Appendix 12: Characterisation of Regolith Materials – Outback (2011)





Tectonic Resources

Phillips River Project

Characterisation of soils from the Trilogy Deposit and waste material from the Kundip Deposit

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Executive Summary

Outback Ecology was commissioned by Tectonic Resources (Tectonic) to characterise soil and selected waste materials from the Phillips River Project. The Philips River Project comprises two deposit areas, Trilogy and Kundip (note: there are several smaller deposits within the Kundip Deposit area), located approximately 450 km southeast of Perth and 20 km southeast of Ravensthorpe.

The soil and waste material assessment comprised the following:

- an assessment of the physical and chemical characteristics of 'surface' soils (to approximately 0.5 m depth) within the Trilogy Deposit area;
- an assessment of baseline surface soil conditions for future dust monitoring assessment (0 to 5 cm depth); and
- characterisation of selected waste regolith samples from the Kundip Deposits.

Laboratory analyses indicated a wide range of soil properties between, and in some instances within, the soil associations investigated. Based on analysis of the samples collected, the following conclusions have been made regarding the properties of the soils and regolith materials (refer to Table ES1).

Trilogy Deposit surface soil

Soil samples from the Trilogy Deposit were allocated into five different soil associations, namely red clay dominant soil, phyllite outcrop, sand-dominant soil, gravel-dominant soil and calcrete-dominant soil, based on a previous survey of the Trilogy Deposit area.

Soil physical characteristics

There were a range of particle size distributions within the individual soil profiles investigated. Soil texture ranged from sandy loam (approximately 10 to 20 % clay) to heavy clay (> 50 % clay). The majority of soil materials were classed as sandy loams, sandy clays or light to medium clays, with little correlation between soil texture and depth of sample. Sites from the red clay-dominant soils typically observed the highest clay contents and were classed as sandy clays to medium clays.

A high proportion of the sub-surface soil samples from below the 0 – 10 cm sampling interval were partially or completely dispersive. There was no apparent relationship between soil association and soil structural stability. Sub-surface soils from all soil associations were observed to be completely or partially dispersive. Gravel-dominant soils appeared to be the most stable. Many of the selected soils tested from the Trilogy Deposit exhibited a capacity for hard-setting. The highest MOR values were mainly observed in samples from the red clay-dominant and gravel-dominant soils.

The drainage class (hydraulic conductivity) for selected soil samples from the Trilogy Deposit ranged from 'extremely slow' to 'very rapid'. The plant-available water (PAW), (% volume) values measured within the study area was considered to be ‘moderate’, and typical for the soils of the region. There was substantial variation in the water retention characteristics measured for the < 2 mm soil fraction of most soils, with PAW values ranging from 14.3 to 35.7%.

Soil Chemical Characteristics

Soil pH values (H_2O) ranged between pH 5.1 (very strongly acidic), to 9.3 (strongly alkaline). The majority of soil materials sampled were classed as neutral to moderately alkaline. Soils from the red clay-dominant, phyllite outcrop, sand-dominant and calcrete-dominant materials were generally moderately alkaline, while the gravel-dominant sites were generally classed as neutral. The electrical conductivity (EC) of the surface soils ranged from non-saline to very saline. EC values with the soil profile typically increased with depth.

The majority of soils sampled had moderate to high organic carbon content and typically had low levels of plant-available nutrients. The majority of the soils were classified as non-sodic, with ESP values less than 6 %, however, highly sodic ESP values were measured in sites from the red-clay dominant soils and phyllite outcrop, particularly at sub-surface sampling intervals, below the surface 0 – 10 cm.

Most soils materials sampled were below the detectable limit (limits of reporting) for cadmium (Cd) and mercury (Hg); however, arsenic (As), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn) were regularly detected at a reportable level. There was an observed trend between multi-element concentrations and the sand-dominant soils, which also had levels of As above the Ecological Investigation Level (EIL) guidelines (DEC, 2010).

Trilogy baseline dust monitoring sites

Sixteen surface soil samples were collected from baseline dust monitoring sites from around the Trilogy Deposit. These samples were analysed for pH, electrical conductivity and total metals.

Soil Chemical Characteristics

Surface soil pH values (H_2O) from the dust monitoring sites ranged between pH 5.4 (strongly acidic) and pH 8.4 (moderately alkaline). The majority of soil materials sampled were classed as slightly acidic to neutral. The electrical conductivity (EC) of the soils sampled were all classed as non-saline.

Most soils materials sampled from the dust monitoring sites were below the detectable limit (limits of reporting) for As, Cd, Cr, Zn and Hg, however Cu, Pb and Ni were regularly detected at a reportable level. No samples from the dust monitoring sites reported heavy metal concentrations above the EIL guidelines (DEC, 2010).

Kundip waste regolith samples

Six waste regolith samples from the Kundip Deposits were collected for physical and chemical analysis.

Regolith physical characteristics

The majority of the waste regolith materials were identified as Emerson Class 5 and are not considered to be problematic. One of the samples was identified as potentially hardsetting.

Regolith Chemical Characteristics

The waste regolith pH values ($CaCl_2$) were classed as neutral. The pH values (H_2O) ranged between strongly acidic (pH 5.3) and neutral (pH 7.3). The electrical conductivity (EC) of the waste regolith samples ranged from non-saline to moderately saline.

As would be expected the majority of the waste samples had low to moderate organic carbon content and had low levels of plant-available nutrients. All waste samples were classified as either sodic (6 to 15 % ESP) or highly sodic (> 15 % ESP).

Table ES1: Physical and chemical characteristics for soil and waste material from the Phillips River Project. The figures presented 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

Site Description		Physical Properties						Chemical Properties						
		Soil Texture [1]	Gravel content[2] (%)	Emerson Class[3]	(Modulus of Rupture (kPa)	Water retention characteristics (Potential available water)[4]	Hydraulic conductivity (mm/hr)	pH (H_2O)	Salinity Class (dS/m)	Organic Carbon (%)	Nutrient status	Effective Cation Exchange Capacity (meq/100g)	Exchangeable Sodium Percentage (%)	Total metal concentrations[5]
Trilogy Deposit														
Red clay dominant soil		Sandy clay loam	16	Unstable 1, 3a and 3b	55.8 (Non-hardsetting)	Low-moderate 9.0 - 21.4%	357.6 (Very rapid)	8.14 (Moderately alkaline)	0.33 (Slightly saline)	1.28 (High)	Low	11.27 (Moderate)	6.21 (Sodic)	Below EIL
Phyllite outcrop		Clay loam, sandy	6	Unstable 1	67.3 (Hardsetting)	Low – moderate 13.8 – 20.4%	6.1 (Moderately slow)	8.80 (Moderately alkaline)	0.45 (Moderately saline)	0.54 (High)	Low	6.63 (Moderate)	9.14 (Sodic)	Below EIL
Sand dominant soil		Sandy clay	47	Unstable 1 and 3b	49.2 (Non-hardsetting)	Low – moderate 9.9 – 17.7%	174.3 (Rapid)	8.10 (Moderately alkaline)	0.21 (Non-saline)	0.94 (High)	Low	10.02 (Moderate)	3.95 (Non-sodic)	Elevated As level
Gravel dominant soil		Sandy loam	41	Stable 3b	30.4 (Non-hardsetting)	Not recorded	173.9 (Rapid)	7.06 (Neutral)	0.17 (Non-saline)	1.49 (High)	Low	3.00 (Low)	8.03 (Sodic)	Below EIL
Calcrete dominant soil		Sandy clay	0	Unstable 1 and 2	62.7 (Hardsetting)	Not recorded	Not recorded	8.43 (Moderately alkaline)	0.36 (Slightly saline)	1.06 (High)	Low	11.93 (Moderate)	6.00 (Sodic)	Below EIL
Baseline dust monitoring sites		Not recorded	Not recorded	Not recorded	Not recorded	Not recorded	Not recorded	6.73 (Neutral)	0.11 (Non-saline)	Not recorded	Not recorded	Not recorded	Not recorded	Below EIL
Kundip Deposit														
Waste material	**Kaolin**	Not recorded	Not recorded	Stable 5 and 6	26.5 (Non-hardsetting)	Not recorded	Not recorded	5.50 (Strongly acidic)	0.21 (Non-saline)	0.03 (Low)	Low	0.89 (Low)	18.23 (Highly sodic)	Below EIL
	Saprolite	Not recorded	Not recorded	Stable 5	57.5 (Non-hardsetting)	Not recorded	Not recorded	6.40 (Slightly acidic)	0.61 (Moderately saline)	0.12 (Moderate)	Low	7.42 (Moderate)	66.73 (Highly sodic)	Below EIL

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) (% volume) of total material (< 2 mm fraction and coarse material). Calculation based on the upper storage limit (field capacity) minus the lower storage limit (wilting point). 5. 'High' metal concentrations indicate results above Ecological Investigation Levels (EILs) (Department of Environment and Conservation, 2010)

Conclusions and recommendations

Trilogy baseline soil sites

The soil survey investigated the properties of the five major soil types previously identified within the Project area; these were: the red clay dominant soil, phyllite outcrop, sand-dominant soil, gravel-dominant soil and calcrete-dominant soil.

The results indicate that a number of the samples below the 'topsoil', i.e. below the surface 0 – 10 cm depth interval, from the Trilogy Deposit were identified as being partially or completely dispersive, are sodic, have the capacity to hard-set and have a high potential erodibility. If these sub-surface soils are inappropriately handled or placed on the outer slopes of waste landforms, these intrinsic properties may cause difficulties and result in additional financial costs in the rehabilitation / revegetation process. The following section provides practical recommendations for the effective stripping, stockpiling and management of the surface soil materials within the Trilogy Deposit area.

The separate collection, stockpiling and application of the topsoil materials will be an important component to the successful rehabilitation of target vegetation communities on constructed landforms. Soil stripping and handling guidelines must be flexible to accommodate the logistical operations of earthworks and mining activities.

It is recommended that the top 10 cm of the soil profile in disturbance areas be stripped and stockpiled as topsoil. As a general rule, the 'quality' of the soil decreases with depth and hence it is important that machinery operators remove material only from the recommended profile depth (i.e. the top 10cm). Failure to do so may result in issues related to salinity, hardsetting and soil dispersion and/or create unstable, erodible stockpiles.

Direct return of topsoils is preferred where possible, alternatively, 'paddock-dumped' soil stockpiles are recommended. Given the dispersive nature of the sub-surface soils within the disturbance footprint, it is likely that the volume of 'topsoil' that can be collected will be limited. The application of the salvaged topsoil to the waste landforms should be considered carefully in order to optimise the rehabilitation outcome. Stockpiles and waste landforms should be designed and constructed to minimize the potential for erosion.

Kundip waste samples

It is evident that the sampled waste regolith materials from the Kundip Deposit are relatively stable in terms of dispersive qualities, but are prone to hard-setting and are sodic to highly sodic. Consequently, substantial planning and management will be required to ensure that, if these materials are used as a cover / rehabilitation material on waste landforms, that these materials are placed appropriately.

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1. INTRODUCTION

1.1 Background

Outback Ecology was commissioned by Tectonic Resources to characterise the properties of the surface soils from the Trilogy Deposit and selected waste regolith material from Kundip Deposits, which comprise the Phillips River Project (the Project), located approximately 450 km southeast of Perth and 20 km southeast of Ravensthorpe (Figure 1).

Knowledge of the properties of surface soils and waste regolith materials will assist in the planning and design process for the development of waste landforms and will mitigate the potential impact that the Project may have on the soils and landforms in the surrounding area. Information derived from this investigation will also be used to assist in the development of cost-effective closure and rehabilitation plans specific for the Project area and provide baseline information against which future, post mining assessments of surface soils can be compared.

Figure 1: Location of the Phillips River Project area

1.2 Report scope and objectives

The soil survey was designed to meet the Department of Mines and Petroleum (DMP) Guidelines for Mining Proposals in Western Australia (DoIR, 2006) and the Leading Practice Sustainable Development Program for the Mining Industry (Dept. of Industry, Tourism and Resources, 2006). To minimise the cost of the survey, the field sampling component was completed by Tectonic personnel.

Specifically, the assessment comprised:

- an assessment of the physical and chemical characteristics of 'surface' soils (topsoil and sub-surface soils to approximately 0.5 m depth), corresponding to previously identified soil types and disturbance footprint boundaries within the Trilogy Deposit area;
- an assessment of selected waste regolith materials from the Kundip Deposits;
- identification of potentially-problematic soil / regolith materials and characteristics which may influence rehabilitation practices;
- an assessment of baseline chemical characteristics (soil pH, salinity and total metal concentration) of surface soils (0 – 5 cm) at future dust monitoring locations;
- identification of rehabilitation strategies to minimise potential impacts; and
- the development of recommendations for soil / earthworks components of mining (i.e. soil stripping protocols).

2. MATERIALS AND METHODS

2.1 Sampling regime

Surface samples were collected from a total of 15 sites within the Trilogy Deposit area (Table 1, Figure 2). These samples were collected using a hand-auger by Tectonic personnel, to a depth of 0.5 metres. Samples were taken from three depth intervals within the profile (0 – 10 cm; 20 – 30 cm; and 40 – 50 cm) for physical and chemical analysis (45 samples in total).

Surface soil sampling was undertaken to achieve an adequate representation of the different materials within the proposed disturbance area (Figure 2); the soil types sampled included:

- Red clay-dominant soil;
- Phyllite outcrops;
- Sand-dominant soil;
- Gravel-dominant soil; and
- Calcrete-dominant soil.

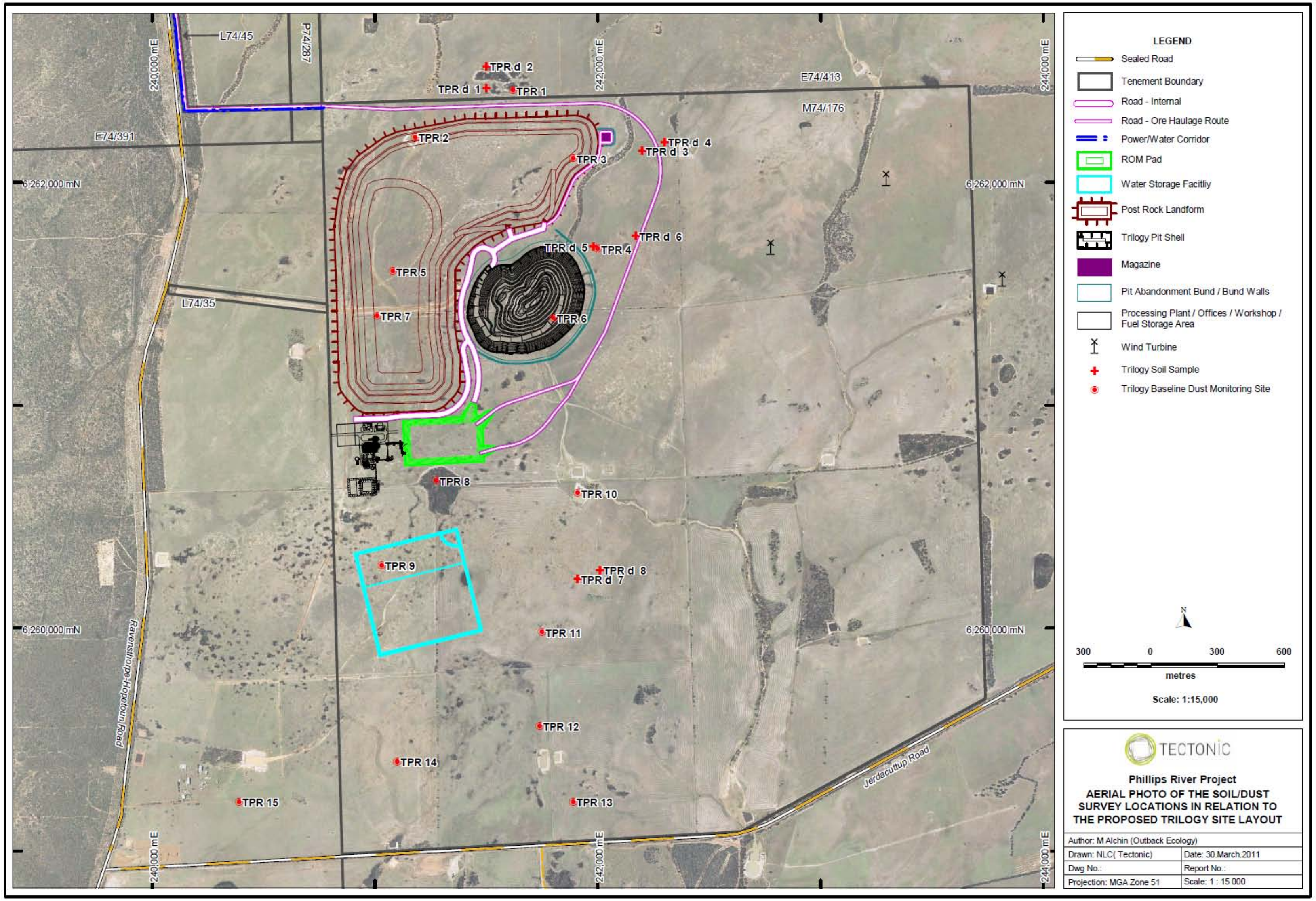


Figure 2: Soil sampling locations within the Trilogy study area

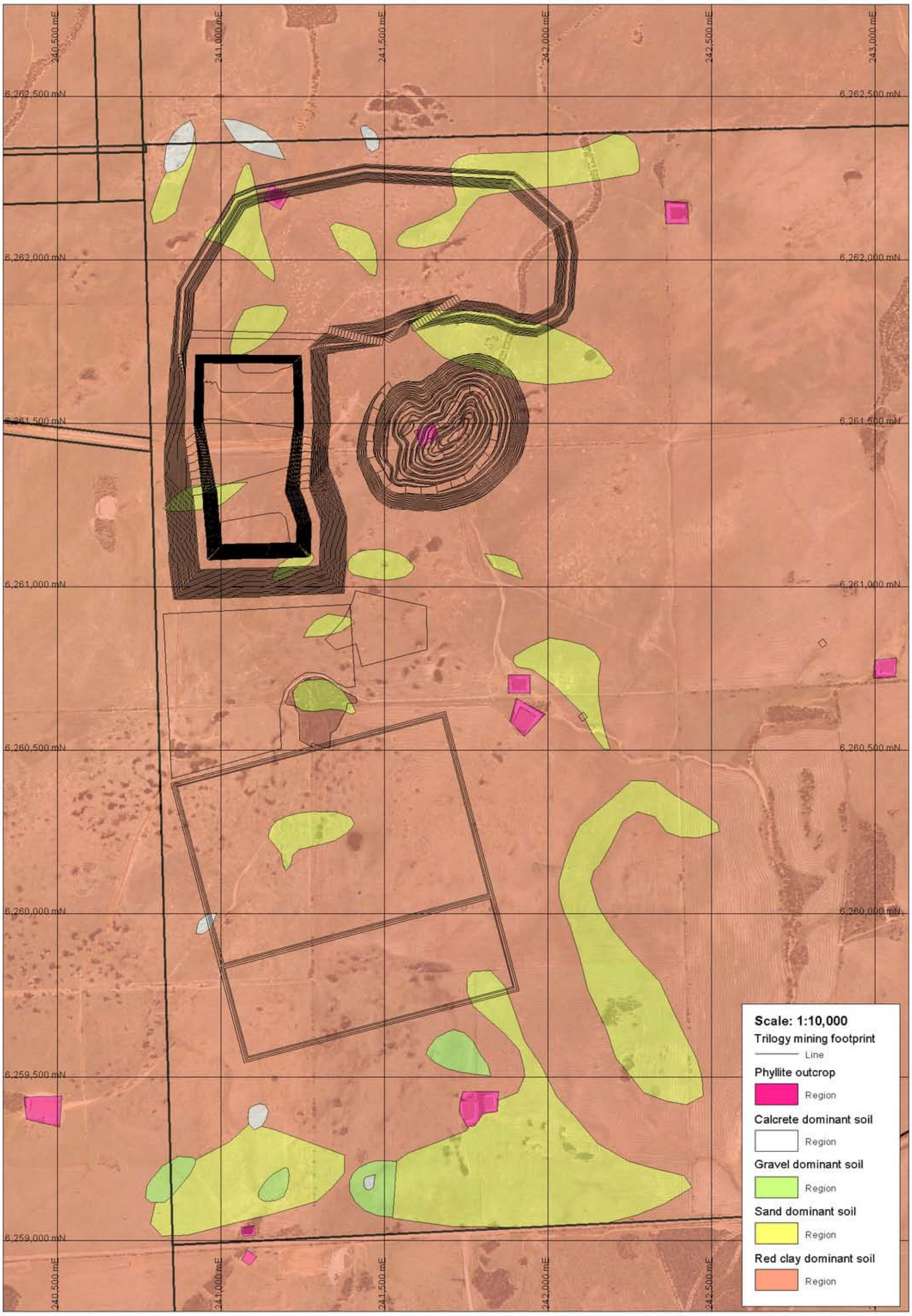


Figure 3: Surface soil types present within the study area (map supplied by Tectonic Resources)

