Greenbushes Mining Operations

Rehabilitation - Materials Characterisation

Prepared for Talison Lithium
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Preamble

Talison is a Western Australian mining company with operations based at Greenbushes in the south-west of Western Australia. The Greenbushes Mine is located approximately 250 km south of Perth and 80 km south-east of the port of Bunbury (Figure 1).

The site has historically comprised a number of open cut mining operations for tantalum, tin and spodumene (lithium). An underground tantalum operation has also been developed but is currently under care and maintenance. The Greenbushes pegmatitie is the world's largest hard rock tantalum resource and the largest and highest-grade lithium minerals resource in the world. Minerals produced at Talison's Greenbushes Mine can be found in many different applications including mobile phones, computers, surgical implants, electronic devices, glassware, ceramics and batteries.

Talison is proposing to undertake an expansion at the Greenbushes mining operation aimed at increasing supply of lithium to the market. As part of native rehabilitation planning, Onshore Environmental was engaged to characterise variation in the upper soil profile within the proposed development footprint, and calculate indicative volumes for topsoil and subsoil available for rehabilitation.

The *in situ* soil strata can be broadly matched to vegetation types mapped during the baseline flora and vegetation survey (Onshore Environmental 2018a). Soil strata that can be anticipated on the basis of historical mining at the site include sandy topsoil with elevated organic matter, subsoil comprising friable gravelly loam, sandy loam or grey sand, above laterite caprock. Below the caprock there is typically a gradual change into orange clay, then light orange clay grading into white heavy clay. The clays within these deeper soil strata were not expected to be intersected during the shallow test pit work and are less desirable for native rehabilitation.

The soil test pit data can be used to estimate volumes of characterised soil materials within clearing phases, which then inform the most appropriate composition and depth of soil strata within the remade soil profile.

1.2 Previous Surveys

1.2.1 Flora and Vegetation

There have been five previous flora and vegetation surveys undertaken within the Greenbushes Mine area, or that partially overlap with the mine area:

- Trudgen and Morgan (1991) *A Flora and Vegetation Survey of part of the Greenbushes Leases*;
- Onshore Environmental Consultants (2006) *Flora and Vegetation Survey Greenbushes Mine Site: Vegetation surrounding south east corner of the TSF*;
- AECOM Australia Pty Ltd (2010) *Bridgetown RWSS Pipelines Millstream Dam to Greenbushes Link Biological Survey*;
- Onshore Environmental (2012) *Flora and Vegetation Survey Greenbushes Mining Leases*; and
- Onshore Environmental (2018a) *Detailed Flora and Vegetation Survey Greenbushes Mining Operations.*

The baseline surveys have confirmed that vegetation within the Greenbushes mining area is well represented within the Southern Jarrah Forest, and none of the associations described and mapped are determined to have elevated conservation significance. Similarly, flora represented within the proposed mine expansion area is well represented regionally with no taxa considered to have conservation significance.

One population of the Threatened Flora taxon *Caladenia harringtoniae* has been recorded in close proximity to the southwest of the mine expansion footprint, but will not be impacted directly or indirectly.

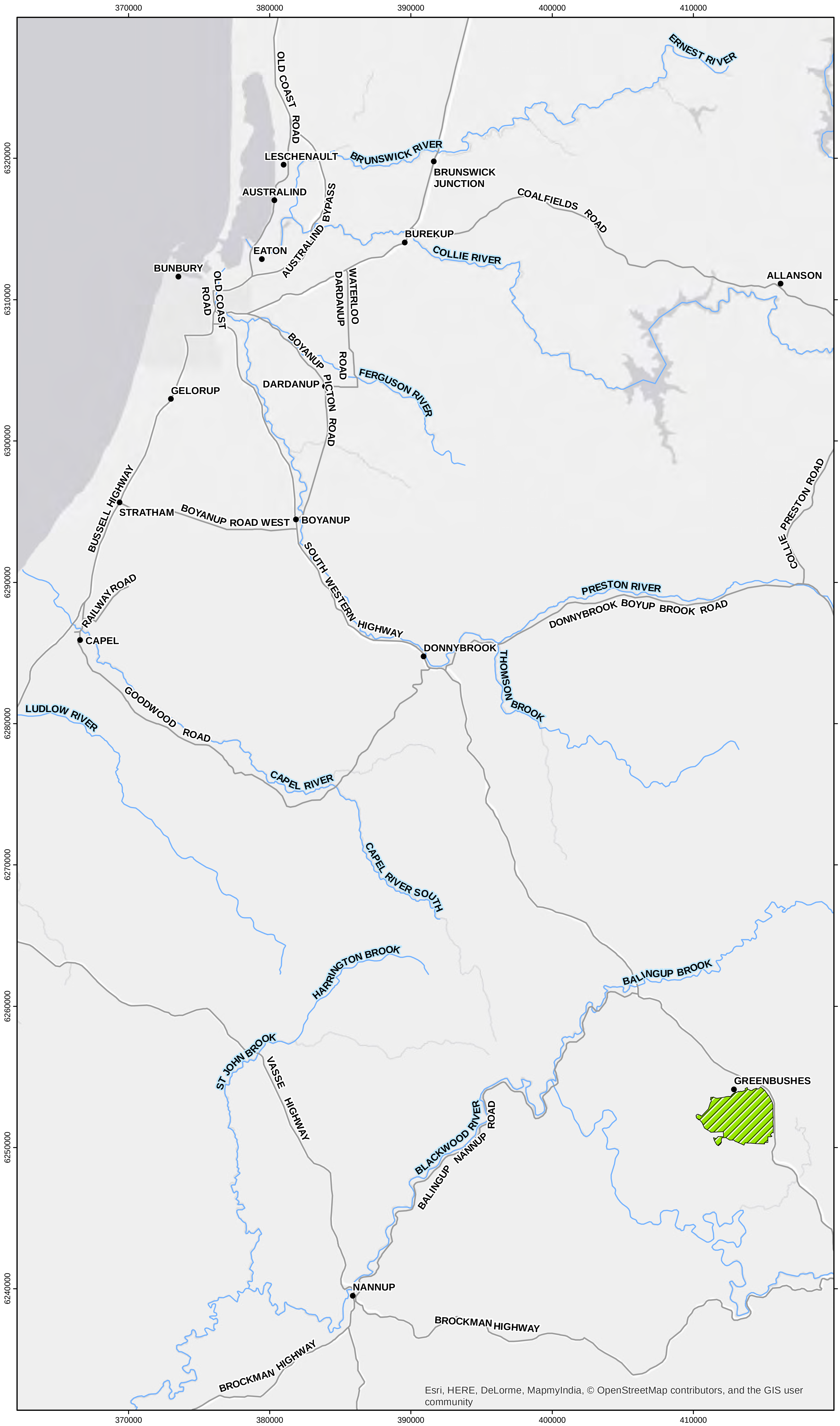
Three plants of the Priority 2 flora taxon *Melaleuca viminalis* were recorded in historical revegetation adjacent to the Greenbushes Swimming Pool. These plants will not be impacted directly or indirectly by the proposed mine expansion.

1.2.2 Materials Characterisation

An investigation of the physical and chemical properties of the remade soil profile that has historically been reinstated in native rehabilitation at the Greenbushes Mine, was completed by the University of Western Australia (Rose 2001). The remade soil profile comprised a 300mm cover of weathered regolith material (referred to as 'soft rock') over waste rock. Due to the age of the mining operation and status of mining, there is minimal to no topsoil or subsoil (gravel) resources available for rehabilitation. The physical properties investigated were soil texture, cation exchange capacity, exchangeable sodium percentage, water retention, hydraulic conductivity, bulk density, aggregate stability, organic matter, pH and electrical conductivity.

