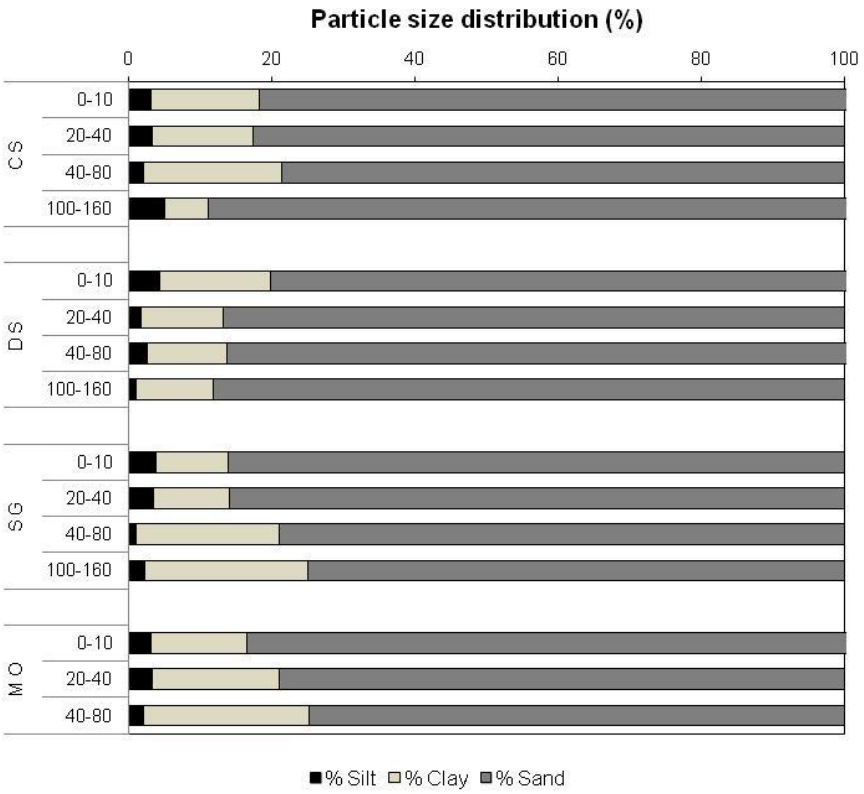
- Colluvium gravelly soils (C S);
  - gravelly sand soil profiles, often found on the slopes of the hills or as low rises throughout the plains;
  - sometimes massive (uniformly dense consistence) at depth;.
- Deep sandy plains (D S);
  - wide gently sloping sandy plains and generally unchannelled valley floors;
  - deep soil profiles dominated by structureless sand, often massive at depth;
- Metamorphic outcrops with rocky soils (M O);
  - rocky outcrops often rising 20 to 40 m above the surrounding plains, dominated by outcropping competent rock at the surface;
  - typically shallow soils dominated by a high proportion of coarse fragments; and
- Sand over gravel plains (S G);
  - distinguished from the deep sandy plains by an increase in gravel content with increasing depth through the profile;
  - often adjacent to stony hills or rocky outcrops.

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 material.

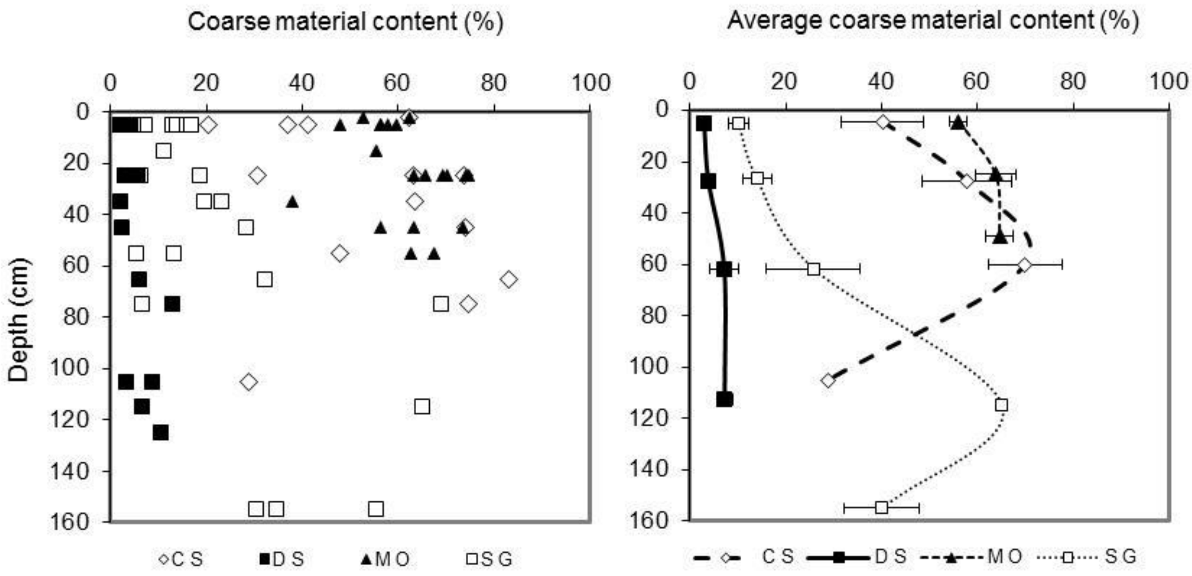
There were a range of particle size distributions exhibited throughout the surface soil samples, with soil textures ranging from 'sand' (less than 10% clay) to 'sandy clay loam' (approximately 25% clay) (**Figure 7**). The majority of samples tested were classed as 'sandy loam' (approximately 15% clay). The percentage of silt in the <2 mm soil fraction was low overall for all soils from the different soil-landform associations. The highest percentage of silt was approximately 5% in the 'colluvium gravelly sand' soil-landform association, compared to the lowest of approximately 1% in the deep sandy plains. The percentage of clay varied between soil-landform associations and at different depths within the soil profiles. In the 'colluvium gravelly sands', average clay content decreased with depth from 15.1% at the surface (0 to 10 cm) to approximately 6% at 100 to 160 cm. In comparison, the average clay content increased with depth in the 'sand over gravel' soil-landform association, with less clay in the surface 0 to 10 cm (10.1% clay) compared to deeper in the profile (20% clay).

Surface soils exhibited a wide range of coarse fragment (>2 mm) content, ranging between 2 and 75% coarse material (**Figure 8**). The 'deep sandy plain' soil-landform association varied little in coarse material with depth through the soil profile, with only two sample sites exceeding 10% coarse materials. The soil-landform association of 'metamorphic outcrops with rocky soils' also varied little through the profile but consistently had the highest average coarse material content overall (**Figure 8**). Coarse material content typically increased with depth through the profile within both the 'colluvium gravelly soils' and the 'sand over gravel plains' soil-landform associations.



C S: colluvium gravelly soils; D S: deep sandy plains; S G: sand over gravel plains; M O: metamorphic outcrops with rocky soils

Figure 7: Average particle size distribution (%) for surface soils grouped into soil-landform associations



C S: colluvium gravelly soils; D S: deep sandy plains; S G: sand over gravel plains; M O: metamorphic outcrops with rocky soils

Figure 8: Individual and average coarse material content (%) for surface soils grouped into soil-landform associations

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 (Needham *et al.* 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.

Soil structure varied between the different soil-landform associations, ranging from single grained structure-less sands, to soils with weak to moderate strength aggregates, to 'massive' soils with a strong, dense consistency (particularly at depth). Soils from the 'deep sandy plains' and the 'sand over gravel plains' soil-landform associations were predominantly single grained, with some weak to moderate strength aggregates in the upper soil profile. The surface 0 to 5 cm layers often included a thin, platy surface crust. Both of these soil-landform associations often had ‘massive’ soil structure at various depths (from 40 cm at BR10 and 80 cm at BRP04) and showed varying degrees of mottling (BR09 and BRP02). The ‘metamorphic outcrops of rocky soils’ and ‘colluvium gravelly soils’ soil-landform associations were dominated by high coarse material contents throughout the profiles with predominately single grained soils. Some weak to moderate aggregates were evident in the upper 0 to 20 cm. The ‘metamorphic outcrops’ tended to be shallow (<90 cm) and showed boulders and sometimes weathered rock at excavation refusal depth (BRP01 and BRP11), whereas the ‘colluvium gravel soils’ tended to be deeper with a ‘massive’ soil structure (BR02) or very high gravel (BR07).

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 disperse indicate a weak soil structure that is easily degraded. These soils should be seen as potentially problematic when used for the reconstruction of soil profiles for rehabilitation, 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 dispersive properties and therefore be the most problematic.

The majority of surface soil samples from the Soil Study Area were identified as Emerson Class 5 (slakes, 1:5 suspension remains dispersed), and Emerson Class 8 (aggregate did not slake or swell) (**Table 4Error! Reference source not found.**). This indicates that the surface soils are ‘non-dispersive’ to ‘partially dispersive’ and unlikely to become dispersive following severe disturbance. Susceptibility to dispersion and instability decreased with depth for soils of the ‘sand over gravel’ and ‘colluvium gravelly soils’ soil-landform associations.

Soils from the ‘deep sandy plains’ soil-landform association were the most dispersive, with some partially to highly dispersive samples from deeper in the soil profile (e.g. 20 to 110 cm). One sample from site BR08 at 20 to 30 cm depth (‘deep sandy plains’ soil-landform association) was classed as ‘completely dispersive’ (Emerson Class 1). Four samples were classified as ‘partially dispersive’ (Emerson Class 2) from Sites BR05, 07 and 08 (**Table 4Error! Reference source not found.**). ispersive soil materials, such as those identified as Emerson Class 1 or 2, have the potential to become problematic (e.g. hardsetting, low water infiltration, high erodibility) particularly following severe disturbance such as earthworks or heavy rainfall.

These results demonstrate that care should be taken to minimise the handling of soil materials where possible, particularly when wet, with consideration given to the appropriate placement of potentially dispersive materials in reconstructed soil profiles and waste landforms.

Table 4: Summary of slaking/dispersion properties (Emerson Test) results of the surface soils

Soil-landform association	Depth (cm)	Emerson class (20 hour)[1]	Description
Colluvium gravelly soils (C S)	0 to 10	2, 3a, 5	2: Slaked, soil partly dispersed. 3a: Slaked, remould disperses completely. 5: Slaked, remould does not disperse, suspension remains dispersed.
	20 to 40	3a, 5	3a: Slaked, remould disperses completely 5: Slaked, remould does not disperse, suspension remains dispersed
	40 to 80	3a, 5	3a: Slaked, remould disperses completely 5: Slaked, remould does not disperse, suspension remains dispersed
	100 to 110	5	5: Slaked, remould does not disperse, suspension remains dispersed
Deep sandy plains (D S)	0 to 10	3a, 8	3a: Slaked, remould disperses completely. 8: Aggregate does not slake, disperse or swell.
	20 to 40	1, 3a, 5, 8	1: Slaked, soil dispersed completely. 3a: Slaked, remould disperses completely. 5: Slaked, remould does not disperse, suspension remains dispersed. 8: Aggregate does not slake, disperse or swell.
	40 to 80	2, 3a, 5	2: Slaked, soil partly dispersed. 3a: Slaked, remould disperses completely. 5: Slaked, remould does not disperse, suspension remains dispersed.
	100 to 110	2, 3b, 5	2: Slaked, soil partly dispersed 3b: Slaked, remould partly disperses. 5: Slaked, remould does not disperse, suspension remains dispersed.
Metamorphic outcrops with rocky soils (M O)	0 to 10	5, 8	5: Slaked, remould does not disperse, suspension remains dispersed. 8: Aggregate does not slake, disperse or swell.
	20 to 40	5, 8	5: Slaked, remould does not disperse, suspension remains dispersed. 8: Aggregate does not slake, disperse or swell.
	40 to 80	5, 6	5: Slaked, remould does not disperse, suspension remains dispersed 6: Slaked, remould does not disperse, suspension remains flocculated.
Sand over gravel plains (S G)	0 to 10	3a, 5, 8	3a: Slaked, remould disperses completely. 5: Slaked, remould does not disperse, suspension remains dispersed. 8: Aggregate does not slake, disperse or swell.
	20 to 40	3a, 5, 8	3a: Slaked, remould disperses completely. 5: Slaked, remould does not disperse, suspension remains dispersed. 8: Aggregate does not slake, disperse or swell.
	40 to 80	2, 5, 8	2: Slaked, soil partly dispersed. 5: Slaked, remould does not disperse, suspension remains dispersed. 8: Aggregate does not slake, disperse or swell (8)
	100 to 160	5, 6	5: Slaked, remould does not disperse, suspension remains dispersed 6: Slaked, remould does not disperse, suspension remains flocculated.

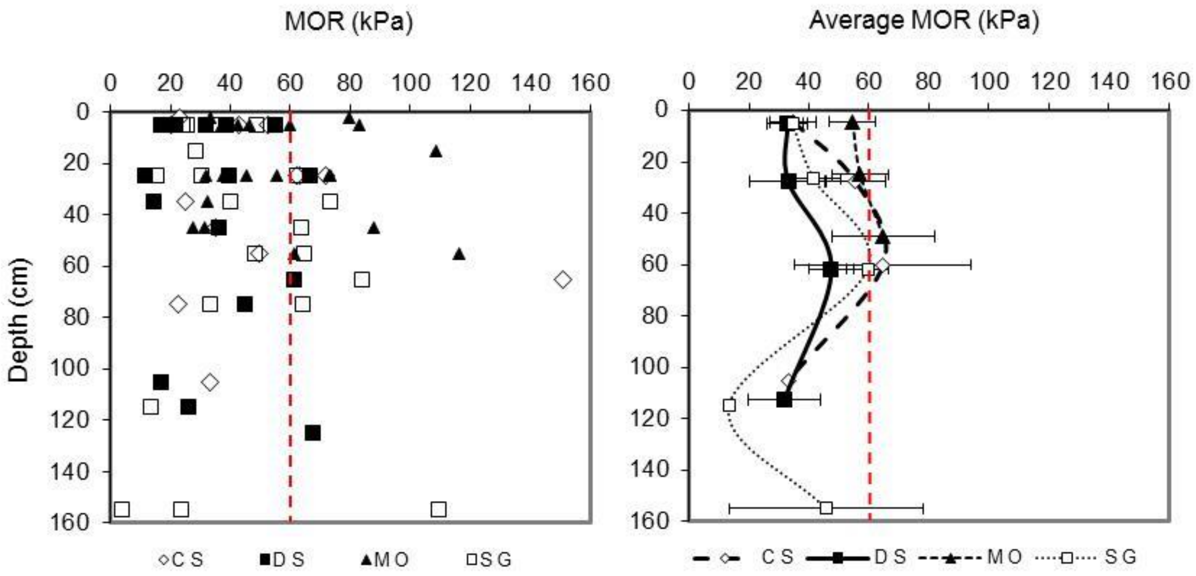
1. Emerson Test Classes are included in Appendix B

4.2.5 Soil strength

A modified Modulus of Rupture (MOR) test was conducted on all samples collected from the Study Area. The MOR test is a measure of soil strength and identifies the tendency of a soil to hard-set as a direct result of soil slaking and dispersion (Elmore and Sills 1982; Harper and Gilkes 1994). A MOR of over 60 kPa has been described as the critical value for distinguishing potentially problematic soils in agricultural scenarios (Cochrane and Aylmore 1997).