In addition to the surface soil characterisation, surface soil samples (0 – 5 cm) were also collected from future dust monitoring sites (Table 1). The dust contamination soil samples were taken from 16 sites located at approximately 100 and 200 m radii around the mine disturbance area at a depth interval of 0 - 5 cm (Figure 4).

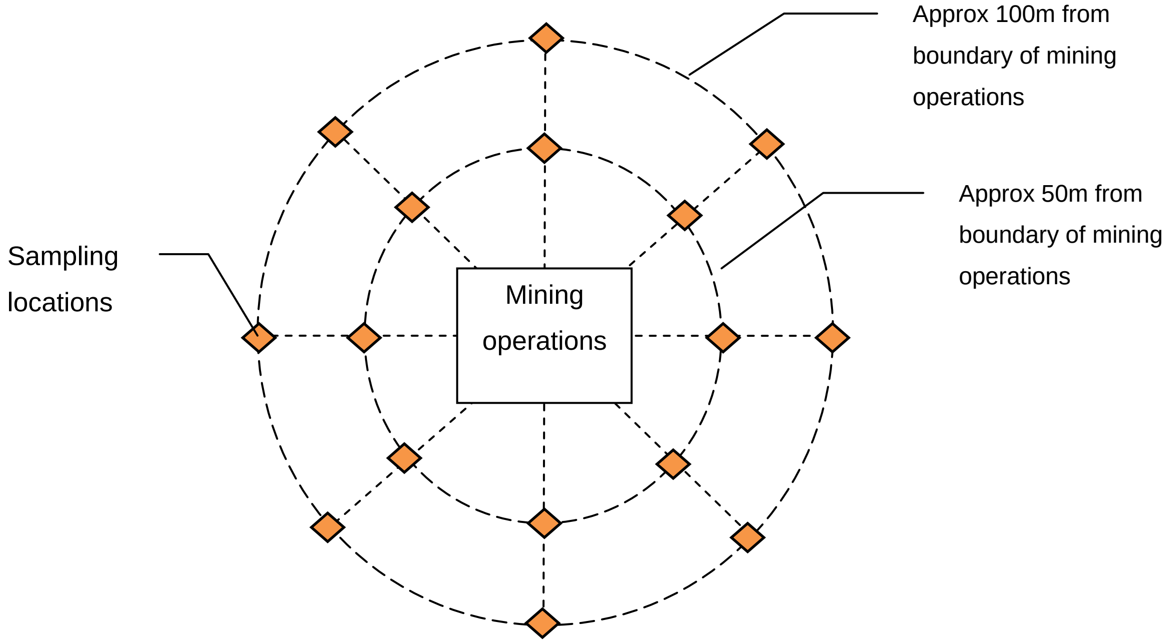


Figure 4: **Schematic design of surface soil (0 – 5 cm) sampling locations for baseline assessment and future comparison for windborne contaminants**

Six samples of waste regolith material from the Kundip Deposits were also submitted by Tectonic for characterisation of physical and chemical characteristics . These included: kaolin, weathered kaolin, saprolites, dacite and fresh dacite (Table 1).

Table 1: Details of soil survey sites within the Phillips River Project area

Site ID	Site description	Coordinates (Projection: UTM Zone 51J, Datum: GDA94)	
		Easting	Northing
Trilogy soil samples			
TPR 1	Red clay dominant	241620	6262410
TPR 2	Phyllite outcrop	241180	6262200
TPR 3	Red clay dominant	241890	6262105
TPR 4	Gravel dominant	242000	6261700
TPR 5	Red clay dominant	241080	6261600
TPR 6	Red clay dominant	241800	6261390
TPR 7	Red clay dominant	241010	6261400
TPR 8	Gravel dominant	241275	6260660
TPR 9	Red clay dominant	241030	6260280
TPR 10	Phyllite outcrop	241910	6260605
TPR 11	Red clay dominant	241750	6259980
TPR 12	Gravel dominant	241740	6259560
TPR 13	Gravel dominant	241890	6259220
TPR 14	Calcrete dominant	241100	6259400
TPR 15	Gravel dominant	240390	6259220
Trilogy baseline dust monitoring sites			
TPR d 1	Dust drift baseline - red clay dominant	241500	6262420
TPR d 2	Dust drift baseline - red clay dominant	241500	6262520
TPR d 3	Dust drift baseline - red clay dominant	242200	6262140
TPR d 4	Dust drift baseline - red clay dominant	242300	6262180
TPR d 5	Dust drift baseline - red clay dominant	241980	6261710
TPR d 6	Dust drift baseline - red clay dominant	242170	6261760
TPR d 7	Dust drift baseline - red clay dominant	241910	6260220
TPR d 8	Dust drift baseline - gravel dominant	242010	6260260
Kundip waste samples			
Kaolin 1	Kaolin material	Not provided	Not provided
Kaolin 2	Kaolin material	Not provided	Not provided

Site ID	Site description	Coordinates (Projection: UTM Zone 51J, Datum: GDA94)	
		Easting	Northing
Kaolin 3	Kaolin material	Not provided	Not provided
KP342	Saprolite material	Not provided	Not provided
KP345	Saprolite material	Not provided	Not provided
KP474	Saprolite rock	Not provided	Not provided
KP749	Kaolin and weathered material	Not provided	Not provided

2.2 Laboratory analyses

CSBP Soil and Plant Laboratory conducted analyses only on the soils from the 15 surface soil sampling 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), soil pH (1:5 H_2O and 1:5 $CaCl_2$), 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 (McKenzie *et al.* 2002) was also assessed on selected samples.

ALS Environmental Laboratory analysed 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). CV/FIMS was used to analyse for Hg, while ICPAES was used for the other elements.

Soil texture was assessed by Outback Ecology 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 using a modified Modulus of Rupture test (Aylmore and Sills 1982, Harper and Gilkes 1994).

The water retention characteristics of selected samples were assessed by Outback Ecology using a pressure plate apparatus, as described in McKenzie *et al.* (2002). Samples assessed using the pressure plate apparatus 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. A summary of the analyses performed and the methods used are detailed in Table 2.

Table 2: Analyses conducted for soil and waste regolith samples from the Phillips River Project area

Soil parameter	Measurement method	Laboratory	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	61	All samples were analysed
Total Metals (Hg)	Cold vapour/ Flow injection mercury system (CV/FIMS method)	ALS	61	All samples were analysed
Soil pH	pH measured in 1:5 soil:water and 1:5 Soil:$CaCl_2$ (Rayment and Higginson, 1992)	CSBP/ALS	67	Dust monitoring sites were excluded from analysis
Electrical conductivity	Measured in 1:5 soil:water (Rayment and Higginson, 1992)	CSBP	67	Dust monitoring sites were excluded from analysis
Plant-available nitrogen (ammonium and nitrate)	Scarle (1984)	CSBP	51	Dust monitoring sites were excluded from analysis
Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+)	Rayment and Higginson (1992)	CSBP	51	Dust monitoring sites were excluded from analysis
Plant-available phosphorus and potassium	Colwell (1965); Rayment and Higginson (1992)	CSBP	51	Dust monitoring sites were excluded from analysis
Plant-available sulphur	Blair *et al.*, (1991)	CSBP	51	Dust monitoring sites were excluded from analysis
Organic carbon percentage	Walkley and Black (1934)	CSBP	51	Dust monitoring sites were excluded from analysis
Physical properties				
Particle size distribution	Pipette method (Day, 1965)	CSBP	30	Representative soil samples only
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	8	Representative soil samples only
Soil slaking and dispersive properties	Emerson Aggregate Test (McKenzie *et al.*, 2002)	Outback Ecology	51	Dust monitoring sites were excluded from analysis
Soil strength	Modified Modulus of Rupture test (Aylmore and Sills, 1982; Harper and Gilkes, 1994)	Outback Ecology	51	Dust monitoring sites were excluded from analysis

Soil parameter	Measurement method	Laboratory	Number of samples analysed	Sample selection criteria
Soil texture	McDonald *et al.*, (1998)	Outback Ecology	45	Representative soil samples only
Water retention characteristics	Using pressure plate apparatus (McKenzie *et al.*, 2002)	Outback Ecology	8	Representative soil samples only

3. RESULTS AND DISCUSSION

3.1 Soil physical properties

3.1.1 Soil texture

Field texture describes the proportions of sand, silt and clay (the particle size distribution) within a soil. The particle size distribution and resulting textural class of soils 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 soil texture.

There were a range of particle size distributions exhibited throughout the surface soils from the Trilogy Deposit study area, with soil textures ranging from sandy loam (approximately 10 - 20 % clay) to heavy clay (> 50 % clay) (Figure 5). The majority of soil materials were classed as sandy loams, sandy clays or light to medium clays, with little correlation between soil texture and depth of sample. Sites from the red clay-dominant soils typically observed the highest clay contents and were classed as sandy clays to medium clays. Soils from the sand-dominant and calcrete-dominant areas were typically classified as sandy clays in texture. Soils from the phyllite outcrop were typically classed as sandy clay loams, with the gravel-dominant soils were typically classed as sandy loams.

There was a strong correlation between coarse material (> 2 mm) content and soil type (Figure 6). The sand-dominant and gravel-dominant soils recorded the highest coarse material content. Soils sampled from the calcrete-dominant soils recorded the lowest coarse material content (0 % overall). There did not appear to be a relationship between coarse material content and depth of the samples from the upper 0.5 m of the soil profiles.

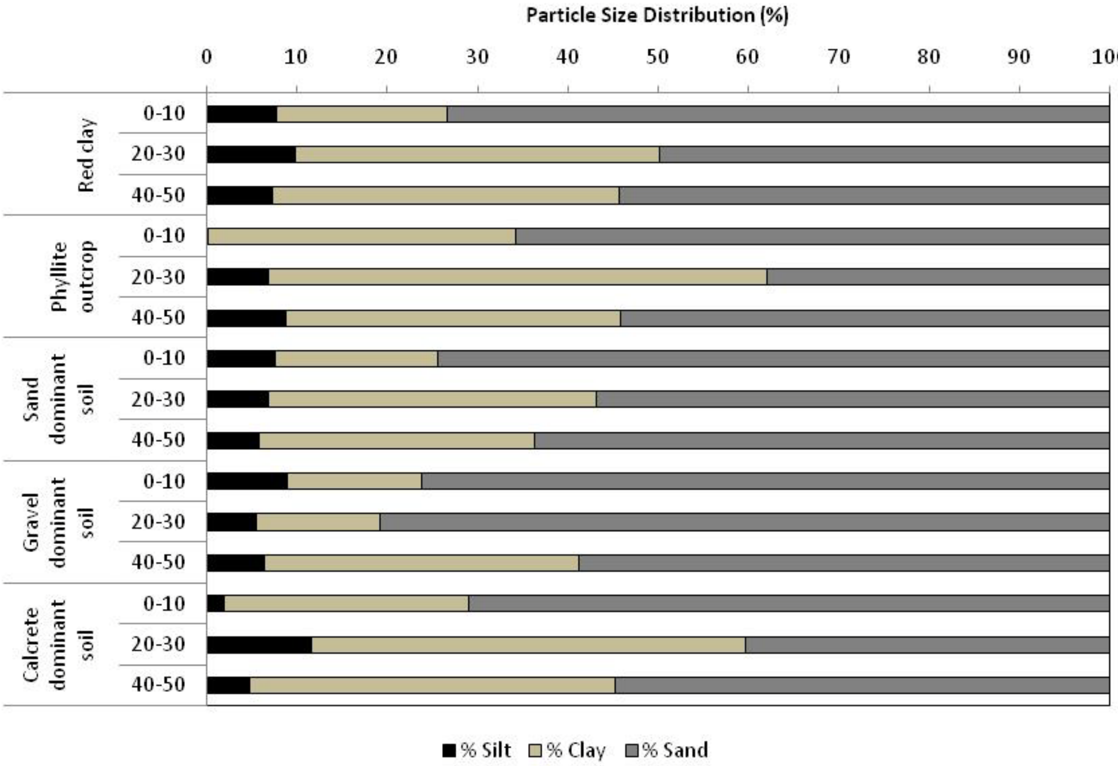


Figure 5: Average particle size distributions (%) of selected samples grouped into soil types from the Trilogy Deposit

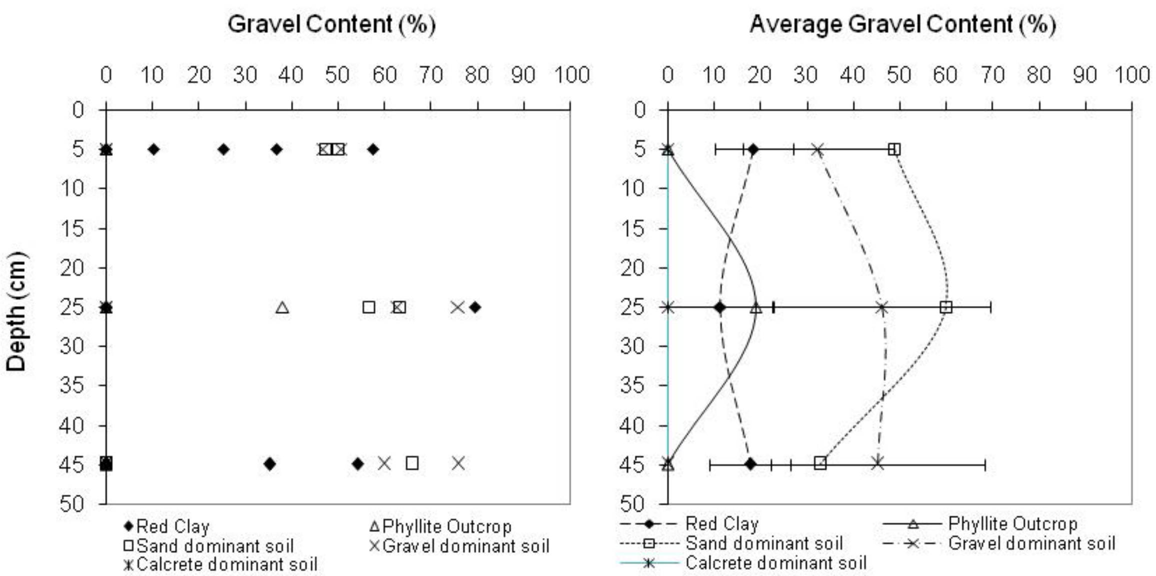


Figure 6: Individual and average gravel content (%) values grouped into soil types from the Trilogy Deposit (error bars represent standard error)

3.1.2 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.

3.1.2.1 Trilogy surface soil samples

The results indicate that a high proportion of the soils sampled from the Trilogy Deposit are relatively unstable and are prone to clay dispersion (Table 3). A large number of collected samples, particularly from below the 0 to 10 cm sampling interval, were classified as Emerson Class 1 which indicates that the soil is likely to slake and disperse if it is disturbed and/or the topsoil is removed. Exposure or use of dispersive soils can be a major cause of erosion, particularly if placed on the outer surface of constructed landforms. The results indicate that those soils classified as clay loam sandy and medium clay were the most unstable. In contrast, the sandy loam soils were more stable and pose minimal risk in terms of structural stability. None of the soil samples had significant amounts of carbonates present which are known to stabilise material.

3.1.2.2 Kundip waste regolith samples

All of the waste regolith samples from the Kundip Deposits were characterised as Emerson Class 5 or 6 (Table 3), indicating that the materials are only likely to become dispersive following severe disturbance and prolonged waterlogging.