The remade soil profile at two of three rehabilitation sites assessed was not considered to limit successful establishment of revegetation. Factors limiting plant growth at the third site included elevated clay content and associated low hydraulic conductivity, low infiltration rates and low plant available water, along with structural instability due to high exchangeable sodium percentage, low aggregate stability and high bulk density. These limiting factors for the spoil material became more severe at increasing depth from the *in situ* profile; visually, the more appropriate material was a bright orange colour, with less appropriate material becoming increasingly paler orange and white in white.

Excavated soil pits confirmed plant roots were unable to penetrate the underlying waste rock layer, which was considered unfavourable as a plant establishment medium. A recommendation was made to trial incorporating weathered regolith material with rock fragments <200 mm in diameter to increase the useable depth of the remade soil profile.

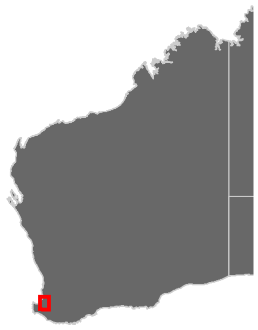


TALISON

Study Area Location

Legend

Talison DEC Active Mining Location



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Date:	31/01/2018
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Figure:	1
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Drawn by:	GSM
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1.3 Climate

The study area occurs on a boundary between the dry Mediterranean region to the north which experiences six dry months per year, and the moderate Mediterranean region to the south which experiences four dry months per year (Bureau of Meteorology [BOM] 2018). The Greenbushes region has cool wet winters and hot dry summers. Average annual rainfall for the town of Greenbushes is 928.7 mm (BOM 2018), with the majority of falls occurring during the winter months of June and July (Figure 2) associated with cold fronts moving across the south-west of Western Australia. The lowest annual rainfall on record was 472 mm in 2010, with the highest annual total of 1,687 recorded in 1917.

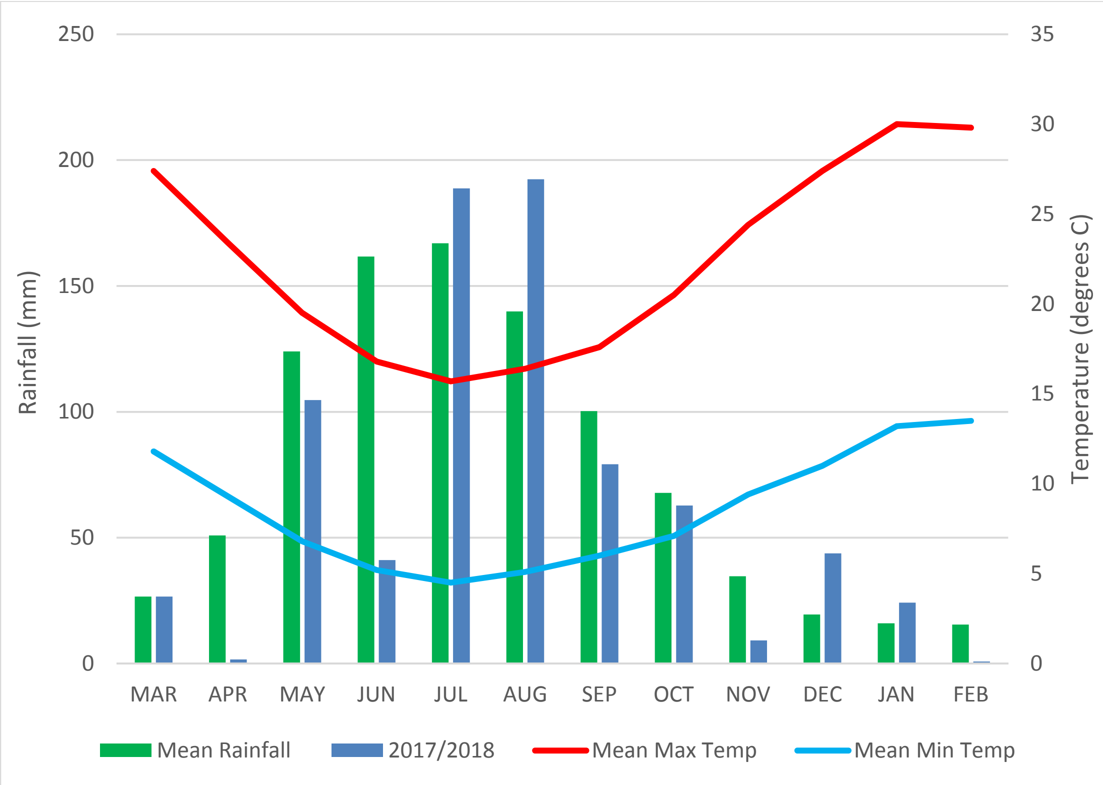

Figure 2 Climatic data for Greenbushes. Rainfall data is from the Greenbushes Weather Station and temperature data from the Bridgetown Weather Station (Bureau of Meteorology 2018).

1.4 Biogeographic Regions

The latest version of the Interim Biogeographic Regionalisation for Australia (IBRA7) divides Australia into 89 bioregions based on climate, geology, landform, native vegetation and species information, and includes 419 sub-regions (Department of Environment 2013). The bioregions and sub-regions are the reporting unit for assessing the status of native ecosystems and their level of protection in the National Reserve System.

The study area is located within the Southern Jarrah Forest (JF2) sub-region within the Jarrah Forest bioregion. The Southern Jarrah Forest sub-region is described as, “Duricrusted plateau of Yilgarn Craton characterised by Jarrah-Marri forest on laterite gravels and, in the eastern part, by Marri-Wandoo woodlands on clayey soils. Eluvial and alluvial deposits support Agonis shrublands. In areas of Mesozoic sediments, Jarrah forests occur in a mosaic with a variety of species-rich shrublands. The climate is Warm

Mediterranean" (Hearn *et al*. 2002).

The vegetation of the sub-region is described as "Jarrah - Marri forest in the west grading to Marri and Wandoo woodlands in the east. There are extensive areas of swamp vegetation in the south-east, dominated by Paperbarks and Swamp Yate. The understory component of the forest and woodland reflects the more mesic nature of this area. The majority of the diversity in the communities occurs on the lower slopes or near granite soils where there are rapid changes in site conditions" (Hearn *et al*. 2002).

1.5 Land Use

The major land uses within the study area and surroundings are State Forest, residential, mining and agriculture. The study area predominantly encompasses State Forest with a smaller block of privately-owned farmland to the south. Nearby towns include Bridgetown (approximately 15 km to the south-east) and Balingup (approximately 10 km to the north-west). The Greenbushes township is situated on the northern fringes of the active mining area and supports a residential community of approximately 350 people.

1.5.1 Agriculture and Associated Industry

Bridgetown is the oldest town in the south-west of Western Australia. It was first settled by sheep farmers E. Hester and John Blechyden in 1857. The Bridgetown Agricultural Society was formed in 1885 and by this time the area had a well-established agricultural industry, including sheep, cattle, dairy products, timber, fruit and nuts. In 1889 the railway line was extended to Bridgetown allowing the expansion of the fruit and timber markets. Many of these agricultural industries are still operational with wineries and olive farms also established in the area.

1.5.2 Mining

The Greenbushes Mine is situated on the oldest mining tenement in Western Australia and has a long history of mining activities dating back to 1888. Tin was first reported in 1886 in a Government geological survey, and mining commenced in 1888. Since it was first discovered, tin has been mined almost continuously in the Greenbushes area, although in recent years the lower tin prices and emergence of tantalum as the major revenue earner have relegated tin to the position of a by-product. The presence of tantalite was noted as far back as 1893 but at that time the mineral had no value in its own right and was seen as a nuisance because it downgraded the value of tin. Although open cut mining began to be practiced on a small scale in the 1900s much of the tin mined in the early years by small operators came from underground workings to access weathered pegmatite below the caprock. Shafts were blasted in the surface rock and tunnels dug out into the tin bearing alluvium. The dirt was hauled to the surface and stockpiled during the summer months then puddled and sluiced in winter when there was an abundance of water. Tin mining continued more or less as a cottage industry under the control of many small mining companies up to the early 1960s when, for the first time, a major mining company became involved in the tinfields.

