THUNDERBIRD MINERAL SANDS PROJECT SOIL AND LANDFORM ASSESSMENT

PREPARED FOR:

SHEFFIELD RESOURCES LIMITED

OCTOBER 2016

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Thunderbird Mineral Sands Project
Soil and Landform Assessment

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EXECUTIVE SUMMARY

Sheffield Resources Limited (Sheffield Resources) is proposing to develop the Thunderbird Mineral Sands Project (the project), located on the Dampier Peninsula within the west Kimberley region of Western Australia. The project will involve the mining of heavy mineral sands to produce various products (ilmenite, zircon and HiTi88 leucoxene) and subsequent export to overseas markets from Derby Port.

The principal objective of this study was to characterise the soils and landforms of the project area as well as their representation within the greater region. Other objectives include:

- Characterisation of geology, soils and morphology of project landforms.
- Determination of the spatial extent of landforms impacted by the project.
- Assessment of the existing condition of project landforms.
- Assessment on the robustness of project landforms and their sensitivity to disturbance.
- Characterisation of the physical and chemical properties of surface soil and subsoil materials to be disturbed during mining operations.
- Classification of soil materials in terms of their suitability or otherwise for use in rehabilitation.
- Proposition of appropriate management strategies for the handling and utilisation of soil materials during mining and rehabilitation.

After reviewing published information, biological surveys, aerial photography, digital terrain data and site assessment, the following soil and landform mapping units were identified within the project area:

- The Fraser land system (ASRIS mapping unit 335Fz) - characterised by sandplains and dunes with Pindan woodlands and spinifex/tussock grasslands.
- The Reeves land system (ASRIS mapping unit 335Re) - characterised by sandplains, scattered hills and minor plateaux.
- The Waganut land system (ASRIS mapping unit 335Wa) - characterised by low-lying sandplains and dunefields with through-going drainage.
- The Yeeda land system (ASRIS mapping unit 335Ye) - characterised of sandplains and occasional dunes.

Soils in the project area are dominated by red sands (Pindan) of aeolian origin, which are widespread throughout the Dampier Peninsula. Soil profiles are typically deep (greater than 1 m), although relatively shallow profiles were recorded at several locations where Cretaceous sandstone sedimentary rocks were present within 1 m of the natural soil surface.

Four soil types were identified within the project area:

- Shallow red Pindan sands over sandstone.
- Deep red sandy Pindan soils.
- Yellow sandy soils.
- Bleached sands over clay/loam subsoil.

Assessment of the physical and chemical properties of project area soils by field assessment of profiles exposed in test pits and laboratory analysis of selected samples indicate the following characteristics:

- Topsoil textures of sand, sandy loam and loamy sand.
- Uniform physical and chemical soil properties throughout the depth of sandy soil profiles.

- Variable pH, with a majority (70%) of soils being circum-neutral or slightly alkaline. Underlying deeper regolith, referred to as "overburden" in a mine waste characterisation report prepared by MBS (MBS 2016a) was assessed as being slightly acidic to circum-neutral.
- Non-saline (except for one saline soil sample collected from a depression with restricted drainage).
- Low cation exchange capacity values, with calcium being the dominant exchangeable cation.
- Low sodicity, although this characteristic is not considered important for structural stability of predominantly sandy soils. Sodicity levels were generally lower than those associated with deeper overburden regolith (MBS 2016a).
- Typically low concentrations of organic matter, major plant nutrients and some minor nutrients. The importance of nutrient recycling processes, including frequent low intensity fires, was recognised.
- Very low concentrations of environmentally significant metals and metalloids. Despite enrichment of uranium in ore and mineralised waste (MBS 2016a), there was no evidence of uranium enrichment in project area soils.

Sheffield Resources proposes to use conventional mineral sands mining with progressive vegetation and topsoil stripping, mining, backfilling and rehabilitation. Recognising the importance of woody debris as a nutrient bank, the role of termites for nutrient recycling and low inherent fertility of surface Pindan soils, procedures for removing vegetation and topsoil prior to mining should consider the following requirements:

- Coarse woody debris should be stockpiled and not burnt. It should be re-applied as a surface layer over topsoil during rehabilitation of mined areas.
- Fine woody debris, leaf litter and termite mounds (if present) should be harvested and mixed with topsoil.
- Harvested topsoil should either be immediately re-applied to mine rehabilitation areas, or stored in stockpiles for no more than one or two years. Stockpiles should be no higher than 2 m. Pindan soils are not anticipated to present a dust hazard and stockpiles are expected to be stabilised by grass cover after a typical wet season.

Mined areas will be progressively backfilled and rehabilitated. Most of the mine waste (MBS 2016a) and process residues (MBS2016b) are expected to be physically stable and chemically benign and, apart from an initial (year 1) above tailings storage facility, will be returned to the mine void. Based on the findings of this study, a thin cover (approximately 100 mm) of stockpiled or recently stripped topsoil is expected to be sufficient for rehabilitation requirements; there is no requirement for a subsoil water storage layer between overburden mine waste and topsoil. Deeper subsoil, while potentially useful as a rehabilitation material, can be managed as overburden. Fine textured process wastes (namely slimes) incorporated as blended backfill for the mined areas should be placed at least 2 m below the final soil surface and covered with overburden to ensure establishment of a well-drained sandy soil profile to replicate pre-mining soil conditions.

Although the low coherence and limited wet strength of Pindan soils are not favourable for rehabilitation of sloping surfaces, the soils are well suited for rehabilitation of flat or gently sloping surfaces which exist over the extensive pit footprint (approximately 1,529 ha). The only requirement to rehabilitate sloping surfaces is on the embankments of an initial above ground tailings storage facility. Pindan soil blended with ferruginous sandstone overburden is expected to provide a suitable cover medium for this facility.

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1.1 BACKGROUND

Sheffield Resources Limited (Sheffield Resources) is proposing to develop the Thunderbird Mineral Sands Project (the project), located on the Dampier Peninsula within the west Kimberley region of Western Australia (Figure 1). The project will involve the mining of heavy mineral sands to produce various products (ilmenite, zircon and HiTi88 leucoxene) and subsequent export to overseas markets from Derby Port.

Sheffield Resources is investigating development options for the project and commissioned MBS Environmental (MBS) to undertake a soil and landform assessment to support project planning and environmental impact assessment processes. This report details the methodology, processes and results of the assessment and provides recommendations for the management of project soils for minesite rehabilitation.

1.2 OBJECTIVES

The principal objective of the study was to characterise the soils and landforms of the project area as well as their representation within the greater region. Other objectives include:

- Characterisation of geology, soils and morphology of project landforms.
- Determination of the spatial extent of landforms impacted by the project.
- Assessment of the existing condition of project landforms.
- Assessment on the robustness of project landforms and their sensitivity to disturbance.
- Characterise the physical and chemical properties of surface soil and subsoil materials to be disturbed during mining operations.
- Classify soil materials in terms of their suitability or otherwise for use in rehabilitation.
- Propose appropriate management strategies for the handling and utilisation of soil materials during mining and rehabilitation.

1.3 SCOPE OF WORK

The scope of work for this soil and landform assessment involved the following:

- Collation of relevant information and data from aerial photographs, information provided by Sheffield Resources and national soil databases.
- Site visit to assess and describe representative soil profiles.
- Collection of representative soil samples for laboratory analysis by a NATA accredited laboratory.
- Analysis and interrogation of findings using Geographic Information Systems (GIS).
- Prepare a baseline soil and landform assessment report.

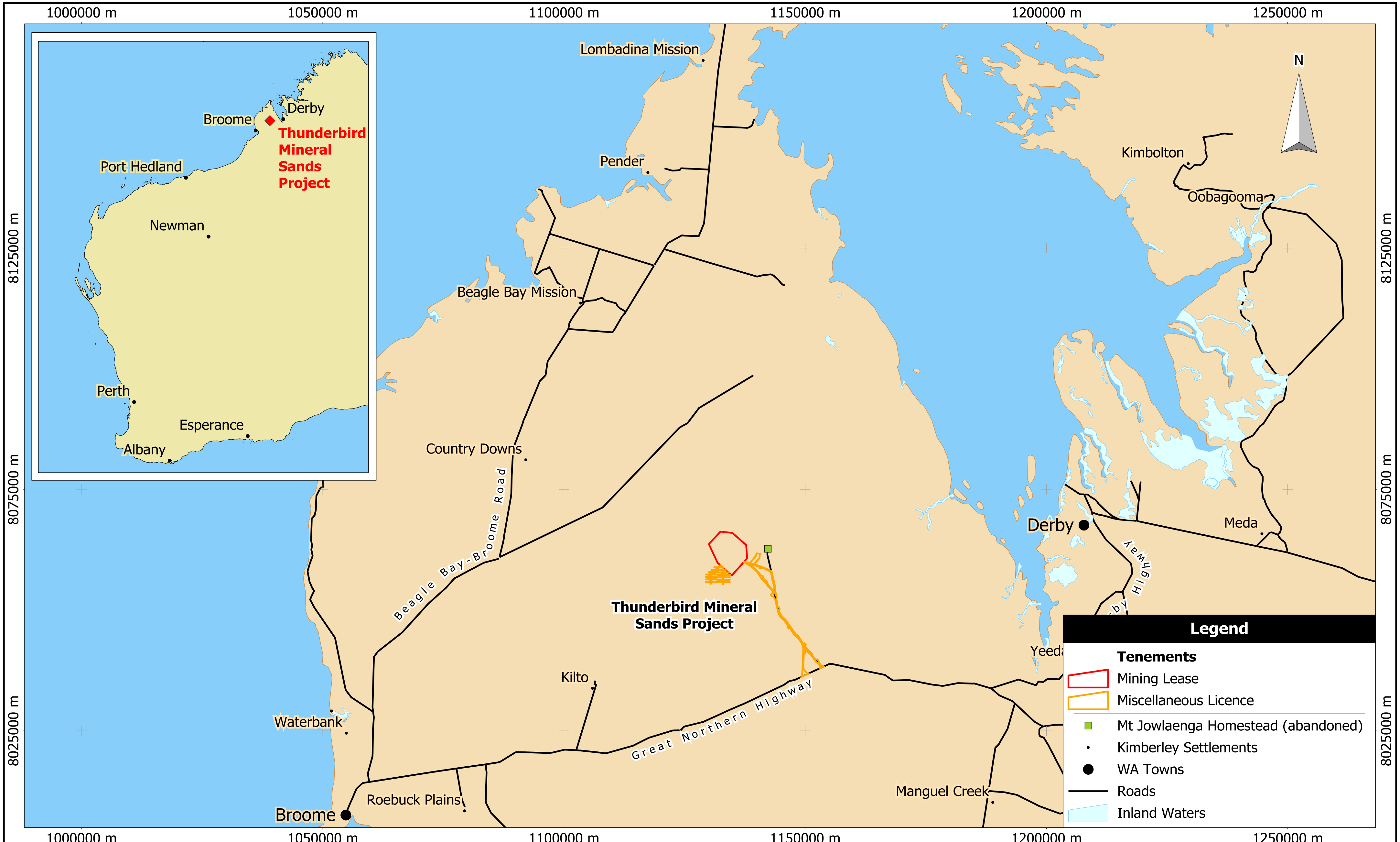

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Figure 1

Location Plan

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2. PROJECT DESCRIPTION

The project is located approximately 95 km northeast of Broome and 75 km west of Derby at the southeast edge of the Dampier Peninsula in Western Australia. It is situated within Pastoral Lease H910623 (Mt Jowlaenga) held by Yeeda Pastoral Company Pty Ltd (used for cattle grazing). The project will be accessed via the Great Northern Highway and then via a proposed 30 km long site access road. Project tenements have been applied for, or are currently held by Sheffield Resources and comprise M04/459 (pending), L04/82, (pending), L04/83 (pending), L04/84, L04/85 and L04/86. The project includes:

- Progressive mining of heavy mineral sands from an open cut pit.
- Processing infrastructure including an initial TSF.
- Progressive backfilling and rehabilitation of the mined pit.
- A site access road to the Great Northern Highway.
- Groundwater abstraction from a borefield with supporting infrastructure.
- Reinjection of excess dewatering water via a series of bores approximately 20 km southeast of the mine, adjacent to the site access road.
- Supporting infrastructure including an accommodation camp, power station, landfill and internal roadways.

The project will comprise mining of heavy mineral sands from the Thunderbird deposit over a 47 year mine life, onsite processing and transportation of final products (ilmenite, zircon, and HiTi88 leucoxene) by road to Derby Port for temporary storage and subsequent export to overseas markets. Sheffield Resources proposes to extract mineral products using conventional mineral sand mining techniques. Mining will be undertaken progressively, with approximately 200 ha of the proposed 1,529 ha deposit area open at any one time. Mined areas will undergo progressive backfilling and rehabilitation. A summary of the proposed mining, ore processing and export operations is shown in Plate 1.

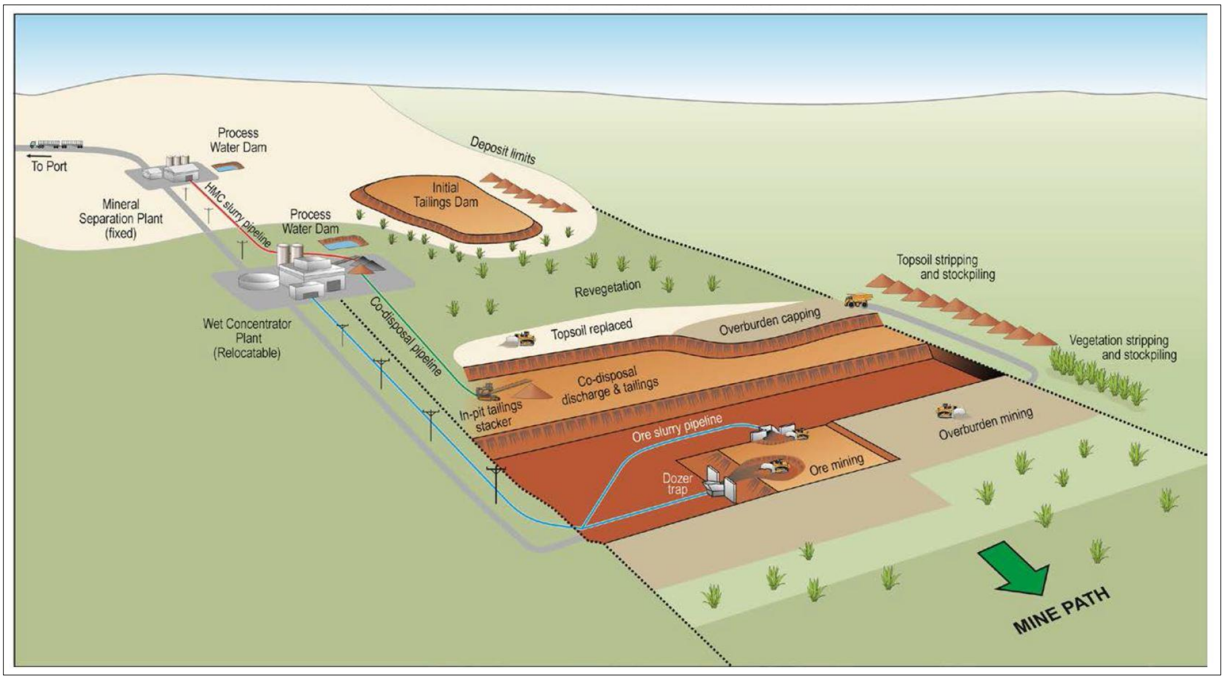


Plate 1: Proposed Mining Schematic for Thunderbird

3. EXISTING ENVIRONMENTAL

3.1 CLIMATE

The project is located on the Dampier Peninsula in the west Kimberley region of Western Australia, which experiences a tropical climate. Most rainfall occurs during the wet season between November and April. Potential evapotranspiration for the area is very high, averaging 1,980 mm per year and varies moderately across seasons. It generally remains higher than rainfall even in the wet season, resulting in water limited conditions for vegetation.

Weather data has been collected from an automatic weather station at the project site since November 2014. Maximum and minimum temperatures and mean humidity are shown in Chart 1. This shows maximum temperatures generally between 35 and 45ºC. Minimum temperatures rarely drop below 15ºC. Average humidity is around 40% in the dry season and approaches 80% in the wet season. Days with maximum humidity over 90% were observed in all months.

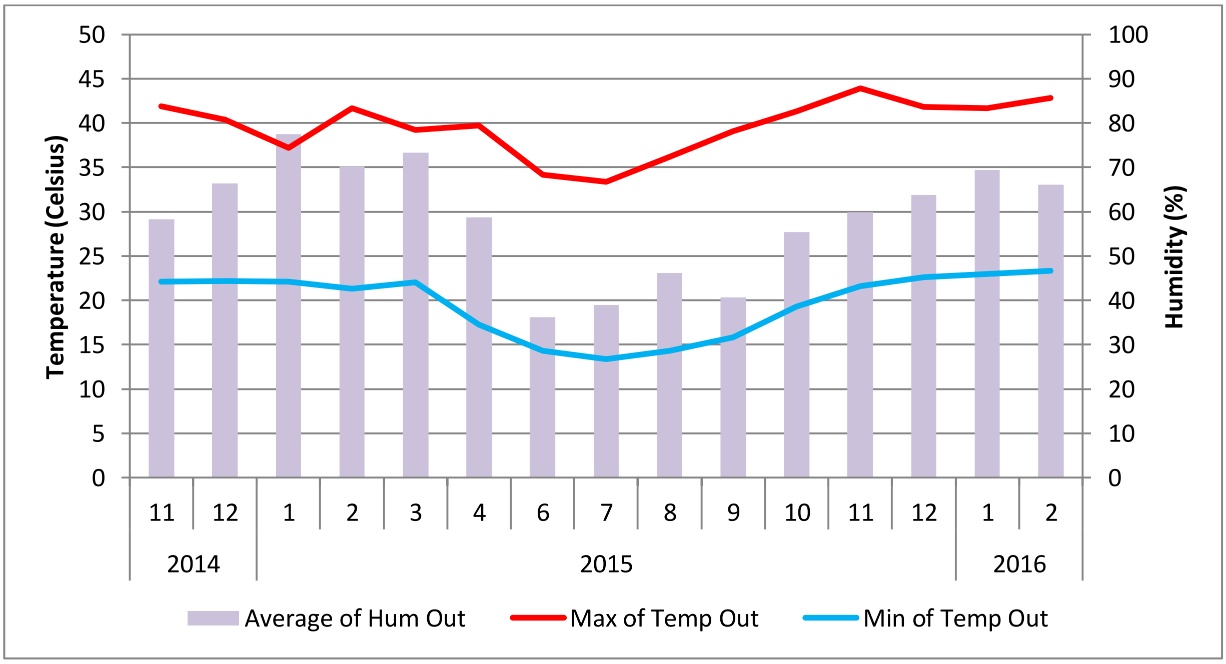


Chart 1: Temperature and Humidity at Thunderbird

Monthly rainfall statistics for the project area from 1889 to 2015 are shown in Table 1 and Chart 2. The annual figures presented are based on a rainfall year from September to August. Mean annual rainfall is 694 mm. Rainfall is very variable with a minimum annual rainfall of 153 mm and maximum of 1,503 mm. Median annual rainfall is 675 mm. Median monthly rainfall is 1.2 mm or less during the dry season from May to October. Zero or very low rainfall may occur in any month.

Table 1: Rainfall Statistics for Thunderbird Mine Site 1889 to 2015 (Data Drill)

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Annual
Mean	1.0	3.9	17.8	92.4	193.1	181.0	128.9	29.9	23.4	14.9	6.5	3.5	695.3
Highest	48.5	53.9	229.1	668.5	1031.8	556.9	535.1	261.7	308.4	159.4	157.6	56.1	1502.7
90th percentile	1.1	12.0	44.3	181.4	365.3	334.9	288.1	73.5	80.6	53.7	19.8	5.9	1003.6
Median	0.0	0.3	8.4	66.1	156.6	164.7	96.7	12.4	0.9	0.3	0.0	1.2	675.2
10th percentile	0.0	0.0	0.3	10.8	54.7	47.0	26.0	0.0	0.0	0.0	0.0	0.7	401.2
Lowest	0.0	0.0	0.0	1.1	21.0	12.7	1.8	0.0	0.0	0.0	0.0	0.5	152.6

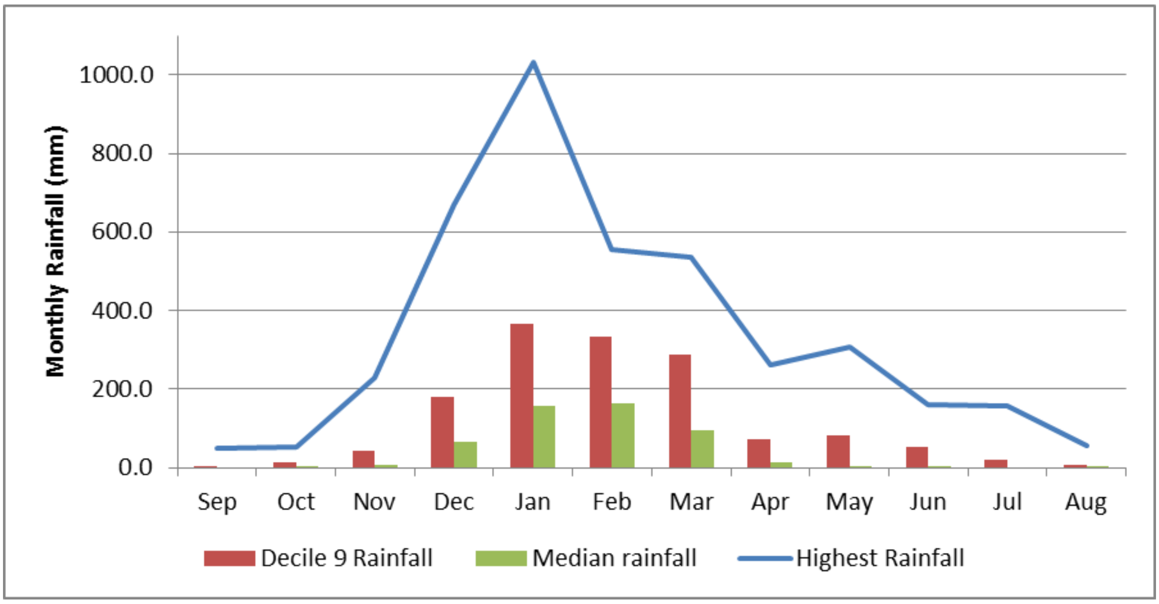


Chart 2: Monthly Rainfall Statistics for the Thunderbird Mineral Sands Project

3.2 GEOLOGY

3.2.1 Regional Geology

The project is located within the Phanerozoic Canning Basin, an intracratonic basin covering 640,000 km^2 with a dominant onshore area of 530,000 km^2. The Canning Basin contains a sequence of folded and faulted sediments approximately 18 km thick.