Table 3: Summary of soil slaking / dispersion (Emerson Test) results, indicating structural stability

Sample ID	Depth (cm)	Emerson Class[1] (24 hour)	Description
Trilogy soil samples			
TPR 1.1	0-10	3a	Slaked, remoulded soil dispersed completely
TPR 1.2	20-30	1	Slaked, complete dispersion
TPR 1.3	40-50	1	Slaked, complete dispersion

Sample ID	Depth (cm)	Emerson Class[1] (24 hour)	Description
TPR 2.1	0-10	2	Slacked, partial dispersion
TPR 2.2	20-30	1	Slaked, complete dispersion
TPR 2.3	40-50	1	Slaked, complete dispersion
TPR 3.1	0-10	3a	Slaked, remoulded soil dispersed completely
TPR 3.2	20-30	1	Slaked, complete dispersion
TPR 3.3	40-50	1	Slaked, complete dispersion
TPR 4.1	0-10	3b	Slaked, remoulded soil dispersed partially
TPR 4.2	20-30	1	Slaked, complete dispersion
TPR 4.3	40-50	1	Slaked, complete dispersion
TPR 5.1	0-10	5	Slaked, 1:5 suspension remains dispersed
TPR 5.2	20-30	3b	Slaked, remoulded soil dispersed partially
TPR 5.3	40-50	5	Slaked, 1:5 suspension remains dispersed
TPR 6.1	0-10	2	Slacked, partial dispersion
TPR 6.2	20-30	1	Slaked, complete dispersion
TPR 6.3	40-50	1	Slaked, complete dispersion
TPR 7.1	0-10	3b	Slaked, remoulded soil dispersed partially
TPR 7.2	20-30	1	Slaked, complete dispersion
TPR 7.3	40-50	1	Slaked, complete dispersion
TPR 8.1	0-10	5	Slaked, 1:5 suspension remains dispersed
TPR 8.2	20-30	4	Slaked, no dispersion, carbonates and gypsum present
TPR 8.3	40-50	2	Slacked, partial dispersion
TPR 9.1	0-10	5	Slaked, 1:5 suspension remains dispersed
TPR 9.2	20-30	3a	Slaked, remoulded soil dispersed completely
TPR 9.3	40-50	3a	Slaked, remoulded soil dispersed completely
TPR 10.1	0-10	1	Slaked, complete dispersion
TPR 10.2	20-30	1	Slaked, complete dispersion
TPR 10.3	40-50	1	Slaked, complete dispersion
TPR 11.1	0-10	5	Slaked, 1:5 suspension remains dispersed
TPR 11.2	20-30	1	Slaked, complete dispersion
TPR 11.3	40-50	1	Slaked, complete dispersion
TPR 12.1	0-10	3b	Slaked, remoulded soil dispersed partially
TPR 12.2	20-30	2	Slacked, partial dispersion
TPR 12.3	40-50	1	Slaked, complete dispersion
TPR 13.1	0-10	4	Slaked, no dispersion, carbonates and gypsum present
TPR 13.2	20-30	4	Slaked, no dispersion, carbonates and gypsum present
TPR 13.3	40-50	1	Slaked, complete dispersion
TPR 14.1	0-10	5	Slaked, 1:5 suspension remains dispersed
TPR 14.2	20-30	1	Slaked, complete dispersion
TPR 14.3	40-50	1	Slaked, complete dispersion

Sample ID	Depth (cm)	Emerson Class[1] (24 hour)	Description
TPR 15.1	0-10	5	Slaked, 1:5 suspension remains dispersed
TPR 15.2	20-30	3b	Slaked, remoulded soil dispersed partially
TPR 15.3	40-50	3b	Slaked, remoulded soil dispersed partially
Kundip waste regolith samples			
kaolin 2	-	6	Slaked, 1:5 suspension remains flocculated
kaolin 3	-	5	Slaked, 1:5 suspension remains dispersed
KP749	-	5	Slaked, 1:5 suspension remains dispersed
KP342	-	5	Slaked, 1:5 suspension remains dispersed
KP345	-	5	Slaked, 1:5 suspension remains dispersed
KP474	-	5	Slaked, 1:5 suspension remains dispersed

[1]Emerson Test classes are included in Appendix B

3.1.3 Soil strength (Modulus of Rupture)

A modified Modulus of Rupture (MOR) test was conducted on soil samples collected from the Trilogy Deposit (excluding baseline dust monitoring samples) and waste regolith samples collected from the Kundip Deposit. 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. 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 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 landscapes, soil materials from deeper layers are often re-deposited closer to the surface. If the re-deposited soils have a high MOR, 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 layers to hard-set and compact with repeated wetting and drying cycles, and the ability of roots to fracture and penetrate the soil profile.

3.1.3.1 Trilogy surface soil samples

Many of the selected soils tested from the Trilogy Deposit exhibited soil strength values which suggest they are prone to hard-setting (Figure 7). The highest MOR values were observed in samples from the red clay-dominant and gravel-dominant soils. There did not appear to be a strong correlation between soil strength, soil type and profile depth.

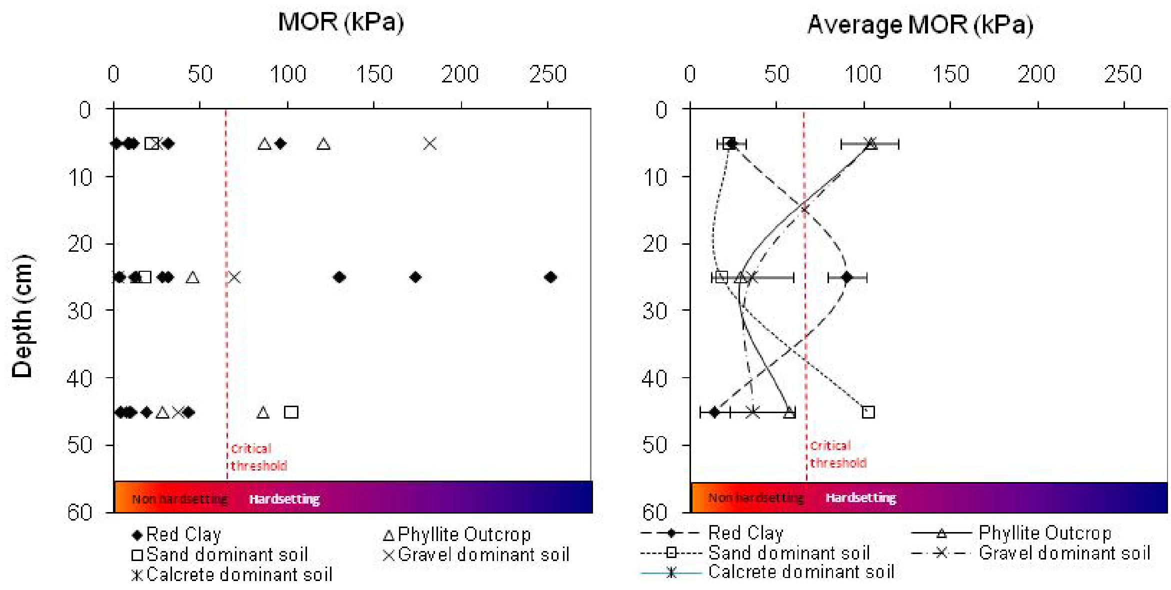


Figure 7: Individual and average modulus of rupture (kPa) values grouped into soil type from the Trilogy Deposit. Red line indicates potential restrictions to plant and root development (Cochrane and Aylmore 1997), (error bars represent standard error)

3.1.3.2 Kundip waste regolith samples

Seven waste regolith samples were tested for soil strength upon drying. Only one of the seven samples exhibited soil strength greater than the critical value of 60 kPa (KP342 at 69 kPa) (Figure 8).

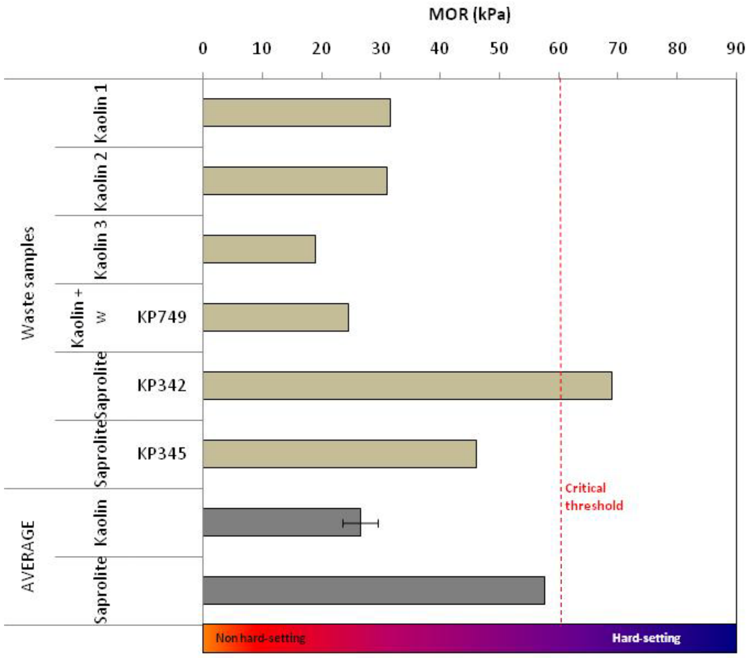


Figure 8: Individual and average modulus of rupture (kPa) values of waste regolith samples from the Kundip Deposit. Red line indicates potential restrictions to plant and root development (Cochrane and Aylmore 1997), (error bars represent standard error)

3.1.4 Hydraulic conductivity

Hydraulic conductivity (K_{sat}) refers to the permeability of soil, or the ability of water to infiltrate and drain through the soil matrix, and is dependant on soil properties such as texture and structure (Hunt and Gilkes 1992; Hazelton and Muphy 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 selected samples which were collected in the field and repacked to bulk densities likely to be achieved following disturbance and deposition. Drainage classes were determined for each core according to their K_{sat} (Hunt and Gilkes 1992) (Table 4).

The drainage class for selected surface soil samples from the Trilogy Deposit ranged from ‘extremely slow’ to ‘very rapid’ (Table 4). The material from the phyllite outcrop generally had the slowest drainage rate, ranging from ‘very slow’ to ‘moderately slow’, which is attributable to the lower percentage of coarse fragments compared to the other materials tested.

Table 4: Saturated hydraulic conductivity (K_{sat}) values, soil texture and drainage class for selected soil samples from the Trilogy Deposit

Site description	Sample ID	Depth (cm)	Field Texture	Coarse fragments (%)	K_{sat} (mm/hr)	Drainage class
Red clay	TPR 9.1	0-10	Sandy clay	36.73	699.14	Very rapid
	TPR 9.3	40-50	Light clay	0	16.09	Moderately slow
Phyllite outcrop	TPR 2.1	0-10	Sandy clay loam	0	11.64	Moderately slow
	TPR 2.3	40-50	Sandy clay	0	0.73	Very slow
Sand dominant soil	TPR 4.1	0-10	Sandy loam	50.02	255.86	Very rapid
	TPR 4.3	40-50	Sandy clay	65.84	92.89	Moderately rapid
Gravel dominant soil	TPR 12.1	0-10	Sandy loam	46.58	347.85	Very rapid
	TPR 12.3	40-50	Sandy clay	59.74	0	Extremely slow

3.1.5 Soil water retention

The water retention properties of the soils within the Project 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 area, 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; the primary factors are: the particle size (and pore space) distribution, soil structure and organic matter content.

Eight soil samples from the Trilogy deposit were selected for analysis of water retention properties. Samples were taken from profile depths of 0 - 10 and 40 - 50 cm. The samples comprised material from sites dominated by: phyllite outcrop, sand dominant soils and red clay.

The water retention characteristics of the soil surface samples were relatively low but typical of analogue soils with the range of soil textures exhibited (Figure 9). There was considerable variation in the water retention curves between the eight different samples. Figure 9 indicates that as the water pressure increases the amount of water that is held within the pores of the soil materials is reduced. The soil water (% volume) at 10 kPa is considered to be the field capacity of the soil (upper storage capacity) and 1500 kPa is considered to be the wilting point (lower storage limit) of the soil. Field capacity is the percentage of water remaining in a soil two or three days after it has been saturated and free drainage has practically ceased. Wilting point is the percentage of water in the soil at which plants wilt and fail to recover.

The upper storage limit of soil water (% volume; <2 mm fraction) of the samples ranged from 32.6 to 68.3% (Table 5, Figures 10 to 12). This means that when the soil samples are at field capacity, 32.6 to 68.3% of the volume (< 2mm fraction) comprises of water. The lower storage limit of the surface soils ranged from 8.2 to 33.0%. This means that when the soil samples are at wilting point 8.2 to 33.0% of the volume comprises of water. Therefore, the plant-available water (PAW, % volume) of the soil fraction (<2 mm) ranged from 14.3 to 35.7% (i.e. upper storage limit minus lower storage limit).

Taking the percentage of coarse material into consideration, the upper storage limit of both the soil and coarse fractions combined (i.e. the total material) ranges from 17.5 to 41% (Table 5). Therefore, the plant-available water content of the coarse and fine fractions ranges from 9.0 to 21.4%. These are relatively low PAW values, but are typical of weathered surface soils, particularly those with high gravel / coarse material contents.

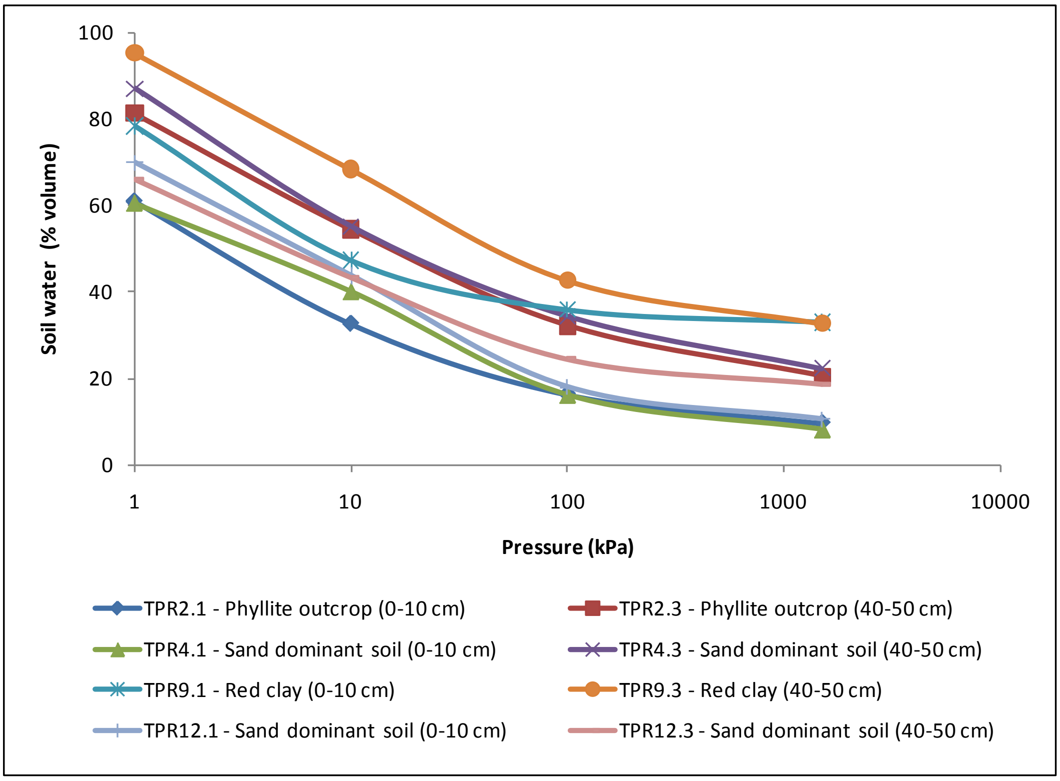


Figure 9: Soil water retention curves for selected surface soils from the Trilogy Deposit

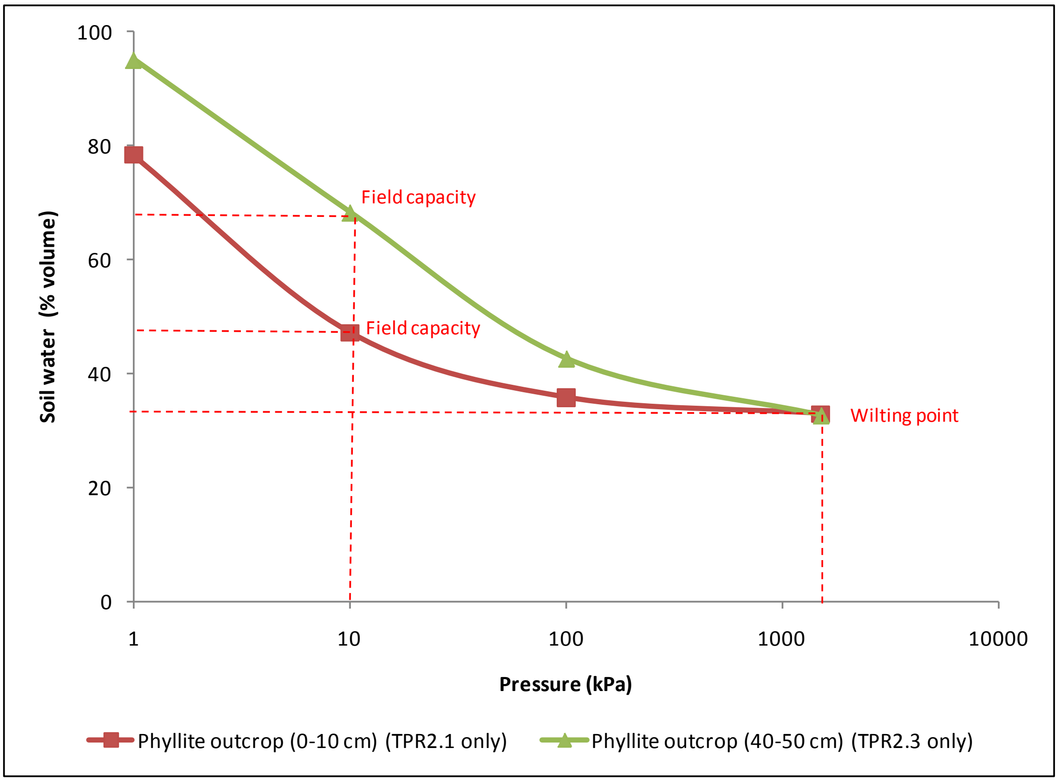


Figure 10: Soil water retention curve for surface soils from phyllite outcrop sites of the Trilogy Deposit (NB: the difference between field capacity and wilting point is the potential available water)

