POTENTIAL GROUNDWATER DEPENDENT ECOSYSTEMS

IN THE

THUNDERBIRD MINERAL SANDS PROJECT AREA

Prepared for

Sheffield Resources Limited

Prepared by

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ABBREVIATIONS

The following abbreviations are used throughout this document:

BOM	Bureau of Meteorology
DBH	Diameter at breast height
DPaW	Department of Parks and Wildlife
GDE	Groundwater Dependent Ecosystem
Mattiske	Mattiske Consulting Pty Ltd
Sheffield	Sheffield Resources Limited
WAH	Western Australian Herbarium

1. SUMMARY

The Thunderbird Project Area occupies an area of 18,886 ha and is situated on the Dampier Peninsula, between Broome and Derby, across the Mt Jowlaenga and Yeeda Stations. The Thunderbird Project Area has been the subject of four flora and vegetation surveys completed between 2012 and 2016. Three of these were completed by Ecologia Environment between 2012 and 2015. A fourth survey was completed by Mattiske Consulting Pty Ltd in June 2016.

Mattiske Consulting Pty Ltd was commissioned in November 2016 to review the vegetation within the Thunderbird Project Area to determine if any of the vegetation communities defined could be classified as a groundwater dependant ecosystem (GDE). The previous survey by Mattiske (2016) defined six vegetation communities within the Thunderbird Project Area which either associated with a drainage channel of were in a location likely to be associated with seasonal inundation. The present survey focused on two of these vegetation communities, the W1 and W14 vegetation communities, on the basis of their species assemblage and topographical location. These vegetation communities were primarily associated with drainage channels. The other four vegetation communities were situated in areas with a flat topography and did not comprise species assemblages which were considered likely to support GDEs. The W1 vegetation community was primarily associated with drainage channels, and was defined as: "*Melaleuca viridiflora*, *Melaleuca alsophila* and *Eucalyptus tectifica* low sparse woodland over *Bauhinia cunninghamii*, *Carissa lanceolata* and *Atalaya hemiglauca* tall sparse shrubland over *Ectrosia schultzii*, *Eriachne sulcata* and *Cyperus conicus* low sparse grassland on grey-white to light brown sandy soils in drainage channels and low lying drainage areas". The W14 vegetation community was associated with the Fraser River South and was defined as "*Eucalyptus camaldulensis* mid open woodland over *Melaleuca viridiflora, Melaleuca alsophila* and *Bauhinia cunninghamii* mid sparse shrubland over *Ectrosia schultzii*, *Eriachne sulcata* and *Fimbristylis littoralis* low sparse grassland on grey to light brown sandy clay soils in drainage channels".

Dewatering associated with the Thunderbird project has been assessed by Sheffield Resources Limited as potentially having an impact on GDEs, should they occur in the Thunderbird Project Area. A desktop assessment for areas with the greatest potential to support groundwater dependent vegetation identified an intermittent soak located approximately 3 km south of the proposed mining area and Fraser River South, located approximately 7 km south of the proposed mining.

A field survey, designed to ground truth the results of the desktop assessment, concluded that the intermittent soak area is not be considered as a GDE. The reasons for this included a modelled 18 m depth to groundwater (Rockwater 2016), very poor vegetation condition in the soak, and surface topography which indicates that the area is low lying in the landscape and likely to be internally draining.

The western section of the Fraser River South, mapped as the W1 vegetation community, was not considered to represent a GDE. The eastern section of the Fraser River South, which was mapped as the W14 vegetation community, contained a large number of *Eucalyptus camaldulensis* trees, which are

considered to be groundwater dependent. Interpolated groundwater levels in the area were calculated as shallow (2-5m), based on relatively distant bore data, with no data available within or immediately adjacent to the drainage line itself to provide certainty on the groundwater levels and hydrogeological structures which may be providing plant available water where the *Eucalyptus camaldulensis* was located (Rockwater 2016).

All other vegetation communities within the project area that have been mapped by Mattiske (2016) are not considered to be GDEs. Proposed mining operations are not considered likely to adversely impact any vegetation communities that may have groundwater dependence.

2. INTRODUCTION

2.1 Background

Sheffield Resources Limited (Sheffield) proposes to develop a mineral sands (zircon and ilmenite) mining operation at its Thunderbird Mineral Sands Project Area, hereinafter referred to as the Thunderbird Project Area, in the West Kimberley region of Western Australia. The proposed operation is projected to have a life of mine in excess of 40 years. Water to support the mining operation will be supplied from local groundwater sources (a combination of mine dewatering and local bores).

The Thunderbird Project Area has been the subject of four flora and vegetation surveys since 2012. Three flora and vegetation surveys were completed by Ecologia Environment (Ecologia) between 2012 and 2015. These surveys were a Level 1 flora and fauna assessment (Ecologia 2012), a Level 2 flora and vegetation survey (Ecologia 2014) and a Haul Road and Accommodation Camp flora and fauna assessment (Ecologia 2015). Sheffield commissioned Mattiske Consulting Pty Ltd (Mattiske) to undertake a fourth flora and vegetation survey of the Thunderbird Project Area in 2016 to address vegetation mapping deficiencies resulting from altered boundaries to the original project area and to address issues of concern identified from the previous surveys (Mattiske 2016).

Mattiske Consulting Pty Ltd (Mattiske) was commissioned in November 2016 to review the vegetation communities within the Thunderbird Project Area (Mattiske 2016) to determine if any could be classified as a groundwater dependant ecosystem (GDE).

2.1 Scope of Work

The Thunderbird Project Area is located approximately 98 km northeast of Broome and 72 km west of Derby in the West Kimberley region of Western Australia (Figure 1). The Thunderbird Project Area is situated on the Mt Jowlaenga and Yeeda Stations, and occupies an area of approximately 18,886 ha.

The scope of the survey was to complete a desktop assessment and field reconnaissance survey to determine the potential for GDEs to be present within the Thunderbird Project Area. The previous survey by Mattiske (2016) defined six vegetation communities within the Thunderbird Project Area which were either associated with a drainage channel of were in a location likely to be associated with seasonal inundation. The present survey focused on two of these vegetation communities, the W1 and W14 vegetation communities, on the basis of their species assemblage and topographical location. These vegetation communities were primarily associated with drainage channels. The other four vegetation communities were situated in areas with a flat topography and did not comprise species assemblages which were considered likely to support GDEs.

The W1 vegetation community was defined as: "*Melaleuca viridiflora*, *Melaleuca alsophila* and *Eucalyptus tectifica* low sparse woodland over *Bauhinia cunninghamii*, *Carissa lanceolata* and *Atalaya hemiglauca* tall sparse shrubland over *Ectrosia schultzii*, *Eriachne sulcata* and *Cyperus conicus* low sparse grassland on grey-white to light brown sandy soils in drainage channels and low lying drainage areas" (Figure 2). The

W14 vegetation community was defined as: "*Eucalyptus camaldulensis* mid open woodland over *Melaleuca viridiflora, Melaleuca alsophila* and *Bauhinia cunninghamii* mid sparse shrubland over *Ectrosia schultzii*, *Eriachne sulcata* and *Fimbristylis littoralis* low sparse grassland on grey to light brown sandy clay soils in drainage channels" (Figure 2).

Within the Thunderbird Project Area, the W1 vegetation community occupied approximately 127.45 ha, or 0.68% of the Thunderbird Project Area. The W1 vegetation community was associated with three identifiable features within the Thunderbird Project Area. These were:

1. minor drainage channel areas intersecting the extreme north of the Thunderbird Project Area, and which are likely form components of the headwaters of the Fraser River;
2. a section of the Fraser River South which traverses the southern section of the Thunderbird Project Area, approximately 7 km south-east of the proposed impact area; and.
3. an area identified as a soak, located approximately 3 km south of the proposed impact area.

The W14 vegetation community was associated with the eastern section of the Fraser River South, and occupied and area of 13.56 ha, or 0.07% of the Thunderbird Project Area.

3. OBJECTIVES

The aim of this survey was to complete desktop study to identify areas within the Thunderbird Project Area which may comprise GDEs, and a field survey to ground truth any areas identified from the desktop assessment as potential GDEs. Specifically, the objectives of the survey of the Study Area included:

- Undertake a desktop assessment to identify potential GDE locations within the Thunderbird Project Area using aerial imagery and vegetation mapping data;
- Review hydrological studies of the Thunderbird Project Area to complement the aerial imagery and vegetation mapping data, in terms of identifying the locations of potential GDEs within the Thunderbird Project Area;
- Undertake botanical data collection related to the presence of *Eucalyptus camaldulensis* (location and health) and any other species present which may be associated with a GDE; and
- Prepare a report summarising the findings.