Geology of the onshore section of the Canning Basin is characterised by five major periods of sedimentation. Each sedimentation period comprises a number of marine and continental phases with each phase separated by major intervals of erosion, with or without tectonism (Towner and Gibson 1983):

- Early Ordovician to Silurian - deposition of marine to marginal marine and evaporitic sedimentation, initially during a phase of extension and rapid subsidence, followed by prolonged sagging in the late Ordovician and early Silurian when evaporitic and restricted marine conditions prevailed.
- Devonian to early Carboniferous - sedimentation comprised marine and fluvio-deltaic environments in the north and marginal marine to terrestrial conditions in the south.
- Late Carboniferous to mid Triassic - renewed phase of extension and rapid subsidence resulting in marine sedimentation and glacial conditions. Following glaciation, deposition in the onshore part of the basin gradually became restricted to the Fitzroy Trough-Lennard Shelf-Gregory sub-basin.

- Late Jurassic - transgression led to the deposition of sand and mud in a marine environment. The Broome Sandstone was deposited in shallow marine conditions during an early Cretaceous regression. As the regression continued the Melligo Sandstone was deposited throughout the basin.
- Cainozoic - laterisation occurred and a variety of thin deposits of shoreline, alluvial, lacustrine and aeolian material was deposited across the Canning Basin.

The Canning Basin is subdivided into a number of north-westerly trending tectonic elements identified predominantly from seismic and other geophysical data. Structural element boundaries, typically fault zones, were active at various times during deposition. The structural elements include two elongate series of major depocentres, separated by mid-basinal platforms and flanking shelves or terraces. The northern depocentres comprise the Fitzroy Trough (northwest) and Gregory sub-basin (southeast) which are separated by the Jones Arch. These depocentres contain about 15 km of strata, the thickest being of Devonian to Permian age. Pre-Devonian strata are assumed at depth, but have not been reached by drilling.

Stratigraphic units present within or adjacent to the project comprise sand units of the Upper Jurassic to the Lower Cretaceous, including the Jarlemai Siltstone, the Broome Sandstone and the Melligo Sandstone (Table 2). These formations are dipping at a shallow angle of less than 5° to the southwest.

Table 2: Stratigraphic Units Present Near the Project

Unit Name	Description
Jarlemai Siltstone	• Dated as Upper Jurassic but may extend up to the Early Cretaceous (Crowe *et al.* 1978). • Deposited at the height of the Jurassic-Cretaceous marine transgression in the Canning Basin. • Lithology varies from siltstone to claystone and sandstone and is glauconitic to ferruginous in part (Towner and Gibson 1983).
Broome Sandstone	• Originally defined to cover sandstone cropping out along the west coast of the Dampier Peninsula near Broome and overlying the Jarlemai Siltstone (Brunnschweiler 1957). • Contains a wide variety of sandstone lithologies and sedimentary structures, consistent with deposition in a shallow-marine (tidal) environment as the Early Cretaceous sea regressed (Towner and Gibson 1980). • Lithology varies from a fine to very coarse sandstone to a mudstone with some minor conglomerate. • Sedimentary features like ripple-marks, cross-bedding and bioturbation can be observed. • The topmost part contains well rounded heavy minerals (Towner and Gibson 1983).
Melligo Sandstone	• Conformably to disconformably overlies the Broome Sandstone. • High silicified unit but unsilicified Melligo Sandstone has been recognised in the Mount Jowlaenga area on the basis of sedimentary structures and fabric (Brunnschweiler 1957, McWhae *et al*. 1958, Towner and Gibson 1980). • Good sorting and rounding of the constituent grains, which include heavy minerals, coupled with thin bedding, flat to low-angle cross bedding and parting lineation indicate that it is a beach deposit, laid down as the sea in which the Broome Sandstone was deposited regressed. • Lithology of the Melligo Sandstone is fine to medium, well-sorted, thin-bedded to laminated sandstone that is pebbly in places. • Contains heavy minerals (Towner and Gibson 1983). • Considered by Sheffield Resources geologists to be an equivalent unit to the Broome Sandstone and therefore the primary target lithology for heavy mineral concentrations.

3.2.2 Project Geology

The Thunderbird deposit is a heavy mineral sands deposit containing valuable heavy minerals ilmenite, zircon, leucoxene and rutile and is hosted by deeply weathered Cretaceous-aged formations. Mineralisation is in a thick, broad anticlinal sheet-like body striking northwest. The areal extent, width, grade, geological continuity and grain size of the Thunderbird deposit are interpreted to indicate an off-shore sub-wave base depositional environment.

Five stratigraphic units have been defined by Sheffield Resources geologists via a combination of surface mapping and drillhole lithological logs. These are locally referred to as the Fraser Beds, Reeves, Melligo, Thunderbird and Jowlaenga Formations. Of these, the Thunderbird Formation is the main mineralised unit with the Fraser Beds acting as a distinct marker unit toward the base of the Thunderbird Formation.

The Thunderbird Formation is a medium to dark brown/orange, fine to very fine, well sorted, loose sand unit. The formation has a thickness of up to 90 m (average of 38 m) and is very rich in heavy minerals (up to 40%). The formation has been modelled to be at least 8.5 km along strike and more than 2.5 to 5.5 km wide. The following features are present within the formation:

- Layers of siliceous and iron cemented sandstone. The latter layers are interpreted to have been formed by post-deposition chemical processes of ferruginisation from ancient water table movements with iron oxides leached from the sand (e.g. ilmenite). These cemented mineralised layers occur throughout the formation in a patchy nature, with extents rarely continuous between holes at 60 and 250 m spacing. This cemented mineralised sandstone is estimated to comprise no more than 10% of the deposit.
- Continuous, very high grade heavy mineral (greater than 7.5%) zone named the GT Zone. The GT Zone is up to 29 m thick (average 15 m) over an area of at least 7 km by 3.5 km, striking approximately north-south, open along strike and following the dip of the Thunderbird Formation. The high grade of heavy minerals in the GT Zone is interpreted to result from deposition in off-shore higher wave energy shoals.

3.3 LANDFORM AND SOILS

3.3.1 Land Systems

Nine land systems have been identified within the eastern Dampier Peninsula (Payne and Schoknecht 2011; ASRIS 2016). These systems are summarised below:

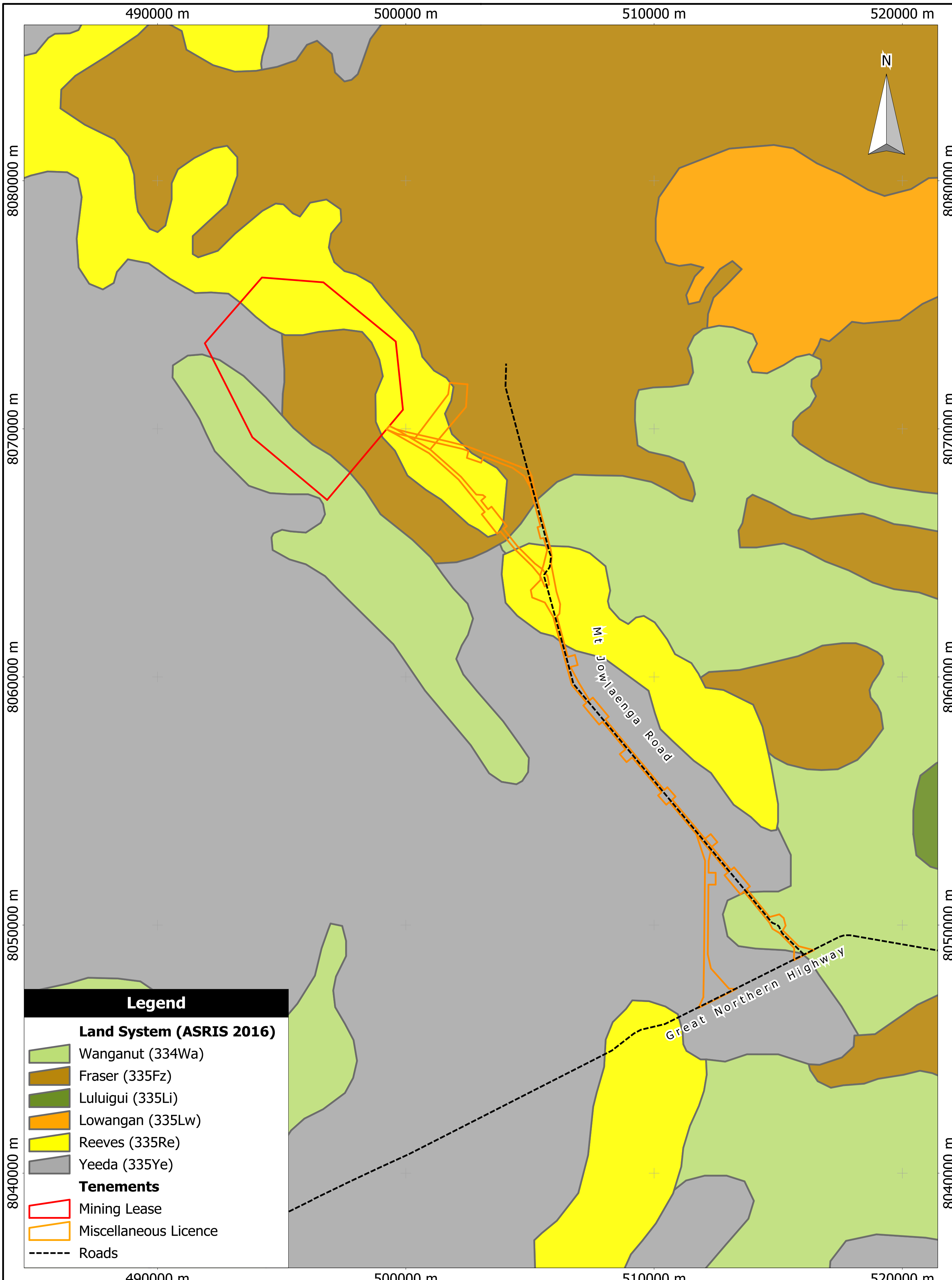
- Fraser land system (ASRIS mapping unit 335Fz) - characterised by sandplains and dunes with Pindan woodlands and spinifex/tussock grasslands.
- Reeves land system (ASRIS mapping unit 335Re) - characterised by sandplains, scattered hills and minor plateaux.
- Waganut land system (ASRIS mapping unit 335Wa) - characterised by low-lying sandplains and dunefields with through-going drainage.
- Yeeda land system (ASRIS mapping unit 335Ye) - characterised by sandplains and occasional dunes.
- Luluigui land system (ASRIS mapping unit 335Li) – characterised by sandplains, dunes, stony plains and loamy plains supporting Pindan vegetation of acacia shrubs, sparse bloodwoods, spinifex and ribbon grass, also spinifex grasslands with patchy low trees.
- Lowangan land system (ASRIS mapping unit 335Lw) – characterised by sandy interfluves, sandplains and alluvial plains supporting Pindan woodlands with acacias and eucalypts and curly spinifex-ribbon grass; also beefwood low woodlands with ribbon grass.
- Carpentaria land system (high and low subsystems, ASRIS mapping units 335Cr_1 and 335Cr_2 respectively) – High subsystem characterised by sandy surfaced coastal plains supporting rice grass and saltwater couch. Low subsystem characterised by bare coastal mudflats, minor sandy margins and seaward margins, little vegetation except for mangrove fringing thickets.

- Sisters land system (ASRIS mapping unit 335Si) – characterised by low sandy plateaux and lower slopes supporting Pindan woodlands with acacias and eucalypts and curly spinifex-ribbon grass, and valley plains supporting mixed woodlands with ribbon grass.
- Camelgooda land system (ASRIS mapping unit 335Cm) – characterised by sandplains, swales and linear sand dunes supporting low Pindan woodlands of acacias and low woodlands of bauhinia and bloodwood with curly spinifex and ribbon grass.

Four of these land systems are located within the immediate project area (Figure 2); Yeeda, Fraser, Reeves and Wanganut land systems. Summaries of geomorphology, surficial geology and vegetation characteristics of these land systems are presented in Table 3.

Table 3: Characteristics of Major Regional Land Systems (ASRIS 2016)

Land System	Geomorphology	Geology	Vegetation	Land Management
Fraser	Sandplain and dunefields with through-going drainage, sandplain with irregular dunes, plains with thin sand cover and local outcrop, low-lying sandplain flanking drainage features. Relief less than 9 m.	Quaternary aeolian sand and minor outcrops of gently dipping Cretaceous sandstones.	Pindan woodlands and spinifex/tussock grasslands.	Generally stable with low susceptibility to erosion except for sand dunes, which are moderately susceptible after fire but stabilise after rain.
Reeves	Formed by dissection of the Kimberley surface - scattered hills, dip slopes with thin sand cover and local outcrop and sandplain. Sparse branching drainage pattern. Relief to 60 m.	Subhorizontal or gently dipping sandstone, silty sandstones and silicified sandstones of Cretaceous age. Quaternary aeolian sand.	Pindan woodlands and spinifex/tussock grasslands.	Pindan vegetation subject to frequent fires. Sandplains sand dunes are moderately susceptible to wind erosion after fire but stabilise after rain.
Waganut	Sandplain and dunefields with through-going drainage, sandplain with stable dunefields, scattered pans and depressions. Sparse to moderately dense branching drainage pattern. Relief less than 9 m.	Quaternary aeolian sands.	Pindan woodlands and spinifex/tussock grasslands. Dense wattle scrub.	Subject to frequent fires, but generally not prone to degradation or erosion.
Yeeda	Sandplains and dunefields with little organised drainage.	Quaternary aeolian sands.	Shrubby spinifex grasslands and Pindan woodlands.	Subject to frequent fires, but generally not prone to degradation or erosion.



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Sheffield Resources Limited
Thunderbird Mineral Sand Project

Figure 2

Land Systems of the Eastern Dampier Peninsula

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W:\Sheffield Resources\Baseline Studies\Soil and Landform\Drawings\Soil and Landform.map 19/10/2016 F2 Land Systems Layout

3.3.2 Soil Types

The four main soil types (Bettenay *et al*. 1967) within the land systems described in Section 3.3.1 are:

- Red earthy sands with associated hummocks of siliceous sands.
- Red earthy sands associated with soils on the plains, with dunes and hummocks of red sands. Some soils in lower sites often have a heavy surface layer of ferruginous gravel.
- Neutral red earths and sandy neutral red soils on plains with minor sandstone residuals overlain by extensive rocky outcrops.
- Neutral red earths and red earthy sands within sand plains with irregular dunes/active drainage systems.

More detailed soil mapping by the Department of Agriculture and Food Western Australia (Schoknecht and Payne 2011) identified six soil types within the Yeeda, Fraser and Reeves Land Systems and eight soil types within the Wanganut Land System. Descriptions of these soil types are summarised in Table 4.

Table 4: Soil Types of Each Land System (Payne and Schoknecht 2011)

Land System	Soil Types
Fraser	• Red sandy soils (Yabbagoddy family) with brown heavy clays in pans. • Deep red sands (Cockatoo family). • Shallow gravelly reddish skeletal sands with some rocky outcrop. • Yellow mottled sandy soils (Tableland family). • Yellow mottled loamy soils (Elliott family). • Drainage channels with deep sand and banks of brown alluvium loamy soils (Robinson family).
Reeves	• Outcrop with scree slope colluvium. • Outcrop with red sandy sands of variable depth (Yabbagoddy family). • Red sandy soils (Yabbagoddy family). • Yellow mottled sandy soils (Tableland family). • Greyish massive, intractable, silty to heavy clays in pans. • Drainage channels with deep sand, gravel and cobbles. Banks of brown alluvium loamy soils (Robinson family).
Waganut	• Deep red sands (Cockatoo family). • Pindan dunes with reddish sandy soils (Yabbagoddy family). • Yellow mottled sandy soils (Tableland family). • Yellow mottled loamy soils (Elliott family). • Brown, massive intractable heavy clays in pans. • Drainage channels with deep sand and banks of brown alluvium loamy soils (Robinson family). • Yellow mottled sandy soils (Tableland family). • Scalded brown and grey sands and loams over clays (Hooper family).
Yeeda	• Deep red sands (Cockatoo family). • Red sandy soils (Yabbagoddy family). • Deep yellow sands (Pago family) in higher rainfall areas. • Yellow sandy soils (Tableland family). • Scalded areas of bleached sands over loam subsoils (Tarraji family). • Brownish massive intractable silty to heavy clays.

3.3.3 Acid Sulfate Soils

The project area is characterised in the Australian Soil Resources Information System (ASRIS) Acid Sulfate Soil (ASS) mapping as having 'Extremely Low" probability (low confidence) of occurrence within 2 m of the natural soil surface.

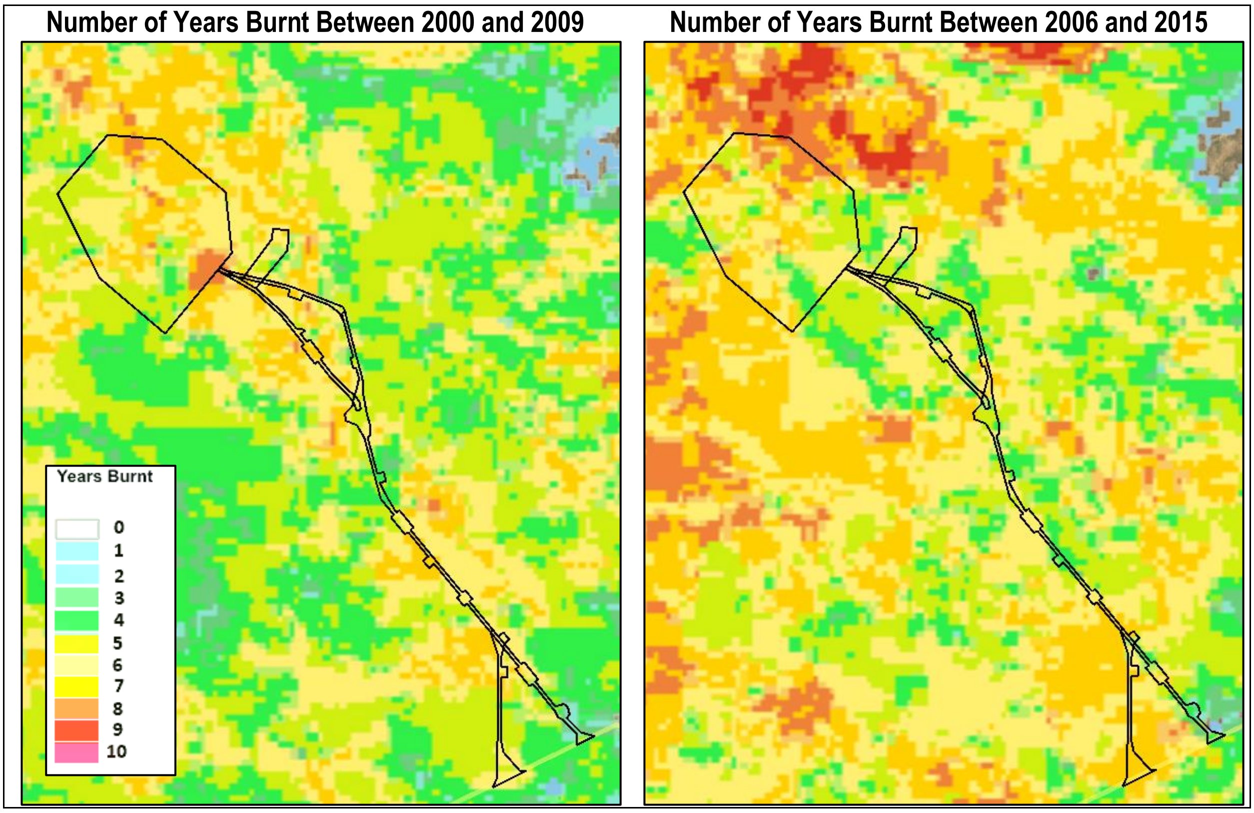
The proposed site access route from the Great Northern Highway transverses areas mapped as "Extremely Low" for the probability of ASS occurrence.

3.4 FIRE IMPACTS

The Mine Site Development Envelope is located within the Mt Jowlaenga pastoral lease and is subject to regular burning by pastoralists, other stakeholders and natural causes such as lightning strikes. The burning pattern within the Mine Site Development Envelope is reflective of controlled burning by land users to reduce the amount of combustible fuel in the area rather than sporadic and localised burning caused by wet season thunderstorms (Ecologia 2015c).

A 2006 EPA investigation into the frequency and intensity of fires in the Kimberley and other regions suggested that areas of the Dampier Peninsula have been historically burnt by Aboriginal people, pastoralists, authorities, travellers, accidents and natural sources (EPA 2006). EPA (2006) and an assessment of the North Australian Fire Information (NAFI) database for the Mine Site Development Envelope indicates that there is an increasing trend in fire activity as shown in Figure 3, which may be impacting on flora and fauna in the region (EPA 2006). Fire regimes in the Kimberley are very different from those once managed by Aboriginal people, where historic burning was guided by seasons as well as cultural and hunting practices.

