HASTINGS
Technology Metals Limited

APPENDIX 5-2

Soils Assessment

YANGIBANA PROJECT
SOIL ASSESSMENT

Hastings Technology Metals Limited

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Landloch

EXECUTIVE SUMMARY

The Yangibana Rare Earths Project is located approximately 280km north east of Carnarvon and 900km north of Perth in the arid interior of Western Australia. The project is seeking to extract rare earth (RE) (neodymium, praseodymium, dysprosium and europium) from ironstone-hosted mineralisation and potentially from carbonatite-hosted mineralisation at greater depths. Landloch was engaged by Ecoscape on behalf of Hastings Technology Metals Ltd to undertake an assessment of the soil of the Yangibana Project.

The Project resides within the Gascoyne Complex near the boundary of the Edmund Basin and Collier Basins. The Project area comprises sills, dykes, and veins of ferrocarbonatite that intrudes Pimbyana and Yangibana Granites of the Durlacher Supersuite. The north-west trending ferrocarbonatite sills and dykes that host the target rare earths at Yangibana North dip towards the south west and outcrop on higher elevations as the characteristic Yangibana ironstone. Numerous quartz veins are also found within the site. More recent colluvial and alluvial regolith units are associated with lower relief areas and drainage lines.

The Hill Soil is associated with the granite low hills and rises of the site and soil depths vary from shallow near hill tops adjacent to rock outcrops or more sloping hills around Bald Hills (~20cm), to 40-50cm on lower hill flanks. Hill Soils are dark brown sandy duplex soils and can be divided into an A and B horizon that overlies a C horizon of decomposing granite. The surface horizon was covered in a stone mantle but the coarse fraction (>2mm diameter) content was only ~20%. The surface horizon was massive to weakly pedal and field textures were typically sandy loams. The subsurface horizon is less sandy and more clay rich than the horizon immediately above. The Hill Soil has a neutral to slightly acidic pH that does not vary much through the profile or between soil pits. The soil has very low salinity levels ($EC_{1:5}$<0.02dS/m) and a maximum exchangeable sodium percent (ESP) of 4.7%.

The Plain Soils are associated with the low relief areas and flood plains of the drainage lines of the site. There is a thin surface sandy loam topsoil overlying a silty loam subsoil. These soils are located in areas of recent deposition and will be influenced by the nature and frequency of past flooding events, and the character of the contributing catchment. The Plain Soils tend to be shallow (<30cm), but the depth of refusal and hence the reported soil depth was a function of the clay hardpan encountered, most likely the result of wetting and baking of the clayey subsoil. The Plain Soil is a dark brown sandy loam over clay loam. The surface horizon is approximately 5cm think over a subsurface horizon that is 20-30cm thick. The soil is massive (i.e., weak) in structure, strongly alkaline throughout the profile, saline ($EC_{1:5}$ 0.55 - 9.35dS/m), and sodic (ESP 2.85 – 33.96%). There are large surface areas of bare quartz sand and pebbles which are most likely due to sheet wash. The Plain Soil was mapped to include areas of variation such as recent alluvial/colluvials along drainage lines, and quartzofeldspathic derived soils in discrete areas along Fraser's Creek.

Details on soil management for available quantities, stripping, and handling techniques are contained within this report.

1 INTRODUCTION

1.1 Overview

Landloch has been engaged by Ecoscape Australia on behalf of Hastings Technology Metals Ltd (Hastings) to undertake a baseline soil assessment of the proposed Yangibana rare earths mining project (the Project). The Project encompasses a mining area consisting of pits, waste dumps, tailings dams, mine infrastructure (workshop, offices, etc.), an accommodation camp, and connecting haul roads and tracks.

The Yangibana Project is in the pre-approval stage and is therefore required to undertake baseline environmental studies. The baseline soil assessment will be used as part of the approval process, as well as in preparing the mine closure plan in accordance with the Department of Mines and Petroleum's (DMP) *Guidelines for Mining Proposals in Western Australia* (2016a) and *Guidelines for Preparing Mine Closure Plans* (2015). The mining proposal guideline states that material (including soil) characterisation is to be undertaken to identify the physical and geochemical properties that have a potential to cause environmental harm, or contribute or detract from the success of rehabilitation and closure (DMP 2016a). Early detection of both beneficial and detrimental material properties means that through the planning process, specifically tailored management strategies can be implemented to achieve the closure aims. That is, that mine sites are safe to humans and animals, geo-technically stable, non-polluting/non-contaminating, and ecologically sustainable (DMP 2015).

Specifically, the purpose and scope of this baseline soil assessment is to provide information on the properties of the undisturbed soil resource of the project area, including an indication of any adverse properties such as salinity, dispersion, and poor structure. The tasks to be completed for the baseline soil assessment include:

- A review of publically available information relating to the soils and landforms of the Yangibana project area;
- A field survey of the soils of the Yangibana project area, including sampling of soils and description of soil profiles;
- Physical and chemical characterisation of selected soil samples;
- Interpretation of the physical and chemical soil test results;
- Mapping of the approximate functional undisturbed soil boundaries and estimation of available soil volumes; and
- Production of a report that outlines the assessment method, provides the results of the field assessment and soil test results and their interpretation, provides the mapping, and broadly details the implication the soil's properties in terms of landform rehabilitation and mine closure planning.

1.2 Project background

The Project is located approximately 280km north east of Carnarvon and 900km north of Perth in the arid interior of Western Australia (Figure 1). The Project is located on tenements that cover ~650km^2. The project is seeking to extract rare earth (RE) (neodymium, praseodymium, dysprosium and europium) from ironstone-hosted mineralisation and potentially from carbonatite hosted mineralisation at greater depths.

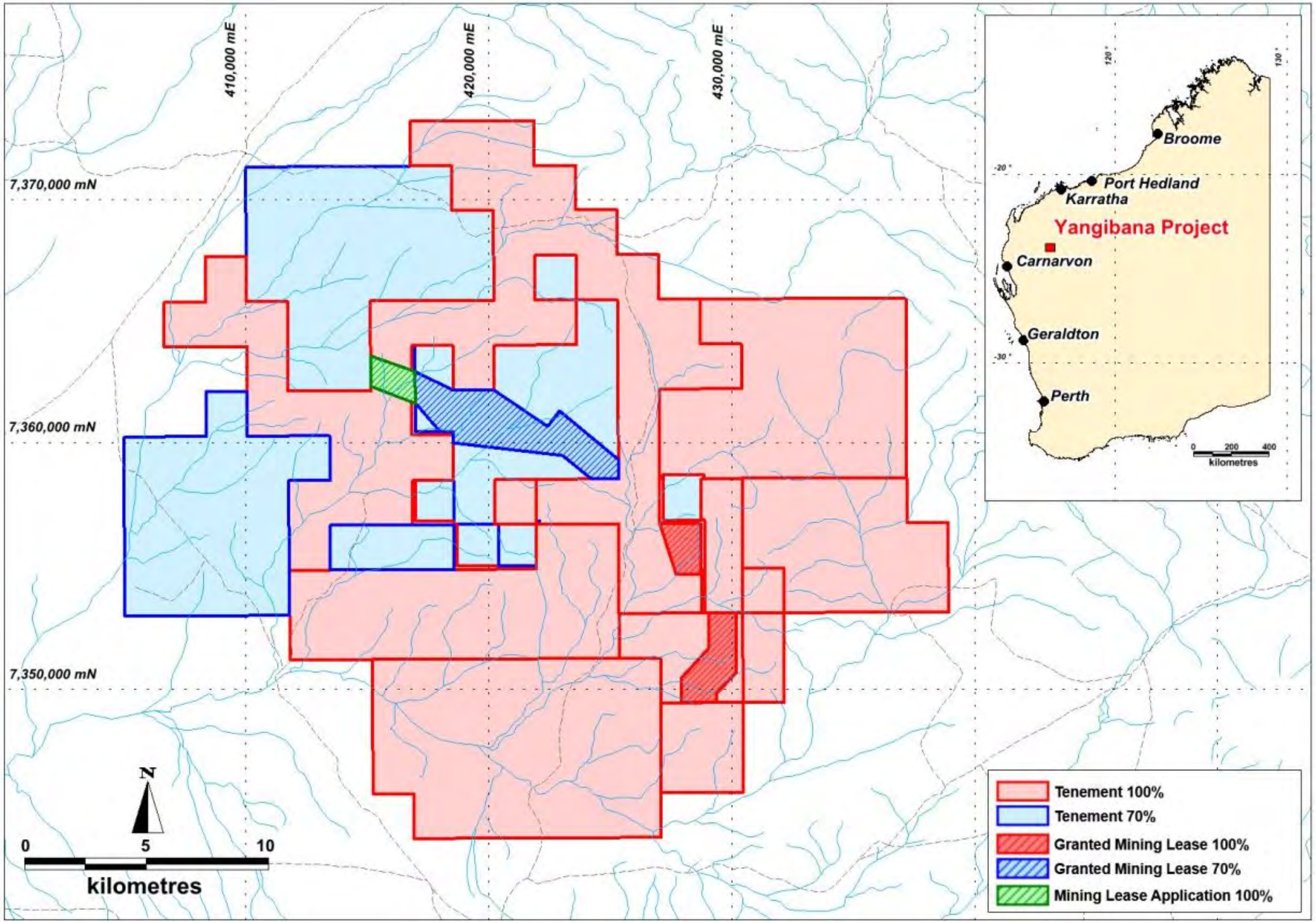


Figure 1: Location of the Yangibana Project. (Source: Hastings)

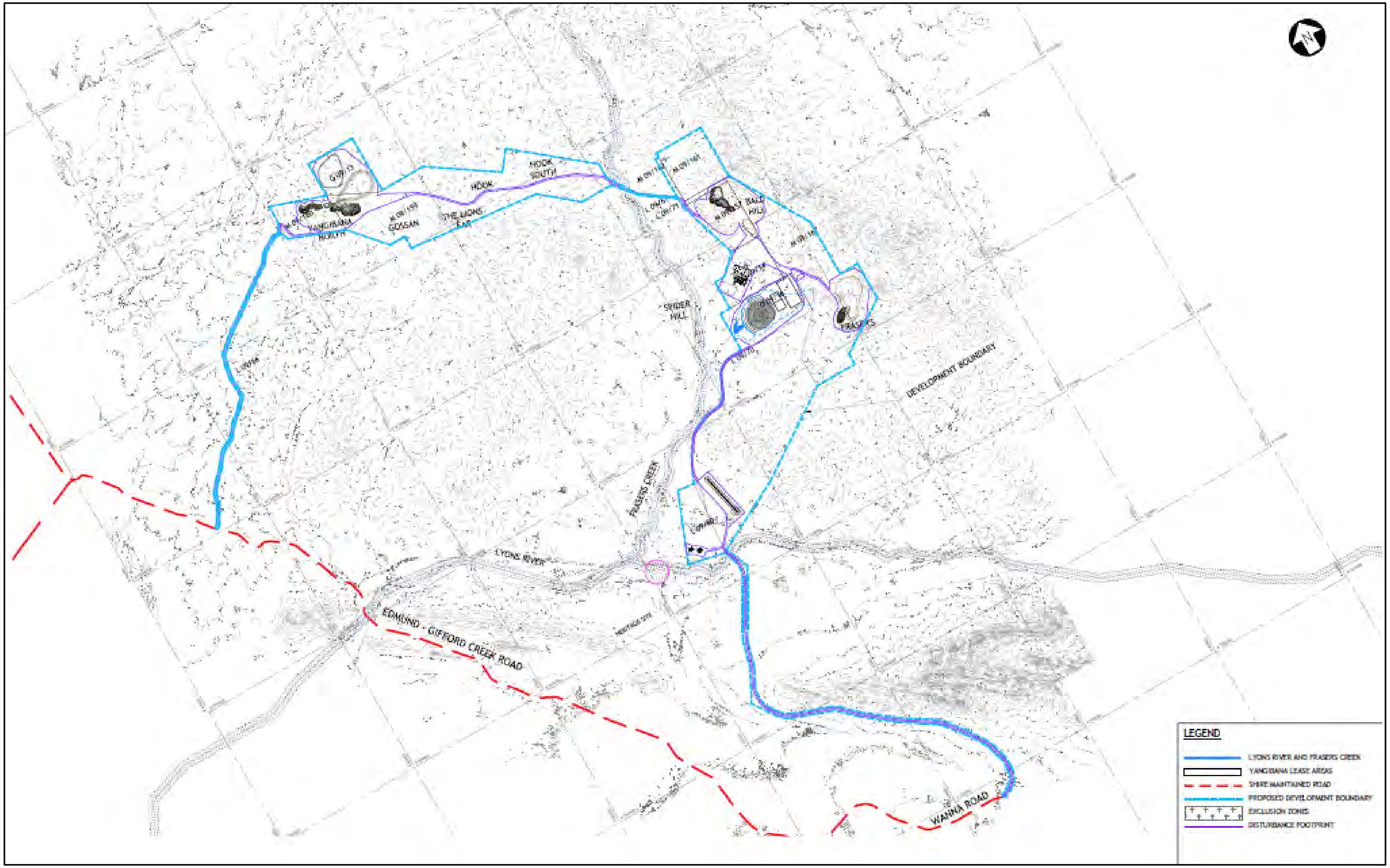


Figure 2: Proposed mining disturbance area of the Yangibana Project (4/11/2016). (Wave 2016a)

Pre-feasibility drilling studies have been undertaken and indicate that the most economic resources are located in the eastern and western belts (Figure 2). The planned mining schedule will focus on the Bald Hill South and Fraser's areas in the first years before moving on to Yangibana North (Figure 2). This schedule will mean a mine life of approximately 7 years with 66Mt of waste generated from these open pits.

1.3 Existing environment

1.3.1 Climate

The climate of Yangibana is described as semi-desert Mediterranean. The mean annual rainfall is low and occurs mainly from January to June, with the driest months being spring to early summer. The winter months are cool with summers being very hot (Table 1).

Table 1: Mean monthly rainfall and daily maximum temperature for weather stations near to the proposed Yangibana site (BOM 2016).

