



Soil and Overburden Assessment of Murrays Hill

Hancock Prospecting
Pty Ltd

July 2009

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To reference this report:

Landloch Pty Ltd (July 2009), *Soil and overburden assessment of Murrays Hill*. Report prepared for Hancock Prospecting Pty Ltd.

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EXECUTIVE SUMMARY

Hancock Prospecting Pty Ltd (HPPL) plan to develop the Murrays Hill iron ore project (the project). Murrays Hill is located within the Mulga Downs pastoral station, 230 km south east of Karratha and 180 km north west of Newman, in the Shire of Ashburton, in the Pilbara region of Western Australia.

Landloch Pty Ltd was engaged by HPPL to provide baseline information on the soils within and adjacent to the project, including an assessment of potential environmental impacts associated with mining operations. In addition, an assessment of overburden materials likely to be generated by mining was also requested.

Two soil associations were defined within the project area – upland soils and lowland soils. All soils inspected across the site have similar properties, being red in colour. Soil texture is invariably clay loam. Surface coarse fragments are common in both upland and lowland soils. Coarse fragments are also present throughout the profile. Soil depth varies from very shallow (< 0.10 m) to deep (> 1.0 m). Shallower soils are typically found in upland soils, and lowland soils tend to be deeper. Soils typically have neutral to mildly alkaline soil pH and are non-saline. Fertility is adequate. Soils are moderately permeable and tend to be moderately well-drained with water movement being limiting by underlying rock. All soils are likely to have moderate plant available water holding capacity. Water repellence was not observed on any soils in the project area.

The overburden materials sampled typically have properties that will not adversely impact on vegetation growth, though some samples had high ESP. When placed within a waste dump, it is likely that the overburden materials increase the volume of material from which vegetation can access water and nutrients. Sheeting of the overburden material with subsoil and topsoil materials is recommended for the management of potentially dispersive (high ESP) overburdens.

Soil handling – stripping, stockpiling, and respreading – should be done with great care. Only those soils that need to be disturbed should be disturbed. Guidance on appropriate soil handling has been provided.

1. INTRODUCTION

1.1. *Background*

Hancock Prospecting Pty Ltd (HPPL) plan to develop the Murrays Hill iron ore project (the project). Murrays Hill is located within the Mulga Downs pastoral station, 230 km south east of Karratha and 180 km north west of Newman, in the Shire of Ashburton, in the Pilbara region of Western Australia.

Landloch Pty Ltd was engaged by HPPL to provide baseline information on the soils within and adjacent to the project, including an assessment of potential environmental impacts associated with mining operations. In addition, an assessment of overburden materials likely to be generated by mining was also requested.

The project will generate waste materials that will be stockpiled within a waste landform. No tailings will be produced as a result of ore processing (there is no ore processing). Disturbance to land will also be caused by the establishment of the ROM pad, administration areas, workshops, access and haul roads, and a camp to the north of the current lease (M 47/206). Currently, there is no provision for any soil stockpiles or for the stockpiling of other potentially useful resources such as vegetation and rocky surface and regolith materials.

Dust suppression activities will involve use of non-saline water. This may include application of water to roads, and potentially to stockpile areas, particularly if they are stockpiled for long periods and left unvegetated.

1.2. *Project area description*

Figure 1 shows the extent of the project area. It consists predominantly of Murrays Hill and its associated foot slopes sloping to the south and uplands to the north. A mesa exists on Murrays Hill and within the proposed pit area. Gradients on Murrays Hill can be greater than 30% (the mesa face is precipitous), with the gradient decreasing to level (< 1%) or gently inclined (3-10%) towards the southern side of the project area.

The total project area (same as the tenement (M 47/206) area) is approximately 900 ha. Within the project area, the proposed disturbance area (data supplied by HPPL) is approximately 107 ha. Table 1 outlines the indicative footprint of each project component.

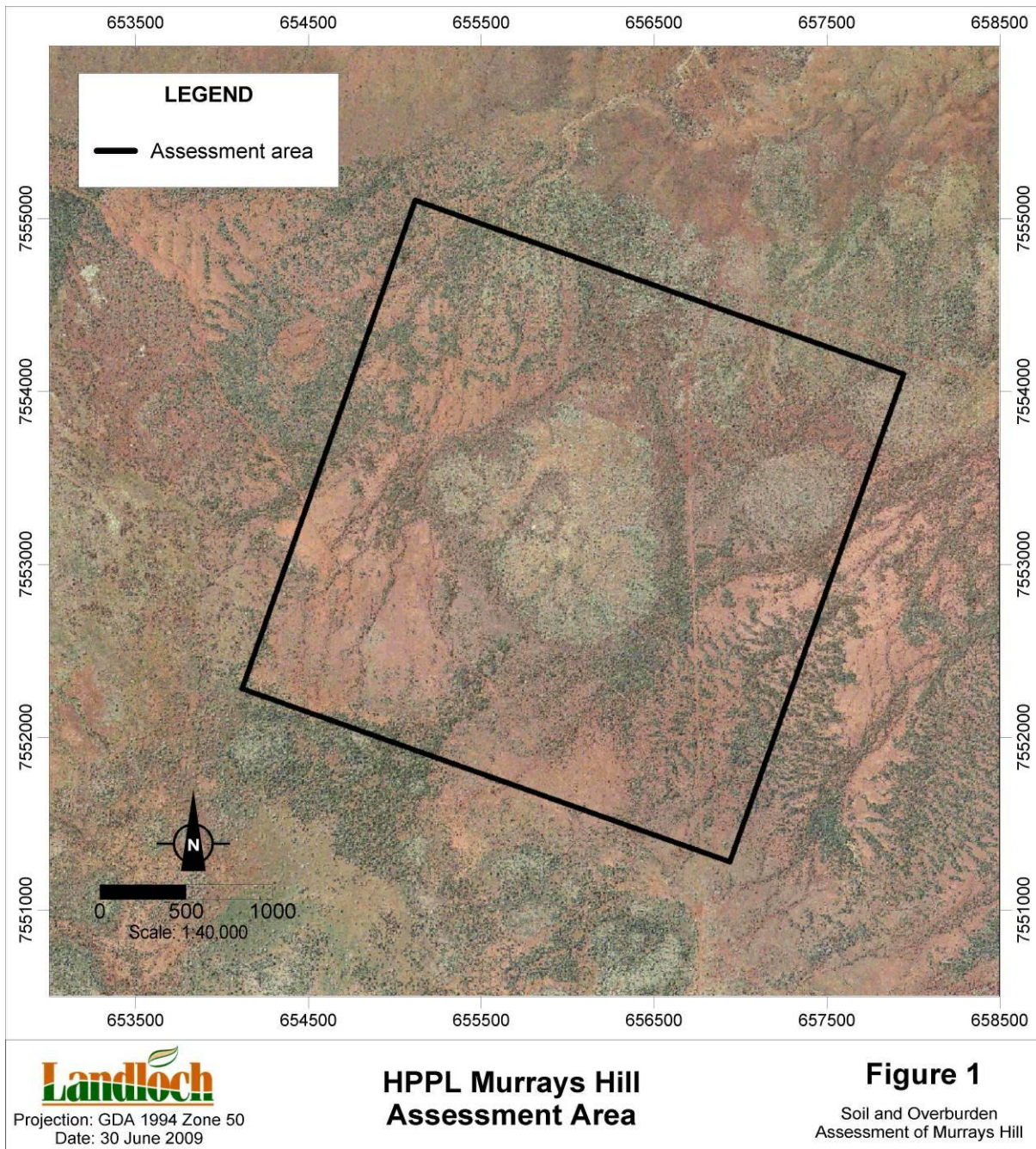


Figure 1: Extent of the soil and overburden assessment for the Murrays Hill Project.

Table 1: Project components and indicative footprints (data provided by HPPL).

Project Component	Indicative Footprint (ha)	Percent of Total Disturbance (%)
<i>Open pit</i>		
<i>Administration/workshop facilities</i>		
<i>Vegetation stockpile</i>	No provision yet made	No provision yet made
<i>Topsoil/subsoil stockpile</i>	No provision yet made	No provision yet made
<i>Waste dump</i>		
<i>Access and haul roads</i>		

Mining activities will disturb soils. The major potential impacts due to this disturbance include:

- Mixing of topsoil with subsoils where subsoil exist;
- Placement of erodible materials near the surface of constructed landforms;
- Reduction in soil seed bank;
- Reduction in plant available water capacity;
- Soil structural changes; and
- Loss of nutrients from topsoils.

Therefore, proper management of the soil resource is required to increase the potential for successful rehabilitation of disturbed land.

1.3. Assessment objectives

The objectives of the soil and overburden assessment are to:

- Describe the existing geological and geomorphic conditions of the project area using existing data.
- Characterise the soils within the project area.
- Assess the impacts of the proposed project on soil and landform.
- Identify measures to avoid, minimise, or mitigate adverse impacts upon soils and landform.
- Characterise the overburden materials that will be generated.
- Inform the design and rehabilitation of the waste rock dump based on characterisation of soils and overburdens.
- Recommend a research and monitoring programs to inform the management of soils and landforms.

2. ASSESSMENT REQUIREMENTS

Soils in the project area and in particular, those soils within planned disturbance areas will be stripped and most likely stockpiled for use during rehabilitation activities, and will be the main source of growth media materials used for rehabilitating the waste rock dump, roads, and infrastructure areas. Disturbance to soil can:

- Detrimentially impact on soil structure.
- Decrease plant growth potential.
- Result in placement of unsuitable materials nearer the surface.
- Increase potential for erosion and sediment movement.

The Western Australian Department of Mining and Petroleum (DMP), formerly the Department of Industry and Resources (DoIR) requires an assessment of soils that are the subject of a mining proposal. Analysis of both topsoil and subsoil layers is required and should “*identify possible adverse parameters such as low or high pH, high salinity, nutrient/trace element deficiencies, poorly structured soils, dispersive or sodic soils and potentially hazardous compounds*” (DoIR, 2006). Impacts of proposed mining activities on soil properties should also be considered. These impacts and their management should be outlined in a topsoil management plan and should outline:

- Topsoil and subsoil characteristics in relation to plant growth;
- Harvestable topsoil and subsoil volumes, stockpile dimensions, and location on mine site plans;
- Estimated volumes of topsoils and subsoils required for rehabilitation;
- Redeployment objectives;
- Harvest and preservation methodologies; and
- Proposed field trials relating to soil depth requirements, suitability for plant growth, and amendment and fertiliser requirements.

This report will (among other things) provide the data necessary for the development of a topsoil management plan for Murrays Hill.

2.1. Map scale and sampling intensity

Map scale is important and describes the detail of mapping and the likely precision and accuracy of a map. More detailed maps require more intense sampling. The use of a map will determine both the required map scale and sampling intensity.

DMP gives no firm guidelines on the required scale of mapping, though it is assumed that a map should be detailed enough to enable its use in planning activities, including among other things:

- Soil stripping and stockpiling;
- Positioning waste dumps; and
- Locating roads and other infrastructure.

Map scale has a significant bearing on the sampling intensity. For example, 1:50,000 scale mapping requires approximately 1 sample site per 20 – 100 ha whereas 1:25,000 scale mapping requires four times as many sample sites. Guidance on the appropriateness of different mapping scales and associated sampling intensities is provided by McKenzie *et al.* (2008). Maps used for detailed project planning purposes should be performed at a cartographic scale of between 1:10,000 and 1:25,000. The Western Australian Department of Agriculture and Food recommends that for strategic planning of intensive land uses, mapping with cartographic scale between 1:10,000 and 1:50,000 would be suitable (Schoknecht *et al.*, 2004). The soil assessment of the project area was performed to ensure that a map scale larger than 1:40,000 was achieved. This represents mapping at a detailed level, useful for site scale project planning.

3. AVAILABLE DATA SOURCES

3.1. Soil assessment

The following data were supplied by HPPL and were used in conjunction with data collected in the field to delineate soil boundaries:

- Aerial imagery,
- Contour data,
- Vegetation survey, and
- Geology mapping.

HPPL also supplied all information relating to tenure boundaries. At the time of the assessment, the location of disturbance areas was unknown. Therefore, assessment of soils for the project was performed independently of disturbance area.

Van Vreeswyk *et al.* (2004) provide a regional inventory and descriptive reference of the land resources of 181,723 km² of the Pilbara region of Western Australia in which Murrays Hill is situated. Large scale land systems mapping from this report provides broad information on landform, soils, vegetation, and drainage patterns. Their study was too broad, however, to provide adequate information on soils in the project area, and a more detailed study was required. Two land systems are identified within the project area – Jamindie and Newman. These land systems are discussed below. Fuller descriptions of these land systems found in Van Vreeswyk *et al.* (2004) can be found in Appendix A.

Local geology of the project area and surrounds has been provided by HPPL. Hematite goethite; shales; chert and jaspilite; and scree have been identified within the elevated, steeper areas of the project area. Lower lying areas with low gradients

(south and west of Murrays Hill) are dominated by colluvium. Land of greater relief in the north east of the project area is underlain by chert. Local geology mapping used in this assessment (supplied by HPPL) is provided in Appendix B.

Vegetation mapping of Murrays Hill was also used in determining soil boundaries. Differences in vegetation in the region are due largely to differences in soil depth and soil water holding capacity. Vegetation mapping used in this assessment (supplied by HPPL) is provided in Appendix C.

3.2. Overburden assessment

Classification and locations of various overburden materials was sourced from HPPL's drilling database. For this project overburden materials were defined as materials that will be disturbed during mining, but that do not represent a mineable resource or soil. Therefore, low grade ore materials were not assessed.

4. SOIL ASSESSMENT APPROACH

4.1. Prior to field assessment

Prior to completing the field-based assessment, the landscape and landforms of Murrays Hill was assessed using:

- (a) Existing land systems mapping;
- (b) Aerial imagery;
- (c) Contour information;
- (d) Vegetation mapping; and
- (e) Local geology mapping.

These data provided a broad understanding of the landscape and some understanding of the soil types likely to be found in the project area. These data also assisted in the selection of suitable soil inspection sites. Other factors considered when selecting the soil inspection sites included:

- 1) Required map scale – no less than 1:40,000.
- 2) Ease of access (soil inspection sites were located adjacent to access tracks where possible).

4.2. Field assessment

Soils were inspected and described in detail at 24 sites within and adjacent to the project. Sample sites were selected based on the assessment carried out prior to the field-based assessment.

Soils within the project area were inspected in detail from:

- a 10 cm diameter hand operated soil auger;
- existing soil pits constructed by HPPL as part of previous geology investigations; or
- exposed soil cuttings.

The land surrounding each inspection site was described in terms of the:

- location (GPS coordinates);
- approximate height above mean sea level (using hand-held GPS);
- land gradient (using supplied contour data);
- aspect;
- existing land disturbance (i.e. cleared land, grazed land, etc);
- presence of erosion and its severity;
- abundance, size, shape, and lithology of surface coarse fragments;
- presence of rock outcrops;
- soil surface condition (soft, loose, hard setting etc); and
- relative position in the landscape (relief).

The soil profiles at each inspection site were typically separated into the following depths:

- a) 0-10 cm,
- b) 10-30 cm, and
- c) 30-60 cm.

Not all sites were observed to the same depth. The depth observed was often limited by the presence to significant amounts of coarse fragments (auger refusal). Where soil was observed from existing pits and cuttings, deeper soil profiles were observed. Each soil depth was further described in terms of:

- texture;
- abundance, size, shape, and lithology of coarse fragments;
- structure;
- pedality and ped size;
- strength;
- water repellence;
- field pH;
- field salinity (EC);
- presence of roots;
- indicative permeability; and
- drainage.