4. METHODS

Eamus (2006) and Evans *et al*. (2013) provide a range of techniques which can be used to assist in the identification of GDEs. Some of the techniques listed, such as measuring leaf water potentials, depth and morphology of plant root systems, leaf area index measurements, and plant water use studies, require the use of specialist equipment and/or relatively longer term field studies than are practical in the context of the survey reported here. Techniques which were less equipment dependant and time consuming, and which were more practical for the present survey included reviewing aerial imagery and existing vegetation mapping to select areas with greater potential to contain GDEs, ground truthing of areas with the potential to support groundwater dependent vegetation, assessment of the species composition of areas with the potential to support groundwater dependent vegetation, and assessment

of the condition of the vegetation in areas identified as having the potential to support groundwater dependent vegetation.

4.1 Aerial Imagery and vegetation Maps

Aerial photographic maps at a 1:10,000 scale of the Thunderbird Project Area, based on high resolution aerial imagery taken between October 2014 and September 2015 (0.15 m resolution overall, 0.05 m resolution in part), were prepared by CAD Resources of Carine, Western Australia. This was used, in conjunction with the vegetation community maps prepared, based on flora and vegetation surveys completed by Ecologia (2012, 2014, 2015) and Mattiske (2016), to identify areas within the Thunderbird Project Area likely to support species dependent on groundwater, such as drainage lines and their surrounding floodplains.

4.2 Hydrological Modelling

The hydrological report prepared for the Thunderbird project Area (Rockwater 2015) was reviewed to identify the presence of aquifers in the project area, the depth to groundwater within the project area, and the potential for areas with near to surface groundwater which may indicate the potential for vegetation dependent on groundwater to be located within the Thunderbird project Area.

4.3 Field Assessment

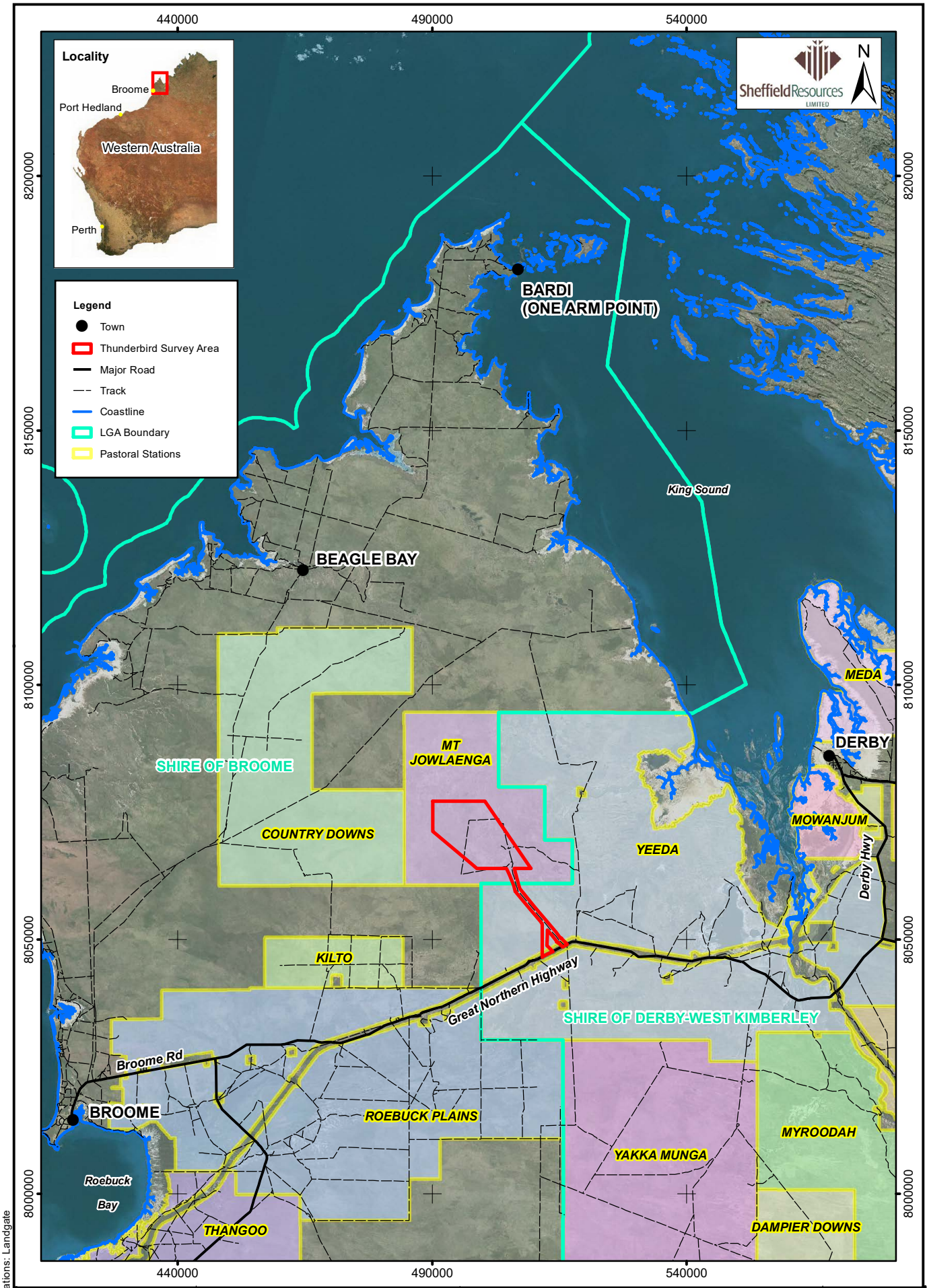
A field assessment of vegetation with the potential to support groundwater dependent species within the Thunderbird Project Area was completed by a Botanist from Mattiske and an Environmental Scientist from MBS Environmental on the 22nd and 23rd November 2016. Based on the desktop assessment, two regions within the Thunderbird Project Area were selected for inspection. These were the Fraser River South, located approximately 7 km south-east of the proposed mining area, and a small isolated intermittent soak, located approximately 3 km south of the proposed mining area. Both areas are indicted in Figure 2. The soak area was mapped by Mattiske as the W1 vegetation community. The Fraser River South forms a major drainage channel in the southern portion of the Thunderbird Project Area, and was mapped by Mattiske (2016) as being composed of the W1 vegetation community in its western section, and as the W14 vegetation community in the eastern portion.

Both the small soak area and the length of the Fraser River South were traversed on foot to enable a thorough inspection of the vegetation in the soak, the drainage channel and its banks. The length of the Fraser River South within the Thunderbird Project Area was approximately 5.8 km. The W1 vegetation community had previously been defined by Mattiske (2016), based on 12 vegetation survey quadrats established by Ecologia (2012, 2014) and Mattiske (2016). The W14 vegetation community had previously been defined by Mattiske (2016), based on two vegetation survey quadrats. Access to both areas by vehicle and foot was good due to the presence of nearby tracks.

The length of the Fraser River South was searched, in particular for *Eucalyptus camaldulensis*, which had been recorded as being present in two of the survey quadrats established by Mattiske (2016). The location of all mature *Eucalyptus camaldulensis* trees along the length of the Fraser River South was recorded. In addition, three groups of *Eucalyptus camaldulensis* trees, comprising 15 consecutive trees from the point of the first recording of the species within the Fraser River South, and at 1.5 km and 3.0 km downstream respectively, were assessed in terms of their height, diameter at breast height (DBH) and health. Only trees which had a DBH > 1 cm or height > 2m were assessed. The health ranking of *Eucalyptus camaldulensis* trees in the field was based on the scale set out in Table 1, which was developed by E.M. Mattiske and Associates. Notes on the soil, rock outcropping and presence of surface water at both areas surveyed, together with photographic records, were made.