Roots are often unable to penetrate soil profiles which have high soil strength and this has many flow-on effects for the level of biological activity and general health of the soil matrix. In rehabilitated soil profiles, soil and other regolith materials from deeper layers are often re-deposited closer to the surface. Some of the soils may have a higher MOR than the surface soil and this can lead to problems related to plant germination, emergence and root penetration.
The MOR test is conducted on reconstructed soil blocks composed of the < 2 mm soil fraction. The test does not take into account the effect of gravel content or soil structure on soil strength, nor any degree of compaction that may be present in the field. However, the MOR test does provide insight into the potential for soil layers to hard-set and compact with repeated wetting and drying cycles, and the ability of roots to fracture and penetrate the soil profile.

The surface soils sampled within the Study Area exhibited a large degree of variation in soil strength values, ranging from 3.8 to 151.2 kilopascals (KPa) (**Figure 9**). There were a number of individual sample values exceeding 60 KPa, particularly from the ‘metamorphic outcrops with rocky soil’ and ‘sand over gravel’ soil-landform associations. On average however, the soils from the above soil-landform associations only slightly exceed the critical recommended value at one of the sampling depth intervals. Average MOR results from all soil-landform associations exhibited a slight increase in soil strength with increasing depth, with the highest average MOR values for all soil-landform association found at the 50 to 60 cm depth interval.



C S: colluvium gravelly soils; D S: deep sandy plains; S G: sand over gravel plains; M O: metamorphic outcrops with rocky soils

Figure 9: Individual and average MOR (KPa) values of the surface soils, grouped into soil-landform associations (error bars represent standard error). Red line indicates potential restrictions to plant and root development (Cochrane and Aylmore 1997)

4.2.6 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, and is dependent on soil properties such as texture and structure (Hunt and Gilkes 1992; Hazelton and Murphy 2007; 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 12 selected samples representative of the different soil-landform associations identified within the Study Area. The selected samples were collected in the field and repacked to their approximate field bulk densities for analysis (coarse fraction included). Drainage classes were determined for each sample according to their K_{sat} results (Hunt and Gilkes 1992) (**Table 5**). Overall, drainage classes were variable, ranging from 'moderately slow' to 'very rapid' with the majority of samples found to have 'moderate' drainage or higher. The 'deep sandy plains' and 'sand over gravel plains' soil-landform associations exhibited drainage classes ranging from 'moderate' to 'very rapid' due to their predominantly single grained sandy soil profiles.

Table 5: Saturated hydraulic conductivity (Ksat) values, texture and drainage class for selected representative soil samples

Soil-landform association	Site	Depth (cm)	Texture	Coarse fragments (%)	k_{sat} (mm/hr)	Drainage class
Colluvium gravelly soils (C S)	BRP09	0-5	Sandy loam	62	18	Moderately slow
	BR02	40-50	Sandy loam	74	290	Very rapid
Deep sandy plains (D S)	BR04	20-30	Sand	3	234	Rapid
	BR08	0-10	Loamy sand	2	37	Moderate
	BR09	0-10	Sandy clay loam	2	120	Moderately rapid
	BR10	0-10	Sandy loam	4	47	Moderate
Metamorphic outcrops with rocky soils (M O)	BRP01	0-10	Sandy loam	56	18	Moderately slow
	BRP11	10-20	Sandy loam	55	702	Very rapid
Sand over gravel plains (S G)	BRP02	0-10	Sand	13	33	Moderate
	BRP04	150-160	Sandy clay loam	35	422	Very rapid
	BRP07	60-70	Sandy clay loam	33	163	Rapid
	BR05	150-160	Sandy clay loam	56	248	Rapid

4.2.7 Soil 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 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, with the soil particle size (and pore space) distribution, soil structure and organic matter content being the most influential (Moore 1998).

The nine samples chosen for water retention measurements were representative of the range of surface soils sampled from different soil-landform associations across the Soil Study Area (**Figure 10**). The volumetric water content of the <2 mm fraction at 'field capacity' (upper storage limit [USL]), for the soils tested, ranged between 20.8% and 38.0% (**Table 6**). The volumetric water content of the <2 mm fraction at the maximum dryness likely to be achieved by plants (lower storage limit [LSL]), for the soils tested, was between 4.4% and 9.9% (**Table 6**).

The actual level of soil water suction able to be achieved differs between plant species, but an indicative level of 1500 kPa is used for these estimates (Peverill *et al.* 1999). It is known however, that some semiarid plant species can extract water at higher suctions. The difference between the upper and lower storage limits is regarded as 'plant available water' (PAW; represented as % volume) or the amount of water likely to be available to plants. The PAW, for the <2 mm fraction, of the soils tested ranged between 12.4% and 29.5% (**Figure 11, Table 6**).

A major factor influencing the amount of total material PAW is the percentage of coarse material present. Once the coarse fraction is taken into account, the PAW (% volume) in the total material (i.e. including coarse fraction) is considerably reduced for those soils with substantial coarse fractions. Consequently the USL and PAW content for all surface soils tested was reduced to between 7.7 and 21.9%, and 5.4 to 22.1% respectively (**Table 6**). The PAW for the total soil material (i.e. including the <2 mm fraction and coarse fraction) ranged between 5.4% ('colluvium gravelly soils' soil-landform association, 40 to 50 cm depth) and 22.1% ('sand over gravel plains' soil-landform association, 0 to 10 cm depth). The lowest PAW values were typically found for samples from deeper in the soil profile (e.g. samples from 40 to 50 cm in the 'colluvium gravelly soil', 10 to 20 cm in the 'metamorphic outcrops with rocky soils', and 150 to 160 cm in the 'sand over gravel plains' soil-landform associations), indicating a general reduction in water holding capacity with depth.

The implication of these results for the Project are that the depth of soil and waste materials that will be required to support vegetation must be carefully considered for rehabilitation planning. The depth of re-deposited soil materials required to store the expected rainfall can be calculated from the USLs of the soil materials assessed.

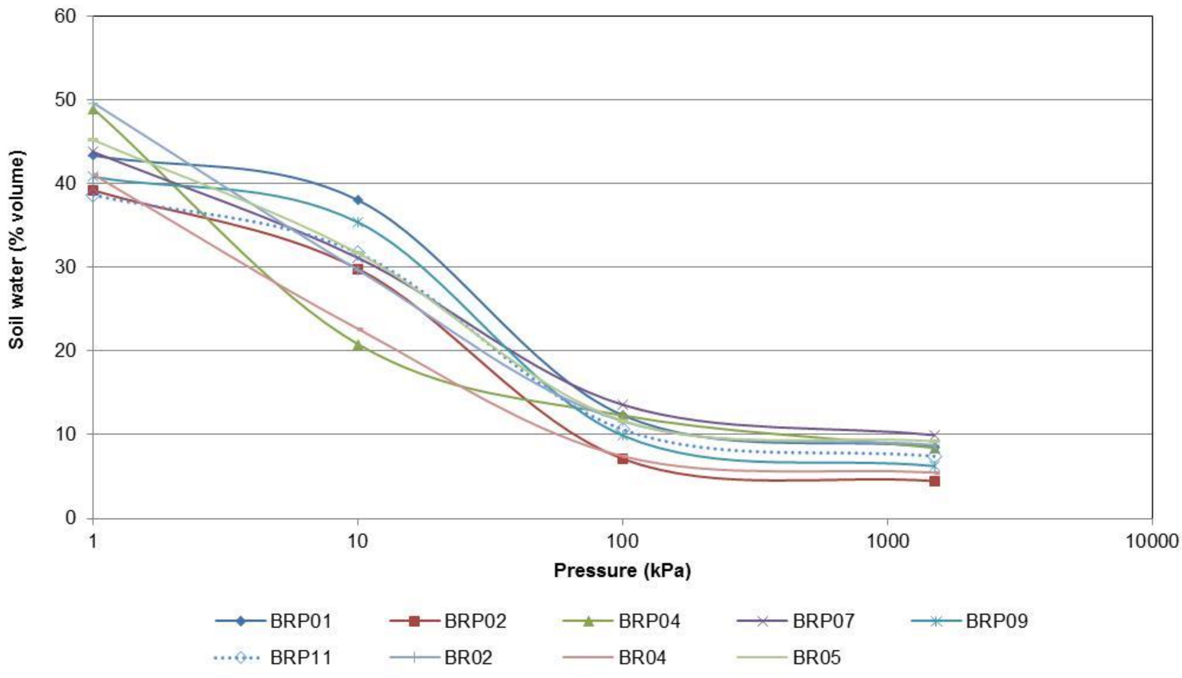


Figure 10: Water retention curves for the <2 mm soil fraction of selected surface soil samples (note: logarithmic scale on x-axis)

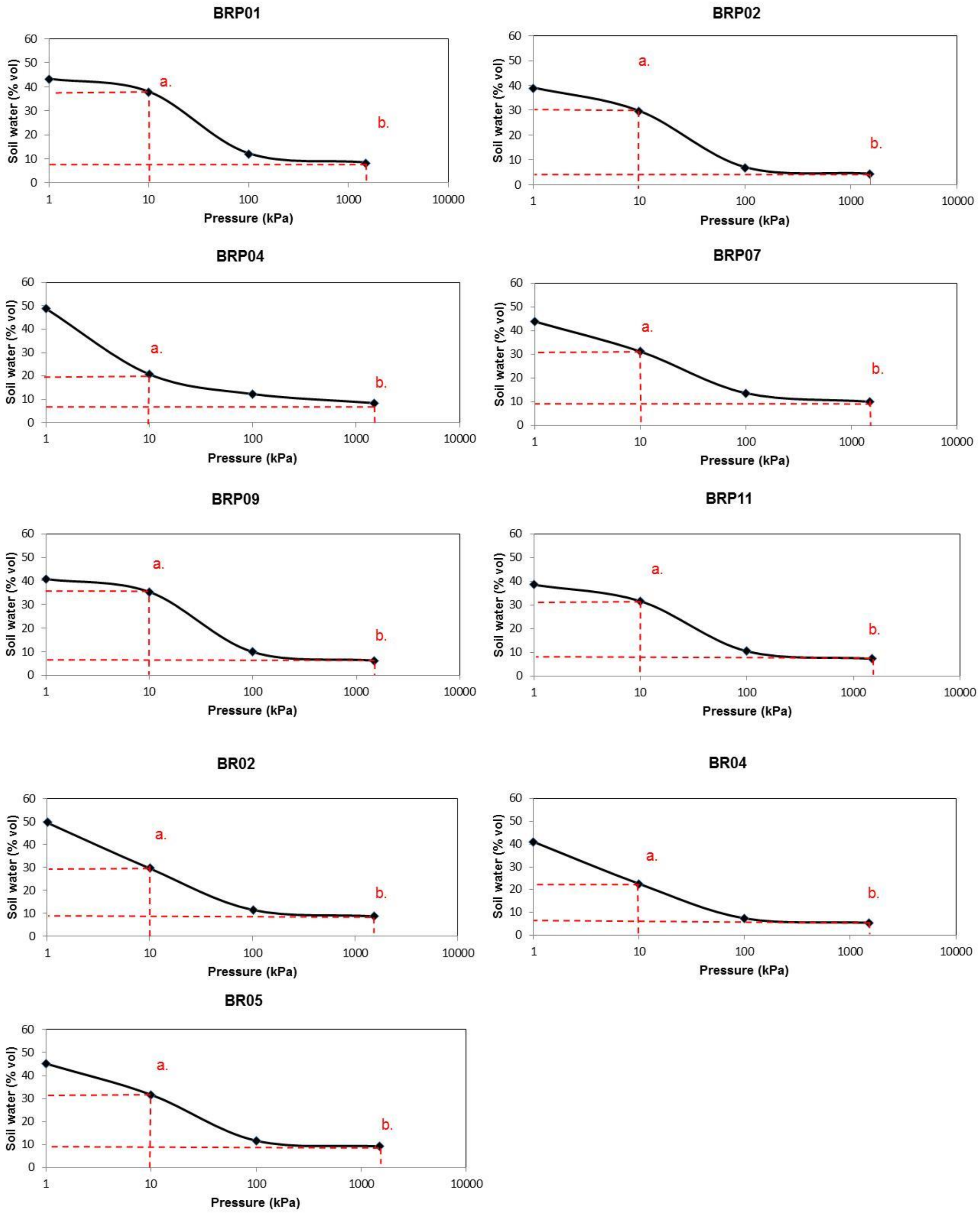


Figure 11: Water retention curves for the <2 mm soil fraction of individual surface soil samples (water content at point a. is the USL and point b. is the LSL (the difference in water content between a. and b. is the PAW)

Table 6: Water retention and availability characteristics for selected surface soils

Soil-landform association	Site	Depth (cm)	USL[1] (% vol) of <2 mm fraction	LSL[1] (% vol) of <2 mm fraction	PAW (% vol) of <2 mm fraction	USL (% vol) of total material[2]	PAW (% vol) of total material[2]
Colluvium gravelly soils (C S)	BRP09	0 to 5	35.4	6.2	29.1	13.4	11.1
	BR02	40 to 50	29.7	8.8	20.9	7.7	5.4
Deep sandy plains (D S)	BR04	20 to 30	22.6	5.5	17.1	21.9	16.6
Metamorphic outcrops with rocky soils (M O)	BRP01	0 to 10	38.0	8.5	29.5	16.7	13.0
	BRP11	10 to 20	31.7	7.4	24.3	14.3	10.9
Sand over gravel plains (S G)	BRP02	0 to 10	29.8	4.5	25.4	13.7	22.1
	BRP04	150 to 160	20.8	8.4	12.4	13.7	8.2
	BRP07	60 to 70	31.1	10.0	21.2	21.2	14.4
	BR05	150 to 160	31.7	9.2	22.5	14.3	10.1

1. USL taken as 10kPa (pF 2); LSL taken as 1500kPa (pF 5.5).
2. Taking gravel / coarse material (>2 mm) for each material into account. This assumes water holding capacity of >2 mm coarse fraction is negligible.