For several years a dredge was used to recover surface deposits of tin and tantalum. By 1970 alluvial resources were dwindling and it was necessary to increase exploration activity. As a direct result of this work development of the weathered pegmatite commenced in 1974. This tin/tantalum source sustained the operation until 1992. Small parcels of tantalite were sold occasionally, but it was not until 1944, when war had stimulated interest in the element tantalite, that the mineral began to be produced steadily for use in telecommunications, electronics and radar equipment.

Spodumene, the major lithium mineral, was first identified by the Western Australian Government Survey in 1949 from a specimen collected in 1928 which was initially thought to be feldspar. During the extensive diamond drilling programme for tantalum that took place between 1977 and 1980, substantial spodumene rich zones were identified. Later drilling confirmed the existence of the richest spodumene ore body ever discovered, with resources sufficient to maintain production well into the 21st Century. However, being a new product, markets had to be developed, so it was not until 1983 that the initial development of the lithium ore body at Greenbushes commended, and the first lithium processing plant was commissioned in 1985. Since that time, the lithium processing plant has been expanded several times to produce a range of lithium concentrates, with the most recent expansion of the Greenbushes operations occurring in 2012.

1.5.3 Tourism

Tourism is the other major industry in the area with the scenery, historical sites, wineries, and galleries serving as the major attractions. Events such as the annual Blues at Bridgetown Festival also draw large numbers of people to the area.

1.6 Topography

The Greenbushes Mine is located within the Jarrah Forest Interim Biogeographic Region and is situated approximately 300 mAHD on the Darling Plateau. The Australian Soil Resource Information System (ASIRO 2018) describes landforms of the Greenbushes locality broadly as “Sand plains; low hills and ridges; breakaways; salt lakes and dune fields.”

The local topography is characterised by a broad ridgeline that extends from the Greenbushes township (310 mAHD) in a southeasterly direction (270 mAHD) to include the major identified deposits and existing open cut pits. Floyd’s Waste Dump is located on the east face of the ridgeline which descends to 266 mAHD adjacent to the South Western Highway. The waste dump drains into Saltwater Gully, a tributary of Hester Brook. The mine infrastructure including processing plant, tailing storage facilities, and reservoir dams are located on the west face of the main ridgeline, which descends to 245 mAHD and drains into Norilup Brook.

1.7 Geology

The ASIRO (2011) describes the local stratigraphy as “Archaean sequence (greenstone belts) of fine to coarse clastic sediments, chert and felsic, mafic and ultramafic volcanics.” ASIRO list three sediment types within the resource area at Greenbushes; highly weathered bedrock (>50%), alluvial sediments (<20%) and residual sand (20-50%). ASIRO have mapped the Greenbushes area as having low probability of acid sulphate soil occurring.

The local geology has previously been interpreted as granofelsic and amphibolitic greenstones, with the granofelsic rocks being finely banded and granular with gneissic to schistose textures, and the amphibolitic rocks being massive to schistose (RPS Aquaterra 2011). The Greenbushes orebody comprises a series of pegmatite dykes trending northwest over a 7 km strike which is cross-cut with dolerite dykes. The rocks are locally faulted and sheared. West of the orebody, the Archaean basement rocks are either extensively laterised or underlie the alluvial Greenbushes Formation which has been extensively disturbed by historical tin mining operations in the region.

1.8 Soils

The Environmental Geology Series maps (Geological Survey of Western Australia 1980) describe the geology as Archean granite of the Yilgarn Block, with following the soil types:

- Bt - Shallow red and yellow earths and rock outcrops on slopes and narrow alluvial terraces;
- Ba - Red and yellow earths, duplex soils on slopes, narrow alluvial terraces, swampy floors;
- G - Grey sands and some swamps;
- Hr - Duricrust and gravels flanked by gravelly duplex soils; and
- Cc - Yellow and duplex soils and red earths on slopes, and narrow alluvial terraces.

Tille (1996) has more recently mapped soils of the Wellington-Blackwood District, which includes the town sites of Greenbushes and Bridgetown on its southern boundary. The study area occurs within the Hester Sub-system of the Darling Plateau System, and consists of undulating ridges and hill crests formed on laterite and gneiss which typically slope downwards off the main plateau into the surrounding Lowden Valleys System. The soils are predominantly described as loamy gravels, sandy gravels and loamy earths.

1.9 Flora and Vegetation

The Greenbushes Mine area occurs in the Menzies Sub-district of the Darling Botanical District, in the South-West Botanical Province (Beard 1981). The Menzies Sub-district (southern jarrah forest) covers a total area of 26,572 km^2, of which 18,715 km^2 (70%) originally supported jarrah and jarrah-marri forest (Beard 1990). It is estimated that approximately 61% of the total area has been cleared since European settlement, mainly in the valleys which are free of laterite, leaving the forest intact on laterised higher plateau levels.

The Menzies Sub-district is characterised by Jarrah stands on laterite within some Marri and Wandoo woodlands. Valley soils are often richer and Blackbutt (*Eucalyptus patens)* is more dominant in these areas. Flooded Gum (*Eucalyptus rudis)* is common along stream banks and Bullich (*Eucalyptus megacarpa)* is also present in some areas. Within the study area vegetation is dominated by Jarrah *(Eucalyptus marginata)* and Marri *(Corymbia calophylla)* forest over the tall shrubs bull banksia *(Banksia grandis)* and snotty gobble *(Persoonia longifolia).* The lower understorey strata contains a range of plant genera including *Hakea, Acacia, Xanthorrhoea, Adenanthos, Hovea, Leucopogon, Macrozamia, Leucopogon, Bossiaea, Daviesia, Grevillea, Patersonia, Styphelia* and *Kennedia.*

A variety of published studies that relate to flora and vegetation of the southern jarrah forest are listed below:

- Distribution and prehistory of karri, jarrah and marri - Churchill (1968);
- Structure and composition of the karri forest around Pemberton - McArthur and Clifton (1975);
- Vegetation mapping of the Manjimup-Pemberton area - (Smith 1972);
- Vegetation mapping of the Swan area - Beard (1981);
- Vegetation mapping of the Darling System - Heddle *et al.* (1980); and
- Vegetation mapping as part of the Regional Forest Agreement - Mattiske and Havel (1998).

Vegetation complexes of the southern jarrah forest have most recently been defined by Heddle *et al.* (1980) and updated by Mattiske and Havel (1998). Mattiske and Havel (1998) describe vegetation of the survey area as ‘mixture of open forest of *Eucalyptus marginata - Corymbia calophylla* with some *Eucalyptus patens* on slopes’.

2.0 METHODOLOGY

On the 23rd May 2018 a total of eight test pits were excavated to assess native soil profiles across the proposed development footprint at the Greenbushes mining operation (Attachment 1). The test pit work was completed by Dr Darren Brearley, a Principal Botanist and Managing Director at Onshore Environmental Consultants, accompanied by Mr Glen Mountford of Talison Lithium.

The eight soil test pits were strategically positioned to ensure coverage of the most extensive vegetation associations recently described and mapped during a detailed flora and vegetation survey (Figure 3, Onshore Environmental 2018a). Five of the nine vegetation associations mapped within the proposed development footprint were covered by at least one soil test pit; vegetation types not assessed occurred over small areas and/or had site access constraints (Table 1).

Table 1 Soil test pit coverage across vegetation types within the proposed development footprint.