Soils and landscapes were described using the terminology of The Third Edition of the Australian Soil and Land Survey Field Handbook (National Committee on Soil Terrain, 2009). Colour names used are those of the Munsell Soil Color Charts (2000). Field pH and salinity was measured using a hand-held meter in a 1:5 soil:water solution.

4.3. Soil analyses

Soil samples from 5 inspection sites (of the 24) were sent to a commercial soils laboratory (SGS Agritech) for chemical characterisation and the generated data used in the mapping of soils, the assessment of risks to soil quality posed by mining, and the development of rehabilitation methodologies to mitigate these risks. These sites were representative of the different soils and landscapes present within the project area. Characterisation of physical properties was performed by Landloch Pty Ltd. Twelve soil samples (from the 5 sites) were analysed in total, consisting of 5 topsoil and 7 subsoil samples. In this report (and from a practical perspective), topsoils are defined as soils in the surface 0.1 m, and subsoils are soils below 0.1 m.

Figure 2 shows the locations of the inspection sites and the sites from which samples were taken for chemical and physical analysis. Sites marked in blue were inspected during the field assessment. All soil samples were analysed for salinity and pH (as well as other observations) in the field. Sites marked in red were inspected in the same way. However, in addition, samples taken for chemical and physical analysis by a commercial soils laboratory. The following analyses were conducted on these soil samples (in addition to attributes measured in the field):

- Soil pH;
- Soil salinity ($EC_{1:5}$);
- Exchangeable cations (Ca^{2+} , Mg^{2+} , Na^+ and K^+);
- Cation Exchange Capacity (CEC);
- Exchangeable Sodium Percentage (ESP);
- Total P;
- Total N;
- Available P;
- Available K;
- Trace elements (Cu, Fe, Mn, Zn); and
- Emerson dispersion index.

Table 2 lists analyses performed and the reference for the test methods used.

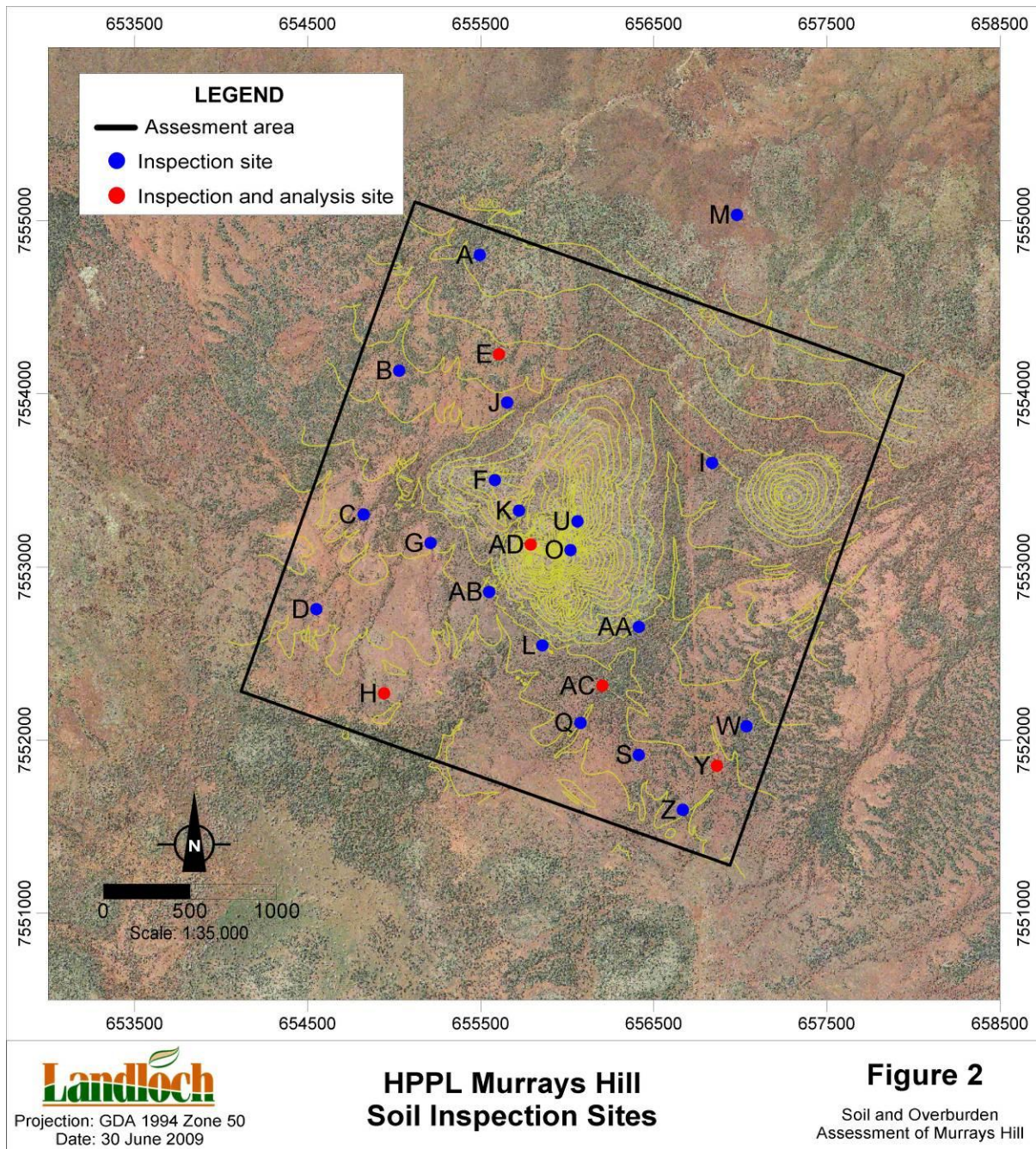


Figure 2: Soil inspection and analysis sites.

Table 2: Analysis methods used on soils in the project area.

Analysis	Method
pH, EC, Exchangeable cations, Total P, Total N, Available P, Available K, Trace elements.	Rayment & Higginson (1992)
CEC	Sum of exchangeable cations (Ca ²⁺ , Mg ²⁺ , K ⁺ , Na ⁺)
ESP	Ratio of exchangeable sodium cations and CEC
Emerson Index	Standards Association of Australia (AS1289.3.8.1)

4.3.1. Suitability of guideline requirements

DMP provides guidance on the minimum set of soil parameters that should be measured as part of the development of mining proposals (DoIR, 2006). This set includes:

- Soil pH;
- Soil salinity (EC_{1:5});
- Particle size distribution;
- Slake;
- Total P;
- Total N;
- Available P;
- Nitrate N; and
- Trace elements (Cu, Fe, Mn, Zn).

The parameters specified by DMP to be measured are – broadly – consistent with normal assessments of soil quality and cover most of the major soil properties affecting plant growth. However, some modifications to the parameter set were made.

Assessment of soil nitrate N (NO₃⁻) was not conducted in this assessment. Measurement of NO₃⁻ is often not helpful, as nitrate levels vary greatly through time depending on recent rainfall patterns and microbial activity. For rangelands soils, assessing soil fertility and development of fertiliser recommendations typically considers Total N rather than NO₃⁻. Hence Total N levels were assessed.

Measurement of available K is not specified by DMP, but is also important, as it is a macronutrient required for satisfactory plant growth. Available K are rarely limiting in Australian soils, however, it was included in this assessment.

While assessment of soil structure and stability is required by the guidelines, DMP provides no guidance on specific soil properties they consider necessary, apart from measurement of soil slaking. Soil properties that indicate soil structure and stability include exchangeable cations (Ca²⁺, Mg²⁺, K⁺, and Na⁺), Cation Exchange Capacity (CEC), and Exchangeable Sodium Percentage (ESP). Measurement of CEC is also used to gain an understanding of clay mineralogy, important when considering

erosion and fertility issues. Therefore, these properties were included in the assessment.

DMP guidelines list slaking as a suitable measure of soil stability. Slaking is the breakdown of large aggregates into smaller aggregates on wetting. It is caused when air trapped in the aggregates explodes, bursting the aggregate apart. Measuring slake indicates the stability of aggregates when rapidly submerged, but does not indicate whether a soil is potentially dispersive (as required by the guidelines). Dispersion is the separation of soils into individual particles, and the degree to which a soil disperses is largely governed by complex interactions between soil texture, soil salinity, and exchangeable cations. These interactions are soil specific, and no general rule can be applied with confidence. To deal with the complexities of soil dispersion, the Emerson Index (AS1289.3.8.1) is often used in conjunction with clay content and soil salinity. It involves placing soil aggregates into deionised water and visually assessing whether clay dispersion has occurred. The Emerson test cannot be performed on soils with clay contents too low to facilitate particle aggregation. Soils at Murrays Hill do contain sufficient clay for issues of dispersion to require consideration. Emerson was only performed on soils with ESP values >6%.

Soil texture was measured as a surrogate for particle size distribution as it:

- is equally informative for the purpose of assessing a soil's suitability as a growth medium for use in minesite rehabilitation,
- can be performed quickly in the field, and
- is cheaper than the measurement of particle size distribution.

The DMP guidelines do not specify "acceptable" levels of the various parameters, which is a sensible omission. The range of environments and plant communities impacted by mining in WA is enormous, and soil properties that would be detrimental to plant growth in one area may be quite acceptable at a different location.

4.3.2. Soils mapping

Soils associations rather than individual soils were mapped. Soil associations represent a number of soils that have been grouped based on appropriate soil properties. Procedures employed to develop the soil associations map largely followed those outlined by McKenzie *et al.* (2008).

5. OVERBURDEN ASSESSMENT APPROACH

5.1. Overburden materials

For the purposes of this characterisation, overburden was assumed to be all material positioned above the ore, but below the surface 2 m (arbitrarily classed as soil). Overburden materials have been categorised by HPPL into 2 broad classes – alluvials, and detritals. These materials are typically situated above the ore, and

represent the overburden materials that will be mined and placed into surface waste landforms. While not listed in the drilling database, calcrete is also located within the mineralisation zone and was sampled. The following materials were sampled as part of the overburden assessment (HPPL drilling database codes in brackets):

- 1) Alluvial materials (ALU),
- 2) Detrital materials (GZ), and
- 3) Calcrete (CC).

5.2. Sample selection

Samples of the overburden materials were sourced from RC drilling material. A total of 27 samples were taken across the project. Table 3 lists the materials sampled. Subsequent to selecting the overburden materials for sampling, changes were made to the conceptual pit outline and as a result, several of the sampled overburden materials lie outside the current pit outline. Of the 27 materials samples, 13 remain inside or close to the revised pit outline. Data from these 13 materials will be presented in this report. A full listing of overburden characterisation data is provided in Appendix D. Results of analyses performed on the 14 omitted samples were not significantly different to the 13 materials sampled inside or close to the revised pit outline.

Table 3: Overburden materials sampled and the number of samples taken within each broad overburden class.

Overburden class	No. of samples inside or close to pit outline	Total no. of samples analysed
Alluvial materials (ALU)	2	4
Detrital materials (GZ)	10	19
Calcrete (CC)	1	4

More detrital materials were sampled as – based on their classification within the HPPL drilling database – the detrital materials are more variable in their properties. As samples were sourced from RC drilling materials, sampling locations were constrained by the:

- 1) Location of RC drilling holes, and
- 2) Availability of enough physical sample from the RC drilling holes.

An overburden sample list was generated by Landloch Pty Ltd. The sample list was used by HPPL to source the required samples and supply them to Landloch Pty Ltd for analysis. Figure 3 shows the sample locations of the overburden materials. The conceptual put outline is shown in white. Further information regarding the sample location – drill hole ID, “down-hole” depth, and GPS coordinates of the drill hole collar – can be found in Appendix D.

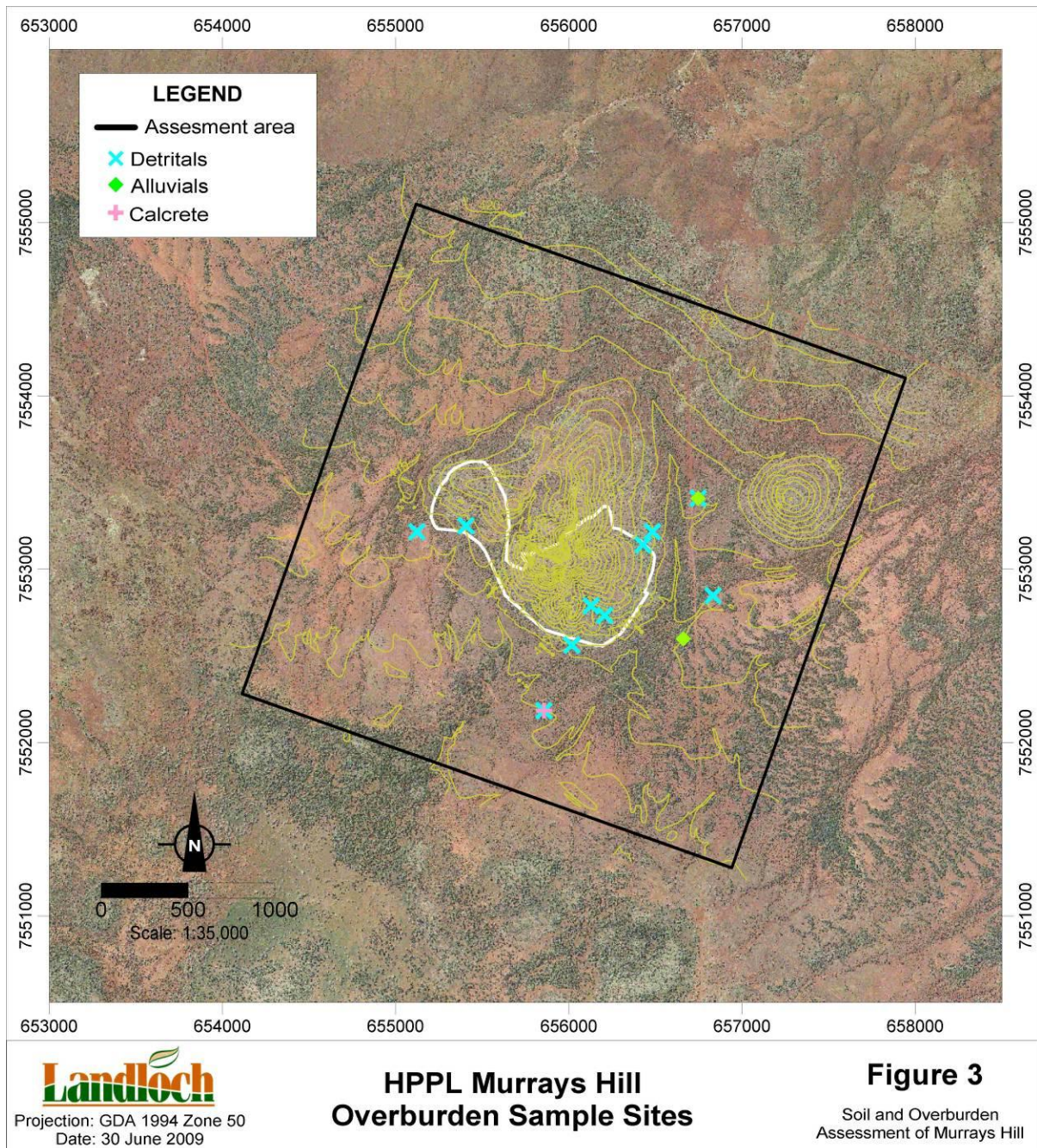


Figure 3: Overburden sample locations.

5.3. Required overburden analyses

DMP guidelines (DoIR, 2006) state that, “the mining proposal should clearly outline methods to manage and rehabilitate waste rock and tailings. Management strategies should be based on material characteristics, encapsulation of hostile materials, designing for long term stability, visual amenity (aesthetic revegetated landforms) and the integration of final outcomes (closure planning) into daily mining operations”.