4.2.8 Root growth

Assessment of root growth provides an indication of any potential physical or chemical soil properties that may restrict root growth or distribution within the soil profile. Root abundance classification within the surface soil profiles ranged from 'few' to 'abundant' (based on Australian Soil and Land Survey classification: McDonald *et al.* 1998) (**Appendix B**), and was obviously dependant on proximity to plants and the number of plants present. At the majority of sites, root abundance classifications were 'common' (10 to 25 roots per 10 cm^2) to 'many' (25 to 200 roots per 10 cm^2) and only a few registering 'few' (1 to 10 roots per 10 cm^2). Root abundance generally increased between 10 to 50 cm depth in many of the soil profiles. Root growth was mostly well distributed through the soil matrix with few impediments to root exploration, with the exception of a shallow depth to fractured rock typical of the 'metamorphic outcrops with rocky soils' soil-landform associations.

4.2.9 Soil colour

Soil colour is the most distinctive soil property and is frequently used by soil scientists for the identification and classification of soil. As a function of parent material, soil colour may also be used as an indicator of physical and chemical properties such as texture, mineralogy and iron content (Schwertmann 1993), as well as biological properties and soil processes. Soil colour is described using three colour dimensions known as hue, value and chroma, which are coded to describe each individual grade of colour (Munsell® Soil Colour Charts 2000). Hue indicates the relation of a colour to red, yellow, green, blue and purple, value indicates lightness and chroma indicates strength.

The range of soil colours exhibited by the surface soils was quite similar. Eight different soil colour descriptions, based on 24 colour codes using the Munsell® soil colour system, were used to express the range of colours determined for all samples, ranging from red to strong brown, with the most common colour being strong brown.

The Yellow-Red (notated YR) hue was identified for the majority of the samples. Seven samples were classed within the Red (notated R) hue, and all were hue rated 10R. The majority of samples were ranked with medium chroma and value ratings, indicating muted, strong colours.

While there are no direct implications of soil colour to the physical and chemical characteristics of the materials, colour may be used in some circumstances to identify target soils types or potentially problematic materials during soil stripping operations.

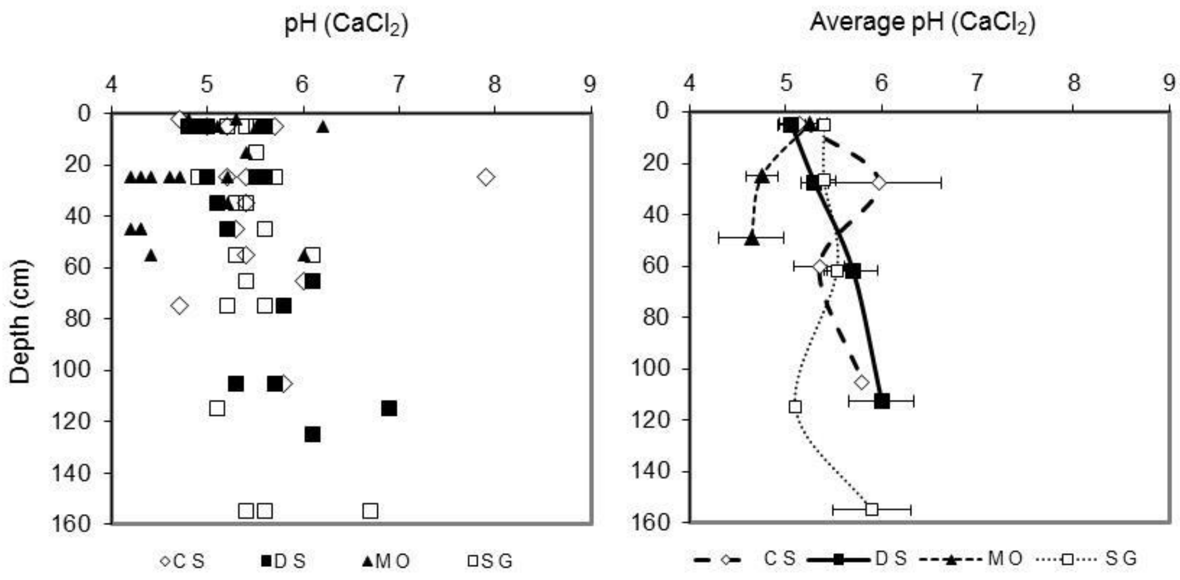
4.3 Soil chemical properties

4.3.1 Soil pH

The soil pH gives a measure of the soil acidity or alkalinity. The ideal pH range for plant growth of most agricultural species is considered to be between 5.0 and 7.5 (Moore 1998). Outside this range, the plant-availability of some nutrients is affected, while various metal toxicities (e.g. Al and Mn) can become limiting at low pH. For native species, which are known to be tolerant of wider ranges in soil pH, preferred pH ranges are best inferred from the soil in which they are observed to occur.

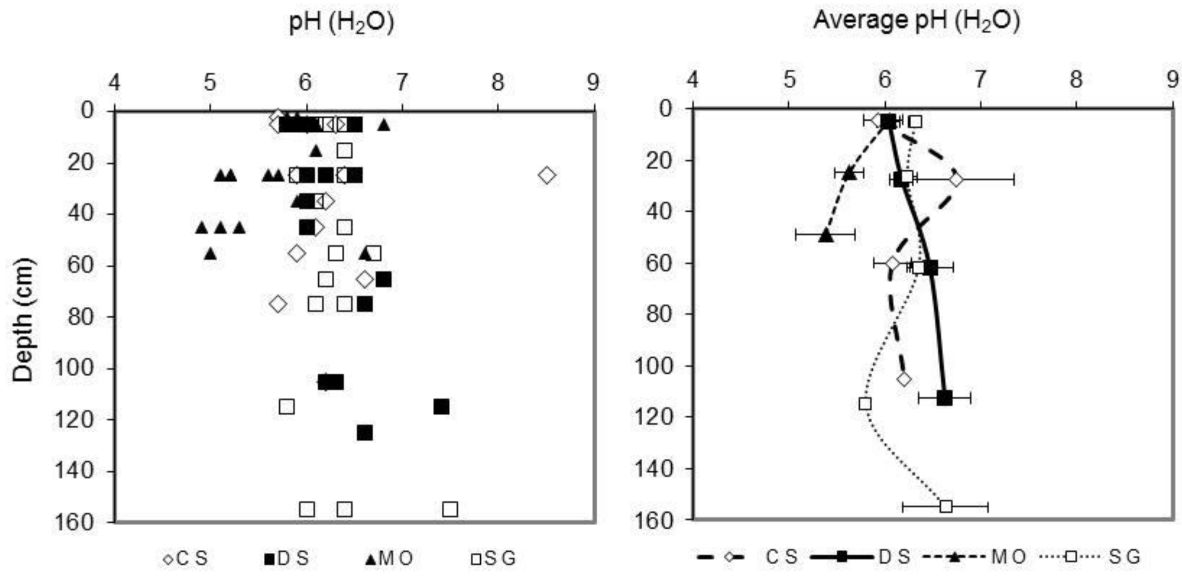
Soil pH measured in 0.01 M calcium chloride ($CaCl_2$) is considered a more accurate measurement of hydrogen ion concentration (H^+) and closer to that of the natural soil solution which is taken up by plants (Hunt and Gilkes 1992). As a result, soil pH measured in $CaCl_2$ is lower than pH measured in water, however both measurements are taken for a complete assessment.

Soil pH values for surface soils in the Soil Study Area ranged between 'strongly acid' (pH 4.2 $CaCl_2$) and 'moderately alkaline' (pH 7.9 $CaCl_2$) (Moore 1998) (**Figure 12**). Typically, soil pH increased with depth within the 'deep sandy plains' soil-landform association, in comparison to the 'metamorphic outcrops with rocky soils' soil-landform association where pH was found to decrease with depth. Average pH for samples from the 'sand over gravel' soil-landform association remained relatively similar through the soil profile, while results from the 'colluvium gravelly soils' were variable (**Figure 13**).



C S: colluvium gravelly soils; D S: deep sandy plains; S G: sand over gravel plains; M O: metamorphic outcrops with rocky soils

Figure 12: Individual and average soil pH ($CaCl_2$) values of the surface soils grouped into soil-landform associations (error bars represent standard error)



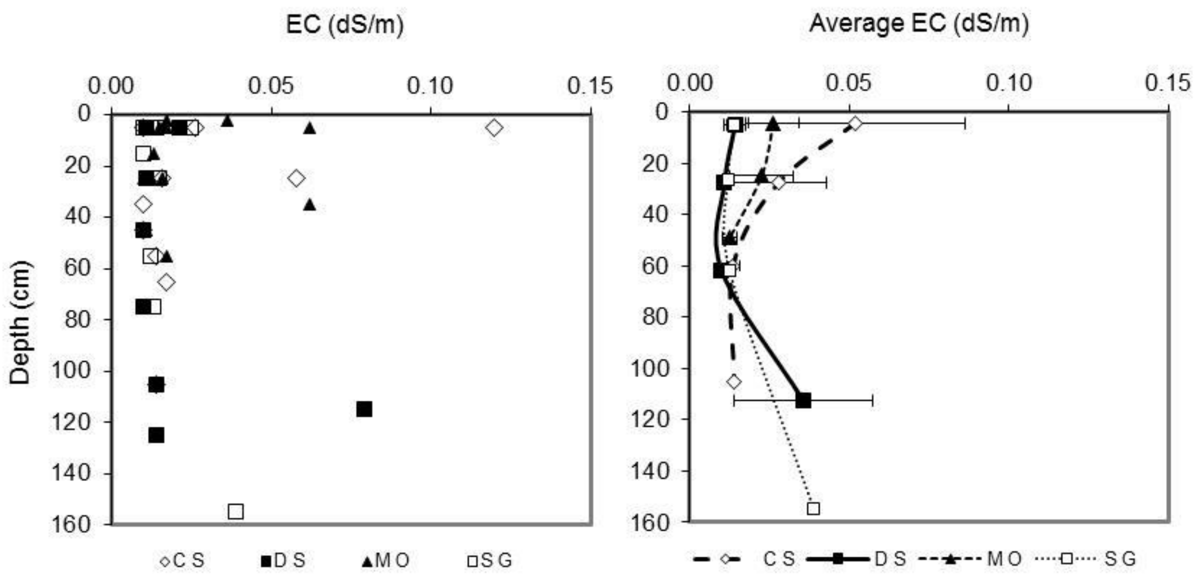
C S: colluvium gravelly soils; D S: deep sandy plains; S G: sand over gravel plains; M O: metamorphic outcrops with rocky soils

Figure 13: Individual and average soil pH (H_2O) values of the surface soils grouped into soil-landform associations (error bars represent standard error)

4.3.2 Electrical conductivity

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). Based on the standard USDA and CSIRO categories (**Appendix B**), all soil texture classes with EC values below 0.13 dS/m are considered non-saline.

Surface soils sampled within the Soil Study Area recorded low EC values that ranged from negligible (below the level of analytical detection) to 0.12 dS/m (**Figure 14**). All samples were therefore classed as non-saline, based on the standard USDA and CSIRO categories (**Appendix B**). Of the 71 samples analysed, 27 samples were below the level of detection for EC (<0.01 dS/m), indicating very low salinities. On average, there was little variation in EC with depth through the majority of the soil profiles (**Figure 14**).



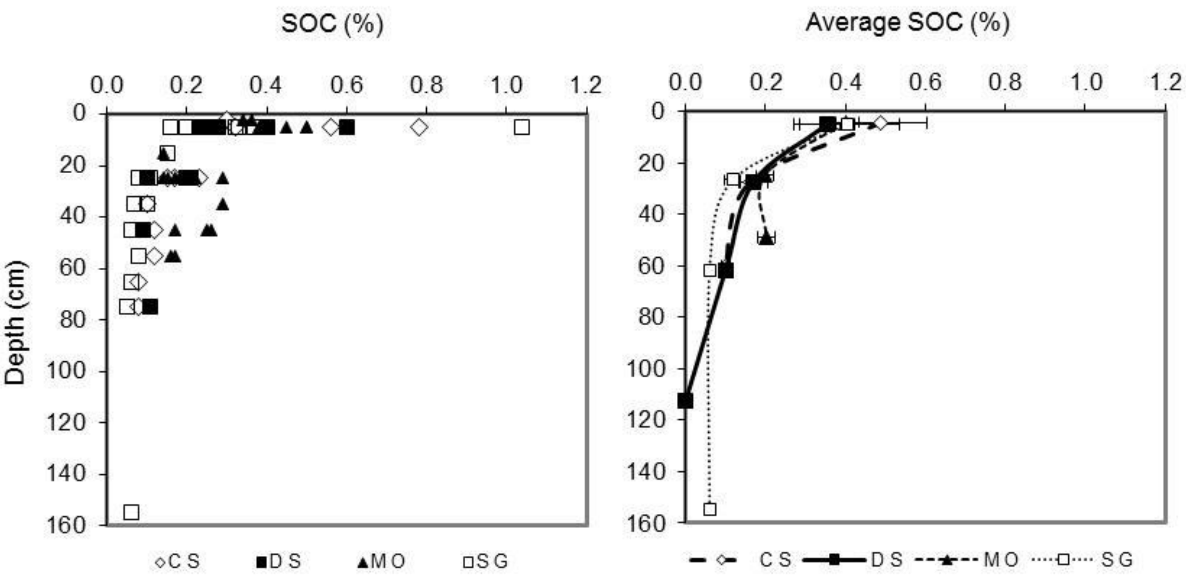
C S: colluvium gravelly soils; D S: deep sandy plains; S G: sand over gravel plains; M O: metamorphic outcrops with rocky soils

Figure 14: Individual and average electrical conductivity (EC 1:5 H2O) values of the surface soils grouped into soil-landform associations (error bars represent standard error)

4.3.3 Soil organic carbon

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 in the soil, increasing the water retention capacity, buffering pH and improving soil structure. The organic matter content of the soils within the Soil Study Area was determined as a measure of the soil organic carbon percentage (SOC %).