Code	Area (ha)	Test Pits	Description
HS Bg	119.3	2	Forest of *Corymbia calophylla* and *Eucalyptus marginata* subsp. *marginata* over Low Woodland A of *Banksia grandis*, *Persoonia longifolia*, *Corymbia calophylla* and *Eucalyptus marginata* subsp. *marginata* over Open Low Scrub A of *Pteridium esculentum* and *Macrozamia riedlei* over Low Heath D of *Bossiaea ornata* and/or *Leucopogon capitellatus* on brown sandy loam on upper hillslopes
HS Bo	484.9	1, 5	Forest of *Eucalyptus marginata* subsp. *marginata* and *Corymbia calophylla* over Low Heath D of *Bossiaea ornata* and *Leucopogon capitellatus* on grey/brown loamy sand on hillslopes
HS Pd TpBl	43.0	3, 7	Heath A of *Podocarpus drouynianus* (*Pultenaea ocheata*) with Woodland (to Forest) of *Eucalyptus marginata* subsp. *marginata* and *Corymbia calophylla* over Scrub of *Taxandria parviceps* (*Bossiaea linophylla*) over Dwarf Scrub C/D of *Dasypogon bromeliifolius*, *Adenanthos obovatus* and *Leucopogon oxycedrus* on grey sand on lower hillslopes
DL EpCc Tp	17.9	6	Woodland (to Forest) of *Eucalyptus patens* and *Corymbia calophylla* (sometimes with *Banksia seminuda* or *Banksia littoralis*) over Thicket of *Taxandria parviceps* (sometimes with *Bossiaea linophylla*, *Acacia extensa* and *Pteridium esculentum*) over Open Dwarf Scrub D of *Dasypogon bromeliifolius* and *Conospermum capitatum* on grey sand on drainage lines
DF Pe	3.6	4	Dense Heath B of *Pteridium esculentum* on grey sand on seasonally wet drainage flats
HS Xp	12.3	Not assessed	Forest of *Corymbia calophylla* and *Eucalyptus marginata* subsp. *marginata* over Scrub of *Xanthorrhoea preissii* (*Bossiaea linophylla*) over Dwarf Scrub C of *Xanthorrhoea gracilis* and *Phyllanthus calycinus* on brown sandy loam on hillslopes
HS Ew	1.3	Not assessed	Low Heath C of *Hypocalymma angustifolium*, *Babingtonia camphorosmae* and *Banksia dallanneyi* (*Xanthorrhoea gracilis* and *Bossiaea ornata*) with Low Woodland A of *Eucalyptus wandoo* (*Corymbia calophylla*) over Open Low Scrub B of *Xanthorrhoea preissii*, *Acacia celastrifolia* and *Corymbia calophylla* on grey clay loam soil on lower hillslopes
DL Er	1.2	Not assessed	Forest of *Eucalyptus rudis* subsp. *rudis* (sometimes mixed species) over Scrub of *Trymalium odoratissimum* subsp. *odoratissimum*, *Taxandria linearifolia* and/or *Hakea prostrata* over Open Tall Sedges of *Lepidosperma tetraquetrum* or *Chorizandra enodis* on brown sandy clay loam on minor drainage lines
DF MpEp AsTl	4.9	Not assessed	Forest of *Melaleuca preissiana* and *Eucalyptus patens* over Scrub of *Astartea scoparia* and *Taxandria linearifolia* over Low Scrub B of *Aotus gracillima* and *Pteridium esculentum* over Open Low Grass of **Anthoxanthum odoratum* and **Vulpia* sp. indet over Very Open Tall Sedges of *Isolepis cyperoides* and *Juncus pallidus* on black sandy clay loam on seasonally wet drainage flats

Test pits were excavated with a mini-excavator down to the intersection with lateritic caprock; this was encountered at a maximum depth of 1.1 metres. The face of each test pit was cleaned with a shovel and a tape measure extended down the face. The depth at which a colour change or physical change in soil properties occurred was recorded, and a representative soil sample collected for later laboratory analysis. A GPS coordinate, relief (mAHD) and photograph of each test pit was recorded.

The laboratory soil analysis undertaken by the CSBP laboratory tested the following parameters, noting that raw data is provided in Appendix 1:

- Colour
- % Gravel
- Texture
- Ammonium Nitrogen
- Nitrate Nitrogen
- Phosphorus Colwell
- Potassium Colwell
- Sulfur
- Organic carbon
- Conductivity
- pH Level ($CaCl_2$ and H_20)
- DTPA Copper
- DTPA Iron
- DTPA Manganese
- Exc. Aluminium
- Exc. Calcium
- Exc. Magnesium
- Exc. Potassium
- Exc. Sodium
- Boron Hot $CaCl_2$

Test pit data was collated and interpreted, with three soil profiles defined:

- Lateritic crests and upper hill slopes;
- Lateritic mid and lower slopes; and
- Sandy lower slopes and flats.

The three soil profile groups were then spatially represented by linking their occurrence within specific vegetation associations mapped during the detailed flora and vegetation survey (Figure 4, Onshore Environmental 2018a). The database was then clipped to only include areas of remnant native vegetation that will be cleared as part of the proposed mine expansion (Figure 5). This allowed indicative soil volumes to be estimated for each material across each of the three soil profile types, with further interrogation possible for individual polygons during mine planning to identify weed status of topsoil, and most appropriate locations for stockpiles.

TALISON LITHIUM
FIGURE 3
Vegetation Types and Test Pit Locations
Legend
Study Area
Soil Sample Location
Vegetation Types
Hill Slope
HS Bg
HS Pd TpBl
HS Xp
HS Bo
HS Ew
Drainage Flats
DF Pe
DF MpEp AsTl
Drainage line
DL EpCc Tp
DL Er
Others
Rehab
Annual Pasture
N
0 250 500 750
Meters
1:25,000
Datum: GDA94
Projection: MGA Zone 50
Date: 07/06/2018
Status: Draft
Figure: 3
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Internal Reference: TL_Tar_Veg_Type
Drawn by: GSM
Requested by: DB
PIT 1
PIT 2
PIT 3
PIT 4
PIT 5
PIT6
PIT7
PIT8
CHARNLEY RD
SOUTH WESTERN HWY
STANIFER ST
SPRING CREEK
POOL RD
SPRING GULLY RD
ASHCROFT RD
MARANUP FORD RD
SALT WATER GULLY
CATTERICK RD
WILKES RD
HUITSON RD
BUCHANAN RD
RUSSELL RD
WOLJENUP CREEK
HALLS RD
FOREST PARK AV
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

3.0 RESULTS

3.1 Broadscale Soils Mapping

Broadscale soils mapping for southwestern Western Australia was sourced from the GIS group at the Department of Agriculture and Food (DAFWA) (van Gools 2013). The mapping is based on a grouping of Western Australian Soil Groups by Schoknecht and Pathan (2013), where soils were classified into broad functional groups based on their suitability for cropping. These groupings have been applied proportionally to the soil-landscape subsystem and phase level mapping to produce a spatial dataset.

Broadscale soils mapping combined with field test pit work confirmed two characteristic soil types, as defined by Schoknecht and Pathan (2013), occurring within the proposed expansion footprint at Greenbushes (Table 2).

Table 2 Soil types (Schoknecht and Pathan 2013) occurring within the project area.

Agricultural Soil Description	WA Soil Group	WA Soil Group Description
Ironstone gravelly soils Ironstone gravelly soils supergroup Loamy gravel Duplex sandy gravel Deep sandy gravel	 300 303 302 301	Soils with prominent ironstone gravels that are greater than 80cm deep • Ironstone gravels are a prominent feature of the profile • Layer with >20% gravel and >20 cm thick begins within the top 15 cm of the profile • Yellow, brown, grey and red colours in top 30 cm • Neutral to acid pH • Native vegetation, especially proteaceous species, appears to have a role in the formation of these soils
Pale sands Pale deep sand Gravelly pale deep sand Deep sands supergroup	 444 443 440	Pale coloured sands extending to depths of 80 cm or more • Sandy textures throughout the top 80 cm • Top soil is pale coloured, usually white, light yellow/brown or grey • Subsoil is often similar colour top soil but can also be yellow or brown • Ironstone gravel sometimes common in the subsoil • Loose sandy surface • Profile often very deep

Specifically, within the Kwinana zone, there were 18 characteristic soils types (Figure 3) with deep sandy duplexes (18%), sandy earths (18%) and ironstone gravelly soils (16%) being the most dominant. See Appendix 1 for further details on soil types.