Figure 3: Mine Site Development Envelope Fire History



3.5 HYDROLOGY

3.5.1 Regional Catchments

The project is located within the National Catchments Boundaries (NCB) Level 2 Cape Leveque Coast River Region of the NCB Level 1 Tanami-Timor Sea Coast Division (Stein *et al.* 2011). The Cape Leveque Coast River Region consists of several river systems draining to the coast and extending about 100 km inland. All of the catchments in the project area drain east to King Sound (Figure 4). The project lies within the catchments of Fraser River (including Fraser River South) and Logue River (including Little Logue River). While the Fraser River enters King Sound from the west, the Logue River discharges to King Sound at Jarrananga Plain immediately adjacent to the Fitzroy River. The adjacent Fitzroy River Basin is a much larger river basin extending about 500 km inland and representing the primary surface water inflow to King Sound.

The project area includes catchments of the four rivers discussed above and shown in Figure 4. These comprise:

- Fraser River (total catchment area of 1,529 km^2).
- Fraser River South (total catchment area of 1,024 km^2).
- Little Logue River (total catchment area of 323 km^2).
- Logue River (total catchment area of 1,056 km^2).

3.5.2 Local Catchments

The majority of the project is within the Fraser River South catchment. The deposit area extends slightly into the Fraser River catchment and the proposed accommodation camp location is entirely within that catchment. The Logue and Little Logue River catchments are crossed only by the site access road and do not contain any other project infrastructure.

The southern extent of the deposit area encroaches slightly on the ephemeral drainage line at the northwestern limit of the Fraser River south catchment (Figure 5), and the borefield may extend across the same drainage line. This drainage line has a catchment area of 108 km^2 and extends 17 km upstream of the deposit area.

3.6 HYDROGEOLOGY

Five distinctive hydrogeological units have been identified within the project area:

- Superficial sediments ‘Pindan’.
- Broome upper aquifer.
- Heavy mineral sands (HMS) ore zone.
- Broome lower aquifer.
- Jarlemai Siltstone.

Ground level elevations within the mining area range from 89 m AHD in the south to 119 m AHD in the north, while the water table ranges from 66 m AHD in the south to 75 m AHD in the north (Rockwater 2016). The resulting depth to water is between 44 m BGL on elevated ground and 23 m BGL in local areas adjacent to drainage lines. The hydraulic gradient in the project region is approximately 1.6 m per km and decreases in the southwest to about 0.7 m per km. The steeper groundwater gradient near the project area is the result of lower permeability material where the ore occurs and at the base of the Broome aquifer.

A numerical groundwater model has been used to estimate the volume of dewatering required to ensure suitable working conditions in the base of the pits. The conceptual mining schedule and pit shell definition (developed from the resource block model) were used in groundwater modelling assessments (Rockwater 2016).

The water supply borefield will provide about 10.7 GL/yr for the first 15 years (12.2 GL/yr in Year 1) of mining. Mine dewatering will be required after Year 15. Dewatering volumes are predicted to increase gradually over the subsequent 17 years as mining depths increase. Pumping from the water supply borefield will be scaled back as mine dewatering takes on an increasing role in supplying the ore processing facilities' requirements. From mining Year 32 to mining Year 47, excess mine water will be injected into the Broome aquifer at a rate of up to 7 GL/yr initially and up to 22 GL/yr during the last four years of mining.

Groundwater salinity in the Broome aquifer ranges from less than 100 to more than 30,000 mg/L total dissolved solids (TDS) (GSWA 1991). It is generally low in elevated landscapes, including the project area, with saline groundwater only recorded towards discharge areas along the coast and Roebuck Plains above the saltwater wedge. Groundwater in the Broome Sandstone is essentially a sodium chloride type, with occasional high levels of bicarbonate.

An intermittent soak is situated about 3 km to the southeast of the mine. This feature exhibits groundwater levels in the Broome aquifer of about 20 m below land surface and is therefore unlikely to be connected to the regional Broome aquifer and is more likely related to local perched water (Rockwater 2016).

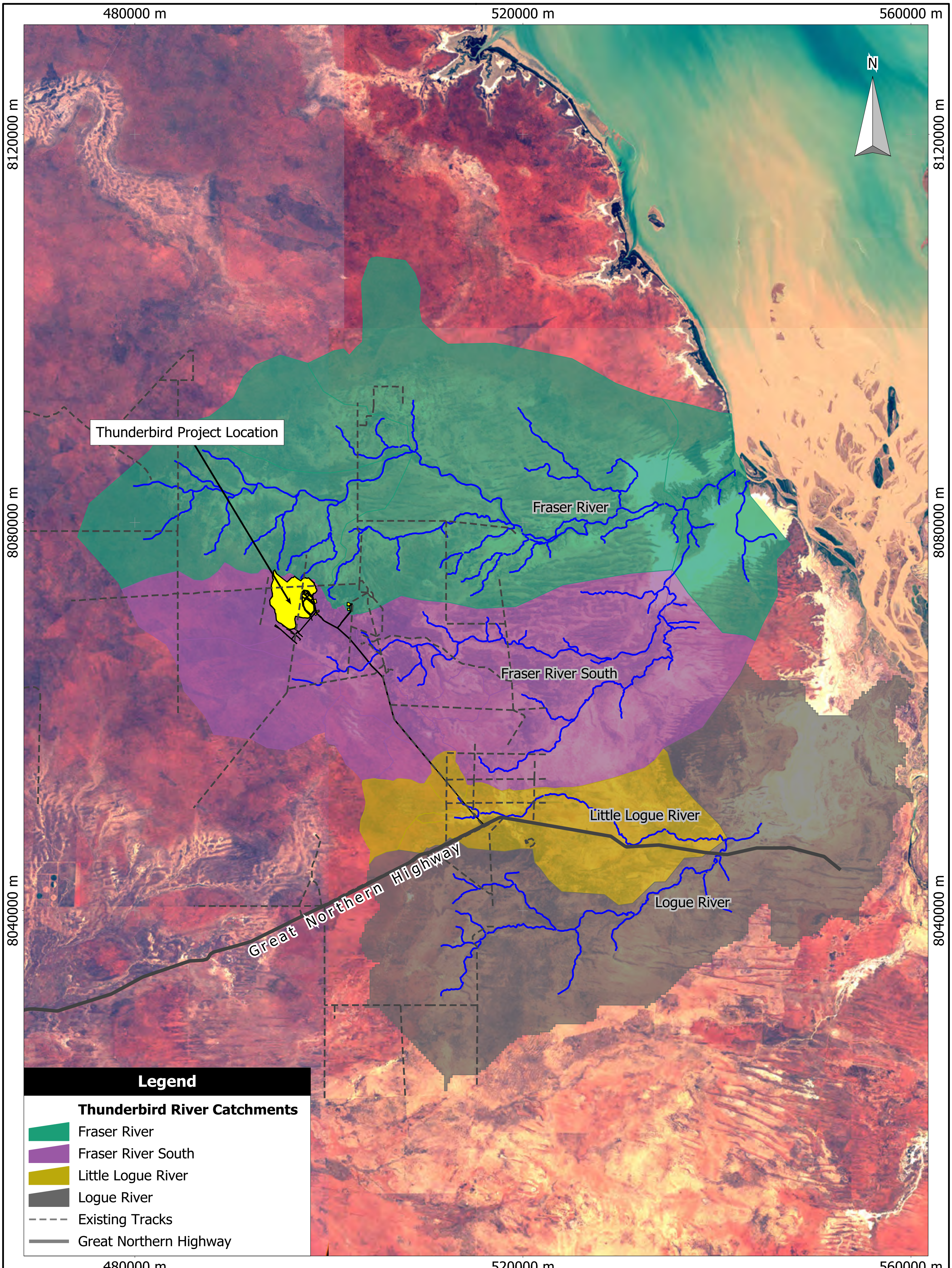


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Figure 4

Regional River Catchment Boundaries

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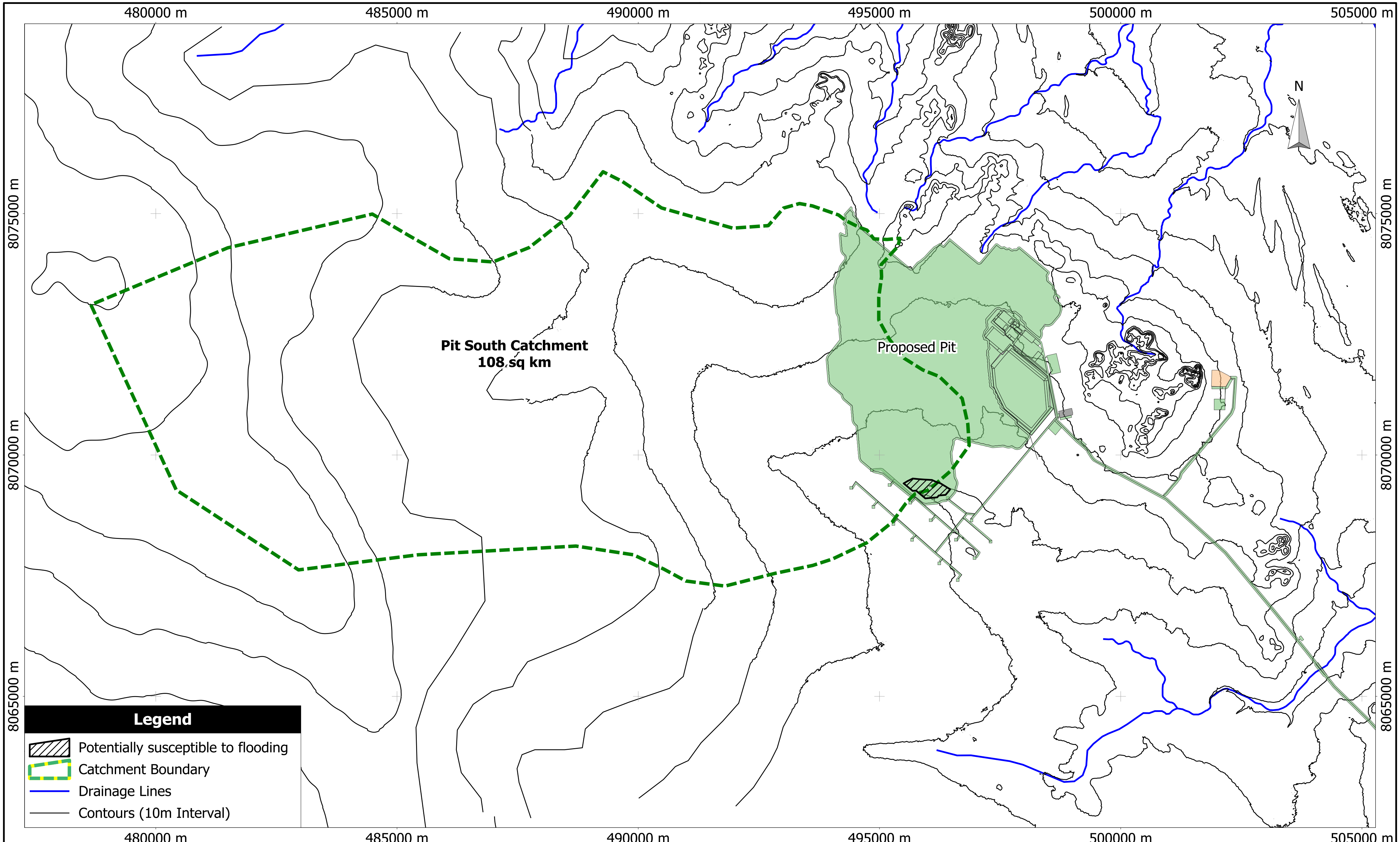

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Figure 5

Deposit Area South Catchment

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W:\Sheffield Resources\Baseline Studies\Soil and Landform\Drawings\Catchments.map 19/10/2016 F5 Pit South Catchment Layout

4. SOIL ASSESSMENT FIELD AND LABORATORY METHODS

4.1 TEST PIT ASSESSMENT

A total of 29 test pits were excavated across the project area, as shown in Figure 6 (North) and Figure 7 (South). Test pit locations were selected to provide a broad coverage across the project footprint, including key infrastructure areas such as the deposit area, processing plant and site access road. Test pits were excavated using a 5 tonne backhoe to a maximum depth of 2 m below existing ground levels or refusal, whichever was encountered first.

Test pit soil profile characteristics were described and assessed using methodologies described in the Australian Soil and Land Survey Handbook (McDonald and Isbell 2009) and Department of Agriculture and Food, Resource Management Technical Report 280 (DAFWA 2004). Soil attributes described included:

- Depth of soil horizons, including presence of any "hardpan" layers.
- Soil colour.
- Soil texture.
- Soil fabric, including level of compaction.
- Moisture content.
- Presence or absence of plant roots at depth.
- Presence of distinctive soil genesis features such as mottling, gleying, calcrete and ferruginous pisoliths.

Relevant landscape features including topography (slope), termite mounds, vegetation and surface conditions (leaf litter, woody debris, rock fragments, cryptogamic crusts, surface cracking) were also recorded.

4.2 LABORATORY TESTS

A program of laboratory testing was undertaken to characterise physical and chemical properties of the soils and assess their suitability for use as cover materials for rehabilitation. For this reason, the test program focused on parameters relating to physical stability and plant nutrition characteristics.

The following tests were undertaken by ChemCentre (Bentley, Western Australia), generally using in-house modifications of standard soil tests described by Rayment and Lyons (2011):

- pH and electrical conductivity (EC).
- Exchangeable cations (calcium, sodium, potassium and sodium) and relative sodicity.
- Organic carbon and total nitrogen.
- Particle size (gravel content, greater than 2 mm).
- Potential for dispersion (Emerson Class, AS 1289 C8.1 1980).
- Nutrients and plant available heavy metals (Mehlich extract, Mehlich 1984).
- Ten element heavy metals and metalloids screen to establish pre-mining baseline levels.

4.3 INTERPRETATION OF RESULTS

The following sources of information were used to assess the significance of laboratory test results:

- Soil Analysis: An Interpretation Manual (Peverill *et al.* 1999).

- Interpreting Soil Test Results. What do all the numbers mean? (Hazelton and Murphy 2007).
- Soil Guide. A handbook for understanding and managing agricultural soils. Department of Agriculture and Food Western Australia (DAFWA) Bulletin 4343 (DAFWA 1998).
- Soil-Landscape Mapping in South-Western Australia, Overview of methodology and outputs. Resource Management Technical Report 280 (DAFWA 2004).
- The author's experience from coordinating chemical analysis for DAFWA soil surveys conducted between 1988 and 1998.

A summary of the information sources and ratings tables used for this assessment is presented in Appendix 1.

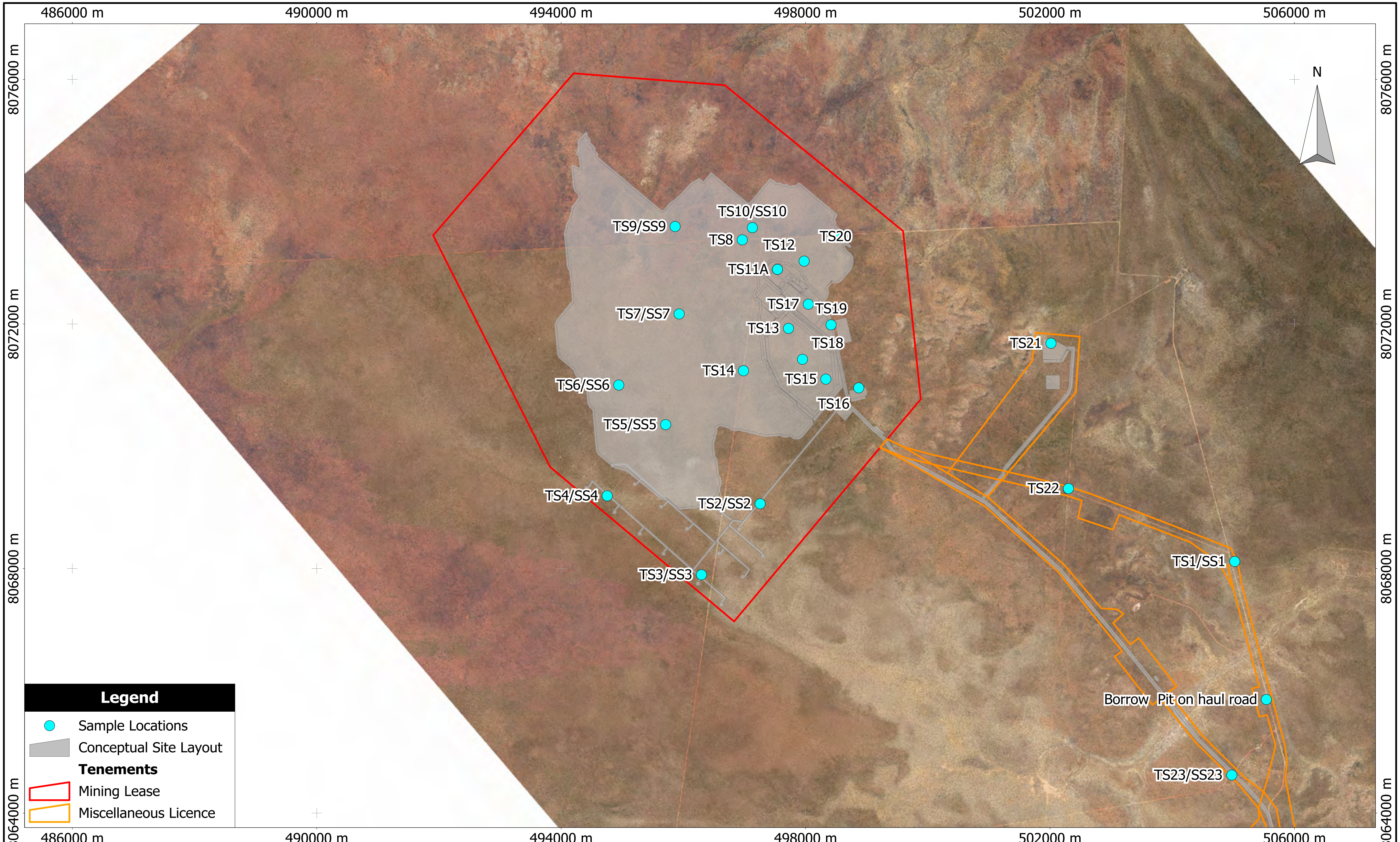

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Figure 6

Soil Sample Locations (North)

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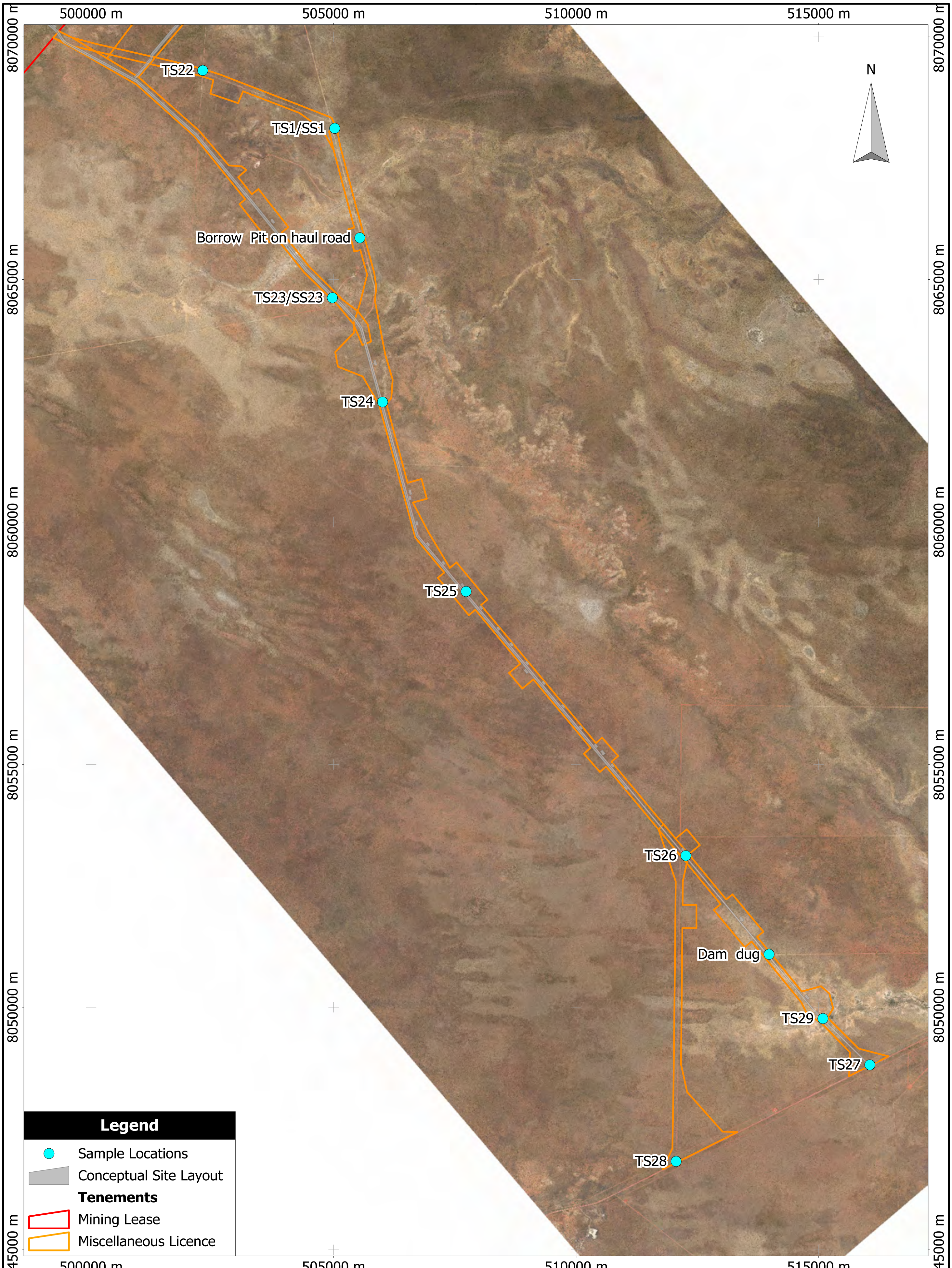

Scale: 1:100000 Original Size: A4 Air Photo Date: 2015 Grid: Australia MGA94 (51) 0 2000 m	Sheffield Resources Limited Thunderbird Mineral Sand Project	**Figure 7** **Soil Sample Locations (South)**	Martinick Bosch Sell Pty Ltd 4 Cook St West Perth WA 6005 Ph: (08) 9226 3166 Fax: (08) 9226 3177 info@mbsenvironmental.com.au www.mbsenvironmental.com.au MBS ENVIRONMENTAL

5. LANDFORM DESCRIPTIONS AND SOIL PROFILES

5.1 TOPOGRAPHY

Topography within the project area is relatively subdued, with elevations ranging between 89 and 119 m RL AHD (Australian Height Datum), with an average elevation of approximately 110 m RL AHD (Figure 8). Rocky hills associated with the Reeves Land System as outcrop of shallow dipping Cretaceous sediments cover approximately 20% of the project area. Plate 2 shows a typical low hilly landscape within the Reeves Land System. This System (Section 3.3.1) runs as a band along the northeastern boundary of the project area (Figure 8).