The SOC % within the majority of the surface soils sampled from the Soil Study Area was classed as 'low' (<1.0 SOC %) (Moore 1998), with 12 samples recording levels below the detectable limit (**Figure 15**). As would be expected there was, on average, a rapid decrease in SOC % with depth. There was little consistent difference in the SOC % values measured for the soils from different positions in the landscape.



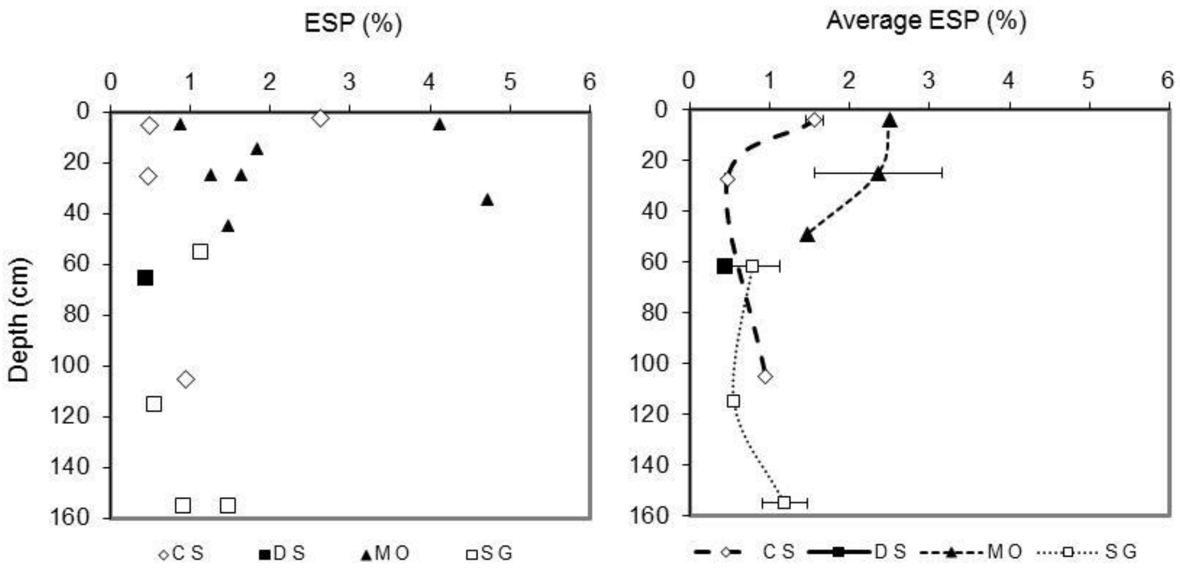
C S: colluvium gravelly soils; D S: deep sandy plains; S G: sand over gravel plains; M O: metamorphic outcrops with rocky soils

Figure 15: Individual and average soil organic carbon (%) values of the surface soils grouped into soil-landform associations (error bars represent standard error)

4.3.4 Exchangeable cations and exchangeable sodium percentage (ESP)

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 exceed 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).

All surface soils from within the Soil Study Area were classified as 'non-sodic', with all ESP results less than 6% (**Figure 16**). Out of 71 samples, only 17 reported ESP results, due to negligible exchangeable Na^{+} results for the majority of samples (below detectable levels).



C S: colluvium gravelly soils; D S: deep sandy plains; S G: sand over gravel plains; M O: metamorphic outcrops with rocky soils

Figure 16: Individual and average ESP (%) values of the surface soils grouped into soil-landform associations

4.3.5 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 of the Project.

4.3.5.1 Plant-available nitrogen

A significant proportion of soil nitrogen is held in organic matter and it is not immediately available for plant uptake (Hazelton and Murphy 2007). The nitrogen that is readily available to plants is generally measured as nitrate. Nitrogen is an integral component of many essential plant compounds. It is a major part of all amino acids, which are the building blocks of all proteins, including the enzymes which effectively control all biological processes (Brady and Weil 2002). A good supply of nitrogen stimulates root growth and development, and enhances the uptake of other nutrients (Brady and Weil 2002).

Plant-available nitrogen concentrations were analysed for all surface soils sampled within the Soil Study Area. Out of the 71 samples analysed, 17 recorded plant-available nitrogen levels of 1 mg/kg, and two samples recorded 2 mg/kg. The majority of samples reported plant-available nitrogen concentrations below the level of detection. While the measured concentrations of nitrogen are very low, these levels of plant-available nitrogen are considered adequate to support the native vegetation within the Study Area.

4.3.5.2 Plant-available phosphorus

Phosphorus is essential for the growth of plants and animals 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).

Plant-available phosphorus concentrations for the surface soil samples were similar to those of nitrogen, with 59 out of 71 samples reporting phosphorus concentrations below detectable levels (<2 mg/kg). All phosphorus levels were classed as 'low' (Moore 1998) (< 10 mg/kg), including six samples with 2 mg/kg, five samples with 3 mg/kg and one sample recording the highest result of 4 mg/kg. There was no apparent correlation between plant-available phosphorus concentration and position within the landscape. The majority of detectable phosphorus results were in the top 0 to 10 cm of the soil profile, as would be expected in relation to the organic matter content.

4.3.5.3 Plant-available potassium

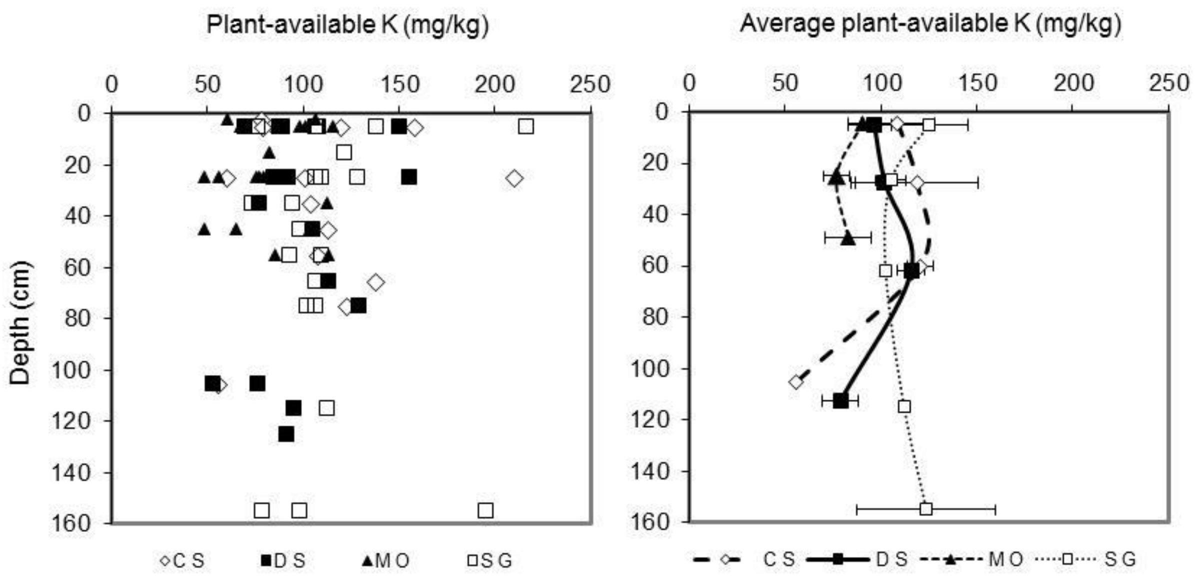
Potassium (K) plays a critical role in a number of plant physiological processes. Adequate amounts of K have been linked to improved drought tolerance, improved winter hardiness, better resistance to certain fungal diseases, and greater tolerance to insect pests. Potassium can also improve the structural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

Plant-available potassium concentrations for the surface soils ranged between 48 and 216 mg/kg (**Figure 17**), and were classed as 'low' (<70 mg/kg) to 'high' (>200 mg/kg) (Moore 1998). All average plant-available potassium concentrations were less than 150 mg/kg and varied considerably with depth and between soil-landform associations (**Figure 17**). There was little apparent correlation between plant-available phosphorus, depth of sample or position within the landscape.

4.3.5.4 Plant-available sulphur

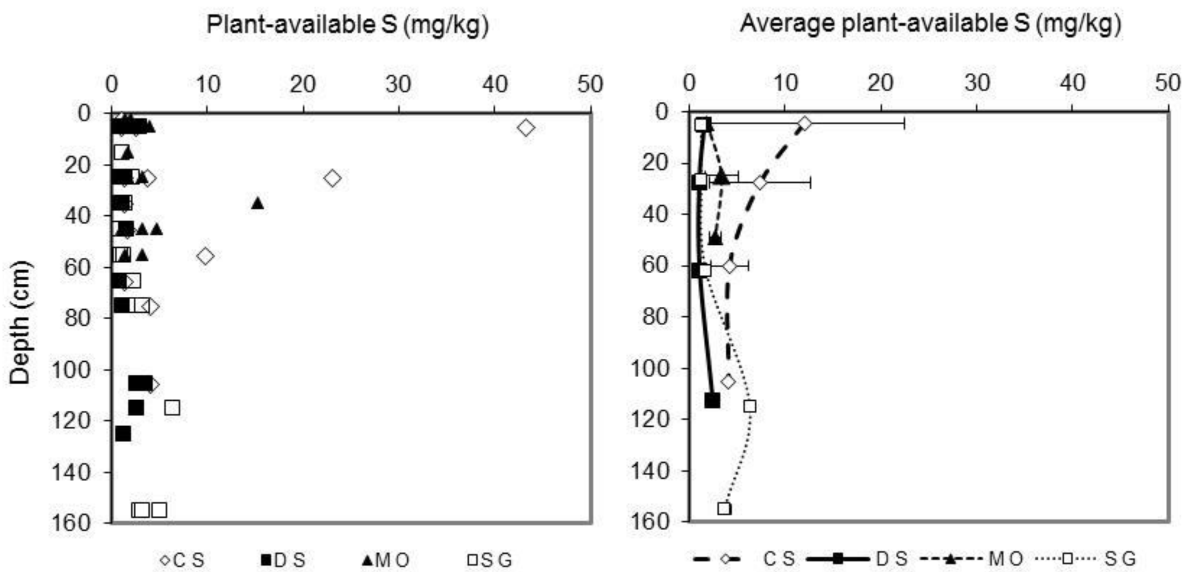
Sulphur is a constituent of many protein enzymes that regulate plant activities such as photosynthesis and nitrogen fixation (Brady and Weil 2002). Symptoms of sulphur deficiency are similar to those associated with nitrogen deficiency, including a tendency to become spindly, develop thin stems and petioles, with slowed plant growth and delayed maturity. The plants will also develop a light green or yellow appearance. Sulphur is relatively immobile in the plant, so chlorosis (light-green shading) develops first on the youngest leaves as sulphur supplies are gradually depleted (Brady and Weil 2002).

Plant-available sulphur concentrations for the surface soils were low and ranged between 1.1 and 43.3 mg/kg (**Figure 18**). Average plant-available sulphur concentrations were typically highest in soils from the 'colluvium gravelly soils' soil-landform association, particularly within the surface 0 to 10 cm, and decreased with depth through the soil profile (**Figure 18**).



C S: colluvium gravelly soils; D S: deep sandy plains; S G: sand over gravel plains; M O: metamorphic outcrops with rocky soils

Figure 17: Individual and average plant-available potassium (K) (mg/kg) values of the surface soils grouped into soil-landform associations (error bars represent standard error)



C S: colluvium gravelly soils; D S: deep sandy plains; S G: sand over gravel plains; M O: metamorphic outcrops with rocky soils

Figure 18: Individual and average plant-available sulphur (S) (mg/kg) values of the surface soils grouped into soil-landform associations (error bars represent standard error)

4.3.6 Total metal concentrations

Metal concentrations in the soil are significant due to their role in many biological functions; however, many metals can also become toxic at relatively low concentrations. Many metals actually occur in inert forms in soils and rocks and only become available to plants and animals if severe weathering events occur (Hazelton and Murphy 2007).

Measurements of total metal concentrations of surface soils sampled within the Soil Study Area indicated that levels of arsenic (As), cadmium (Cd), zinc (Zn) and mercury (Hg) were all below the limit of reporting (LOR) (**Table 7**). All concentrations of Cr, Cu, Pb and Ni were well below the relevant 'Ecological Investigation Levels' (EILs) for soils (Department of Environment and Conservation (DEC) 2010) for each element. Out of the 43 samples analysed for total metal concentrations, only three samples reported concentrations of Pb at or just above the LOR; eight were above the LOR for Ni and seven were above the LOR for Cu. The only consistent results were found for Cr, which exceeded the LOR for all samples, with the highest levels found at site BR07 with 29 and 30 mg/kg Cr, at 0 to 10 depth and 20 to 30 cm depth respectively. There was no apparent correlation between total metal concentration and soil-landform association.

Table 7: Average total metal concentrations (mg/kg) for surface soils, grouped into soil-landform associations, with associated ecological Investigation levels (EILs) and limits of reporting (LOR)

Soil-landform association	Depth	Analyte (mg/kg)							
		Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Zinc	Mercury
Colluvium gravelly soils (C S)	0-10	<5	<1	**15**	<5	<5	**5**	<5	<0.1
	10-40	<5	<1	**15**	<5	**5**	**6**	<5	<0.1
	40-80	<5	<1	**15**	<5	**6**	<2	<5	<0.1
	100-110	<5	<1	**13**	**12**	**6**	**3**	<5	<0.1
Deep sandy plains (D S)	0-10	<5	<1	**14**	**6**	<5	<2	<5	<0.1
	10-40	<5	<1	**17**	<5	<5	<2	<5	<0.1
	40-80	<5	<1	**17**	**6**	<5	**2**	<5	<0.1
Metamorphic outcrops with rocky soils (M O)	0-10	<5	<1	**11**	<5	<5	3	<5	<0.1
	10-40	<5	<1	**12**	**7**	<5	3	<5	<0.1
	40-80	<5	<1	**12**	**7**	<5	<2	<5	<0.1
Sand over gravel plains (S G)	0-10	<5	<1	**11**	<5	<5	<2	<5	<0.1
	10-40	<5	<1	**13**	<5	<5	<2	<5	<0.1
	40-80	<5	<1	**15**	**9**	<5	<2	<5	<0.1
LOR		**5**	**1**	**2**	**5**	**5**	**2**	**5**	**0.1**
EIL (mg/kg)		**20**	**3**	**1* / 400^**	**60**	**300**	**60**	**200**	**1**

Note: Values in bold indicate levels detected above the LOR, levels above the EILs (DEC, 2010) are highlighted in orange.
* = EIL for Chromium VI
^ = EIL for Chromium III

5. SOIL-LANDFORM ASSOCIATION MAPPING

Four soil-landform associations were identified within the Soil Study Area, namely; 'colluvium gravelly soil', 'sand over gravel plains', 'deep sandy plains', and 'metamorphic outcrops with rocky soils'. Identification of the soil-landform associations was based on field observations of morphological differences between the soil profiles and position within the landscape.