3.1 Soil Profiles

The results for each of the eight soil test pits are summarised in Appendix 2.

Based on results from eight soil test pits excavated across the five dominant vegetation types mapped within the proposed expansion footprint at Greenbushes, the upper soil profile ranges in depth from 450 mm to 1,100 mm and is underlain by laterite caprock. The upper profile material comprises a topsoil cover (dark brown sand) at 50-100 mm depth, over subsoil comprising either gravelly sandy loam (hill crests or slopes in areas of higher relief) or grey sand (lower slopes, foot slopes and drainage flats) between 400 mm and 1050 mm depth.

The soil profiles for the eight test pits excavated can be classified into three groups (Figures 4 and 5):

1. Gravelly sandy loam over laterite caprock
    a. Lateritic crests and upper hill slopes; and
    b. Lateritic mid and lower slopes.
2. Grey sand over laterite caprock
    a. Sandy lower slopes and flats.

1a Lateritic crests and upper hill slopes

Test Pit 2 was excavated at the crest of a hill where there was extensive outcropping of laterite. The resultant soil profile comprised a sandy topsoil (100 mm) over shallow subsoil layer of gravelly sandy loam (450 mm). Laterite caprock was encountered at 550 mm depth. The vegetation type (HS Bg) reflected the shallow soil profile characterised by *Banksia grandis* as a dominant in the low woodland stratum.

1b Lateritic mid and lower slopes

Test Pits 1 and 5 were excavated on lateritic hill slopes with minor outcropping in the most widely distributed vegetation type within the proposed development footprint, HS Bo. The soil profile comprised a sandy topsoil over subsoil layer comprising gravelly sandy loam recorded up to 1,100 mm depth (deeper than HS Bg). Vegetation was characterised by an open understorey dominated by the low shrubs *Bossiaea ornata* and *Leucopogon capitellatus.*

2a Sandy lower slopes and flats

Test Pits 3 and 7 were excavated on lower (foot) slopes supporting characteristic mid and low stratum shrubs found on grey sand; *Podocarpus drouynianus, Pultenaea ocheata, Taxandria parviceps, Bossiaea linophylla, Dasypogon bromeliifolius*, *Adenanthos obovatus* and *Leucopogon oxycedrus*. The soil profile typically comprised grey sand up to a minimum depth of 800 mm over laterite caprock.

Test Pit 4 was situated south of the tailing storage facility (cell 1) at a highly disturbed site on seasonally wet drainage flats supporting *Pteridium esculentum* (Bracken); in the pre-disturbance state, this unit likely supported a similar vegetation to that at Test Pits 3 and 7. The soil profile was the same as that recorded for Test Pits 3 and 7, with grey sand to 950 mm depth over laterite caprock.

Test Pit 6 supported grey sand to 400 mm depth over a 600 mm deep mottled zone of brown orange pebbly loam over laterite caprock. There was moisture evident to within 200 mm of surface, reflecting the low lying position in the landscape (drainage line). Characteristic riparian plant taxa included *Eucalyptus patens, Banksia seminuda, Banksia littoralis* and *Taxandria parviceps,* occurring with plant taxa more typical of the grey sandy soils *(Dasypogon bromeliifolius, Conospermum capitatum).*

3.2 Indicative Stripping Volumes

Indicative topsoil volumes have been calculated on the basis of a consistent 100 mm surface strip (Table 3). In reality, the surface area will be reduced by the basal area of established trees. Furthermore, it is difficult to remove a consistent cover layer over undulating ground when the depth of material is shallow. Topsoil volumes are estimated at 692,598 m^3 over the entire project area, and 303,472 m^3 over areas where clearing of native vegetation will be required.

A range (maximum and minimum volumes) has been calculated for subsoil volumes to be recovered within each of the three soil profile types (Table 4). The average volume of subsoil over the entire project area is estimated at 4,798,568 m^3, and 2,013,779 m^3 over areas where clearing of native vegetation will be required.

3.3 Suitability of Soil Types for Rehabilitation

3.3.1 Surface Profile

This investigation has focused on the friable soil profile occurring above laterite caprock and consolidated laterite and/or clay layers that were encountered up to 1.1 metres below natural ground level. Suitable materials identified for post-mining rehabilitation within this zone include sandy topsoil up to 100 mm in depth, gravelly sandy loam up to 1,100 mm in depth, and grey sand up to 950 mm in depth. All three materials are suitable to use in reconstructing the upper profile of post-mining landforms, with no parameters likely to limit plant establishment and growth.

There may be a limitation for topsoil originating from clearing blocks close to the existing operations, where the areas have been subjected to historical disturbance that has resulted in contamination from “weed seed”. These areas pose an elevated risk to future native rehabilitation from introduced species establishment, and ongoing liability associated with annual weed control. Areas that may be at risk from weed contamination and require closer inspection in this regard are identified in Figure 6.

All topsoil and subsoil stockpiles will need to be strategically positioned to minimise potential contamination from weed seed. Practically, this should include distancing them from existing cleared ground including that associated with mining operations and adjacent farmland.

3.3.2 Deeper Profile

Current rehabilitation at the Greenbushes Mine utilises a 300 mm cover of weathered regolith material (also known as ‘soft rock’) as a substitute in the absence of any viable topsoil or subsoil material from the surface profile. The relatively shallow cover material is spread over waste rock recovered during the mining operation. This post-mining soil profile has been implemented at Greenbushes since 1998 and is proven to support a native vegetation cover which has elements of the surrounding state forest ecosystem, but is not directly comparable. Rehabilitation blocks up to 20 years of age support native species richness levels ranging between 20 and 50 taxa, plant densities in the range 10,000 to 20,000 plants per hectare, and ground coverage between 30 and 85 percent (Onshore Environmental 2018b).

The soft rock material is the upper layer recovered from the deeper soil profile, i.e. clays commencing below the friable gravel stratum. Investigation of the physical and chemical properties of soft rock by Rose (2001) confirmed that bright orange material recovered from higher in the soil profile had capacity to support native rehabilitation. In contrast, material from progressively deeper strata, visually identifiable by being paler orange grading to white in colour, was less appropriate for use as a surface substrate in the rehabilitation profile. Factors limiting plant growth in the deeper materials included elevated clay content and associated low hydraulic conductivity, low infiltration rates and low plant available water, along with structural instability due to high exchangeable sodium percentage, low aggregate stability and high bulk density.

Based on the native rehabilitation experience at the Greenbushes supported by results from scientific investigations summarised above, bright orange soft rock from the upper stratum of the deeper mined profile is an appropriate rehabilitation material that should be incorporated into integrated mining and rehabilitation planning. Clay materials from lower in the deeper profile are unlikely to have value as a rehabilitation material, and should be buried at depth in the rehabilitation landform.

Landform design should consider mixing bright orange weathered regolith material (soft rock) with rock fragments (<200 mm) in diameter to increase the useable depth of the remade soil profile and improve landform stability. The upper remade profile is likely to comprise the *in situ* sandy topsoil layer (up to 100 mm in depth) over a subsoil layer comprising gravelly sandy loam (depth to be determined by recovered volume, but likely to exceed 300 mm depth).