Characterisation of overburden materials is necessary to meet these requirements. Characterisation of overburden often considers nothing more than the potential for acid drainage, and fails to consider other factors of similar or arguable more critical significance. These factors include salinity and pH levels, material stability (dispersion potential), and the competence of waste rock (tendency to weather). Construction of a waste dump using unstable materials will guarantee unsuccessful rehabilitation. Further, where hostile materials are encapsulated with unstable materials, failure to consider material properties can lead to:

- 1) inappropriate placement of the hostile materials in the waste landform,
- 2) use of inappropriate encapsulation materials, and
- 3) eventual exposure of the hostile materials, and adverse impacts on the surrounding environment.

DMP provides no guidance on the parameters that should be measured for overburden materials. However, given that salinity, pH and stability are of critical importance, overburden samples were analysed for:

- pH;
- Salinity (EC);
- Exchangeable cations (Ca^{2+} , Mg^{2+} , Na^{+} and K^{+});
- Cation Exchange Capacity (CEC); and
- Exchangeable Sodium Percentage (ESP).

The methods by which the data were determined are the same as those for soils (Table 2). Issues of acid mine drainage are not considered in this report.

6. LANDFORM AND SOIL MORPHOLOGY

6.1. Land systems overview

Van Vreeswyk *et al.* (2004) completed a resource condition survey of the Pilbara region. The survey covers a 181,723 km² (9,471,300 ha) area, which extends from 19°30' S in the north to 24° S in the south, and 115° E in the west to 121°30' E in the east (Figure 4). The lands surrounding the project area are largely used for pastoral purposes, predominantly cattle grazing.

Temporal climate variability in the vicinity of the project area is very high (Figure 5). The area is typified by monsoonal weather patterns, with mean annual rainfall of approximately 460 mm (Wittenoom data). The majority (~73% of annual rainfall on average) of the rain falls between December and March inclusive. The remainder of the year is dry and hot, particularly in the summer months. Mean annual pan evaporation is approximately 3,000 mm. Historically, the region has experienced cyclones, with cyclone John in 1999 tracking just north of the site (Van Vreeswyk *et al.*, 2004).

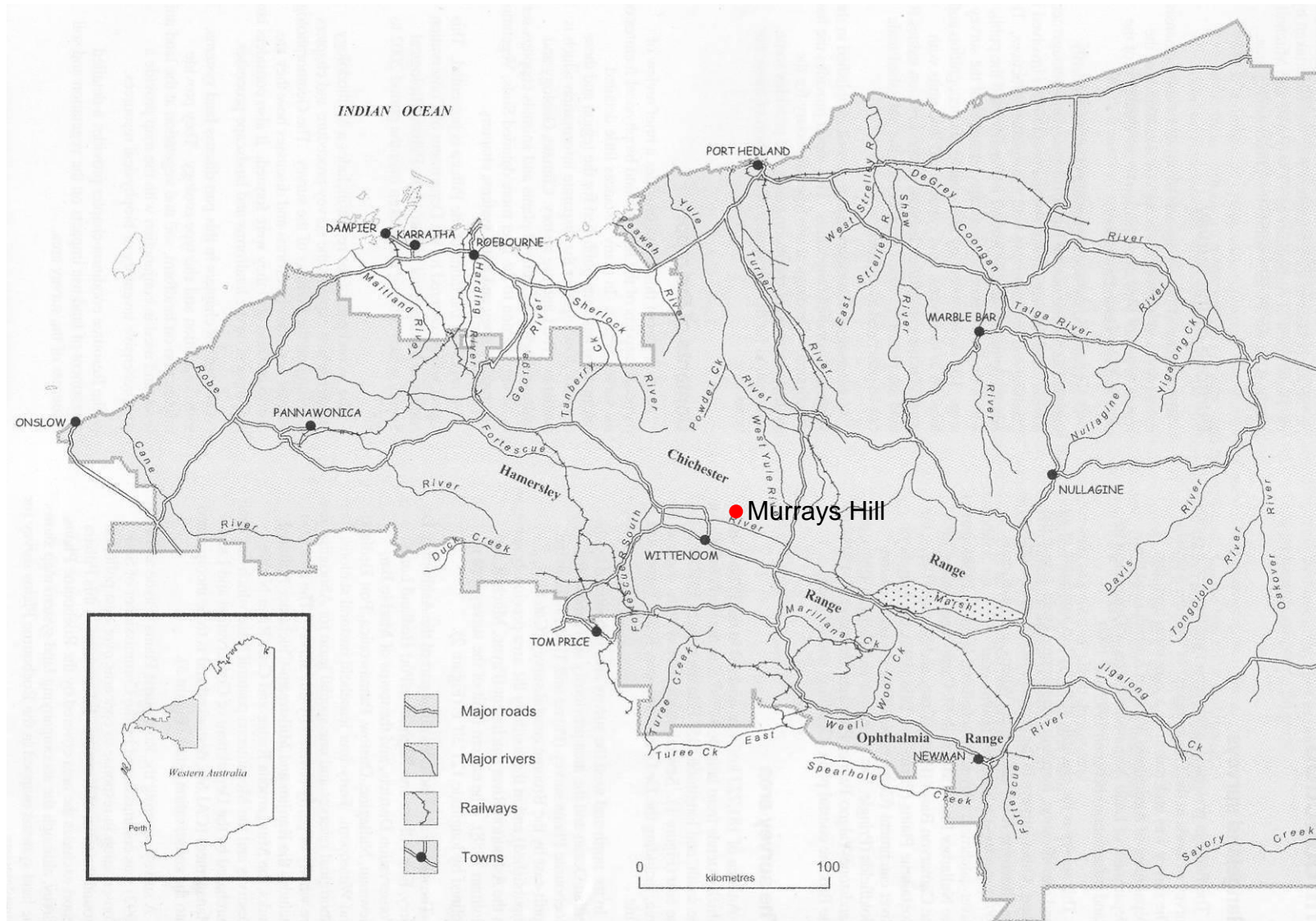


Figure 4: Extent of the Pilbara survey area and approximate location of Murrays Hill (from Van Vreeswyk et al., 2004).

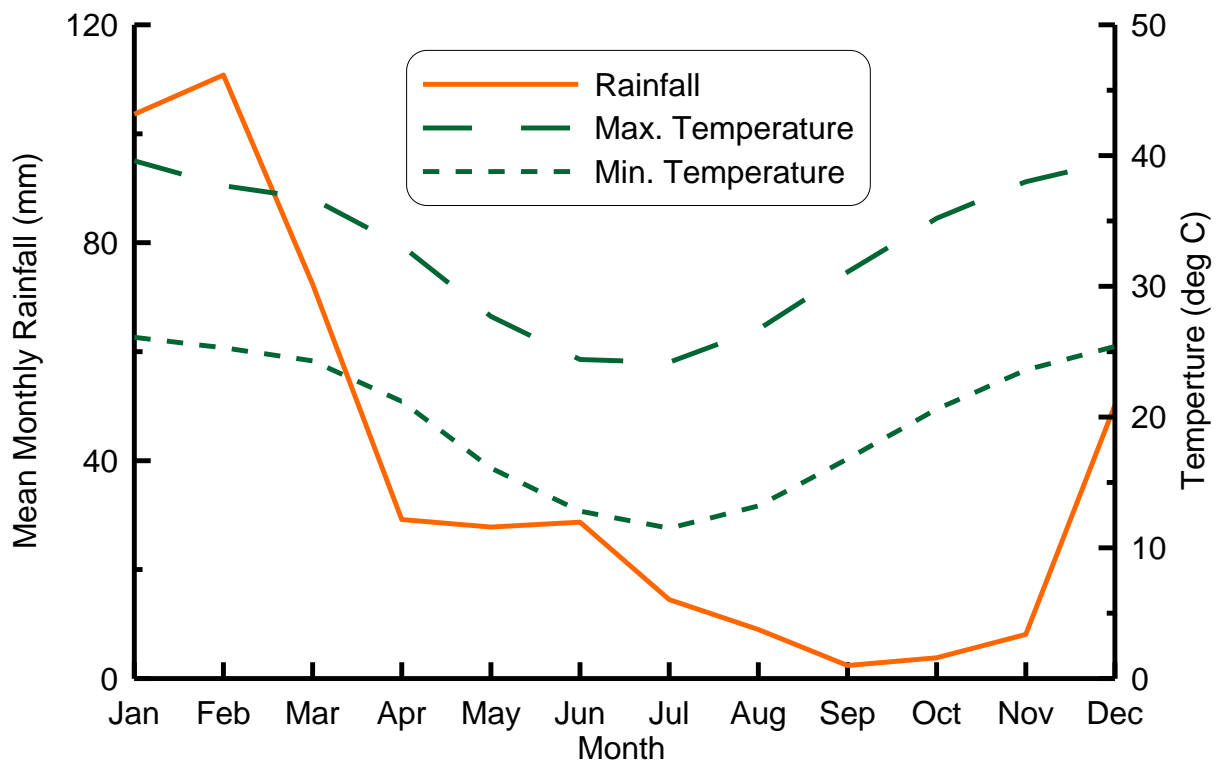


Figure 5: Mean monthly rainfall and maximum and minimum temperatures for the Murrays Hill region (Wittenoom data).

Within the survey area, 102 separate land systems have been mapped. Of the 102 land systems in total, 2 land systems occur within the project area – Jamindie and Newman. These land systems are not uncommon within the survey area, though Newman is much more common than Jamindie. The boundary between these land systems is closely associated with the changing relief and rock content, with:

- a) Newman occurring on areas with higher relief than Jamindie; and
- b) Newman containing shallower, rocky soils and significant rock outcropping.

The Newman land system is typically gently to moderately inclined (3-30%) whereas the Jamindie system is level or very gently inclined with gradients less than 3%.

6.1.1. Jamindie land system

The Jamindie land system covers 81 % of the Murrays Hill project area. Table 4 summaries the characteristics of the land system.

The Jamindie land system is common in the central south and east of the Pilbara survey area (Van Vreeswyk *et al.*, 2004). It is common within the vicinity of Murrays Hill. Condition of perennial vegetation on this land system is typically good to fair. However, it is estimated that approximately 27% of the land systems does contain poor or very poor vegetation. Degraded vegetation is associated with grazed lands.

Further, areas of poor vegetation are associated with increased soil erosion. However, the rocky nature of the soils provides increased resistance to erosion. The Jamindie land system can be considered to be in fair condition with moderate pastoral potential (Van Vreeswyk *et al.*, 2004).

Table 4: Characteristics of the Jamindie land system.

Characteristic	Jamindie Land System
<i>Occurrence in survey area</i>	207,423 ha. Equivalent to 1.1 % of land system survey area.
<i>Occurrence in Murrays Hill project area</i>	728 ha. Equivalent to 0.4 % of the Jamindie land system within survey area. 81 % of the project area lies within the Jamindie land system.
<i>Geology</i>	Partly cemented Quaternary colluviums, alluvium and laterite; minor sedimentary rocks of Proterozoic age.
<i>Geomorphology</i>	Depositional surfaces; non-saline plains with hardpan at shallow depth and groved vegetation, stony upper plains and low rises on hardpan or rock, very widely spaced tributary drainage tracts and channels; minor stony gilgai plains, sandy banks and low ridges and hills. Relief up to 30 m.
<i>Typical soils</i>	Stony soils; red-brown shallow loams
<i>Land management</i>	Most vegetation is only moderately preferred by grazing animals but can become degraded by overgrazing.
<i>Area mapped as severely degraded</i>	0.93%

6.1.2. Newman land system

The Newman land system covers the remaining 19% of the project area. Table 5 summaries the characteristics of this land system. It is widely spread across the southern Pilbara survey area and is common within the vicinity of Murrays Hill. Condition of perennial vegetation on this land system is typically very good to good. The improved condition of vegetation in this land system compared to Jamindie is related to the inaccessibility of the land to stock. Only 1% land system contains poor or very poor vegetation. The Newman land system can be considered to be in good condition, but has very low pastoral potential.

The two land systems often contain similar soil types. However, soils in the Jamindie system are likely to be deeper than those in the Newman system. The Jamindie system contains depositional surfaces while the Newman system contain erosional surfaces

Table 5: Characteristics of the Newman land system.

Property	Waguin Land System
<i>Occurrence in survey area</i>	1,457,984 ha. Equivalent to 8.0 % of land system survey area.
<i>Occurrence in Murrays Hill project area</i>	172 ha. Equivalent to 0.01 % of the Newman land system within survey area. 19 % of the project area lies within the Newman land system.
<i>Geology</i>	Lower Proterozoic jaspilite, chert, siltstone, shale, dolomite, and minor acid volcanics.
<i>Geomorphology</i>	Erosional surfaces; plateaux and mountains – extensive high plateaux, mountains and strike ridges with vertical escarpments and steep scree slopes and more gently inclined lower slopes; moderate spaced dendritic and rectangular tributary drainage patterns of narrow valleys and gorges with narrow drainage flors and channels. Relief up to 450 m.
<i>Typical soils</i>	Stony soils; red shallow loams and some red shallow sands
<i>Land management</i>	Most of the system is inaccessible or poorly accessible and is unsuitable for pastoral purposes. Spinifex is the dominant vegetation and the system is burnt fairly frequently.
<i>Area mapped as severely degraded</i>	Nil

7. SOIL ASSOCIATIONS OF MURRAY'S HILL

Two soil associations were described within the project area. Figure 6 shows the distribution of these soils. For the purposes of this report, each soil association has been given the following description:

- 1) Upland soils.
- 2) Lowland soils.

Properties of these soil associations are summarised in Tables 6 and 7. Complete listings of field measurements taken from each inspection site are given in Appendix E. Photos of each soil association are provided (Figures 7-11).

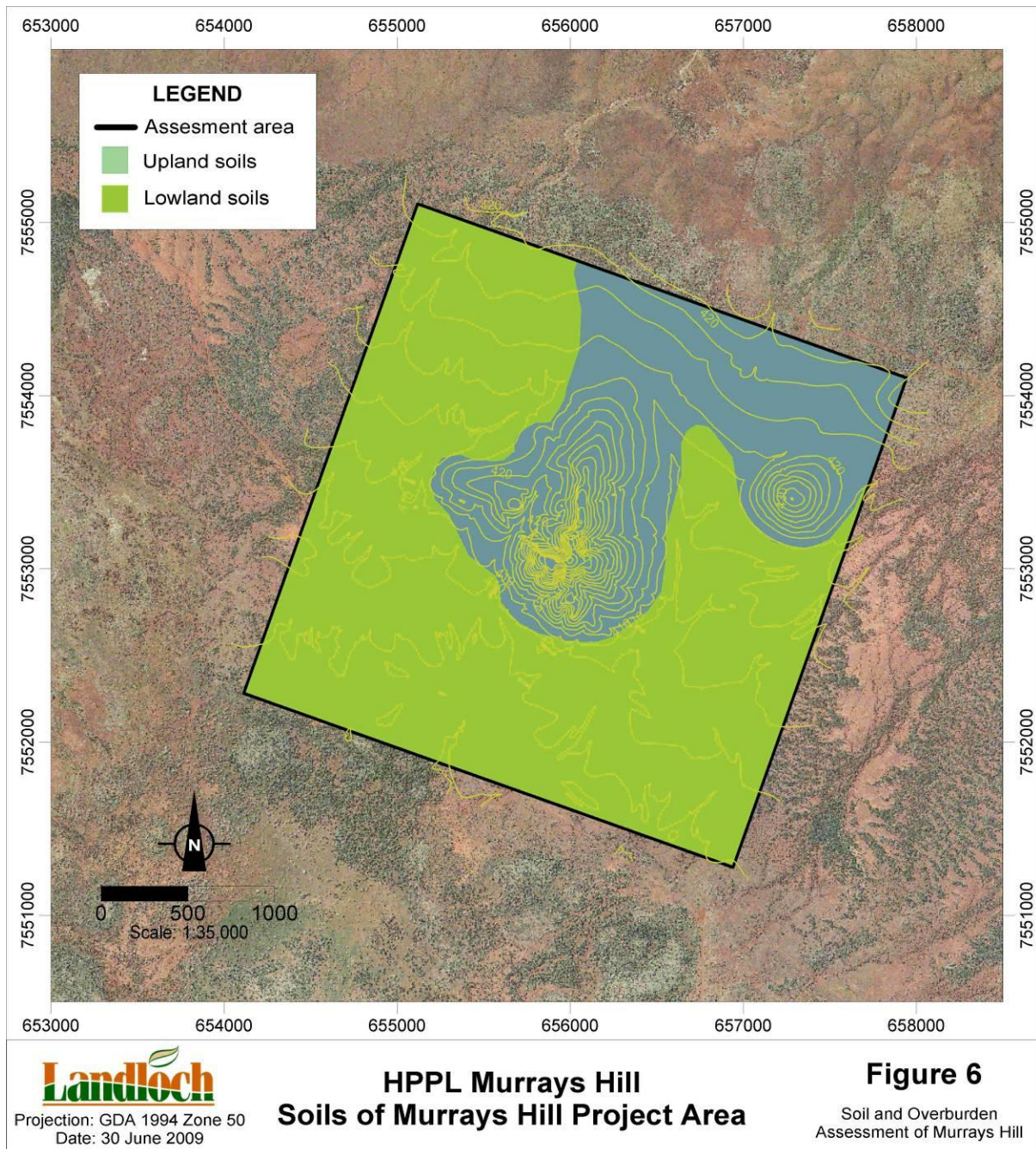


Figure 6: Soils of Murrays Hill project area.