Month	Mean Monthly Rainfall* (mm)	Mean Daily Maximum Temperature^ (°C)
January	32.5	40.3
February	59	38.8
March	32.3	37
April	18.1	32.6
May	25.3	27.4
June	32	22.9
July	18.9	22.5
August	10.1	24.8
September	2.7	28.4
October	3	32.3
November	3.3	35.2
December	7.7	38.5
	240.2 (MEAN ANNUAL)	**31.8** (DAILY AVERAGE)

* Wanna (#007028) ^ Mt Phillip (#007058)

1.3.2 Geology

The Project resides within the Gascoyne Complex near the boundary of the Edmund Basin and Collier Basins (Figure 3). The Project area comprises sills, dykes, and veins of ferrocarbonatite that intrudes Pimbyana and Yangibana Granites of the Durlacher Supersuite that are exposed in a northeast-southwest window through the younger Edmund Basin (Bangemall Supergroup) sedimentary rocks. The north-west trending ferrocarbonatite sills and dykes that host the target rare earths at Yangibana North (Figure 4) dip towards the south west and outcrop on higher elevations as the characteristic Yangibana ironstone. Numerous quartz veins are also found within the site. More recent colluvial and alluvial regolith units are associated with lower relief areas and drainage lines (Pearson *et al.* 1996, Martin *et al.* 2005, Pirajno *et al.* 2014, Pirajno *et al.* 2015).

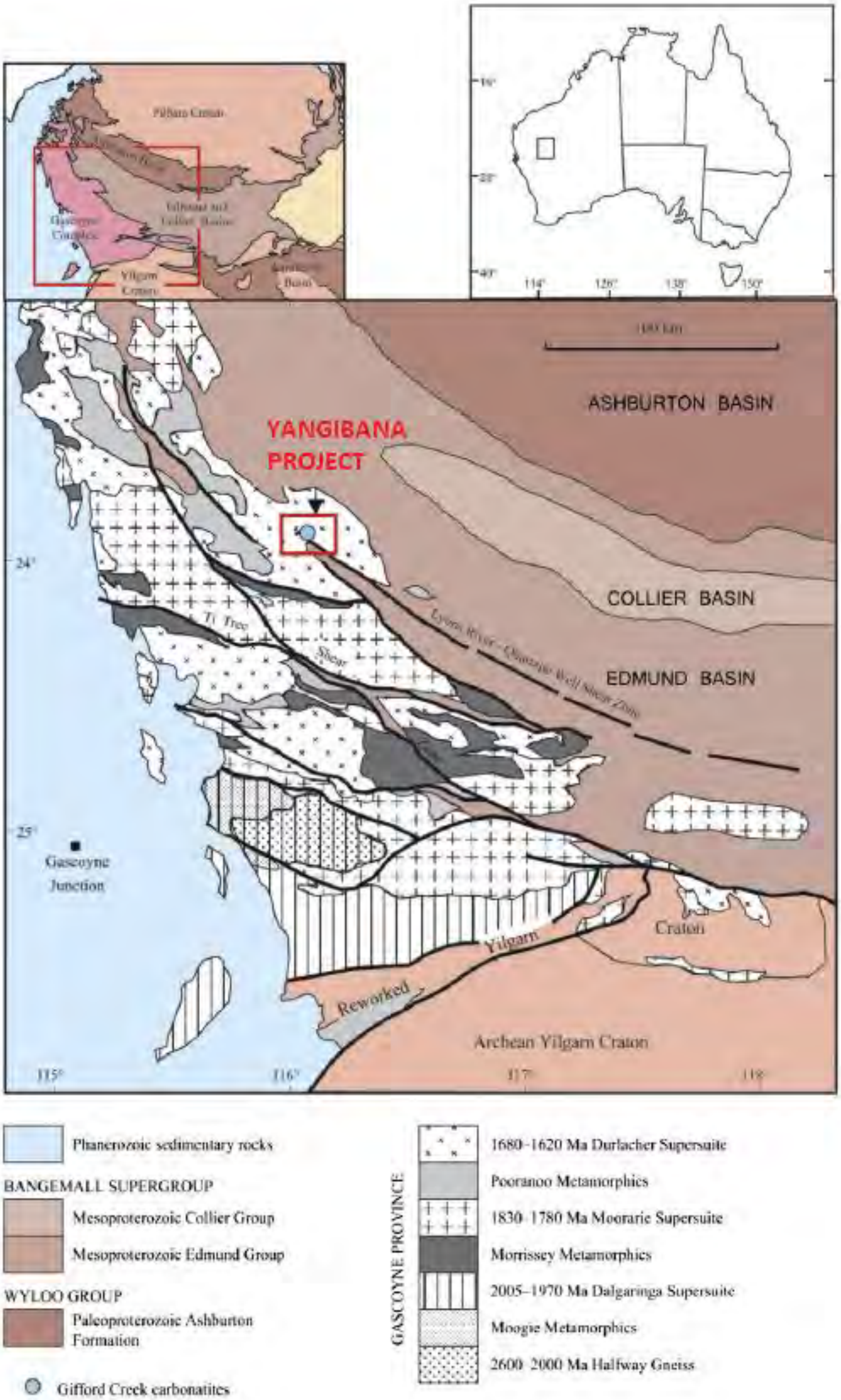


Figure 3: Regional geological setting of the Yangibana Project marked by the red box (Pirajno *et al.* 2014).

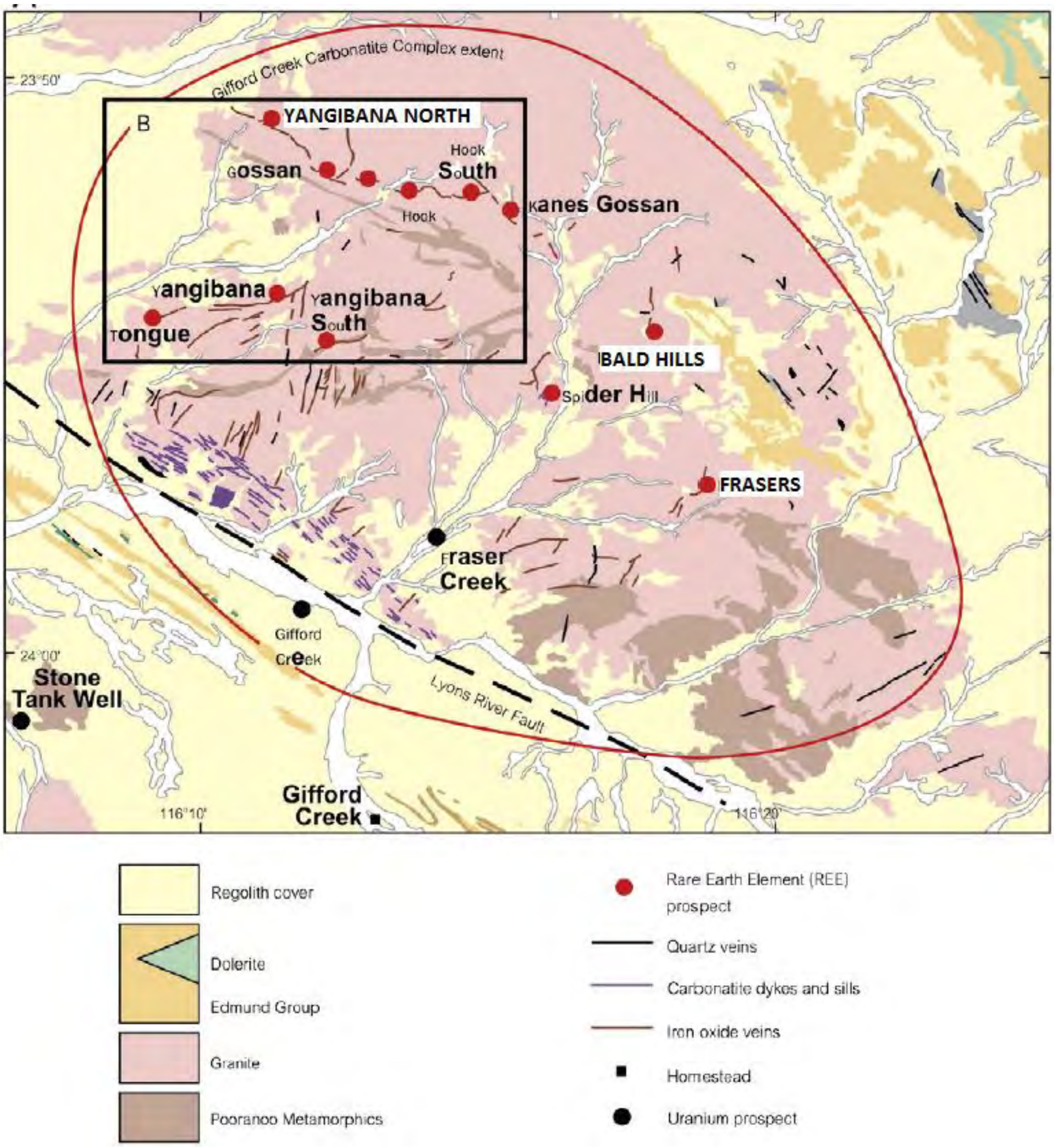


Figure 4: Site geology with the Frasers, Bald Hills, and Yangibana North proposed pits highlighted (Pirajno *et al.* 2014).

1.3.3 Geomorphology, soil, and vegetation

The Project falls within the Yaragner Hills and Plains soil landscape mapping zone (zone 294) of the Ashburton Province (Tille 2006). The landform of the area consists of undulating stony uplands, plains, hills and ranges on the Gascoyne Complex granites and sedimentary rocks.

The soils of the upland areas are described as stony soils with red shallow loamy duplexes, red deep sandy duplexes, and red shallow loams on lower landscape positions. Smaller areas of red shallow sandy duplexes and red/brown non-cracking clays have also been reported. The main vegetation type is mulga-snakewood-prickly wattle shrubland with some spinifex grasslands and halophytic shrublands on low relief landscapes (Tille 2006).

2 SOIL ASSESSMENT METHODOLOGY

2.1 Regulatory requirements

The DMP requires an assessment of soils that are the subject of Mining Proposals. Analysis of both topsoil and subsoil layers is required and should identify the physical and geochemical properties of materials and classify them as to whether they have the potential to cause environmental harm, or contribute to or detract from success of rehabilitation and closure (DMP 2016b). Potential environmental harm might be adverse pH, high salinity, nutrient/trace element deficiencies, poorly structured soils, dispersive or sodic soils, and potentially hazardous compounds. The impacts of proposed mining activities on soil properties, and any topsoil management plan that is developed should include consideration of:

- Topsoil and subsoil characteristics in relation to plant growth;
- Harvestable topsoil and subsoil volumes;
- Estimated volumes of topsoils and subsoils required for rehabilitation;
- Stockpile dimensions (footprint) and their location on mine site plans;
- Soil harvest, preservation, and redeployment methodologies; and
- Proposed field trials relating to soil depth requirements, suitability for plant growth, and amendment/fertiliser requirements.

DMP provides guidance on the minimum set of soil parameters that should be measured as part of the development of Mining Proposals (DMP 2016b). This set includes:

- Soil pH;
- Soil salinity (Electrical Conductivity [EC]);
- Exchangeable cations;
- Particle size distribution (texture is used as a surrogate by Landloch except where potentially dispersive soils are encountered);
- Emerson dispersion test;
- Organic carbon;
- Total Phosphorus (Total P);
- Total Nitrogen (Total N);
- Available P (as phosphate); and
- Nitrate N.

These parameters specified by DMP are broadly consistent with normal assessments of soil quality and address most of the major soil properties affecting plant growth. Although specified by the DMP, Landloch does not test for Nitrate N. This is because Nitrate N is highly variable in soils and will vary with soil depth, time of sampling, and rainfall/soil moisture. The soil samples also require very careful collection and handling protocols. It is for these reasons that Landloch does not test for this parameter at the assessment stage.

2.2 Assessment methodology

2.2.1 Survey scale

Broad area project feasibility and land resource inventory studies are typically conducted at a 1:100,000 map scale which as a minimum, requires the assessment of one soil pit for every $1km^2$ (McKenzie *et al.* 2008). At this scale and with the entire lease area over $500km^2$, a more practical approach was required rather than analysing over 500 soil pits. Disturbance area polygons were drawn around the main planned mine infrastructure areas shown in Figure 5; they are Yangibana North, Spider Hill tailings storage facility (TSF1), and the Bald Hills and Frasers pits/mine infrastructure areas. Note that these disturbance areas were based on the June 2016 drawing (Wave 2016b). These disturbance areas were the focus of the soil assessment with the aim of producing a 1:100,000 soil map for the disturbance areas. The pre-deployment aim was to sample three soil pits for Yangibana North, four pits for TSF1, and ~20 for the mine infrastructure area. Soils within these three disturbance areas denoted in Figure 5 have been mapped to this higher intensity, and hence more confidence can be placed in the soil boundaries developed. Outside these areas, soils were mapped at a lower intensity, and soils types and boundaries were inferred based on the desktop review, site observations, and measured soil properties within the more detailed mapping areas.

2.2.2 Preliminary desktop review

A preliminary desktop review of available information relevant to this assessment was conducted from publically available sources. The information sources included:

- Technical Bulletins from the Department of Agriculture (WA);
- Geological maps from Geological Survey (WA), and Geoscience Australia; and
- Online journal articles.

The review of soil, geology, land systems, and vegetation attributes (summarised in Section 1) was used to develop an understanding of the soils likely to be encountered and their location within the landscape. Soil description pit locations were allocated for each land system and used to describe the different soils found in each location.

2.2.3 Field assessment

A three day field inspection was conducted by Landloch staff from the 24th of July 2016. The purpose of the field trip was to record data on soils and soil profiles, and to collect soil samples. These data were used to validate the information collated as part of the desktop review. Soils data were recorded from soil pits. The data recorded consisted of general observations of the landscape and land surfaces, and detailed descriptions of the soils and soil profiles. These data were supplemented with laboratory analysis of selected soil samples.

Description of soil profiles and landscape characteristics was conducted in accordance with McDonald *et al* (1998), and soils were classified according Isbell (1996). Broad colour names are those of Isbell (1996), while more detailed colour descriptions were defined using the Munsell Soil Colour Charts. Field pH was measured using the paste calorimetric method described by Raupach and Tucker (1959).