Table 1: Tree condition scale description

Condition	Code	Classification Contributing Factors
Healthy	H	> 90% foliage present canopy essentially intact no epicormic growth none to little evidence of leaf discolouration none to little evidence of insect damage
Slightly Stressed	SS	75% - 90% foliage present some minor canopy loss minor epicormic growth none to minor evidence of leaf discolouration, potentially some dead leaves at branch tips none to minor evidence of insect damage
Stressed	S	50% - 75% foliage present moderate canopy loss some epicormic growth evidence of leaf discolouration, evident damage to leaves significant evidence of insect damage obvious
Very Stressed	VS	< 50% foliage present major canopy loss epicormic growth present leaf discolouration significant; evident damage to leaves significant evidence of insect damage obvious
Dead Recent	DR	tree dead, but foliage still present
Dead Moderate	DM	tree dead, foliage absent, bark and fine twigs still present
Dead Old	DO	tree dead, foliage and fine twigs absent, bark partially to completely fallen off



Source: Pastoral Stations: Landgate

0 5 10 15 20 km

Scale: 1:1,000,000
MGA94 (Zone 51)

CAD Ref: a2409_f50_01

Date: Jul 2016 | Rev: A | A4

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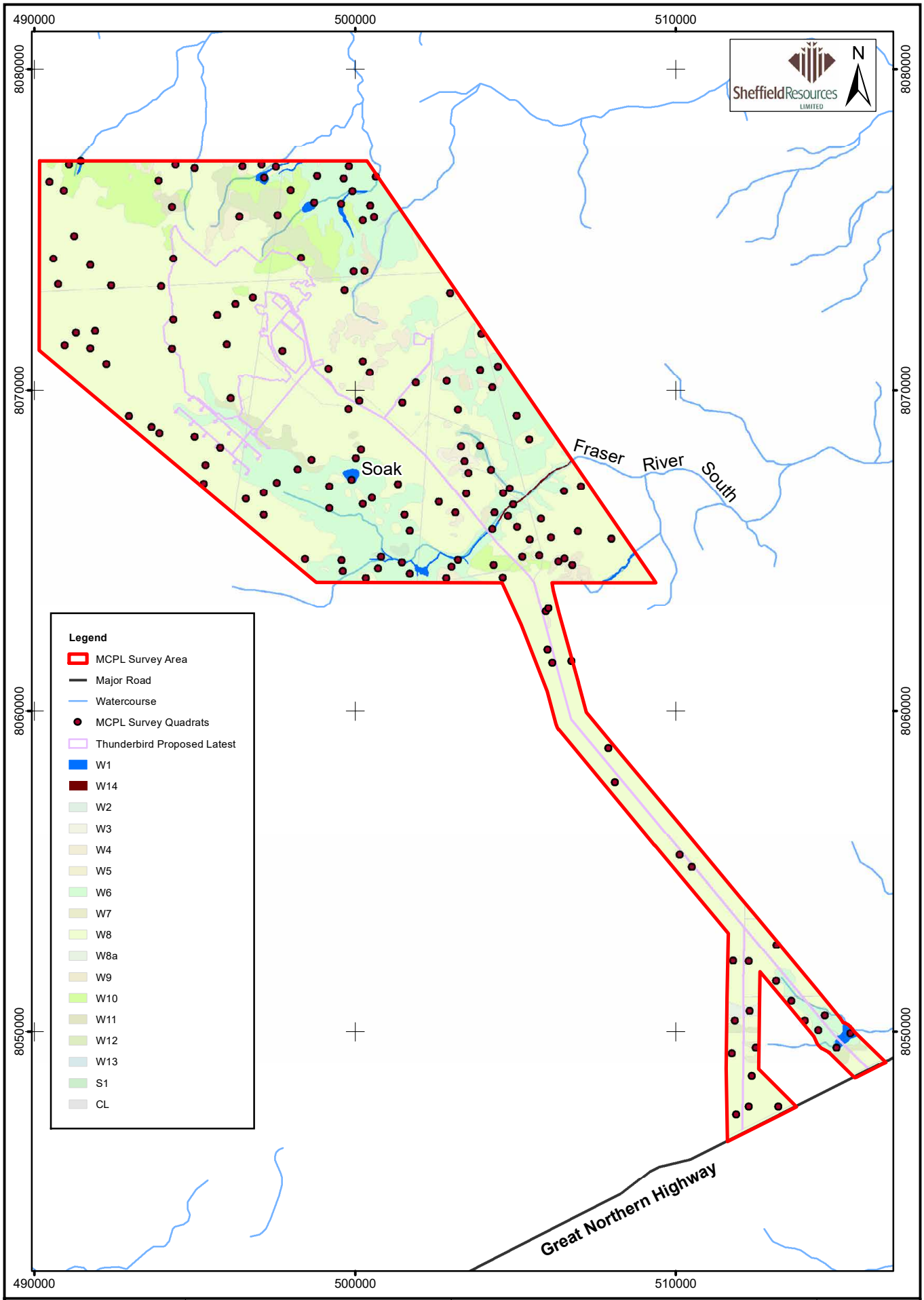
Thunderbird Mineral Sands Project
Locality
Showing Pastoral Stations

Figure: **1**



Source: Vegetation: MCPL, Site Layout: MBS

0 1 2 3 4 km

Scale: 1:160,000
MGA94 (Zone 51)

CAD Ref: a2409_f51_01

Date: Dec 2016 | Rev: B | A4

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Thunderbird Mineral Sands Project
Vegetation

Figure: **2**

4.3 Statistical Analysis

A one-way ANOVA was used to assess if there was any statistically significant differences in the height, DBH or health of the three groups of 15 *Eucalyptus camaldulensis* trees assessed along the Fraser River South. Prior to statistical analysis tree health data was converted to a numerical value (healthy = 4, slightly stressed = 3, stressed = 2, very stressed = 1; dead = 0). Where a significant difference between groups of trees was determined, a Tukey's honestly significant different post-hoc test was used determine which groups were significantly different. R (R Core team 2016) was used for statistical analyses.

5. DESKTOP SURVEY RESULTS

5.1 Climate

Beard (1990) described the climate of the West Kimberley, where the Thunderbird Project Area is situated, as having a semi-arid to dry hot tropical climate, with summer rainfall and annual precipitation of 250-800 mm. Much of the rain comes from thunderstorms. The heaviest and most widespread falls are associated with cyclonic disturbances. Derby Aero, which is located approximately 72 km to the east of the Thunderbird Project Area, has an average annual rainfall of 691 mm (Bureau of Meteorology, BOM 2016a). Rainfall and temperature data for Derby Aero is illustrated in Figure 3. Rainfall in the four months preceding the November field survey totalled 34 mm, which was above the long term average of 12.6 mm, for the corresponding period.

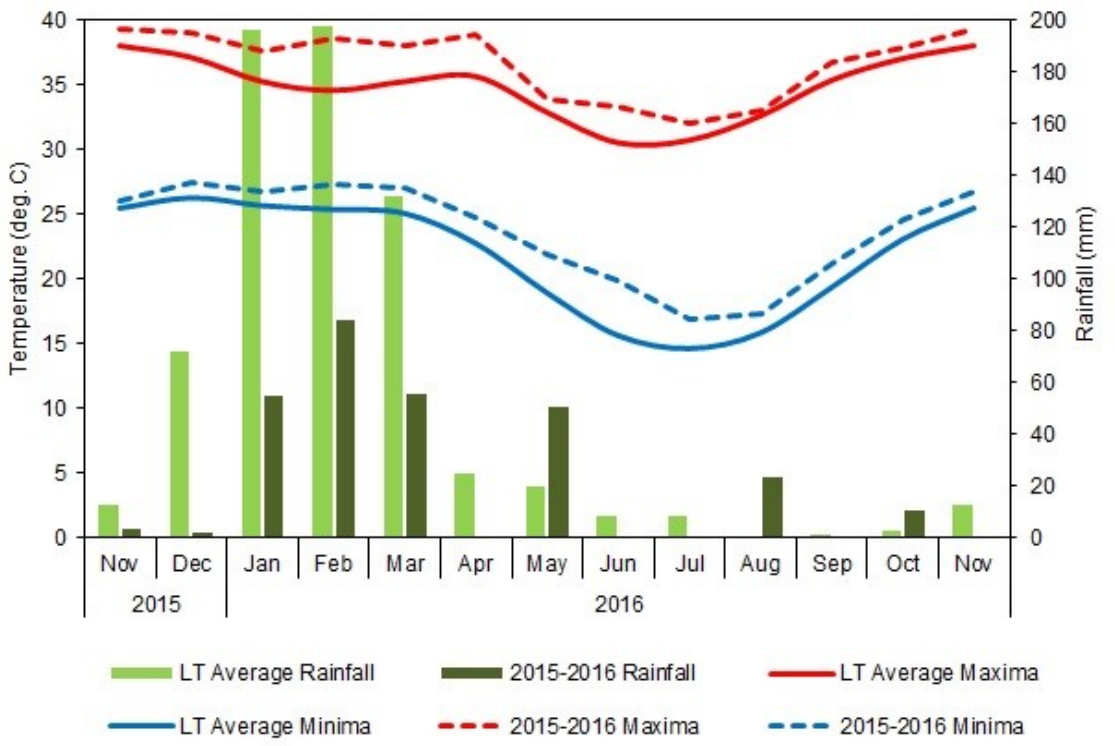


Figure 3: Rainfall and temperature data for Derby Aero
Long term average (LTA) rainfall and temperature data, together with monthly rainfall data for the period November 2015 to November 2016 (November 1st to 20th) are shown (BOM 2016a).

5.2 Hydrology of the Thunderbird Project Area

A hydrological assessment by Rockwater (2016) to fulfil the requirements for an application to the Department of Water for a Section 5C licence to take groundwater for the Thunderbird Project was reviewed. Data relating to groundwater levels derived from bores either on the Dampier Peninsula and Broome town water supply bore field were accessed from the Department of Water database and used as a basis for modelling. Limitations and uncertainty associated with the modelling of groundwater levels on the impacts of abstraction include gaps in available data associated with the uneven

distribution of monitoring bores and the absence of dedicated monitoring bores with long-term groundwater level data within the Thunderbird Project area (Rockwater 2016).