Table 6: Characteristics of upland soils.

Property	Typical Inspection Site Description
<i>Brief Description</i>	Upland soils. Soils on upper slopes and crests of hills; land with RL > ~414 m or relief < ~10 m.
<i>Inspection/Observation Sites</i>	F, K, M, O, U, AD
<i>Gradient</i>	5-30 %
<i>Soil Classification</i>	Rock Outcrop with little or no soil, Ferric Clastic Rudosol
<i>Surface Coarse Fragments</i>	50-90% abundance, >90% at times 20-200mm diameter fragments. Rocky outcropping common on top of hills.
<i>Surface Condition</i>	Rocky, rock outcrop
<i>Permeability</i>	Moderately permeable, rock obstructs water infiltration
<i>Water Repellent</i>	No
<i>Drainage</i>	Moderately well-drained
<i>Plant Available Water Capacity</i>	Moderate, ~80 mm water per m depth of soil (factored down to account for rock)
Soil Depth (m)	Typical Soil Profile Description
0-0.1	Red clay loam; moderate peds 10-20 mm in size; 50%-90 6-20mm ironstone coarse fragments, at times >90% 20-60 mm; loose soil; field soil pH 6.0 – 7.5.
>0.1	Red clay loam; weak peds 5-10 mm in size; >90 20-60mm ironstone coarse fragments; loose soil; field soil pH 7.5; non-saline.



Figure 7: View from the uplands to the lowlands (in background).

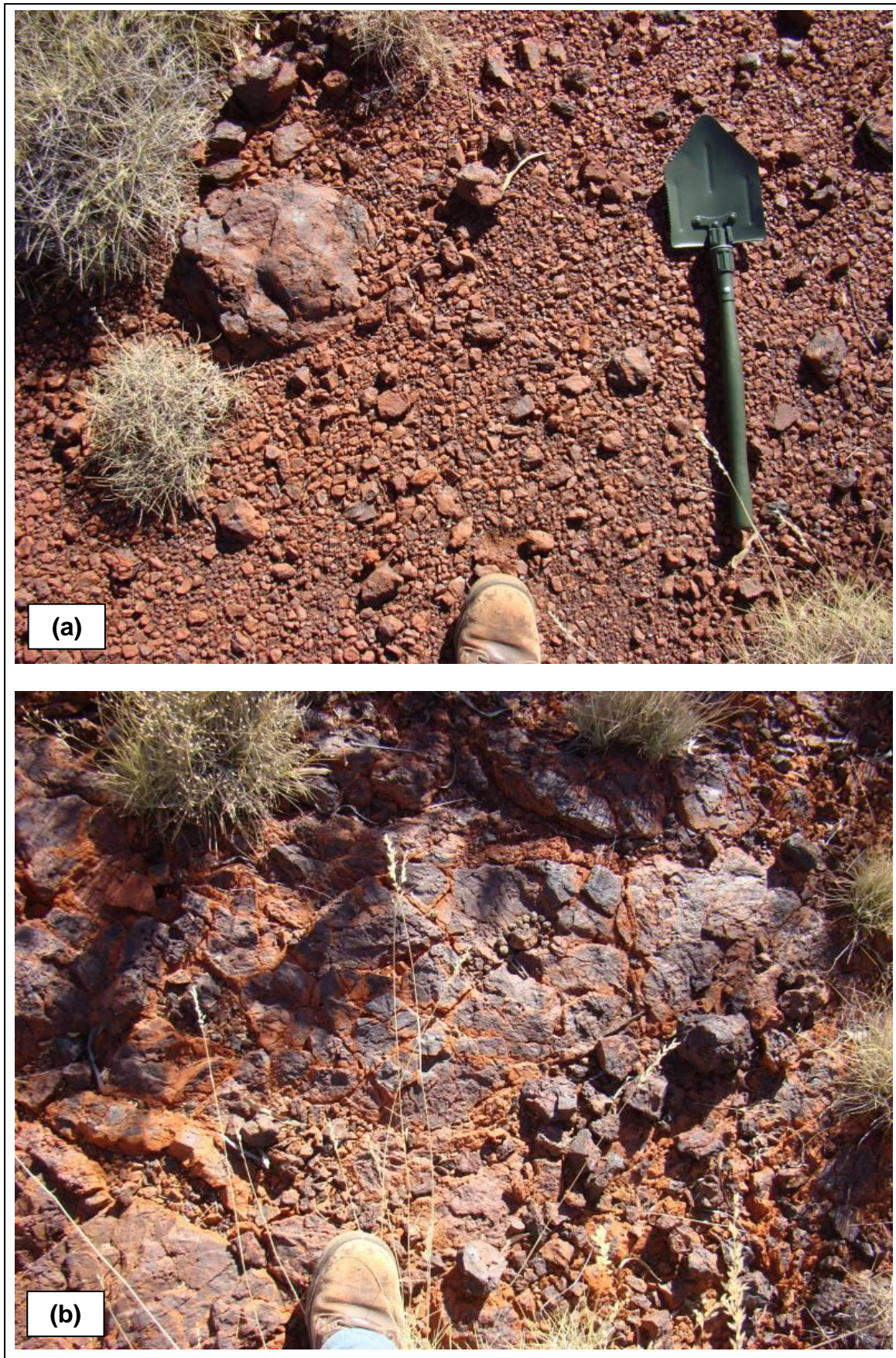


Figure 8: Surfaces of uplands soils are dominated by (a) coarse fragments and (b) rock outcropping.

Table 7: Characteristics of lowland soils.

Property	Site Description
Brief Description	Soils on lower slopes and plains; land with RL typically less than 410 m.
Inspection/Observation Sites	A, B, C, D, E, G, H, I, J, L, Q, S, W, Y, Z, AA, AB, AC
Gradient	<5 %
Soil Classification	Ferric Clastic Rudosol, Colluvic Clastic Rudosol
Surface Coarse Fragments	Typically 20-90% abundance, 6-20mm ironstone or colluvium. Can be less abundant in places (2-10%).
Surface Condition	Rocky, loose
Permeability	Moderately permeable
Water Repellent	No
Drainage	Moderately well-drained
Plant Available Water Capacity	Moderate, ~80 mm water per m depth of soil (factored down to account for rock)
Soil Depth (m)	Typical Soil Profile Description
0-0.1	Red clay loam; weak to moderate peds 10-20 mm in size; 20-50% 6-20mm ironstone coarse fragments, at times 2-10% 2-6 mm; loose soil; no water repellence; field soil pH 7.0 – 8.0; non-saline.
0.1-0.3	Red clay loam; weak to moderate peds 10-50 mm in size; 10-20% 6-20 mm coarse fragments, at times 20-50% 6-20 mm; loose soil; no water repellence; field soil pH 7.0 – 7.5; non-saline.
0.3-0.6	Red clay loam; weak to moderate peds 10-50 mm in size; 10-50% 6-20 mm coarse fragments; loose soil; no water repellence; field soil pH 7.5; non-saline.
>0.6	Red clay loam; weak to moderate peds 10-20 mm in size; 20-90% 10-60 mm coarse fragments; loose soil; no water repellence; field soil pH 7.5; non-saline.



Figure 9: Typical lowland landscape.



Figure 10: *Surfaces of lowland soils contain coarse fragments at various abundances.*



Figure 11: Coarse fragments exist throughout the profile of lowland soils.

7.1. General description

Soils inspected across the site have similar properties. Soil associations are largely differentiated based on soil depth and the presence of rock outcropping. Existing vegetation is also a useful indicator of soils, with Spinifex grasslands dominating the shallow soils with rock outcropping (upland soils). Deeper soils located in areas of lower relief (lowland soils) typically support open acacia woodlands or have sparse vegetation on open pan areas.

Soils in the project area are red in colour and are weakly to moderately pedal. These soils, once disturbed tend to form angular soil clods 10-50 mm in diameter. Soils with weak pedality will potentially become bulldust when disturbed. Soil texture is invariably clay loam. Clay loam soils typically have clay contents ranging from 30-35%.

Surface coarse fragments are common in both upland and lowland soils. Abundance of surface coarse fragments typically ranges from 50-90% with typical fragment sizes being 6-20 mm. Surface coarse fragments larger than 20 mm occur more frequently on upland soils. Land on top of Murrays Hill and with gradients greater than 30% is dominated by rock outcropping. Both upland and lowland soils contain significant proportions of coarse fragments within the profile. Abundance tends to be more variable in lowland soils.

Soil depth varies from very shallow (< 0.10 m) to deep (> 1.0 m). Shallower soils are typically found in upland soils, and lowland soils tend to be deeper. Soil depths greater than 3.0 m were observed in lowland soils (from existing pits dug by HPPL for exploration purposes).

Surface soils typically have neutral to mildly alkaline soil pH when measured in the field. One sample (K, an upland soil) had a moderately acid soil pH and two samples (B and J, both lowland soils) had moderately or strongly alkaline soil pH. Subsoil pH values measured in the field were similar to those measured for surface soils.

Soils are typically non-saline, though high salinity was measured at one site (H). This site is located in a depression area. The soils sampled at this site (from multiple depths through the profile) were moister than those sampled at other sites. It is not uncommon for depression areas to be moister and have higher salinity values, particularly in areas with high potential evaporation rates and moderate permeability. All soils except for those at the saline site had low ESP and are unlikely to contain a dispersive clay fraction.

Soils are moderately permeable and tend to be moderately well-drained with water movement being limiting by underlying rock. All soils are likely to have moderate plant available water holding capacity. Water repellence was not observed on any soils in the project area.

7.2. Soil properties

Samples were analysed from 5 sites within and adjacent to the project area. The locations of inspection sites from which samples were taken for analysis are shown in Figure 3. Analysis data for the soils of the project area are shown in Table 8.

7.2.1. Soil pH and electrical conductivity (EC)

Surface soils sampled were neutral to mildly alkaline, with pH similar at depth. These results from laboratory analyses correspond well with field measurements of soil pH (Appendix E). These soils support good to fair vegetation that appears well adapted to neutral to mildly alkaline pH soils. Some lowland soils support limited vegetation. However, these soils have similar properties to those that support good vegetation.

Soil salinity – as measured by EC of a 1:5 soil:water solution – is low for all soils sampled except for site H, a depression area. EC_{1:5} measured are unlikely to adversely impact on native vegetation species. It can be concluded that:

- (a) Soils within the project area have soil pH and salinity levels not likely to cause adverse impacts to vegetation; and
- (b) Soil pH and salinity does not change appreciably with soil depth.

Table 8: Typical characteristics of soils in the project area.

Property	Upland soils		Lowland soils		
Depth (m)	0 – 0.1	0.1-0.3	0-0.1	0.1-0.3	0.3-0.6
Soil pH (-)	7.3	7.3	7.2	7.1	7.5
EC _{1:5} (dS/m)	0.01	0.02	0.03 ¹	0.06	0.02
CEC (m.eq./100g)	3.6	4.4	6.9	7.6	10.2
Texture (-)	Clay loam	Clay loam	Clay loam	Clay loam	Clay loam
ESP (%)	1.7	1.8	1.5	1.0	0.8
Emerson Index	-	-	-	-	-
Total P (mg/kg)	173	193	355	398	513
Total N (mg/kg)	558	569	570	555	472
Available P (mg/kg)	5	4	16	9	15
Available K (mg/kg)	270	252	490	567	622
Trace Cu (mg/kg)	0.7	0.8	1.4	1.4	0.8
Trace Fe (mg/kg)	12	9	7	8	4
Trace Mn (mg/kg)	34	28	37	46	10
Trace Zn (mg/kg)	0.2	0.1	0.8	1.0	0.4

EC_{1:5} - Electrical conductivity; CEC - Cation Exchange Capacity; ESP - Exchangeable Sodium Percentage.

7.2.2. CEC, texture, clay mineralogy and ESP

The CEC of upland soils is very low, indicating that their capacity to hold exchangeable cations and nutrients will be low. This is consistent with the rudimentary development of soil profiles in upland areas. Lowland soils have higher CEC, though the value is still low. All soils in the project area have clay loam texture. Clay contents are likely to range from 30-35%. The ratio of CEC and clay content is an indicator of clay mineralogy. As a general guide to the ratios:

- 0.75-0.95 indicates that clay is largely smectite;
- 0.55-0.75 indicates mixed mineralogy with a significant proportion of smectite;
- 0.35-0.55 indicates mixed mineralogy;
- 0.2-0.35 indicates kaolinite and illite present; and
- <0.2 indicates dominantly kaolinite.

Soils typically have CEC:clay ratios less than 0.35². Therefore, it can be inferred that the clay fraction of soils in the project area is predominantly kaolinite. Kaolinite clays

¹ EC_{1:5} of one site (H) was high, and has been excluded from this table.

² The saline sample (H) had a CEC:clay ratio greater than 0.35. However, this value is impacted by the high salinity and cannot be used in estimation of clay mineralogy.

are highly weathered. They do not shrink and swell and are less prone to erosion than soil dominated by smectite clays. Additionally, the rocky nature of these materials is likely to result in elevated erosion resistance and reduced erosion potential.

ESP is an indicator of soil stability. Typically, soils with an ESP >6% are classed as sodic and potentially dispersive. Clay dispersion can lead to increased erosion, particularly where:

- water is concentrated over, or ponded above the dispersive material,
- where land gradient increases, or
- where vegetation is cleared.

All soils have low ESP except for soil H which is situated in a localised depression area. This sample is outside the disturbance area. Therefore, clay dispersion is unlikely to be of significant concern.

7.2.3. Chemical fertility

Data on soil chemical fertility (Table 8) show generally good fertility for the soils sampled. Total P, Total N, Available P, and Available K values are generally good and adequate for growth of native vegetation. Trace element deficiencies were not observed.