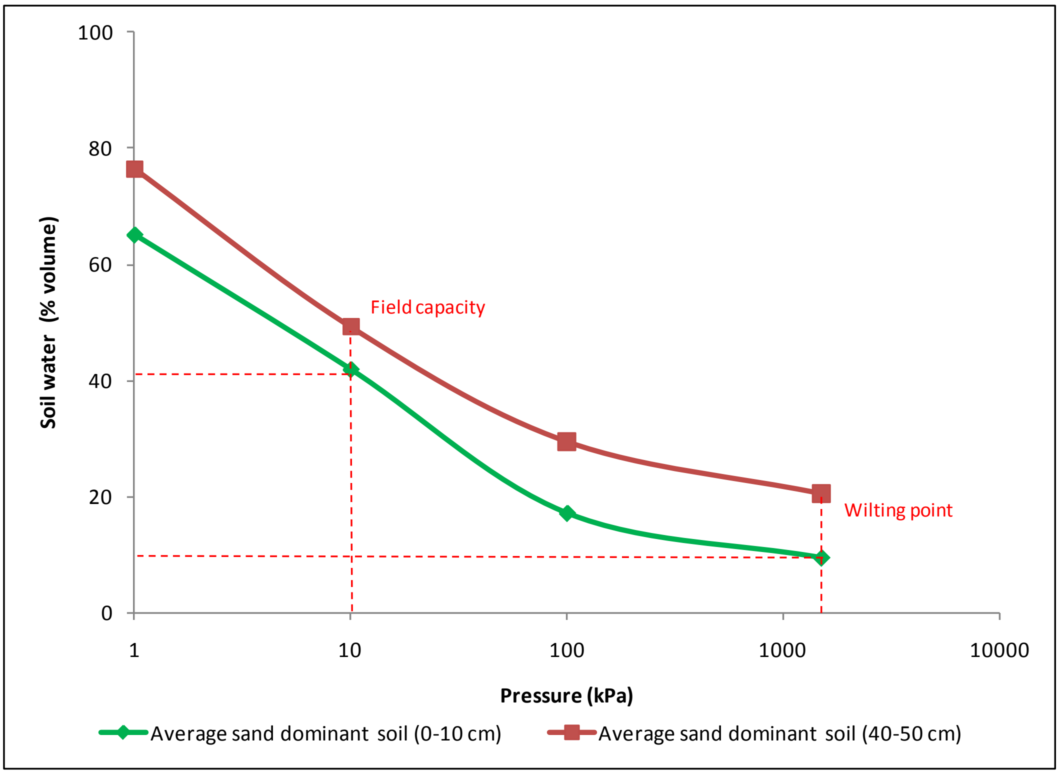


Figure 11: Average soil water retention curve for surface soils from sand dominant soil sites of the Trilogy Deposit (NB: the difference between field capacity and wilting point is the potential available water)

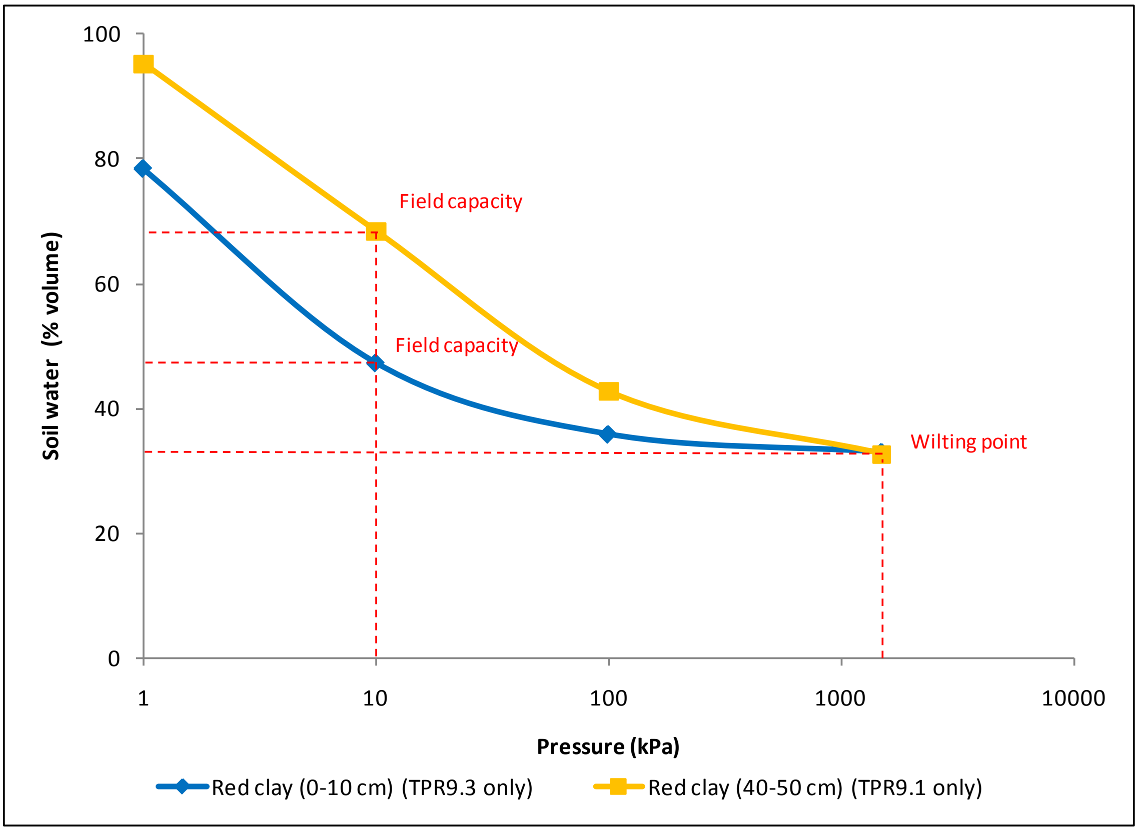


Figure 12: Average soil water retention curve for surface soils from red clay sites of the Trilogy Deposit (NB: the difference between field capacity and wilting point is the potential available water)

Table 5: Water retention and availability characteristics for selected materials from the Trilogy Project area

Site	Landform	Depth	% coarse material	Water retention and availability characteristics				
				Upper storage limit[1] (% volume) of <2 mm fraction	Lower storage limit[1] (%) of <2 mm fraction	Plant available water (PAW) (% vol) of <2 mm fraction	Upper storage limit (% vol.) of total material[2]	Plant available water (PAW) (% vol.) of total material[2]
TPR2.1	Phyllite outcrop	0-10	40.0	32.65	9.7	23.0	19.6	13.8
TPR2.3	Phyllite outcrop	40-50	40.0	54.41	20.5	33.9	32.6	20.4
TPR4.1	Sand dominant soil	0-10	50.0	40.14	8.2	31.9	20.1	16.0
TPR4.3	Sand dominant soil	40-50	65.3	55.12	22.3	32.8	19.1	11.4
TPR9.1	Red clay	0-10	36.7	47.27	33.0	14.3	29.9	9.0
TPR9.3	Red clay	40-50	40.0	68.36	32.7	35.7	41.0	21.4
TPR12.1	Sand dominant soil	0-10	46.6	43.71	10.6	33.1	23.3	17.7
TPR12.3	Sand dominant soil	40-50	59.7	43.35	18.7	24.6	17.5	9.9

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

3.2 Soil chemical properties

3.2.1 Soil pH

The soil pH provides a measure of the soil acidity or alkalinity. Soil pH is affected by the parent material from which the soil is formed. Soils in higher rainfall areas tend to be more acidic because the rainfall leaches the basic nutrients from the soil. Similarly, weathering of a soil profile can also increase acidity as it depletes the soil of the basic cations (i.e. Ca, Mg and K). 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 can be affected, while various metal toxicities (e.g. Al and Mn) can occur in acidic conditions (low pH).

Soil pH affects the mobility of many pollutants in the soil by influencing the rate of their biochemical breakdown, their solubility, and their absorption to colloids. Thus, soil pH is a crucial factor in predicting the probability that a given pollutant will contaminate groundwater, surface water and food chains (Brady and Weil, 2002). Native plant species are known to be tolerant of a broader range of soil pH values. Therefore, optimal pH levels for native plants are best inferred from the soil in which they naturally occur.

Two methods were used to measure soil pH; the $CaCl_2$ and the H_2O method. Soil pH measured in 0.01 M calcium chloride ($CaCl_2$) is considered a more accurate measurement of hydrogen ion concentration ($[H^+]$), 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 were completed in order to obtain a thorough assessment.

3.2.1.1 Trilogy surface soil samples

A broad range of pH values were found, particularly within the surface soils. Soil pH values ($CaCl_2$) ranged between pH 4.3 (strongly acidic) and pH 9.3 (strongly alkaline) (Figure 13). Soil pH values (in H_2O) ranged between pH 5.1 (very strongly acidic) and pH 9.3 (strongly alkaline) (Figure 14). Soil pH values were observed to increase (i.e. become more alkaline) with profile depth. The majority of samples were classified as neutral to moderately alkaline (Moore, 1998).

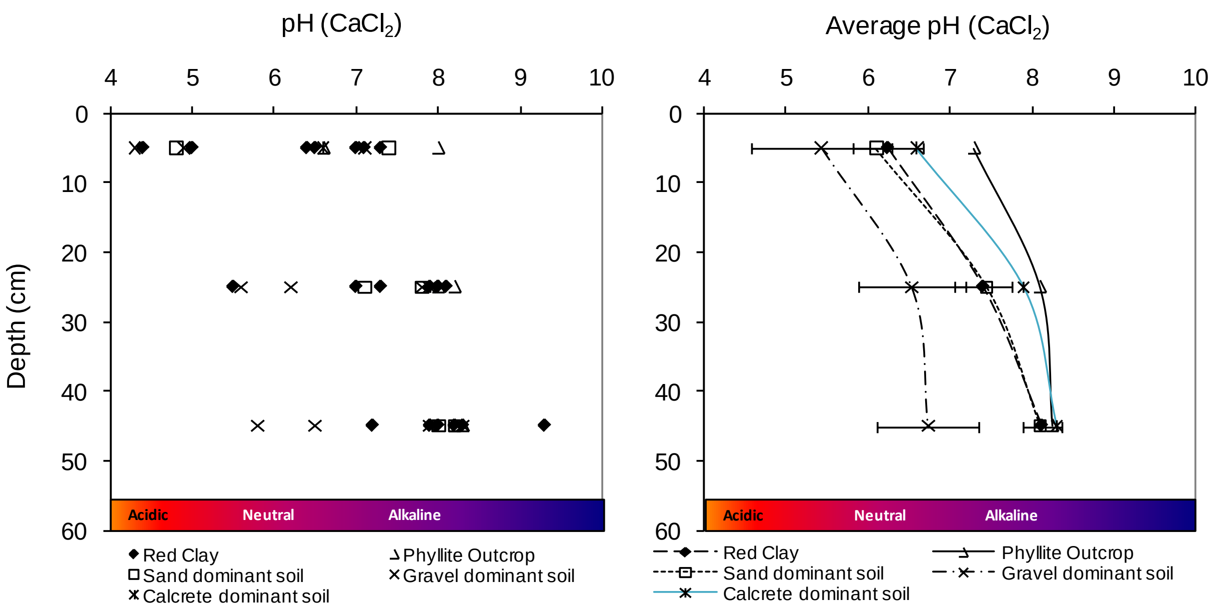


Figure 13: Individual and average soil pH ($CaCl_2$) values grouped into soil types from the Trilogy Deposit (error bars represent standard error)

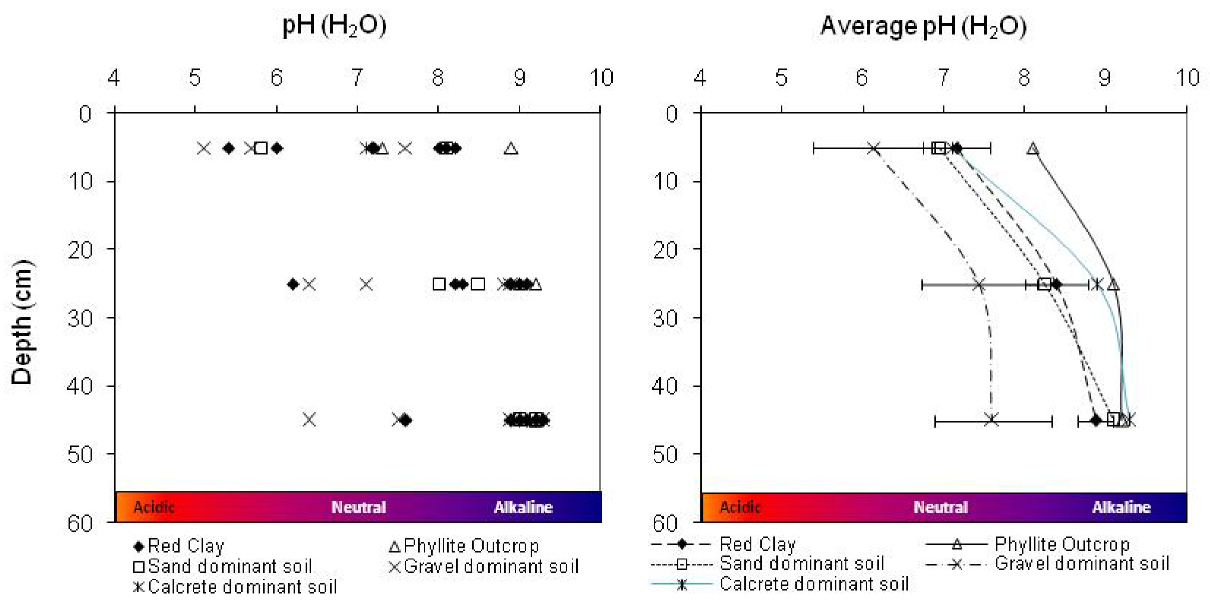


Figure 14: Individual and average soil pH (H_2O) values grouped into soil types from the Trilogy Deposit (error bars represent standard error)

3.2.1.2 Trilogy baseline dust monitoring sites

There was a broad range of pH values were found within dust monitoring sites with values reflecting the heterogeneity of the soils sampled. Soil pH values (H_2O) ranged between pH 5.4 (strongly acidic) and pH 8.4 (moderately alkaline) (Figure 15). The majority of samples were classified as slightly acidic to neutral (Moore, 1998).

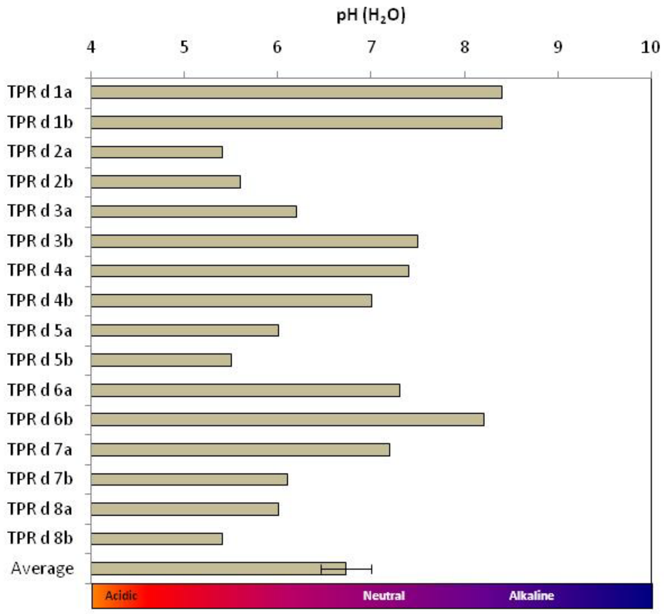


Figure 15: Individual and average soil pH (H_2O) values of baseline dust monitoring samples from the Trilogy Deposit (error bars represent standard error)

3.2.1.3 Kundip waste regolith samples

There was minimal variation in the pH of the waste regolith samples for both the $CaCl_2$ and H_2O pH measurements. Soil pH values ($CaCl_2$) ranged between pH 5.7 and 6.5 (neutral) (Figure 16). Soil pH values (H_2O) ranged between pH 5.3 and 7.3 ((strongly acidic to neutral) (Figure 17). The majority of samples were classified as slightly acidic to neutral (Moore, 1998).

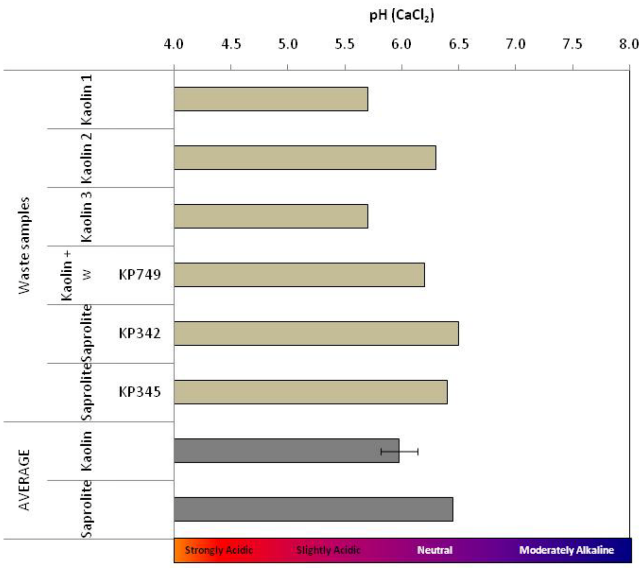


Figure 16: Individual and average soil pH ($CaCl_2$) values of waste regolith samples from the Kundip Deposit (error bars represent standard error)

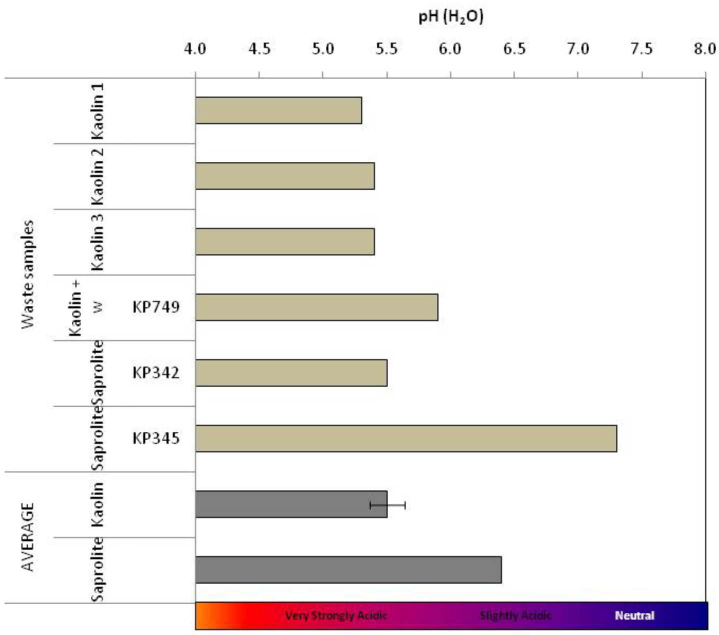


Figure 17: Individual and average soil pH (H_2O) values of waste regolith samples from the Kundip Deposit (error bars represent standard error)

3.2.2 Electrical conductivity

Electrical conductivity (EC) is a measurement of the soluble salts in soils or water. The amount of salt in the soil determines its ability to conduct an electric current. High levels of soluble salts lower the osmotic potential of the soil water, making it more difficult for roots to remove water from the soil (Brady and Weil, 2002). Plants need to expend greater energy to lower the osmotic potential insider their root cells to counteract the low osmotic potential of the soil solution outside the root. The energy that is expended on lowering the osmotic potential places a greater demand on the plant and the soil nutrient supply. Plants are usually most vulnerable to salt damage in the early stages of growth, and therefore a gradual accumulation of salts in the soil tends to thwart recruitment and mature plants are affected in the later stages of salinity (Brady and Weil, 2002). In extreme cases, soil salinity can cause widespread mortality of the native vegetation.