Rocky hills are characterised by sparse *Corymbia dendromerinx* over moderately dense *Acacia drepanocarpa* subsp. *latifolia* over a ground vegetation layer of dense *Triodia caelestialis* hummock grassland and *Sorghum plumosum* tussock grassland on rocky hilltops, slopes, gullies and outcrops (Ecologia 2012).

The remainder of the project area is flat to undulating. Two distinct vegetation and fauna habitats are observed within this landscape:

- Pindan plains associated mainly with the Yeeda and Fraser Land Systems (Section 3.3.1). Vegetation communities comprise *Corymbia greeniana* over a moderately dense to dense shrub layer consisting primarily of *Acacia tumida* var t*umid*a, *Acacia platycarpa* and *Grevillea refracta* woodlands. The ground vegetation layer consists of a mix of grasses including *Triodia caelestialis*, *Aristida holathera* var *holathera*, *Crysopogon* sp., *Eriachne obtusa* and *Sorghum plumosum* (Ecologia 2012).
- Savannah woodlands are associated with the Wanganut Land System. Vegetation communities comprise scattered *Corymbia greeniana* over a ground vegetation layer of *Eriachne obtusa* tussock grassland and *Triodia caelestialis* hummock grassland on firm soils, often with the presence of large termite mounds.

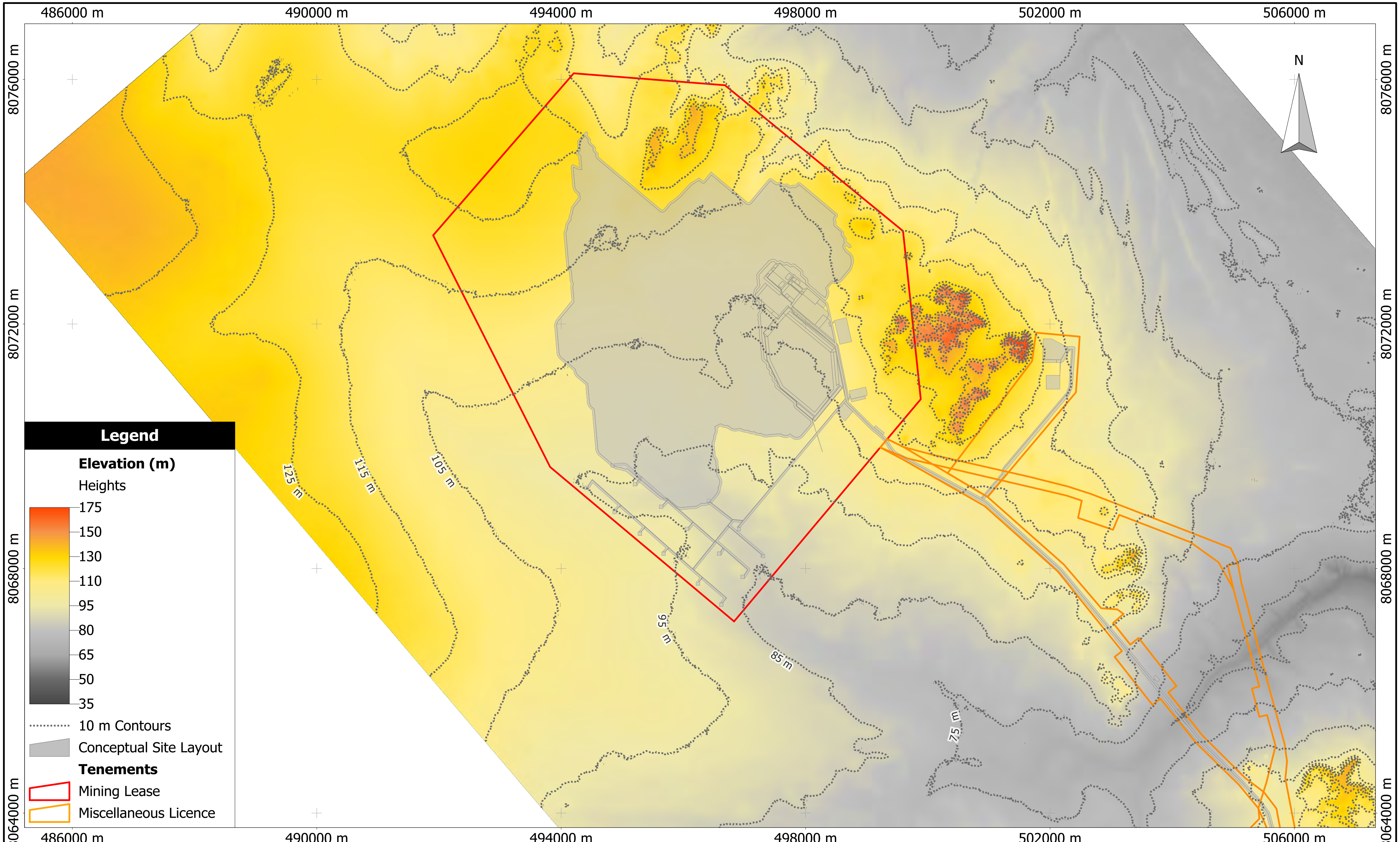

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Figure 8

Topographical Map of Thunderbird Project Area (North)

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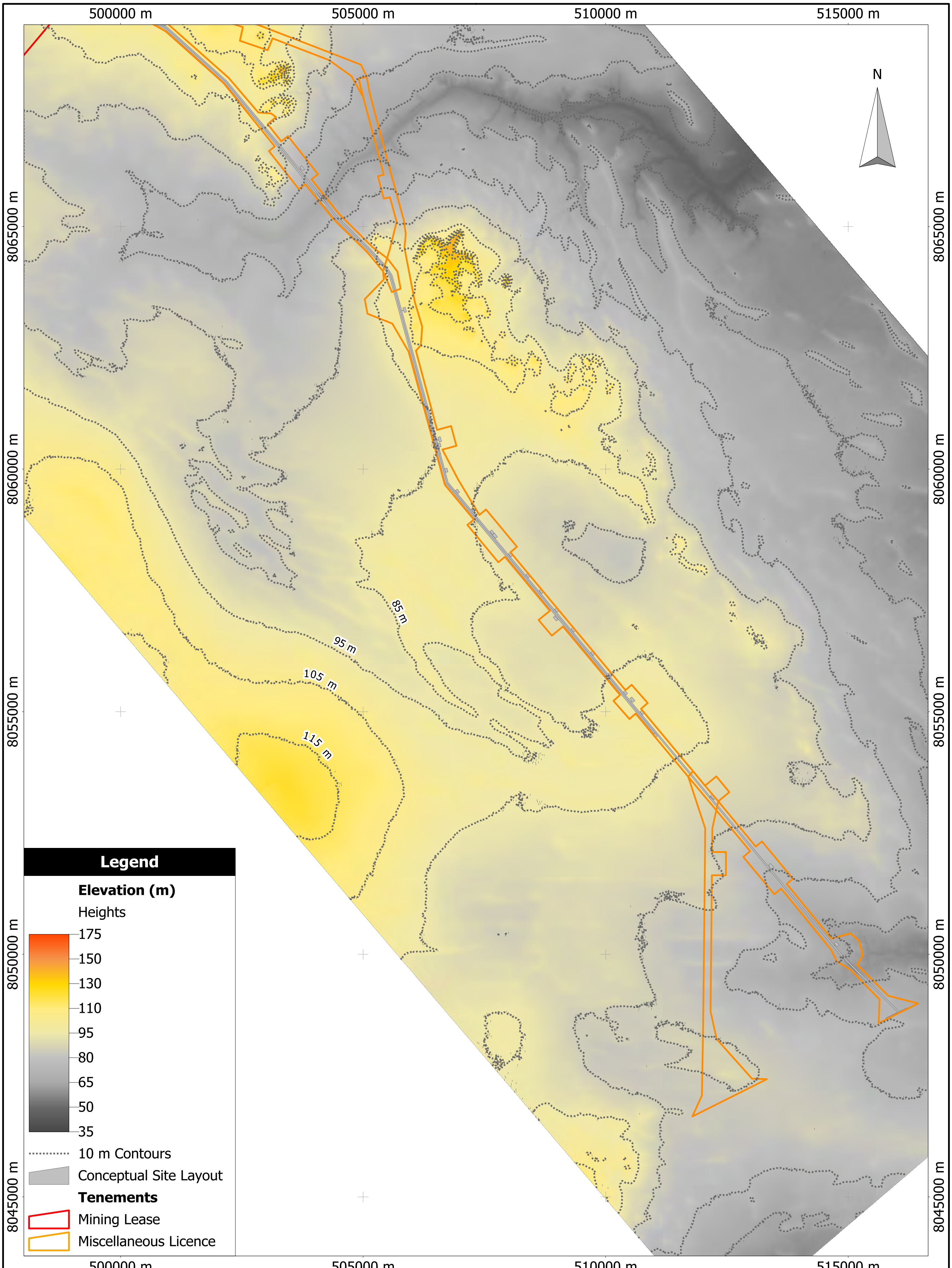

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0 2000 m

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Figure 9

Topographical Map of the Thunderbird Project Area (South)

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Plate 2: Outcrop of Cretaceous Sandstone Hills

5.2 SOIL TYPES

From review of aerial photographs, DAFWA soil survey information (Payne and Schoknecht 2011; Section 3.3.1), previous flora (Ecologia 2012; 2014a; 2015a) and fauna (Ecologia 2014b; 2015b) surveys and site observations, the following soil types were identified within the project area:

- Shallow red Pindan sands over sandstone.
- Deep red sandy Pindan soils (Yabbagoddy family).
- Yellow sandy soils (Pago family).
- Bleached sands over clay/loam subsoil (Tarraji family).

Classifications of these soil types using Western Australian (Schoknecht and Pathan 2013) and Australian Soil Classification (ASC) (Isbell 2002) are presented in Table 5.

Table 5: Project Area Soil Type Classifications

Soil Type Description	WA Soil Group1	ASC Soil Order[2]
Deep red Pindan sands	Red sandy earth	Red Kandosol
Shallow red Pindan sands over sandstone	Red sandy earth	Orthic Tenosol
Yellow sands	Yellow deep sand	Yellow-Orthic Tenosol
Bleached sands over clay/loam subsoil	Grey shallow loamy duplex	Yellow Chromosol

1 *Based on Soil Groups of Western Australia from Schoknecht and Pathan (2013).*

2 *ASC Order descriptions from Isbell 2002.*

5.2.1 Deep Red Pindan Sands

Much of the Dampier Peninsula, including the project area, is covered by a uniform fine to medium red sandy soil referred to as 'Pindan'. Characteristics of Pindan sands include:

- Abundant leaf litter, typically comprising partly decomposed grasses (including spinifex), twigs and leaves from eucalypts and other shrubland species.
- General absence of pedogenic gravels, either as a surface lag or subsoil component.
- Uniform fine to medium sand B-horizon to at least 1 m for the deep sand soil type, as shown in Plate 3.
- Uniform characteristic red colour, with no visible distinction between the upper A horizon and underlying red sandy B horizon. Deeper subsoil may be more yellowish or gray, with the dominant colour of subsoils evident in termite mounds.

Plate 3: Deep Red Pindan Sand Profile

5.2.2 Shallow Red Pindan Sands over Sandstone

A similar, but pedogenically distinct, soil type was observed when the depth of the red sandy B horizon was limited due to presence of weathered sandstone or a silcrete hardpan at less than 1 m from the natural soil surface (Plate 4). Physical characteristics of the A and B horizons were identical to those of the deep red Pindan sands, including an absence of gravel in the B horizon subsoil.

Plate 4: Shallow Red Pindan Sand over Sandstone

5.2.3 Yellow Sands

A second similar, but pedogenically distinct, soil type was observed in areas within the Yeeda Land System. This soil type differed from the deep red Pindan sands only by the distinctive yellow colour of the B-horizon and a pale surface A-horizon (Plate 5). Other pedogenic characteristics, include texture and lack of gravel in the B-horizon, were similar to red Pindan sands. The different colour of these soils is attributed to more humic soil conditions, caused by either high rainfall or poor drainage. The red colour of the Pindan soils is associated with a coating of hematite (Fe_2O_3) on silica sand grains, whereas the yellow colour of these soils is more likely caused by the presence a coating by the yellow-orange hydrous iron oxide, goethite (FeOOH). Areas of yellow sand were limited in extent and restricted to topographically lower lying areas compared to the red Pindan sands.

5.2.4 Bleached Sands Over Clay/Loam

Minor areas of a distinctive grey soil were associated with shallow depressions or drainage lines. The soil profile (Plate 6) consisted of shallow bleached grey loamy sand over a compact grey clay or loam. These soils are expected to be prone to seasonal water-logging after heavy wet season rainfall events. Abundant termite mounds were a distinctive feature of this soil type.

Plate 5: Deep Yellow Sand Profile

Plate 6: Bleached Sands Over Clay

5.3 SOIL PROFILE DESCRIPTIONS

GPS coordinates and soil types observed at each topsoil and subsoil sampling location are summarised in Table 6 and shown in Figure 6 (mining area and northern haul road route) and Figure 7(southern haul road route). Test pit photographs, soil profile descriptions, laboratory sample details and general descriptions for each soil test pit and sample details are presented in Appendix 2.

Table 6: Test Pit and Sampling Locations

Location	GPS Coordinates		Soil Type
	Easting	Northing	
TS1/SS1	505023	8068115	Deep yellow sand
TS2/SS2	497257	8069059	Deep red Pindan sand
TS3/SS3	496296	8067898	Deep red Pindan sand
TS4/SS4	494754	8069189	Deep red Pindan sand
TS5/SS5	495711	8070354	Deep red Pindan sand
TS6/SS6	494943	8071001	Deep red Pindan sand
TS7/SS7	495931	8072164	Deep red Pindan sand
TS8	496964	8073376	Shallow red Pindan sand over sandstone
TS9/SS9	495865	8073594	Deep red Pindan sand
TS10/SS10	497129	8073576	Shallow red Pindan sand over sandstone
TS11A	497540	8072893	Shallow red Pindan sand over sandstone
TS12	497976	8073028	Shallow red Pindan sand over sandstone
TS13	497720	8071928	Deep red Pindan sand
TS14	496984	8071235	Deep red Pindan sand
TS15	498332	8071098	Deep red Pindan sand
TS16	498870	8070955	Deep red Pindan sand
TS17	498045	8072323	Deep red Pindan sand
TS18	497949	8071422	Deep red Pindan sand
TS19	498417	8071986	Deep red Pindan sand
TS20	498491	8073431	Deep red Pindan sand
TS21	502016	8071684	Deep red Pindan sand
TS22	502302	8069308	Shallow red Pindan sand over sandstone
Borrow Pit on haul road	505541	8065858	Shallow red Pindan sand over sandstone
TS23/SS23	504975	8064622	Deep red Pindan sand
TS24	506010	8062475	Deep red Pindan sand
TS25	507731	8058569	Deep red Pindan sand
TS26	512261	8053123	Deep red Pindan sand
Pastoral Dam	513977	8051090	Bleached sands over clay
TS27	516055	8048812	Deep red Pindan sand
TS28	512061	8046823	Deep red Pindan sand
TS29	515087	8049766	Bleached sands over clay

6. PHYSICAL AND CHEMICAL ASSESSMENT

Assessment of the physical and chemical properties of Thunderbird soils from results of laboratory analysis of surface and subsoil samples is presented in the following sections. The full laboratory report is presented in Appendix 3.

6.1 PHYSICAL ATTRIBUTES

6.1.1 Particle Size Distribution and Texture

Results for gravel (>2 mm fraction) content of selected samples and sand, silt and clay percentages on the <2 mm fraction of topsoil samples are presented in Table 7. Gravel contents were all below 0.1%, which is consistent with a general lack of gravel throughout the A and B horizons from field observations (Appendix 2).

Soil texture classifications, based on laboratory results for sand, silt and clay contents in a representative selection of surface soil and subsoil samples are presented in Table 7. Samples for laboratory testing were selected to give a spatial spread across the project area and noted differences in soil types from field observations. Texture classes based on laboratory particle size analysis ranged from sands to sandy loams, which were consistent with field observations.

Table 7: Particle Size Distribution and Texture

Sample	Coarse Fraction (>2 mm) Gravel (%)	Fine Fraction (<2 mm) percentage breakdown			Texture Class
		Sand (0.02-2 mm)	Silt (0.002-0.02 mm)	Clay (<0.002 mm)	
Surface Soils					
TS1	Not measured				(Sand)
TS2	<0.1	93.5	1	5.5	Sand
TS3	Not measured				(Sand)
TS4	Not measured				(Sand)
TS5	Not measured				(Sand)
TS6	Not measured				(Sand)
TS7	<0.1	88.5	1.5	10	Sandy loam
TS8	Not measured				(Sand)
TS9	Not measured				(Sand)
TS10	Not measured				(Sand)
TS11A	<0.1	85.5	2.5	12	Sandy loam
TS11B	Not measured				(Sand)
TS12	Not measured				(Sand)
TS13	Not measured				(Sand)
TS14	<0.1	86.5	2.5	11	Sandy loam
TS15	Not measured				(Sand)
TS16	Not measured				(Sand)
TS17	Not measured				(Sand)

Sample	Coarse Fraction (>2	Fine Fraction (<2 mm) percentage breakdown			Texture Class
TS18	<0.1	91	1.5	7.5	Sand
TS19	Not measured				(Sand)
TS20	Not measured				(Sand)
TS21	Not measured				(Sand)
TS22	Not measured				(Sand)
TS23	Not measured				(Sand)
TS24	Not measured				(Sand)
TS25	Not measured				(Sand)
TS26	Not measured				(Sand)
TS27	Not measured				(Loamy sand)
TS28	Not measured				(Loamy sand)
TS29	Not measured				(Sandy clay)
Subsoils					
SS1	Not measured				(Sand)
SS2	Not measured				(Sand)
SS3	Not measured				(Sand)
SS4	Not measured				(Sandy loam)
SS5	<0.1	88.5	1	10.5	Sandy loam
SS6	Not measured				(Sand)
SS7	Not measured				(Sand)
SS9	Not measured				(Loamy sand)
SS10	Not measured				(Loamy sand)
SS14	Not measured				(Sand)
SS18	Not measured				(Sand)
SS23	Not measured				(Sand)

Texture Class description presented in parentheses refer to field test classifications. Other Texture Classes were assigned by comparing laboratory sand, silt and clay contents with the Australian Soil Texture Triangle as described in Appendix 1.

6.1.2 Emerson Aggregate Class

The structural stability of loams and clay soils is generally determined by the Emerson aggregate test (AS 1289 C8.1 1980). The test involves observation of the behaviour of natural soil aggregates (peds) and subsamples of soil remoulded at field capacity when placed in deionised water. Poorly structured soils, often containing sodic clays, exhibit low strength when wet, resulting in rapid slaking of aggregates and dispersion of fine clays and a cloudy halo when placed in deionised water (Appendix 1).

Sandy topsoil and subsoil samples are not suitable for this test, especially unconsolidated topsoil samples that do not provide stable natural soil aggregates required for the test. None of the samples submitted for laboratory analysis contained peds suitable for the test.

6.2 pH AND SALINITY

Deionised water leachates (1:5 soil:water ratio) of all samples were tested for pH and EC to indicate natural levels of soil acidity, alkalinity and salinity. Results are presented in Table 8.

6.2.1 pH

Surface soil pH values were variable, ranging from 5.5 to 8.0. These values correspond to soil pH ratings of very strongly acid to moderately alkaline (Table A1-3 of Appendix 1). However, a majority of the surface soils (70%) had pH values within the slightly acid to circum-neutral range, as indicated by the histogram of values shown in Chart 3. Where subsoil pH was measured, subsoil pH values were usually similar to or lower than the corresponding topsoil values. This observation is typical of pH profiles of non-calcareous sandy soils in a leaching environment (McArthur 1991).

The highest pH value (8.0; Table 8) was recorded for the surface soil from location TS29 on the access road (**Error! Reference source not found.**). Surface soil at TS29 was described as very shallow sandy clay surface soil (Appendix 1) over compacted grey clay.

Chart 3 also presents pH values from deeper regolith material classified as "overburden" in the MBS mine waste characterisation report (MBS 2016a). Overburden samples were less variable than soil samples, with 77% of samples recording pH values between 6.1 and 6.5, and no samples with alkaline pH values (greater than 7.0).

6.2.2 Salinity

Surface soil EC values were very low, generally ranging from 1 to 4 mS/m in surface soil samples with the exception of TS29 with an EC value of 1,400 mS/m. This elevated salinity (and soil pH) is interpreted as the location being a drainage sump as a consequence of low permeability of the clay subsoil, evidenced by the area being prone to prolonged periods of surface water ponding following high rainfall events during the wet season. Although surface runoff in the region is expected to have low salinity, salts accumulate in the soil profile following evaporation of ponded water during the dry season.