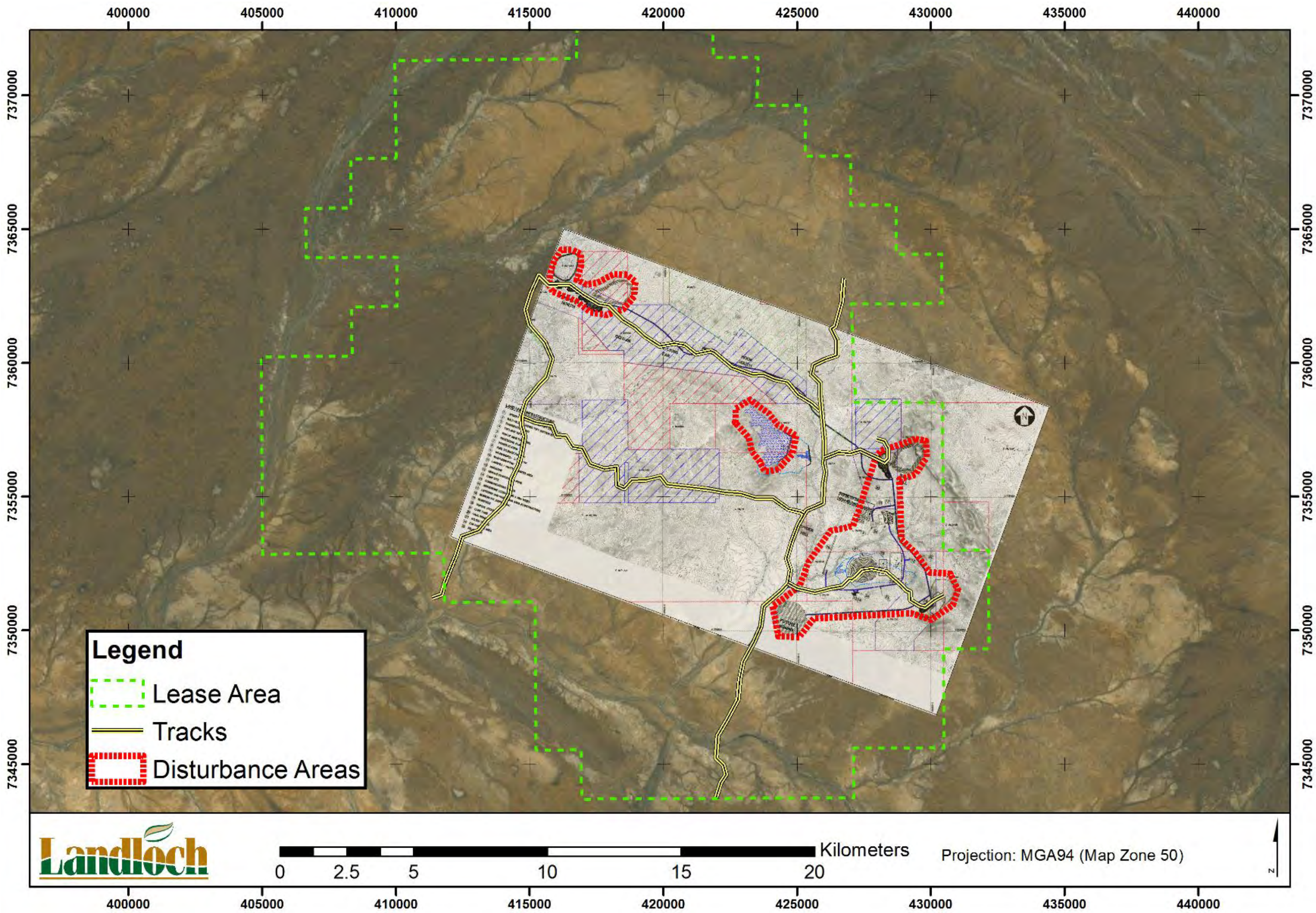


Figure 5: The lease area shown with planned mine infrastructure bounded by disturbance area polygons (red dots). (Wave 2016b).

Soil pits were excavated within the development envelope. The soil pits were constructed using a 1.6 tonne excavator to dig to a maximum depth of 1.5m, although the depth of refusal was typically much shallower at around 300-400mm. The soil pit sampling sites were numbered sequentially as they were collected during the field inspection.

At each soil pit location, observations of the topography and surface condition included:

- Location (GPS);
- Aspect and slope;
- Elevation;
- Geomorphology;
- Vegetation;
- Drainage;
- Surface condition; and
- Coarse fragment percentage.

Soils descriptions within each soil pit included:

- Depth;
- Horizonation;
- Colour;
- Field texture;
- Coarse fragment percentage;
- Structure;
- Fabric;
- Consistence; and
- Permeability.

The information collected during the pit descriptions was used to draw estimated boundaries of the different soils on hard copy maps. Locations of the soil pits are shown in Figure 6. Due to site limitations (limited exploration tracks), extensive stone surface cover with the potential to cause tyre damage, and recent rain, it was necessary to focus the pits around the existing tracks.

2.2.4 Soil characterisation

During the field visit soil samples were collected for laboratory analysis. Samples were collected from the A horizon (surface) and subsurface (B horizon) for every soil pit. The samples were returned to Landloch's Perth laboratory and an initial assessment on all samples was made by in-house tests for field pH, electrical conductivity, colour, and texture. From the initial assessment, a representative selection of each soil type (approximately 50% of the samples) were sent to a National Association of Testing Authorities (NATA) accredited soils laboratory for more detailed assessment. This approach is consistent with the *Guidelines for Surveying Soil and Land Resources* (McKenzie *et al* 2008). The soil material analysed for chemical and physical properties was labelled with a sample number corresponding to the soil pit from which the sample was sourced.

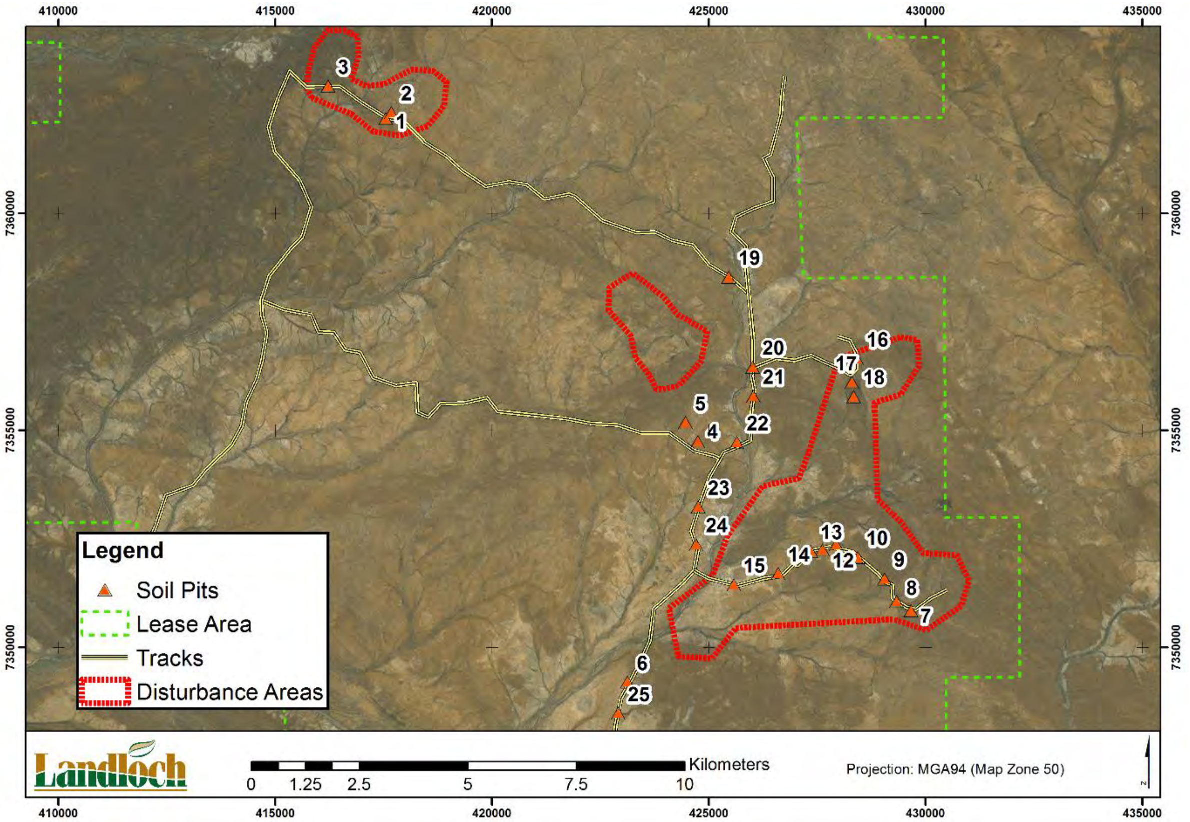


Figure 6: Soil pit locations in relation to proposed infrastructure at the Yangibana Project.

Surface soils were assessed for the following properties:

- Soil $pH_{1:5}$;
- Electrical Conductivity ($EC_{1:5}$);
- Particle size distribution (gravel, sand, silt, clay);
- Total N;
- Total P;
- Available (Colwell) P and K;
- Available Sulphur (KCl);
- Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and Al^{3+});
- Effective Cation Exchange Capacity;
- Available trace elements (Cu, Zn, Mn, and Fe);
- Organic Carbon; and
- Emerson class number.

The subsoils were assessed for the following properties:

- Soil $pH_{1:5}$;
- Electrical Conductivity ($EC_{1:5}$);
- Particle size distribution (gravel, sand, silt, clay);
- Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and Al^{3+}); and
- Effective Cation Exchange Capacity.

Test details are contained in Appendix A.

3 RESULTS

3.1 Soils of the Yangibana Project

A combination of geology and geomorphology exert the main controls over the site's soils. The main soil type is a Hill Soil that is associated with the extensive granite geology that forms the low hills and rises across the site. Typical Hill Soils are associated with extensive stone mantles and outcrops of granite and ironstone (Figure 7). A second Plain Soil was defined and is associated with low relief areas associated with the drainage lines across the site (Figure 8). A typical profile is detailed in this report but variations within this soil mapping unit will be discussed below.

Vegetation communities associated with the soil types also differed. The Hill Soils were associated with scattered low woodlands and shrublands of mulga/acacia species with grass ground cover (Figure 7), while the Plain Soils had extensive bare sandy patches in low resource areas with scatted grass and shrubs in higher resource areas, and tall eucalypt and acacia species along drainage lines (Figure 8).

The demarcation of the two soil types was defined by the soil pits, vegetation mapping, and the desktop study which delineated geology boundaries. An example is shown in Figure 9 where the bare sandy plains meets the low granite rises with more extensive vegetation cover of grasses and shrubs. The distribution of the two soil types is shown in Figure 10, including the disturbance footprint. The soil mapping area has been extended to include the latest site plan (Wave 2016a).

Figure 7: Example of low hills of the Hill Soil showing extensive stone mantle and granite outcrops.

Figure 8: Example of Plain Soil landscape with pale sandy surface with scattered small pebbles and rocks with a tree lined drainage line in the background.

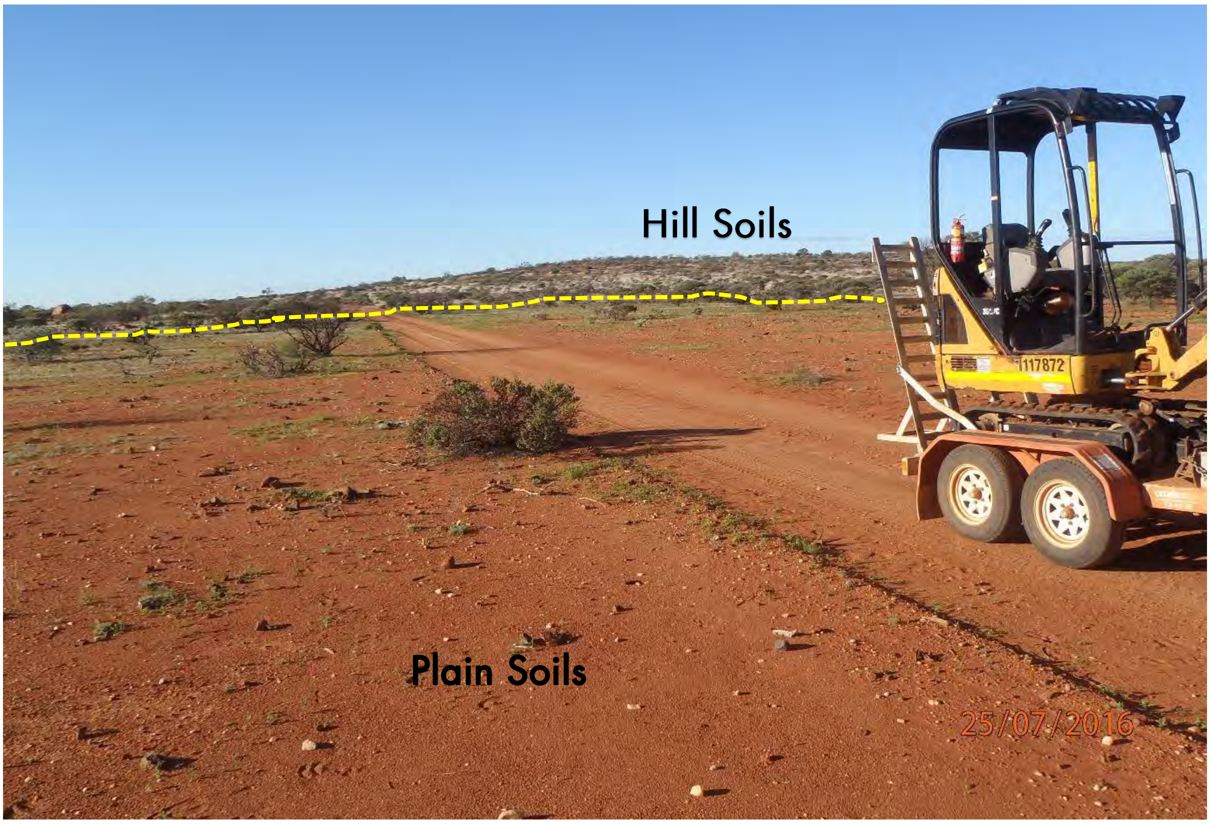


Figure 9: Example of the boundary of the Plain Soil with the Hill Soil approximately 1.5km north of the existing exploration camp along the access track.