A soil management unit (SMU) map was developed from the 2012 survey based on the surface soil properties and their location in relation to the soil-landform associations (**Figure 19**). Approximate boundaries of the soil-landform associations, comprising the soil management units within the Soil Study Area, were based on the outcomes of the field survey, assessment of the physical and chemical analysis results, and interpretation of aerial photography and existing surface regolith mapping (**Section 2.4**).

The soil management units represent a preliminary classification of potential soil resources that occur within the Soil Study Area. The classification of these SMUs provides a means of identifying suitable soil and subsoil materials that may be considered for salvage, storage and use in future rehabilitation activities associated with the Project. When identifying these units, the practicalities of soil stripping and material handling activities are considered, as well as the benefits of retaining soil resources from specific positions in the landscape for similar placement and use in the rehabilitation of constructed waste landforms. Based on the characteristics of soils within the identified soil-landform associations, the SMU map consists of three management units, namely;

- colluviums gravelly sands / sands over gravel;
- deep sandy plains; and
- metamorphic outcrops with shallow rocky soils.

The 'colluvium gravelly sands' and 'sand over gravel' soil-landform associations have been combined into one SMU due to difficulties in defining the boundaries between these soil-landform associations, and due to similarities in the majority of physical and chemical properties of the soils present. Of the three soil management units, the 'deep sandy plains' comprise the largest proportional area within the Soil Study Area, while the 'metamorphic outcrops with rocky soils' covers the smallest area.

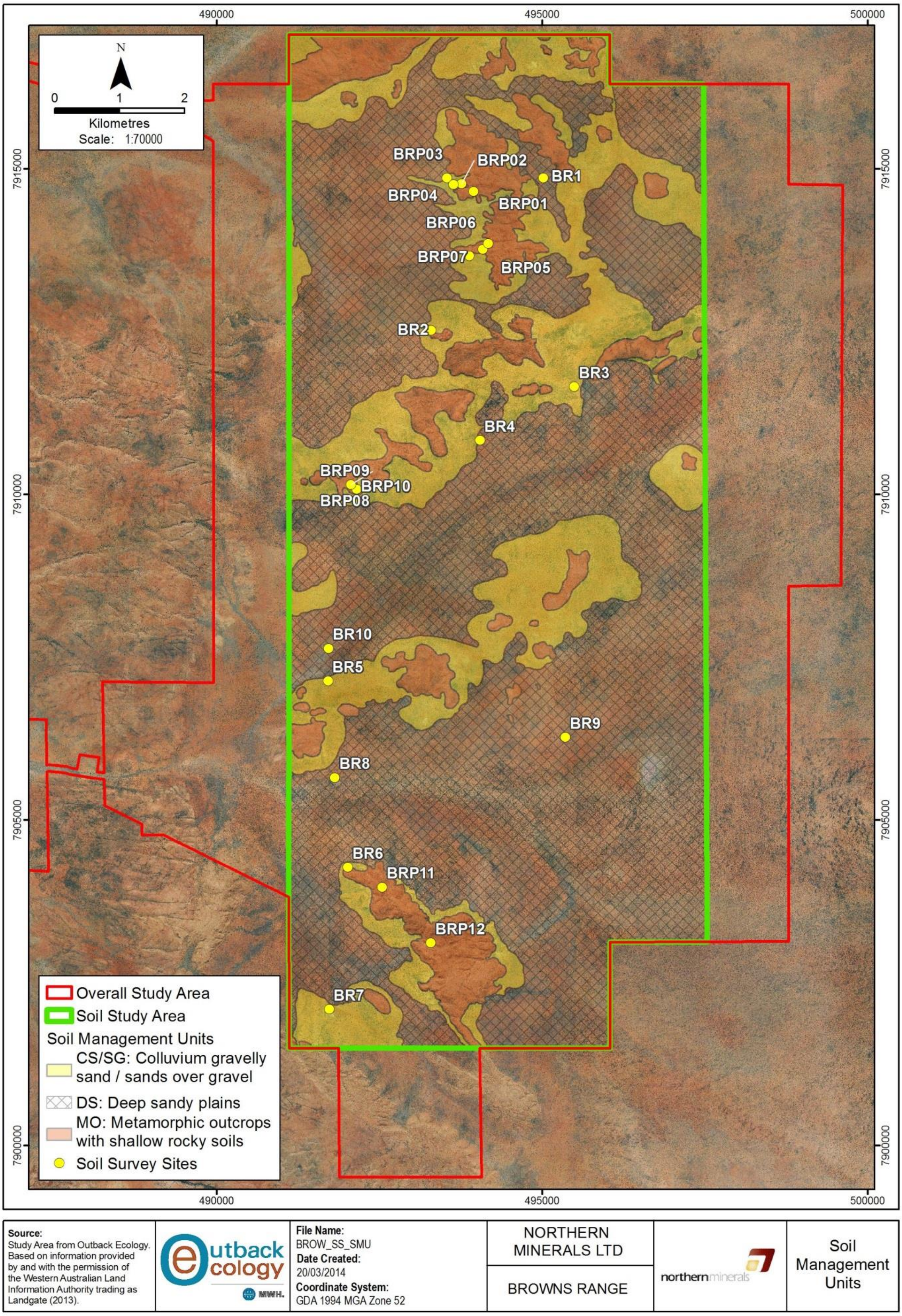


Figure 19: Soil management units (SMUs) within the Browns Range Soil Study Area

6. PRELIMINARY SOIL RESOURCES INVENTORY

Based on the SMU mapping, a preliminary inventory of soil resources for the Soil Study Area has been developed (**Table 8**). The development of a soil resource inventory has been shown to be an effective method of planning for the most effective use of available soil and mine waste resources. The inventory includes proportional areas of each soil management unit calculated for the Soil Study Area, potential topsoil stripping depths, typical characteristics, potential volumes of surface soils salvageable from disturbance areas and broad recommendations for the use and placement of the soil materials in rehabilitation prescriptions. The disturbance areas calculated are based on disturbance footprints as supplied by Northern Minerals (**Figure 20**).

Table 8: Potential surface soil inventory within the Browns Range Soil Study Area

SMU	Approx. topsoil depth (cm)	Area of SMU within Soil Study Area (ha)	% of total Soil Study Area	Area of SMU to be disturbed (ha) [1.]	Volume salvageable from disturbance areas (m^3) [2.]	Key characteristics	Suitability for use / placement in rehabilitation applications
Colluvium gravelly sands / sands over gravel (C S / S G)	15	2363	25	131	197,182	• Low-to-moderate coarse fragment content, increasing with depth; • Variable soil depth extending to 90 to 200 cm, with weak to moderate structure; • Loamy sand to sandy clay loam; • Slightly to strongly acidic; • Non-sodic, non-saline; • Non-hardsetting at surface, increasing to hardsetting at depth; • Low plant-available nutrient status; • Low-to-moderate water holding capacity.	Mid and lower slopes of constructed landforms
Deep sandy plains (D S)	15	6221	65	314	471,381	• Very low coarse fragment content; • Very deep soil depth extending to 200 cm, with weak to negligible structure; • Sand to sandy loams; • Neutral pH; • Non-sodic, non-saline; • Non-hardsetting; • Low plant-available nutrient status; • Moderate water holding capacity.	Limited to lower slopes of constructed landforms and flats/low lying rehabilitation areas only

Metamorphic outcrops with shallow rocky soils (M O)	15	1022	10	58	87,175	• High coarse fragment content, increasing with depth; • Variable soil depth extending to 60 to 120 cm, with moderate structure decreasing to single-grained; • Sandy loams; • Slightly acidic ; • Non-sodic, non-saline; • Non-hardsetting at surface, increasing to hardsetting at depth; • Low plant-available nutrient status; • Moderate water holding capacity.	Upper, mid and lower slopes of constructed landforms. Rock armouring of steep slopes.
TOTAL		**9606**	**100**	**503**	**755,738**	**-**	

1. Based on disturbance areas as detailed in Figure 20
2. Volume of soil within disturbance areas assuming 0.15m salvage depth.

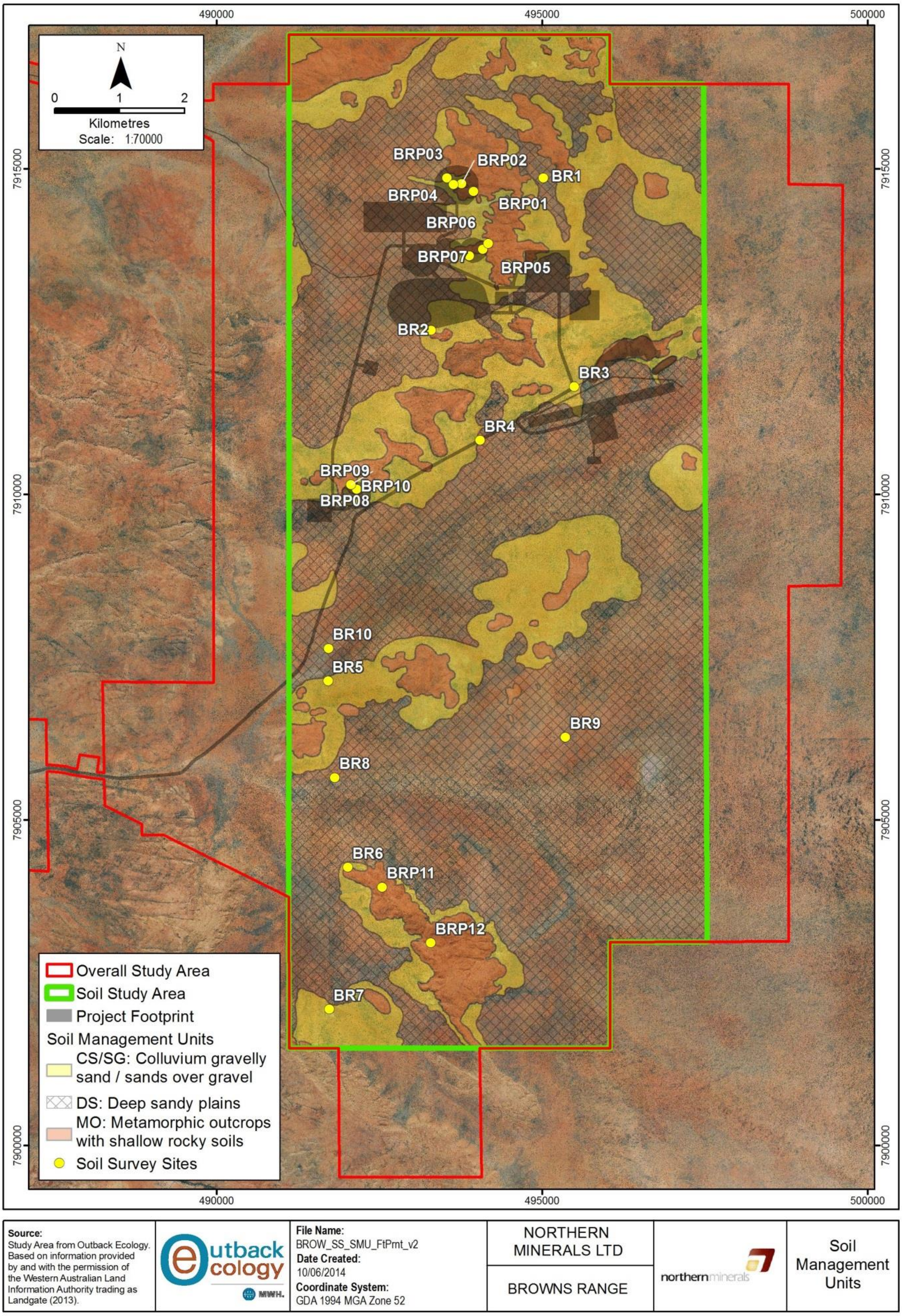


Figure 20: Disturbance footprint areas and Soil Management Units

An estimated stripping depth of approximately 15 cm for salvaging topsoil is considered appropriate for the SMUs based on information from the soil and landform assessment. Given the shallow nature of the soils and amount of outcropping rock present within the 'metamorphic outcrops with rocky soils' soil-landform associations, it is probable that the volume of topsoil that can be collected from these areas will be limited. It is likely however, that opportunistic collection of topsoil materials will be possible over some areas of the disturbance footprints where outcropping rock is less prevalent. Additional subsoil materials (i.e. from approximately 15 to 100 cm depth) may be salvaged from the deeper soil management units if required to supplement topsoil volumes, or for use as a rehabilitation medium. Further refinement of this information can occur as the disturbance footprints associated with mining activities are defined for the Browns Range Project.

The results of the physical and chemical investigations indicate that the vast majority of soil materials present in the Soil Study Area are likely to be physically and chemically benign. Topsoils from the 'metamorphic outcrops' are considered suitable for use as an outer surface rehabilitation medium on the upper, mid and lower slopes of constructed waste landforms, due to a high proportion of coarse fragments in these predominantly rocky soils, which will provide a degree of surface armouring for stability. Topsoils from the colluvium gravelly sands / sands over gravel SMU have a lower proportion of coarse fragments and are recommended for use on mid to lower slopes. Topsoil materials from the deep sandy plains SMU would predominantly comprise free-draining sands with minimal structure and low coarse fragment content, and are therefore considered more suitable for use on low slope or flat rehabilitation areas.

Recommendations for the use and placement of soil materials can be refined dependent on further investigations into aspects such as; the physical and geochemical properties of the waste materials expected to be generated during the life of the Project, waste rock landform design, tailings storage facility (TSF) design and other requirements for mine closure.

7. CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this report was to characterise the existing surface soils occurring within the Soil Study Area and to identify any potentially problematic materials that may cause issues for material handling during the proposed mining activities and for use as a rehabilitation resource. Information contained within this report can be used to assist the planning and adoption of appropriate rehabilitation prescriptions for the Project.

7.1 Surface soil properties

Four soil-landform associations were identified within the Soil Study Area, including 'colluvium gravelly soils', 'sand over gravel plains', 'deep sandy plains' and 'metamorphic outcrops with rocky soil'. The following section provides a summary of the individual characteristics of soils present within each of these soil-landform associations.

The 'colluvium gravelly soils' soil-landform association was generally located on the slopes leading to outcropping rock. The surface soil was typically shallow with moderate amounts of coarse material (>20%), non-saline, non-sodic and had a low nutrient status. The soil was 'slightly acidic', with a loamy sand to sandy loam texture, and a moderate water holding capacity decreasing to low with depth.

The 'deep sandy plains' soil-landform association describes soils with very little coarse material (<10%) sand to sandy loam texture, non-saline, neutral pH, low nutrient status and a moderate water holding capacity. The characteristics of this soil-landform association are consistent with the description of gently sloping plains within the Coolindie land system in Payne and Schoknecht (2011) (see **Section 2.3**).

The 'metamorphic outcrops with rocky soils' soil-landform association, consists of relatively shallow soils that had high coarse material content (>56%) were sandy loams, slightly acid, non-saline and had low nutrient status. These soils were also found to have a moderate water holding capacity. The characteristics of this soil-landform association are consistent with the description of low linear or rounded hills within the Winnecke land system in Payne and Schoknecht (2011) (see **Section 2.3**).

The 'sand over gravel plain' soil-landform association, consisted of soils similar to the deep sandy plains however increased in coarse material content through the profile. The water holding capacity was variable and typically decreased with depth. The surface soils were classed as a sandy loam and increased in clay content with depth to sandy clay loams. They were non-saline, slightly acidic and had a low nutrient status.

7.2 Potentially problematic soil properties

Soils within each of the four identified soil-landform associations typically had very low plant-available nutrient concentrations (plant-available N, P K and S). However, the native vegetation in this region is well adapted to soils that are low in plant-available nutrients. These results are not considered problematic.

The majority of soils present within each of the soil-landform associations exhibited MOR values less than 60 kPa, and hence, do not have the potential to hardset upon wetting and drying. Some samples from the ‘metamorphic outcrops with rocky soils’ soil-landform association did exhibit MOR values exceeding the threshold considered problematic from a hardsetting perspective. The potential of these soils to form hard, impenetrable layers however, is likely to be mitigated by the high coarse material content.

The majority of the surface soil samples were identified by the Emerson Aggregate Test as being non-dispersive or partially dispersive (3a, 3b, 5, 6 and 8) and are considered unlikely to become particularly erodible. Nevertheless, the partially dispersive samples (3a, 3b) do have the potential to become problematic (e.g. hardsetting, low infiltration, high erodibility) following severe disturbance such as earthworks or heavy rainfall. Care should be taken to minimise the handling of these soil materials where possible, particularly when wet. In addition, taking the high percentage of coarse material in soils from the ‘metamorphic outcrops with rocky soils’ soil-landform association into account, the susceptibility of these soils to erosion is likely to be reduced.

The ‘metamorphic outcrops with rocky soils’ soil-landform association had some ‘strongly acidic’ surface soil samples compared to the majority of soils from the other soil-landform associations, which were mostly found to be ‘slightly acidic’ to pH neutral. Soil pH values classed as ‘slightly’ to ‘strongly acidic’ fall within the range exhibited by surface soils within the region and are therefore unlikely to be problematic or inhibit growth of native plant species.

7.3 Soil stripping and management of soil resources

Topsoil refers to the fraction of surface soil which is enriched in organic matter, nutrients, seeds and has a high degree of microbial activity. In agriculture, the topsoil traditionally refers to the 0 to 10 cm depth interval of soil profile. However, in the arid regions of Australia, topsoils from undisturbed soil profiles, may be limited to 5 cm or extend to >20 cm depth.

The separate collection, stockpiling and re-application of topsoil will be an important component of the successful rehabilitation of target vegetation communities. Differences in soil properties and vegetation characteristics between areas constituting different habitats or soil-landform-vegetation associations can often complicate the requirements for material handling. Soil stripping and handling guidelines however, must be broad enough to fit into the logistical operations of earthworks and mining activities, and tailored to suit the characteristics of landforms and soils associated with the Project. In most instances, practices which retain the natural properties of the soil material may also reduce the level of operational expenditure. Practises which increase the intensity of soil disturbance (e.g. excavation, transportation, crushing, washing, stockpiling, re-working) lead to the breakdown of many inherent soil properties.

Three SMUs have been identified (based on consolidation of the four soil-landform associations) within the Soil Study Area, with little variation in the majority of the chemical and physical characteristics measured for the soils, other than the coarse material content and soil structure. The ‘metamorphic outcrops with rocky soil’ and the ‘colluvium gravelly soil’ soil-landform associations have greater amounts of coarse material which is likely to be beneficial for surface stability when used as a rehabilitation resource. Given that topsoil resources are often scarce in comparison to the volume of soil materials required for rehabilitation, it is recommended that the topsoil from within each major disturbance area be collected and handled as one unit within disturbance footprints of the Project. This would maximise the value of the limited soil resources within the study area by preserving the seed store, and the chemical, physical and biological attributes of the topsoil within the major soil-landform associations.

As a general guide it is recommended that, where possible, the top 15 cm of soil (plus any existing vegetation) be stripped and stockpiled as topsoil. If additional subsoil materials are required to supplement topsoil volumes, subsoils may be stripped and stockpiled from the deeper within the soil profile if required for rehabilitation purposes.

Topsoil stockpiles should be kept as low as practicable (ideally <2 m) to preserve biological activity and viable seed reserves. It is recommended that the topsoil materials be dumped by trucks rather than deposited using scrapers. Topsoil stockpiles should be re-seeded as soon as possible or covered with any removed vegetation. The use and placement of the salvaged topsoil on constructed waste landforms should be carefully considered. The strategic placement of suitable soil materials in particular areas of the waste landforms is likely to be a key to successful rehabilitation.

7.4 Recommendations

The preliminary soil resource inventory can be further developed for the Project, and incorporate waste materials based on waste characterisation studies (focussing on the characterisation of weathered regolith). Recommendations for the use and placement of soil materials can be refined dependent on further investigations into the physical and geochemical properties of the waste materials expected to be generated during the life of the Project, waste rock landform design and other requirements for mine closure.

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Appendix A
Glossary of terms

Glossary of terms

Aggregate (or ped)	A cluster of primary particles separated from adjoining peds by natural planes of weakness, voids (cracks) or cutans.
Bulk density	Mass per unit volume of undisturbed soil, dried to a constant weight at 105°C.
Clay	The fraction of mineral soil finer than 0.002 mm (2 μm).
Coarse fragments	Particles greater than 2 mm in size.
Consistence	The strength of cohesion and adhesion in soil.
Dispersion	The process whereby the structure or aggregation of the soil is destroyed, breaking down into primary particles.
Electrical conductivity	How well a soil conducts an electrical charge, related closely to the salinity of a soil.
Massive soil structure	Coherent soil, no soil structure, separates into fragments when displaced. Large force often required to break soil matrix.
Modulus of Rupture (MOR)	This test is a measure of soil strength and identifies the tendency of a soil to hard-set as a direct result of soil slaking and dispersion.
Organic carbon	Carbon residue retained by the soil in humus form. Can influence many physical, chemical and biological soil properties. Synonymous with organic matter (OM).
Plant-available water	The ability of a soil to hold that part of the water that can be absorbed by plant roots. Available water is the difference between field capacity and permanent wilting point.
Regolith	The unconsolidated rock and weathered material above bedrock, including weathered sediments, saprolites, organic accumulations, soil, colluvium, alluvium and aeolian deposits.

Single grain structure Loose, incoherent mass of individual particles. Soil separates into individual particles when displaced.

Slaking The partial breakdown of soil aggregates in water due to the swelling of clay and the expulsion of air from pore spaces.

Soil horizon Relatively uniform materials that extend laterally, continuously or discontinuously throughout the profile, running approximately parallel to the surface of the ground and differs from the related horizons in chemical, physical or biological properties.

Soil pH The negative logarithm of the hydrogen ion concentration of a soil solution. The degree of acidity or alkalinity of a soil expressed in terms of the pH scale, from 2 to 10.

Soil structure The distinctness, size, shape and arrangement of soil aggregates (or peds) and voids within a soil profile. Can be classed as *'apedal'*, having no observable peds, or *'pedal'*, having observable peds.

Soil strength The resistance of a soil to breaking or deformation. '*Hardsetting'* refers to a high soil strength upon drying.

Soil texture The size distribution of individual particles of a soil.

Subsoil The layer of soil below the topsoil or A horizons, often of finer texture (i.e. more clayey), denser and stronger in colour. Generally considered to be the 'B-horizon' above partially weathered or un-weathered material.

Topsoil Soil consisting of various mixtures of sand, silt, clay and organic matter; considered to be the nutrient-rich top layer of soil – The 'A-horizon'.

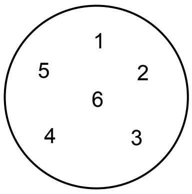
Appendix B

Outback Ecology soil analysis methods

1. Emerson dispersion test

Emerson dispersion tests were carried out on all samples according to the following procedure:

1. A petri dish was labelled 1 to 6. eg.



2. The petri dish was filled with DI water.
3. A 3 to 5 mm soil aggregate is taken from each sample and gently placed into the labelled petri dish (3 per dish).
4. Additional aggregates, remoulded by hand, are placed into the labelled petri dish (3 per dish).
5. Observations are made of the dispersivity or slaking nature of the sample according to the following table:

Emerson Aggregate 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

The samples were left in the dish for a 20 hour period, after which the samples were observed again and rated according to the above Table.

2. 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

3. Root abundance scoring

Root abundance is scored on a visual basis within the categories defined by McDonald *et al.* 1998:

Score	**Roots per 10 cm^2**	
	Very fine and fine roots	*Medium and coarse roots*
0 – No roots	0	0
1 – Few	1 - 10	1 or 2
2 – Common	10 - 25	2 – 5
3 – Many	25 - 200	>5
4 - Abundant	>200	>5

4. General soil pH ratings

These ratings are based on the Land Evaluation Standards for Land Resource Mapping categories, (Van Gool *et. al*. 2005).

The pH of a soil measures its acidity or alkalinity. The standard method for measuring pH in WA is 1:5 0.01M $CaCl_2$ (pH_{Ca}). However, in most land resource surveys it has been measured in a 1:5 soil:water suspension (pH_w). It is preferable to record actual data rather than derived data, therefore pH should be recorded according to the method used. The pH measured using different methods should not be compared directly for site investigations. For general land interpretation purposes, the relationship between pH_w and pH_{Ca} can be estimated by the equation:

$$pH_{Ca} = 1.04\ pH_w - 1.28$$ (Van Gool *et. al*. 2005)

The most widely available pH measurement is for the surface layer. However, the pH of the topsoil varies dramatically, and based on a comparison of map unit and soil profile data, estimated mean values for topsoil pH is commonly underestimated. Hence it is suggested that only an estimate of subsoil pH should be attempted. Even for subsoil the value can only be used as an indicator because pH varies dramatically with land use and minor soil variations.

Soil depth

The pH should be recorded for each soil group layer (see Section 1.6 and Figure 6). It is then reported at the following predefined depths:

• 0 - 10 cm (the surface layer);

• 20 cm (used for assessing subsoil acidity); and

• 50 - 80 cm. If there is a layer boundary within this depth use the higher value (used for assessing subsoil alkalinity).

	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 C
Outback Ecology soil analysis results

Table C1: Summary of Outback Ecology results for coarse fragment content, Emerson Class and soil/ material strength (modulus of rupture MOR)

Site	Depth (cm)	Soil-landform association	% Coarse fragments (>2 mm)	Emerson Test Class	MOR (kPa)
BRP01	0-10	Metamorphic outcrop with rocky soil	56.27	8	59.9
BRP01	20-30	Metamorphic outcrop with rocky soil	69.13	5	73.0
BRP01	40-50	Metamorphic outcrop with rocky soil	56.18	6	87.9
BRP02	0-10	Sand over gravel	12.93	5	35.3
BRP02	20-30	Sand over gravel plain	18.51	5	62.3
BRP02	40-50	Sand over gravel plain	28.31	5	63.6
BRP02	150-160	Sand over gravel plain	30.28	5	109.4
BRP03	0-10	Metamorphic outcrop with rocky soil	57.78	5	46.3
BRP03	20-30	Metamorphic outcrop with rocky soil	65.55	5	45.2
BRP03	40-50	Metamorphic outcrop with rocky soil	63.24	5	27.5
BRP04	0-10	Sand over gravel plain	4.79	8	25.7
BRP04	20-30	Sand over gravel plain	6.16	8	30.3
BRP04	50-60	Sand over gravel plain	5.44	5	64.7
BRP04	150-160	Sand over gravel plain	34.46	6	3.8
BRP05	0-10	Metamorphic outcrop with rocky soil	56.42	5	83.0
BRP05	20-30	Metamorphic outcrop with rocky soil	74.56	5	73.4
BRP06	0-10	Metamorphic outcrop with rocky soil	59.52	5	42.2
BRP06	20-30	Metamorphic outcrop with rocky soil	70.13	5	37.5
BRP06	50-60	Metamorphic outcrop with rocky soil	67.57	5	61.3
BRP07	0-10	Sand over gravel plain	16.94	5	48.9
BRP07	30-40	Sand over gravel plain	23.00	5	73.3
BRP07	60-70	Sand over gravel plain	32.32	5	83.8
BRP08	0-5	Metamorphic outcrop with rocky soil	62.31	5	33.1
BRP08	20-30	Metamorphic outcrop with rocky soil	74.03	5	31.8
BRP08	40-50	Metamorphic outcrop with rocky soil	73.42	5	31.1
BRP09	0-5	Colluvium gravelly soil	62.16	5	23.0
BRP09	20-30	Colluvium gravelly soil	73.72	5	71.7
BRP09	50-60	Colluvium gravelly soil	47.73	5	49.8
BRP09	100-110	Colluvium gravelly soil	28.86	5	33.2
BRP10	0-10	Colluvium gravelly soil	37.13	5	20.4
BRP10	30-40	Colluvium gravelly soil	63.59	5	25.2
BRP10	70-80	Colluvium gravelly soil	74.65	5	22.7
BRP11	0-5	Metamorphic outcrop with rocky soil	52.55	5	79.7
BRP11	10-20	Metamorphic outcrop with rocky soil	55.36	8	108.3
BRP11	30-40	Metamorphic outcrop with rocky soil	38.06	5	32.4
BRP12	0-10	Metamorphic outcrop with rocky soil	47.85	5	37.2
BRP12	20-30	Metamorphic outcrop with rocky soil	63.35	5	55.3
BRP12	50-60	Metamorphic outcrop with rocky soil	62.64	5	116.4