The inferred depth to groundwater is in excess of 20 m over most of the project area, with depths to groundwater in river valleys associated with the Fraser River South ranging from less than 5 m to more than 20 m (Rockwater 2016). However, as noted above, there is a level of uncertainty in the interpolated groundwater levels due to the lack of data and relative distance from the central drainage channel of measured data. Figure 4, adapted from Rockwater (2016), presents a localised interpretation of groundwater in the area. Notwithstanding the uncertainty in the interpolated groundwater levels within the Thunderbird Project Area, the depth to groundwater is modelled to be at its shallowest in the Fraser River South valley, most notably in the eastern portion of the valley. In terms of the predicted impacts groundwater abstraction may have on the two areas which may contain potential GDEs, i.e. the soak and the Fraser River South, Rockwater (2016) provide the following potential impact descriptions:

Drawdown in the Fraser River South Valley

Groundwater drawdown has the potential to impact on vegetation communities in the Fraser River South valley. Groundwater drawdown of up to about 2 m is predicted in a gradual process over approximately 32 years from Year 15 until the end of the mine life where it will rapidly rebound following cessation of dewatering at closure (Rockwater 2016). Vegetation communities in this region are likely to experience seasonal variability in groundwater levels.

Drawdown impacts on the Soak

Groundwater levels in the Broome aquifer are about 18 m below land surface in this region and the "intermittent soak" is therefore unlikely to be connected to the regional Broome aquifer (targeted for abstraction) and is more likely related to localised seasonal surface water ponding.

5.3 Groundwater Dependent Ecosystems

A GDE is an ecosystem (composed of flora, fauna, fungi and microbes) whose current composition, structure and function is reliant on a supply of groundwater (Eamus 2009). The reliance on groundwater may be continuous or only for part of the year, but the reliance becomes apparent when the groundwater supply is removed for a sufficient length of time that changes in plant function become observable. Whilst groundwater can be defined as water which occupies the pores within the rock or soil profile, the use of this term in defining a GDE is more specific. Hatton *et al*. (1998) identified, for the purpose ecosystem dependence, groundwater to mean that water which would be unavailable to plants and animals were it to be extracted, for example, by pumping.

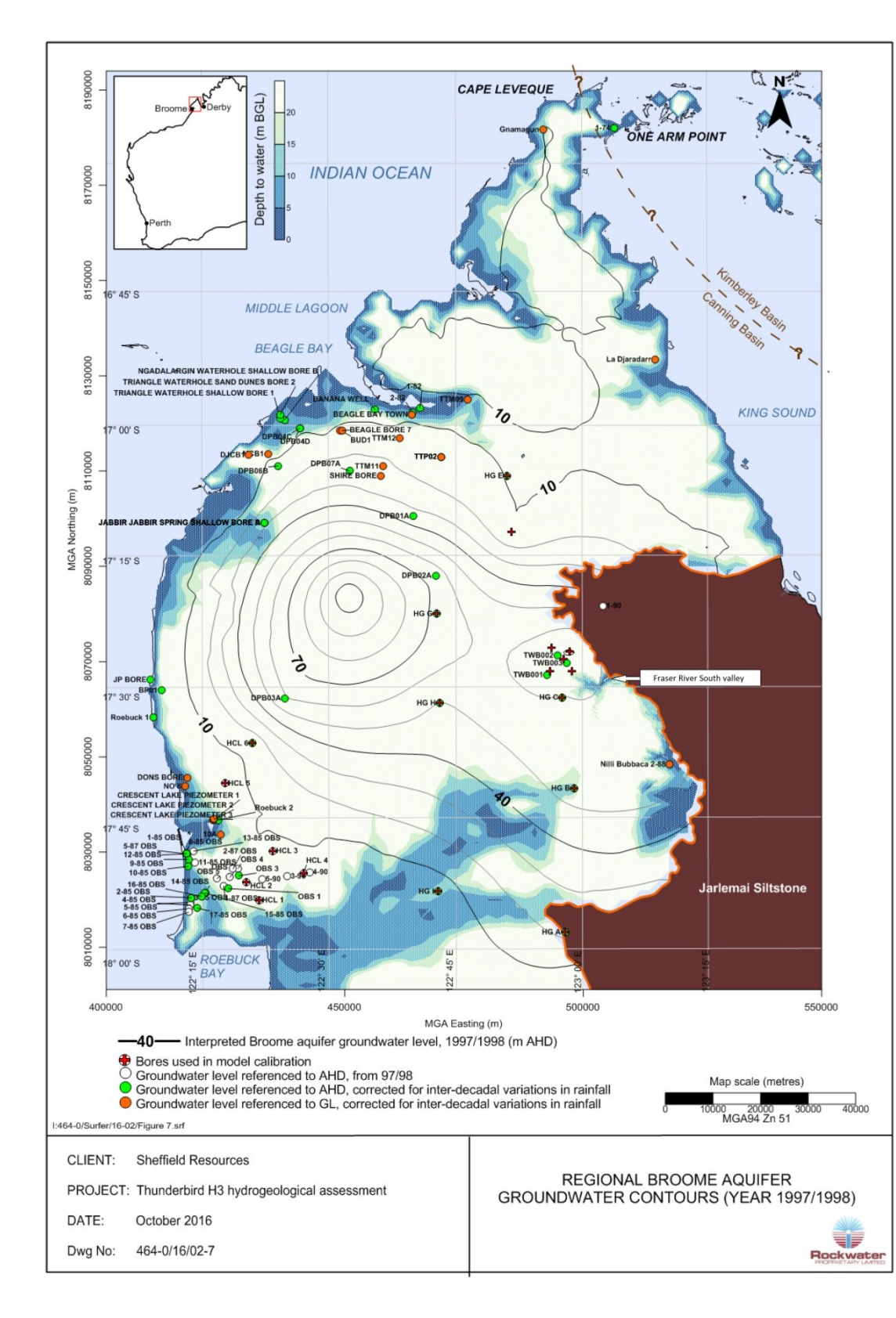


Figure 4: Shallow water tables in the Broome aquifer in the Thunderbird project Area vicinity (adapted from Rockwater 2014)

Eamus *et al*. (2006) and Eamus (2009) proposed three simple primary classes of GDEs. These were:

1. aquifer and cave systems;
2. ecosystems dependent on the surface expression of groundwater. This includes base-flow rivers and streams, wetlands, riparian vegetation, estuarine seagrass beds, some floodplains and mound springs; and,
3. ecosystems dependent on the subsurface presence of groundwater, often accessed via the capillary fringe (non-saturated zone above the saturated zone of the water table when roots penetrate this zone. These ecosystems include River Red Gum (*Eucalyptus camaldulensis*) forests, *Banksia* woodlands. and riparian forests.

Vegetation dependent on groundwater is commonly associated with riparian zones and floodplains of ephemeral creeks and rivers in arid and semi-arid areas of Australia. Plants that utilise ground water, either from a ground supply or from the water table, are referred to as phreatophytes. Whilst changes in depth to groundwater occur naturally, anthropogenic alterations may exacerbate these fluctuations and, thus, affect vegetation reliant on groundwater. Depending on the level of dependence on the ground water, phreatophytes can be subdivided into obligate or facultative phreatophytes.

Obligate phreatophytes, which are deep rooted plants that only inhabit areas where they can access groundwater, via the capillary fringe, to satisfy at least some proportion of their environmental water requirement. Access to groundwater is a critically important to their presence in a landscape. Obligate phreatophytes tend to be associated with the surface expression of groundwater. *Melaleuca argentea* is an example of an obligate phreatophyte.

Facultative phreatophytes are deep rooted plant species that tap into groundwater, via the capillary fringe, to satisfy at least some portion of their environmental water requirement, but will also inhabit areas where their water requirements can be met by soil moisture reserves alone. Facultative phreatophytes tend to be associated with the subsurface presence of groundwater. *Eucalyptus camaldulensis* is an example of a facultative phreatophyte (Mensforth et al. 1994, cited in Colloff 2014).

5.4 Species potentially associated with a GDE in the Kimberley Region

There is relatively little detailed information available in relation to GDEs within the Kimberley region. The National Atlas of Groundwater Dependent Ecosystems (BOM 2016b) indicates that the south eastern corner of the Thunderbird Project Area may contain a GDE with a low potential for groundwater interaction. This area covers the eastern portion of the Fraser River South within the Thunderbird Project Area. According to the BOM (2016b), a GDE with a potential for groundwater interaction is an ecosystems that relies on groundwater that has been discharged to the surface, for example, as base flow or spring flow. However, the BOM (2016b) states that given the limitations of the remote sensing data used to derive the inflow dependent landscapes layer, and that the scale and resolution of the mapped information are only as detailed as the input mapping used, caution should be used in interpreting the data. The Fraser River, to the north of the Thunderbird Project Area is listed by the BOM (2016b) as an ecosystem that relies on the surface expression of groundwater that has a low

potential for ground water interaction. The main GDE situated in the Kimberley region is associated with the Fitzroy River (BOM 2016b).