Subsoil EC values from sandy profiles were also very low, ranging from 1 to 2 mS/m. With the exception of TS29, these values correspond to a nil risk rating for salinity (Table A1-4 of Appendix 1) and indicate very good drainage conditions.

Table 8: pH and EC for 1:5 Soil Extracts of Thunderbird Soils

Surface Soils			Subsoils		
Sample	EC (mS/m)	pH (pH units)	Sample	EC (mS/m)	pH (pH units)
TS1	2	6.9	SS1	1	6.6
TS2	1	6.8	SS2	1	5.7
TS3	1	6.3	SS3	1	6.3
TS4	2	6.9	SS4	2	7.0
TS5	1	6.7	SS5	1	5.5
TS6	1	5.7	SS6	1	5.7
TS7	1	6.5	SS7	1	6.6
TS8	3	5.8	Subsoil not sampled		
TS9	1	6.1	SS9	1	5.9
TS10	2	6.2	SS10	2	6.5
TS11A	2	5.5	Subsoil not sampled		
TS11B	1	5.6	Subsoil not sampled		
TS12	1	6.5	Subsoil not sampled		
TS13	4	7.7	Subsoil not sampled		
TS14	1	7.0	Subsoil not sampled		

Surface Soils			Subsoils		
TS15	1	6.8	Subsoil not sampled		
TS16	1	6.1	Subsoil not sampled		
TS17	1	6.2	Subsoil not sampled		
TS18	1	6.8	Subsoil not sampled		
TS19	1	6.5	Subsoil not sampled		
TS20	1	6.2	Subsoil not sampled		
TS21	2	6.5	Subsoil not sampled		
TS22	2	7.4	Subsoil not sampled		
TS23	3	6.7	SS23	2	5.3
TS24	2	6.4	Subsoil not sampled		
TS25	2	6.6	Subsoil not sampled		
TS26	1	6.1	Subsoil not sampled		
TS27	1	5.6	Subsoil not sampled		
TS28	1	7.1	Subsoil not sampled		
TS29	1400	8.0	Subsoil not sampled		

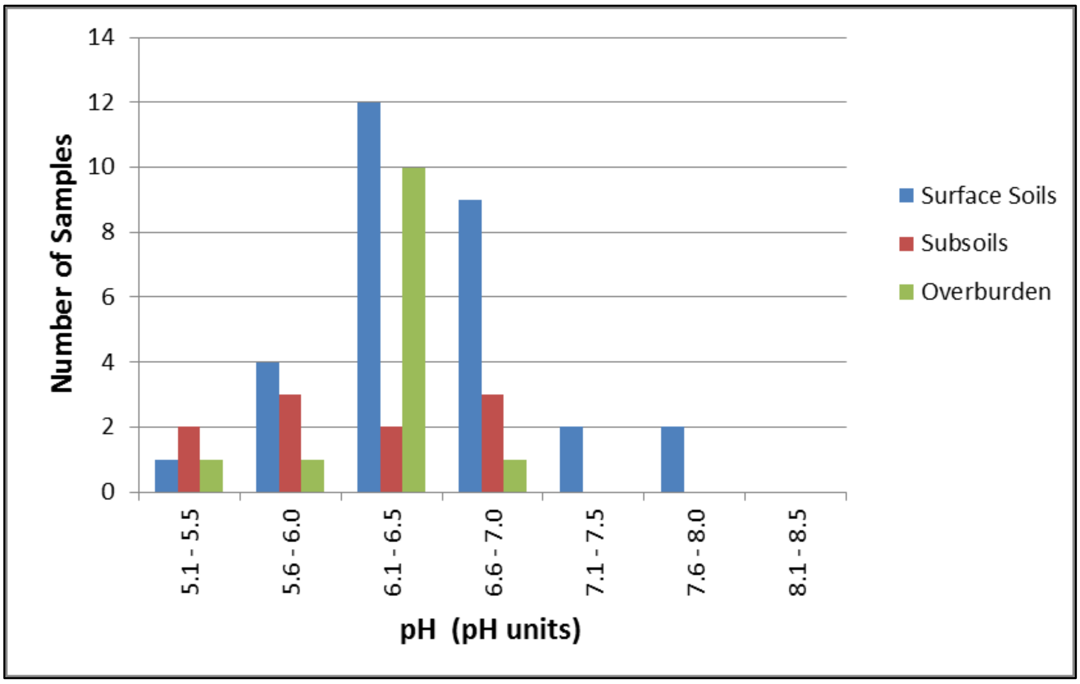

Chart 3: Distribution of pH Values

6.3 CATION EXCHANGE CHARACTERISTICS

Results for exchangeable basic cations (calcium, magnesium, sodium and potassium), acidic cations (aluminium and manganese) and the derived cation exchange parameters Effective Cation Exchange Capacity (ECEC) and Exchangeable Sodium Percentage (ESP) (Section 3.3 of Appendix 1) for selected samples are presented in Table 9.

Table 9: Exchangeable Cation Data

Sample	Ca	Mg	Na	K	Al	Mn	ECEC	ESP
	centimoles (+)/kg							%
Surface Soils								
TS1	1.1	0.28	0.03	0.12	Not Analysed		1.5	2.2
TS2	1.1	0.32	0.04	0.08	Not Analysed		1.5	2.4
TS3	1.2	0.17	0.03	0.09	Not Analysed		1.5	2.3
TS4	1.1	0.20	0.06	0.10	Not Analysed		1.5	4.3
TS5	0.69	0.34	0.02	0.15	Not Analysed		1.2	1.7
TS6	0.67	0.19	0.02	0.09	Not Analysed		1.0	1.7
TS7	1.0	0.21	0.03	0.06	Not Analysed		1.3	2.6
TS8	0.84	0.31	0.08	0.12	Not Analysed		1.4	6.0
TS9	0.70	0.20	0.03	0.08	Not Analysed		1.0	3.1
TS10	1.2	0.22	0.03	0.12	Not Analysed		1.6	1.9
TS11A	0.68	0.24	<0.02	0.11	0.24	0.03	1.3	0.7
TS12	1.6	0.41	0.04	0.14	Not Analysed		2.2	2.0
TS13	2.9	0.53	0.05	0.20	Not Analysed		3.7	1.4
TS14	1.8	0.27	0.04	0.12	Not Analysed		2.2	2.0
TS15	1.2	0.31	0.03	0.14	Not Analysed		1.7	1.9
TS16	0.65	0.19	0.03	0.09	Not Analysed		1.0	2.7
TS17	1.4	0.45	0.04	0.13	Not Analysed		2.0	1.8
TS18	1.6	0.26	0.03	0.13	Not Analysed		2.0	1.4
TS19	1.3	0.22	0.07	0.06	Not Analysed		1.6	4.0
TS20	1.2	0.29	0.04	0.14	Not Analysed		1.7	2.6
TS21	1.6	0.27	0.03	0.17	Not Analysed		2.1	1.3
TS22	1.6	0.22	0.05	0.11	Not Analysed		2.0	2.4
TS23	2.8	0.67	0.05	0.22	Not Analysed		3.7	1.4
TS24	1.7	0.57	0.04	0.18	Not Analysed		2.5	1.7
TS26	0.70	0.20	0.03	0.12	Not Analysed		1.0	2.9
TS28	1.2	0.21	0.02	0.11	Not Analysed		1.5	1.5
TS29	2.0	3.1	3.8	1.2	Not Analysed		10	38
Subsoils								
SS1	0.86	0.37	<0.02	0.14	Not Analysed		1.4	1.4
SS2	0.34	0.25	<0.02	0.09	Not Analysed		0.7	1.6
SS6	0.66	0.29	<0.02	0.11	Not Analysed		1.1	1.8

ECEC values for all but one sample were low according to the ratings table (Table A1-5) in Appendix 1. Surface soil sample TS29 collected from a drainage line with poor infiltration had the highest EC value of 10 cmol(+)/kg, which is consistent with the field distribution of a sandy clay texture (Table 7).

Surface soils collected with the proposed mining area footprint (Figure 6) had relatively consistent and low ECEC values, typically within the range of 1.0 to 2.0 cmol(+)/kg. This observation is consistent with the dominance of red Pindan sandy soils within the Mine Site Development Envelope.

Surface soils along the proposed transport corridor, particularly the southern section (Figure 7), typically had slightly higher and more variable ECEC values. The highest values were 3.7 and 10 cmol(+)/kg for samples TS23 and TS29, respectively.

Except for surface soil sample TS29, calcium was the dominant exchangeable cation in all samples, followed by (in decreasing order), magnesium, potassium and sodium. Consequently, ESP values for sandy soils were very low, ranging from 1.4 to 6.0% and classified as non-sodic by criteria presented in Table A1-5 of Appendix 1.

Sandy clay surface sample TS29 was classified as highly sodic based on an ESP value of 38%. This is consistent with the explanation of elevated salinity in this sample/location discussed in Section 6.2.2.

One sample (TS11A) was analysed for exchangeable aluminium and manganese. These acidic exchangeable cations (as discussed in Section 3.3 of Appendix 1) are only measured in the laboratory if the corresponding soil pH value is less than or equal to 5.5. Although this sample had a pH value of 5.5 (Table 8), it contained a significant amount of exchangeable aluminium, but not manganese (when compared to criteria in Table A1-5 of Appendix 1. The Base Saturation Percentage (BS%) of this sample is 79%, which is rated as high when compared to criteria in Table A1-5 of Appendix 1. High BS% values (greater than 60%) are a desirable soil characteristic for healthy plant growth.

6.4 ORGANIC CARBON, NITROGEN AND PHOSPHORUS

Results for analysis of selected soil samples for organic carbon, total nitrogen, C/N ratio and extractable major nutrients (phosphorus, potassium, calcium, magnesium and sulfur) (Mehlich 1984) are presented in Table 10.

Table 10: Organic Carbon and Major Nutrients

Sample	Organic C %	Total N %	C/N ratio -	Extr.-P mg/kg	Extr.-K mg/kg	Extr.-Ca mg/kg	Extr.-Mg mg/kg	Extr.-S mg/kg
TS1	0.22	0.019	11.6	1	38	230	37	1
SS1	0.12	0.015	8.0	<1	47	180	49	2
TS2	0.30	0.019	15.8	2	28	240	43	1
SS2	0.07	0.006	11.7	<1	26	67	33	6
TS3	0.41	0.028	14.6	2	27	280	23	<1
TS4	0.17	0.016	10.6	<1	29	230	28	1
TS5	0.27	0.020	13.5	2	52	150	44	<1
TS6	0.30	0.020	15.0	2	30	140	25	1
SS6	0.14	0.012	11.7	<1	35	130	38	4
TS11A	0.37	0.024	15.4	2	52	140	31	4
TS13	0.56	0.038	14.7	4	70	660	73	2
TS15	0.22	0.019	11.6	<1	49	280	43	1
TS16	0.21	0.013	16.2	<1	28	140	26	1
TS17	0.55	0.032	17.2	2	42	300	56	1
TS21	0.58	0.032	18.1	3	61	380	37	1

Key findings are summarised as follows:

- Surface soil organic carbon concentrations ranged from 0.17% to 0.56% and are rated low to medium for northern WA soils according to the ratings criteria presented in Table A1-6 of Appendix 1.
- Subsoil soil organic carbon concentrations ranged from 0.07% to 0.14% and are rated medium for northern WA soils (A2 and B horizons) according to the ratings criteria presented in Table A1-6 of Appendix 1.
- Surface soil total nitrogen concentrations ranged from 0.013% to 0.038% and are rated as low for northern WA soils according to the ratings criteria presented in Table A1-6 of Appendix 1.
- C/N ratios ranged from 8.0 to 17.1, which are considered low to medium according to criteria presented in Table A1-6 of Appendix 1. These values indicate that soil organic matter is highly decomposed, which is typical of soils in northern Australia.
- Extractable phosphorus concentrations ranged from <1 to 4 mg/kg. According to the ratings criteria presented in Table A1-7 of Appendix 1, bio-available phosphorus concentrations were below to within the lower typical range in terms of WA soil types.
- Extractable potassium concentrations ranged from 26 to 70 mg/kg, which are typical of expected levels in WA soil types (Table A1-7 of Appendix 1).
- Extractable calcium concentrations ranged from 67 to 660 mg/kg, which are typical of expected levels in WA soil types (Table A1-7 of Appendix 1).
- Extractable magnesium concentrations ranged from 23 to 73 mg/kg, which are typical of expected levels in WA soil types (Table A1-7 of Appendix 1).
- Extractable sulfur concentrations ranged from 1 to 6 mg/kg. According to the ratings criteria presented in Table A1-7 of Appendix 1, bio-available sulfur concentrations were generally below the typical range of WA soil. Well drained soils, especially those containing low levels of soil organic matter, generally contain low concentrations of bio-available sulfur (DAFWA 1998; Peverill *et al*. 1999).

As a consequence of the inherently low concentrations of organic matter and associated nutrients in Pindan soils and an environment of strong leaching associated with free-draining sandy soils and moderate to high rainfall, nutrient cycling is critical for sustaining healthy vegetation communities. Woody debris, leaf litter and termite mounds are important repositories of nutrients and organic matter. Frequent fires (Section 3.4) and soil biological activity, especially by termites, are essential for efficient nutrient recycling in this environment.

Even though surface soils within the project area generally contain low concentrations of organic matter and major plant nutrients (and some minor nutrients; Section 6.5), nutrient deficiency is not expected to be a constraint to successful rehabilitation of mine waste landforms.

6.5 MINOR NUTRIENTS

Results for extractable minor nutrients (boron, copper, iron, manganese, molybdenum and zinc) using a Mehlich (Mehlich 1984) extraction are presented in Table 11 and compared with ratings established for WA soil types presented in Table A1-7 of Appendix 1.

Table 11: Extractable Minor Nutrients

Sample	Extr.-B mg/kg	Extr.-Cu mg/kg	Extr.-Fe mg/kg	Extr.-Mn mg/kg	Extr.-Mo mg/kg	Extr.-Zn mg/kg
TS1	<0.1	0.2	30	64	<0.01	0.1
TS2	<0.1	0.4	14	28	<0.01	0.1
TS3	<0.1	0.3	20	35	<0.01	0.1
TS4	<0.1	0.2	25	44	0.01	<0.1
TS5	<0.1	0.4	17	26	<0.01	<0.1
TS6	<0.1	0.2	24	50	0.01	0.2
TS11A	<0.1	1.2	28	69	<0.01	<0.1
TS13	<0.1	0.8	18	80	<0.01	0.3
TS15	1.2	0.2	22	66	0.01	0.1
TS16	0.6	0.3	26	47	<0.01	0.1
TS17	<0.1	0.9	24	48	<0.01	0.2
TS21	<0.1	0.5	24	65	<0.01	0.2
SS1	<0.1	0.1	29	29	0.01	0.1
SS2	<0.1	0.2	9	3.2	0.01	<0.1
SS6	<0.1	0.1	17	24	<0.01	<0.1

Key findings are summarised as follows:

- Extractable boron concentrations ranged between <0.1 to 1.2 mg/kg for all samples analysed, corresponding to ratings of low to within typical range. Boron is a relatively soluble nutrient, readily leached from surface soils and often accumulates in subsoils, particularly in low rainfall environments.
- Extractable copper concentrations ranged from 0.1 to 1.2 mg/kg, corresponding to typical ranges for WA soil types (Table A1-7 of Appendix 1).
- Extractable iron concentrations ranged from 9 to 30 mg/kg, which is considered low to within typical range for WA soil types (Table A1-7 of Appendix 1). Although the distinctive red and yellow colours of Pindan sands are associated with coating of silica sand particles with iron oxide minerals, these minerals (hematite and goethite) are almost insoluble in the extractant used to measure bio-available iron.
- Extractable manganese concentrations were variable, ranging from 3.2 mg/kg to 80 mg/kg, which is considered low to within typical range for WA soil types (Table A1-7 of Appendix 1).
- Extractable molybdenum concentrations ranged from <0.01 to 0.01 mg/kg, rating the soils as low to typical by WA standards (Table A1-7 of Appendix 1).
- Extractable zinc concentrations ranged from <0.1 to 0.3 mg/kg, rating the soils as low to typical by WA standards (Table A1-7 of Appendix 1).

6.6 METALS AND METALLOIDS

Results for analysis of selected surface samples from the project for environmentally significant metals and metalloids are presented in Table 12. Included for comparison are average concentrations for the earth's crust and typical ranges present in soil (AIMM 2001). Results indicate low concentrations of these elements are present, which is consistent with the transported nature of the surface regolith, extensive leaching and only minor enrichment of certain elements in the underlying sedimentary rock associated with ore mineralisation.

Table 12: Metals and Metalloids (mg/kg)

Sample	As	Cd	Cr	Cu	Fe	Ni	Pb	Se	U	Zn
TS1	<1	<0.05	15	1.2	4100	2	3.0	0.06	0.30	0.72
TS11A	3	<0.05	37	4.0	21000	6	7.7	0.13	0.73	3.0
TS11B	3	<0.05	37	3.8	20000	5	7.5	0.14	0.70	3.1
TS13	2	<0.05	19	2.6	11000	4	4.9	0.07	0.48	2.7
TS15	1	<0.05	15	1.4	8400	3	4.3	0.06	0.35	1.1
TS16	<1	<0.05	12	1.2	5900	2	3.4	0.05	0.32	1.1
TS17	2	<0.05	27	3.4	17000	5	6.5	0.11	0.74	3.4
TS21	2	<0.05	11	1.9	4400	2	3.7	<0.05	0.26	0.85
TS27	2	<0.05	14	1.4	8100	2	3.7	0.09	0.24	1.3
Crustal average	1.8	0.2	100	55	-	75	12.5	0.05	2.7	70
Typical soil	1-50	1	5-1,000	2-100	-	5-100	2-200	0.2	1	10-300

7. CONCLUSIONS

7.1 LANDFORMS

All of the proposed mine site and other areas of potential disturbance are located within flat or gently undulating Pindan sandplain areas within the Fraser, Wanganut and Yeeda Land Systems (3.3.1). These land systems are widely represented within the Dampier Peninsula, with the following areas provided by Payne and Schoknecht (2011):

- Yeeda, 21,308 km^2.
- Wanganut, 6,973 km^2.
- Fraser, 728 km^2.

These land systems are described by Payne and Schoknecht (2011) as generally being not prone to degradation or erosion by pastoral activities, provided grazing pressure is controlled and frequency of burning is maintained. As livestock will be excluded from the project area, risk of degradation within undisturbed areas will be reduced.

Elevated topography (typically up to 50 m above surrounding ground levels) is associated with the Reeves Land System. This system is not widely represented within the Dampier Peninsula, with an area estimate of 428 km^2 comprising hills (11%), sandy surfaces with local outcrop (29%), sandplains (52%), pans and depressions (7%) and drainage channels (1%) (Payne and Schoknecht 2011). Reeves Hill, Dampier Hill and several unnamed smaller hills to the east and north of the proposed operational areas (Figure 8) will not be disturbed by mining activities. These hills are located within the Mount Jowlaenga pastoral property which has a long history of disturbance by cattle grazing. A small sandstone quarry near Dampier Hill has been established to provide construction stone for various requirements.

7.2 SOILS

Soils in the project area are dominated by red sands (Pindan) of aeolian origin, which are widespread throughout the Dampier Peninsula. Soil profiles are typically deep (greater than 1 m), although relatively shallow profiles were recorded at several locations where Cretaceous sandstone sedimentary rocks or silcrete hardpan were present within 1 m of the natural soil surface. Minor soil types included deep yellow sand and shallow bleached sand over clay or loam, usually associated with drainage lines or depressions.

Assessment of the physical and chemical properties of sandy soils by desktop studies, field assessment of profiles exposed in test pits and laboratory analysis of selected samples indicate the following characteristics:

- Topsoil textures of sand, sandy loam and loamy sand.
- Uniform physical and chemical soil properties throughout the depth of the sandy soil profile.
- Variable pH, with a majority of surface soils (70%) being circum-neutral or slightly alkaline.
- Non-saline (except for one saline soil collected from a depression with restricted drainage).
- Low CEC values, with calcium being the dominant exchangeable cation.
- Low sodicity, although this characteristic is not considered important for structural stability of predominantly sandy soils.
- Typically low concentrations of organic matter, major plant nutrients and some minor nutrients. Despite these low concentrations, nutrient deficiency is not expected to be a constraint to successful progressive rehabilitation of mine waste landforms.
- Very low concentrations of heavy metals and metalloids. Despite enrichment of uranium in ore and mineralised waste (MBS 2016a), there was no evidence of uranium enrichment in project area

soils. Uranium concentrations ranged between 0.24 and 0.74 mg/kg, which is well below the estimated earth's crustal abundance of 2.7 mg/kg (AIMM 2001).

7.3 REHABILITATION CONSIDERATIONS

The depth of potentially recoverable soil from project locations to be disturbed by mining operations is expected to be very deep, with rock or clay materials being encountered at shallow depth (less than 1 m) at a relatively small number of test pits excavated for this survey. However, as there is very little development of a humus-rich surface A horizon on Pindan soils within the project area, harvesting of topsoil for rehabilitation requirements should be restricted to approximately 100 mm.

As discussed in Sections 3.4 and 6.4, efficient nutrient recycling is critical for sustaining healthy vegetation communities on nutrient depleted, free-draining sandy soils in northern Australia. Recognising the importance of woody debris and termites as nutrients stores and the low inherent fertility of surface Pindan soils, procedures for removing vegetation and topsoil prior to mining should consider the following requirements:

- Coarse woody debris should be stockpiled and not burnt. It should be re-applied as a surface layer over topsoil during rehabilitation of mined areas.
- Fine woody debris, leaf litter and termite mounds (if present) should be harvested and mixed with topsoil.
- Harvested topsoil should either be immediately re-applied to mine rehabilitation areas, or stored in stockpiles for no more than one or two years. Stockpiles should be no higher than 2 m. Pindan soils are not anticipated to present a dust hazard and stockpiles are expected to be stabilised by grass cover after a typical wet season.