Salts occur naturally in the soil, as a result of natural processes of landscape evolution, hydrological processes and rainfall (Hunt and Gilkes, 1992), and many native plant species are adapted to saline conditions. However, major disturbance to the soil as a result of mining activity can significantly increase the levels of soluble salts at, or close to the surface, and thereby present challenges for the revegetation / rehabilitation of a site.

3.2.2.1 Trilogy surface soil samples

The electrical conductivity (EC) of the majority of the materials samples ranged from non-saline (0 – 0.2 dS/m) to very saline (0.7 – 2.0 dS/m), based on the standard USDA and CSIRO categories (Appendix B). The majority of soils were classed as either non-saline or slightly saline (Figure 18). There was a trend of increasing EC values with profile depth. Surface layers of the soil profile (0 – 10 cm) were the least variable and least saline. Slightly saline to moderately saline salt levels were observed at depth (i.e. greater than 20 cm) for the majority of sites.

Samples from the gravel-dominant material were observed to be the least saline, with all samples classed as non-saline except for one sample (TPR 8.3 had an EC of 0.72 dS/m and was classed as moderately saline). The phyllite outcrop material was observed to be the most saline, with most sites classed as slightly saline or moderately saline, increasing in salinity with profile depth (Figure 18).

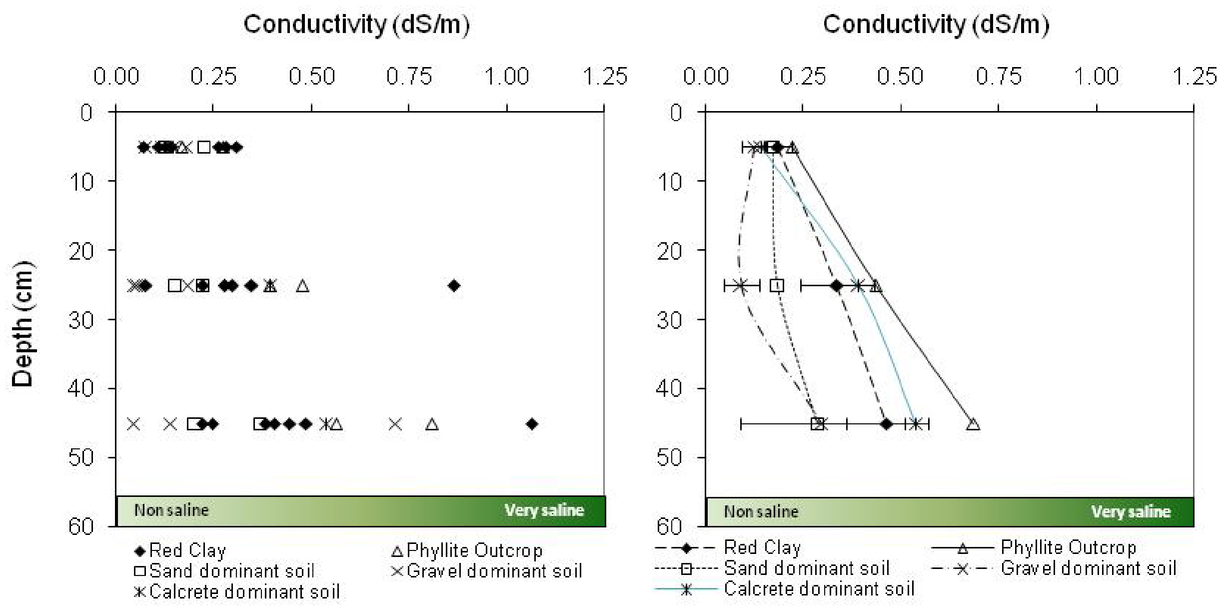


Figure 18: Individual and average electrical conductivity (EC 1:5 H_2O) values grouped into soil types from the Trilogy Deposit (error bars represent standard error)

3.2.2.2 Trilogy baseline dust monitoring sites

The electrical conductivity (EC) of the surface soil at all the dust monitoring sites were classed as non-saline (0 to 0.2 dS/m) based on the standard USDA and CSIRO categories (Figure 19) (Appendix B).

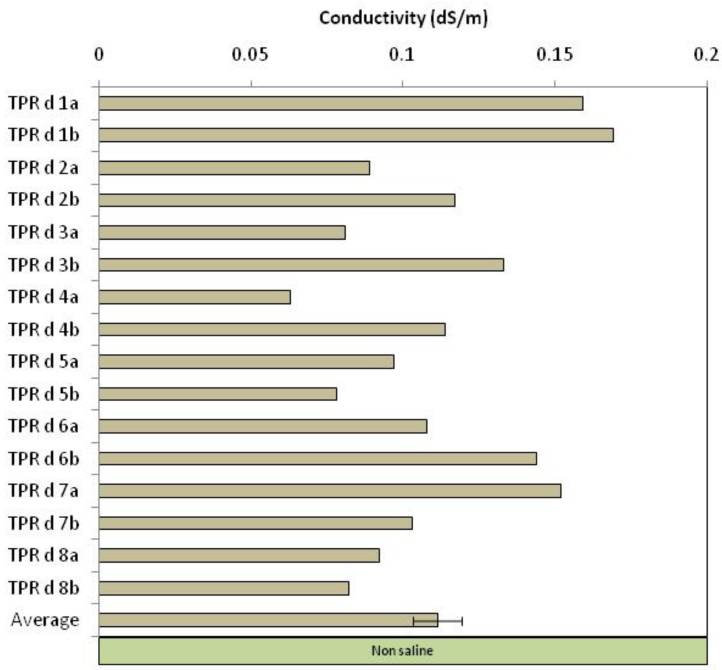


Figure 19: Individual and average electrical conductivity (EC 1:5 H_2O) values of surface soils at baseline dust monitoring sites from the Trilogy Deposit (error bars represent standard error)

3.2.2.3 Kundip waste regolith samples

The electrical conductivity (EC) of the waste regolith samples ranged between non saline (0 to 0.2 dS/m) to moderately saline (0.3 to 1.0 dS/m), based on the standard USDA and CSIRO categories (Figure 20) (Appendix B).

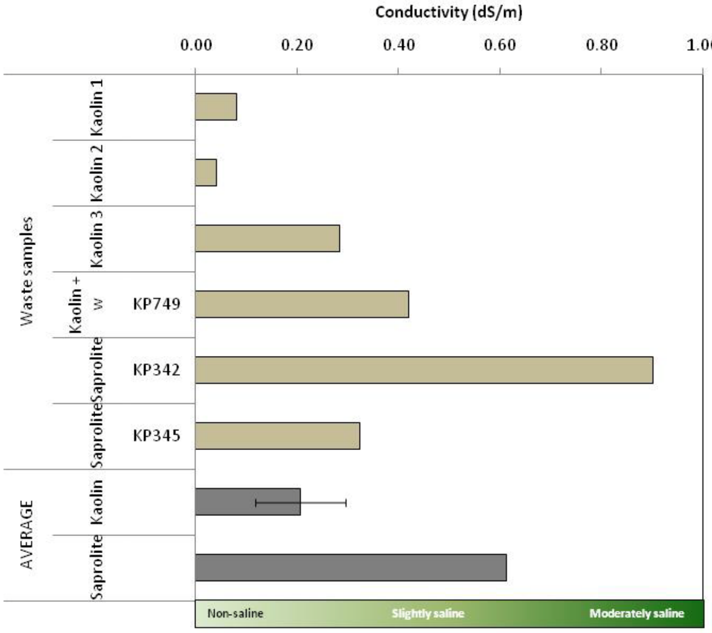


Figure 20: Individual and average electrical conductivity (EC 1:5 H_2O) of waste regolith samples from the Kundip Deposit (error bars represent standard error)

3.2.3 Soil organic matter

The organic matter content of soil is an important factor influencing many physical, chemical and biological soil characteristics. Directly derived from plants and animals, its functions in the 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 Philips River Project area was determined as a measure of the organic carbon percentage (SOC%).

3.2.3.1 Trilogy soil samples

The organic carbon percentage within the majority of the surface soils sampled from the Trilogy Deposit was moderate (0.1 to 0.5 % SOC) to high (> 0.5 % SOC) (Purdie 1998). The highest organic carbon contents were measured in the upper surface soils (0 – 10 cm), and typically decreased with depth (> 10 cm) (Figure 21). The highest organic carbon value (5.9%) was recorded at red clay-dominant site TPR 5.1, 0 – 10 cm. The lowest organic carbon value (0.2%) was recorded at two sites; TPR 10.2, 20 – 30 cm (phyllite outcrop) and TPR 12.2, 20 – 30 cm (gravel-dominant soil).

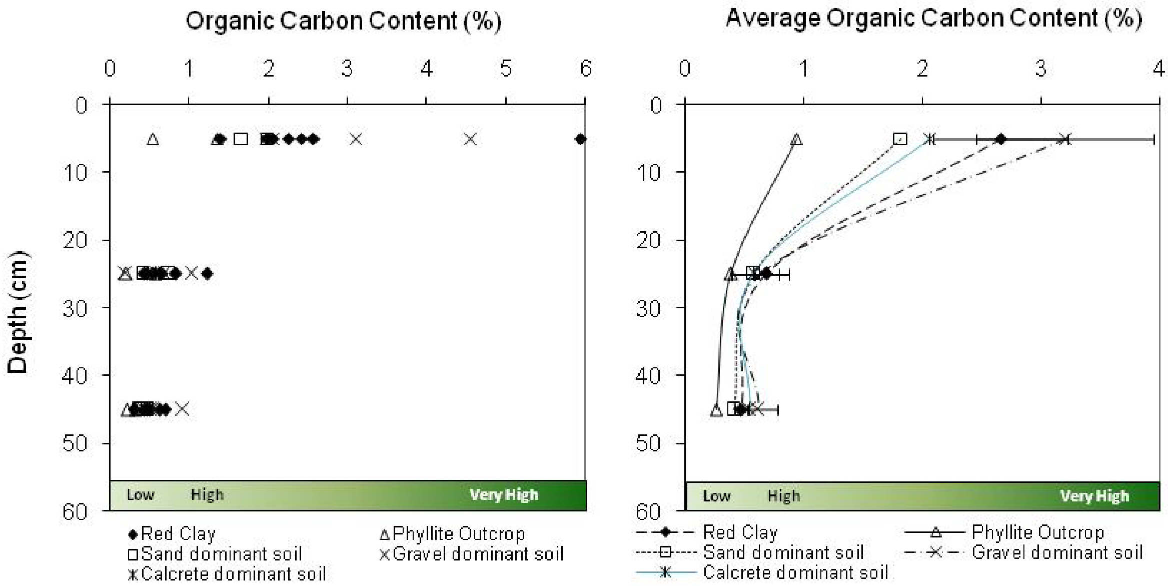


Figure 21: Individual and average soil organic carbon content (%) values grouped into soil types from the Trilogy Deposit (error bars represent standard error). NB: Different scales

3.2.3.2 Kundip waste regolith samples

As would be expected from samples deep within the regolith profile, the organic carbon percentage of the waste regolith samples from the Kundip Deposits ranged from low (< 0.1 % SOC) to medium (0.1 to 0.5% SOC) (Purdie 1998). The highest organic carbon value was measured in saprolite samples KP342 and KP345 at 0.12 % SOC. The lowest organic carbon value was measured in kaolin samples kaolin 1 and kaolin 2 at < 0.05 % SOC (Figure 22).

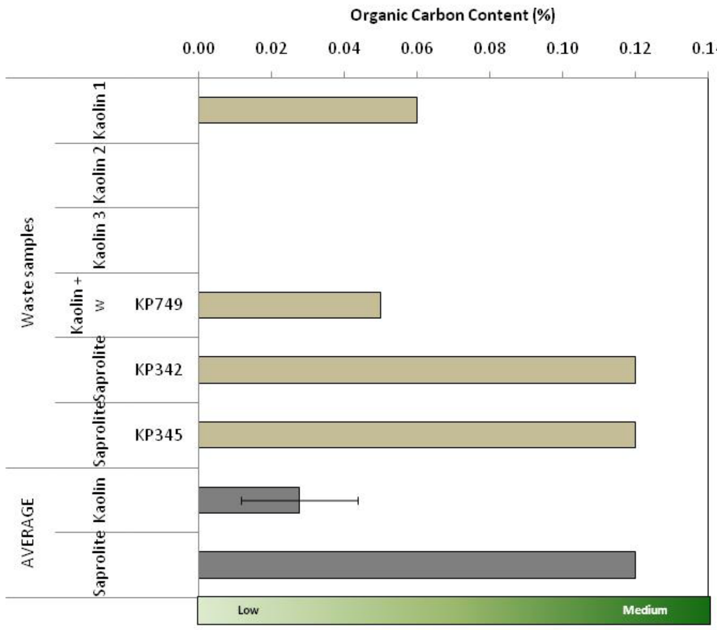


Figure 22: Individual and average soil organic carbon content (%) values of waste regolith samples from the Kundip Deposit (error bars represent standard error)

3.2.4 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 the 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, hard-setting and erosion in clay-rich soils).

If the ESP exceeds more than 15 %, then the soil is considered to be *highly sodic* (Hazelton and Murphy, 2007). Sodic soils have an increased tendency to disperse upon wetting and are therefore more prone to hard-setting at the soil surface, and erosion when placed on the slopes of constructed landforms.

3.2.4.1 Trilogy surface soil samples

All of the surface soils assessed from the Trilogy Deposit within the top 10cm of the soil profile were classified as non-sodic with ESP values less than 6 %, however, many samples from deeper in the soil profiles were classified as sodic (6 – 15 % ESP) to highly sodic (> 15 % ESP) (Figure 23). Highly sodic ESP values were measured in sites from the red-clay dominant soils and phyllite outcrop. Sodic ESP values were measured in sites from all soil types. There did not appear to be a correlation between soil / landform association and ESP value. The sodic and highly sodic ESP values of the sub-surface soils (i.e. below the 0-10 cm sampling interval) indicate that there would be a high risk of clay dispersion, hard-setting and / or erosion if this material was placed on the outer slopes of constructed waste landforms.

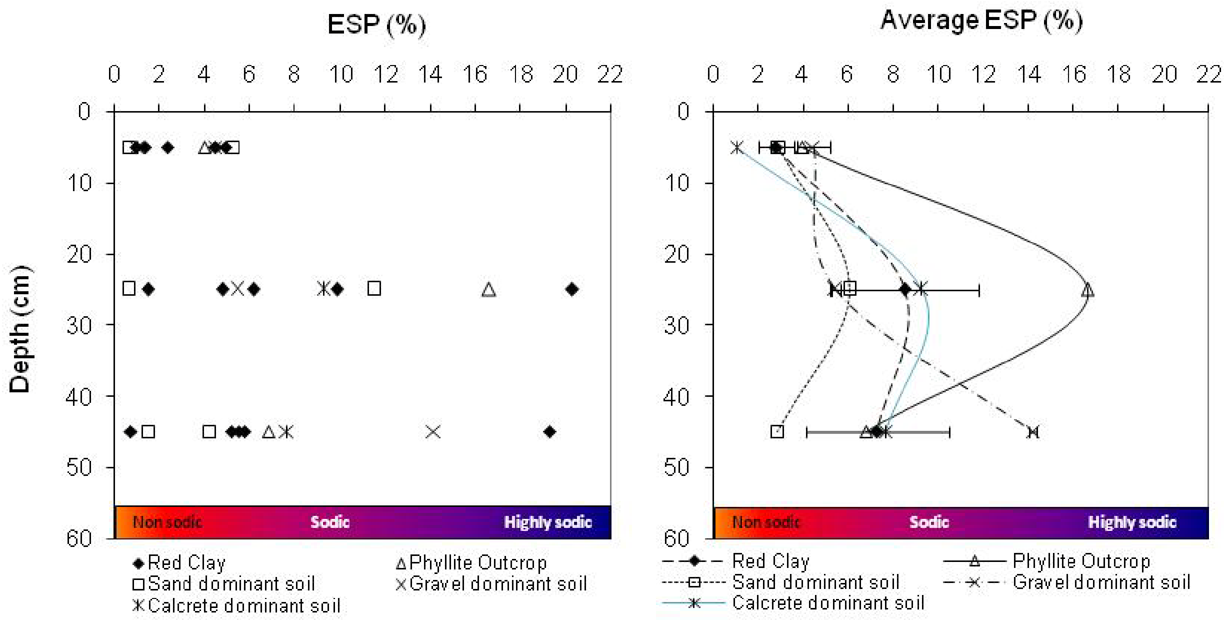


Figure 23: Individual and average exchangeable sodium percentage (%) values grouped into soil types from the Trilogy Deposit (error bars represent standard error)

3.2.4.2 Kundip waste regolith samples

All of the waste samples were either classified as sodic (6 – 15 % ESP) or highly sodic (> 15% ESP) (Figure 24). Saprolite site KP345 had the highest ESP value at 86.1% (highly sodic) and Kaolin site kaolin 1 had the lowest ESP value of 13.2% (sodic).