Vegetation clearing and topsoil stripping and handling will effectively remove existing biomass and restrict the soil's access to nutrients. For these reasons, successful and rapid re-establishment of vegetation will require proper management of topsoil resources. Poor topsoil management is likely to degrade topsoil quality.

8. OVERBURDEN PROPERTIES

Overburden properties of selected materials inside or near the current conceptual put outline are given in Table 9.

All materials have neutral to alkaline pH values and are non-saline. The range of pH and EC_{1:5} values measured are similar to that measured for the soils. The materials typically have higher ESP than the soils, with 3 detrital samples having ESP >6%. These materials contained less rocky fragments and had a finer texture to other samples. This indicates that these materials are likely to have an appreciable clay fraction, and should be considered potentially dispersive. One detrital sample was water repellent (hydrophobic).

The overburden materials sampled typically have properties that will not adversely impact on vegetation growth. When placed within a waste dump, it is unlikely that the overburden materials will restrict root growth. In fact, the overburden is likely to increase the volume of material from which vegetation can access water and nutrients. Sheeting of the overburden material with subsoil and topsoil materials is

recommended and is likely to be effective in the management of potentially dispersive (high ESP) overburdens. If material with high ESP was to be placed on the outside of the final landform (as may happen if sufficient soil reserves are not secured) these areas would certainly experience increased erosion rates, gullyng, and potentially tunnelling.

Table 9: Properties of selected overburden samples.

Sample ID	Drill Hole ID	pH (-)	EC _{1:5} (dS/m)	CEC (meq/100g)	ESP (%)	Comments
Detrital material						
501641	MD0231	7.2	0.03	7.9	2.4	
511893	MD0548	7.4	0.03	0.6	19.4	
512326	MD0563	7.0	0.09	19.0	6.3	
511850	MD0547	7.7	0.03	5.2	3.7	
512332	MD0563	7.8	0.05	5.3	4.7	
512411	MD0565	8.6	0.03	10.3	3.4	
510708	MD0508	7.6	0.02	2.0	3.0	
510776	MD0510	9.1	0.12	17.9	3.9	Hydrophobic
512492	MD0567	8.1	0.04	3.0	7.1	
513036	MD0583	7.1	0.04	6.1	2.8	
Alluvial material						
511841	MD0547	8.9	0.03	14.0	5.7	
511308	MD0527	7.4	0.03	6.0	3.3	
Calcrete						
511406	MD0530	9.0	0.08	18.0	2.5	

9. SOIL MANAGEMENT FOR REHABILITATION

9.1. Soil extent and estimated soil volumes

The majority of the disturbance will occur in the vicinity of the pit and waste dump. These areas represent the most useful sources of topsoil materials (and subsoil materials where subsoil disturbance occurs). Disturbance of the roads and the infrastructure areas are likely to yields small volumes of soil in comparison, particularly where only minimal levelling is required.

Table 10 lists the extent of each soil association within the pit and waste dump disturbance areas only. Also shown are the estimated usable depths and volumes of each soil association. Estimations do not consider changes in topography, and are likely to underestimate actual volumes of materials available.

Topsoil (the surface 0.1 m of soil) is biologically active and contains significant amounts of nutrients, seeds, and beneficial organisms. In fact, the biologically active layer is likely to be shallower than 0.1 m. However, stripping soil in layers thinner than 0.1 m is generally not possible with available machinery. All subsoils in the project area have similar properties and mixing and inversion of these layers is of little concern and unlikely to result in any adverse soil conditions.

Table 10: Extent, stripping depth, and estimated volume for each soil association.

Soil Type	Extent in project area (ha)	Extent in pit and waste dump area (ha)	Stripping depth (m)		Estimated volume available (x 1000 m ³)	
			Topsoil	Subsoil	Topsoil	Subsoil
<i>Upland soils</i>	300	85.5	0.1	0.2	85.5	171
<i>Lowland soils</i>	600	10.5	0.1	1.0	10.5	105

9.2. Soil management

Soil handling – stripping, stockpiling, and respreading – should be done with great care. Only those soils that need to be disturbed should be disturbed. Topsoils contain significant amounts of nutrients, seeds, and beneficial organisms. Reducing damage during handling can:

- minimise issues of compaction;
- reduce potential for material to turn to bulldust;
- reduce the loss of nutrients;
- reduce the loss of beneficial organisms; and
- greatly assist rehabilitation activities.

Currently, no provision has been made for stockpiling of topsoil or subsoils. It is likely that the materials removed from within the waste dump and pit outline will be stored in stockpiles. Provision of stockpiles is required.

9.2.1. Soil stripping principles

Soil stripping should be performed at a time of year when the soil seed bank is likely to be highest. This is likely to be in autumn, just after the wetter months, when daytime temperatures are still warm. To minimise the risk of handling soils when wet, soil stripping (or any soil handling for that matter) should be scheduled for dryer months, and should avoid the wetter summer months.

Soil should not be handled when wet, as this tends to increase compaction. The optimal moisture content for soil handling is soil dependent, though the rocky nature of the soils is likely to effectively limit compaction.

Inevitably, some degradation of soils will occur during stripping and other soil handling activities. However, different types of machinery cause different levels of degradation. The use of scrapers for soil stripping is not recommended. The *Mine Rehabilitation* handbook, that forms part of a series produced by the *Leading Practice Sustainable Development Program for the Mining Industry* (DITR, 2006) states that, "combined use of a front-end loader, truck and bulldozer for the removal, transport, and spreading of topsoil is the best combination to reduce compaction".

9.2.2. Soil stockpiling principles

Ideally, stockpiling soils should be avoided, and stripped soils should be directly respread to areas prepared for rehabilitation. However, this is not always achievable, and stockpiles are often constructed as part of mining operations.

Stockpiling soils for periods longer than 6-12 months can cause structural degradation (particularly of the soil at the bottom of the stockpile) and loss of biota (DITR, 2006). Loss of biota is especially significant for topsoil stockpiles. If soils are to be stockpiled for longer than 12 months, they should be actively fertilised and seeded to:

- reduce erosion risk;
- maintain and accumulate soil organic matter levels; and
- increase soil seed banks.

Given the generally adequate fertility of the soils, fertilisation is likely to be unnecessary. Species seeded should be fast growing, and ideally leguminous to provide nitrogen input to the soil. Nitrogen is likely to be most rapidly lost from disturbed soils.

Topsoil stockpiles should be no deeper than 1.0 m. Stockpiling topsoils deeper than 1.0 m tends to kill the topsoil seed bank and, to a lesser extent, will degrade the structure of the soil at the bottom of the stockpile (Keipert *et al.*, 2002). This will largely negate the properties of topsoil that are advantageous to rehabilitation activities. For best preservation of the seed bank and biota, the tops of the topsoil stockpiles should be very slightly domed (1-2% gradient), and ripped to maximise water entry and seed germination and reduce any compaction caused by the dozer. Slight doming of the top reduces the risk of waterlogging. Maximising water entry will make more water available to plants and minimise the risk of erosion and sediment movement from the stockpile.

Subsoils do not contain significant seed banks and, as a result, can be stockpiled deeper. However, to minimise the risk of significant soil compaction, subsoil stockpile depth should not exceed 4.0 m. Subsoils are rocky, and respreading is likely to remove compaction caused as a result of stockpiling to this depth. Stockpiling subsoil to this depth will also provide a clear delineation between the subsoil and topsoil stockpiles, reducing the risk that topsoils and subsoils will become confused. Similar to the topsoil stockpiles, subsoil stockpiles should be

slightly domed, and ripped to maximise water entry. Maximising water entry will minimise the risk of erosion and sediment movement from the stockpile.

Currently, no provision has been made for stockpiling topsoils or subsoils. Using figures from Table 10, it is estimated that 96,000 m³ of topsoil and 276,000 m³ of subsoil can be sourced from the waste dump and open pit components.³ Therefore, stockpiling all the available topsoil to a height of 1.0 m will require approximately 9.6 ha, while the available subsoil will require approximately 6.9 ha (assuming a 4.0 m deep stockpile). A total footprint of approximately 16.5 ha is required to store available topsoil and subsoil. Upland soils contain significant rock outcropping. This material will be highly desirable as a cover/stabilisation layer on waste dump batter slopes or other areas of high gradient. To maximise the usefulness of this material it should be stockpiled separately (its required footprint is included in the estimation of the topsoil stockpile footprint).

Clear signage should also be installed to ensure that topsoil remains separated from subsoils until it is used in future rehabilitation activities.

Soil stockpiles should be monitored for erosion (wind and water), and weed infestations. Control of weeds in stockpiled soil is likely to be more cost effective than controlling infestations once the soil is respread.

Materials disturbed by creation of roads and the infrastructure area should directly respread on other rehabilitation areas or stockpiled close to the disturbance areas for use during their rehabilitation. Therefore, stockpiles should be created and located near these disturbance areas. Their management will be the same as the management of the stockpile near the waste rock dump outlined below.

9.2.3. General resspreading practices

Many native species have maximum germination emergence depths shallower than 0.1 m. Therefore, application of topsoil deeper than 0.1 m is not likely to be greatly beneficial. Where topsoil volumes are limited, thin layers of topsoil overlying suitable depth of growth media are more beneficial to soil fertility and biota than application of no topsoil (DTIR, 2006).

No preliminary landform design for the waste dump or likely volumes of waste rock are available, and in the absence of these, only a broad understanding of the adequacy of the volumes of topsoil and subsoil available is possible. It is certain that the volume of topsoil located within the waste rock dump component will be insufficient to cover the final landform to a depth of 0.1 m. Topsoil from the pit area will be required.

Generally, as the height of waste dump or the batter gradient increases, the volume of topsoil and subsoil required also increases. To estimate the likely adequacy of the topsoil resource a waste rock dump with the following characteristics was assumed:

³ Changes in topography were not accounted for in this estimate. Estimated volumes used the planar areas of each soil type within the waste dump and open pit components and multiplied them by the stripping depths for the respective soil provided in Table 10.

- a) Rectangular footprint;
- b) 35.5 ha in size; and
- c) Linear batter gradient of 20 % (11.3°).

For the above waste dump with a height of 20 m, it is estimated that approximately 40,000 m³ of topsoil will be required. Assuming 0.3 m of subsoil is placed under the topsoil, approximately 120,000 m³ of subsoil would be needed. For a waste dump 40 m high, approximately 53,000 m³ of topsoil and 160,000 m³ of subsoil would be required.

A more accurate estimation of topsoil supplies should be undertaken as part of the landform design process. The landform design process should focus on determining the:

- Volume of waste rock;
- Maximum waste rock dump height that is stable to erosion; and
- Waste dump batter profiles that are stable and able to support a functional ecosystem.

Using the broad estimates of plant available water provided in Tables 6 and 7, soil (topsoil and subsoil) depths of approximately 0.3 m are likely to provide sufficient soil water holding capacity to hold rainfall events of approximately 25 mm or less, assuming the soil was dry prior to rain. The underlying overburden material is likely to also provide some water holding capacity.

Once soil has been respread and directly prior to seeding, the final topsoil surface should be lightly ripped on the contour. Reduced germination occurs on soils with consolidated surfaces. Large rip lines (>20 cm) should be avoided. Ripping on the contour is important, as poor control of contour ripping is often associated with initiation of rill and gully erosion.

9.3. Waste dump design and construction

All soils in the project area appear highly suitable for rehabilitation purposes, as their high content of rock will provide considerable erosion resistance and improve the capture of incident rainfall and reduce potential soil evaporative losses. Sheeting of the overburden materials with subsoil and topsoil will be required.

Typically, waste rock dumps have a flat top and sloping outer batter slopes. Beyond that, waste dump design has historically followed a prescriptive approach where material placement, dump heights, batter profiles, and batter gradients are determined with little regard for material properties. This approach has often resulted in rehabilitation failure. These failures are often more costly to fix than the original cost of rehabilitating the waste dump, and often result in:

- degradation of topsoil resources;

- failure to establish a sustainable ecosystem;
- the need for ongoing costly maintenance; and
- sub-optimal rehabilitation outcomes.

Soils form the basis of all functional ecosystems. Failure to fully appreciate and consider soil properties when designing landforms greatly increases the likelihood that other vital aspects of the ecosystem — vegetation and fauna — will fail to develop properly. Regulators are increasingly favouring approaches to landform design that can clearly demonstrate a link between final landform shape and measureable material properties.

Achievement of successful rehabilitation outcomes requires planning, and typically not only reduces environmental risk, but also minimises the actual cost of rehabilitation activities. Application of good soil science is fundamental to the development of waste dump designs with the highest probability of success.

Batter slope stability for this site will be largely governed by the presence of rock on the surface that is created, highlighting the need for rocky materials to be used in slope stabilisation and rehabilitation. Vegetation will provide some stabilisation, but its effects are often overstated. If batter slope heights or gradients greater than those currently present on natural slopes at Murrays Hill are planned, and assuming that similar rocky surfaces to those that naturally occur are also planned for the waste dump, it should be recognised that those designs are, effectively, increasing erosion potential above that to which the area is currently stable.

While erosion is not currently widespread on undisturbed soils, batter slopes with steeper gradients and constructed using disturbed materials are likely to be more erodible. Therefore, landform design must consider the erodibility and water infiltration characteristics of the materials used for rehabilitation.

Use of berms on the constructed waste dump is not recommended. Berms are costly to install, and a largely redundant on waste dump constructed using rocky materials. In fact, berms can increase slope instability by acting to concentrate runoff on the berms. This concentrated runoff is then discharged at a low point in the berm, causing rilling and gullying to occur (even in rocky materials).

9.4. Waste dump monitoring

Waste dump monitoring programmes must be consistent with site requirements. Otherwise, the data collected are likely to be of little value.

Often erosion monitoring is interpreted to mean erosion measurement, and there are certainly situations where the rate of erosion is of primary concern. There are also situations where trends in erosion rates are just as important as actual erosion rates. For example, knowing whether a gully is stabilising or becoming more active is often more important than the actual rate of erosion from the gully.

Erosion monitoring may include:

- Measurements of average erosion rates
- Measurements of gully/rill activity,
- Sediment concentration in runoff,
- Presence/absence of gullies.

Measurement of erosion trends (not withstanding any site requirements to the contrary), is likely to be more beneficial than measurement of actual erosion rates. Demonstration that erosion rates are not increasing or are trending downwards and that the frequency of rills and gullies is not increasing is likely to effectively demonstrate that the constructed landform is stable.

Monitoring of vegetation and fauna should also be performed. However, establishment of landscape stability is a prerequisite to any function ecosystem and monitoring of vegetation and fauna prior to establishment of a stable soil profile is likely to be of little value.

9.4.1. Measuring erosion trends

Indicators of erosion can be used to measure erosion trends rather than measuring actual erosion rates. One common system is the use of the soil stability indicators contained within the Landscape Function Analysis (LFA) system. The soil stability indicators essentially consider the erodibility of the soil surface, and enable temporal trends in erodibility to be assessed and compared with erodibility of natural surfaces on analogue sites.

10. RECOMMENDATIONS FOR RESEARCH

10.1. Landform design

Development of a preliminary waste dump design based on material erodibility and water infiltration characteristics is recommended. When soil erodibility, water infiltration, and the usefulness of all available resources are considered, the likelihood of successful rehabilitation is greatly increased. Preliminary waste dump designs can be developed through analysis of the materials to be used near the surface of the waste dump. Such designs allow:

- Investigation of the suitability of different materials for different rehabilitation activities i.e. placement of materials on batter slopes or dump tops.
- Estimation of the maximum possible stable waste dump height, based on erosion risk and potential off-site impacts.
- Estimation of the likely batter profiles that reduce erosion risk and potential off-site impacts.