Sheffield Resources proposes to use conventional mineral sands mining with progressive backfilling and rehabilitation. Most of the mine waste (MBS 2016a) and process residues (MBS2016b) are expected to be physically stable and chemically benign and will be returned to the mine void. A thin cover (approximately 100 mm) of stockpiled or recently stripped topsoil is expected to be sufficient for rehabilitation requirements as there is no requirement for a subsoil water storage layer between mine waste and topsoil. Deeper subsoil, while potentially useful as a rehabilitation material, can be managed as overburden. Blended fine textured process wastes (namely slimes), should be placed at least 2 m below the final soil surface and covered with overburden to ensure establishment of a well-drained sandy soil profile to replicate pre-mining soil conditions.

As process tailings deposited in early stages of processing to the TSF are expected to be geochemically benign (MBS 2016b), a substantially thinner soil cover will be suitable to satisfy closure requirements. The optimum cover design will be dependent on characteristics of the upper layer of tailings in the facility.

Although Pindan soils have low coherence and limited wet strength and are not favourable for rehabilitation of sloping surfaces, the soils are well suited for rehabilitation of flat or gently sloping surfaces which are present over the proposed pit footprint. The only requirement to rehabilitate sloping surfaces is for the embankments of a small initial (year 1) above ground tailings storage facility. Pindan soil blended with ferruginous sandstone overburden is expected to provide a suitable cover medium for this facility.

As pre-mining stripping of soil at Thunderbird is expected to provide sufficient material for rehabilitation of mined areas, there is no requirement to transport any soil stripped from the proposed access road corridor. It is recommended that soil disturbed by construction of the access road be pushed aside as low windrows for subsequent on site rehabilitation at mine closure.

Topsoil removed from permanent infrastructure areas such as the processing plant, camp and hardstand areas is unlikely to retain its biological activity and seed bank if stockpiled for the expected life of project. Coarse woody debris should be stockpiled and re-applied as mulch when the area is rehabilitated. Re-seeding supplemented by application at low rates of a balanced fertiliser will be required for rehabilitation of these areas. Although sandy soils are typically not responsive to ripping, the relatively high silt and clay contents of Pindan sands are expected to be suitable for ripping to alleviate compaction and promote water infiltration during the first wet season after rehabilitation.

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APPENDICES

APPENDIX 1: SOIL ASSESSMENT METHODOLOGY

SOIL ASSESSMENT METHODOLOGY

1. INTRODUCTION

1.1 SOIL TEST METHODOLOGY

Understanding the physical, chemical and biological properties of soils is dependent on the ability of scientists and land managers to critically evaluate and assess data provided by meaningful soil tests. A multitude of different soil tests, often intended to measure the same soil quality parameter, have been developed over many years for various reasons, including:

- Characterisation of the diversity of soil types around the world with widely different physical and chemical properties.
- Cost - market forces by land managers, especially farmers, have driven development of soil tests that are simple, rapid and cheap to form, even though technically superior procedures exist.
- Speed of assessment: Rapid advances in laboratory automation, technical capabilities of modern instruments and data management systems.
- Increasing demands to deal with emerging issues of natural resource management including sustainability issues, environmental protection, soil health and food safety.

Unlike water and geological analysis, total elemental composition of soils generally provides will little predictive capacity for assessing the ability of soil to provide necessary levels of nutrients for good plant growth. For this reason, different soil tests for specific nutrients have been developed using extracting solutions that mimic the role of plant roots for taking up nutrients from soil.

In recent times, there have been attempts by various organisations to standardise laboratory methods throughout Australia. Most government and commercial soil testing laboratories in Australia now use standard methods, or validated variations derived from the following sources:

- Chemical analysis for agriculture and land management: Soil Chemical Methods – Australian (Rayment and Lyons 2011).
- Environmental assessment: NEPM. 2013. National Environment Protection (Assessment of Site Contamination) Measure. Guideline on Laboratory Analysis of Potentially Contaminated Soil. Schedule B3. National Environment Protection Council.
- Physical and engineering properties of soil: Australian Standard AS 1289.0-2000.

MBS Environmental provides soil characterisation assessments, mainly for the mining industry in WA and other Australian states, to inform pre-feasibility studies, mining proposals and closure planning to meet regulators' requirements. Soil test data and interpretation is provided to meet the following objectives:

- Properties of regional and project areas soils in terms of:
  - Physicochemical attributes including acidity, alkalinity, salinity, sodicity, texture, fertility and structural stability.
  - An indication of the volumes of suitable topsoils and subsoils that can be harvested and stockpiled for rehabilitation activities.
  - Ability to assimilate potential environmental contaminants such as hydrocarbons, metals, metalloids, nutrients, salts, acidity and pathogens.
- Achieving acceptable mine closure outcomes to provide a land surface that is:
  - Structurally stable and safe.
  - Non-polluting (surface water run-off, groundwater and air quality).

- Compatible with post-mineral land use requirements.

Note that MBS Environmental does not offer geophysical and geotechnical soil assessment for engineering purposes such as constructions of roads, structures and water storages.

1.2 INFORMATION SOURCES

Interpretation of laboratory and field soil testing results and observations requires not only accurate data, but also a "Decision Support System" that provides meaningful predictions of soil properties and behaviour. A reliable Decision Support System needs to be:

- Developed and validated for local conditions including soil types, climate and land use.
- Able to predict soil constraints that may limit productivity and health of vegetation including:
  - Crop plants for agricultural land use on different soil types and environmental settings.
  - Pasture and feed value for pastoral land use.
  - Native plants for rehabilitation of degraded or disturbed areas, especially for WA plant species that are specially adapted to low nutrient and poorly structured soils.
- Able to quantify the risk of ecological and human health impacts for a specific location relating to:
  - Heavy metals and metalloids.
  - Nutrient runoff and leaching.
  - Petroleum hydrocarbons.
  - Agro-chemicals including insecticides and herbicides.

There is an enormous volume of interpretative soil test information available in response to the diversity of soil test methods and differences in soil types throughout the world. However, it is important that the information used be validated against local conditions and for this reason, much of the information published by reputable authorities in overseas countries is not applicable to Australian conditions.

The following sources of information are used by MBS Environmental to assess the significance of laboratory test results:

- Soil Analysis: An Interpretation Manual (Peverill et al. 1999). This reference was compiled by specialists from CSIRO and State Government agricultural research agencies. It is biased towards agricultural production, mainly in the eastern states, although it does reference large volumes of research provided by WA researchers between 1960 and 1998.
- Interpreting Soil Test Results. What do all the numbers mean? (Hazelton and Murphy 2007). This document was written specifically for officers in the former Soil Conservation Service of NSW, but is now used widely by soil professionals in other Australian States.
- Soil Guide. A handbook for understanding and managing agricultural soils. DAFWA Bulletin 4343 (DAFWA 2001). This document was prepared specifically for WA agricultural land use.
- Land Evaluation Standards for Land Resource Mapping (assessing land qualities and determining land capability in south-western Australia). DAFWA Resource Management Technical Report 298 (DAFWA 2006). This report describes the standard method for attributing and evaluating conventional land resource survey maps in the south-west agriculture region of Western Australia so that strategic decisions about the management, development and conservation of land resources can be based on the best information available.

- Soilquality.org.au website, with contributions from the University of Western Australia, DAFWA, Wheatbelt Natural Resource Management, Grains Research & Development Corporation, South Coast Natural Resource Management and the Grower Group Alliance.

MBS Environmental also draws upon the author's experience from coordinating physical and chemical laboratory analysis for DAFWA and DPaw soil and biological surveys conducted between 1988 and 2008. These include:

- Reference soils of south-western Australia (McArthur 1991). This publication presents soil profile descriptions and laboratory analysis of samples from the O, A and B soil horizons from 161 locations between Geraldton and Esperance in south-western Australia.
- Laboratory soil test results for approximately 10,000 soil samples from soil surveys of WA conducted by DAFWA between 1989 and 2007. Details of these surveys are presented in DAFWA Resource Management Technical Report 280, Soil-Landscape Mapping in South-Western Australia, Overview of methodology and outputs (DAFWA 2004).
- Soil analysis data to support the following biological surveys conducted by the Department of Parks and Wildlife (DPaW):
    - Pilbara region biological survey, 2002-2007 (George et al. 2009).
    - Floristic surveys of the banded iron formation ranges of the Yilgarn, 2005 to 2008 (Meissner and Caruso, 2008).
    - Wetland flora and vegetation of the WA wheatbelt, 2004.

2. PHYSICAL PROPERTIES

2.1 PARTICLE SIZE AND TEXTURE

2.1.1 Field Measurements

Soil texture describes the proportions of sand, silt and clay particles; the particle size distribution. Sands are mineral particles with an effective diameter between 0.02 and 2 mm, silt from 0.002 to 0.02 mm and clay less than 0.002 mm.

The field (or hand texture) of soil can be assigned by describing the behaviour of a sample of field sieved (<2 mm) soil when moistened to field capacity and kneaded into a ball or bolus and then pressed out between the thumb and forefinger to form a ribbon (bolus) (McDonald et al. 1990). The behaviour of the soil during bolus formation and the length of the ribbon define the field texture grade, as summarised in Table A1-1.

Table A1-1: Field Texture Grades

Texture Grade	Behaviour of Moist Bolus	Approximate Clay Content
Sand	Nil to very slight coherence; cannot be moulded; single sand grains adhere to fingers	<5%
Loamy sand	Slight coherence; can be sheared between thumb and forefinger to give a small ribbon (~5 mm)	About 5%
Clayey sand	Slight coherence; sticky when wet; many sand grains stick to fingers, discolours fingers with stain; ribbon 5 to 15 mm	5-10%
Sandy loam	Coherent bolus but very gritty; dominant sand grains of medium size and readily visible; ribbon of 15 to 25 mm	10-20%

Texture Grade	Behaviour of Moist Bolus	Approximate Clay Content
Loam	Bolus coherent and spongy; no obvious grittiness or silkiness; ribbon approximately 25 mm	About 25%
Sandy clay loam	Strongly coherent bolus; sandy to touch; ribbon of 25 to 40 mm	20-30%
Clay loam	Coherent plastic bolus; smooth to manipulate; ribbon of 40 to 50 mm	30-35%
Clay loam, sandy	Coherent plastic bolus; sand grains visible in finer matrix; ribbon of 40 to 50 mm	30-35%
Light clay	Plastic bolus; smooth to touch; slight resistance to shearing; ribbon of 50 to 75 mm	35-40%
Light medium clay	Ribbon of approximately 75 mm; slight to moderate resistance to ribboning shear	40-45%
Medium clay	Smooth plastic bolus; can be moulded into rods without fracture; moderate resistance to ribboning shear; ribbons 75 mm of longer	45-55%
Medium heavy clay	Ribbons of 75 mm or longer; moderate to firm resistance to ribboning shear	≥50%
Heavy clay	Extremely plastic; firm resistance to ribboning shear; ribbons of 75 mm or longer	≥50%

2.1.2 Laboratory Measurements

Soil texture assessment can be undertaken by two distinct laboratory methodologies:

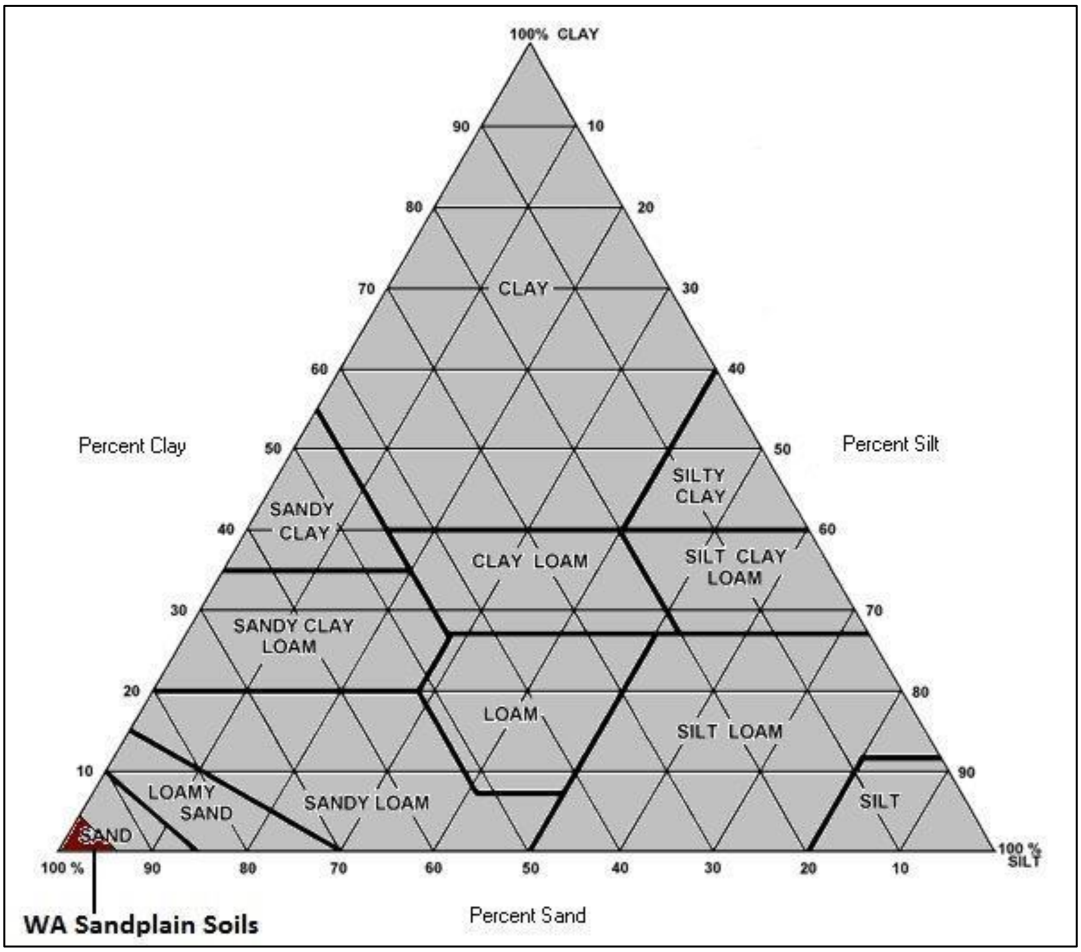
- Particle size determination. This method involves determination of the relative proportions of and, silt and clay sized particles, usually by a combination of sedimentation (hydrometer measurements) and sieving, and classifying the sol texture using the "soil texture triangle" (Figure 1). The method is preferred by land capability and land management professionals.
- Atterberg limits. This methodology, favoured by engineers, classifies soil on the basis of measurements for:
  - Plastic limit, defined as the amount of water added to dry soil to reach a plastic state.
  - Liquid limit, defined as the amount of water added to dry soil to reach a fluid state.
  - Plasticity Index, defined as the difference between the liquid limit (% by weight, dry soil basis) and plastic limit ((% by weight, dry soil basis).

In most cases, field texture grades align well with laboratory based classifications. Poor correlation is occasionally observed for unusual soil types, especially highly saline soils and compacted ferruginous soils (plinthites).

Soil texture information based on laboratory particle size measurements is often used to predict other soil physical characteristics such as hydraulic permeability and water holding capacity (DAFWA 2004). Although laboratory tests are available for direct measurement of these properties, the methodology is comparatively expensive and requires specific sample collection and preservation techniques.

The southwest and arid interior of WA is represented by vast tracts of sandplain, especially dune fields in the Great Sandy and Great Victoria Deserts and coastal plains between Geraldton and Esperance. The sandy nature of these soils in indicated in Figure 1.

Figure 1: Soil Texture Triangle



2.2 DISPERSION POTENTIAL

The structural stability of loams and clay soils can be assessed by a simple field test referred to as the Emerson aggregate test (AS 1289 C8.1 1980). The test involves observation of the behaviour of natural soil aggregates (peds) and subsamples of soil remoulded at field capacity when placed in deionised water. Poorly structured soils, often containing sodic clays (Section 3.3), exhibit low strength when wet, resulting in rapid slaking of aggregates and dispersion of fine clays, resulting in a cloudy halo when placed in deionised water.

The Emerson Aggregate Test provides an Emerson class number ranging from 1 to 8, with Emerson class number 1 indicating soils with weak structure and high potential for clay dispersion, while Emerson class number 8 indicating soils that do not slake, swell or disperse when placed in water. Soil aggregates that slake and disperse readily (Emerson class numbers 1, 2 and 3) indicate weak structure that is easily disrupted by raindrop impact or mechanical disturbance and therefore prone to water erosion, especially on sloping landforms.

The Emerson aggregate test requires submission of a field sample in which natural aggregates have been preserved and not destroyed by crushing and grinding. For this reason, samples provided by reverse circulation drilling are not suitable.

Description of Emersion class numbers are presented in Table A1:2.

Table A1:2: Emerson Aggregate Test Class Numbers

Class Number	Description
Class 1	Dry aggregates slake and completely disperse within several hours.
Class 2	Dry aggregates slake and partly disperse after 24 hours.
Class 3a	Dry aggregates slake but do not disperse. Remoulded soil disperses completely.
Class 3b	Dry aggregates slake but do not disperse. Remoulded soil partly disperses.
Class 4	Dry aggregates slake but do not disperse. Remoulded soil does not disperse. Soil contains free carbonate minerals and / or gypsum.
Class 5	Dry aggregates slake but do not disperse. Remoulded soil does not disperse. No carbonates or gypsum present. 1:5 suspension in water remains dispersed
Class 6	Dry aggregates slake but do not disperse. Remoulded soil does not disperse. No carbonates or gypsum present. 1:5 suspension in water flocculates.
Class 7	Dry aggregates do not slake. Aggregates swell.
Class 8	Dry aggregates do not slake. Aggregates do not swell.

3. CHEMICAL PROPERTIES

3.1 PH

As with many measurements on soil, pH values vary with the procedure used. Being a solution measurement, pH of dry soil is effectively meaningless. Soil pH estimates are undertaken in the laboratory by shaking a sample of dry, sieved soil with a standard volume of either deionised water or a dilute salt solution, followed by pH measurement with a calibrated pH meter. pH measurements using deionised water at a sample : solution ratio of 1:5 are widely used for land capability assessment, while use of 0.01 M calcium chloride as the equilibrating solution is preferred for agricultural purposes as this method has been shown by researchers as a superior indicator of phytotoxicity of soil.

The soil pH rating Table adopted for use by MBS Environmental is presented in Table A1-3. The rating table applies to measurements using the 1:5 deionised water extraction method.

Table A1-3: Soil pH Rating Table

pH Range	Rating
1.8 - 3.4	Ultra acid
3.5 - 4.4	Extremely acid
4.5 - 5.0	Very strongly acid
5.1 - 5.5	Strongly acid
5.6 - 6.0	Moderately acid
6.1 - 6.5	Slightly acid
6.6 - 7.3	Circum-neutral
7.4 - 7.8	Slightly alkaline
7.9 - 8.4	Moderately alkaline
8.5 - 9.0	Strongly alkaline
9.1 - 10	Very strongly alkaline
>10	Ultra alkaline

From Rayment and Lyons (2011), adapted from Bruce and Rayment 1982 and USDA-NRCS 2004.

3.2 ELECTRICAL CONDUCTIVITY AND SALINITY

Measurement of electrical conductivity (EC) of recovered soil porewater, or more commonly either porewater recovered after wetting the sample to saturation or using the 1:5 soil:water extract from pH measurement. EC of the saturation extract is referred to as ECe, while EC of the 1:5 soil:water extract is referred to as EC (1:5).

ECe is considered to be the superior indication of salinity; values of <200 mS/m indicate very low salinity, while values >1,600 indicate high salinity, regardless of the soil type. However, measurement of ECe involves a labour intensive test method and therefore not commonly requested. Salinity risk assessment based on EC (1:5) measurements need to consider the soil type. Table A1-4 presents soil salinity rating classes used by MBS Environmental for sand, loam and clay soil types.

Table A1-4: Salinity Rating Table

Soil Type	Salinity Rating Based on EC (1:5) (mS/m)				
	Nil	Slight	Moderate	High	Extreme
Sand	0 – 15	15 - 25	25 – 50	50 – 100	>100
Loam	0 – 20	20 – 35	35 – 70	70 – 150	>150
Clay	0 - 25	25 - 50	50 - 100	100 - 200	>200

3.3 EXCHANGEABLE CATIONS

The ability of soil to behave as a cation exchange material has been known for more than a century. The major soil cations fall into two distinct groups:

- Basic soil cations comprising Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}.
- Acidic cations comprising H^{+}, Al^{3+} and Mn^{2+}. The sum of these cations is referred to as either "exchangeable" or "titratable" acidity.

At a fixed pH, the sum of all soil cations (when expressed in units of centimoles of positive charge per kilogram, cmol(+)/kg) is constant. This value is referred to as the Cation Exchange Capacity (CEC), which is measured at either pH 7 for circum-neutral soils or pH 8.5 for soils containing free calcium carbonate.

The main soil components contributing to CEC are organic matter and clay minerals. CEC values typically range from <2 cmol(+)/kg) for highly weathered siliceous sands, to 10 cmol(+)/kg) for clay loam soils containing kaolinite as the dominant clay mineral, to greater than 50 cmol(+)/kg) for soils containing clay minerals belonging to the smectite (montmorillonite) or illite group. CEC is an important property for productive agricultural soils as it plays a major role in retention of essential plant nutrients and influencing the physical structure of clay rich soil types.

While most laboratories provide cost-effective methods for measuring soil CEC, it is more common to measure the individual soil cations after extraction with ammonium chloride solution (at either pH 7 or pH 8.5). These procedures are effective at extracting the basic soil cations, but the acidic soil cations are not extracted. For circum-neutral and alkaline soil types, the sum of the concentrations of basic soil cations is very close to the measured CEC. In such cases, the sum of the basic soil cations (expressed in units of cmol(+)/kg)) is referred to as Effective CEC (ECEC).