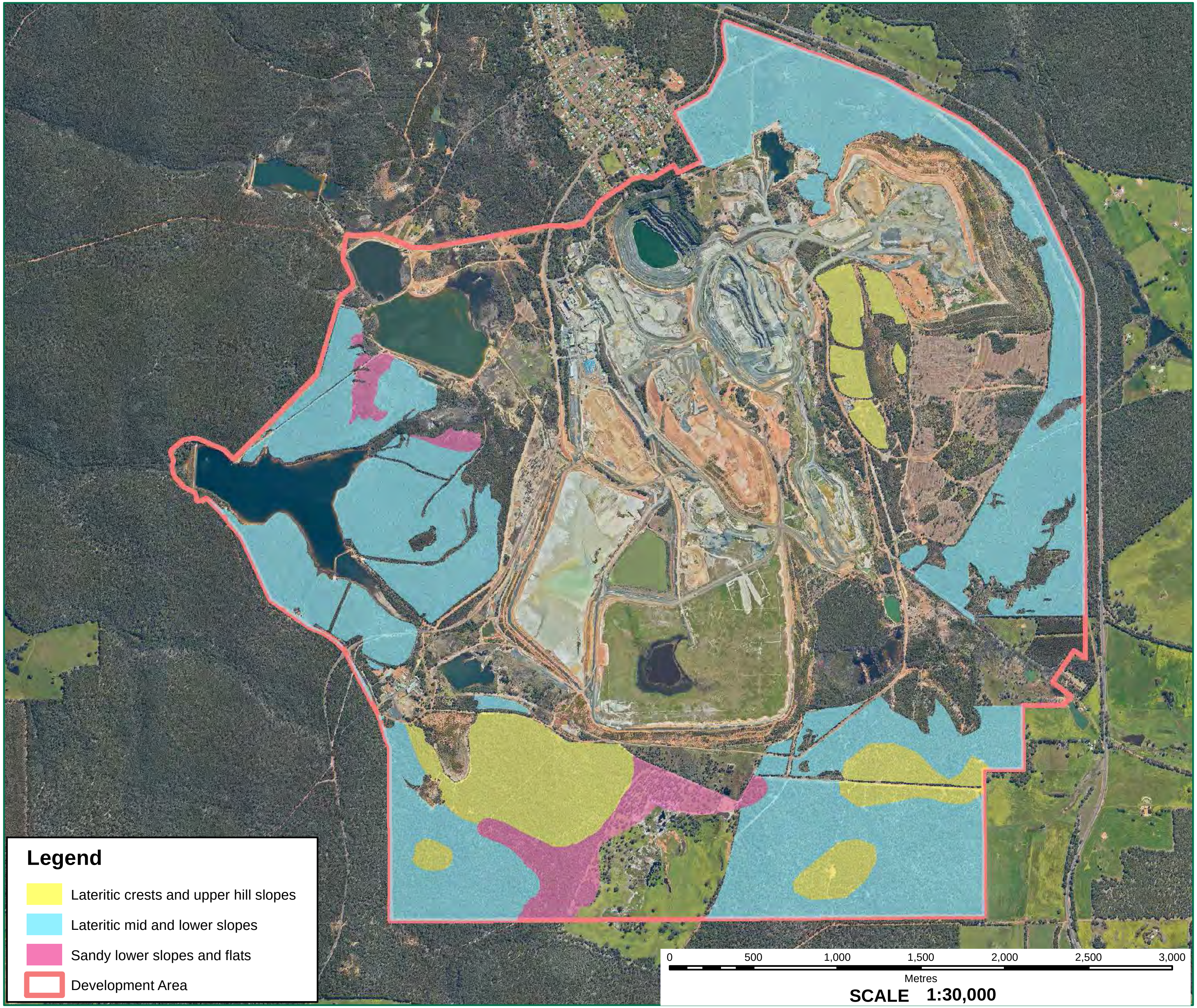
Table 3 Indicative native topsoil and subsoil volumes present over the entire project area.

Soil Description	Subsoil Depth (m)	Minimum Subsoil Depth (m)	Maximum Subsoil Depth (m)	Average Topsoil Volume (m^3)	Average Subsoil Volume (m^3)	Maximum Subsoil Volume (m^3)	Minimum Subsoil Volume (m^3)	Area (ha)
1a Lateritic crests and upper hill slopes	0.50	0.25	0.5	125,904	472,140	629,520	314,760	125.90
1b Lateritic mid and lower slopes	0.75	0.50	1.0	515,888	3,869,166	5,158,888	2,579,444	515.89
2a Sandy lower slopes and flats	0.90	0.80	1.0	50,806	457,262	508,069	406,455	50.81

Table 4 Indicative native topsoil and subsoil volumes present over areas where native vegetation clearing will be required.

PROBABLE SOIL STRIPPING AREAS								
Soil Description	Subsoil Depth (m)	Minimum Subsoil Depth (m)	Maximum Subsoil Depth (m)	Average Topsoil Volume (m^3)	Average Subsoil Volume (m^3)	Maximum Subsoil Volume (m^3)	Minimum Subsoil Volume (m^3)	Area (ha)
1a Lateritic crests and upper hill slopes	0.50	0.25	0.5	85,890	322,107	429,477	214,738	85.89
1b Lateritic mid and lower slopes	0.75	0.50	1.0	177,718	1,332,890	1,777,186	888,593	177.72
2a Sandy lower slopes and flats	0.90	0.80	1.0	39,864	358,782	398,647	318,918	39.86

FIGURE 4
Location of soil profile types across the entire project area



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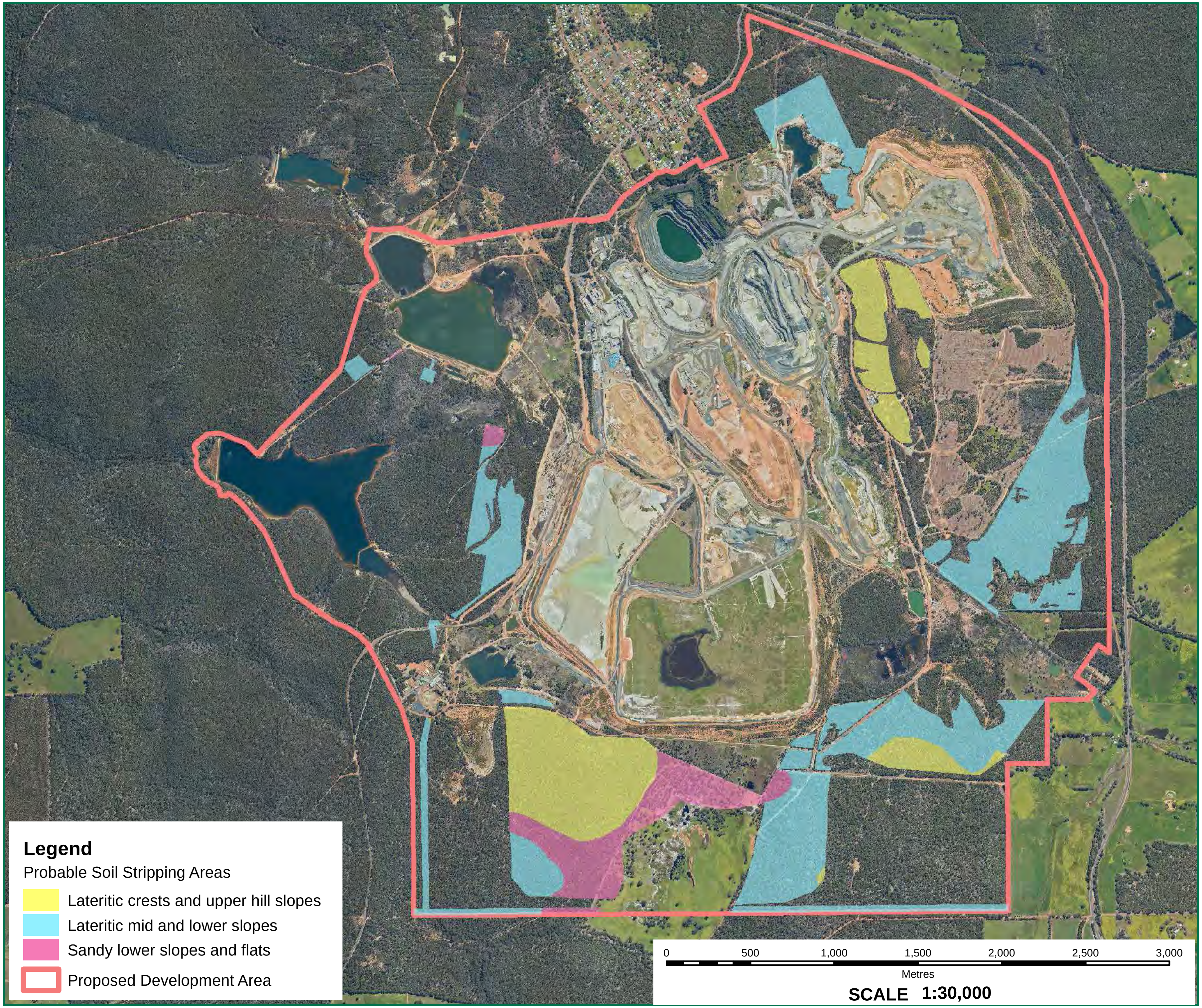
Requested by:	Req