In the Kimberley region, overstorey species tend to dominate riparian communities. Species commonly present in the Fitzroy Valley include *Eucalyptus camaldulensis*, *Eucalyptus victrix*, *Melaleuca argentea*, *Melaleuca glomerata*, *Melaleuca bracteata* and *Atalaya hemiglauca*. In addition, there are a number of phreatophtyic species common to both the Dampier Peninsula and Fitzroy Valley such as *Melaleuca dealbata*, *Melaleuca alsophila*, *Melaleuca nervosa*, *Melaleuca viridiflora*, *Corymbia bella* and *Lophostemon grandiflorus* (Pusey and Kath, 2015).

Kenneally *et al.* (1996) state that species locally restricted to the banks of the Fitzroy River include *Barringtonia acutangula*, *Melaleuca argentea*, *Nauclea orientalis*, *Pandanus aquaticus*, and *Terminalia platyphylla*. *Eucalyptus camaldulensis*, *Eucalyptus flavescens* and *Planchonia careya* are also conspicuous on the riverbanks and levees, with *Eucalyptus tectifica*, *Eucalyptus* aff. *microtheca*, and *Eremophila bignoniiflora* prominent on the back of flood plains.

Pusey and Kath (2015) provide a list of species which have the potential to be dependent on groundwater in the Fitzroy River Valley (Table 2). Whilst the list of species is based on data from the Fitzroy River Valley, it nonetheless provides a useful list of potential species which may be present within the Thunderbird Project Area in any potential GDE.

A description of *Eucalyptus camaldulensis*, which is considered to be a species with groundwater dependence (Colloff 2014, Pusey and Kath 2015), is set out below. This is followed by a brief description of the two *Melaleuca* species recorded within the Thunderbird Project Area, *Melaleuca alsophila* and *Melaleuca viridiflora* (Mattiske 2016).

***Eucalyptus camaldulensis* (River Red Gum)**

Eucalyptus camaldulensis is a small to large tree (5m to 20 m) with smooth white, grey, brown or red bark. *Eucalyptus camaldulensis* is the most widespread eucalypt, occurring across most of the Australian mainland (Chippendale 1988, DPaW 2016). In Western Australia, *Eucalyptus camaldulensis* grows across most of the state, with the exception of the more southern parts of the State (DPaW 2016). *Eucalyptus camaldulensis* grows in deep alluvial sands and loams along or near watercourses.

Eucalyptus camaldulensis root structure comprises vertical tap roots with lateral roots branching off at right angles at several levels, with sinker roots extending downward from the lateral roots. This provides strong support for the above ground part of the tree and deep penetration of the vertical roots over a broader area than would be afforded by a single tap root. This root architecture allows for *Eucalyptus camaldulensis* to access water at different depth in the soil profile depending on the availability of water during different seasons and conditions. The roots of mature *Eucalyptus camaldulensis* extend to depths of at least 10 m, and possibly as far as 30 m (Davies 1953, cited in Colloff 2014).

Table 2: Potentially groundwater dependent plant species in the Fitzroy River Valley (adapted from Pusey and Kath, 2015)

Species	Habit
*Abrus precatorius**	Climber
Alternanthera nana	Herb
Atalaya hemiglauca	Small tree/shrub
*Atalaya variifolia**	Tree
*Bauhinia cunninghamii**	Tree
Barringtonia acutangula	Tree
*Caesalpinia major**	Tall shrub
*Capparis lasiantha**	Climber
*Celtis philippensis**	Tree
*Clerodendrum floribundum var. ovatum**	Tree
Corymbia bella	Tree
Cyperus conicus	Sedge
Eucalyptus camaldulensis	Tree
*Exocarpos latifolius**	Tree
*Flueggea virosa**	Tall shrub
*Grewia breviflora**	Tree
*Gyrocarpus americanus**	Tree
*Helicteres rhynchocarpa**	Shrub
*Hypoestes floribunda var. varia**	Shrub
*Jasmin didymium**	Climber
*Lophostemon grandiflorus**	Tree
Melaleuca alsophila	Tree
Melaleuca argentea	Tree
Melaleuca dealbata	Tree
Melaleuca nervosa	Tree
Melaleuca nervosa	Small tree
Melaleuca viridiflora	Tree
*Mimusops elengi**	Tree
*Operculina aequisepala**	Climber
*Opilia amentacea**	Climber
Pandanus spiralis	Shrub
Pandanus aquaticus?	NA
*Planchonia careya**	Shrub
Schoenoplectus subulatus	Sedge
*Sersalisia sericea**	Tree
*Terminalia ferdinandiana**	Tree
*Terminalia petiolaris**	Tree
*Tinospora smilacina**	Climber
*Tylophora cinerascens**	Climber
Typha domingensis	Sedge

* indicates species associated with vine thickets.

The depth to groundwater tends to be predictive of the conditions of *Eucalyptus camaldulensis* trees (Colloff 2014). Studies of *Eucalyptus camaldulensis* trees in the Barmah Forest of Victoria, which form the largest *Eucalyptus camaldulensis* forests in the world (Parks Victoria 2016), suggest that a sharp decline in the health of the trees occurs below a threshold depth of 10 m to 12 m, (England *et al*. 2009, cited in Colloff 2014). A more relevant study by Pusey and Kath (2015) associated with the Fitzroy River valley in the Kimberley region of Western Australia, indicates that *Eucalyptus camaldulensis* has a preference for depths to the water table of between 2 m and 5 m, and that at these shallow depths the species is likely to be highly groundwater dependent. A more generalised consideration of depths to groundwater in the Fitzroy River Valley, taking into account the range of riparian species present, indicates that at depths to groundwater of less than 10 m, riparian and floodplain vegetation is likely to be groundwater dependent. Pusey and Kath (2015) caution extrapolating the latter figure beyond the Pilbara region without undertaking specific tests within the area of interest. O'Grady *et al*. (2010) also state that *Eucalyptus camaldulensis,* on the Chowilla floodplain on the Murray River, relies on groundwater for maintenance water requirements in between flooding events.

***Melaleuca viridiflora* (Broadleaf Paperbark)**

Melaleuca viridiflora is a shrub or tree (2.5 m to 20 m) with papery white, light brown or grey bark. *Melaleuca* viridiflora occurs in woodlands, swamps and streams in a range of soil types in the Kimberley region of Western Australia, Northern Territory, Queensland and Papua New Guinea (DPaW 2016, Brophy *et al*. 2013). *Melaleuca viridiflora* is tolerant of a wide range of soil salinities, prefers seasonally saturated soils, and readily coppices (Tweddell 1982, cited in Skull and Congdon 2008). Specifically, in the Kimberley, it is very common on river-washed sand banks, fringing freshwater pools and seasonal claypans (Kenneally *et al*. 1996)

Melaleuca alsophila

Melaleuca alsophila is a shrub or tree (2 m to 15 m) with white, pale grey or brownish-white papery bark. *Melaleuca alsophila* occurs in the Kimberley region of Western Australia and the adjacent region of the Northern Territory, and the northern coastal region of the Great Sandy Desert region of Western Australia (DPaW 2016, Brophy *et al*. 2013). *Melaleuca alsophila* has been recorded growing in woodlands, along water courses, swamps and saline habitats in sandy soils (DPaW 2016).

5.5 Vegetation of the Thunderbird Project Area

The Thunderbird Project Area has been the subject of four flora and vegetation surveys since 2012. Three flora and vegetation surveys were completed by Ecologia between 2012 and 2015. Mattiske (2016) completed a fourth flora and vegetation survey of the Thunderbird Project Area in June 2016.

Mattiske (2016) mapped 15 vegetation communities across the Thunderbird Project Area. This was based on a total of 243 vegetation survey quadrats (156 quadrats established by Mattiske and 87 quadrats established by Ecologia) from the combined four surveys (Figure 2).