For acidic soils, the contribution of the acidic soil cations becomes increasingly significant. In such cases, ECEC calculation requires inclusion of the 'exchangeable acidity" component. Alternatively, use of unbuffered 0.1 M barium chloride as the cation displacing extractant allows for measurement of extraction aluminium and manganese, in addition to the basic soil cations. Although exchangeable hydrogen has not been measured, this sum of the basic cations plus exchangeable aluminium and manganese provides an acceptable estimate of ECEC.

The relative proportions of the four basic cations play a major role on the structure of clay rich soil type. Calcium, magnesium and potassium are essential plant nutrients and contribute to good soil structure by allowing effective exchange of air and water into the soil matrix during both wetting and drying cycles. Exchangeable sodium, however, is not conducive to good soil structure and sodium rich (sodic) clays are prone to spontaneous dispersion (Section 2.2), resulting in hard-setting soils when dry and highly erodible soils when saturated.

The acidic soil cations are also undesirable components of a healthy soil, particularly the aluminium component as soluble aluminium is phytotoxic to plants. Elevated concentrations of soluble manganese, which is associated with high concentrations of exchangeable manganese in acidic soils, may also be phytotoxic.

Two important derived parameters from exchangeable cation soil measurements are Base Saturation Percentage (BS%) and Exchangeable Sodium Percentage (ESP). BS% is the sum of the basic soil cations divided by the measured CEC (or ECEC if exchangeable acidity has been measured) and expressed as a percentage. Circum-neutral and alkaline soils have very high BS% values, while acidic soils may have much lower BS% values. BS% provides a better indication of potential soil acidity problems than pH measurements. For example, a soil with a pH of 4.5 and BS% of 30% is likely to be toxic to plants, while a soil with pH of 4.5 and BS% of 80% may not be toxic.

ESP is the exchangeable sodium concentration divided by the measured CEC (or ECEC for circum-neutral and alkaline soils) and expressed as a percentage. ESP values as low as 6% can be responsible for poor structure. ESP values greater than 6% identify sodic soils (Northcote and Skene 1972), which are highly susceptible to structural degradation and erosion.

Table A1-5: Ratings for Exchangeable Cations and Related Parameters

Parameter	Units	Rating		
		Low	Medium	High
CEC	cmol(+)/kg	<5	5 - 15	>15
Calcium	cmol(+)/kg	<5	5 - 10	>10
Magnesium	cmol(+)/kg	<1	1 - 5	>5
Sodium	cmol(+)/kg	<0.3	0.3 – 1.0	>1.0
Potassium	cmol(+)/kg	<0.5	0.5 -2.0	>2.0
Aluminium	cmol(+)/kg	<0.1	0.1 – 1.0	>1.0
Manganese	cmol(+)/kg	<0.02	0.02 – 1.0	>1.0
BS%	%	<20	20 - 60	>60
ESP	%	<6 (non-sodic)	6 – 15 (moderately sodic)	>15 (highly sodic)

Adapted from DAFWA 2004.

3.4 ORGANIC CARBON AND SOIL NITROGEN

Soil organic matter is a critical component of a healthy soil. It plays a major role in maintaining good soil structure, retaining moisture and nutrients and a source of food and energy for soil microbial activity.

Soil organic matter contains 45% to 55% carbon, with most of the balance being oxygen, hydrogen and nitrogen, with lower but still important concentrations of phosphorus and sulfur. There are two reliable laboratory methods for measuring soil organic carbon, which is a very good indicator of soil organic matter content:

- Wet oxidation, with the Walkley and Black method (Walkley and Black 1934) being the most common variation.
- Combustion, occasionally referred to as LECO® Total Organic Carbon.

By international standards, WA soils contain low concentrations of organic carbon. Organic carbon content is dependent upon soil texture and climate, with sandy soils and soil from tropical northern WA and arid central WA containing lower carbon contents (typically <1% in topsoil) compared to clay and loam soils from the temperature southwest corner of WA.

Soil organic matter is also responsible for most of the total nitrogen content of soil, with the remainder (typically <5% of total nitrogen) being in the mineral ammonium (NH_4^+) and nitrate (NO_3^-) forms. Mineralisation of soil organic matter by microbial activity can convert some of this organic nitrogen into mineral nitrogen, which is then available for uptake by plants. However, the amount of nitrogen that can be released by mineralisation is variable and determined largely by the ratio of organic carbon to nitrogen (C/N ratio). For soils with low C/N ratios, mineralisation of soil organic matter releases substantial amounts of mineral nitrogen. Alternatively, microbes breaking down carbon rich soil organic matter require more nitrogen than is available from organic matter, resulting in removal of mineral forms of nitrogen naturally present in soil. This is known as “nitrogen drawdown” and is common when carbon rich woody mulch or leaf litter is added to soil as a soil conditioner or water retentive mulch. Ratings descriptions for organic carbon, total nitrogen and C/N ratio are presented in Table A1-6.

Table A1-6: Ratings Table for Organic Carbon, Total Nitrogen and C/N Ratio

Parameter	Rating		
	Low	Medium	High
Organic carbon, A1 horizon, northern and eastern WA	<0.5%	0.5 – 1.5%	>1.5%
Organic carbon, A2 and B horizon, northern and eastern WA	<0.05%	0.05 – 0.3%	>0.3%
Organic carbon, A1 horizon, southwest WA	<1%	1 – 2%	>2%
Organic carbon, A2 and B horizon, southwest WA	<0.1%	0.1 – 0.5%	>0.5%
Total nitrogen, A1 horizon, northern and eastern WA	<0.05%	0.05 – 0.3%	>0.3%
Total nitrogen, A1 horizon, southwest WA	<0.1	0.1 – 0.5%	>0.5%
Total nitrogen, A2 and B horizons	Generally not measured		
C/N ratio	<10	10 - 16	>16

Adapted from DAFWA 2004.

3.5 BIOAVAILABLE NUTRIENTS

Soil testing is widely used for diagnosing potential nutrient deficiencies and imbalances in soils used for agriculture. Large fertiliser companies often provide cost-effective soil testing packages that provide fertiliser recommendations based on soil test results.

The decision support systems required for provision of reliable fertiliser recommendations based on soil test require a large volume of calibration data based on field trials conducted over many years for different crop plants and on different soil types. The soil tests used also vary for different nutrients as summarised below:

- Phosphorus and potassium use 0.5 M sodium bicarbonate.
- Sulfur uses 0.25 M potassium chloride.
- Boron uses extraction with hot 0.01 M calcium chloride solution.
- Multi-element test for micro-nutrients (Cu, Fe, Mn and Zn) uses 0.005 M DTPA solution.

With the exception of phosphorus (Handreck 1997a and 1997b), there is very little published information available that relates nutrient soil test results with the health of Australian native plants. Also, native plant establishment on disturbed WA soil types is considered to be limited mainly of constraints such as low water holding capacity, salinity or elevated acidity/alkalinity rather than nutrient deficiencies or imbalances. Even in circumstances where nutrient deficiency has been identified as a potential limitation for rehabilitating disturbed sites with WA native plants, land managers are often reluctant to apply additional nutrients in the form of organic or chemical fertilisers on the potential for promoting weed establishment.

MBS Environmental has adopted the Mehlich 3 multi-element soil test methodology (Mehlich 1984) as a cost-effective alternative method to the suite of nutrient soil tests listed above to assess mine site soils for potential nutrient deficiencies, toxicity or imbalance that may affect revegetation outcomes. Concentrations assigned to low, typical and elevated ranges presented in Table A1-7 were derived from the following information:

- Correlations between calibrated single nutrient soil test values (specific for each nutrient) and plant response, typically crop plants under glasshouse or controlled field experiments (Peverill et al. 1999).
- Correlations between Mehlich 3 and calibrated single nutrient soil test results (Walton and Allen 2004). Most of the single nutrient tests correlate well the Mehlich 3 test for acidic, neutral and slightly alkaline (but non-calcareous) WA soil types.
- Results for surface samples analysed from DAFWA and DPaW soil surveys (Section 1.2) and previous mine site surveys conducted by MBS Environmental.

The "Low" rating corresponds approximately to the lowest fifth percentile of unfertilised WA surface soil types and indicates conditions that may result in deficiency to plants not adapted to very low nutrient concentrations in soils. These soil types are often highly weathered siliceous sands in moderate to high rainfall areas in the southwest of WA.

The "Elevated" rating corresponds approximately to the 95th percentile of unfertilised WA surface soil types and may indicate conditions resulting in either nutrient imbalances or toxicities to plant not adapted to high nutrient (especially micronutrients such as boron) concentrations.

Table A1-7: Ratings Table for Bio-available Nutrients (mg/kg), Mehlich 3 Test

Nutrient	Rating		
	Low	Typical Range	Elevated
Phosphorus	<2	2 - 10	>10
Potassium	<10	10 - 300	>300
Calcium	<50	50 – 5,000	>5,000
Magnesium	<20	20 – 2,000	>2,000
Sulfur	<5	5 - 200	>200
Boron	<0.1	0.1 - 2	>2
Copper	<0.1	0.1 - 5	>5
Iron	<10	10 – 200	>200
Manganese	<5	5 - 100	>100
Molybdenum	<0.01	0.01 – 0.05	>0.05
Zinc	<0.2	0.2 - 5	>5

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APPENDIX 2: SOIL PIT DESCRIPTIONS

Site	TB5	GPS Coordinates	505023 mE 8068115 mN	Date	23/06/2016	Sheet 1 of 31

Vegetation and Landscape

Slope:	Gently undulating
Vegetation:	Sparse woodland with scattered grasses
Landscape:	Low depression in otherwise gently undulating plain

Pit Description	Sample Register
O horizon topsoil to 10 cm sampled as TS1. Fine browny yellow sand with numerous roots and organic matter. Root depth extends to ~70 cm from larger trees (Kurrajong). No obvious B horizon – sand is merely more compacted with depth. One slightly darker band at ~1 m otherwise uniform yellow, no rocks.	TS1 SS1

Soil Pit

Landscape

Site	GTE40	GPS Coordinates	497257 mE 8069059 mN	Date	23/06/2016	Sheet 2 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Woodland
Landscape:	Pindan plains

Pit Description	Sample Register
Pit to 1.8 m. Roots to 1.5 m. Fine brown organic rich sand to 30 cm then red/brown Pindan to 18 m. Sampled at 20 cm and 1.5 m. No significant compacting at depth.	TS2 SS2

Soil Pit

Landscape

Site	GTE54	GPS Coordinates	496296 mE 8067898 mN	Date	23/06/2016	Sheet 3 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Flat spear grass, Bohemia and Kurrajong
Landscape:	Pindan grasslands

Pit Description	Sample Register
Brown Pindan O horizon to 35 cm then red/brown Pindan to 1.5 m. Roots to 1.4 m.	TS3 SS3

Soil Pit

Landscape

Site	GTE53	GPS Coordinates	494754 mE 8069189 mN	Date	23/06/2016	Sheet 4 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Grassland with scattered eucalypts
Landscape:	Pindan grasslands

Pit Description	Sample Register
Root zone to 80 cm. O horizon/brown soil to 80 cm then compacted yellow fine sand to 1.5 m. No roots in this zone.	TS4 SS4

Soil Pit

Landscape

Site	GTE50	GPS Coordinates	495711 mE 8070354 mN	Date	23/06/2016	Sheet 5 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Eucalypt and fine grasses.
Landscape:	Pindan woodlands

Pit Description	Sample Register
30 cm in O horizon brown pindan. Roots to 1.3 m. Total depth 1.9 m in only minor consolidated red/brown Pindan sand.	TS5 SS5

Soil Pit

Landscape

Site	Between GTE50 and GTE49	GPS Coordinates	494943 mE 8071001 mN	Date	23/06/2016	Sheet 6 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Iron bark trees, grevillea.
Landscape:	Pindan woodlands

Pit Description	Sample Register
Depth of hole 1.4 m. 30 cm of O horizon. Pindan sand. Roots to 1 m in red/brown Pindan sand.	TS6 SS6

Soil Pit

Landscape

Site	GTE47	GPS Coordinates	495931 mE 8072164 mN	Date	23/06/2016	Sheet 7 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Iron bark/Bohemic some spear grass.
Landscape:	Pindan woodlands

Pit Description	Sample Register
O horizon 30 cm. Pindan sand grading from brown (30 cm) to red/brown to depth. Hole to 1.5 m. Roots to 1.3 m.	TS7 SS7

Soil Pit

Landscape

Site	Roughly west of GTE51	GPS Coordinates	496964 mE 8073376 mN	Date	23/06/2016	Sheet 8 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Woodlands with scattered grasses
Landscape:	Pindan woodlands

Pit Description	Sample Register
Red/brown Pindan sand to 0.8 m – refusal mineral sand/sandstone rock (mineralised)	TS8

Soil Pit

Landscape

Site	cost02	GPS Coordinates	495865 mE 8073594 mN	Date	23/06/2016	Sheet 9 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Woodlands with scattered grasses
Landscape:	Pindan woodlands

Pit Description	Sample Register
Depth Pit 1.4 m. Silcrete at bottom. O horizon to 30 cm then Pindan red/brown to 1.4 m. Silcrete/sandstone base.	TS9 SS9

Soil Pit

Landscape

Site	GTW51	GPS Coordinates	497129 mE 8073576 mN	Date	23/06/2016	Sheet 10 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Woodlands with scattered grasses
Landscape:	Pindan woodlands

Pit Description	Sample Register
O horizon and roots to 20 cm then red/brown Pindan to 70 cm. Hole depth to 1 m – refusal Mineralised sand stone. Subsoil (SS10) between 70 cm and 1 m in compacted yellow sand.	TS10 SS10

Soil Pit

Landscape

Site	GTE28	GPS Coordinates	497540 mE 8072893 mN	Date	23/06/2016	Sheet 11 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Woodlands with scattered shrubs
Landscape:	Pindan woodlands

Pit Description	Sample Register
O horizon to 20 cm. Roots to 50 cm. Rocks at 50 cm, refusal/depth of hole 1 m.	TS11A TS11B (duplicate)

Soil Pit

Landscape

Site	GTE52	GPS Coordinates	497976	mE	Date	23/06/2016	Sheet 12 of 31
			8073028	mN			

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Woodlands with scattered shrubs
Landscape:	Pindan woodlands

Pit Description	Sample Register
Red/brown Pindan sand to depth of hole (1 m) refusal – mineralised sandstone.	TS12

Soil Pit

Landscape

Site	GTE24	GPS Coordinates	497720 mE 8071928 mN	Date	23/06/2016	Sheet X of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Woodlands with scattered shrubs
Landscape:	Pindan woodlands

Pit Description	Sample Register
Red brown Pindan sand to depth of 1.5 m only. Loosely consolidated. Roots to 1.5 m.	TS13

Soil Pit

Landscape

Site	GTE33 (pit shell)	GPS Coordinates	496984 mE 8071235 mN	Date	23/06/2016	Sheet 14 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Woodlands with scattered grasses
Landscape:	Pindan woodlands

Pit Description	Sample Register
Surface 0 to 30 cm. O horizon brown Pindan sand then brown/red Pindan sand to depth 1.2 m.	TS14

Soil Pit

Landscape

Site	GTE22	GPS Coordinates	498332 mE 8071098 mN	Date	23/06/2016	Sheet 15 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Woodlands with scattered grasses
Landscape:	Pindan woodlands

Pit Description	Sample Register
1.6 roots to 800 m. 30 cm O horizon red/brown Pindan sand.	TS15

Soil Pit

Landscape

Site	GTE34	GPS Coordinates	498870 mE 8070955 mN	Date	23/06/2016	Sheet 16 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Woodlands with scattered grasses
Landscape:	Pindan woodlands

Pit Description	Sample Register
20 cm horizon Roots to 1 m, depth pit 1.8 m. Uniform to depth red/brown Pindan sand.	TS16

Soil Pit

Landscape

Site	GTE25	GPS Coordinates	498045 mE 8072323 mN	Date	25/06/2016	Sheet 17 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Woodlands with scattered grasses
Landscape:	Pindan woodlands

Pit Description	Sample Register
Dense roots in “O” horizon to 30 cm then red/brown Pindan sand to sandstone rock at 1.6 m.	TS17

Soil Pit

Landscape

Site	GTE23	GPS Coordinates	497949 mE 8071422 mN	Date	25/06/2016	Sheet 18 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Woodlands with scattered grasses
Landscape:	Pindan woodlands

Pit Description	Sample Register
Organic stained O horizon to 20 cm then red/brown sand to 1.2 m (depth of hole). Roots all through to 1.2 m, loosely packed.	TS18

Soil Pit

Landscape

Site	GTE42 (haul road)	GPS Coordinates	498417	mE	Date	25/06/2016	Sheet 19 of 31
			8071986	mN			

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Woodlands with scattered grasses
Landscape:	Pindan woodlands

Pit Description	Sample Register
Horizon of 10-20 cm then uniform red/brown Pindan sand to 1.5 m. Roots to 1.3 m.	TS19

Soil Pit

Landscape

Site	GTE46 (NW corner of pit)	GPS Coordinates	498491 mE 8073431 mN	Date	25/06/2016	Sheet 20 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Grasses with scattered eucalypts
Landscape:	Pindan grasslands

Pit Description	Sample Register
Surface sample Pindan sand.	TS20

Soil Pit

Landscape

Site	TB3 (proposed village)	GPS Coordinates	502016 mE 8071684 mN	Date	25/06/2016	Sheet 21 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Woodlands with scattered grasses
Landscape:	Pindan woodlands

Pit Description	Sample Register
0 to 20 cm surface sample brown red. High organic matter, leaves etc.	TS21

Soil Pit

No Photo Available

Landscape

Site	TB4 (haul road)	GPS Coordinates	502302 mE 8069308 mN	Date	25/06/2016	Sheet 22 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Woodlands with scattered grasses
Landscape:	Pindan woodlands

Pit Description	Sample Register
0 to 10 cm surface sample. Tried augering refusal at 40 cm.	TS22

Soil Pit

Landscape

Site	Borrow Pit on haul road	**GPS Coordinates**	505541	mE	**Date**	25/06/2016	Sheet 23 of 31
			8065858	mN			

Vegetation and Landscape	
Slope:	
Vegetation:	
Landscape:	

Pit Description	**Sample Register**
30 cm topsoil. Pindan sand red brown then 30 to 90 cm of iron coated (ferricrete) sandstone colluvium (chocolate colour) semirounded 90 cm below coarser colluvium which is rounded and not coated (white leached sandstone). Profile is graded top to bottom.	

Soil Pit

Landscape

Site	TB6 (alternate haul road adjusted for access)	GPS Coordinates	504975 mE 8064622 mN	Date	25/06/2016	Sheet 24 of 31

Vegetation and Landscape

Slope:	Undulating
Vegetation:	Woodlands with sparse/scattered grasses
Landscape:	Pindan woodlands

Pit Description	Sample Register
Fine red sand (Pindan) on surface. Area is slightly more elevated from nearby hill – soil not leached. Red Pindan sand extends to depth of hole – 1 m. Sampled O horizon as TS23. 1 m depth as SS23.	TS23 SS23

Soil Pit

Landscape

Site	TB7 (haul road)	GPS Coordinates	506010 mE 8062475 mN	Date	25/06/2016	Sheet 25 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Sparse eucalypts with grasses
Landscape:	Pindan grasslands

Pit Description	Sample Register
Left hand side of road heading out. Small ridgeline finishes just to the north. O horizon 20 cm. Brown Pindan sand. A horizon to 1 m. Red/brown Pindan sand. Loosely consolidated uniform to depth.	TS24

Soil Pit

Landscape

Site	TB8 (haul road)	GPS Coordinates	507731 mE 8058569 mN	Date	25/06/2016	Sheet 26 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Ironbark and wattle with mixed grass undergrowth.
Landscape:	Pindan grasslands

Pit Description	Sample Register
Left hand side of road heading south. O horizon 30 cm then uniform Pindan A horizon soil to 1 m. No termite mounds this area or for most of northern section haul road.	TS25

Soil Pit

Landscape

Site	TB9 (haul road)	GPS Coordinates	512261 mE 8053123 mN	Date	25/06/2016	Sheet 27 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Mixed wattle, eucalypt and grevillea.
Landscape:	Pindan woodland

Pit Description	Sample Register
Shallow O horizon 10 cm then red/brown Pindan sand uniform to depth.	TS26

Soil Pit

Landscape

Site	Dam dug (unplanned sample)	GPS Coordinates	513977	mE	Date	25/06/2016	Sheet 28 of 31
			8051090	mN			

Vegetation and Landscape

Slope:	Flat
Vegetation:	Scattered trees low grass and lots of termite mounds.
Landscape:	Drainage line

Pit Description	Sample Register
Highly leached quartz sand (grey) to 30 cm then a 60 cm thick layer of leached and weathered sandstone hardpan set with silcrete. Small nodules cemented together. More leached sand underneath. Floodplain area.	