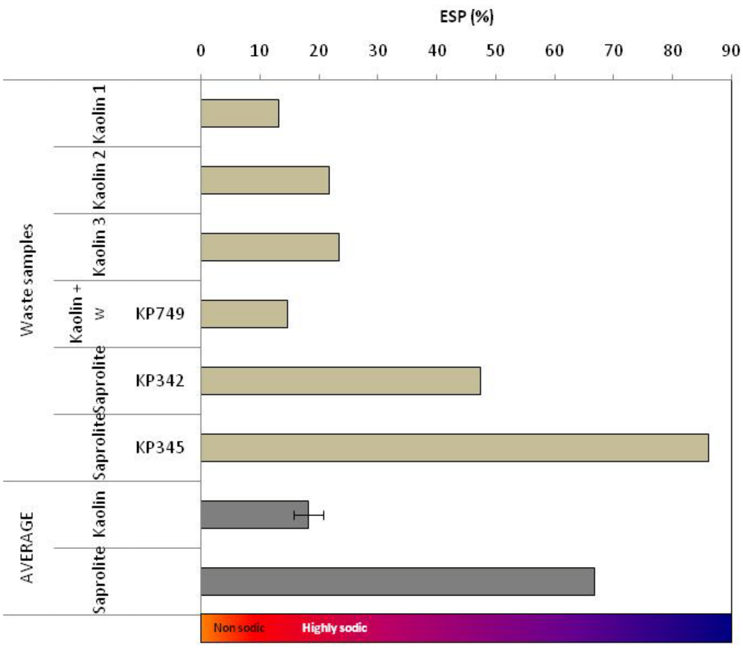


Figure 24: Individual and average exchangeable sodium percentage (%) values of waste regolith samples from the Kundip Deposit (error bars represent standard error)

3.2.5 Soil nutrients

3.2.5.1 Plant-available macronutrients

The most important macronutrients 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.

3.2.5.2 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).

The amount of plant-available nitrate as N measured in the surface soil and waste regolith materials from the Project are was variable, but typically low, and decreased in concentration with depth (Figure 25 and Figure 26). The nitrate as N value for three waste regolith samples was measured below the Limit of Reporting (LOR) (Figure 24).

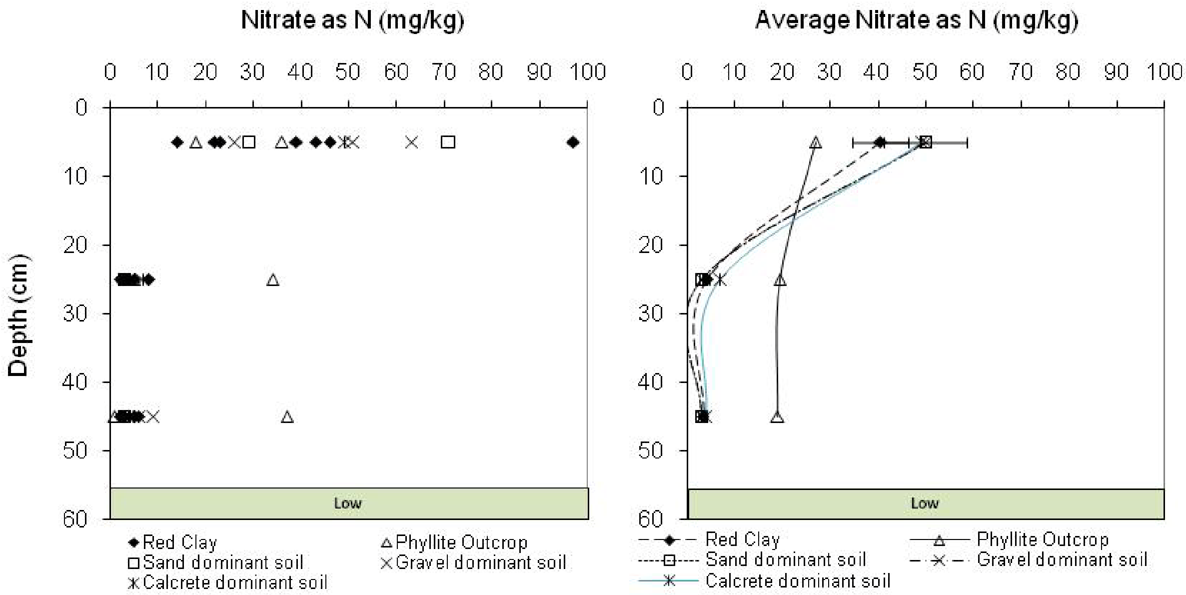


Figure 25: Individual and average nitrate N (mg/kg) values grouped into soil types from the Trilogy Deposit (error bars represent standard error)

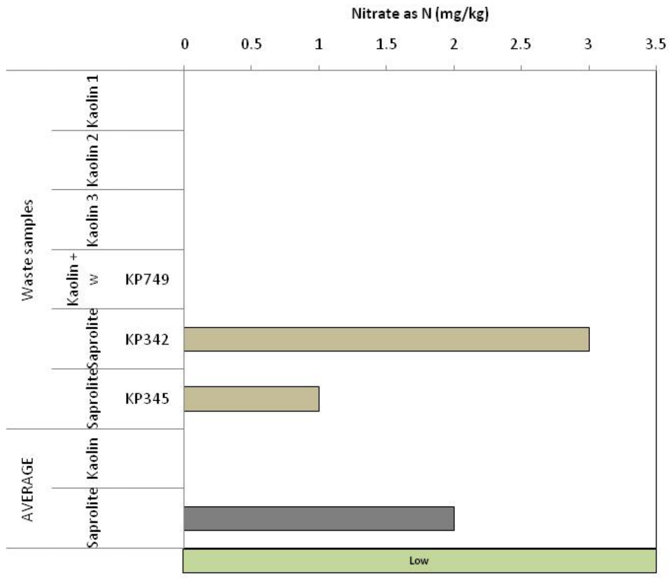


Figure 26: Individual and average nitrate N (mg/kg) values of waste regolith samples from the Kundip Deposit

3.2.5.3 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).

The amount of plant-available phosphorus measured in the surface soils and waste regolith material from the Project area was variable, but typically low, and decreased in concentration with depth (Figure 27 and Figure 28). Plant-available phosphorus was measured below the LOR in four of the six waste regolith samples from the Kundip Deposits (Figure 28).

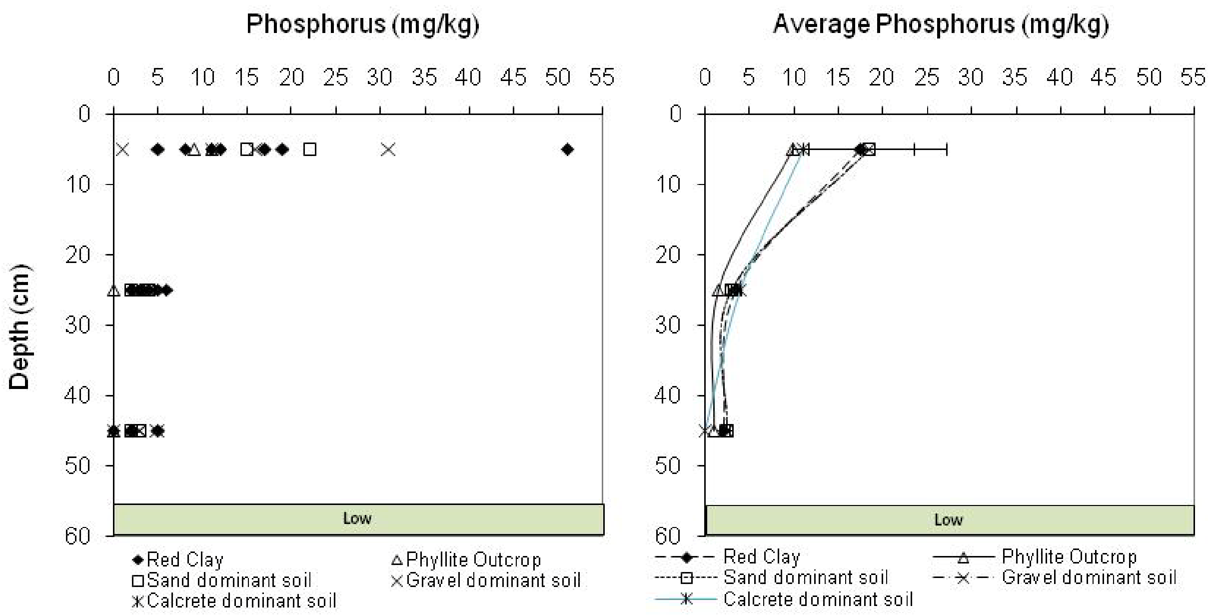


Figure 27: Individual and average plant-available phosphorus (P) (mg/kg) values grouped into soil types from the Trilogy Deposit (error bars represent standard error)

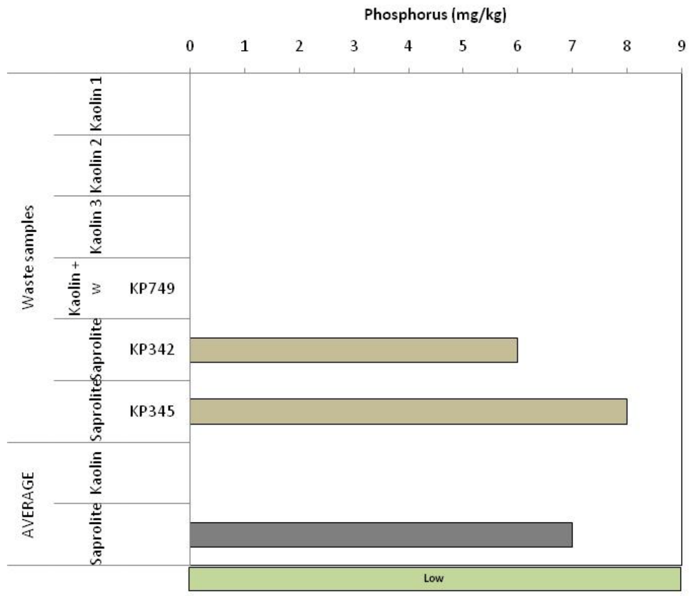


Figure 28: Individual and average plant-available phosphorus (P) (mg/kg) values of waste regolith samples from the Kundip Deposit (error bars represent standard error)

3.2.5.4 Plant-available potassium

Potassium plays a critical role in a number of plant physiological processes. Adequate amounts of plant-available potassium 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).

The amount of plant-available potassium measured in the surface soils and waste regolith materials from the Project area ranged from low (< 70 mg/kg) to high (> 200 mg/kg) (Figure 29 and Figure 30). The highest plant-available potassium values were measured in red clay-dominant, gravel-dominant and calcrete-dominant soils. The highest plant-available potassium value measured from the waste samples was at 364 mg/kg in saprolite sample KP345 (Figure 30).

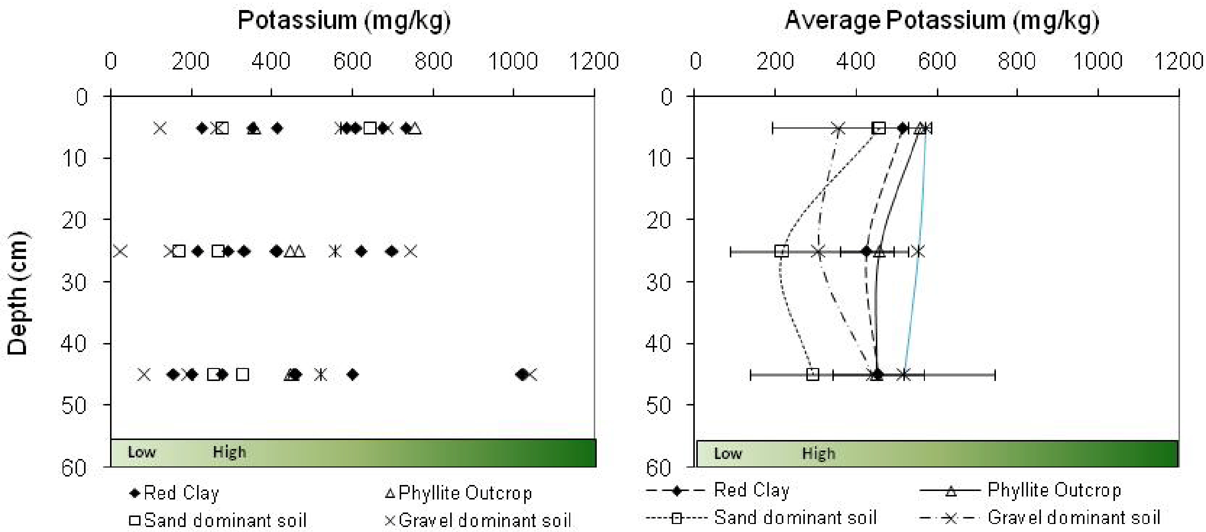


Figure 29: Individual and average plant-available potassium (K) (mg/kg) values grouped into soil types from the Trilogy Deposit (error bars represent standard error)

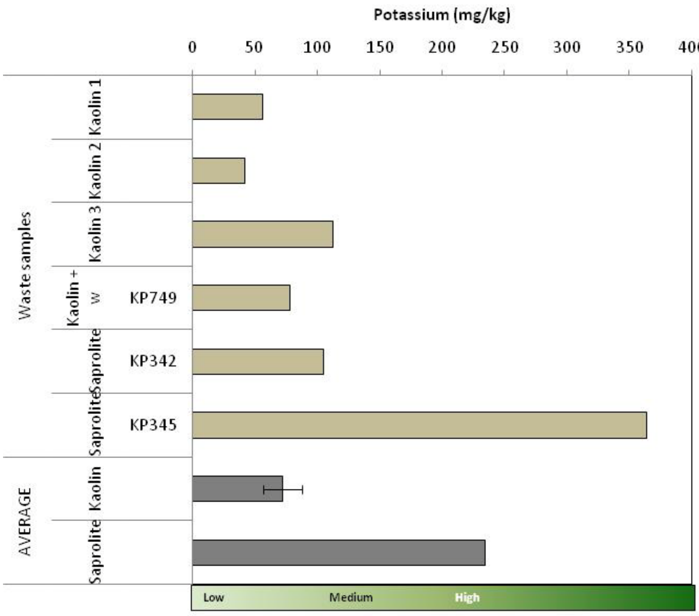


Figure 30: Individual and average extractable potassium (K) (mg/kg) values of waste regolith samples from the Kundip Deposit (error bars represent standard error)

3.2.5.5 Plant-available sulphur

Sulphur is a constituent of many protein enzymes that regulate activities such as photosynthesis and nitrogren fixation (Brady and Weil, 2002). Symptoms of sulphur deficiency are similar to those associated with nitrogen deficiency. Plants deficient in sulphur tend to become spindly and develop thin stems and petioles. Plant growth will be slowed, and maturity may be delayed. 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 values in the surface soil samples ranged from 1.72 to 80.95 mg/kg (both measured in red clay-dominant soils) (Figure 31). Sulphur values were generally lower in the shallower depth interval (0 – 10 cm) and increased with depth. Plant-available sulphur values in the waste regolith samples varied from 6.74 (kaolin) to 87.92 mg/kg (saprolite) (Figure 32).

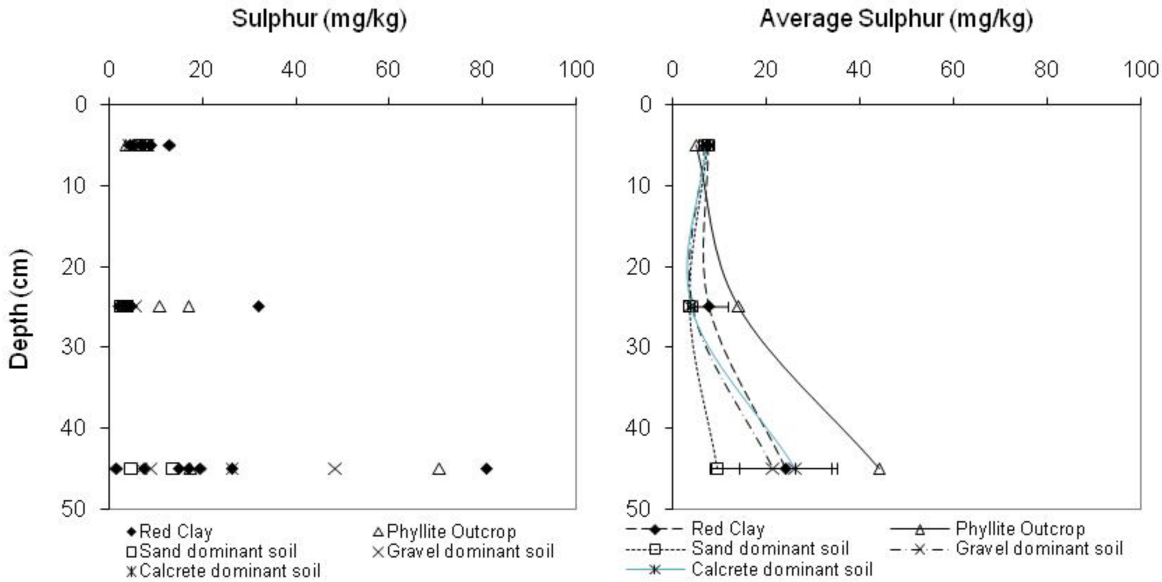


Figure 31: Individual and average plant-available sulphur (S) (mg/kg) values grouped into soil types associations from the Trilogy Deposit (error bars represent standard error)

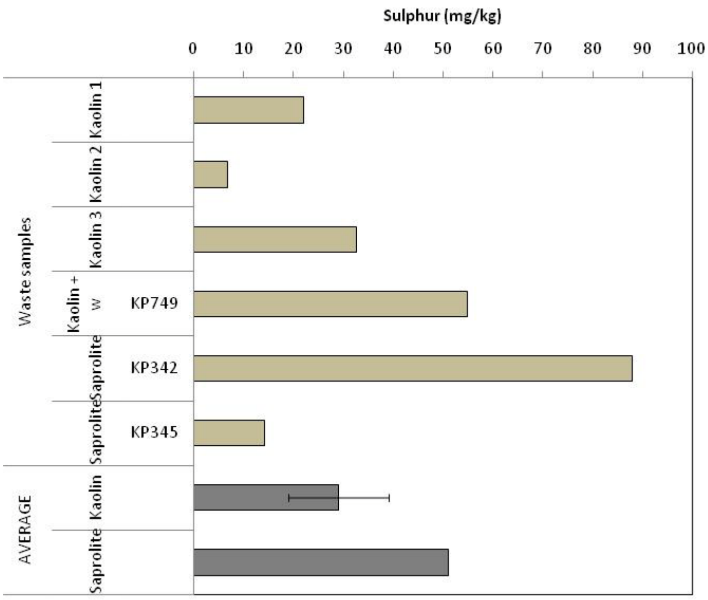


Figure 32: Individual and average plant-available sulphur (S) (mg/kg) values grouped of waste regolith samples from the Kundip Deposit (error bars represent standard error)

3.2.6 Total metal concentrations

Metal concentrations in the soil are significant because they play an important role in many biological functions; however, many of them can also become toxic at relatively low concentrations. Many heavy 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 samples indicated that variable levels of As, Cd, Cr, Cu, Pb, Ni, Zn and Hg were present (Table 6). All results were compared with ‘Ecological Investigation Levels’ (EILs) for soils (Department of Environment and Conservation (DEC) 2010). The EILs are intended as a guide only, as higher EIL values may be acceptable for some metal concentrations, such as As, Cr, Cu, Ni, Pb and Zn, in areas where soils naturally have high background concentrations of these substances (DEC, 2010).