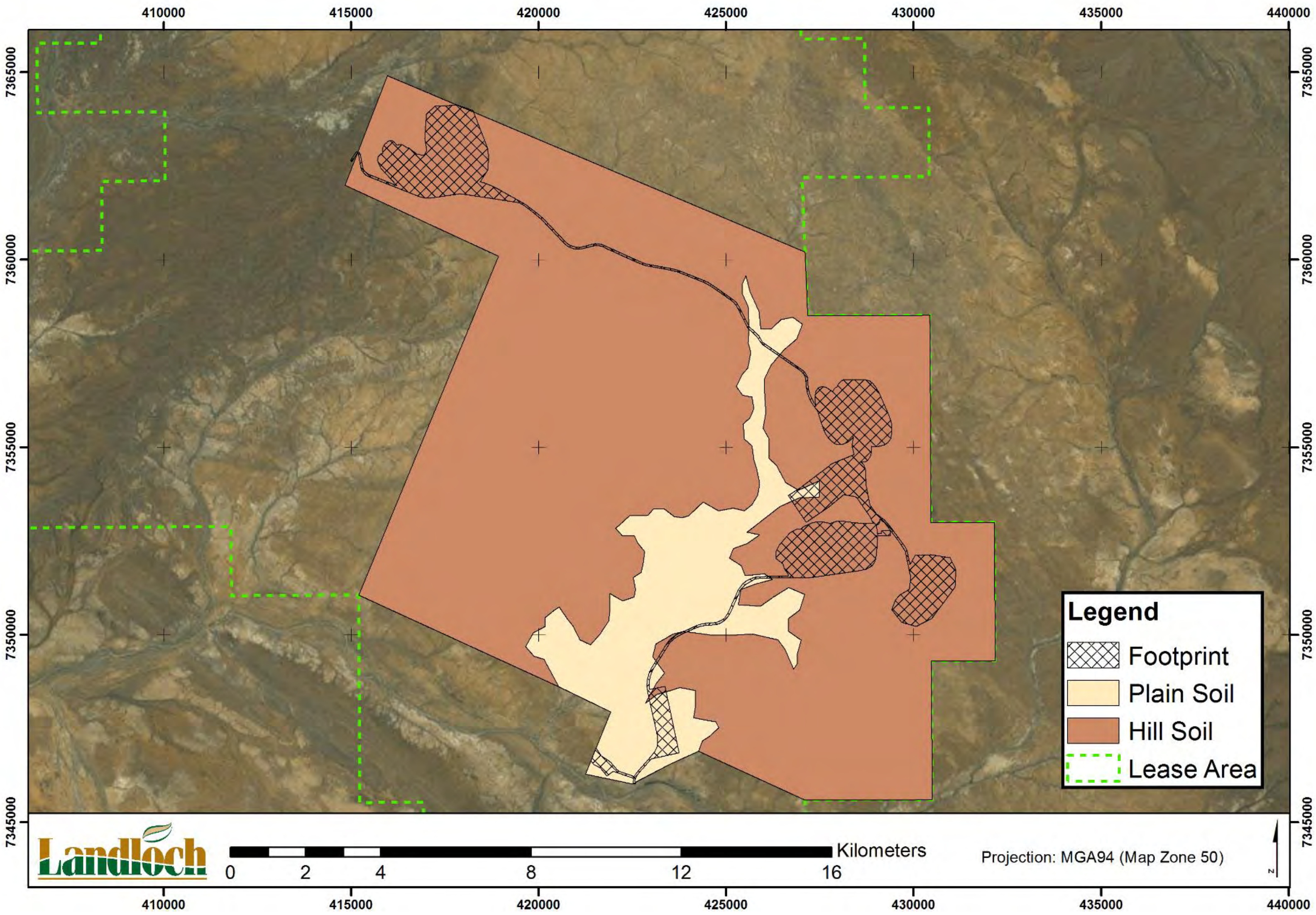


Figure 10: Soil extents of the Hill and Plain Soil types with the disturbance footprint overlain.

3.1.1 Hill Soils

The Hill Soil is associated with the granite low hills and rises of the site (see Figure 4). Depending on the landscape location, soil depths vary from shallow near hill tops adjacent to rock outcrops or more sloping hills around Bald Hills (~20cm), to 40-50cm on lower hill flanks. Figure 11 is an example of the maximum depth to which the excavator could dig.

A B

Figure 11: Range of soil depths for the Hill Soils: A) ~50cm soil pit depth near Yangibana North pit, and B) ~20cm refusal depth for a soil pit at Bald Hills.

The Hill Soil is a dark brown sandy duplex soil and can be divided into an A and B horizon that overlies a C horizon of decomposing granite. The weathering of granite in arid areas produces sands and clays (Bettenay 1983). The A_1 horizon has a thickness of ~5-10cm, the B_2 horizon has a thickness of ~3-15cm, and the B_2 horizon was ~10-30cm thick. The surface (A_1) horizon was covered in a stone mantle but the coarse fraction (>2mm diameter) content was only ~20%. The surface horizon was massive to weakly pedal and field textures were typically sandy loams. The subsurface horizon was denoted 'B' as it is less sandy and more clay rich than the horizon immediately above. The B_1 was a dark brown, weakly pedal, loam to clay loam with few coarse fragments. The B_2 horizon was a dark brown weakly pedal clay loam (up to sandy clay). The boundaries between the horizons were often not clear due to similar colours, and were distinguished by texture changes. Figure 12 shows a Hill Soil pit with the horizons marked. Note that the A_1 appears distinct due to drying after recent rain. Also shown in Figure 12 is the smearing made by the excavator bucket which was typical in the clay rich B_2 horizon.

The Hill Soil has a neutral to slightly acidic pH that does not vary much through the profile or between soil pits. The soil has very low salinity levels ($EC_{1:5}$<0.02dS/m) and a maximum exchangeable sodium percent (ESP) of 4.7% which is below the 6% threshold and indicative of a non-sodic soil. The exception to this is the surface samples from the soil pits around the proposed Bald Hills mining area with ESP values of 7.6%. Small sub-angular blocky peds were observed in the B horizon and while extensive surface stone mantles were common with the Hill Soils (Figure 13), there were typically few coarse fragments within the soil profile. Characteristics of the Hill Soils are shown in Table 2.

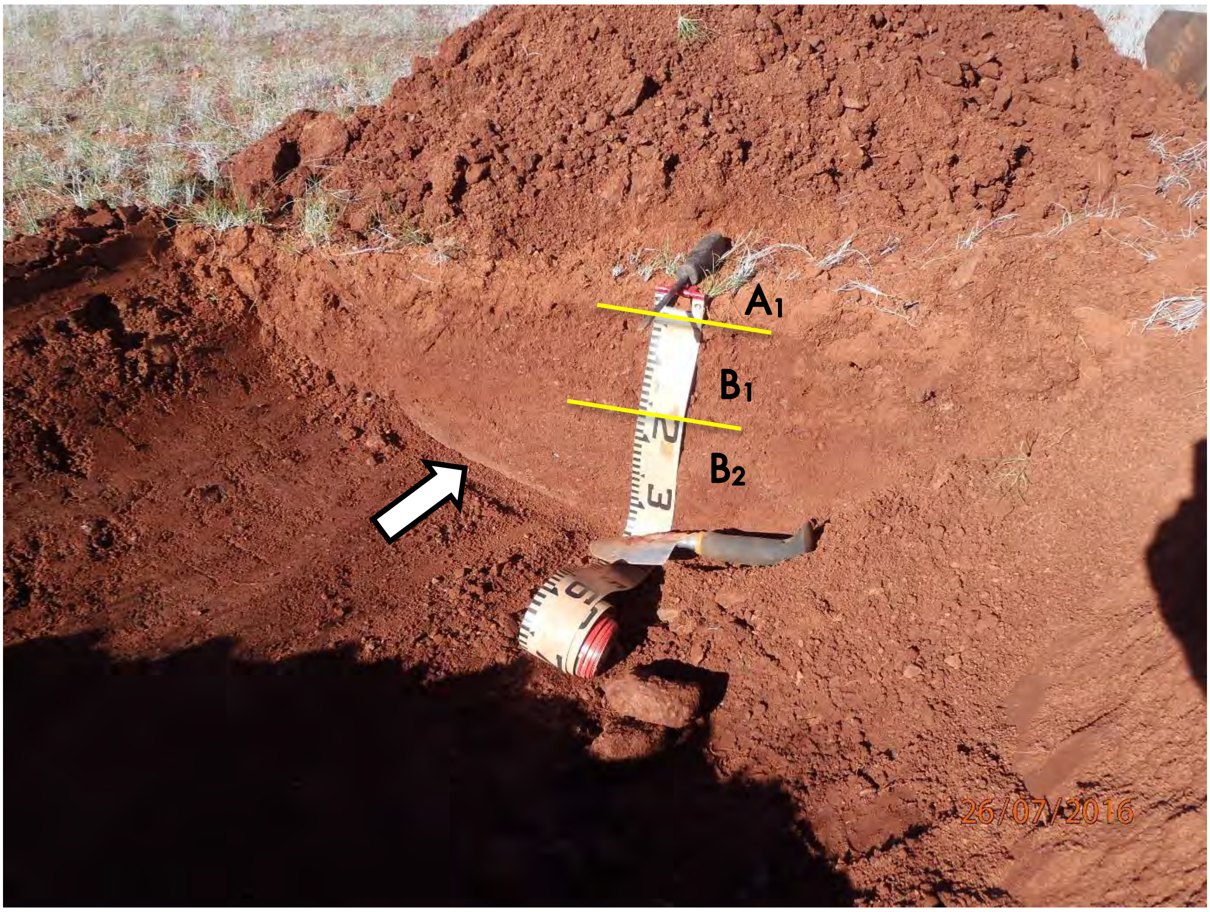


Figure 12: Horizonation of the Hill Soil. Smearing by the excavator bucket highlighted by the arrow.

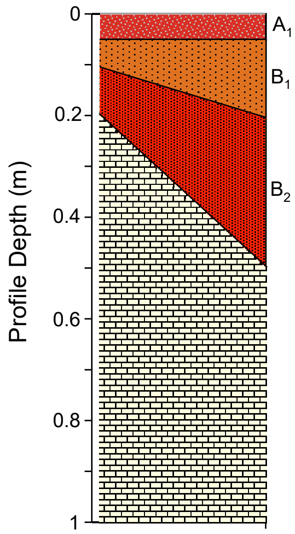
A

B

Figure 13: Examples of stone mantle variation of the Hill Soils from Fraser's access road (A) and Bald Hills (B).

Table 2: Characteristics of the Hill Soils.

Property	Inspection Site Description
Brief description	Shallow dark brown sandy loam duplexes
Extent	17,613.7ha (mapped)
Soil samples	Pit 1 to 5, 7 to 14, 16 to 19
Gradient	Gently undulating to low rises
Soil Landscape	James, Agamemnon, Glenburgh
Soil classification	Brown shallow loamy duplex^/ Brown Chromosol#
Surface coarse fragments	50–100% abundance, sub-angular pebbles to rocks of granite, ironstone, and quartz origin
Surface condition	Soft to moderate
*Permeability**	Slow to Moderate
*Water repellent**	No
*Drainage**	Sheet wash and distinct drainage lines between hills
Soil depth (cm)	**Soil Profile Description**
0–5	A_1 Dark brown (2.5YR-2.5/3), weakly structured, sandy loam, <10% coarse pebble fragments, pH 6.5 (field)
5-20	B_1 Dark brown (2.5YR-2.5/4), weakly pedal, loam to clay loam, <5% coarse fragments, pH 6 (field)
20-40	B_2 Dark brown (2.5YR-2.5/4), weakly pedal, clay loam, <5% coarse pebble fragments, pH 6 (field)
>40	C Decomposing grey granite (but also red/yellow)



* Glossary of terms contained in Appendix B. ^ Schoknecht & Pathan 2013 # Isbell 1996

3.1.2 Plain Soils

The Plain Soils are associated with the low relief areas and flood plains of the drainage lines of the site. There is a thin surface sandy loam topsoil overlying a silty loam subsoil. These soils are areas of recent deposition and will be influenced by the nature and frequency of past flooding events, and the character of the contributing catchment. The Plain Soils tended to be shallow (<30cm), but the depth of refusal was a function of the clay hardpan encountered, most likely the result of wetting and baking of the clayey subsoil. As seen in Figure 14, changing to a narrower bucket on the excavator had little effect in penetrating this layer.

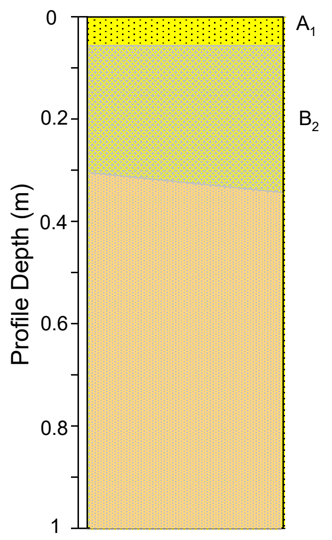
The Plain Soil is a dark brown sandy loam over clay loam. The A_1 horizon is approximately 5cm think over a B_2 horizon that is 20-30cm thick. The soil is massive (i.e., weak) in structure, strongly alkaline throughout the profile, saline ($EC_{1:5}$ 0.55 - 9.35dS/m), and sodic (ESP 2.85 – 33.96%). There appears large surface areas of bare quartz sand and pebbles which are most likely due to sheet wash (Figure 15). The characteristics of the Plain Soils are shown in Table 3.

Figure 14: Plain Soil depth of resistance and narrow excavator bucket scraping indicated by the arrow.

Figure 15: Plain Soil surface coarse fragments.

Table 3: Characteristics of the Deep Yellow Sands.

Property	Inspection Site Description
Brief description	Loamy sand over alkaline silty clay
Extent	2,419.9ha (mapped)
Soil samples	Pit 6, Pit 20-25
Gradients	Flat
Soil Landscape	Nadarra
Soil classification	Shallow brown sandy duplex^/Brown Sodosol#
Surface coarse fragments	<5%
Surface condition	Soft – Thin Surface Crust
Permeability	Moderate
Water repellent	No
Drainage	Surface sheet
Soil depth (cm)	**Soil Profile Description**
0–5	A_1 Dark brown (2.5YR-3/6), massive, loamy sand, few coarse fragments, pH ~8.5 (field)
10-30	B_2 Dark brown (2.5YR-3/6), massive, silty clay, few coarse fragments, pH ~9 (field)



* Glossary of terms contained in Appendix B. ^ Schoknecht & Pathan 2013 # Isbell 1996

3.1.2.1 Variations within the Plain Soil unit

At the scale of mapping and time constraints, it was not possible to accurately map the variations that exist within the Plain Soil type. The description above is of a typical profile observed in the field, but other soil types of limited (but not insignificant) extents were also observed.