The majority of the Thunderbird Project Area consisted of pindan vegetation (low sparse eucalypt woodlands over *Acacia tumida* shrubland over *Triodia*| *Chrysopogon* grasslands), and accounted for approximately 86% of the surveyed area. The other main communities mapped were associated with the drainage channels (*Melaleuca viridiflora*| *Melaleuca alsophila* woodland) and rocky hills within the Thunderbird Project Area. Overall, the vegetation communities mapped and species recorded in the Thunderbird Project Area were consistent with the historical mapping of John Beard (1979) and the more recent land systems mapping of Kimberley by Schoknecht and Payne (2010). Of the 15 defined and mapped vegetation communities, six had an association with drainage areas. These were the W1, W2, W3, W10, W12 and W14 communities (Mattiske 2016). Communities W2, W3, W10 and W12 were either low lying areas which were likely to experience seasonal inundation to some extent, and which occurred in patches across the Thunderbird Project Area, or were associated with landforms adjacent to headwaters of the Fraser River in the northern part of the Thunderbird Project Area. These communities were not defined by the presence of *Eucalyptus camaldulensis*, *Melaleuca alsophila* or *Melaleuca viridiflora* (Mattiske 2016).

Of particular interest, from the perspective of potential GDEs, were the W1 and W14 vegetation communities. The W1 vegetation community was defined as: "*Melaleuca viridiflora*, *Melaleuca alsophila* and *Eucalyptus tectifica* low sparse woodland over *Bauhinia cunninghamii*, *Carissa lanceolata* and *Atalaya hemiglauca* tall sparse shrubland over *Ectrosia schultzii*, *Eriachne sulcata* and *Cyperus conicus* low sparse grassland on grey-white to light brown sandy soils in drainage channels and low lying drainage areas". The W14 vegetation community was defined as: "*Eucalyptus camaldulensis* mid open woodland over *Melaleuca viridiflora, Melaleuca alsophila* and *Bauhinia cunninghamii* mid sparse shrubland over *Ectrosia schultzii*, *Eriachne sulcata* and *Fimbristylis littoralis* low sparse grassland on grey to light brown sandy clay soils in drainage channels".

The W1 vegetation community was restricted in its distribution within the Thunderbird Project Area (Figure 2). Small areas of the W1 community intrude into the most northern parts of the Thunderbird Project Area, and are components of the headwaters of the Fraser River. One small area, a soak, is located approximately 3 km south-east of the proposed mining area (Figure 2). The largest single area of the W1 community is in the southern section of the Thunderbird Project Area and is an upstream section of the Fraser River South (Figure 2). The W14 vegetation community occupies the approximately eastern 3 km of the Fraser River South. Twelve vegetation survey quadrats were established in the W1 vegetation community and two in the W14 vegetation community during the June and November 2016 surveys. Only the W14 vegetation community contained *Eucalyptus camaldulensis*.

6. FIELD SURVEY RESULTS

6.1 Soak

The soak area (Figure 2) was traversed on foot to determine if any perennial flora not recorded by either Ecologia (2014) or Mattiske (2016) were present. No additional perennial flora taxa were recorded. During the time of the survey completed by Ecologia in April 2013 (Ecologia 2014), free surface water was present in the soak (Plate 1). This survey was completed in April 2013, after the main rainfall season in the Kimberley region. Rainfall in the four months preceding this survey totalled 742 mm, representing 124% of the long term average (BOM 2016a). At the time of both the June 2016 flora and vegetation survey (Plates 2 and 3) and the November 2016 survey (Plates 4 and 5), the soak area was dry, with rainfall amounting to 34 mm in the four months preceding the November 2016 survey. Compared to the June 2016 site visit, the dominant species present, namely *Melaleuca alsophila* and *Melaleuca viridiflora*, were in a very stressed condition. Leaves on all individual specimens were desiccated and brown to reddish brown in colour. This indicated that these plants within the soak were severely water restricted, and unlikely to have access to ground water.

Plate 1: Soak, April 2013 (Source: Ecologia 2014)

Plate 2: Soak (western periphery), June 25th 2016

Plate 3: Soak (central area), June 25th 2016

Plate 4: Soak (western periphery), November 22nd 2016

Plate 5: Soak (central area), November 22nd 2016

6.2 Distribution of *Eucalyptus camaldulensis* along the Fraser River South

The length of the Fraser River South, within the Thunderbird Project Area, was traversed on foot to determine the distribution of *Eucalyptus camaldulensis.* *Eucalyptus camaldulensis* was first recorded at 504443 mE, 8065950 mN (GDA94), which is 1.1 km due west of the main access road to Mt Jowlaenga Station, and 1.2 km upstream along the river channel from its intersection with the main access road to Mt Jowlaenga Station, the point at which the Fraser River South starts to become wider and deeper. The river channel becomes more incised east of this point, and the banks steeper. To the west, the river channel becomes broader and less defined, with a wider flood plain area. Mature *Eucalyptus camaldulensis* trees were sparsely scattered along the river channel for the first 350 m from the location of the first recorded specimen, after which the trees became more frequent in number and more evenly distributed along the river channel and its banks. The locations of *Eucalyptus camaldulensis* trees along the Fraser River South are shown in Figure 5. The tree locations shown in Figure 5 do not include juvenile trees (generally being less than 2 m high or having a DBH < 1 cm). *Eucalyptus camaldulensis* grew in a range of soils along the course of the river, ranging from sandy to sandy clays soils which were brown to grey brown in colour. *Eucalyptus camaldulensis* trees were often found to be growing in close association with a laterized rocky mantle exposed on the banks of the Fraser River South (Plate 6), particularly in the western portion of their distribution, to the west of the main access road to Mt Jowlaenga Station. The soils along the length of the Fraser River South were dry in the western (upstream) section, grading to slightly moist towards the boundary of the Thunderbird Project Area. There was no free surface water present in the Fraser River South either within the Thunderbird Project Area or within 200 m to the east of the boundary.

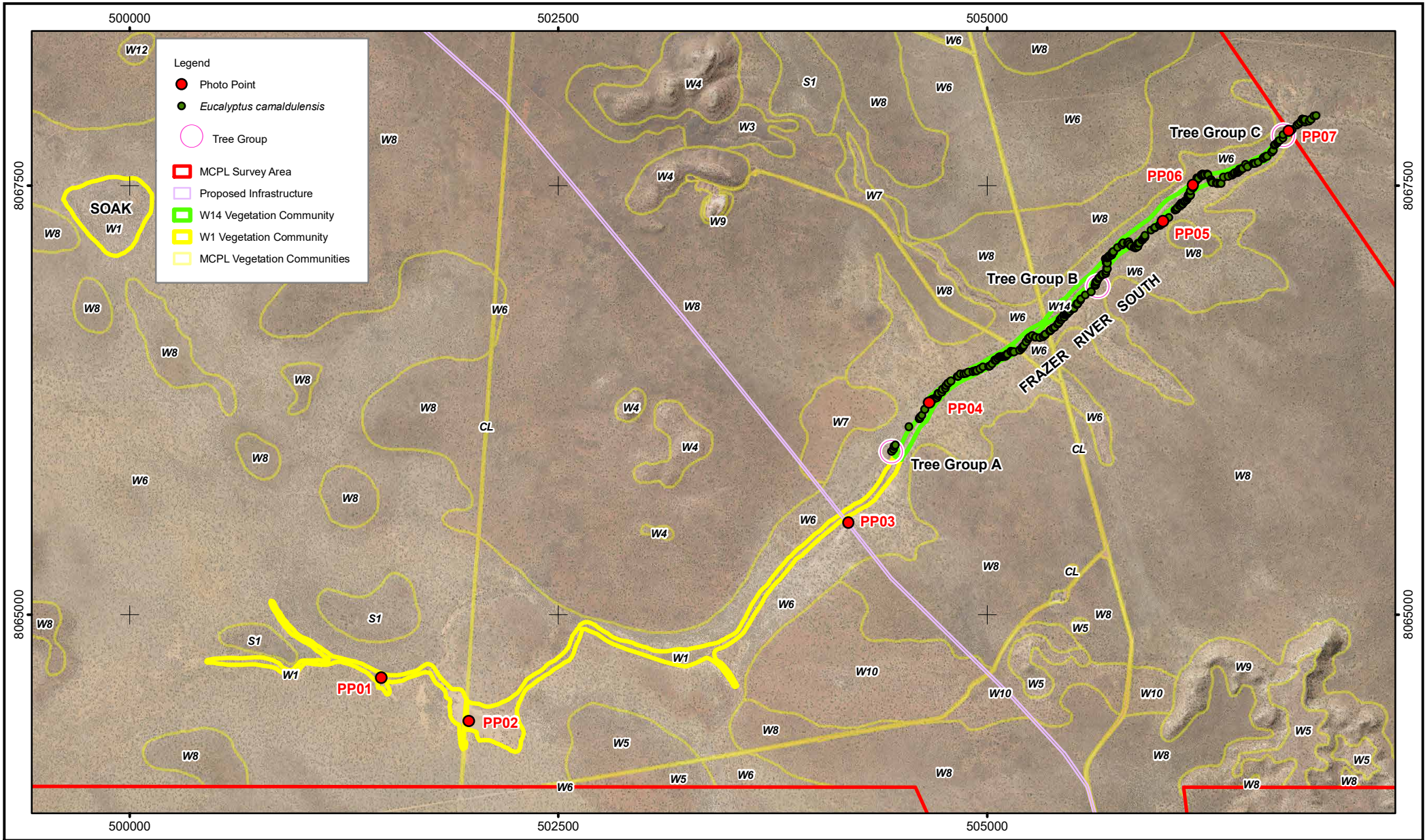
A series of photographs taken along the length of the Fraser River South, to show the vegetation present, are presented as Appendix A. The locations of each photograph are indicated in Figure 5.