Soil Pit

Landscape

Site	TB10 (adjacent highway right hand side of access road)	GPS Coordinates	516055 mE 8048812 mN	Date	25/06/2016	Sheet 29 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Dovegrass , bohemia and wattle.
Landscape:	Pindan woodland

Pit Description	Sample Register
O horizon shallow (5 cm). Dry on surface, moisture at depth. Uniform to depth 1 m.	TS27

Soil Pit

Landscape

Site	TB11 (adjacent highway left hand side of proposed access road)	GPS Coordinates	512061 mE 8046823 mN	Date	25/06/2016	Sheet 30 of 31

Vegetation and Landscape

Slope:	Flat/gently undulating
Vegetation:	Overgrown since last clearing
Landscape:	Pindan woodland

Pit Description	Sample Register
Shallow O horizon 5 cm then Pindan sand to depth 1 m. Slightly more clay than previous. Between sand and sandy loam.	TS28

Soil Pit

Landscape

Site	-	GPS Coordinates	515087 mE 8049766 mN	Date	25/06/2016	Sheet 31 of 31

Vegetation and Landscape

Slope:	Flat
Vegetation:	Sparse grasses and shrubs
Landscape:	Drainage depression

Pit Description	Sample Register
Deposited alluvial clay underlying leached alluvial quartz sand. Medium clay.	TS29

Soil Pit

Landscape

APPENDIX 3: LABORATORY REPORTS

ChemCentre
Inorganic Chemistry Section
Report of Examination

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www.chemcentre.wa.gov.au
ABN 40 991 885 705

Purchase Order: None
Your Reference:
ChemCentre Reference: 15S2816 R1

Sheffield Resources Ltd
PO Box 205
West Perth WA 6872

Attention: David Boyd

Final Report on 42 samples of soil received on 10/06/2016

LAB ID	Client ID and Description
15S2816 / 001	TS1
15S2816 / 002	SS1
15S2816 / 003	TS2
15S2816 / 004	SS2
15S2816 / 005	TS3
15S2816 / 006	SS3
15S2816 / 007	TS4
15S2816 / 008	SS4
15S2816 / 009	TS5
15S2816 / 010	SS5
15S2816 / 011	TS6
15S2816 / 012	SS6
15S2816 / 013	TS7
15S2816 / 014	SS7
15S2816 / 015	TS8
15S2816 / 016	TS9
15S2816 / 017	SS9
15S2816 / 018	TS10
15S2816 / 019	SS10
15S2816 / 020	TS11A
15S2816 / 021	TS11B
15S2816 / 022	TS12
15S2816 / 023	TS13
15S2816 / 024	TS14
15S2816 / 025	SS14
15S2816 / 026	TS15
15S2816 / 027	TS16
15S2816 / 028	TS17
15S2816 / 029	TS18
15S2816 / 030	SS18
15S2816 / 031	TS19
15S2816 / 032	TS20
15S2816 / 033	TS21
15S2816 / 034	TS22
15S2816 / 035	TS23
15S2816 / 036	SS23

LAB ID	Client ID and Description
15S2816 / 037	TS24
15S2816 / 038	TS25
15S2816 / 039	TS26
15S2816 / 040	TS27
15S2816 / 041	TS28
15S2816 / 042	TS29

Analyte		As	Cd	Cr	Cu	Fe	H2O_105C
Method		iMET2SAICP	iMET2SAICP	iMET2SAICP	iMET2SAICP	iMET2SAICP	iMOIS1SAGR
Unit		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%
Lab ID	Client ID						
15S2816/001	TS1	<1	<0.05	15	1.2	4100	<0.1
15S2816/002	SS1	1	<0.05	19	1.5	8000	<0.1
15S2816/020	TS11A	3	<0.05	37	4.0	21000	<0.1
15S2816/021	TS11B	3	<0.05	37	3.8	20000	<0.1
15S2816/023	TS13	2	<0.05	19	2.6	11000	<0.1
15S2816/026	TS15	1	<0.05	15	1.4	8400	<0.1
15S2816/027	TS16	<1	<0.05	12	1.2	5900	<0.1
15S2816/028	TS17	2	<0.05	27	3.4	17000	<0.1
15S2816/033	TS21	2	<0.05	11	1.9	4400	<0.1
15S2816/040	TS27	2	<0.05	14	1.4	8100	<0.1

Analyte		Ni	Pb	Se	U	Zn	EC
Method		iMET2SAICP	iMET2SAICP	iMET2SAMS	iMET2SAMS	iMET2SAMS	(1:5)
Unit		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mS/m
Lab ID	Client ID						
15S2816/001	TS1	2	3.0	0.06	0.30	0.72	2
15S2816/002	SS1	4	3.8	0.06	0.37	1.3	1
15S2816/003	TS2						1
15S2816/004	SS2						1
15S2816/005	TS3						1
15S2816/006	SS3						1
15S2816/007	TS4						2
15S2816/008	SS4						2
15S2816/009	TS5						1
15S2816/010	SS5						1
15S2816/011	TS6						1
15S2816/012	SS6						1
15S2816/013	TS7						1
15S2816/014	SS7						1
15S2816/015	TS8						3
15S2816/016	TS9						1
15S2816/017	SS9						1
15S2816/018	TS10						2
15S2816/019	SS10						2
15S2816/020	TS11A	6	7.7	0.13	0.73	3.0	2
15S2816/021	TS11B	5	7.5	0.14	0.70	3.1	1
15S2816/022	TS12						1
15S2816/023	TS13	4	4.9	0.07	0.48	2.7	4
15S2816/024	TS14						1
15S2816/025	SS14						2
15S2816/026	TS15	3	4.3	0.06	0.35	1.1	1
15S2816/027	TS16	2	3.4	0.05	0.32	1.1	1
15S2816/028	TS17	5	6.5	0.11	0.74	3.4	1
15S2816/029	TS18						1
15S2816/030A	SS18						1
15S2816/031	TS19						1
15S2816/032	TS20						1
15S2816/033	TS21	2	3.7	<0.05	0.26	0.85	2

Analyte		Ni	Pb	Se	U	Zn	EC
Method		iMET2SAICP	iMET2SAICP	iMET2SAMS	iMET2SAMS	iMET2SAMS	(1:5)
Unit		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mS/m
Lab ID	Client ID						
15S2816/034	TS22						2
15S2816/035	TS23						3
15S2816/036	SS23						2
15S2816/037	TS24						2
15S2816/038	TS25						2
15S2816/039	TS26						1
15S2816/040	TS27	2	3.7	0.09	0.24	1.3	1
15S2816/041	TS28						1
15S2816/042	TS29						1400

Analyte		pH	Sand.	Silt.	Clay.	OrgC	N
Method		(H2O)	fraction	fraction	fraction	(W/B)	(total)
Unit			%	%	%	%	%
Lab ID	Client ID						
15S2816/001	TS1	6.9				0.22	0.019
15S2816/002	SS1	6.6				0.12	0.015
15S2816/003	TS2	6.8	93.5	1.0	5.5	0.30	0.019
15S2816/004	SS2	5.7				0.07	0.006
15S2816/005	TS3	6.3				0.41	0.028
15S2816/006	SS3	6.3					
15S2816/007	TS4	6.9				0.17	0.016
15S2816/008	SS4	7.0					
15S2816/009	TS5	6.7				0.27	0.020
15S2816/010	SS5	5.5	88.5	1.0	10.5		
15S2816/011	TS6	5.7				0.30	0.020
15S2816/012	SS6	5.7				0.14	0.012
15S2816/013	TS7	6.5	88.5	1.5	10.0		
15S2816/014	SS7	6.6					
15S2816/015	TS8	5.8					
15S2816/016	TS9	6.1					
15S2816/017	SS9	5.9					
15S2816/018	TS10	6.2					
15S2816/019	SS10	6.5					
15S2816/020	TS11A	5.5	85.5	2.5	12.0	0.37	0.024
15S2816/021	TS11B	5.6					
15S2816/022	TS12	6.5					
15S2816/023	TS13	7.7				0.56	0.038
15S2816/024	TS14	7.0	86.5	2.5	11.0		
15S2816/025	SS14	7.0					
15S2816/026	TS15	6.8				0.22	0.019
15S2816/027	TS16	6.1				0.21	0.013
15S2816/028	TS17	6.2				0.55	0.032
15S2816/029	TS18	6.8	91.0	1.5	7.5		
15S2816/030A	SS18	6.2					
15S2816/031	TS19	6.5					
15S2816/032	TS20	6.2					
15S2816/033	TS21	6.5				0.58	0.032
15S2816/034	TS22	7.4					
15S2816/035	TS23	6.7					

Analyte		pH	Sand.	Silt.	Clay.	OrgC	N
Method		(H2O)	fraction	fraction	fraction	(W/B)	(total)
Unit			%	%	%	%	%
Lab ID	Client ID						
15S2816/036	SS23	5.3					
15S2816/037	TS24	6.4					
15S2816/038	TS25	6.6					
15S2816/039	TS26	6.1					
15S2816/040	TS27	5.6					
15S2816/041	TS28	7.1					
15S2816/042	TS29	8.0					

Analyte		P	Ca	K	Mg	Na	Al
Method		PRI	(exch)	(exch)	(exch)	(exch)	(exch)
Unit		mL/g	cmol(+)/kg	cmol(+)/kg	cmol(+)/kg	cmol(+)/kg	cmol(+)/kg
Lab ID	Client ID						
15S2816/001	TS1		1.1	0.12	0.28	0.03	
15S2816/002	SS1		0.86	0.14	0.37	<0.02	
15S2816/003	TS2		1.1	0.08	0.32	0.04	
15S2816/004	SS2		0.34	0.09	0.25	<0.02	
15S2816/005	TS3		1.2	0.09	0.17	0.03	
15S2816/007	TS4		1.1	0.10	0.20	0.06	
15S2816/009	TS5		0.69	0.15	0.34	0.02	
15S2816/011	TS6		0.67	0.09	0.19	0.02	
15S2816/012	SS6		0.66	0.11	0.29	<0.02	
15S2816/013	TS7		1.0	0.06	0.21	0.03	
15S2816/015	TS8		0.84	0.12	0.31	0.08	
15S2816/016	TS9		0.70	0.08	0.20	0.03	
15S2816/018	TS10		1.2	0.12	0.22	0.03	
15S2816/020A	TS11A		0.68	0.11	0.24	<0.02	0.24
15S2816/022	TS12		1.6	0.14	0.41	0.04	
15S2816/023	TS13		2.9	0.20	0.53	0.05	
15S2816/024	TS14		1.8	0.12	0.27	0.04	
15S2816/026	TS15		1.2	0.14	0.31	0.03	
15S2816/027	TS16		0.65	0.09	0.19	0.03	
15S2816/028	TS17		1.4	0.13	0.45	0.04	
15S2816/029	TS18		1.6	0.13	0.26	0.03	
15S2816/031	TS19		1.3	0.06	0.22	0.07	
15S2816/032	TS20		1.2	0.14	0.29	0.04	
15S2816/033	TS21	1.8	1.6	0.17	0.27	0.03	
15S2816/034	TS22		1.6	0.11	0.22	0.05	
15S2816/035	TS23		2.8	0.22	0.67	0.05	
15S2816/037	TS24		1.7	0.18	0.57	0.04	
15S2816/039A	TS26		0.70	0.12	0.20	0.03	
15S2816/041	TS28		1.2	0.11	0.21	0.02	
15S2816/042A	TS29		2.0	1.2	3.1	3.8	

Analyte		Mn	ESP	Al	B	Ca	Cd
Method		(exch)	(exch)	(M3)	(M3)	(M3)	(M3)
Unit		cmol(+)/kg	%	mg/kg	mg/kg	mg/kg	mg/kg
Lab ID	Client ID						
15S2816/001	TS1		2.2	160	<0.1	230	0.01
15S2816/002	SS1		1.4	240	<0.1	180	<0.01

Analyte		Mn	ESP	Al	B	Ca	Cd
Method		(exch)	(exch)	(M3)	(M3)	(M3)	(M3)
Unit		cmol(+)/kg	%	mg/kg	mg/kg	mg/kg	mg/kg
Lab ID	Client ID						
15S2816/003	TS2		2.4	240	<0.1	240	<0.01
15S2816/004	SS2		1.6	280	<0.1	67	<0.01
15S2816/005	TS3		2.3	230	<0.1	280	<0.01
15S2816/007	TS4		4.3	200	<0.1	230	<0.01
15S2816/009	TS5		1.7	270	<0.1	150	<0.01
15S2816/011	TS6		1.7	200	<0.1	140	<0.01
15S2816/012	SS6		1.8	290	<0.1	130	<0.01
15S2816/013	TS7		2.6				
15S2816/015	TS8		6.0				
15S2816/016	TS9		3.1				
15S2816/018	TS10		1.9				
15S2816/020A	TS11A	0.03	0.7	480	<0.1	140	<0.01
15S2816/022	TS12		2.0				
15S2816/023	TS13		1.4	330	<0.1	660	<0.01
15S2816/024	TS14		2.0				
15S2816/026	TS15		1.9	260	1.2	280	0.01
15S2816/027	TS16		2.7	190	0.6	140	0.01
15S2816/028	TS17		1.8	360	<0.1	300	0.01
15S2816/029	TS18		1.4				
15S2816/031	TS19		4.0				
15S2816/032	TS20		2.6				
15S2816/033	TS21		1.3	260	<0.1	380	<0.01
15S2816/034	TS22		2.4				
15S2816/035	TS23		1.4				
15S2816/037	TS24		1.7				
15S2816/039A	TS26		2.9				
15S2816/041	TS28		1.5				
15S2816/042A	TS29		38				

Analyte		Co	Cu	Fe	K	Mg	Mn
Method		(M3)	(M3)	(M3)	(M3)	(M3)	(M3)
Unit		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Lab ID	Client ID						
15S2816/001	TS1	1.0	0.2	30	38	37	64
15S2816/002	SS1	0.84	0.1	29	47	49	29
15S2816/003	TS2	0.99	0.4	14	28	43	28
15S2816/004	SS2	0.22	0.2	9	26	33	3.2
15S2816/005	TS3	0.95	0.3	20	27	23	35
15S2816/007	TS4	1.7	0.2	25	29	28	44
15S2816/009	TS5	0.99	0.4	17	52	44	26
15S2816/011	TS6	1.3	0.2	24	30	25	50
15S2816/012	SS6	1.2	0.1	17	35	38	24
15S2816/020	TS11A	1.6	1.2	28	52	31	69
15S2816/023	TS13	1.4	0.8	18	70	73	80
15S2816/026	TS15	1.4	0.2	22	49	43	66
15S2816/027	TS16	1.5	0.3	26	28	26	47
15S2816/028	TS17	1.5	0.9	24	42	56	48
15S2816/033	TS21	0.99	0.5	24	61	37	65

Analyte Method Unit Lab ID	Client ID	Mo (M3) mg/kg	Na (M3) mg/kg	Ni (M3) mg/kg	P (M3) mg/kg	S (M3) mg/kg	Zn (M3) mg/kg
15S2816/001A	TS1	<0.01	1	0.3	1	1	0.1
15S2816/002	SS1	0.01	<1	0.1	<1	2	0.1
15S2816/003	TS2	<0.01	1	0.2	2	1	0.1
15S2816/004	SS2	0.01	<1	<0.1	<1	6	<0.1
15S2816/005	TS3	<0.01	<1	0.2	2	<1	0.1
15S2816/007	TS4	0.01	6	0.3	<1	1	<0.1
15S2816/009	TS5	<0.01	<1	0.2	2	<1	<0.1
15S2816/011	TS6	0.01	<1	0.4	2	1	0.2
15S2816/012	SS6	<0.01	<1	0.2	<1	4	<0.1
15S2816/020A	TS11A	<0.01	<1	0.1	2	4	<0.1
15S2816/023	TS13	<0.01	<1	0.5	4	2	0.3
15S2816/026	TS15	0.01	1	0.4	<1	1	0.1
15S2816/027	TS16	<0.01	2	0.4	<1	1	0.1
15S2816/028	TS17	<0.01	3	0.3	2	1	0.2
15S2816/033A	TS21	<0.01	3	0.3	3	1	0.2

Analyte Method Unit Lab ID	Client ID	As (M3) mg/kg	Pb (M3) mg/kg	Se (M3) mg/kg	+2.00 mm Sieve %	+4.00 mm Sieve %	+8.00 mm Sieve %
15S2816/001A	TS1	<0.1	1.2	<0.1			
15S2816/002	SS1	<0.1	1.2	0.1			
15S2816/003	TS2	<0.1	0.8	0.2	<0.1	<0.1	<0.1
15S2816/004	SS2	<0.1	0.6	<0.1			
15S2816/005	TS3	<0.1	0.8	<0.1			
15S2816/007	TS4	0.1	1.3	<0.1			
15S2816/009	TS5	<0.1	0.7	<0.1			
15S2816/010	SS5				<0.1	<0.1	<0.1
15S2816/011	TS6	<0.1	1.1	<0.1			
15S2816/012	SS6	0.2	1.0	<0.1			
15S2816/013	TS7				<0.1	<0.1	<0.1
15S2816/020	TS11A	0.2	1.3	<0.1	<0.1	<0.1	<0.1
15S2816/023	TS13	<0.1	0.9	<0.1			
15S2816/024	TS14				<0.1	<0.1	<0.1
15S2816/026	TS15	0.1	1.1	<0.1			
15S2816/027	TS16	0.1	1.0	<0.1			
15S2816/028	TS17	0.2	1.0	<0.1			
15S2816/029	TS18				<0.1	<0.1	<0.1
15S2816/033A	TS21	<0.1	1.1	<0.1			

Analyte	Method	Description
EC	(1:5)	Electrical conductivity of 1:5 soil extract at 25 C by in-house method S02
ESP	(exch)	Exchangeable Sodium Percentage (calculated)
K	(exch)	Potassium, K exchangeable (ref. Rayment & Lyons 2011)
Mg	(exch)	Magnesium, Mg exchangeable (ref. Rayment & Lyons 2011)
Mn	(exch)	Manganese, Mn exchangeable (ref. Rayment & Lyons 2011)
Na	(exch)	Sodium, Na exchangeable (ref. Rayment & Lyons 2011)
Al	(exch)	Aluminium, Al exchangeable (ref. Rayment & Lyons 2011)
Ca	(exch)	Calcium, Ca exchangeable (ref. Rayment & Lyons 2011)
pH	(H2O)	pH of 1:5 soil extract in water by in-house method S01
S	(M3)	Sulphur, S extracted by Mehlich No 3 - method S42
Se	(M3)	Selenium, Se extracted by Mehlich No 3 - method S42
P	(M3)	Phosphorus, P extracted by Mehlich No 3 - method S42
Pb	(M3)	Lead, Pb extracted by Mehlich No 3 - method S42
Zn	(M3)	Zinc, Zn extracted by Mehlich No 3 - method S42
Ca	(M3)	Calcium,Ca extracted by Mehlich No 3 - method S42
Cd	(M3)	Cadmium,Cd extracted by Mehlich No 3 - method S42
Al	(M3)	Aluminium,Al extracted by Mehlich No 3 - method S42
As	(M3)	Arsenic, As extracted by Mehlich No 3 - method S42
B	(M3)	Boron,B extracted by Mehlich No 3 - method S42
Co	(M3)	Cobalt,Co extracted by Mehlich No 3 - method S42
Cu	(M3)	Copper,Cu extracted by Mehlich No 3 - method S42
Na	(M3)	Sodium, Na extracted by Mehlich No 3 - method S42
Ni	(M3)	Nickel, Ni extracted by Mehlich No 3 - method S42
Mn	(M3)	Manganese, Mn extracted by Mehlich No 3 - method S42
Mo	(M3)	Molybdenum, Mo extracted by Mehlich No 3 - method S42
Mg	(M3)	Magnesium, Mg extracted by Mehlich No 3 - method S42
K	(M3)	Potassium, K extracted by Mehlich No 3 - method S42
Fe	(M3)	Iron, Fe extracted by Mehlich No 3 - method S42
N	(total)	Nitrogen N, total by method S10
OrgC	(W/B)	Organic Carbon C, Walkley and Black method S09.
Silt.	fraction	Silt, 0.02 to 0.002mm by method S06. ref. Australian Standard AS1289.C6.3
Sand.	fraction	Sand, 0.02 to 2.0mm by method S06. ref. Australian Standard AS1289.C6.3
Clay.	fraction	Clay, less than 0.002mm by method S06. ref. Australian Standard AS1289.C6.3
Cu	iMET2SAICP	Copper, dry basis
Cr	iMET2SAICP	Chromium, dry basis
As	iMET2SAICP	Arsenic, dry basis
Cd	iMET2SAICP	Cadmium, dry basis
Ni	iMET2SAICP	Nickel, dry basis
Fe	iMET2SAICP	Iron, dry basis
Pb	iMET2SAICP	Lead, dry basis
Se	iMET2SAMS	Selenium, dry basis
U	iMET2SAMS	Uranium, dry basis
Zn	iMET2SAMS	Zn, dry basis Zinc has not been validated HB 28.12
H2O_105C	iMOIS1SAGR	Moisture, loss at 105C
P	PRI	Phosphorus Retention Index by method S15
+2.00 mm	Sieve	Particle size distribution by sieving, method S07.
+4.00 mm	Sieve	Particle size distribution by sieving, method S07.
+8.00 mm	Sieve	Particle size distribution by sieving, method S07.

The results apply only to samples as received. This report may only be reproduced in full.

Unless otherwise advised, the samples in this job will be disposed of after a holding period of 30 days from the report date shown below.Exchangeable Sodium Percentage (ESP)

The ESP is a measure of sodicity (i.e exchangeable Na+) based on a soils exchange complex . High levels of sodium can adversley effect plant growth and soil structure.
The table below (categorised by Northcote and Skene, 1972) relates %ESP to soil sodicity. This table should only be used as a guide as it tolerance can vary on soil type and plant species.

ESP<6   non-sodic
ESP6-15   sodic
ESP>15   strongly sodic

Multi-Element Soil Extraction Universal Extractants (Mehlich No.3)

The Mehlich No.3 Test is an alternate soil test using universal extractants for multi-elemental analysis. Results obtained using the Mehlich 3 extractant are highly correlated with the standard "single element" soil tests currently used for a wide range of Western Australian soil types.   The test provides information on the amount of plant-available nutrients including phosphorus, potassium, sulphur, calcium, magnesium, sodium, boron, copper, iron, manganese and zinc, in the soil . It can be used as a "screening*" tool (see note below) to measure concentrations of cobalt, aluminium, molybdenum and toxic metals such as cadmium, lead, arsenic, selenium and nickel in soil. It is ideally suited to acid and neutral soils, the amounts of nutrients extracted being similar to those of other soil tests used in WA.

*Results that are reported as ">" are outside the linear range of the calibration and outside the scope of the method. This results should only be used as a guide and consideration should be given to a more specific test method if the actual "value" need to be determined, hence these results should only be used as a guide.
Bolland, Allen & Walton. Aust J Soil Research 2002.
Soil Chemical Methods, Australasia (Rayment & Lyons) 2010

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