- More accurate estimation of the required disturbance area. To do this, information on the volumes of waste material, likely stable batter profiles, and maximum possible waste dump height are required.
- Development of dump construction strategies that minimise cut and fill during rehabilitation activities. For dumps constructed in lifts, each lift can be offset appropriately so that bulk pushing is reduced. Construction of waste dumps in such a way that reduces bulk pushing can significantly reduce earthworks costs and speed up rehabilitation activities.

Further, knowledge of final landform shape can assist during mining, with the waste dump able to be constructed to the final design. Effectively, as new lifts are started, the toe of the upper lift can be set back from the crest of the lower lift so that reshaping of the dump for rehabilitation is largely a cut and fill exercise rather than needing significant bulk pushing. Loch and Lowe (2008), using an example square waste dump with a footprint of 20 ha, demonstrate that such an approach can reduce the cost of bulk pushing by approximately 35%.

Further cost savings can be achieved where careful consideration is given to the dump shape. Batter slopes are the most expensive part of a waste dump to rehabilitate. The top of a waste dump is relatively inexpensive in comparison. Therefore, a dump shape that minimises batter length will be less expensive to rehabilitate than a dump with a large batter length.

10.2. Water holding capacity

It is desirable that some investigations be carried out to clearly identify the importance of the water holding capacity of the “soil” profile that is created. Water holding capacity may be a greater limitation to vegetation growth than fertility. Knowledge of the importance of water holding capacity will enable construction of soil profiles that maximise vegetation growth. Consideration should be given to the degree to which overburden materials contribute to water holding capacity.

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APPENDIX A – DETAILED LAND SYSTEMS INFORMATION

(from Van Vreeswyk *et al.*, 2004)

JAMINDIE LAND SYSTEM (2,074 km², 1.1% of the survey area)

(modified from Wilcox and McKinnon 1972)

Stony hardpan plains and rises supporting groved mulga shrublands, occasionally with spinifex understorey.

Land type: 12

Geology: Partly cemented Quaternary colluvium, alluvium and laterite; minor sedimentary rocks of Proterozoic age.

Geomorphology: Depositional surfaces; non-saline plains with hardpan at shallow depth and groved vegetation. stony upper plains and low rises on hardpan or rock, very widely spaced tributary drainage tracts and channels; minor stony gilgai plains, sandy banks and low ridges and hills. Relief up to 30 m.

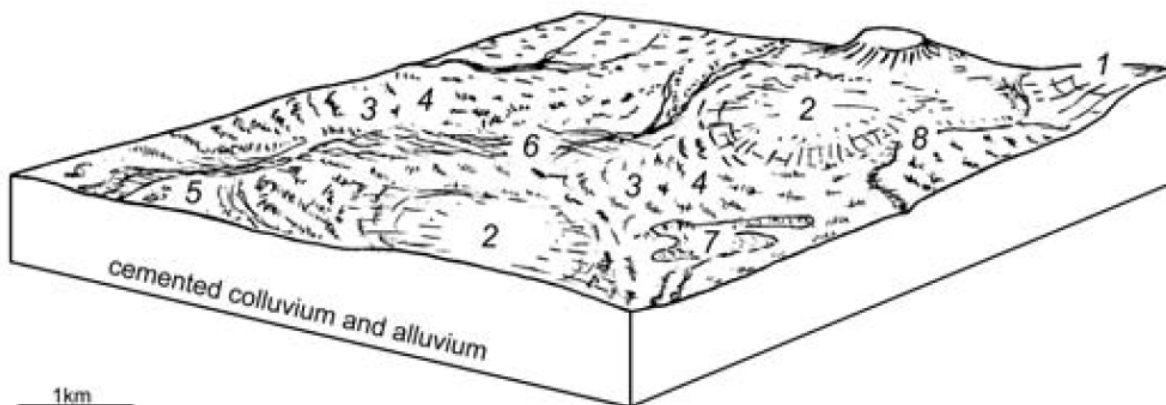
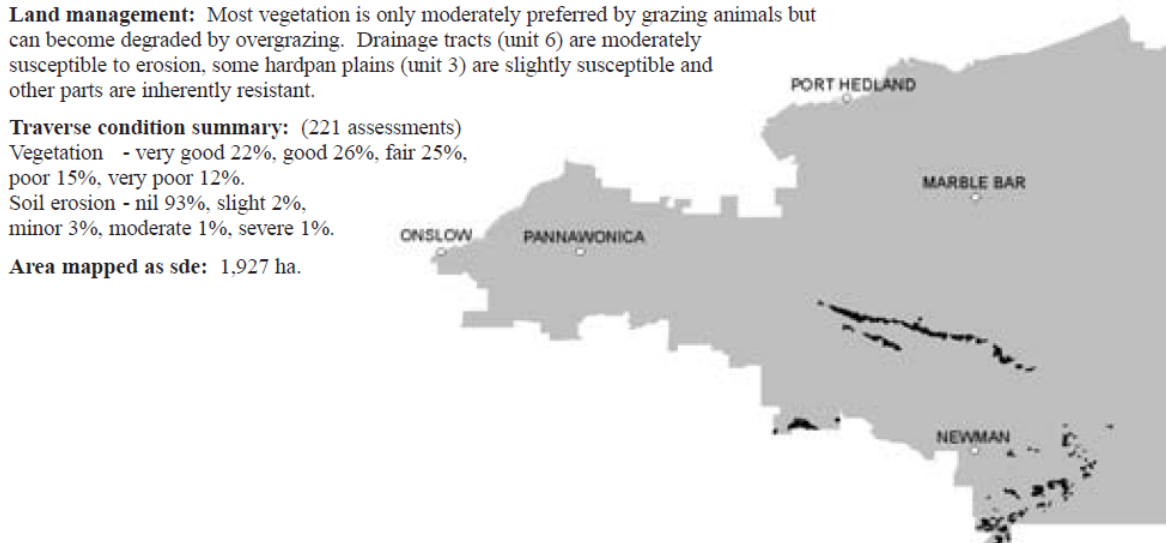
Land management: Most vegetation is only moderately preferred by grazing animals but can become degraded by overgrazing. Drainage tracts (unit 6) are moderately susceptible to erosion, some hardpan plains (unit 3) are slightly susceptible and other parts are inherently resistant.

Traverse condition summary: (221 assessments)

Vegetation - very good 22%, good 26%, fair 25%, poor 15%, very poor 12%.

Soil erosion - nil 93%, slight 2%, minor 3%, moderate 1%, severe 1%.

Area mapped as sde: 1,927 ha.



No.	Unit name	Traverse recordings	Inventory sites
1.	Low ridge and hill	6	3
2.	Stony upper plain and low rise	51	3
3.	Hardpan plain	79	2
4.	Grove	59	-
5.	Gilgai plain	1	1
6.	Drainage tract	14	-
7.	Sandy bank	10	-
8.	Channel and bank	1	-
Total		221	9*

* Seven of these sites described from field work done in 1990 as part of an assessment of the impact of Ophthalmia Dam on the flood plains of the Fortescue River (see Payne and Mitchell 1992).

Jamindie land system

Unit	Area (%)	Landform	Soil	Vegetation
1.	5%	Low ridges and hills - ridges and hills up to 25 m high and 1.5 km long, gently inclined footslopes with mantles of abundant pebbles and cobbles and some rock outcrop.	Stony soils (203).	Hummock grasslands of <i>Triodia</i> spp. (hard spinifex) with very scattered <i>Acacia</i> spp. shrubs and occasional eucalypt trees (HSPG, HESG).
2.	20%	Stony upper plains and low rises - gently undulating plains up to 3 km in extent, up to 20 m above lowest units; surface mantles of many to very abundant pebbles and cobbles of ironstone and other rocks.	Stony soils (203) and red shallow loams (522).	Shrubby hummock grasslands of <i>Triodia</i> spp. (hard spinifex) (PHSG) or scattered to moderately close tall shrublands with <i>Acacia xiphophylla</i> (snakewood), <i>A. aneura</i> (mulga) with shrub understoreys (PSCS, PSMS) or <i>Triodia</i> spp. (hard and soft spinifex) understorey (PMSS).
3.	50%	Hardpan plains - almost level plains up to 8 km in extent by 4-5 km wide between shallow drainage tracts (unit 6); surface mantles of many to very abundant pebbles of ironstone and chert, subject to sheet overland flow.	Red-brown hardpan shallow loams (523).	Very scattered tall shrublands of <i>Acacia aneura</i> and other acacias with sparse <i>Eremophila</i> and <i>Ptilotus</i> spp. low shrubs (HPMS, PSMS). Occasionally <i>Triodia pungens</i> (soft spinifex) in ground layer.
4.	15%	Groves - accurate drainage foci, up to 400 m long and 20 m wide but commonly much less, on hardpan plains (unit 3), arranged with long axes at right angles to direction of sheet overland flow.	Red loamy earths (544).	Close tall shrublands/woodlands of <i>A. aneura</i> with numerous <i>Eremophila</i> , <i>Ptilotus</i> and <i>Sida</i> spp. mid and low shrubs and sparse tussock grasses (GMUW, GMGW). Less frequently <i>Triodia pungens</i> in ground layer (DAHW).
5.	2%	Gilgai plains - level plains less than 1 km in extent associated with drainage tracts (unit 6) or as isolated areas within unit 3; gilgai microrelief.	Self-mulching cracking clays (602).	Very scattered tall shrublands of <i>Acacia</i> spp. with variable low shrubs and sparse tussock grasses (ARPG).
6.	5%	Drainage tracts - nearly level tracts associated with hardpan plains (unit 3), receiving more concentrated through flow and usually 300-400 m wide but up to 1 km, channelled or unchannelled; hardpan exposed in parts, variable pebbly mantles.	Red-brown hardpan shallow loams (523) and minor red loamy earths (544).	Scattered tall shrublands of <i>A. aneura</i> and other acacias and understorey of low shrubs and sparse tussock or hummock grasses (DEGW, DAHW).
7.	2%	Sandy banks - banks up to 0.5 m high, mostly less than 100 m long and 10 to 20 m wide, on unit 3; loose hummocky surfaces.	Red deep sands (445).	Shrublands with <i>A. aneura</i> and other acacias with <i>Eremophila</i> and <i>Senna</i> spp. low shrubs and <i>Triodia</i> spp. (hard and soft spinifex) ground layer (PMSS).
8.	1%	Channels and banks - channels 5-50 m wide, finely incised 1-2 m in hardpan on broad plains, up to 5 m in lower parts.	River bed soils (705).	Scattered to moderately close tall shrublands/woodlands with <i>A. aneura</i> and other acacias and tussock grasses (DEGW).

NEWMAN LAND SYSTEM (14,580 km², 8.0% of the survey area)

(modified from Payne, Mitchell and Holman 1988)

Rugged jaspilite plateaux, ridges and mountains supporting hard spinifex grasslands.

Land type: 1

Geology: Lower Proterozoic jaspilite, chert, siltstone, shale, dolomite and minor acid volcanics.

Geomorphology: Erosional surfaces; plateaux and mountains - extensive high plateaux, mountains and strike ridges with vertical escarpments and steep scree slopes and more gently inclined lower slopes; moderately spaced dendritic and rectangular tributary drainage patterns of narrow valleys and gorges with narrow drainage floors and channels. Relief up to 450 m.

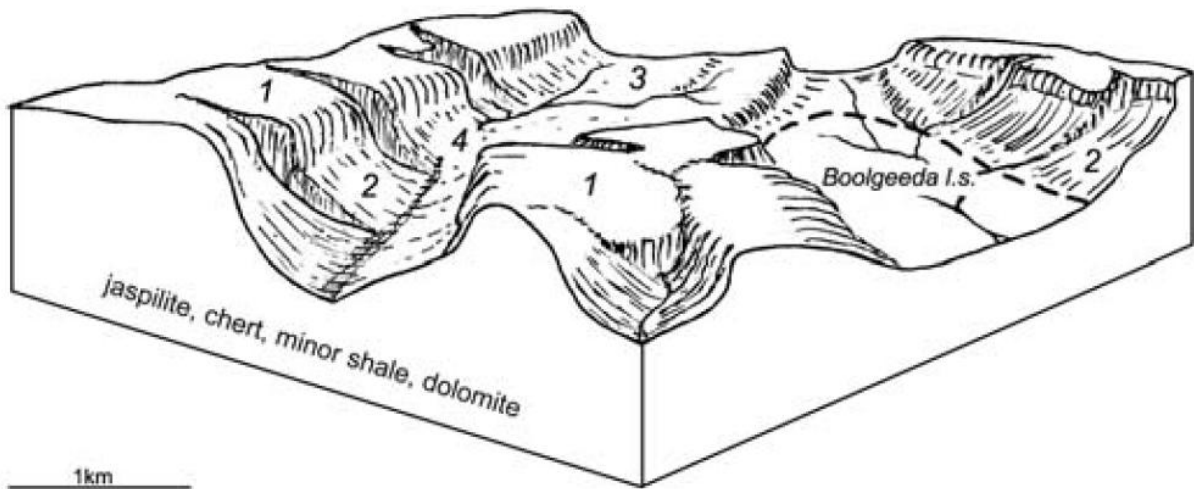
Land management: Much of the system is inaccessible or poorly accessible and is unsuitable for pastoral purposes. The system contains iron ore deposits which are currently being mined and deposits which are likely to be mined in the future. Spinifex is the dominant vegetation and the system is burnt fairly frequently.

Traverse condition summary: (228 assessments)

Vegetation - very good 91%, good 7%, fair 1%, poor 1%.

Soil erosion - nil 99%, minor 0.5%, moderate 0.5%.

Area mapped as sde: Nil.