Plate 6: *Eucalyptus camaldulensis* growing in exposed rocky mantle on the edge of the Fraser River South (location 504660 mE, 8066232 mN, GDA94, zone 51)

6.3 Size and Health of *Eucalyptus camaldulensis* trees in the Fraser River South

Three groups of consecutive trees, each comprising 15 *Eucalyptus camaldulensis* trees, were assessed in terms of their height, DBH and health. One group of trees was located at the origin of *Eucalyptus camaldulensis* in the Fraser River South (group A), and the other two, 1.5 km (group B) and 3.0 km (group C) (Figure 5) respectively downstream from the origin, to avoid any bias in tree selection. The results of these measurements are summarised graphically in Figures 6, 7, and 8.

A one-way ANOVA was used to determine if there was any statistically significant difference between the three groups of trees, with respect to their height, DBH and health measurements. There was no statistically significant difference, in terms of tree height and tree health, between the group means as determined by one-way ANOVA ($F(2,65)=1.241$, $p=0.296$) and ($F(2,65)=1.119$, $p=0.333$) respectively. There was a statistically significant difference, in terms of tree DBH, between the group means as determined by a one-way ANOVA ($F(2,65)=4.848$, $p=0.011$). A post hoc Tukey test, using the tree DBH data, demonstrated that tree group A and C differed significantly ($p=0.0101$) and that tree groups A and B differed statistically at the 90% confidence level ($p=.0654$).



Notes:
Vegetation: MCPL
Site Layout: MBS
Aerial Photography Sheffield Resources

Sheet Location:

Client: Sheffield Resources Limited

N

0 200 400 600 800m
Scale: 1:30,000
MGA94 (Zone 50)

CAD Ref: a2409_f51_02
Date: Dec 2016 | Rev: B | A4

Mattiske Consulting Pty Ltd
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Thunderbird Mineral Sands Project
Distribution of *Eucalyptus camaldulensis* along the Fraser River South

Figure: 5

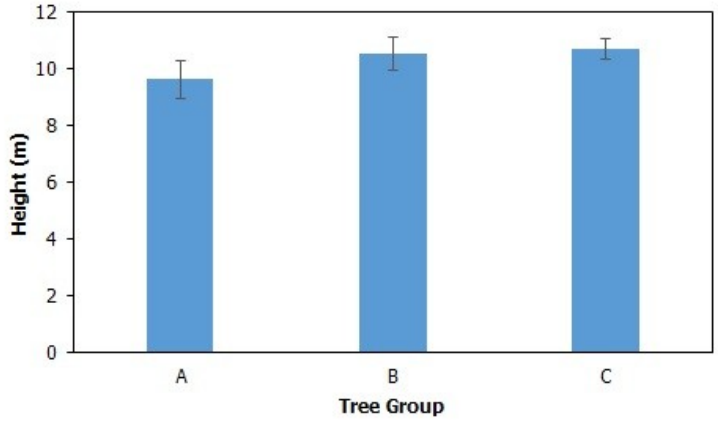

Figure 6: Average height ± s.e.m of adult *Eucalyptus camaldulensis* trees growing along the Fraser River South located at the origin (group A), at 1.5 km (group B) and 3.0 km (group C) downstream from the origin

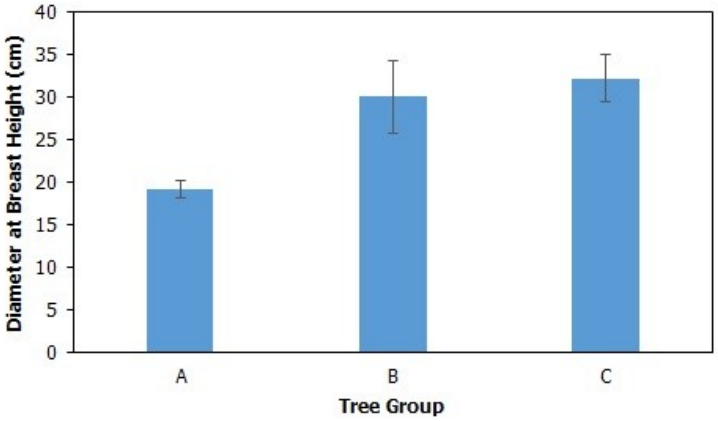

Figure 7: Average DBH ± s.e.m of adult *Eucalyptus camaldulensis* trees growing along the Fraser River South located at the origin (group A), at 1.5 km (group B) and 3.0 km (group C) downstream from the origin

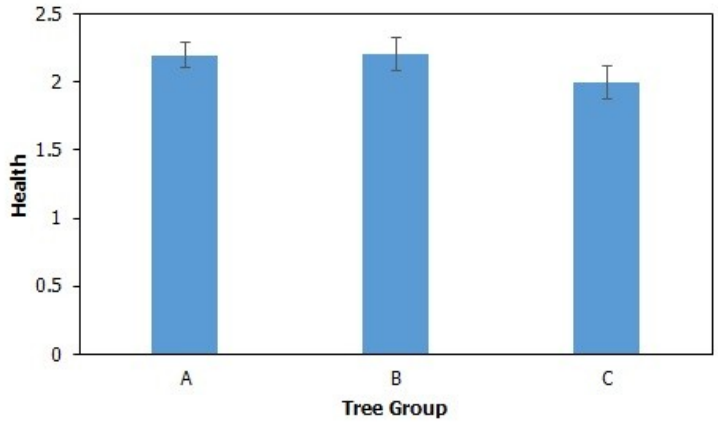

Figure 8: Average health ± s.e.m of adult *Eucalyptus camaldulensis* trees growing along the Fraser River South located at the origin (group A), at 1.5 km (group B) and 3.0 km (group C) downstream from the origin. Health ranks: 1 = very stressed; 2 = stressed; 3 = slightly stressed; 4 = healthy

7. DISCUSSION

Mattiske Consulting Pty Ltd was commissioned in November 2016 to review the vegetation within the Thunderbird Project Area to determine if any of the vegetation communities defined could be classified as a groundwater dependant ecosystem (GDE). The previous survey by Mattiske (2016) defined six vegetation communities within the Thunderbird Project Area which either associated with a drainage channel of were in a location likely to be associated with seasonal inundation.

The present survey focused on two of these vegetation communities, the W1 and W14 vegetation communities, on the basis of their species assemblage and topographical location. These vegetation communities were primarily associated with drainage channels. The other four vegetation communities (W2, W3, W10, and W12) were situated in areas with a flat topography and did not comprise species assemblages which were considered likely to support GDEs. The W1 and W14 vegetation communities, defined by Mattiske (2016), were assessed for their potential to contain GDEs. Within the Thunderbird Project Area, the W1 vegetation community occupied 0.68% of the project area and the W14 vegetation community occupied 0.07% of the project area. The W1 vegetation community was associated with three identifiable features within the Thunderbird Project Area. These were:

1. minor drainage channel areas intersecting the extreme north of the Thunderbird Project Area, and which are likely form components of the headwaters of the Fraser River;
2. a western section of the Fraser River South which traverses the southern section of the Thunderbird Project Area, approximately 7 km south-east of the proposed impact area; and
3. an area identified as a soak, located approximately 3 km south of the proposed impact area.

The W14 vegetation community was associated with the eastern approximately 3 km of the Fraser River South within the Thunderbird Project Area.

A desktop review of the Thunderbird Project Area indicated that the small sections of the W1 vegetation community in the northern portion of the Thunderbird Project Area (Figure 2), which comprise headwaters of the Fraser River, do not contain vegetation likely to be groundwater dependent.

A small, intermittent soak area (Figure 2), located approximately 3 km to the south of the proposed mining area is, on the basis of both the desktop assessment and field reconnaissance survey, unlikely to contain vegetation which is dependent on groundwater. The desktop review of the topography about the soak indicates that the soak is situated in a relatively low lying region of the landscape, and is a local low lying drainage area. Whilst the soak contains two *Melaleuca* species which tend to favour moister sites (DPaW 2016, Pusey and Kath 2015), namely *Melaleuca viridiflora* and *Melaleuca alsophila*, both species were recorded at numerous survey quadrats not associated with drainage channels (Ecologia 2015, Mattiske 2016). *Melaleuca viridiflora* was recorded as being associated with six of the 15 vegetation communities defined by Mattiske (2016). *Melaleuca alsophila* was recorded as being associated with five of the 15 vegetation communities defined by Mattiske (2016). Both species occurred as occasional species within the Pindan vegetation, rather than being restricted in distribution to drainage channels. Additionally, the very dry nature of the soak area (Plates 2 to 5) and the poor

health of the vegetation in general, and that of both *Melaleuca viridiflora* and *Melaleuca alsophila* specifically, tends to support the conclusion that these species are not accessing groundwater. This is further supported by interpreted groundwater levels presented in Rockwater (2016), which indicates that the depth to groundwater in this region is approximately 18 m below the surface.