Site	Depth (cm)	Soil-landform association	% Coarse fragments (>2 mm)	Emerson Test Class	MOR (kPa)
BR1	0-10	Deep sandy plain	3.57	8	38.4
BR1	40-50	Deep sandy plain	2.48	5	36.1
BR1	110-120	Deep sandy plain	6.67	5	25.8
BR2	0-10	Colluvium gravelly soil	41.35	3a	52.4
BR2	20-30	Colluvium gravelly soil	63.14	3a	63.1
BR2	40-50	Colluvium gravelly soil	74.18	5	35.3
BR3	0-10	Sand over gravel plain	7.18	3a	36.9
BR3	10-20	Sand over gravel plain	11.03	8	28.6
BR3	50-60	Sand over gravel plain	13.15	5	48.0
BR3	110-120	Sand over gravel plain	65.13	5	13.3
BR4	0-10	Deep sandy plain	3.28	8	17.1
BR4	20-30	Deep sandy plain	2.94	8	11.7
BR4	100-110	Deep sandy plain	3.12	3b	16.9
BR5	0-10	Sand over gravel plain	4.89	3a	24.0
BR5	20-30	Sand over gravel plain	5.64	3a	15.3
BR5	70-80	Sand over gravel plain	6.57	2	33.2
BR5	150-160	Sand over gravel plain	55.49	5	23.8
BR6	0-10	Sand over gravel plain	13.77	8	36.0
BR6	30-40	Sand over gravel plain	19.56	8	39.8
BR6	70-80	Sand over gravel plain	68.95	8	64.0
BR7	0-10	Colluvium gravelly soil	20.33	2	42.9
BR7	20-30	Colluvium gravelly soil	30.79	3a	62.0
BR7	60-70	Colluvium gravelly soil	83.08	3a	151.2
BR8	0-10	Deep sandy plain	2.10	3a	21.9
BR8	20-30	Deep sandy plain	5.81	1	39.5
BR8	60-70	Deep sandy plain	6.00	2	61.3
BR8	120-130	Deep sandy plain	10.49	2	67.4
BR9	0-10	Deep sandy plain	1.96	3a	31.6
BR9	30-40	Deep sandy plain	2.11	5	14.6
BR9	100-110	Deep sandy plain	8.81	5	17.0
BR10	0-10	Deep sandy plain	3.93	3a	55.2
BR10	20-30	Deep sandy plain	4.67	3a	66.4
BR10	70-80	Deep sandy plain	13.03	3a	45.0

Appendix D
CSBP analysis results

Table D1: Summary of CSBP analyses

Site	Depth (cm)	Plant-available nutrients (mg/kg)					Organic Carbon (%)	Conductivity (dS/m)	pH Level ($CaCl_2$)	pH Level (H_2O)	Particle size distribution (%)					Exchangeable cations (meq/100g)			
		Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulphur					% Clay	% Course Sand	% Fine Sand	% Sand	% Silt	Ca	K	Mg	Na
BR01	0-10	1	< 1	< 2	89	1.5	0.40	0.011	4.9	5.9	12.2	63.6	22.3	85.8	2.04	1.46	0.2	0.46	< 0.01
BR01	40-50	2	< 1	< 2	105	1.5	0.09	0.010	5.2	6.0	-	-	-	-	-	-	-	-	-
BR01	110-120	1	1	< 2	95	2.5	<0.05	0.079	6.9	7.4	-	-	-	-	-	-	-	-	-
BR02	0-10	7	1	2	120	2.5	0.78	0.026	5.0	5.7	10.1	34.7	51.1	85.9	4.07	1.62	0.27	0.37	< 0.01
BR02	20-30	2	< 1	< 2	101	1.4	0.15	0.016	5.4	6.4	-	-	-	-	-	-	-	-	-
BR02	40-50	1	< 1	< 2	113	1.6	0.12	0.010	5.3	6.1	19.3	32.6	46.0	78.6	2.04	1.09	0.26	0.5	< 0.01
BR03	0-10	1	1	2	107	1.1	0.37	0.012	5.4	6.1	11.1	45.1	39.7	84.8	4.07	1.63	0.22	0.38	< 0.01
BR03	10-20	< 1	< 1	< 2	121	1.0	0.15	0.010	5.5	6.4	-	-	-	-	-	-	-	-	-
BR03	50-60	< 1	1	< 2	109	1.2	<0.05	0.012	6.1	6.7	19.2	40.7	39.2	79.8	1.01	0.91	0.24	0.61	0.02
BR03	110-120	1	< 1	< 2	112	6.3	<0.05	<0.010	5.1	5.8	22.7	48.2	27.1	75.4	1.98	0.86	0.26	0.69	0.01
BR04	0-10	2	< 1	< 2	69	1.3	0.28	0.011	5	6.0	-	-	-	-	-	-	-	-	-
BR04	20-30	< 1	< 1	< 2	84	1.3	0.21	<0.010	5	6.0	8.9	64.2	25.9	90.1	0.99	0.68	0.19	0.21	< 0.01
BR04	100-110	< 1	< 1	< 2	53	2.5	<0.05	<0.010	5.3	6.2	10.9	56.6	31.5	88.1	0.99	0.69	0.14	0.29	< 0.01
BR05	0-10	2	< 1	3	138	1.0	0.33	0.012	5.5	6.5	11.1	53.9	30.9	84.8	4.07	2.24	0.29	0.52	< 0.01
BR05	20-30	< 1	< 1	< 2	128	1.0	0.11	0.015	5.6	6.5	-	-	-	-	-	-	-	-	-
BR05	70-80	< 1	< 1	< 2	102	3.1	0.05	0.013	5.6	6.4	-	-	-	-	-	-	-	-	-
BR05	150-160	1	< 1	3	78	3.1	<0.05	<0.010	5.6	6.4	23.3	40.4	35.3	75.7	1.01	1.22	0.19	0.79	0.02
BR06	0-10	< 1	< 1	< 2	76	1.2	0.2	0.012	5.6	6.5	-	-	-	-	-	-	-	-	-
BR06	30-40	< 1	< 1	< 2	73	0.9	0.07	<0.010	5.3	6.1	9.2	50.5	37.2	87.7	3.09	0.6	0.16	0.3	< 0.01
BR06	70-80	1	< 1	3	106	1.7	<0.05	<0.010	5.2	6.1	17.9	47.2	34.9	82.1	<0.01	0.72	0.25	0.56	< 0.01
BR07	0-10	1	1	< 2	158	38.9	0.56	0.120	5.7	6.3	-	-	-	-	-	2.87	0.31	0.82	0.02
BR07	20-30	1	1	< 2	210	3.8	0.23	0.058	7.9	8.5	15.0	37.5	42.6	80.0	5.0	4.92	0.37	1.09	0.03
BR07	60-70	< 1	1	< 2	138	1.3	0.08	0.017	6	6.6	-	-	-	-	-	-	-	-	-
BR08	0-10	< 1	< 1	4	87	0.9	0.23	<0.010	5	6	-	-	-	-	-	-	-	-	-
BR08	20-30	< 1	< 1	< 2	92	0.7	0.1	<0.010	5.6	6.5	13.0	48.1	36.0	84.1	3.0	1.52	0.22	0.46	< 0.01
BR08	60-70	< 1	< 1	2	113	0.7	< 0.05	<0.010	6.1	6.8	19.0	44.6	34.4	79.1	2.0	1.57	0.25	0.48	0.01
BR08	120-130	< 1	< 1	< 2	91	1.2	< 0.05	0.014	6.1	6.6	-	-	-	-	-	-	-	-	-
BR09	0-10	< 1	< 1	< 2	87	1.2	0.26	<0.010	4.8	5.8	11.0	55.5	32.5	88.0	1.0	0.83	0.2	0.2	< 0.01
BR09	30-40	1	< 1	< 2	77	1.0	< 0.05	<0.010	5.1	6.0	12.9	51.3	34.9	86.2	1.0	0.72	0.17	0.23	< 0.01

Site	Depth (cm)	Plant-available nutrients (mg/kg)					Organic Carbon (%)	Conductivity (dS/m)	pH Level ($CaCl_2$)	pH Level (H_2O)	Particle size distribution (%)					Exchangeable cations (meq/100g)			
		Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulphur					% Clay	% Course Sand	% Fine Sand	% Sand	% Silt	Ca	K	Mg	Na
BR09	100-110	< 1	1	< 2	76	3.5	< 0.05	0.014	5.7	6.3	-	-	-	-	-	-	-	-	-
BR10	0-10	1	< 1	3	150	2.8	0.60	0.021	5.6	6.5	11.7	47.5	31.1	78.6	9.8	2.89	0.28	0.54	< 0.01
BR10	20-30	< 1	< 1	< 2	155	1.1	0.2	0.011	5.5	6.2	-	-	-	-	-	-	-	-	-
BR10	70-80	< 1	< 1	< 2	129	1.0	0.11	<0.010	5.8	6.6	24.8	40.1	32.1	72.2	3.0	1.86	0.30	0.50	< 0.01
BRP01	0-10	1	< 1	3	98	1.8	0.5	0.015	5.1	6.1	11.3	27.5	58.1	85.6	3.1	1.61	0.21	0.38	< 0.01
BRP01	20-30	1	< 1	2	85	1.1	0.17	<0.010	4.3	5.1	14.7	36.73	44.63	81.36	3.93	0.44	0.17	0.18	0.01
BRP01	40-50	1	< 1	< 2	103	4.6	0.25	0.010	4.3	5.1	-	-	-	-	-	-	-	-	-
BRP02	0-10	2	< 1	< 2	106	1.5	0.16	0.010	5.5	6.4	8.1	25.4	63.5	88.8	3.1	1.38	0.22	0.23	< 0.01
BRP02	20-30	< 1	< 1	< 2	109	1.1	0.08	0.011	5.7	6.4	-	-	-	-	-	0.96	0.23	0.29	< 0.01
BRP02	40-50	1	< 1	< 2	98	0.8	0.06	<0.010	5.6	6.4	-	-	-	-	-	-	-	-	-
BRP02	150-160	2	2	< 2	195	2.8	<0.05	0.039	6.7	7.5	-	-	-	-	-	-	-	-	-
BRP03	0-10	2	< 1	3	101	3.9	0.50	0.017	5.5	6.1	9.2	19.9	68.8	88.7	2.1	1.58	0.2	0.34	< 0.01
BRP03	20-30	1	< 1	2	75	3.1	0.22	0.016	4.2	5.2	-	-	-	-	-	-	-	-	-
BRP03	40-50	1	< 1	< 2	65	1.1	0.26	0.011	4.2	4.9	23.2	27.2	47.6	74.8	2.0	0.33	0.15	0.19	0.01
BRP04	0-10	2	1	3	216	1.5	1.04	0.025	5.2	6.2	-	-	-	-	-	-	-	-	-
BRP04	20-30	< 1	1	< 2	106	2.1	0.2	<0.010	4.9	5.9	8.0	37.1	51.9	88.9	3.0	1.20	0.22	0.33	< 0.01
BRP04	50-60	< 1	2	< 2	93	0.9	0.08	<0.010	5.3	6.3	-	-	-	-	-	-	-	-	-
BRP04	150-160	1	< 1	< 2	98	5.0	0.06	<0.010	5.4	6.0	22.4	27.4	46.2	73.6	3.9	0.96	0.21	0.85	0.03
BRP05	0-10	2	1	2	115	1.3	0.45	0.062	6.2	6.8	11.0	18.5	65.5	84.0	5.0	1.49	0.25	0.59	0.1
BRP05	20-30	1	1	< 2	77	1.7	0.29	0.010	4.7	5.7	-	-	-	-	-	-	-	-	-
BRP06	0-10	< 1	< 1	< 2	67	1.1	0.38	<0.010	4.9	5.8	-	-	-	-	-	0.99	0.15	0.23	< 0.01
BRP06	20-30	1	1	< 2	56	1.2	0.15	<0.010	4.6	5.6	7.9	34.2	54.8	89.1	3.0	0.42	0.14	0.18	< 0.01
BRP06	50-60	< 1	< 1	< 2	113	1.3	0.16	<0.010	4.4	5.0	-	-	-	-	-	-	-	-	-
BRP07	0-10	1	< 1	< 2	108	1.1	0.32	0.014	5.2	6.2	-	-	-	-	-	-	-	-	-
BRP07	30-40	1	< 1	< 2	94	1.3	0.10	<0.010	5.4	6.1	14.8	28.1	53.1	81.3	4.0	1.11	0.20	0.37	< 0.01
BRP07	60-70	< 1	< 1	< 2	106	2.3	0.06	<0.010	5.4	6.2	23.0	26.2	48.8	75.0	2.0	1.54	0.20	0.51	0.01
BRP08	0-5	1	< 1	< 2	60	1.3	0.36	0.036	4.8	5.8	-	-	-	-	-	-	-	-	-
BRP08	20-30	< 1	< 1	< 2	48	1.3	0.14	<0.010	4.4	5.2	12.2	32.7	50.0	82.7	5.1	0.35	0.12	0.13	0.01
BRP08	40-50	< 1	< 1	< 2	48	3.2	0.17	<0.010	4.3	5.3	-	-	-	-	-	-	-	-	-
BRP09	0-5	< 1	< 1	3	78	1.1	0.30	<0.010	4.7	5.7	10.3	25.1	60.5	85.6	4.1	0.75	0.18	0.18	0.03