Talison Lithium

Greenbushes Operations

FIGURE 5

Location of soil profile types within areas of vegetation proposed to be cleared



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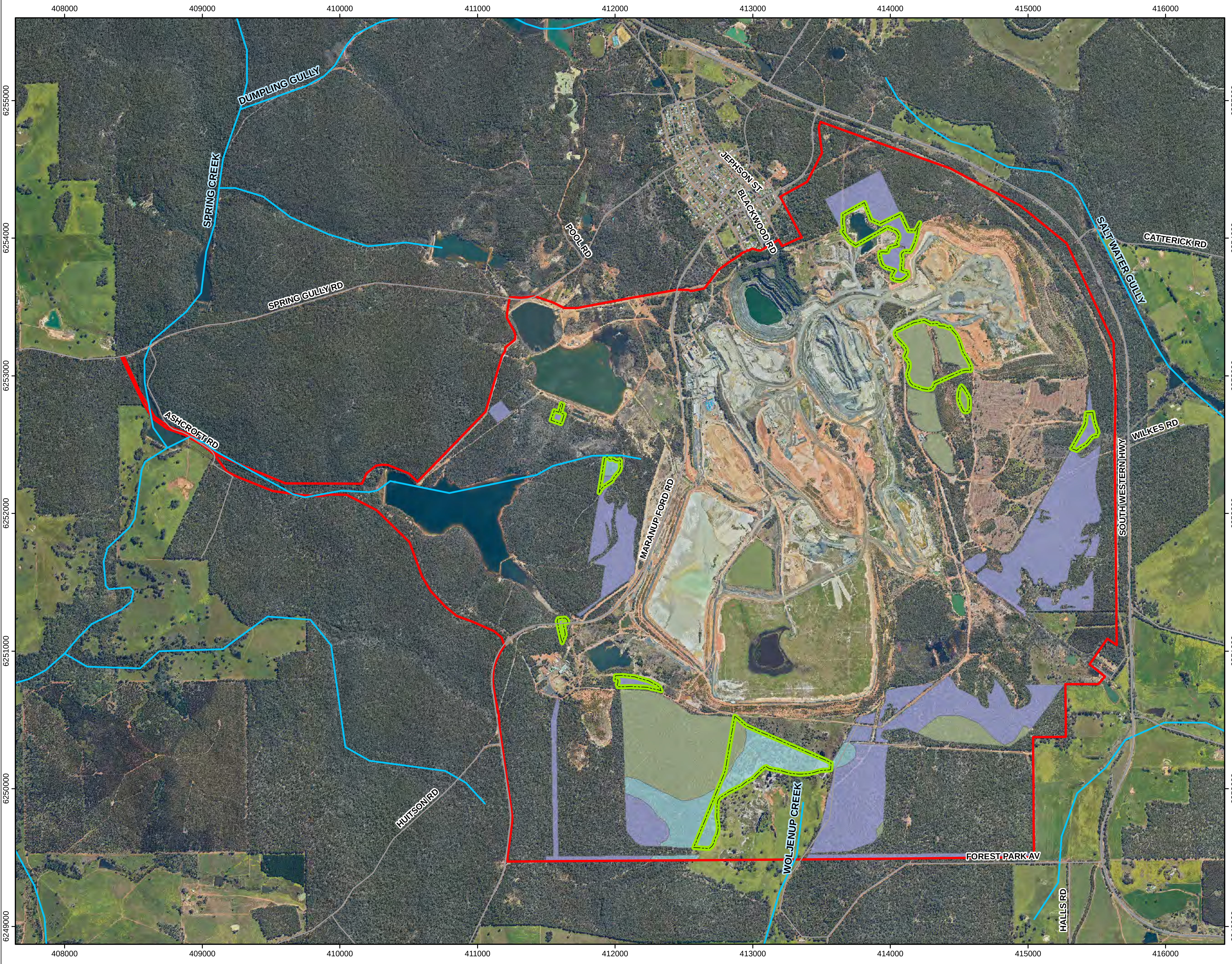
Talison Lithium

Greenbushes Operations



TALISON LITHIUM

Proposed clearing areas where further investigation of topsoil resource is required to confirm if it meets standard for utilisation in native rehabilitation at site

Figure. 6

Legend

- Mine Development Area
- Areas requiring further investigation

Soil Type

Code

- Lateritic crests and upper hill slopes
- Lateritic mid and lower slopes
- Sandy lower slopes and flats

N

0 250 500 750

Meters

1:25,000

Datum: GDA94

Projection: MGA Zone 50

Date:	06/09/2018
Status:	Draft
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Sheet Size:	A3
Internal Reference:	TL_Soil_invest
Drawn by:	GSM
Requested by:	DB

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APPENDIX 1

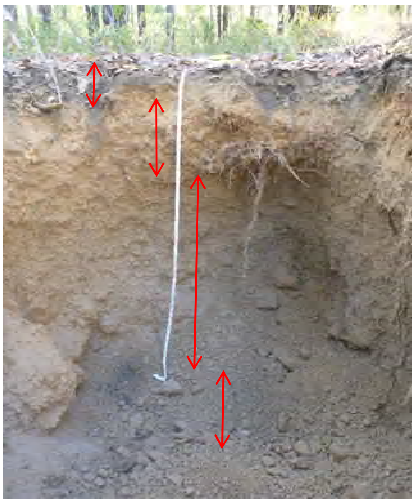
Soil analysis data for test pits excavated within the proposed development footprint at Greenbushes.