The soils around the creek lines are included in the Plain Soil types. They range from sandy gravels within the creek bed (Figure 16A) to silts and clays with rounded stones and rock proximal to the drainage lines (Figure 16B). No major mine infrastructure is planned across creek lines and this recent alluvial soil is not expected to be disturbed.

A B

Figure 16: Recent alluvial soils around drainage lines in the Plain Soil type; A) gravel creek bed, and B) clay, silts, and rounded stones and rocks adjacent to creek lines.

The other soil type encountered within the Plain Soil was that at Pit 15 (data is given below in Table 8). It was deeper than the typical Plain Soil, saline, sodic, and clay-rich. The profile was more mottled that the other Plain Soils and was red/yellow/white in appearance (Figure 17). In the 1:100,000 geology map (Martin *et al*. 2005), there are areas mapped as 'weathered quartzofeldspathic rocks' (Figure 18) which is an older (~65Ma) geological unit as opposed to the more recent alluvials and colluvials that are more typical of the Plain Soil type. There is potential to disturb this soil type with the construction of the proposed infrastructure and as this will be difficult to stockpile and rehabilitate, the best option may be to minimise its disturbance. Alternately, further studies to define its extent should be conducted.

Figure 17: Pit 15 showing older weathered relict soil.

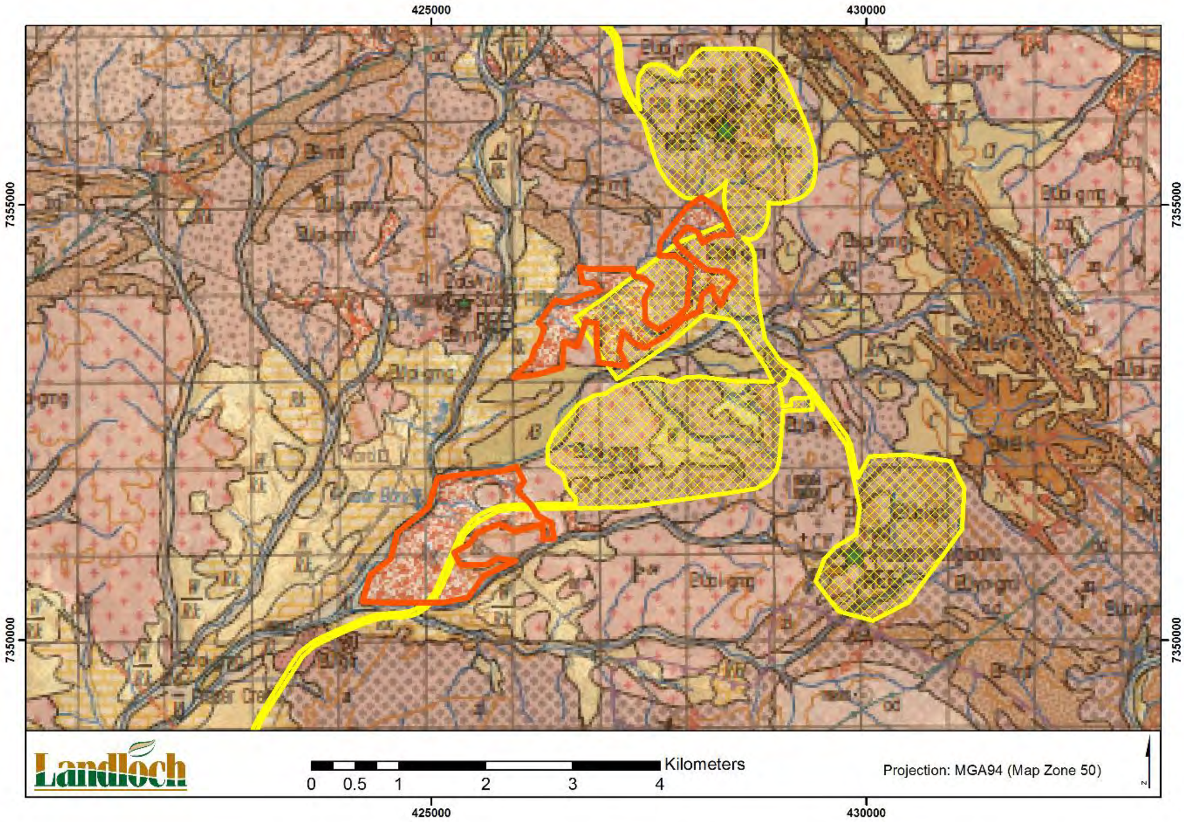


Figure 18: Weathered quartzofeldspathic rocks (orange lines) from the 1:100,000 geology map (Martin *et al.* 2005) in relation to planned mine infrastructure disturbance footprint (yellow hatching).

3.2 Laboratory analysis

3.2.1 Soil analysis results

Laboratory results are shown in Tables 4-7 (Hill Soil) and Table 8 (Plain Soil), and are interpreted against industry standards using references such as *Interpreting Soil Test Results* (Hazelton and Murphy, 2011), and against Landloch's database of soil characterisation data. For soil chemistry, much of the descriptive criteria within industry standards was developed for the agricultural industry that focuses on exotic crops that have very specific chemical and nutrient requirements. So when soil fertility results are described as 'very low,' it is important to note that the native vegetation in the Yangibana Project area have adapted to low nutrient status conditions. For reference, an agricultural guide has been included in Appendix C. High levels of salinity and ESP have been highlighted in red.

It should also be noted that results listed in the following tables are for soils from a selection of soil pits. It is therefore prudent to consider the results as an indication of the nature of the site's undisturbed soils. Although adequate at the proposal stage, further testing will be required if the project is approved to gain a more detailed understanding of the soils for long term storage and use to rehabilitate the mine at closure.

Table 4: Chemical and physical soil test results for the Yangibana Project.

Analyses		Unit	Sample ID					
			Hill Soils					
			YG1-05	YG1-515	YG1-20	YG3-05	YG3-520	YG3-20
			0-5cm	***5-15cm***	***>20cm***	***0-5cm***	***5-15cm***	***>20cm***
pH1:5		*pH units*	6.86	6.97	6.92	6.51	6.34	6.62
Electrical Conductivity (EC1:5)		*dS/m*	0.01	0.01	0.01	0.01	0.01	0.02
Total Nitrogen		*mg/kg*	300	*	*	273	*	*
Total Phosphorus		*mg/kg*	364	*	*	552	*	*
Organic Carbon		*%*	0.14	*	*	0.14	*	*
Plant Available Nutrients	*Phosphorus - Colwell*	mg/kg	19.4	*	*	21.8	*	*
	Potassium - Colwell	mg/kg	187	*	*	235	*	*
	Sulphur - KCl	mg/kg	4.7	*	*	4.3	*	*
	Copper – DTPA	mg/kg	0.9	*	*	1.04	*	*
	Iron – DTPA	mg/kg	14	*	*	13.4	*	*
	Manganese – DTPA	mg/kg	9.45	*	*	12.7	*	*
	Zinc – DTPA	mg/kg	0.69	*	*	1.23	*	*
Exchangeable Cations	*Calcium*	meq/100g	3.19	2.31	3.28	1.67	2.06	4.50
	Magnesium	meq/100g	1.97	2.09	2.55	1.04	0.98	1.29
	Potassium	meq/100g	0.28	0.27	0.24	0.36	0.32	0.28
	Sodium	meq/100g	0.22	0.23	0.22	0.14	0.13	0.19
	Aluminium	meq/100g	0.01	0.01	0.01	0.01	0.01	0.01
	Effective Cation Exchange Capacity	meq/100g	5.66	4.91	6.29	3.22	3.48	6.26
	Exchangeable Sodium Percentage	%	3.92	4.67	3.44	4.44	3.61	3.11
Particle Size Distribution of Fine Fraction	*Coarse Sand 0.2-2.0mm*	%	45.3	45.3	44.4	38.3	39.1	44.2
	Fine Sand 0.02-0.2mm	%	36.0	34.3	31.3	44.9	38.4	34.3
	Silt 0.002-0.02mm	%	6.6	6.5	6.5	4.6	6.6	4.6
	Clay <0.002mm	%	12.1	13.8	17.8	12.1	15.9	16.9
Dispersion Index		*Class*	2	2	2	2	2	2

NB: $EC_{1:5}$: Electrical conductivity as measured in a 1:5 soil water solution
$pH_{1:5}$: Soil pH as measured in a 1:5 soil water solution
Exchangeable cations expressed as a ratio of the cation concentration and the ECEC.

ECEC: Effective Cation Exchange Capacity
Clay <0.002 mm, Silt 0.002–0.02 mm, Fine sand 0.02–0.2 mm, Coarse sand 0.2-–2.0 mm, Gravel >2.0 mm
* Below detection limit

Table 5: Chemical and physical soil test results for the Yangibana Project.

Analyses		Unit	Sample ID					
			Hill Soils					
			YG5-05	YG5-515	YG5-20	YG7-05	YG7-510	YG7-20
			0-5cm	*5-15cm*	*>20cm*	*0-5cm*	*5-15cm*	*>20cm*
$pH_{1:5}$		*pH units*	6.41	6.45	6.83	6.49	6.69	6.78
Electrical Conductivity ($EC_{1:5}$)		*dS/m*	0.01	0.01	0.01	0.01	0.01	0.02
Total Nitrogen		*mg/kg*	305	*	*	407	*	*
Total Phosphorus		*mg/kg*	200	*	*	407	*	*
Organic Carbon		*%*	0.17	*	*	0.27	*	*
Plant Available Nutrients	*Phosphorus - Colwell*	mg/kg	19.8	*	*	23.3	*	*
	Potassium - Colwell	mg/kg	189	*	*	232	*	*
	Sulphur - KCl	mg/kg	3.8	*	*	3.1	*	*
	Copper – DTPA	mg/kg	0.61	*	*	0.53	*	*
	Iron – DTPA	mg/kg	14.3	*	*	10.6	*	*
	Manganese – DTPA	mg/kg	3.55	*	*	2.6	*	*
	Zinc – DTPA	mg/kg	0.74	*	*	1.05	*	*
Exchangeable Cations	*Calcium*	meq/100g	1.20	1.58	3.66	1.82	2.19	4.24
	Magnesium	meq/100g	1.08	1.10	1.88	1.67	2.03	2.73
	Potassium	meq/100g	0.23	0.21	0.25	0.31	0.30	0.27
	Sodium	meq/100g	0.12	0.12	0.16	0.13	0.12	0.18
	Aluminium	meq/100g	0.01	0.01	0.01	0.01	0.01	0.01
	Effective Cation Exchange Capacity	meq/100g	2.63	3.02	5.96	3.93	4.63	7.43
	Exchangeable Sodium Percentage	%	4.51	4.07	2.73	3.22	2.61	2.36
Particle Size Distribution of Fine Fraction	*Coarse Sand 0.2-2.0mm*	%	62.0	65.7	62.8	35.7	42.4	44.4
	Fine Sand 0.02-0.2mm	%	27.4	21.8	19.0	44.2	38.2	29.9
	Silt 0.002-0.02mm	%	6.4	8.3	4.5	8.3	3.8	5.8
	Clay <0.002mm	%	4.2	4.2	13.7	11.7	15.6	19.8
Dispersion Index		*Class*	2	2	2	2	2	2

NB: $EC_{1:5}$: Electrical conductivity as measured in a 1:5 soil water solution
$pH_{1:5}$: Soil pH as measured in a 1:5 soil water solution
Exchangeable cations expressed as a ratio of the cation concentration and the ECEC.

ECEC: Effective Cation Exchange Capacity
Clay <0.002 mm, Silt 0.002–0.02 mm, Fine sand 0.02–0.2 mm, Coarse sand 0.2–-2.0 mm, Gravel >2.0 mm
* Below detection limit

Landloch

Table 6: Chemical and physical soil test results for the Yangibana Project.

Analyses		Unit	Sample ID					
			Hill Soils					
			YG10-05	YG10-515	YG10-20	YG13-05	YG13-515	YG13-20
			0-5cm	*5-15cm*	*>20cm*	*0-5cm*	*5-15cm*	*>20cm*
pH1:5		*pH units*	6.58	6.5	6.56	6.35	6.54	6.67
Electrical Conductivity (EC1:5)		*dS/m*	0.01	0.01	0.01	0.01	0.01	0.01
Total Nitrogen		*mg/kg*	259	*	*	338	*	*
Total Phosphorus		*mg/kg*	320	*	*	316	*	*
Organic Carbon		*%*	0.11	*	*	0.21	*	*
Plant Available Nutrients	*Phosphorus - Colwell*	mg/kg	29.4	*	*	17.5	*	*
	Potassium - Colwell	mg/kg	195	*	*	250	*	*
	Sulphur - KCl	mg/kg	3.7	*	*	4	*	*
	Copper – DTPA	mg/kg	0.64	*	*	0.67	*	*
	Iron – DTPA	mg/kg	14.7	*	*	14	*	*
	Manganese – DTPA	mg/kg	3.78	*	*	6.25	*	*
	Zinc – DTPA	mg/kg	0.48	*	*	0.78	*	*
Exchangeable Cations	*Calcium*	meq/100g	1.41	1.98	2.13	1.20	1.84	5.03
	Magnesium	meq/100g	1.42	1.63	1.29	1.69	2.13	3.47
	Potassium	meq/100g	0.26	0.26	0.13	0.28	0.31	0.66
	Sodium	meq/100g	0.11	0.14	0.15	0.10	0.12	0.19
	Aluminium	meq/100g	0.02	0.01	0.01	0.01	0.01	0.01
	Effective Cation Exchange Capacity	meq/100g	3.20	4.01	3.70	3.28	4.40	9.35
	Exchangeable Sodium Percentage	%	3.34	3.37	3.95	3.11	2.67	2.02
Particle Size Distribution of Fine Fraction	*Coarse Sand 0.2-2.0mm*	%	52.7	56.2	60.3	52.9	57.2	52.1
	Fine Sand 0.02-0.2mm	%	33.8	32.0	29.1	32.4	27.7	21.6
	Silt 0.002-0.02mm	%	5.6	3.8	3.7	6.9	9.0	7.4
	Clay <0.002mm	%	7.8	8.0	6.9	7.7	6.1	18.9
Dispersion Index		*Class*	2	2	2	2	2	6

NB: $EC_{1:5}$: Electrical conductivity as measured in a 1:5 soil water solution
$pH_{1:5}$: Soil pH as measured in a 1:5 soil water solution
Exchangeable cations expressed as a ratio of the cation concentration and the ECEC.