The majority of the surface soil samples from the Trilogy Deposit area were below the detectable limit for As, Cd, Cr, Cu, Pb, Ni, Zn and Hg (Table 6). Soil samples TPR13.2, TPR13.3 had elevated concentrations of arsenic, relative to the low levels at the other sites, and were above the default Ecological Investigation Levels for soils (DEC, 2010) of 20 mg/kg. Samples TPR13.2 and TPR13.3 also had elevated concentrations of chromium. Samples TPR14.2, TRP2.2 and TPR5.2 had elevated concentrations of chromium at a profile depth of 20 – 30 cm. These concentrations of chromium are unlikely to impede plant growth and pose minimal risk in terms of toxicity. There was a general trend between the amount of clay present within a soil sample and the concentrations of total metals. Soil samples with higher clay contents typically had higher concentrations of total metals.

The concentrations of total metals in the 0 – 5 cm depth interval at all of the dust monitoring sites were below the EIL values for all metals tested.

Table 6: Total metal concentrations (mg/kg) of surface soils (0 to 50cm) and baseline dust monitoring sites (0-5cm) from the Trilogy Deposit

Site	Depth	Total metal concentration (mg/kg)							
		Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Zinc	Mercury
Trilogy Deposit surface soil samples									
TPR 1.1	0-10	<5	<1	**29**	**10**	**30**	**14**	**7**	<0.1
TPR 1.2	20-30	<5	<1	**34**	**13**	**37**	**18**	**6**	<0.1
TPR 1.3	40-50	**7**	<1	**34**	**14**	**36**	**20**	**6**	<0.1
TPR 2.1	0-10	<5	<1	**24**	**6**	**17**	**6**	<5	<0.1
TPR 2.2	20-30	**8**	<1	**51**	**12**	**36**	**17**	<5	<0.1
TPR 2.3	40-50	**7**	<1	**39**	**11**	**27**	**15**	<5	<0.1
TPR 3.1	0-10	**8**	<1	**22**	**8**	**23**	**7**	<5	<0.1
TPR 3.2	20-30	**14**	<1	**38**	**14**	**37**	**13**	<5	<0.1
TPR 3.3	40-50	**13**	<1	**34**	**12**	**34**	**11**	<5	<0.1
TPR 4.1	0-10	**9**	<1	**25**	**6**	**32**	**4**	<5	<0.1
TPR 4.2	20-30	**14**	<1	**40**	**16**	**40**	**12**	<5	<0.1
TPR 4.3	40-50	**16**	<1	**36**	**17**	**42**	**13**	<5	<0.1
TPR 5.1	0-10	<5	<1	**23**	**14**	**38**	**4**	**10**	<0.1
TPR 5.2	20-30	<5	<1	**52**	<5	**59**	**3**	<5	<0.1
TPR 5.3	40-50	<5	<1	**71**	**20**	**56**	**8**	<5	<0.1
TPR 6.1	0-10	<5	<1	**19**	**10**	**20**	**7**	<5	<0.1
TPR 6.2	20-30	**12**	<1	**37**	**21**	**32**	**17**	<5	<0.1
TPR 6.3	40-50	**13**	<1	**38**	**24**	**32**	**18**	**6**	<0.1
TPR 7.1	0-10	<5	<1	**14**	<5	**12**	<2	<5	<0.1
TPR 7.2	20-30	**5**	<1	**38**	**7**	**23**	**7**	<5	<0.1
TPR 7.3	40-50	**6**	<1	**34**	**8**	**16**	**8**	<5	<0.1
TPR 8.1	0-10	**9**	<1	**45**	**54**	**39**	**32**	**53**	<0.1

Site	Depth	Total metal concentration (mg/kg)							
		Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Zinc	Mercury
TPR 8.2	20-30	**16**	<1	**40**	**82**	**33**	**31**	**45**	<0.1
TPR 8.3	40-50	**14**	<1	**41**	**79**	**32**	**30**	**48**	<0.1
TPR 9.1	0-10	<5	<1	**16**	**7**	**10**	**7**	**6**	<0.1
TPR 9.2	20-30	**9**	<1	**43**	**19**	**29**	**26**	**10**	<0.1
TPR 9.3	40-50	**10**	<1	**37**	**20**	**25**	**26**	**9**	<0.1
TPR 10.1	0-10	**10**	<1	**50**	**21**	**21**	**24**	**7**	<0.1
TPR 10.2	20-30	**11**	<1	**41**	**23**	**15**	**20**	**6**	<0.1
TPR 10.3	40-50	**10**	<1	**36**	**24**	**16**	**18**	**7**	<0.1
TPR 11.1	0-10	<5	<1	**25**	<5	**21**	**5**	5	<0.1
TPR 11.2	20-30	**7**	<1	**42**	**8**	**37**	**12**	<5	<0.1
TPR 11.3	40-50	**10**	<1	**37**	**10**	**30**	**13**	<5	<0.1
TPR 12.1	0-10	**8**	<1	**38**	<5	**51**	**4**	<5	<0.1
TPR 12.2	20-30	**7**	<1	**43**	<5	**61**	<2	<5	<0.1
TPR 12.3	40-50	**5**	<1	**48**	<5	**46**	**7**	<5	<0.1
TPR 13.1	0-10	**18**	<1	**48**	**8**	**11**	**18**	**7**	<0.1
TPR 13.2	20-30	**23**	<1	**60**	**7**	**16**	**22**	<5	<0.1
TPR 13.3	40-50	**27**	<1	**52**	**7**	**18**	**23**	<5	<0.1
TPR 14.1	0-10	**6**	<1	**21**	<5	**12**	**6**	<5	<0.1
TPR 14.2	20-30	**14**	<1	**55**	**14**	**23**	**24**	<5	<0.1
TPR 14.3	40-50	**15**	<1	**49**	**11**	**32**	**16**	<5	<0.1
TPR 15.1	0-10	<5	<1	**8**	<5	**7**	<2	<5	<0.1
TPR 15.2	20-30	<5	<1	**11**	<5	**10**	<2	<5	<0.1
TPR 15.3	40-50	<5	<1	**9**	<5	**8**	<2	<5	<0.1
Trilogy baseline dust monitoring sites									
TPR d 1a	0-5	<1.00	<0.1	<1.0	**3.1**	**18.5**	**1.9**	<5.0	<0.10
TPR d 1b	0-5	<1.00	<0.1	<1.0	**3.1**	**4.4**	**1**	<5.0	<0.10

Site	Depth	Total metal concentration (mg/kg)							
		Arsenic	**Cadmium**	**Chromium**	**Copper**	**Lead**	**Nickel**	**Zinc**	**Mercury**
TPR d 2a	0-5	<1.00	<0.1	<1.0	**1.2**	**6.5**	<1.0	<5.0	<0.10
TPR d 2b	0-5	<1.00	<0.1	<1.0	<1.0	**3.1**	<1.0	<5.0	<0.10
TPR d 3a	0-5	<1.00	<0.1	<1.0	**1.3**	**4.4**	**1**	<5.0	<0.10
TPR d 3b	0-5	<1.00	<0.1	<1.0	**2.1**	**5.3**	**1.6**	<5.0	<0.10
TPR d 4a	0-5	<1.00	<0.1	<1.0	**1.2**	**4.4**	<1.0	<5.0	<0.10
TPR d 4b	0-5	<1.00	<0.1	<1.0	**1.5**	**5.5**	<1.0	<5.0	<0.10
TPR d 5a	0-5	<1.00	<0.1	<1.0	<1.0	**4.6**	**1**	<5.0	<0.10
TPR d 5b	0-5	<1.00	<0.1	<1.0	<1.0	**2.6**	<1.0	<5.0	<0.10
TPR d 6a	0-5	<1.00	<0.1	<1.0	**2.2**	**2.9**	**1.2**	<5.0	<0.10
TPR d 6b	0-5	<1.00	<0.1	<1.0	**1.9**	**4.4**	<1.0	<5.0	<0.10
TPR d 7a	0-5	<1.00	<0.1	<1.0	**1.4**	**2.4**	**1.1**	<5.0	<0.10
TPR d 7b	0-5	<1.00	<0.1	<1.0	<1.0	<1.0	<1.0	<5.0	<0.10
TPR d 8a	0-5	<1.00	<0.1	<1.0	<1.0	**1.5**	<1.0	<5.0	<0.10
TPR d 8b	0-5	<1.00	<0.1	<1.0	<1.0	**1.1**	<1.0	<5.0	<0.10
LOR (mg/kg)		**5**	**1**	**2**	**5**	**5**	**2**	**5**	**0.1**
EIL (mg/kg)		**20**	**3**	**400**	**100**	**600**	**60**	**200**	**1**

Note: Values in bold indicate levels detected above Limits of Reporting (LOR), levels above the Ecological Investigation Levels (EIL) (DEC, 2010) are highlighted in orange.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Management plan

The primary purpose of this study was to characterise the undisturbed surface soil materials (to 0.5 m depth) within the Phillips River Project area and to identify any potentially problematic soil materials that may cause issues during the proposed mining and subsequent rehabilitation activities onsite. It is intended that the information contained within this report be used to assist the planning and adoption of appropriate rehabilitation techniques for the Project area.

Additional baseline information (soil pH, salinity and total metal concentration) has been obtained from 16 sites around the Trilogy Deposit area, for comparison with future monitoring data.

The characteristics of selected waste regolith materials from the Kundip Deposits have also been evaluated to identify the potential for their use as cover / rehabilitation materials on constructed waste landforms.

4.1.1 Trilogy surface soils sites

The soil survey investigated the properties of the five major soil types previously identified within the Project area; these were: the red clay dominant soil, phyllite outcrop, sand-dominant soil, gravel-dominant soil and calcrete-dominant soil.

The results indicate that a number of the samples below the ‘topsoil’, i.e. below the surface 0 – 10 cm depth interval, from the Trilogy Deposit were identified as being partially or completely dispersive, are sodic, have the capacity to hard-set and have a high potential erodibility. If these sub-surface soils are inappropriately handled or placed on the outer slopes of waste landforms, these intrinsic properties may cause difficulties and result in additional financial costs in the rehabilitation / revegetation process. The following section provides practical recommendations for the effective stripping, stockpiling and management of the surface soil materials within the Trilogy Deposit area.

The separate collection, stockpiling and application of the topsoil materials will be an important component to the successful rehabilitation of target vegetation communities on constructed landforms. Soil stripping and handling guidelines must be flexible to accommodate the logistical operations of earthworks and mining activities. The management recommendations for the Project area are detailed as follows.

4.1.2 Soil stripping

- It is recommended that the top 10 cm of the soil profile in disturbance areas be stripped and stockpiled as topsoil.
- Any coarse woody debris, surface litter, plant roots and vegetative material present within the top 10 cm of the soil profiles is an important source of organic matter which can enhance many physical and chemical properties of the soil. This material should be collected and stockpiled with the topsoil as the coarse organic material enhances the capacity of the soil to slow overland flow and capture and retain water and nutrients.
- Where possible the topsoil material should be paddock-dumped into piles no greater than two metres in height. The piles should have adequate distance between them so as to create a series of mounds and troughs. This will serve to maintain the structure of the soil and will limit the potential for erosion to occur as the runoff will be locally redistributed within the heaped piles.
- Machinery operators should minimise the frequency and intensity of disturbance so they do not compromise the structural integrity of the material (i.e. avoid dumping material from significant heights; repetitive rolling and compacting with machinery).
- As a general rule, the quality of the topsoil decreases with depth and hence it is important that machinery operators remove material only from the recommended profile depths (i.e. the top 10cm). Failure to do so may result in issues related to salinity, hardsetting and soil dispersion and/or create unstable, erodible stockpiles.

4.1.3 Soil stockpiling

- Stockpiles should be reseeded as soon as possible. Adequate vegetative cover will maintain the structural and biological integrity of the material for when it is required as a cover material for rehabilitation purposes. It will also maintain a viable seedbank that could potentially reduce the costs associated with ripping and reseeding the area.
- Excessive traffic and disturbance of the stockpiles should be minimised to prevent erosion. Appropriate signage should be erected at each stockpile advising Tectonic site staff and contractors of the type of material that has been stored and the activities that are permitted on or near the stockpile.
- Localised addition of gypsum may be required to mitigate issues associated with the stability of some materials. Potentially dispersive soil was found within all five soil / landform types.
- Timing the removal of the topsoil is important as in some areas it will result in the exposure of potentially dispersive and erodible subsoils. Therefore, soil stripping should occur as close as possible to the time when the pit construction is to commence.

4.2 Trilogy baseline dust monitoring sites

The surface soils from the sites selected as baseline dust monitoring sites have low levels of total metals, low salinity, and a soil pH comparable to the other surface soils in the Project area. It is recommended that a monitoring programme be established at these sites to evaluate the relative impact of the mining operations on the surrounding soils. The monitoring programme would involve periodically sampling at the same sites, or close by, and analysing the material for total metals, soil pH and salinity (as electrical conductivity) and comparing the results to the original baseline monitoring data.

4.3 Kundip waste regolith samples

It is evident that the sampled waste regolith materials from the Kundip Deposit are relatively stable in terms of dispersive qualities, but are prone to hard-setting and are sodic to highly sodic. Consequently, substantial planning and management will be required to ensure that, if these materials are used as a cover / rehabilitation material on waste landforms, that these materials are placed appropriately.

5. REFERENCES

Allen, D. G. and Jeffrey, R. C. (1990) *Report of the Investigation No. 37 'Methods for Analysis of Phosphorus in Western Australian Soils'.*

Aylmore, L. A. G. and Sills, I. D. (1982) Characterisation of soil structure and stability using modulus of rupture – ESP relationships. *Australian Journal of Soil Research* 62: 213-224.

Blair, G. J., Chinoim, N., Lefroy, R. D. B., Anderson, G. C. and Crocker, G. J. (1991) A soil sulphur test for pastures and crops. *Australian Journal of Soil Research* 29: 619-626.

Brady, N. and Weil, R. 2002, *The Nature and Properties of Soils - Thirteenth Edition*, Prentice Hall, Upper Saddle River, New Jersey.

Cochrane, H. R. and Aylmore, L. A. G. (1997) *Assessing management induced changes in the structural stability of hardsetting soils*. *Soil & Tillage Research*.

Coffey Mining (2008) *Tailings Storage Audit and Management Review Checker Tailings Storage Facility 3 Hill 50 Gold Mine, Mt Magnet - 2007 Harmony Mt Magnet Gold Operation*, MWP00310AC-AB Audit report Review 16 February 2008.

Colwell, J. D. (1965) An automated procedure for the determination of phosphorus in sodium hydrogen carbonate extracts of soils. *Chemistry and Industry* May: 893-895.

Costello, J., Lacy, H., Rengel, Z., Jasper, D. and Quaghebeur, M. (2003) *Uptake of arsenic by native plants growing on gold tailings in Western Australian Rangelands*. Meeting of the American Society of Mining and Reclamation and the 9th Billings Land Reclamation Symposium, Billings MT, June 3-6, ASMR, Lexington.

Department of Environment and Conservation (DEC) (2010). Assessment Levels for Soil, Sediment and Water. Contaminated Sites Management Series. Version 4, Revision 1, February 2010.

Harper, R. J. and Gilkes, R. J. (1994) Hardsetting in the Surface Horizons of Sandy Soils and its Implications for Soil Classification and Management. *Australian Journal of Soil Research*.

Hunt, N. and Gilkes, R. (1992) *Farm monitoring handbook, a practical down-to-earth manual for farmers and other land users.* The University of Western Australia, Perth.

King, P. M. (1981) Comparison of methods for measuring severity of Water Repellance of Sandy Soils and Assessment of some factors that affect its measurement.

McDonald, R. C., Isbell, R. F., Speight, J. G., Walker, J. and Hopkins, M. S. (1998) *Australian soil and land survey - field handbook.* CSIRO Land and Water, Canberra.

McKenzie, N., Coughlan, K. and Cresswell, H. (2002) *Soil physical measurement and interpretation for land evaluation.* CSIRO Publishing, Canberra.

Moore, G. (1998) *Soilguide.* A handbook for understanding and managing agricultural soils, Agriculture Western Australia. Bulletin No. 4343.

Needham, P., Moore, G. and Scholz., G. (1998) Soil structure decline. In: G. Moore (ed) *Soil guide - a handbook for understanding and managing agricultural soils*, vol Bulletin No. 4343. Agriculture Western Australia, Perth, Western Australia, pp 64 - 79

Purdie, B. R. (1998) Understanding and interpreting soil chemical and physical data. In, vol Bulletin 4343. Agriculture Western Australia, p 315.

Rayment, G. E. and Higginson, F. R. (1992) *Australian Laboratory Handbook of Soil and Chemical Methods.* Inkata Press,

Scarle, P. L. (1984) *Analyst* 109: 549-568.

Schwertmann, U. (1993) Relations between iron oxides, soil colour and soil formation. *Soil Science Society of America Special Publication* 31: 51-71.

Walkley, A. and Black, I. A. (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic and titration method. *Soil Science* 37: 29-38.

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.
Hydrophobicity	Description of hydrophobic or water repellent characteristics in soil. Primarily caused by hydrophobic organic residues derived from decomposing plant materials, which alter the contact angle between water droplets and the soil surface, in turn affecting the ability of water to infiltrate into the 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. Soil texturing

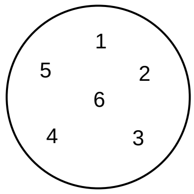
Soils were worked by hand, and the texture, shearing capacity, particle size and ribbon length were observed according to methods described in McDonald *et al.* (1998) as follows.