Parameter	Unit	1A	1B	1C	2A	2B	3A	3B	3C	4A	4B	6A	6B	6C	7A	7B	8A	8B
Colour		DKGR	WH	GR	BRGR	GRBK	GRBR	LTGR	YWBR	DKGR	WH	DKGR	BRGR	DKGR	LTGR	LTBR	LTBR	GRBR
Gravel	%	35-40	0	0	5-10	5	5	0	20-25	0	0	0	15-20	5-10	75-80	75-80	65-70	5-10
Texture		1.5	1.0	1.0	1.0	1.5	1.5	1.0	2.5	1.0	1.0	1.0	1.0	1.0	1.0	1.5	1.0	1.0
Ammonium Nitrogen	mg/kg	2	< 1	< 1	< 1	< 1	2	< 1	< 1	4	< 1	2	< 1	1	< 1	1	< 1	< 1
Nitrate Nitrogen	mg/kg	< 1	< 1	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Phosphorus Colwell	mg/kg	4	< 2	< 2	< 2	< 2	2	< 2	< 2	6	< 2	2	< 2	3	< 2	< 2	< 2	< 2
Potassium Colwell	mg/kg	97	< 15	< 15	< 15	18	18	< 15	32	18	< 15	17	< 15	56	< 15	< 15	< 15	44
Sulfur	mg/kg	4.1	< 0.5	0.9	12.7	16.6	18.9	< 0.5	12.6	3.4	< 0.5	0.8	0.5	1.6	2.5	3.9	0.7	2.0
Organic Carbon	%	4.50	< 0.05	1.06	0.25	1.88	2.72	0.17	0.51	2.68	0.10	0.76	0.31	2.35	0.11	0.24	0.14	1.60
Conductivity	dS/m	0.021	< 0.010	0.013	0.089	0.148	0.178	< 0.010	0.022	0.020	< 0.010	< 0.010	< 0.010	0.021	0.011	0.019	< 0.010	0.024
pH Level (CaCl2)		5.0	4.6	3.9	6.1	5.8	5.4	4.7	5.5	4.2	4.7	4.1	5.9	5.4	5.6	5.1	4.8	5.2
pH Level (H2O)		6.4	5.6	5.4	7.0	6.9	6.2	5.9	6.4	5.6	5.9	5.7	6.8	6.8	6.7	6.3	6.0	6.4
DTPA Copper	mg/kg	0.27	0.11	0.24	0.17	0.37	0.34	0.20	0.30	0.28	0.36	0.25	0.18	0.19	0.15	0.19	0.16	0.16
DTPA Iron	mg/kg	30.26	1.75	13.49	9.24	29.81	25.54	8.40	10.37	45.57	2.56	11.15	10.21	18.10	2.46	11.62	9.56	28.96
DTPA Manganese	mg/kg	19.58	0.04	2.18	0.41	6.38	2.67	0.10	0.52	6.36	0.18	5.18	0.11	7.79	0.12	0.56	0.14	4.74
DTPA Zinc	mg/kg	0.32	0.03	0.10	0.03	0.08	0.09	0.06	0.04	0.14	0.15	0.08	0.08	0.13	0.10	0.07	0.05	0.12
Exc. Aluminium	meq/100g	0.416	0.056	0.244	0.085	0.039	0.069	0.167	0.093	0.976	0.044	0.164	0.052	0.065	0.097	0.102	0.050	0.116
Exc. Calcium	meq/100g	8.47	0.05	1.10	0.68	4.83	6.02	0.15	0.78	2.22	0.15	2.14	0.67	5.47	0.20	0.35	0.24	2.13
Exc. Magnesium	meq/100g	1.87	0.03	0.51	0.32	2.71	2.41	0.07	0.66	0.86	0.05	0.55	0.33	1.91	0.11	0.14	0.10	0.75
Exc. Potassium	meq/100g	0.28	< 0.01	0.03	0.01	0.04	0.05	< 0.01	0.10	0.05	< 0.01	0.05	0.02	0.15	< 0.01	0.01	< 0.01	0.11
Exc. Sodium	meq/100g	0.17	< 0.01	0.04	0.29	0.80	0.58	0.02	0.09	0.16	< 0.01	0.03	0.02	0.12	0.02	0.04	< 0.01	0.09
Boron Hot CaCl2	mg/kg	0.46	< 0.10	0.16	0.23	0.40	0.61	< 0.10	0.39	0.26	< 0.10	0.13	0.11	0.38	0.13	0.13	< 0.10	0.29

APPENDIX 2

Overview of the eight soil test pits excavated within the proposed development footprint at Greenbushes

GB1801	Pit 1	Native 306 m AHD	414139E 6249534N	23/05/2018

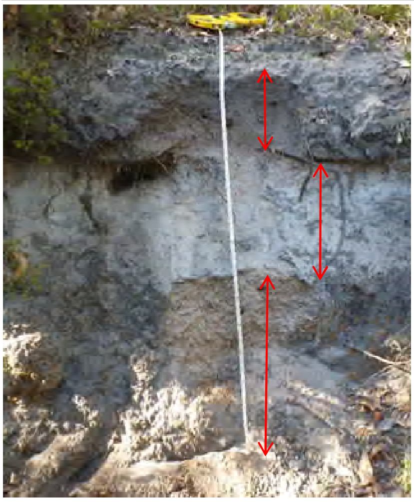


0-50 mm	Dark brown sand, high organics including leaf litter at surface
50-450 mm	Light brown gravelly sandy loam, high concentration of plant roots
450-1,100 mm	Light brown gravelly sandy loam, sparse larger plant roots
>1,100 mm	Laterite caprock

GB1802	Pit 2	Native 284 m AHD	414271E 6250292N	23/05/2018

0-100 mm	Grey sand, high organics including leaf litter at surface, high concentration of plant roots
100-550 mm	Light brown gravelly sandy loam, sparse larger plant roots
>550 mm	Laterite caprock

GB1803	Pit 3	Native 264 m AHD	413697E 6250254N	23/05/2018



0-400 mm	Grey sand, high organics including leaf litter at surface, high concentration of plant roots
400-900 mm	White sand, sparse larger plant roots
>900 mm	Mixture of white sand with laterite pebbles, scattered plant roots

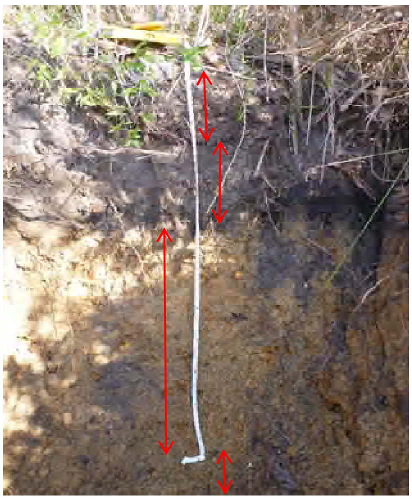
GB1804	Pit 4	Native 263 m AHD	413619E 6250264N	23/05/2018

0-50 mm	Grey sand, high concentration of plant roots
50-950 mm	Grey sand, sparse larger plant roots
>950 mm	Laterite caprock

GB1805	Pit 5	Native 242 m AHD	410633E 6252286N	23/05/2018

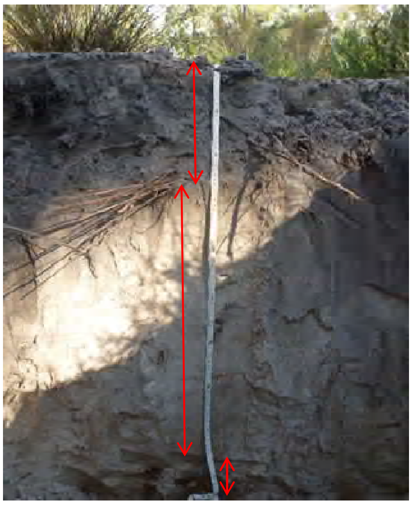
0-300 mm	Dark brown gravelly sandy loam, high concentration of plant roots
300-450 mm	Light brown gravelly sandy loam, sparse larger plant roots
>450 mm	Red to dark orange loam

GB1806	Pit 6	Native 259 m AHD	411496E 6252848N	23/05/2018



0-200 mm	Grey sand, high organics including leaf litter at surface, high concentration of plant roots
200-400 mm	Dark grey sand, moist, high concentration of plant roots
400-1,000 mm	Light brown to light orange loam with laterite pebbles, moist,
>1,000 mm	Laterite caprock

GB1807	Pit 7	Native 268 m AHD	411290E 6252953N	23/05/2018



0-150 mm	Grey sand, high concentration of plant roots
150-800 mm	Light grey sand, scattered plant roots
>800 mm	Laterite caprock

GB1808	Pit 8	Native 267 m AHD	411346E 6253036N	23/05/2018

0-100 mm	Brown sandy loam, high organics including leaf litter at surface, high concentration of plant roots
>100 mm	Laterite caprock