ECEC: Effective Cation Exchange Capacity
Clay <0.002 mm, Silt 0.002–0.02 mm, Fine sand 0.02–0.2 mm, Coarse sand 0.2-–2.0 mm, Gravel >2.0 mm
* Below detection limit

Table 7: Chemical and physical soil test results for the Yangibana Project.

Analyses		Unit	Sample ID				
			Hill Soils				
			YG16-05	YG16-515	YG16-20	YG18-05	YG18-515
			0-5cm	*5-15cm*	*>20cm*	*0-5cm*	*5-15cm*
pH1:5		*pH units*	7.8	7.58	7.64	7.53	8.11
Electrical Conductivity (EC1:5)		*dS/m*	0.03	0.01	0.08	0.02	0.04
Total Nitrogen		*mg/kg*	452	*	*	325	*
Total Phosphorus		*mg/kg*	318	*	*	365	*
Organic Carbon		*%*	0.26	*	*	0.19	*
Plant Available Nutrients	*Phosphorus - Colwell*	mg/kg	5.98	*	*	13.2	*
	Potassium - Colwell	mg/kg	319	*	*	209	*
	Sulphur - KCl	mg/kg	5.6	*	*	4.5	*
	Copper – DTPA	mg/kg	1.22	*	*	0.74	*
	Iron – DTPA	mg/kg	13.5	*	*	11.7	*
	Manganese – DTPA	mg/kg	17	*	*	9.88	*
	Zinc – DTPA	mg/kg	0.59	*	*	0.44	*
Exchangeable Cations	*Calcium*	meq/100g	0.91	1.19	8.37	0.85	5.93
	Magnesium	meq/100g	1.13	1.38	5.59	0.91	4.69
	Potassium	meq/100g	0.25	0.19	0.12	0.16	0.17
	Sodium	meq/100g	0.19	0.17	0.43	0.15	0.37
	Aluminium	meq/100g	0.01	0.01	0.01	0.01	0.01
	Effective Cation Exchange Capacity	meq/100g	2.49	2.93	14.52	2.07	11.16
	Exchangeable Sodium Percentage	%	7.64	5.86	2.97	7.42	3.30
Particle Size Distribution of Fine Fraction	*Coarse Sand 0.2-2.0mm*	%	17.8	20.8	49.0	44.2	51.9
	Fine Sand 0.02-0.2mm	%	61.8	48.2	30.6	37.9	32.3
	Silt 0.002-0.02mm	%	13.3	13.3	7.9	12.8	7.7
	Clay <0.002mm	%	7.1	17.6	12.4	5.0	8.1
Dispersion Index		*Class*	7	2	2	7	7

NB: $EC_{1:5}$: Electrical conductivity as measured in a 1:5 soil water solution
$pH_{1:5}$: Soil pH as measured in a 1:5 soil water solution
Exchangeable cations expressed as a ratio of the cation concentration and the ECEC.

ECEC: Effective Cation Exchange Capacity
Clay <0.002 mm, Silt 0.002–0.02 mm, Fine sand 0.02–0.2 mm, Coarse sand 0.2-–2.0 mm, Gravel >2.0 mm
* Below detection limit

Table 8: Chemical and physical soil test results for the Yangibana Project.

Analyses		Unit	Sample ID					
			Plain Soils					
			YG15-05	YG15-515	YG15-20	YG25-05	YG25-515	YG25-20
			0-5cm	*5-15cm*	*>20cm*	*0-5cm*	*5-15cm*	*>20cm*
$pH_{1:5}$		*pH units*	8.91	8.63	6.43	9.11	8.08	7.84
Electrical Conductivity ($EC_{1:5}$)		*dS/m*	0.55	1.49	6.06	2.24	7.26	9.35
Total Nitrogen		*mg/kg*	232	*	*	320	*	*
Total Phosphorus		*mg/kg*	190	*	*	269	*	*
Organic Carbon		*%*	1.01	*	*	0.14	*	*
Plant Available Nutrients	*Phosphorus - Colwell*	mg/kg	6.72	*	*	13.9	*	*
	Potassium - Colwell	mg/kg	311	*	*	647	*	*
	Sulphur - KCl	mg/kg	14	*	*	26.4	*	*
	Copper – DTPA	mg/kg	0.33	*	*	0.59	*	*
	Iron – DTPA	mg/kg	7.76	*	*	9.15	*	*
	Manganese – DTPA	mg/kg	0.41	*	*	1.13	*	*
	Zinc – DTPA	mg/kg	0.23	*	*	0.27	*	*
Exchangeable Cations	*Calcium*	meq/100g	1.73	2.04	44.65	1.58	2.00	2.40
	Magnesium	meq/100g	0.73	0.64	1.22	0.97	1.18	1.47
	Potassium	meq/100g	0.32	0.34	0.44	0.54	0.51	0.33
	Sodium	meq/100g	0.35	0.48	1.36	1.59	1.22	0.92
	Aluminium	meq/100g	0.01	0.01	0.01	0.01	0.01	0.01
	Effective Cation Exchange Capacity	meq/100g	3.14	3.50	47.67	4.67	4.90	5.11
	Exchangeable Sodium Percentage	%	11.27	13.68	2.85	33.96	24.84	18.02
Particle Size Distribution of Fine Fraction	*Coarse Sand 0.2-2.0mm*	%	34.9	37.1	43.1	34.6	28.5	28.9
	Fine Sand 0.02-0.2mm	%	30.7	28.8	29.7	27.8	29.2	28.6
	Silt 0.002-0.02mm	%	12.9	9.6	9.5	16.7	15.2	14.6
	Clay <0.002mm	%	21.4	24.6	17.6	20.8	27.1	27.8
Dispersion Index		*Class*	2	6	6	2	2	7

NB: $EC_{1:5}$: Electrical conductivity as measured in a 1:5 soil water solution
$pH_{1:5}$: Soil pH as measured in a 1:5 soil water solution
Exchangeable cations expressed as a ratio of the cation concentration and the ECEC.

ECEC: Effective Cation Exchange Capacity
Clay <0.002 mm, Silt 0.002–0.02 mm, Fine sand 0.02–0.2 mm, Coarse sand 0.2–-2.0 mm, Gravel >2.0 mm
* Below detection limit

4 DISCUSSION

4.1 Soil chemistry results

4.1.1 Material $pH_{1:5}$ and salinity ($EC_{1:5}$)

The materials' pH and electrical conductivity (EC) were measured using a 1 part soil to 5 parts deionised water solution. The pH of the Hill Soil was slightly alkaline to slightly acid, while the Plain Soils are characterised by strongly alkaline pH.

The Hill Soil typically has very low salinity levels $EC_{1:5}$ values (<0.2dS/m), which is in contrast to the Plain Soils that had values up to 9.35dS/m. This is most likely due to the deposition of salt by repeated flooding and drying. Although native vegetation has found resource-rich areas within the Plain Soils on which to grow, establishing seedlings in this saline material will prove difficult.

4.1.2 Effective cation exchange capacity and exchangeable cations

The ECEC is a measure of a materials' ability to adsorb and hold cations, and can be used in conjunction with clay content to indicate clay mineralogy[1]. The ECEC values measured for the Hill Soil was 2.5-14.5meq/100g, but typically <6 meq/100g which is considered very low. The Plain Soil had ECEC results of 3.1-5.1meq/100g, with one result as high as 47.7meq/100g.

When considered in conjunction with clay content, the ECEC values indicate that the dominant clay type will be a 1:1 class (such as kaolin) in the Plain Soils, typical of highly weathered soils. Kaolinitic soils tend to have low nutrient status and are not reactive (shrink and swell when wet). The Hill Soils' clay content indicates that they are of mixed mineralogy, with the potential to contain montmorillonite that may shrink/swell when dried and wetted. However, this behaviour was not evident of the soil in the field.

4.1.3 Exchangeable sodium percentage and structural stability

The exchangeable sodium percentage (ESP) value of a material is an indicator of clay dispersion potential. Materials with an appreciable dispersive clay fraction tend to be prone to tunnel erosion, hardsetting, and are prone to high levels of runoff and surface erosion.

The typical threshold value for soils of concern is an ESP >6%. However, whether or not a material will actually disperse is a function of complex interactions between exchangeable cation concentrations, salinity, and clay content. Most of the Hill Soil had low ESP, low exchangeable Na (<0.3meq/100g) and clay contents of 4-20% and would not present a dispersion risk. The possible exception is the soils from around the Bald Hills area (Pits 16 and 18) where the surface samples had ESP values of ~7.5%. However, the low clay content (<7%),

[1] Samples with EC>0.3dS/m were washed of dissolved salts prior to testing for exchangeable cations and ECEC.

low exchangeable Na <0.19meq/100g), and low ECEC (<2.5meq/100g) would mean that the dispersion risk is low.

In contrast, the Plain Soils had high ESP, high exchangeable Na, and high clay contents which would indicate that these soils would represent a significant risk of dispersion if disturbed. They also have high salinity values which may be preserving soil structural stability at present, but if stripped, stockpiled, and respread the free salts may leach out of the soil via percolating rain and lead to increasing soil instability.

4.1.4 Emerson test

The Emerson dispersion test is a simple method to determine the behaviour of soil aggregates when rapidly wet by water. It is an indicator of clay dispersion potential. Class 1 is highly dispersive and Class 8 is highly aggregated in water (Figure 19). A classification range for the Hill Soil was mainly 2 (with some Class 6), and indicates that there is a risk of dispersion, while the Plain Soil has ranges from 2 to 7. Based on the discussion in Section 4.1.3 above, it appears that these results are influenced by the salinity status of the soils. The very low salinity of the Hill Soils is leading to the clayey soils to slake, and the high salinity of the Plain Soils is indicating stability. Considered together with ECEC, exchangeable Na, and clay content the Plain Soils represent a high dispersion risk, and Hill Soils low risk.

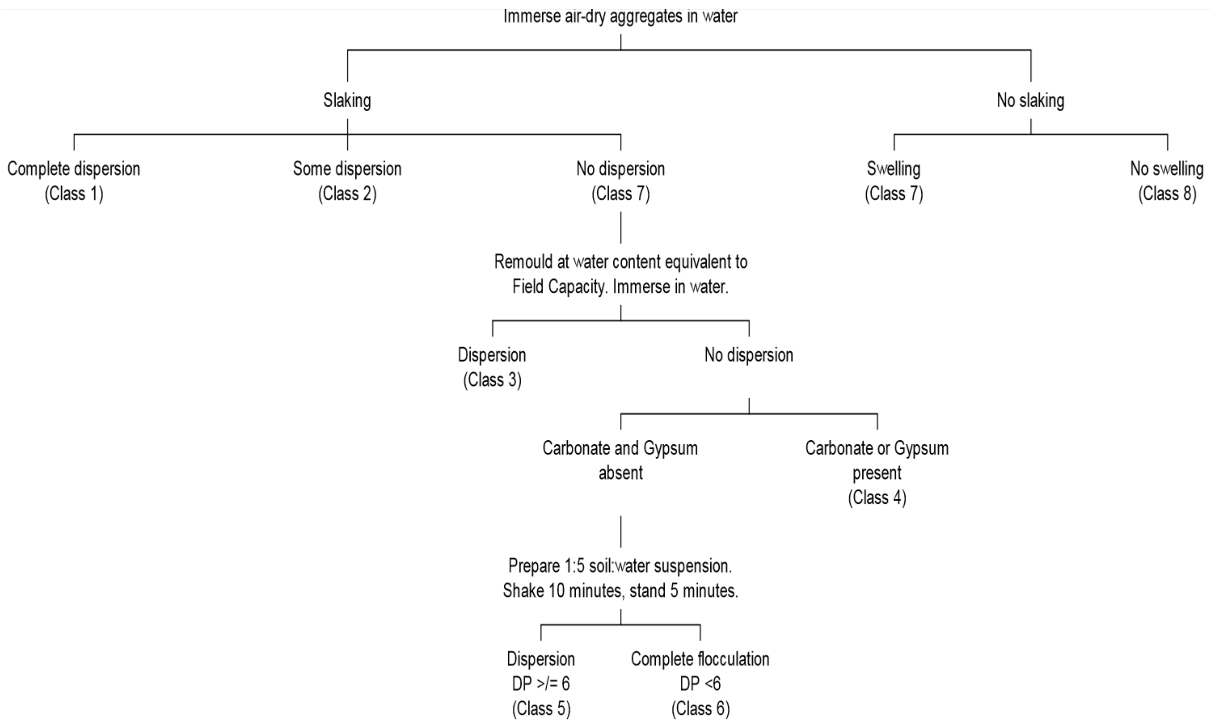


Figure 19: The Emerson classification system of soil based on its dispersion in water (Australian Standards 1997).

4.1.5 Fertility

The arid zone soils of the Western Region are characterised by their low fertility (Bettenay 1983). This reflects their deep weathering, strong leaching, overgrazing, low rainfall and little input of organic material.

All the soils assessed in this report had low nutrient status for total N, total P, plant-available P, plant available K, and organic C. For the arid Gascoyne region, these macro and micro nutrient results are typical. Only species that are adapted to this low nutrient environment should be re-established to ensure long term self-sustainability. Much of arid zone soil fertility is stored in the biomass. Therefore disturbance of these soils by vegetation clearing and stripping is likely to reduce the nutrient status of the soils (to even lower levels) and as such, irrespective of their inherent low fertility, it is likely that application of amendments (fertiliser) will be required during rehabilitation activities to increase the likelihood of successful of vegetation establishment.