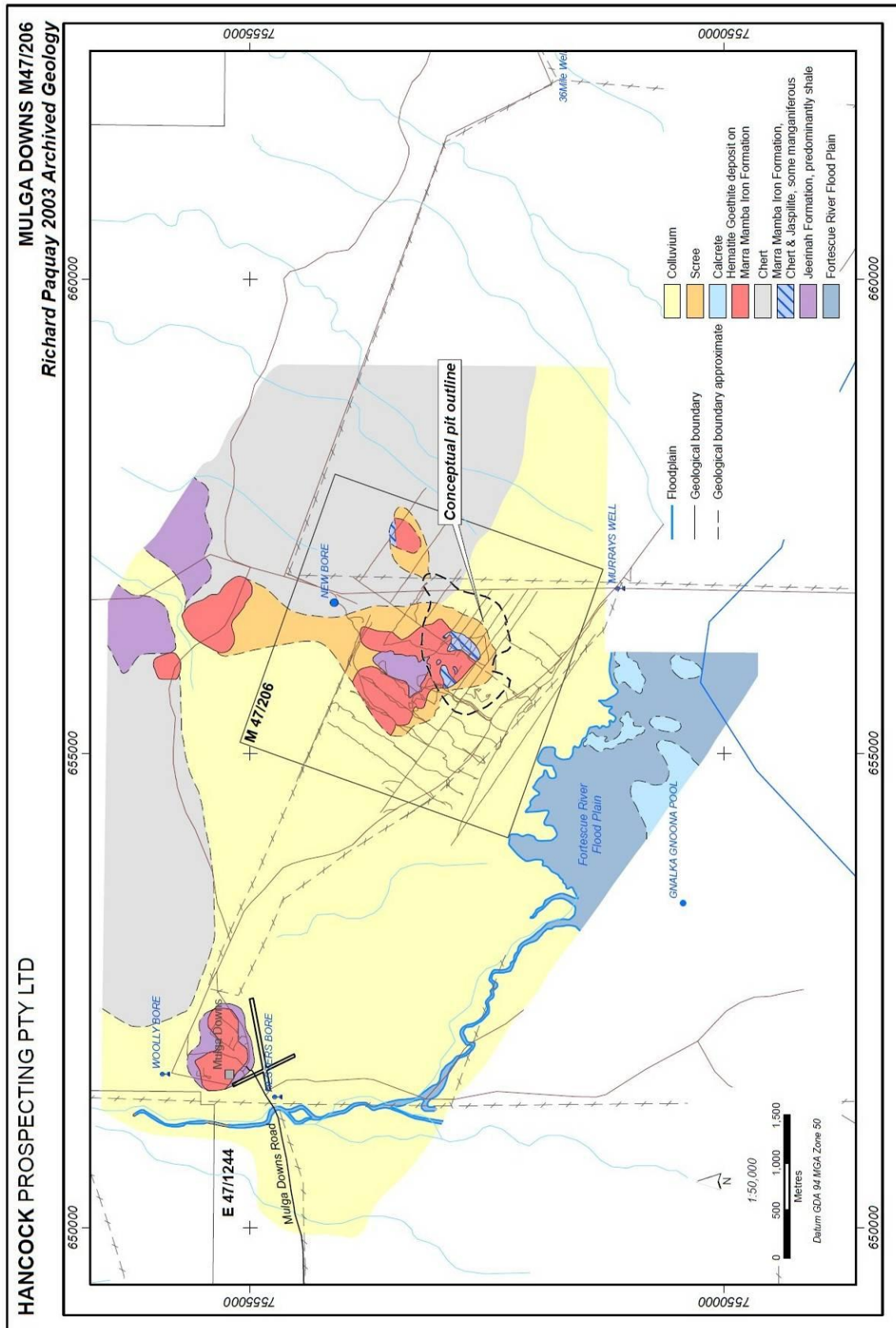
No.	Unit name	Traverse recordings	Inventory sites
1.	Plateau, ridge, mountain and hill	31	10
2.	Lower slope	74	2
3.	Stony plain	57	1
4.	Narrow drainage floor with channel	58	1
	Other	8	-
Total		228	14

Newman land system

Unit	Area (%)	Landform	Soil	Vegetation
1.	70%	Plateaux, ridges, mountains and hills - mountain tracts, plateaux and strike ridges, relief up to 400 m; level or rounded plateaux summits and mountain crests, ridges and indented escarpments with vertical upper cliff faces and moderately inclined to very steep upper scree slopes; surface mantles of abundant to very abundant pebbles, cobbles and stones of ironstone, jaspilite, chert and other rocks. Also outcrop of parent rock.	Stony soils (203), red shallow loams (522) and some red shallow sands (423).	Hummock grasslands of <i>Triodia wiseana</i> , <i>T. brizoides</i> , <i>T. plurinervata</i> (hard spinifex) with very scattered to scattered shrubs and trees including <i>Acacia</i> and <i>Senna</i> spp., <i>Grevillea wickhamii</i> (Wickham's grevillea), <i>Eucalyptus leucophloia</i> (snappy gum) and other eucalypts (HESG, HSPG). Occasionally hummock grass is <i>Triodia biflora</i> (soft spinifex).
2.	20%	Lower slopes - gently inclined concave slopes mostly less than 400 m in extent with mantles of very abundant pebbles and cobbles of ironstone and other rocks.	Stony soils (203) on upper margins with red loamy earths (544) on lower margins.	Similar to unit 1 (HESG, PHSG).
3.	5%	Stony plains - gently undulating lower plains and interfluves up to 500 m in extent with mantles of abundant to very abundant pebbles of ironstone.	Stony soils (203), red shallow loams (522) with some red loamy earths (544).	Hummock grasslands of <i>Triodia wiseana</i> , <i>T. spp.</i> (hard spinifex) with isolated to very scattered shrubs of <i>Acacia</i> and <i>Senna</i> spp. and occasional eucalypt trees (PHSG). Occasionally hummock grasslands of <i>Triodia pungens</i> (soft spinifex) (PSSG).
4.	5%	Narrow drainage floors with channels - almost level floors up to 400 m wide but usually much less in valleys, mantles of abundant pebbles of ironstone and other rocks; channels up to 200 m wide with cobble bedloads.	Red shallow loams (522), red loamy earths (544). Channels with river bed soils (705).	Smaller floors support hummock grassland of <i>Triodia pungens</i> with very scattered shrubs (ASSG). Larger floors and channels support tall shrublands/woodlands of <i>Acacia</i> spp. and <i>Eucalyptus victrix</i> (coolibah) with tussock grass or hummock grass understoreys (DEGW, DAHW, DESG).

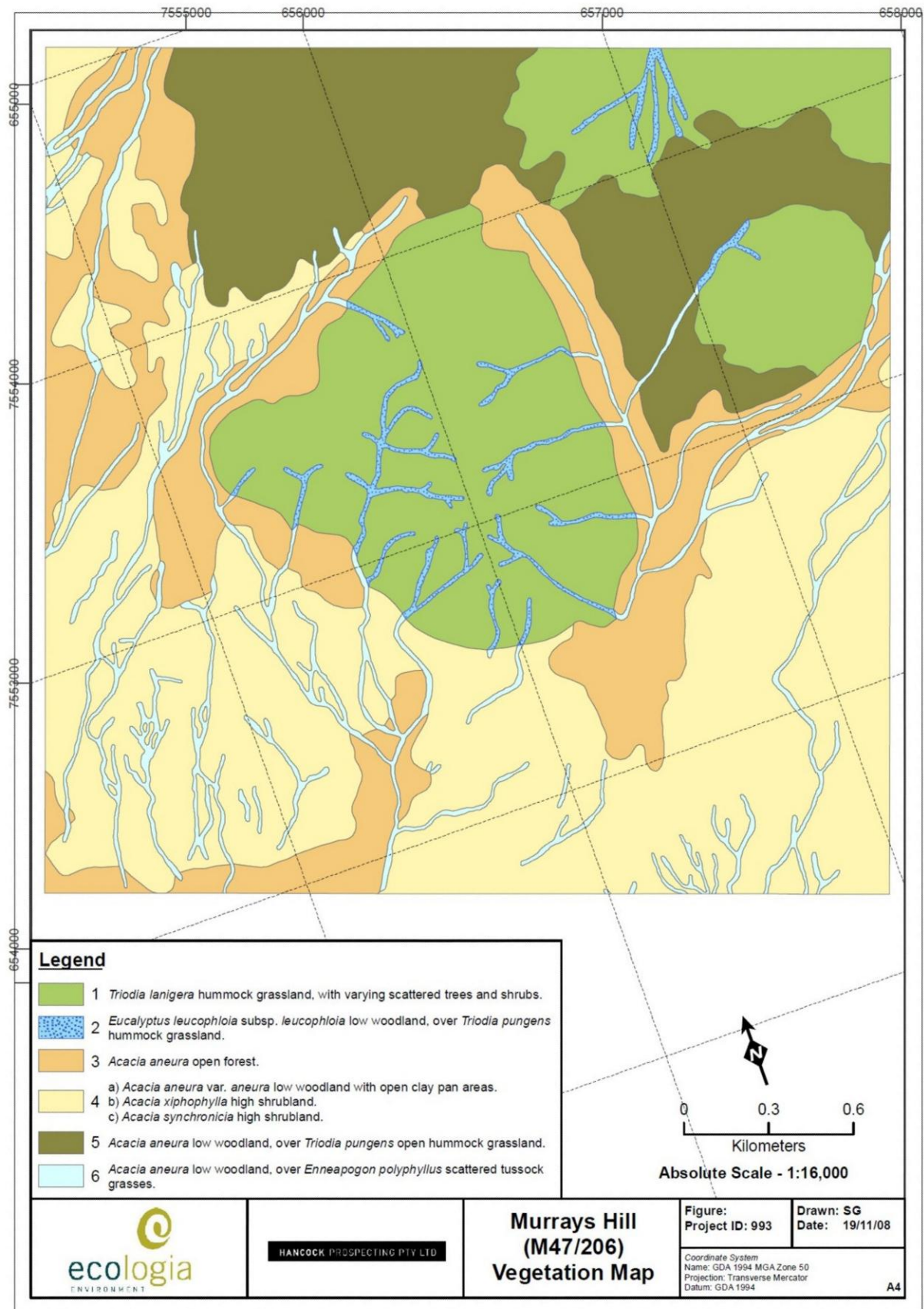
APPENDIX B – LOCAL GEOLOGY MAPPING

(Supplied by HPPL)



APPENDIX C – VEGETATION MAPPING

(Supplied by HPPL)



APPENDIX D – OVERBURDEN SAMPLES

Sample ID	Hole ID	Easting	Northing	Depth from	Depth to	Material Type	pH	EC _{1:5}	CEC	Ca (Sat %)	Mg (Sat %)	K (Sat %)	Na (Sat %)	Rock	Comments
-	-			m	m	-	-	dS/m	meq/100g	Sat %	Sat %	Sat %	Sat %	-	-
501641	MD0231	658282	7554527	4	6	GZFW	7.2	0.03	7.94	52.4	39.7	5.5	2.4	10-20%, 2-6 mm	
509450	MD0458	655856	7552184	22	24	GZIW	7.3	0.04	5.69	45.9	42.4	7.9	3.9	Minor	
511308	MD0527	656589	7552157	14	16	ALU	7.4	0.03	6.04	45.5	43.2	7.9	3.3	50%, <6 mm	
511893	MD0548	656203	7551931	44	46	GZFW	7.4	0.03	0.62	22.6	40.3	17.7	19.4	Nil	
512234	MD0560	656017	7552561	6	8	GZIM	8.4	0.04	5.06	49.2	29.6	14.6	6.5	Minor	
512326	MD0563	654780	7552733	4	6	CC	7.0	0.09	19.02	50.8	33.2	9.8	6.3	Minor	
513347	MD0598	656128	7552789	6	8	GZW	9.3	0.09	5.86	65.9	12.5	13.7	8.0	20-50%, 6-10 mm	
513463	MD0603	656207	7552733	4	6	GZW	8.8	0.10	6.16	35.4	36.0	19.5	9.1	Nil	
509445	MD0458	655856	7552184	12	14	GZW	8.4	0.04	7.69	61.5	30.7	5.7	2.1	Nil	
510452	MD0498	655123	7553216	18	20	GZFW	7.7	0.02	1.46	43.2	41.1	10.3	5.5	Nil	
511406	MD0530	656302	7551753	6	8	CC	9.0	0.08	18.02	57.3	34.2	6.0	2.5	10%, 2-6 mm	
511699	MD0541	656661	7552599	4	6	ALU	8.3	0.05	15.66	46.8	40.6	9.6	2.9	Nil	Hydrophobic
511850	MD0547	656317	7552110	24	26	GZW	7.7	0.03	5.15	43.9	43.7	8.7	3.7	Minor	
512163	MD0557	656428	7553141	8	10	GZFW	8.8	0.1	6.93	37.1	37.4	17.5	8.1	Nil	
512332	MD0563	654780	7552733	16	18	GZW	7.8	0.05	5.30	42.8	42.3	10.2	4.7	50%, 2 mm	
512411	MD0565	654946	7552610	6	8	CC	8.6	0.03	10.29	46.6	40.2	9.8	3.4	50-90%, 6-10 mm	
513818	MD0614	656746	7553410	2	4	ALU	8.6	0.05	11.55	69.4	21.1	7.2	2.3		Rounded angular

Sample ID	Hole ID	Easting	Northing	Depth from	Depth to	Material Type	pH	EC _{1:5}	CEC	Ca (Sat %)	Mg (Sat %)	K (Sat %)	Na (Sat %)	Rock	Comments
-	-			m	m	-	-	dS/m	meq/100g	Sat %	Sat %	Sat %	Sat %	-	-
509442	MD0458	655856	7552184	6	8	CC	8.9	0.09	20.27	68.3	24.9	5.4	1.4	Minor	
510247	MD0490	655406	7553251	4	6	GZW	8.2	0.03	3.38	63.9	23.1	9.8	3.3	10%, 2-6 mm	
510708	MD0508	657571	7553541	2	4	GZIW	7.6	0.02	2.00	59.5	34.5	3.0	3.0	20-50%, 2-6 mm	
510776	MD0510	656984	7552720	6	8	GZW	9.1	0.12	17.91	59.2	27.2	9.7	3.9	Minor	Bulldust, Hydrophobic
511841	MD0547	656317	7552110	6	8	ALU	8.9	0.03	14.03	42.1	41.2	11.0	5.7	50-90%, 6-10mm	
511910	MD0549	656832	7552848	18	20	GZIW	8.0	0.03	6.37	40.5	43.6	12.4	3.5	50%, 2 mm	
512128	MD0556	656483	7553216	4	6	GZIW	9.0	0.01	15.89	88.0	7.5	2.4	2.1	Minor	
512492	MD0567	654761	7552344	30	32	GZIW	8.1	0.04	2.96	56.4	30.4	6.1	7.1	10-20%, 6-10 mm	
513036	MD0583	655928	7553987	2	4	GZFW	7.1	0.04	6.13	39.8	52.4	5.1	2.8	Minor	
513824	MD0614	656746	7553410	14	16	GZFW	7.4	0.06	3.64	41.5	45.6	8.5	4.4	Nil	

APPENDIX E – FIELD OBSERVATIONS

Soil Surface Observations

Hole ID	Site Attributes					Soil Depth (m)	Surface Disturbance (-)	Surface Erosion (-)	Erosion Severity (-)	Surface Coarse Fragments				Rock Outcrop (%)	Notes
	Easting (m)	Northing (m)	Height (m)	Gradient (%)	Aspect (-)					Abundance (%)	Size (mm)	Shape (-)	Lithology (-)		
A	655494	7554802	419	Level	SW	Surface	Selective clearing	Stable	-	50-90	6-20	Subrounded	Fe	0	
						0-0.1	-	-	-	-	-	-	-	-	
						0.1-0.3	-	-	-	-	-	-	-	-	
						0.3-0.6	-	-	-	-	-	-	-	-	
B	655028	7554134	414	Level	SSW	Surface	Selective clearing	Stable	-	20-50	6-20	Subrounded	Fe	0	
						0-0.1	-	-	-	-	-	-	-	-	
						0.1-0.3	-	-	-	-	-	-	-	-	
C	654822	7553303	409	Level	SSW	Surface	Selective clearing	Stable	-	>90	6-20	Subrounded	Fe	0	
						0-0.1	-	-	-	-	-	-	-	-	
						0.1-0.3	-	-	-	-	-	-	-	-	Profile is deeper than 0.3 m
D	654549	7552756	407	Level	SSW	Surface	Light grazing	Stable	-	20-50	6-20	Subangular	Fe	0	Loose surface. Sparse trees, sporadic clumps of grasses.