Texture grade	**Behaviour of moist bolus**	**Approximate clay content**	**Code**
Sand	Nil to very slight coherence; cannot be moulded; single sand grains adhere to fingers	<5 %	S
Loamy sand	Slight coherence; can be sheared between thumb and forefinger to give minimal ribbon of about 5 mm	5 %	LS
Clayey sand	Slight coherence; sticky when wet; many sand grains stick to fingers; discolours fingers with stain; forms minimal ribbon of 5 – 15 mm	5 - 10 %	CS
Sandy loam	Bolus coherent but very sandy to touch; dominant sand grains of medium size and readily visible ; ribbon of 15 – 25 mm	10 – 20 %	SL
Loam	Bolus coherent and rather spongy; no obvious sandiness or silkiness; forms ribbon of about 25 mm	25 %	L
Sandy clay loam	Strongly coherent bolus; sandy to touch; ribbon of 25 – 40 mm	20 - 30 %	SCL
Clay loam	Coherent plastic bolus, smooth to touch, ribbon of 25 mm to 40 mm	30 – 35 %	CL
Clay loam, sandy	Coherent plastic bolus, sand grains visible in finer matrix, ribbon of 40 - 50 mm; sandy to touch	30 - 35 %	CLS
Light clay	Plastic bolus, smooth to touch; slight resistance to shearing; ribbon of 50 – 75 mm	35 – 40 %	LC
Light medium clay	Ribbon of about 75 mm, slight to moderate resistance to ribboning shear	40 - 45 %	LMC
Medium clay	Smooth plastic bolus, handles like plasticine and can be moulded into rods without fracture; moderate resistance to ribboning shear, ribbon of 75 mm or longer	45 – 55 %	MC
Medium heavy clay	Ribbon of 75 mm or longer, handles like plasticine, moderate to firm resistance to ribboning shear	>50 %	MHC
Heavy Clay	Handles like stiff plasticine; firm resistance to ribboning shear, ribbon of 75 mm or longer	>50 %	HC

2. 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 3-5mm 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 24 hour period, after which the samples were observed again and rated according to the above Table.

3. 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

4. General soil pH ratings

These ratings area 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

Soil analysis results

Table 7: Physical characteristics of soil and waste material from the Philips River Project area

Sample ID	Depth Interval (cm)	Field Texture (of <2 mm fraction)	Emerson Test Class[2]	MOR (kPa)	% Coarse Fragments (>2mm)	Particle Size Distribution (<2mm fraction)			
						% Clay	% Coarse sand	% Fine sand	% Silt
Trilogy surface soil samples									
TPR 1.1	0-10	Light clay	3a	8.38	0.0	-	-	-	-
TPR 1.2	20-30	Medium heavy clay	1	-	0.0	-	-	-	-
TPR 1.3	40-50	Medium clay	1	27.53	0.0	-	-	-	-
TPR 2.1	0-10	Sandy clay loam	2	43.24	0.0	34.1	35.6	30.1	0.2
TPR 2.2	20-30	Medium heavy clay	1	-	38.0	55.1	19.4	18.6	6.9
TPR 2.3	40-50	Medium clay	1	87.11	0.0	37.1	36.1	18	8.8
TPR 3.1	0-10	Clay loam	3a	45.62	25.2	22.1	29.4	24.7	23.8
TPR 3.2	20-30	Heavy clay	1	-	0.0	49.3	22.5	21.3	6.9
TPR 3.3	40-50	Medium heavy clay	1	85.84	0.0	44.9	24.4	27.7	3
TPR 4.1	0-10	Sandy loam	3b	8.65	50.0	13.8	56.1	29	1.1
TPR 4.2	20-30	Heavy clay	1	-	56.4	33.8	37.2	22	7
TPR 4.3	40-50	Medium clay	1	173.80	65.8	30.1	37.9	25.3	6.8
TPR 5.1	0-10	Sandy loam	3b	3.93	57.5	-	-	-	-
TPR 5.2	20-30	Sandy clay loam	3b	-	79.3	-	-	-	-
TPR 5.3	40-50	Clay loam	-	22.44	54.1	-	-	-	-
TPR 6.1	0-10	Clay loam sandy	2	17.98	0.0	24.1	42.4	25.5	8

Sample ID	Depth Interval (cm)	Field Texture (of <2 mm fraction)	Emerson Test Class[2]	MOR (kPa)	% Coarse Fragments (>2mm)	Particle Size Distribution (<2mm fraction)			
						% Clay	% Coarse sand	% Fine sand	% Silt
TPR 6.2	20-30	Light clay	1	-	0.0	41	20.2	31.3	7.5
TPR 6.3	40-50	Medium heavy clay	1	102.65	35.1	42.2	26.3	21.9	9.6
TPR 7.1	0-10	Medium clay	3b	11.27	0.0	9	66	21	4
TPR 7.2	20-30	Sandy clay loam	1	-	0.0	36.9	37.3	24.9	0.9
TPR 7.3	40-50	Medium heavy clay	1	251.97	0.0	28.9	46.5	21.9	2.7
TPR 8.1	0-10	Sandy clay	-	6.90	0.0	-	-	-	-
TPR 8.2	20-30	Clay loam	-	-	0.0	-	-	-	-
TPR 8.3	40-50	Heavy clay	2	95.70	0.0	-	-	-	-
TPR 9.1	0-10	Sandy clay	-	3.45	36.7	27.4	49.1	22.5	1
TPR 9.2	20-30	Sandy loam	3a	-	0.0	41	22.7	24.2	12.1
TPR 9.3	40-50	Sandy clay	3a	9.92	0.0	40.5	27.2	15.9	16.4
TPR 10.1	0-10	Sandy clay	1	8.54	0.0	-	-	-	-
TPR 10.2	20-30	Sandy loam	1	-	0.0	-	-	-	-
TPR 10.3	40-50	Sandy clay loam	1	130.24	0.0	-	-	-	-
TPR 11.1	0-10	Clay loam	3b	8.81	10.2	11.8	49.6	36.7	1.8
TPR 11.2	20-30	Sandy clay loam	1	-	0.0	33.4	17.8	27.1	21.7
TPR 11.3	40-50	Sandy clay	1	181.65	35.2	35.2	27.7	32.2	4.9
TPR 12.1	0-10	Medium clay	3b	1.96	46.6	14.9	40.7	35.4	9

Sample ID	Depth Interval (cm)	Field Texture (of <2 mm fraction)	Emerson Test Class[2]	MOR (kPa)	% Coarse Fragments (>2mm)	Particle Size Distribution (<2mm fraction)			
						% Clay	% Coarse sand	% Fine sand	% Silt
TPR 12.2	20-30	Sandy loam	2	-	62.5	13.8	53.5	27.2	5.5
TPR 12.3	40-50	Sandy clay	1	36.71	59.7	34.8	30.9	27.9	6.4
TPR 13.1	0-10	Sandy clay	3b	1.75	47.7	22.2	40.5	23.2	14.1
TPR 13.2	20-30	Clay loam sandy	-	-	63.2	38.7	36.2	18.3	6.8
TPR 13.3	40-50	Light clay	1	12.47	0.0	31	46.3	17.9	4.8
TPR 14.1	0-10	Medium clay	2	4.30	0.0	27	41	30	2
TPR 14.2	20-30	Sandy clay	1	-	0.0	48.1	22.5	17.8	11.6
TPR 14.3	40-50	Medium clay	1	121.12	0.0	40.4	34.3	20.5	4.8
TPR 15.1	0-10	Light clay	3b	12.89	50.5	-	-	-	-
TPR 15.2	20-30	Light clay	3b		75.9	-	-	-	-
TPR 15.3	40-50	Clay loam sandy	3b	28.12	75.7	-	-	-	-
Kundip waste regolith samples									
kaolin 1	n/a	-	6	31.62	-	-	-	-	-
kaolin 2	n/a	-	5	31.04	-	-	-	-	-
kaolin 3	n/a	-	5	18.89	-	-	-	-	-
KP342	n/a	-	5	68.97	-	-	-	-	-
KP345	n/a	-	5	46.10	-	-	-	-	-
KP474	n/a	-	-	-	-	-	-	-	-

Sample ID	Depth Interval (cm)	Field Texture (of <2 mm fraction)	Emerson Test Class[2]	MOR (kPa)	% Coarse Fragments (>2mm)	Particle Size Distribution (<2mm fraction)			
						% Clay	% Coarse sand	% Fine sand	% Silt
KP749	n/a	-	5	24.59	-	-	-	-	-

1. See Appendix B for root growth scoring categories.
2. See Appendix B for Emerson Test class categories.

Table 8: Chemical characteristics of soil and waste material from the Philips River Project area

Sample ID	Depth Interval (cm)	Soil pH ($CaCl_2$)	EC (dS/m)	Organic Carbon (%)	Plant-available Nutrients (mg/kg)					Exchangeable Cations (meq/100 g)				ESP (%)
					Nitrate (NO_3^-)	Ammonium (NH_4^+)	P	K	S	Ca^{2+}	K^+	Mg^{2+}	Na^+	
Trilogy soil samples														
TPR 1.1	0-10	7.1	0.141	1.99	22	7	5	733	4.75	-	-	-	-	-
TPR 1.2	20-30	8	0.277	0.66	5	2	4	698	2.16	-	-	-	-	-
TPR 1.3	40-50	8.2	0.486	0.7	6	2	2	1022	7.65	-	-	-	-	-
TPR 2.1	0-10	6.6	0.168	1.35	36	2	11	357	6.6	2.88	0.52	2.14	0.23	3.99
TPR 2.2	20-30	8	0.394	0.58	5	2	3	466	10.98	1.41	0.19	1.61	0.64	16.62
TPR 2.3	40-50	8.3	0.808	0.32	1	3	2	452	70.85	6.6	0.27	2.71	0.7	6.81
TPR 3.1	0-10	6.4	0.126	2.26	23	2	8	586	9.16	6.99	1.2	4.3	0.17	1.34
TPR 3.2	20-30	8	0.347	0.63	3	1	3	332	4.04	9.75	0.73	7.81	0.92	4.79
TPR 3.3	40-50	7.9	0.404	0.63	3	< 1	2	277	14.99	5.45	0.3	3.49	0.54	5.52
TPR 4.1	0-10	4.8	0.122	1.98	29	4	15	277	6.61	1.11	0.26	0.44	0.1	5.24

Sample ID	Depth Interval (cm)	Soil pH ($CaCl_2$)	EC (dS/m)	Organic Carbon (%)	Plant-available Nutrients (mg/kg)					Exchangeable Cations (meq/100 g)				ESP (%)
					Nitrate (NO_3^-)	Ammonium (NH_4^+)	P	K	S	Ca^{2+}	K^+	Mg^{2+}	Na^+	
TPR 4.2	20-30	7.1	0.221	0.75	3	3	2	169	2.97	1.81	0.12	1.99	0.51	11.51
TPR 4.3	40-50	8.2	0.368	0.47	3	4	2	256	14.01	8.98	0.28	3.56	0.56	4.19
TPR 5.1	0-10	4.4	0.262	5.94	97	78	51	609	13.09	-	-	-	-	-
TPR 5.2	20-30	5.5	0.075	1.23	8	4	6	215	3.53	-	-	-	-	-
TPR 5.3	40-50	7.2	0.221	0.5	5	1	2	156	17.14	-	-	-	-	-
TPR 6.1	0-10	7	0.281	2.05	39	3	11	413	8.82	4.1	0.7	4.12	0.42	4.50
TPR 6.2	20-30	8.1	0.864	0.47	3	1	3	413	32.04	9.48	0.55	4.76	0.97	6.15
TPR 6.3	40-50	9.3	1.063	0.31	3	1	2	458	80.95	8.9	0.34	3.2	0.68	5.18
TPR 7.1	0-10	6.5	0.069	1.4	14	3	17	226	4.53	1.23	0.32	0.76	0.12	4.94
TPR 7.2	20-30	7	0.221	0.54	2	3	2	292	4.95	0.56	0.11	0.74	0.36	20.34
TPR 7.3	40-50	8	0.385	0.31	2	3	2	202	19.65	1.08	0.12	0.93	0.51	19.32
TPR 8.1	0-10	7.1	0.179	4.54	63	11	31	687	8.64	-	-	-	-	-
TPR 8.2	20-30	7.8	0.182	1.03	4	< 1	4	744	5.85	-	-	-	-	-
TPR 8.3	40-50	7.9	0.715	0.93	9	1	3	1043	48.66	-	-	-	-	-
TPR 9.1	0-10	7.3	0.309	2.57	46	3	12	676	5.16	6.85	1.06	2.39	0.1	0.96
TPR 9.2	20-30	7.9	0.298	0.44	4	1	2	622	3.2	14.43	1.62	8.15	0.37	1.51
TPR 9.3	40-50	7.9	0.247	0.43	2	2	< 2	600	1.72	16.56	1.61	7.64	0.19	0.73
TPR 10.1	0-10	8	0.274	0.54	18	< 1	9	756	3.68	-	-	-	-	-

Sample ID	Depth Interval (cm)	Soil pH ($CaCl_2$)	EC (dS/m)	Organic Carbon (%)	Plant-available Nutrients (mg/kg)					Exchangeable Cations (meq/100 g)				ESP (%)
					Nitrate (NO_3^-)	Ammonium (NH_4^+)	P	K	S	Ca^{2+}	K^+	Mg^{2+}	Na^+	
TPR 10.2	20-30	8.2	0.477	0.21	34	< 1	< 2	446	17.12	-	-	-	-	-
TPR 10.3	40-50	8.2	0.564	0.22	37	< 1	< 2	446	17.6	-	-	-	-	-
TPR 11.1	0-10	5	0.109	2.42	43	17	19	352	7.16	2.61	0.47	1.12	0.1	2.33
TPR 11.2	20-30	7.3	0.276	0.84	4	3	5	410	4.01	2.33	0.25	2.18	0.52	9.85
TPR 11.3	40-50	8.3	0.445	0.47	3	8	5	459	26.37	7.83	0.37	2.92	0.68	5.76
TPR 12.1	0-10	4.9	0.073	1.96	26	2	16	268	4.69	1.34	0.3	0.5	0.1	4.46
TPR 12.2	20-30	6.2	0.044	0.21	3	< 1	3	153	3.71	0.92	0.2	0.62	0.1	5.43
TPR 12.3	40-50	6.5	0.137	0.44	3	1	3	191	9.1	1.63	0.29	2.31	0.7	14.20
TPR 13.1	0-10	7.4	0.224	1.67	71	15	22	642	8.15	11.77	1.09	2.56	0.1	0.64
TPR 13.2	20-30	7.8	0.15	0.42	3	1	4	267	4.07	12.45	0.62	4.3	0.11	0.63
TPR 13.3	40-50	8	0.203	0.36	3	3	3	328	5.01	4.74	0.24	2.29	0.11	1.49
TPR 14.1	0-10	6.6	0.144	2.06	49	15	11	572	7	5.45	0.94	2.89	0.1	1.07
TPR 14.2	20-30	7.9	0.393	0.58	7	1	4	556	3.94	5.83	0.59	4.15	1.08	9.27
TPR 14.3	40-50	8.3	0.537	0.55	4	< 1	< 2	520	26.37	8.76	0.62	4.24	1.13	7.66
TPR 15.1	0-10	4.3	0.116	3.1	51	3	1	122	6.67	-	-	-	-	-
TPR 15.2	20-30	5.6	0.05	0.68	4	1	3	27	2.76	-	-	-	-	-
TPR 15.3	40-50	5.8	0.043	0.5	6	2	5	83	6.91	-	-	-	-	-
Trilogy baseline dust monitoring sites														

Sample ID	Depth Interval (cm)	Soil pH ($CaCl_2$)	EC (dS/m)	Organic Carbon (%)	Plant-available Nutrients (mg/kg)					Exchangeable Cations (meq/100 g)				ESP (%)
					Nitrate (NO_3^-)	Ammonium (NH_4^+)	P	K	S	Ca^{2+}	K^+	Mg^{2+}	Na^+	
TPR d 1a	0-5	8.4	0.159	-	-	-	-	-	-	-	-	-	-	-
TPR d 1b	0-5	8.4	0.169	-	-	-	-	-	-	-	-	-	-	-
TPR d 2a	0-5	5.4	0.089	-	-	-	-	-	-	-	-	-	-	-
TPR d 2b	0-5	5.6	0.117	-	-	-	-	-	-	-	-	-	-	-
TPR d 3a	0-5	6.2	0.081	-	-	-	-	-	-	-	-	-	-	-
TPR d 3b	0-5	7.5	0.133	-	-	-	-	-	-	-	-	-	-	-
TPR d 4a	0-5	7.4	0.063	-	-	-	-	-	-	-	-	-	-	-
TPR d 4b	0-5	7	0.114	-	-	-	-	-	-	-	-	-	-	-
TPR d 5a	0-5	6	0.097	-	-	-	-	-	-	-	-	-	-	-
TPR d 5b	0-5	5.5	0.078	-	-	-	-	-	-	-	-	-	-	-
TPR d 6a	0-5	7.3	0.108	-	-	-	-	-	-	-	-	-	-	-
TPR d 6b	0-5	8.2	0.144	-	-	-	-	-	-	-	-	-	-	-
TPR d 7a	0-5	7.2	0.152	-	-	-	-	-	-	-	-	-	-	-
TPR d 7b	0-5	6.1	0.103	-	-	-	-	-	-	-	-	-	-	-
TPR d 8a	0-5	6	0.092	-	-	-	-	-	-	-	-	-	-	-
Kundip waste regolith samples														
kaolin 1	n/a	5.3	0.082	0.06	< 1	< 1	< 2	56	22	0.17	0.05	0.44	0.1	13.16
kaolin 2	n/a	5.4	0.041	< 0.05	< 1	1	< 2	42	6.74	0.17	0.05	0.14	0.1	21.74

Sample ID	Depth Interval (cm)	Soil pH ($CaCl_2$)	EC (dS/m)	Organic Carbon (%)	Plant-available Nutrients (mg/kg)					Exchangeable Cations (meq/100 g)				ESP (%)
					Nitrate (NO_3^-)	Ammonium (NH_4^+)	P	K	S	Ca^{2+}	K^+	Mg^{2+}	Na^+	
kaolin 3	n/a	5.4	0.285	< 0.05	< 1	2	< 2	113	32.62	0.19	0.11	0.39	0.21	23.33
KP342	n/a	5.5	0.902	0.12	3	< 1	6	105	87.92	0.71	0.06	2.61	3.04	47.35
KP345	n/a	7.3	0.323	0.12	1	< 1	8	364	14.24	0.27	0.12	0.78	7.25	86.10
KP474	n/a	-	-	-	-	-	-	-	-	-	-	-	-	-
KP749	n/a	5.9	0.421	0.05	< 1	< 1	< 2	78	54.86	0.17	0.04	1.01	0.21	14.69