4.1.6 Summary of soil properties

From the analysis results and observations of the different soil types in the field, it can be broadly stated that:

- Both soils within the development envelope have low fertility (which is normal for an arid zone soil), are clay rich, are poorly or not well structured, and represent an erosion risk if used on the sloping constructed surfaces of features such as waste dumps. TSFs, or the batters of mining voids;
- The main limiting soil factor for the Hill Soils will be the clay-rich subsoil as it will impact on stripping, stockpiling, and respreading methods;
- The main limiting factor for the Plain Soils will be the potential for clay dispersion once free salts are leached from the profile due to its sodic nature;
- The Hill Soil will require amendment for low fertility in order for them to be used in rehabilitation; and
- The Plain Soil will require specific management if they are to be disturbed, and disturbance should be avoided if possible.

As these conclusions are based on a limited number of samples, continual monitoring of the stockpiled soils' physical and chemical properties is advised during the construction and operation phase.

5 SOIL MANAGEMENT

5.1 Disturbance of Yangibana Soils

The following discussion is based on the management of disturbance of the natural Yangibana soils. Most of the proposed mining infrastructure occurs within the Hill Soil landscape, and smaller areas of offices, workshops, airstrip and camp occur on the Plain Soil.

The proposed site layout supplied to Landloch from Ecoscape (Wave 2016b) and shown in Figure 5 was used to plan the field sampling campaign. The latest site plan (Wave 2016a) shown in Figure 2 has a disturbance footprint within an extensive development area. The area of the individual elements (e.g., airstrip, open pits) within the disturbance footprint from Wave (2016a) are used for the purposes of calculating the soil resource volume.

5.2 Available soil resource

The Hill Soil is the superior resource for rehabilitation in comparison to the Plain Soil. In areas of Plan Soil disturbance, the aim should be to replace the soil in the same location with topsoil over subsoil. As the Plain Soil is associated with low relief areas, so should its placement be restricted to flat areas. If the Plain Soil is used to construct sloping features such as batters or dam walls, it will be highly prone to erosion, including both surface and tunnel erosion. Placement of the Plain Soil back into low-relief and low gradient areas will effectively manage the risk of erosion from these materials. The example shown in Figure 20 is an eroding and tunnelling sodic soil from Queensland.

Figure 20: Sodic soil batter in Queensland.

5.2.1 Soil extent and volumes

Ideally topsoils should be stripped to a depth of 10cm so as to selectively harvest the soil containing the highest amounts of seed, biological activity, and fertility. It should be noted that the stone surface mantle should not be pre-stripped as this rock component will add to the erosional stability of the material when it is used for rehabilitation. A further 30cm of subsoil is also recommended to be stripped, although this depth will vary depending on the depth to the weathered granite. The estimation of recoverable soil materials is made with the following assumptions:

- Topsoil and subsoil will be stripped from all locations where land disturbance will occur; and
- A planar surface was used to calculate the soil type areal extents.

GIS software was used to calculate the disturbance area from the supplied .dxf drawings and PDF file as described above. The disturbance areas are shown in Table 9.

Table 9: Disturbance areas by soil type for the Yangibana Project.

Disturbance Type	Area (ha)	
	Hill Soil	Plain Soil
Yangibana North pit and dumps	228	-
Bald Hills pit and dumps	111	-
Spider Hill Tailings Storage Facility 1	441	-
Workshop, offices, etc.	38	24
Airstrip	-	26
Camp	-	4
Frasers pit and dumps	104	-
Bald Hill Tailings Storage Facility 1	251	7
TOTALS	1,173ha	61ha

Therefore the soil extents within the disturbance area are:

- Hill Soil – 1,173ha
- Plain Soil – 61ha

The Yangibana Project recoverable <u>topsoil</u> volumes based on a strip depth of 10cm are:

- 1,173,000m^3 of Hill Soil
- 61,000m^3 of Plain Soil

The Yangibana Project recoverable <u>subsoil</u> volumes based on a strip depth of 30cm are:

- 3,519,000m^3 of Hill Soil
- 183,000m^3 of Plain Soil

5.2.2 The soil resource for rehabilitation

5.2.2.1 Hill Soil

The clay rich Hill Soil is erosionally stable in its natural state, but this is due to low gradients and typical cover of a stone mantle. When flows are concentrated (such as caused by road drainage) the surface soil appears readily erodible leaving a hard clay B horizon that will desiccate and provide sediment for the next storm event (Figure 21). Use of the Hill Soil in waste dump rehabilitation will require careful planning and most likely the augmentation of the topsoil with rock to increase its erosional resistance. Further testing by Landloch will provide more detail on this subject, but any source of durable, benign waste rock should be treated with equal value to the topsoil resource in terms of achieving successful mine closure.

Figure 21: Example of Hill Soil erosion around Yangibana North where concentrated flows have removed the lighter textured surface soils exposing the clay rich B horizon.

Any tree or scrub debris pushed over before soil stripping should also be preserved. Landloch has used these materials previously to design an erosionally resistant surface, even for very sandy materials. When correctly used, it not only prevents surface water concentration, but also reduces wind erosion and provides organic material, seed trapping areas, and fauna habitat.

5.2.2.2 Plain Soil

Ideally, this soil mapping unit should not be disturbed due to its chemical and physical nature. If disturbance is to occur, soils should be stripped and stockpiled with the aim of replacing them back into the disturbance footprint and not to be used elsewhere on site, such as waste landform batters.

The Plain Soils will have a tendency to set hard when dry, and be boggy and pool very muddy water when wet. Wetting and drying of this soil type may lead to the development of highly compacted areas. Disturbance areas planned on the Plain Soil should look to sheet areas that will be trafficked such as car parks to avoid these problems. Similarly, if flow structures are cut through or made from this soil type they will have to be properly managed to avoid excessive erosion, siltation, and rock barrier collapse as shown in the example in Figure 22.

Figure 22: Example of drain batter erosion in a sodic soil in Queensland.

Stockpiling Plain Soil means that although they are saline, the free salts may be leached from the profile and they will become increasingly dispersive. Stockpiles should be kept as low as possible (<2m height). Subsoils and topsoils should be stockpiled separately and amendment of the topsoil when they are respread during rehabilitation would assist the establishment and growth of vegetation. Fertiliser and potentially gypsum application (to avoid hard setting and dispersion) rates should be based on more detailed chemical characterisation when rehabilitation is due to take place.

5.3 General soil handling

Ideally, stripping and stockpiling of soils should be avoided where possible, and if stripped, soils should be directly respread to areas prepared for rehabilitation rather than stockpiled. This is because stockpiling of soils can lead to compaction, nutrient depletion, and loss of seed stock and soil microfauna. However, direct respreading is not always achievable, and stockpiles are often constructed as part of mining operations. If soil stripping and stockpiling are to be conducted, the following principles should be applied.

5.3.1 Soil stripping

Topsoil stripping to the recommended depth of 10cm should be performed at a time of year when the soil seed bank is highest. This is likely to be just after the wetter months. However, soil should not be handled when wet, as this tends to increase compaction. As previously identified, the Hill Soil would also be susceptible to smearing if stripped when wet. Care also needs to be taken to avoid stripping soils when weed infestation is high.

Inevitably, some degradation of soils will occur during stripping and other soil handling activities, with different types of machinery causing different levels of soil 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) confirms this recommendation by stating 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".*

5.3.2 Soil stockpiling

Stockpiling soils can cause structural degradation (particularly of the soil at the bottom of the stockpile) and loss of soil biota (DITR 2006). Compaction caused by stockpiling may be largely removed by soil respreading during rehabilitation works (although clay soils are more problematic), but the soil biota cannot be replaced without intervention.

Some studies have suggested that much of the loss of soil organic carbon occurs during stripping and stockpile construction (Visser *et al* 1984), and this is particularly likely in sandy soils in arid zones for which rates of organic matter loss can be relatively rapid. For example, Dalal and Mayer (1986) found that the half-life of organic carbon in the surface layer of a tilled sandy loam was only 0.6 years, whereas organic carbon in clay soils was found to have a half-life of up to 12 years.

It is commonly recommended that topsoil stockpiles should be no deeper than 1.0m, though information providing a basis for that recommendation is limited[2]. It is generally considered that stockpiling topsoils deeper than 1.0m tends to kill the topsoil seed bank and, to a lesser extent, degrade the structure of the soil at the bottom of the stockpile (Keipert *et al* 2002). This would largely negate the properties of topsoil that are advantageous to rehabilitation activities. However, at a mine site close to Laverton, WA where rainfall is relatively low, the soil moisture

[2] Interactions between soil texture, environment (particularly rainfall) and vegetation type have yet to be addressed in a logical framework.

content of the stockpiles was consistently low and seed reserves within the stockpile were not encouraged to germinate. The dry conditions within deeper stockpiles therefore enabled the preservation of the seed bank until it was respread. It has also been shown that stockpiles with a height of 2.0m had greater seed survival than 4.0m deep stockpiles (S. Lowe *pers. comm.*).

However, deeper soil stockpiles may potentially decrease the already low soil nutrients and soil microbial populations by creating anaerobic conditions at depth (Abdul-Kareem and McRae 1984). Therefore, where topsoil is stockpiled to greater depths, additional seed and fertiliser may be required to counter the reduction in soil seed bank and soil microbial propagules caused by stockpiling.

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.

Fertiliser application rates for stockpiles should be determined based on the results of field trials. The species seeded should be fast growing, and ideally leguminous to provide some nitrogen input to the soil, though care should be taken to avoid introducing weeds, and to avoid undue distortion of the natural diversity and abundance of species present in the soil seed bank. The low fertility of the available soils however may limit species selection to the locally adapted communities.

For best preservation of the soil seed bank and biota, the topsoil stockpiles should be flat-topped or slightly domed. Slight doming of the topsoil reduces the risk of waterlogging, though this is unlikely to be a significant issue at this site. Encouraging 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 seed, and respreading is likely to remove any compaction caused by stockpiling although the clay rich subsoils will require careful management. Stockpiling subsoil to greater depth also provides clear delineation between subsoil and topsoil stockpiles, reducing the risk that topsoils and subsoils will be mixed. As for topsoil stockpiles, subsoil stockpiles should be built to maximise water entry.

All 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. Weeds can be controlled by planting species that will outcompete the weeds, or by spraying herbicides.

5.3.3 Soil respreading

Once the soil has been respread and directly prior to seeding, the final topsoil surface will require light ripping to break any surface crusting. Landloch has observed surface sealing greatly impacting on germination rates, and a site-specific seeding strategy should be developed based on the specific rehabilitation material.

5.3.4 Soil amendments

The nutrient status of the soils is very low and the native vegetation is adapted to grow in this environment. However from a rehabilitation perspective, it is recommended to replace or supplement the nutrients lost through disturbance to encourage rapid establishment of vegetation.

The precise nature of these nutrient additions will in part be determined by the success of the soil stockpiling strategies outlined above. If done successfully, the topsoil can be spread containing a seed bank of target species and adequate nutritional levels to ensure good germination and growth. Soil stockpile monitoring (soil characterisation) before spreading should be undertaken to determine the nutrient status of the material. Levels should be at least comparable to those found in undisturbed soils.

Application of fertiliser to the topsoil is recommended based on the predicted low nutrient status of the bare soils in the stockpiles and the loss of nutrients caused by the removal of vegetation and disturbance of the soil. Likely fertiliser requirements are not high, and rates and types should be based on soils data for stockpiled materials.

It should be noted that the application of an immobile element such as P (as is likely to be needed) to the surface of soils that are high in iron oxide may not be successful, as the P is likely to be immobilised in the shallow surface layer and would therefore seldom be accessible to plant roots. Therefore, incorporation of fertiliser into the soil profile rather than simply applying it to the surface is strongly recommended.

The results have indicated that there is a dispersion risk for the Plain Soils and these should be left undisturbed if possible. If disturbance is unavoidable, gypsum could be added to stabilise the Plain Soil. Gypsum rates should be based on soils data for the stockpiled materials. A potential amendment programme could target the following:

- reducing the dispersion risk of the Plain Soil (if disturbed),
- decreasing the pH of the Plain Soil, and
- increasing the fertility of both soil types.

Such a programme could be implemented by following these steps:

- conduct soil sampling to assess the variability and chemical nature of the surface soils,
- design a soil amendment programme based on the soil test results,
- strip surface vegetation from the disturbance areas,
- apply soil amendments to the de-vegetated areas, and
- strip the soil materials, thus mixing the soil amendments into the soil to be stockpiled.

5.3.5 Soil monitoring protocols

If topsoil is to be stockpiled, it will require monitoring for changes in its physical and chemical condition. Monitoring should occur at a minimum of every 12 months and should record surface condition and erosion, nutrient status, pH, and EC, and seed germination rates.

The monitoring protocols should form part of the site-wide rehabilitation monitoring strategy so that if monitoring shows deterioration of the topsoil resource, this will trigger actions to address the issues.

5.3.6 Tree debris

Tree debris is often overlooked in soil assessments but can be an important resource for mine site rehabilitation. There are significant amounts of trees, shrubs, brush, and grasses across the site that could be recovered (Figure 7). The surface vegetation should be stripped separately from the topsoil, and also stored separately. The tree debris (trunk diameters greater than ~10cm) can then be used as erosion protection on steep slopes. The trees, shrubs, brushes, and grasses will also add seed, nutrients, and organic carbon to the soil.

5.4 Implications for mine closure design

Successful rehabilitation outcomes require detailed and careful planning that typically not only reduces environmental risk, but also minimises the actual cost of rehabilitation activities. However, mine planners must still design for an erosionally stable surface at closure, and Landloch has seen throughout WA's arid zone that natural stable soils become quite erodible when used to rehabilitate waste landforms, even at low gradients. Surface water control will be key for erosional stability of the final land landform surface. The early identification of competent rock and its partitioning and stockpiling will also be important for designing erosionally stable waste landforms.

Soil management during operations and rehabilitation activities will also be important. It is possible, through poor management of soil and waste resources to cause rehabilitation failure where success was very achievable. This risk exists for the Yangibana Project in the stripping, storage, and placement of soils. Careful planning and management of the soil resource will ensure this goal is met in the most efficient and cost effective manner.