Site	Depth (cm)	Plant-available nutrients (mg/kg)					Organic Carbon (%)	Conductivity (dS/m)	pH Level ($CaCl_2$)	pH Level (H_2O)	Particle size distribution (%)					Exchangeable cations (meq/100g)			
		Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulphur					% Clay	% Course Sand	% Fine Sand	% Sand	% Silt	Ca	K	Mg	Na
BRP09	20-30	1	< 1	2	60	23.0	0.17	<0.010	5.2	5.9	10.9	31.3	54.8	86.1	3.0	0.70	0.14	0.17	< 0.01
BRP09	50-60	< 1	1	< 2	108	9.8	0.12	0.014	5.4	5.9	-	-	-	-	-	-	-	-	-
BRP09	100-110	< 1	1	< 2	56	4.1	< 0.05	0.014	5.8	6.2	26.9	47.2	20.9	68.	5.0	1.14	0.14	0.81	0.02
BRP10	0-10	< 1	< 1	< 2	79	1.1	0.32	0.010	5.2	6.0	6.1	41.9	51.1	92.9	1.0	1.11	0.17	0.22	< 0.01
BRP10	30-40	1	< 1	< 2	104	1.4	0.10	0.010	5.4	6.2	15.2	31.4	51.4	82.8	2.0	0.78	0.22	0.4	< 0.01
BRP10	70-80	< 1	1	< 2	123	4.0	0.08	<0.010	4.7	5.7	-	-	-	-	-	-	-	-	-
BRP11	0-5	< 1	< 1	< 2	106	2.0	0.34	0.017	5.3	5.9	-	-	-	-	-	-	-	-	-
BRP11	10-20	1	< 1	< 2	82	1.6	0.14	0.013	5.4	6.1	13.5	38.9	46.6	85.5	1.0	0.80	0.18	0.62	0.03
BRP11	30-40	< 1	< 1	< 2	112	15.2	0.29	0.062	5.2	5.9	40.4	28.7	27.9	56.6	3.0	1.76	0.23	2.26	0.21
BRP12	0-10	< 1	< 1	< 2	86	1.4	0.27	0.011	5.0	5.8	7.8	28.4	61.8	90.2	2.0	0.71	0.18	0.24	0.01
BRP12	20-30	< 1	< 1	< 2	79	1.4	0.18	0.012	5.2	6.2	-	-	-	-	-	-	-	-	-
BRP12	50-60	1	1	< 2	85	3.2	0.17	0.017	6.0	6.6	-	-	-	-	-	-	-	-	-

Appendix E

ALS Certificate of Analysis

CERTIFICATE OF ANALYSIS

Work Order	: **EP1207570**	Page	: 1 of 11
Client	: **OUTBACK ECOLOGY SERVICES**	Laboratory	: Environmental Division Perth
Contact	: PETER FLAVEL	Contact	: Scott James
Address	: 1/71 TROY TERRACE JOLIMONT WA, AUSTRALIA 6014	Address	: 10 Hod Way Malaga WA Australia 6090
E-mail	: peter.flavel@outbackecology.com	E-mail	: perth.enviro.services@alsglobal.com
Telephone	: +61 08 93888799	Telephone	: +61-8-9209 7655
Facsimile	: +61 08 93888633	Facsimile	: +61-8-9209 7600
Project	: BROW-SS-12001	QC Level	: NEPM 1999 Schedule B(3) and ALS QCS3 requirement
Order number	: OES3413		
C-O-C number	: ----	Date Samples Received	: 11-SEP-2012
Sampler	: ----	Issue Date	: 18-SEP-2012
Site	: ----		
		No. of samples received	: 43
Quote number	: EP-180-10 BQ	No. of samples analysed	: 43

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. All pages of this report have been checked and approved for release.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

NATA Accredited Laboratory 825

Accredited for compliance with ISO/IEC 17025.

WORLD RECOGNISED ACCREDITATION

Signatories

This document has been electronically signed by the authorized signatories indicated below. Electronic signing has been carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Canhuang Ke	Metals Instrument Chemist	Perth Inorganics
Scott James	Laboratory Manager	Perth Inorganics

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting

Analytical Results

Sub-Matrix: **SOIL**

			Client sample ID	BRP01 0-10	BRP01 20-30	BRP02 0-10	BRP02 20-30	BRP03 20-30
			Client sampling date / time	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42
Compound	*CAS Number*	*LOR*	*Unit*	**EP1207570-001**	**EP1207570-002**	**EP1207570-003**	**EP1207570-004**	**EP1207570-005**
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	<1.0	**2.8**	<1.0	**2.2**	**3.7**
EG005T: Total Metals by ICP-AES								
Arsenic	7440-38-2	5	mg/kg	<5	<5	<5	<5	<5
Cadmium	7440-43-9	1	mg/kg	<1	<1	<1	<1	<1
Chromium	7440-47-3	2	mg/kg	**11**	**12**	**11**	**12**	**13**
Copper	7440-50-8	5	mg/kg	<5	<5	<5	<5	<5
Lead	7439-92-1	5	mg/kg	<5	<5	<5	<5	<5
Nickel	7440-02-0	2	mg/kg	<2	<2	<2	<2	<2
Zinc	7440-66-6	5	mg/kg	<5	<5	<5	<5	<5
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.1	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1

Analytical Results

Sub-Matrix: **SOIL**

			Client sample ID	**BRP04 20-30**	**BRP04 50-60**	**BRP05 0-10**	**BRP05 20-30**	**BRP06 0-10**
			Client sampling date / time	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42
Compound	*CAS Number*	*LOR*	*Unit*	**EP1207570-006**	**EP1207570-007**	**EP1207570-008**	**EP1207570-009**	**EP1207570-010**
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	**2.4**	**2.4**	**1.1**	**3.5**	<1.0
EG005T: Total Metals by ICP-AES								
Arsenic	7440-38-2	5	mg/kg	<5	<5	<5	<5	<5
Cadmium	7440-43-9	1	mg/kg	<1	<1	<1	<1	<1
Chromium	7440-47-3	2	mg/kg	**11**	**11**	**11**	**13**	**12**
Copper	7440-50-8	5	mg/kg	<5	<5	<5	<5	<5
Lead	7439-92-1	5	mg/kg	<5	<5	<5	<5	<5
Nickel	7440-02-0	2	mg/kg	<2	<2	**3**	<2	<2
Zinc	7440-66-6	5	mg/kg	<5	<5	<5	<5	<5
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.1	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1

Analytical Results

Sub-Matrix: **SOIL**			Client sample ID	BRP06 20-30	BRP07 0-10	BRP07 60-70	BRP08 20-30	BRP08 40-50
			Client sampling date / time	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42
Compound	*CAS Number*	*LOR*	*Unit*	**EP1207570-011**	**EP1207570-012**	**EP1207570-013**	**EP1207570-014**	**EP1207570-015**
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	**2.1**	<1.0	**4.7**	**3.1**	**5.5**
EG005T: Total Metals by ICP-AES								
Arsenic	7440-38-2	5	mg/kg	<5	<5	<5	<5	<5
Cadmium	7440-43-9	1	mg/kg	<1	<1	<1	<1	<1
Chromium	7440-47-3	2	mg/kg	**11**	**11**	**12**	**11**	**14**
Copper	7440-50-8	5	mg/kg	<5	<5	**9**	<5	<5
Lead	7439-92-1	5	mg/kg	<5	<5	<5	<5	<5
Nickel	7440-02-0	2	mg/kg	<2	<2	<2	<2	<2
Zinc	7440-66-6	5	mg/kg	<5	<5	<5	<5	<5
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.1	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1

Analytical Results

Sub-Matrix: **SOIL**			Client sample ID	BRP09 20-30	BRP09 100-110	BRP10 0-10	BRP10 30-40	BRP10 70-80
			Client sampling date / time	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42
Compound	*CAS Number*	*LOR*	*Unit*	**EP1207570-016**	**EP1207570-017**	**EP1207570-018**	**EP1207570-019**	**EP1207570-020**
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	**1.9**	**6.1**	<1.0	**3.6**	**6.0**
EG005T: Total Metals by ICP-AES								
Arsenic	7440-38-2	5	mg/kg	<5	<5	<5	<5	<5
Cadmium	7440-43-9	1	mg/kg	<1	<1	<1	<1	<1
Chromium	7440-47-3	2	mg/kg	**11**	**19**	**10**	**11**	**12**
Copper	7440-50-8	5	mg/kg	<5	**12**	<5	<5	<5
Lead	7439-92-1	5	mg/kg	<5	**6**	<5	<5	<5
Nickel	7440-02-0	2	mg/kg	<2	**3**	<2	<2	<2
Zinc	7440-66-6	5	mg/kg	<5	<5	<5	<5	<5
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.1	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1

Work Order : EP1207570
Client : OUTBACK ECOLOGY SERVICES
Project : BROW-SS-12001

Analytical Results

Sub-Matrix: SOIL			Client sample ID	BRP11 10-20	BRP11 30-40	BRP12 0-10	BRP12 50-60	BR1 0-10
			Client sampling date / time	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42
Compound	CAS Number	LOR	Unit	EP1207570-021	EP1207570-022	EP1207570-023	EP1207570-024	EP1207570-025
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	**2.0**	**8.3**	<1.0	**3.4**	<1.0
EG005T: Total Metals by ICP-AES								
Arsenic	7440-38-2	5	mg/kg	<5	<5	<5	<5	<5
Cadmium	7440-43-9	1	mg/kg	<1	<1	<1	<1	<1
Chromium	7440-47-3	2	mg/kg	**11**	**16**	**9**	**9**	**13**
Copper	7440-50-8	5	mg/kg	<5	**7**	<5	**7**	<5
Lead	7439-92-1	5	mg/kg	<5	<5	<5	<5	<5
Nickel	7440-02-0	2	mg/kg	<2	**3**	<2	<2	<2
Zinc	7440-66-6	5	mg/kg	<5	<5	<5	<5	<5
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.1	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1

Analytical Results

Sub-Matrix: **SOIL**			Client sample ID	BR1 40-50	BR2 20-30	BR2 40-50	BR3 10-20	BR3 50-60
			Client sampling date / time	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42
Compound	*CAS Number*	*LOR*	*Unit*	**EP1207570-026**	**EP1207570-027**	**EP1207570-028**	**EP1207570-029**	**EP1207570-030**
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	**4.2**	**2.4**	**4.8**	**2.7**	**4.3**
EG005T: Total Metals by ICP-AES								
Arsenic	7440-38-2	5	mg/kg	<5	<5	<5	<5	<5
Cadmium	7440-43-9	1	mg/kg	<1	<1	<1	<1	<1
Chromium	7440-47-3	2	mg/kg	**14**	**10**	**18**	**16**	**23**
Copper	7440-50-8	5	mg/kg	<5	<5	<5	<5	<5
Lead	7439-92-1	5	mg/kg	<5	**5**	**6**	<5	<5
Nickel	7440-02-0	2	mg/kg	<2	<2	<2	<2	<2
Zinc	7440-66-6	5	mg/kg	<5	<5	<5	<5	<5
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.1	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1

Analytical Results

Sub-Matrix: **SOIL**			Client sample ID	BR4 0-10	BR5 0-10	BR5 70-80	BR6 0-10	BR6 30-40
			Client sampling date / time	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42
Compound	*CAS Number*	*LOR*	*Unit*	**EP1207570-031**	**EP1207570-032**	**EP1207570-033**	**EP1207570-034**	**EP1207570-035**
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	<1.0	<1.0	**5.0**	<1.0	**1.6**
EG005T: Total Metals by ICP-AES								
Arsenic	7440-38-2	5	mg/kg	<5	<5	<5	<5	<5
Cadmium	7440-43-9	1	mg/kg	<1	<1	<1	<1	<1
Chromium	7440-47-3	2	mg/kg	**14**	**13**	**16**	**10**	**11**
Copper	7440-50-8	5	mg/kg	<5	<5	<5	<5	<5
Lead	7439-92-1	5	mg/kg	<5	<5	<5	<5	<5
Nickel	7440-02-0	2	mg/kg	<2	<2	<2	<2	<2
Zinc	7440-66-6	5	mg/kg	<5	<5	<5	<5	<5
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.1	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1

Analytical Results

Sub-Matrix: **SOIL**			Client sample ID	BR7 0-10	BR7 20-30	BR8 20-30	BR8 60-70	BR9 0-10
			Client sampling date / time	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42
Compound	*CAS Number*	*LOR*	*Unit*	**EP1207570-036**	**EP1207570-037**	**EP1207570-038**	**EP1207570-039**	**EP1207570-040**
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	<1.0	**4.0**	**2.5**	**4.2**	<1.0
EG005T: Total Metals by ICP-AES								
Arsenic	7440-38-2	5	mg/kg	<5	<5	<5	<5	<5
Cadmium	7440-43-9	1	mg/kg	<1	<1	<1	<1	<1
Chromium	7440-47-3	2	mg/kg	**29**	**30**	**17**	**19**	**15**
Copper	7440-50-8	5	mg/kg	<5	<5	<5	**6**	<5
Lead	7439-92-1	5	mg/kg	<5	<5	<5	<5	<5
Nickel	7440-02-0	2	mg/kg	**5**	**6**	<2	**2**	<2
Zinc	7440-66-6	5	mg/kg	<5	<5	<5	<5	<5
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.1	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1

Analytical Results

Sub-Matrix: **SOIL**			Client sample ID	BR9 30-40	BR10 0-10	BR10 70-80	----	----
			Client sampling date / time	11-SEP-2012 12:42	11-SEP-2012 12:42	11-SEP-2012 12:42	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**EP1207570-041**	**EP1207570-042**	**EP1207570-043**	**----**	**----**
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	**2.4**	**1.0**	**5.2**	----	----
EG005T: Total Metals by ICP-AES								
Arsenic	7440-38-2	5	mg/kg	<5	<5	<5	----	----
Cadmium	7440-43-9	1	mg/kg	<1	<1	<1	----	----
Chromium	7440-47-3	2	mg/kg	**16**	**15**	**18**	----	----
Copper	7440-50-8	5	mg/kg	<5	**6**	**8**	----	----
Lead	7439-92-1	5	mg/kg	<5	<5	<5	----	----
Nickel	7440-02-0	2	mg/kg	<2	**2**	**3**	----	----
Zinc	7440-66-6	5	mg/kg	<5	<5	<5	----	----
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.1	mg/kg	<0.1	<0.1	<0.1	----	----