Ecologia (2014) reported that 'a 14.46 ha section of vegetation unit MaMvEtCpCc (*Melaleuca alsophila* or *Melaleuca viridiflora* and *Eucalyptus tectifica* low, open woodland, over Chry*sopogon pallidus* sparse tussock grassland and *Cyperus conicus* sparse sedgeland) closely resembles vegetation associated with a Priority Ecological Community (PEC) at Lolly Well Springs, 40 km to the north-west'. A review of the topography of the area demonstrates that the *Melaleuca viridiflora* community area is low lying relative to the surrounding land. Irrespective of whether or not this isolated *Melaleuca viridiflora*/*Eucalyptus tectifica*/*Cyperus conicus* community was connected to the main drainage channel nearby at some time in the past, it is nothing more than a low lying section of land which acts as a drainage area during periods of rainfall, thus maintaining conditions which continue to provide suitable habitat for the species present.

Based on the desktop assessment, the W14 section of the Fraser River South (Figure 2) was considered to have the greatest prospect of containing a GDE. *Eucalyptus camaldulensis* was recorded along the eastern section of the Fraser River South, within the Thunderbird Project Area, where the river channel became wider and deeper. The Reeves land system (Schoknecht and Payne 2010) traverses this portion of the Thunderbird Project Area. One of its land units consists of channels supporting fringing woodlands of *Eucalyptus camaldulensis* and *Melaleuca* spp. communities. The major portion of the Thunderbird Project Area falls within the Fraser and Wanganut land systems (Schoknecht and Payne 2010). The vegetation recorded during both the present and previous four surveys (Ecologia 2012, 2014, 2015; Mattiske 2016) recorded vegetation on soils consistent with these land systems.

Whilst digital data relating to depths to groundwater was not available, there is a high degree of conformity between the interpolated shallow depth to groundwater (2 to 5 m) shown in Figure 4, which occurs in the eastern section of the Fraser River South, and the distribution of *Eucalyptus camaldulensis* (Figure 5) along the Fraser River South, within the Thunderbird Project Area. Colloff (2014) and Pusey and Kath (2015) state that *Eucalyptus camaldulensis* is a species with groundwater dependence. In the Kimberley Region, in the nearby Fitzroy River Valley, Pusey and Kath (2015) state that *Eucalyptus camaldulensis* had a preferred depth to groundwater of 2 to 5 m, and that at these depths the species was highly groundwater dependent. A sharp decline in the health of *Eucalyptus camaldulensis*, below a threshold depth of 10 m to 12 m is likely to occur (England et al. 2009, cited in Colloff 2014). The data from the Fitzroy River valley study (Pusey and Kath 2015) is highly relevant, and given the modelled depths to groundwater, particularly along the eastern portion of the Fraser River South, it is likely that this portion of the Fraser River South, defined by Mattiske (2016) as the W14 vegetation community, can be classed as being a GDE. Groundwater drawdown of up to about 2 m is predicted in a gradual process over approximately 32 years from Year 15 until the end of mine life where it will rapidly rebound following cessation of dewatering at closure (Rockwater 2016). Based on this modelling, mine dewatering is unlikely to have long term impacts on the vegetation in this section of the Fraser River

South as interpreted groundwater depth will not fall below 10 m. The western portion of the Fraser River South, which was defined by Mattiske (2016) as the W1 vegetation community, is not considered to contain groundwater dependent vegetation. *Eucalyptus camaldulensis* is absent from this section of the drainage channel. Given the preferred depth to groundwater for this species (Pusey and Kath 2015) and the hydrological modelling of Rockwater (2016) which indicate depths to groundwater in this western section of the Fraser River South to be greater than 10 m, the absence of *Eucalyptus camaldulensis* from the western section of the Fraser River South is consistent with the preferred habitat, in terms of depth to groundwater, for this species. No other vegetation communities within the Thunderbird survey area are considered to have groundwater dependence.

During the present field survey, it was noted that the Fraser River South was dry in its western section within the Thunderbird Project Area. However, in the eastern section, particularly near the boundary of the Thunderbird Project Area, the river bed soils were moist. There had been some recent rainfall in the vicinity of the Thunderbird Project Area, as evidenced by occasional puddles on the main access track into Mt Jowlaenga Station. Due to the lack of local borefield data, it is not possible to draw accurate conclusions as to whether the soil moisture observed in the eastern section of the Fraser River South was associated with surface water expression related to shallow depth to groundwater, or whether the soil moisture observed was a consequence of the recent rainfall. The depth to groundwater is modelled to be at its shallowest in the Fraser River South valley, most notably in the eastern portion of the valley (Rockwater 2016). Given the very dry nature of the soils in the western section of the Fraser River South (and generally in other parts of the Thunderbird Project Area traversed during the survey), the degree of soil moisture observed in the eastern section of the Fraser River South, and the interpolated groundwater levels within the Thunderbird Project Area (Rockwater 2016), it is possible that the levels of soil moisture observed in the eastern section of the Fraser River South, may be associated with the proximity of groundwater to the surface. This would be consistent with both the distribution of *Eucalyptus camaldulensis* within the Fraser River South and the groundwater modelling of Rockwater (2016), notwithstanding the stated uncertainties with the latter.

The preliminary assessment of the height, DBH and health of mature *Eucalyptus camaldulensis* trees at three locations along the Fraser River South resulted in the conclusion that there was no statistical difference, in terms of tree height and health along the section of the Fraser River South within the Thunderbird Project Area. Average tree health was rated as being between slight stressed and stressed (Figure 8). Whilst the foliage of the trees was of a good colour and leaves did not appear to show signs of desiccation, there was a modest level of insect damage. It is also likely, given that the survey was completed at the end of the dry season, that the trees were sampled at the time of year in which they were most likely to be stressed. The statistical analysis of the *Eucalyptus camaldulensis* DBH data revealed that there was a significant difference in tree DBH between the trees at the upstream location (origin of *Eucalyptus camaldulensis*) and those downstream, with the downstream specimens having a significantly greater DBH. Notwithstanding the limitations expressed in the hydrological report (Rockwater 2016) with respect to the depth to groundwater modelling, it is likely that the western limit of *Eucalyptus camaldulensis* is related to the depth to groundwater becoming less favourable to the persistence of this species. The significant difference in the DBH of trees in this region and those

growing downstream, where there is a interpolated shallower depth to groundwater may be related to the availability of water.

8. LIST OF PERSONNEL

The following Mattiske Consulting Pty Ltd personnel were involved in this project:

Name	Position	Survey Involvement	Flora Collection Permit
Dr E.M. Mattiske	Managing Director & Principal Ecologist	planning, management & reporting	N/A
Mr D. Angus	Senior Botanist	fieldwork, data analysis, report preparation	SL011706
Ms J. Li (MBS Environmental)	Environmental Scientist	fieldwork	N/A

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APPENDIX A: PHOTOGRAPHIC RECORD OF FRASER RIVER SOUTH

Photo 1: Photo point 1 (501468 mE, 8064631 mN, GDA94, zone 51, facing east)
W1 vegetation community.

Photo 2: Photo point 2 (501978 mE, 8064379 mN, GDA94, zone 51, facing east)
W1 vegetation community.

APPENDIX A: PHOTOGRAPHIC RECORD OF FRASER RIVER SOUTH

Photo 3: Photo point 3 (504192 mE, 8065536 mN, GDA94, zone 51, facing east)
W1 vegetation community.

Photo 4: Photo point 4 (504662 mE, 8066235 mN, GDA94, zone 51, facing east, showing southern edge of bank).
W14 vegetation community.

APPENDIX A: PHOTOGRAPHIC RECORD OF FRASER RIVER SOUTH

Photo 5: Photo point 5 (506025 mE, 8067293 mN, GDA94, zone 51, facing east)
W14 vegetation community.

Photo 6: Photo point 6 (506200 mE, mN, 8067503 GDA94, zone 51, facing east)
W14 vegetation community.

APPENDIX A: PHOTOGRAPHIC RECORD OF FRASER RIVER SOUTH

Photo 7: Photo point 7 (506760 mE, 8067819 mN, GDA94, zone 51, boundary of Thunderbird Project Area facing east)
W14 vegetation community.