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APPENDIX A. ANALYSIS METHODS USED ON TOPSOILS AND SUBSOILS

Soil Analyses	Abbreviation	Units	Methodology	Reference
pH	pH	na	1:5 soil:water	Rayment & Lyons (2011)
Electrical Conductivity	EC	dS/m	1:5 soil:water	Rayment & Lyons (2011)
Exchangeable Cations	Ex ($Ca^{2+,}$ Mg^{2+}, Na^{+}, K^{+}, Al^{3+})	meq/100 g	NH_4Cl	Rayment & Lyons (2011)
Dispersion Potential	NA	Value 1–8	Emerson Index	Australian Standard (1980)
Total Nitrogen	Total N	mg/kg	Kjeldahl	Rayment & Lyons (2011)
Total Phosphorous	Total P	mg/kg	Nitric/Perchloric	Rayment & Lyons (2011)
Available Phosphorous	Av P	mg/kg	Colwell	Rayment & Lyons (2011)
Available Potassium	Av K	mg/kg	Colwell	Rayment & Lyons (2011)
Available Sulfur	Av S	mg/kg	KCl-40	Rayment & Lyons (2011)
Organic Carbon	OC	%	Walkley–Black	Rayment & Lyons (2011)
Micro Nutrients	Cu^{2+}, Mn^{2+}, Zn^{2+}, Fe	mg/kg	Diethylamine triamine pentaacetic adic (DTPA)	Rayment & Lyons (2011)
Particle size distribution (% of clay, silt and sand)	PSD	%	Hydrometer	Rayment & Lyons (2011)
Phosphorous Buffer Index	PBI	na	PBI_{+ColP}	Rayment & Lyons (2011)
Effective Cation Exchange Capacity	*ECEC*	meq/100g	NH_4Cl	Rayment & Lyons (2011)
Exchangeable Sodium Percentage	*ESP*	%	NH_4Cl	Rayment & Lyons (2011)

Note: Not all tests were conducted on each sample. Subsoil samples were not subjected to fertility analyses.

APPENDIX B. GLOSSARY OF TERMS

Acidic	A soil property expressed by a pH that is less than 7.0 in soil/water suspension.
Active gully	Gully is actively eroding: walls, head and/or bed are unstable.
Aggregate	Unit of soil structure consisting of primary soil particles held together by cohesive forces or by secondary soil materials such as iron oxides, silica or organic matter. Aggregates may be natural, such as peds, or formed by tillage, such as crumbs and clods. See ped. Macro-aggregates are more than 250 µm in diameter and micro-aggregates are less than 250 µm.
Alluvial fan	Fan shaped deposit of alluvium (silt etc) at the mouth of a stream or gully where flows flatten out and sediment is able to fall out the flow.
Alluvium	Sediment (sand, clay, silt etc) deposited by flowing water.
Alkaline	A soil property expressed by a pH that exceeds 7.0 in soil/water suspension.
Ameliorant	A substance used to improve the chemical or physical properties of a soil. For example, gypsum to improve aggregate stability and soil structure, lime to increase pH levels.
Armouring	The accumulation of coarse (rocky) particles at the soil surface due to preferential removal of finer size fractions.
ASWAT test	'Aggregate stability in water' test – developed by Field *et al.* (1997) to assess the stability of a soil.
Biota	Soil biology – eg. earthworms, fungi and algae.
Bulk density (BD)	Ratio of the mass or weight of dry soil to its volume or bulk. Usually shown as grams per cubic centimetre. Is a measure of soil porosity and can be used to measure compaction. A high bulk density has a low porosity and is usually hardest and compacted.
Bund	An impervious embankment of earth that forms part or all of the perimeter or barrier to retain or exclude something such as water.
Cation exchange capacity (CEC)	Measure of the capacity of a soil to hold the major cations (i.e. the amount of exchange sites on negatively charged clay particles and organic matter in a soil). The major cations include calcium, magnesium, sodium, potassium and aluminium. It is also a measure of the potential fertility of the soil.

Compaction	The process whereby soil density is increased as a result of tillage, stock trampling or vehicular traffic. Compaction can lead to lower soil permeability and poorer soil aeration resulting in increased erosion hazard and poorer plant productivity. Deep ripping and conservation tillage can alleviate the condition.
Consolidation	Refers to increases in soil bulk density and cohesive strength that occur as a consequence of repeated wetting and drying under natural conditions.
Crust	See surface crust.
Degradation	Decreasing functionality and sustainability of a landscape.
Dispersive soil	Soils that are structurally unstable and disperse in water into basic particles (such as sand, silt and clay). Dispersive soils tend to be highly erodible and present problems for successfully managing earthworks.
Drainage	Refers to to the rapidity and extent of water removal from the soil profile or site. Drainage is distinct from *permeability* which refers to the rate at which water moves internally through a soil profile.
Electrical conductivity (1:5 soil:water) (EC_w)	A measure of the conduction of electricity through a soil water extract (1:5 soil:water). The value can reflect the amount of salt in a soil extract or the salinity of soil and water. Measured in DeciSeimens per metre (dS/m).
Emerson Aggregate Test	Also referred to as the slaking test – an aggregate or ped of soil is placed into distilled or rain water and assessed for slaking and dispersion characteristics. Describes the inherent stability of a soil.
Erodibility	Refers to the rate of detachment and/or movement of soil in response to some erosive force. The exact definition of erodibility varies from model to model, depending on the types of erosive forces considered. Equally, the units of erodibility may seem somewhat counter-intuitive, but are a function of the units used in calculating erosive forces. Some models, such as the Water Erosion Prediction Project (WEPP), use different erodibility factors for different erosion process.
Exchangeable cations	Cations that can be exchanged in the soil complex for or by other cations.
Exchangeable sodium percentage (ESP)	A measure of exchangeable sodium in relation to other exchangeable cations. Soils with a high ESP are typically unstable and, therefore, have high erodibility.
Gully erosion	Removal of soil in a narrow path by water erosion to considerable depths, typically deeper than 0.5 m.

Gypsum	A naturally occurring soft crystalline material, which is a hydrated form of calcium sulphate ($CaSO_4.H_2O$). Usually, gypsum contains approximately 23% calcium and 18% sulphate. It is used to amend soil structure and reduce crusting in hard setting clay soils. Gypsum also acts to replace exchangeable sodium attached to clay particles with exchangeable calcium, reducing clay dispersion and sodicity.
Hardsetting	Condition of a soil where the surface is dry, hard and compacted with no apparent pedal development. These soils are not disturbed or indented by pressure of the forefinger. These harder setting soils tend to result in high runoff.
Headwall	Vertical wall at the beginning/top of a gully.
Horizons	Horizons refer to the horizontal organisation of the soil profile. An individual horizon will have physical and chemical characteristics that differ from the one above or below it. The A horizon consists of one or more mineral horizons that have organic accumulations but lower clay content then the underlying horizon. The B horizon is a mineral layer that has a concentration of clay/Fe/Al, a structure differnet and stronger colours to the A horizon, and is the horizon of maximum pedological development. The C horizon is dominated by partially weathered rock and little pedological development. The R horizon consists of hard rock.
Hydraulic conductivity	The flow of water through soil per unit of energy gradient. For practical purposes, it may be taken as the steady-state percolation rate of a soil when infiltration and internal drainage are equal, measured as depth per unit.
Infiltration	The movement of water through the soil surface. Soils with a high infiltration capacity allow more rain to enter the soil than those with a low infiltration capacity. Runoff will occur when the rate of rainfall exceeds the soil's infiltration capacity. Surface soil structure and texture are important determinants of the infiltration capacity of a soil.
Interrill erosion	Describes the detachment and movement of particles by the combined action of raindrops and shallow overland flows. When a drop impacts the flow, the resulting turbulence ejects particles up into the flow, and the particles remain in the flow for a period of time, during which the particle travels some distance in the direction of flow. In the absence of raindrop impact, such shallow flows have little or no erosive capacity.
KPI	Key Performance Indicator.
Leaching	Removal in solution of soluble minerals and salts as water moves through the profile.

Macropores	Spaces/voids in soil fabric, generally <2 mm in diameter produced by soil biota, roots, coarse-grained particles, spaces/cracks in the soil structure.
Mass wasting	Mass wasting occurs when a block of soil collapses by soil topple/soil fall/circular slip.
Micro nutrients	An element/nutrient required by plants for growth but only in small/minute quantities.
Nutrient availability	A general expression which refers to the ease with which plants can absorb a particular nutrient from the soil – depending on factors such as solubility.
Ped	An individual, natural soil aggregate. See aggregate.
Permeability	The characteristic of a soil which governs the rate at which water moves through it. It depends on soil texture, soil structure, the presence of compacted or dense soil horizons and the size and distribution of pores in the soil.
pH_w	Measure of soil acidity and alkalinity in 1:5 soil:water on a scale of 0 (extremely acidic) to 14 (extremely alkaline). A pH of 7 is neutral.
Porosity	Degree of pore space in a soil i.e. the percentage of the total space between solid particles.
Remnant vegetation	Native vegetation remaining after widespread clearing has taken place.
Resources	Components that contribute to the functionality and production of a landscape such as water, soil, nutrients and seed.
Rill erodibility	The rate of detachment in a rill per unit of effective shear stress.
Rill erosion	An erosion process on sloping land; small channels of only several centimetres in depth are formed.
Runoff	That portion of precipitation or irrigation on an area that does not infiltrate, but instead is discharged from the area over the surface of the soil.
Salinity	A measure of the total soluble salts in a soil that can hinder plant growth.
Scour	Occurs where the shear (flow sliding/frictional forces) and wrenching forces (flow eddies – turbulent forces) imposed by the flow are greater than the resistant forces of the material of the channel bed.
Seedbed	Soil layer that affects and supports the germination and emergence of seeds.
Sheet erosion	Removal of the upper layers of soil by overland flow, often accelerated by raindrop splash.

Shear strength	The maximum strength of soil at which point significant plastic deformation or yielding occurs due to an applied shear stress. There is no definitive "shear strength" of a soil as it depends on a number of factors affecting the soil at any given time.
Slaking	Partial breakdown of soil aggregates in water due to the swelling of clay and the expulsion of air from pore spaces within the aggregate. These aggregates may subsequently disperse.
Sodic soil	Soil containing sufficient exchangeable sodium (commonly greater than six per cent) to adversely affect soil structure. Sodic soils tend to have poor drainage and have a tendency to disperse.
Sodium adsorption ratio (SAR)	Proportion of sodium cation (Na^+) held in the soil relative to that of calcium and magnesium.
Soil	Soil is a natural body consisting of layers (soil horizons) of mineral constituents of variable thicknesses, which differ from the parent materials in their morphological, physical, chemical, and mineralogical characteristics.
Soil instability	The tendency of soil to break down into smaller granules or individual particles in contact with water as a result of poor chemical or physical conditions or mechanical disturbance. These soils are prone to formation of surface seals, crusts, and erosion.
Soil organic matter	The organic fraction, plant and animal residues, of the soil. **Soil organic carbon** is the organic fraction of the soil exclusive of undecayed plant and animal residues.
Soil profile	Vertical section of the soil from the soil surface down through the layers of soil (eg. topsoil, subsoil) including the parent material.
Soil texture	Proportion of soil particles of different sizes – silt, clay and sand in a soil. It can also be influenced by the presence of organic matter and the clay type. The particle composition of a soil can dictate the behaviour and inherent characteristics of that soil.
Structure	Describes the way the soil particles are arranged to form soil peds. Peds are units of soil structure that are separated from each other by natural planes of weakness. They differ from clods which are formed as a result of soil disturbance such as ploughing.
Subsoil	Layer of soil underneath the topsoil, usually has higher clay content, denser and stronger in colour. In most cases it is a poor medium for growth without the topsoil layer. If exposed, can be quite erosive.

Subsoiling	Deep ploughing into the subsoil (similar to subsoil shattering).
Surface crusting (surface sealing)	The arrangement of dispersed clay particles in the immediate soil surface layers, making a crust that is comparatively impermeable to water. This typically occurs due to raindrop impact on bare soil. The potential for runoff and erosion are increased.
Swelling clay (shrink-swell)	Process that occurs when interacting clay platelets move apart due to the absorption of water molecules between clay platelets.
Tension crack	A crack that develops on gully wall, sidewalls and above tunnel erosion indicating imminent failure or collapse: often the result of undercutting, caving or tunnelling.
Topsoil	Original surface layer of mineral soil containing material that is usually darker, more fertile and better structured than the underlying layers.
Tunnel erosion	Tunnelling is an insidious form of sub-surface erosion, resulting as the name suggests in a tunnel through sub-surface soil layers. Tunnel erosion is caused by the movement of excess water through dispersive (usually sodic) subsoil.
Undercutting	Undercutting occurs where the flow in the main gully channel undercuts the sidewall, often leading to mass wasting.
Water repellent soils	Soils that are resistant to wetting (from a dry state). It is a condition usually associated with sandy surface horizons caused by an organic coating on sand grains
WEPP	Water Erosion Prediction Project – erosion simulation software.

APPENDIX C. SOIL TEST PARAMETERS AND CLASSIFICATION

Test Parameter		Units	Classification				
			Very low	Low	Medium	High	Very high
$EC_{1:5}$		*dS/m*	0.15	0.15-0.45	0.45-0.9	0.9-2	>2
Total N		*mg/kg*	500	500-1500	1500-2500	2500-5000	>5000
Total P		*mg/kg*	50	50-200	200-500	500-1000	>1000
Available P		*mg/kg*	<10	10-20	20-40	40-100	>100
Available K		*mg/kg*	<391	391-782	782-1955	1955-3910	>3910
Organic C		*%*	<0.5	0.5-1.5	1.5-2.5	2.5-5	>5
Trace elements	Copper	*mg/kg*	<0.1	0.1-0.3	0.5-5	5.-15	>15
	Manganese	*mg/kg*	<1	1-2	2-50	50-500	>500
	Zinc	*mg/kg*	<0.3	0.3-0.8	0.8-5	5-15	>15

$pH_{1:5}$	*pH Units*
Extremely acid	<4.5
Very strongly acid	4.5-5
Strongly acid	5.1-5.5
Medium acid	5.6-6
Slightly acid	6.1-6.5
Neutral	6.6-7.3
Mildly alkaline	7.4-7.8
Moderately alkaline	7.9-8.4
Strongly alkaline	8.5-9
Very strongly alkaline	>9

Exchangeable sodium percent (ESP)	%
Non-sodic	<6
Sodic	6-14
Strongly sodic	>15

(Source: Hazelton and Murphy, 2011, and Bruce and Rayment, 2004.)