Hole ID	Site Attributes					Soil Depth (m)	Surface Disturbance (-)	Surface Erosion (-)	Erosion Severity (-)	Surface Coarse Fragments				Rock Outcrop (%)	Notes
	Easting (m)	Northing (m)	Height (m)	Gradient (%)	Aspect (-)					Abundance (%)	Size (mm)	Shape (-)	Lithology (-)		
E	655605	7554229	416	Level	S	Surface	Selective clearing	Stable	-	>90	20-60	Subrounded	Fe	0	
						0-0.1	-	-	-	-	-	-	-	-	-
						0.1-0.3	-	-	-	-	-	-	-	-	-
						0.3-0.6	-	-	-	-	-	-	-	-	-
F	655581	7553502	420	Gently inclined	NW	Surface	Light grazing	Stable	-	>90	6-20	Subangular	Fe	2	Rock outcrop/Very rocky surface
G	655209	7553139	408	Level	SSW	Surface	Light grazing	Rill erosion	Minor	10-20	6-20	Subangular	Fe	0	Loose surface. Edge of dense woodland with trees and some grasses.
						0-0.1	-	-	-	-	-	-	-	-	-

Hole ID	Site Attributes				Aspect (-)	Soil Depth (m)	Surface Disturbance (-)	Surface Erosion (-)	Erosion Severity (-)	Surface Coarse Fragments			Rock Outcrop (%)	Notes	
	Easting (m)	Northing (m)	Height (m)	Gradient (%)						Abundance (%)	Size (mm)	Shape (-)			Lithology (-)
H	654940	7552270	403	Level	S	Surface	Light grazing	Stable	-	>90	6-20	Subangular	Fe	0	
						0-0.1	-	-	-	-	-	-	-	-	Slightly moist material.
						0.1-0.3	-	-	-	-	-	-	-	-	Slightly moist material.
						0.3-0.6	-	-	-	-	-	-	-	-	Slightly moist material.
I	656837	7553601	414	Gently inclined	SW	0-0.1	Light grazing	-	-						
J	655652	7553949	413	Very gently inclined	SSE	Surface	Selective clearing	Stable	-	>90	6-20	Subrounded	Fe	0	No understorey, sparse tree cover. Stony open area.
						0-0.1	-	-	-	-	-	-	-	-	Profile deeper than 0.1 m. Only surface sample taken.
K	655720	7553325	416	Gently inclined	SE	Surface	Undisturbed	Stable	-	50-90	60-200	Subangular	Fe	>50	
						0-0.1	-	-	-	-	-	-	-	-	Very shallow profile.

Hole ID	Site Attributes					Soil Depth (m)	Surface Disturbance (-)	Surface Erosion (-)	Erosion Severity (-)	Surface Coarse Fragments				Rock Outcrop (%)	Notes
	Easting (m)	Northing (m)	Height (m)	Gradient (%)	Aspect (-)					Abundance (%)	Size (mm)	Shape (-)	Lithology (-)		
L	655855	7552547	406	Gently inclined	SSW	Surface	Light grazing	Stable	-	50-90	6-20	Subangular	Fe	0	
						0-0.1	-	-	-	-	-	-	-	-	
						0.1-0.3	-	-	-	-	-	-	-	-	
M	656980	7555034	435	Very gently inclined	SSW	Surface	Undisturbed	Stable	-	50-90	2-6	Subangular	Fe	2	Spinifex grasslands. Minor outcropping
						0-0.1	-	-	-	-	-	-	-	-	Very shallow profile.
O	656019	7553098	438	Gently inclined	NE	Surface	Undisturbed	Stable	-	>90	20-60	Subangular	Fe	10-20	On top of mesa
						0-0.1	-	-	-	-	-	-	-	-	
Q	656076	7552100	406	Level	SW	Surface	Selective clearing	Stable	-	10-20	6-20	Subangular	Fe	0	Loose surface, no ground cover
						0-0.1	-	-	-	-	-	-	-	-	
						0.1-0.3	-	-	-	-	-	-	-	-	
						0.3-0.6	-	-	-	-	-	-	-	-	
U	656058	7553264	435	Moderately inclined	E	Surface	Undisturbed	Stable	-	>90	600-2,000	Subangular	Fe	>50	Outcrop. Spinifex, sporadic trees

Hole ID	Site Attributes					Soil Depth (m)	Surface Disturbance (-)	Surface Erosion (-)	Erosion Severity (-)	Surface Coarse Fragments			Rock Outcrop (%)	Notes		
	Easting (m)	Northing (m)	Height (m)	Gradient (%)	Aspect (-)					Abundance (%)	Size (mm)	Shape (-)			Lithology (-)	
S	656413	7551915	407	Level	SW	Surface	Selective clearing	Stable	-	50-90	6-20	Subangular	Fe	10-20	Erosional surface. Lose surface under slight cementation	
						0-0.1	-	-	-	-	-	-	-	-	-	-
W	657035	7552081	409	Level	SW	Surface	Selective clearing	Stable	-	2-10	6-20	Subangular	Fe	0		
						0-0.1	-	-	-	-	-	-	-	-	-	Loose underfoot
						0.1-0.3	-	-	-	-	-	-	-	-	-	-
Y	656865	7551852	408	Level	S	Surface	Selective clearing	Rill erosion	Minor	50-90	6-20	Subangular	Fe	0		
						0-0.1	-	-	-	-	-	-	-	-	-	Cloddy soil.
						0.1-0.3	-	-	-	-	-	-	-	-	-	-
Z	656667	7551597	406	Level	S	Surface	Light grazing	Stable	-	>90	6-20	Subangular	Fe	0		
						0-0.1	-	-	-	-	-	-	-	-	-	Photo of cleared tree roots taken. Root depth = 0.3 m
AA	656412	7552654	410	Level	SE	Surface	Light grazing	Stable	-	2-10	2-6	Subangular	Fe	0	Pit sample	
						0-0.1	-	-	-	-	-	-	-	-	-	-
						0.1-1	-	-	-	-	-	-	-	-	-	-
						1-3	-	-	-	-	-	-	-	-	-	-

Hole ID	Site Attributes					Soil Depth (m)	Surface Disturbance (-)	Surface Erosion (-)	Erosion Severity (-)	Surface Coarse Fragments				Rock Outcrop (%)	Notes	
	Easting (m)	Northing (m)	Height (m)	Gradient (%)	Aspect (-)					Abundance (%)	Size (mm)	Shape (-)	Lithology (-)			
AB	655549	7552856	408	Very gently inclined	SW	Surface	Light grazing	Stable	-	20-50	2-6	Subangular	Fe	0	Pit sample	
						0-0.1	-	-	-	-	-	-	-	-	-	
						0.1-1.5	-	-	-	-	-	-	-	-	-	
						1.5-3.0	-	-	-	-	-	-	-	-	-	
AC	656202	7552314	407	Level	S	Surface	Selective clearing	Stable	-	0	-	-	-	0		
						0-0.1	-	-	-	-	-	-	-	-	-	
						0.1-0.3	-	-	-	-	-	-	-	-	-	
AD	655789	7553130	424	Moderately inclined	N	Surface	Undisturbed	Stable	-	>90	20-60	Subangular	Fe	0		
						0-0.1	-	-	-	-	-	-	-	-	-	Rocky profile, little "soil". Good vegetation growth
						0.1-1.5	-	-	-	-	-	-	-	-	-	

Soil Profile Observations

Hole ID	Soil Depth (m)	Soil Texture (-)	Profile Coarse Fragments				Soil Structure (-)	Pedality (-)	Ped Size (mm)	Soil Strength (-)	Water Repellence (-)	Field pH (-)	Field EC (dS/m)	Roots (mm)	Permeability (mm/day)	Notes
			Abund. (%)	Size (mm)	Shape (-)	Lith. (-)										
A	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	0-0.1	Clay Loam	-	-	-	-	Weak Peds	Angular Blocky	20-50	Loose	No	7.3	0.022	0	50-500	
	0.1-0.3	Clay Loam	20-50	2-6	Subangular	Fe	Weak Peds	Angular Blocky	20-50	Loose	No	7.3	0.089	1-2	50-500	
	0.3-0.6	Clay Loam	50-90	6-20	Subangular	Fe	Weak Peds	Angular Blocky	20-50	Loose	No	7.5	0.021	1-2	50-500	
B	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	0-0.1	Clay Loam	10-20	6-20	Subangular	Fe	Moderate Peds	Angular Blocky	10-20	Loose	No	8	0.009	0	50-500	
	0.1-0.3	Clay Loam	10-20	6-20	Subangular	Fe	Moderate Peds	Angular Blocky	10-20	Loose	No	7.5	0.047	1-2	50-500	
C	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	0-0.1	Clay Loam	20-50	6-20	Subangular	Fe	Moderate Peds	Angular Blocky	10-20	Loose	No	7.5	0.018	0	50-500	
	0.1-0.3	Clay Loam	10-20	6-20	Subangular	Fe	Moderate Peds	Angular Blocky	10-20	Loose	No	7.5	0.019	1-2	50-500	Profile is deeper than 0.3 m
E	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	0-0.1	Clay Loam	20-50	6-20	Subangular	Fe	Moderate Peds	Angular Blocky	20-50	Loose	No	7.5	0.014	1-2	50-500	
	0.1-0.3	Clay Loam	10-20	6-20	Subangular	Fe	Strong Peds	Angular Blocky	20-50	Loose	No	7.5	0.042	1-2	50-500	
	0.3-0.6	Clay Loam	10-20	2-6	Subangular	Fe	Strong Peds	Angular Blocky	20-50	Loose	No	7.5	0.025	1-2	50-500	

Hole ID	Soil Depth (m)	Soil Texture (-)	Profile Coarse Fragments			Lith. (-)	Soil Structure (-)	Pedality (-)	Ped Size (mm)	Soil Strength (-)	Water Repellence (-)	Field pH (-)	Field EC (dS/m)	Roots (mm)	Permeability (mm/day)	Notes
			Abund. (%)	Size (mm)	Shape (-)											
G	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Loose surface. Edge of dense woodland with trees and some grasses.
	0-0.1	Clay Loam	<2	2-6	Subangular	Fe	Weak Peds	Angular Blocky	10-20	Loose	No	7.7	0.015	0	50-500	Profile deeper than 0.1 m. Only surface sample taken.
H	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	0-0.1	Clay Loam	2-10	2-6	Subangular	Fe	Moderate Peds	Angular Blocky	10-20	Loose	No	7	5.45	<1	50-500	Slightly moist material.
	0.1-0.3	Clay Loam	2-10	2-6	Subangular	Fe	Moderate Peds	Angular Blocky	10-20	Loose	No	7	5.00	0	50-500	Slightly moist material.
	0.3-0.6	Clay Loam	2-10	2-6	Subangular	Fe	Moderate Peds	Angular Blocky	10-20	Loose	No	7.5	3.33	0	50-500	Slightly moist material. No understorey, sparse tree cover. Stoney open area.
J	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	0-0.1	Clay Loam	20-50	6-20	Subangular	Fe	Weak Peds	Angular Blocky	20-50	Loose	No	9	0.01	1-2	50-500	Profile deeper than 0.1 m. Only surface sample taken.

Hole ID	Soil Depth (m)	Soil Texture (-)	Profile Coarse Fragments			Lith. (-)	Soil Structure (-)	Pedality (-)	Ped Size (mm)	Soil Strength (-)	Water Repellence (-)	Field pH (-)	Field EC (dS/m)	Roots (mm)	Permeability (mm/day)	Notes
			Abund. (%)	Size (mm)	Shape (-)											
K	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	0-0.1	Clay Loam	20-50	6-20	Subangular	Fe	Weak Peds	Angular Blocky	10-20	Loose	No	6	0.06	0	50-500	Very shallow profile.
L	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	0-0.1	Clay Loam	50-90	6-20	Subangular	Fe	Moderate Peds	Angular Blocky	20-50	Very firm	No	5.5	5.37	0	50-500	
	0.1-0.3	Clay Loam	50-90	6-20	Subangular	Fe	Moderate Peds	Angular Blocky	20-50	Very firm	No	7.5	0.026	0	50-500	
M	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Spinifex grasslands. Minor outcropping
	0-0.1	Clay Loam	50-90	2-6	Subangular	Fe	Moderate Peds	Angular Blocky	10-20	Loose	No	7.5	0.006	0	50-500	Very shallow profile.
O	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	On top of mesa
	0-0.1	Clay Loam	50-90	6-20	Subangular	Fe	Moderate Peds	Angular Blocky	10-20	Loose	No	7.5	0.016	0	50-500	
Q	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Loose surface, no ground cover
	0-0.1	Clay Loam	10-20	6-20	Subangular	Fe	Weak Peds	Angular Blocky	10-20	Loose	No	7	0.07	1-2	50-500	
	0.1-0.3	Clay Loam	10-20	6-20	Subangular	Fe	Weak Peds	Angular Blocky	10-20	Loose	No	7.5	0.03	2-5	50-500	
	0.3-0.6	Clay Loam	10-20	6-20	Subangular	Fe	Weak Peds	Angular Blocky	10-20	Loose	No	7.5	0.02	0	50-500	

Hole ID	Soil Depth (m)	Soil Texture (-)	Profile Coarse Fragments			Lith. (-)	Soil Structure (-)	Pedality (-)	Ped Size (mm)	Soil Strength (-)	Water Repellence (-)	Field pH (-)	Field EC (dS/m)	Roots (mm)	Permeability (mm/day)	Notes
			Abund. (%)	Size (mm)	Shape (-)											
S	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Erosional surface. Lose surface under slight cementation
	0-0.1	Clay Loam	20-50	6-20	Subangular	Fe	Weak Peds	Angular Blocky	5-10	Loose	No	8	0.01	<1	50-500	
W	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	0-0.1	Clay Loam	<2	2-6	Subangular	Fe	Weak Peds	Angular Blocky	10-20	Loose	No	7.5	0.024	0	50-500	Loose underfoot
	0.1-0.3	Clay Loam	<2	2-6	Subangular	Fe	Weak Peds	Angular Blocky	10-20	Loose	No	-	-	0	50-500	
Y	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	0-0.1	Clay Loam	<2	2-6	Subangular	Fe	Moderate Peds	Angular Blocky	10-20	Loose	No	7.5	0.018	0	50-500	Cloddy soil.
	0.1-0.3	Clay Loam	2-10	6-20	Subangular	Fe	Moderate Peds	Angular Blocky	10-20	Loose	No	7	0.078	0	50-500	
Z	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	0-0.1	Clay Loam	10-20	6-20	Subangular	Fe	Massive	-	-	Loose	No	8	0.016	<1	50-500	Photo of cleared tree roots taken. Rooting depth = 0.3 m

Hole ID	Soil Depth (m)	Soil Texture (-)	Profile Coarse Fragments			Lith. (-)	Soil Structure (-)	Pedality (-)	Ped Size (mm)	Soil Strength (-)	Water Repellence (-)	Field pH (-)	Field EC (dS/m)	Roots (mm)	Permeability (mm/day)	Notes
			Abund. (%)	Size (mm)	Shape (-)											
AA	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Pit sample
	0-0.1	Clay Loam	20-50	2-6	Subangular	Fe	Moderate Peds	Angular Blocky	10-20	Loose	No	7.5	0.007	2-5	50-500	
	0.1-1	Clay Loam	20-50	6-10	Subangular	Fe	Moderate Peds	Angular Blocky	10-20	Loose	No	7.5	0.007	5-10	50-500	
	1-3	Clay Loam	50-90	10-20	Subangular	Fe	Moderate Peds	Angular Blocky	10-20	Loose	No	-	-	-	50-500	
AB	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Pit sample
	0-0.1	Clay Loam	20-50	6-10	Subangular	Fe	Weak Peds	Angular Blocky	10-20	Loose	No	7.5	0.011	1-2	50-500	
	0.1-1.5	Clay Loam	20-50	6-10	Subangular	Fe	Weak Peds	Angular Blocky	10-20	Loose	No	7.5	0.012	0	50-500	
	1.5-3.0	Clay Loam	>90	20-60	Subangular	Fe	Weak Peds	Angular Blocky	-	Very strong	No	-	-	-	50-500	
AC	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	0-0.1	Clay Loam	0	-	-	-	Moderate Peds	Angular Blocky	10-20	Loose	No	7	0.061	1-2	50-500	
	0.1-0.3	Clay Loam	0	-	-	-	Moderate Peds	Angular Blocky	10-20	Loose	No	7	0.053	1-2	50-500	
AD	Surface	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	0-0.1	Clay Loam	>90	20-60	Subangular	Fe	Strong Peds	Angular Blocky	20-50	Loose	No	7.5	0.014	0	50-500	Rocky profile, little soil. Good vegetation growth
	0.1-1.5	Clay Loam	>90	20-60	Subangular	Fe	Weak Peds	Angular Blocky	5-10	Loose	No	7.5	0.016	0	50-500	