Bennelongia Environmental Consultants

Lake Disappointment Subterranean Fauna Desktop Assessment

Prepared for:

Reward Minerals Ltd

June 2016

Final Report

Short-Range Endemics | Subterranean Fauna

Waterbirds | Wetlands

Lake Disappointment Subterranean Fauna Desktop Assessment

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EXECUTIVE SUMMARY

Lake Disappointment is a playa lake in the northern Little Sandy Desert (Trainor IBRA subregion), 138 km south of Telfer and 285 km east of Newman. Reward Minerals Limited is currently scoping the feasibility of mining potash from Lake Disappointment. Mining is expected to continue for 20 years. Groundwater will be required to support the mining process and so Reward is investigating options for a future borefield.

While the location of the borefield is still being determined, a desktop assessment has been undertaken to characterise the subterranean fauna community in the vicinity of the Project. It is considered that the only Project-related activity likely to affect subterranean fauna is groundwater drawdown. Groundwater drawdown has a minimal impact on troglofauna and thus these communities are not expected to be impacted by the project. However, stygofauna that inhabit the aquifers proposed for pumping may be detrimentally affected by groundwater drawdown.

To assess the likelihood of stygofauna occurring in the Project area, a search of the Western Australian Museum was completed for a search area of 100 by 100 km around the Project. This search retrieved no results and thus the search area was extended to the nearest known communities for stygofauna. These communities are located 130-240 km from Lake Disappointment and are rich to moderately rich. The project surveys or studies associated with these communities were:

- The Kintyre Project area was surveyed for stygofauna in 2012 and recorded 15 species of stygofauna from seven higher level groups,
- Telfer gold mine was monitored for stygofauna over a 10 year period and a total of 39 species of stygofauna were recorded.
- The FerrAus Pilbara Project at Davidson Creek yielded 23 species of stygofauna.
- A selection of 30 wells sampled on the eastern boundary of the Pilbara during the Pilbara Biodiversity Survey yielded 56 species.

Overall crustaceans were identified to be the most common group of stygofauna in the vicinity of the Project area, with at least 75 species recorded across all surveys reviewed. This included 17 ostracod species, 36 copepods, five syncarids, 13 amphipods and three isopods. Nineteen species of worms were identified, followed by four insects (although these may not all be stygofaunal), three rotifers, one snail and one nematode. This composition is typical of stygofaunal communities of the neighbouring Pilbara bioregion.

Lake Disappointment lies within a major palaeochannel, which contains some areas of calcrete. Calcretes have previously been shown to host rich stygofaunal communities in areas such as the Yilgarn and Pilbara and this may also be indicative of a potentially rich stygofauna community in the aquifers around Lake Disappointment. Furthermore, it is likely that some suitable habitat for stygofauna will be present in whatever aquifers are selected to supply water unless they are deep aquifers with limited hydraulic connectivity to the surface. In this case, pumping of deep aquifers is likely to lead to drawdown in overlying, shallower aquifers that may support stygofauna. High salinity levels are likely to reduce the number of stygofauna species present but may not prevent the occurrence of stygofauna.

A Level 1 stygofauna survey is recommended to characterise the stygofauna community in within potential borefield areas for the following reasons:

- There is a lack of knowledge of stygofauna communities in the vicinity of Lake Disappointment, with the Western Australian Museum database search results returning no results;
- Further afield, rich to moderately rich stygofauna communities have been recorded;
- There is some calcrete in the vicinity of Lake Disappoint and calcrete aquifers have previously been show to host rich stygofauna communities; and
- The project may impact on any stygofauna communities present through groundwater drawdown and the likely extent of this impact cannot be assessed with the current level of information.

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1. INTRODUCTION

Lake Disappointment is a playa lake located in the northern Little Sandy Desert, 138 km south of Telfer and 285 km east of Newman (**Error! Reference source not found.** and 2). Reward Minerals Limited (Reward) is currently scoping the feasibility of mining potash from Lake Disappointment (the Project), which has an expected life of 20 years. The project proposes to extract potash from lake brine using infrastructure (trenches and/or production bores) located in the north-western part of the playa and on the adjacent shoreline and dune systems. Water will be required to support the production of potash, with groundwater being the only readily available source. Therefore, it is proposed to draw groundwater from a borefield approximately 20 km north of Lake Disappointment (Figure 3). A desktop assessment has been undertaken to characterise the stygofauna community in the vicinity of the borefield (and wider Project area) as a first step in assessing the possible impacts of the Project on subterranean fauna.

The term subterranean fauna refers to two types of animals – stygofauna and troglofauna – that live underground. Stygofauna are aquatic and live in groundwater, while troglofauna are terrestrial species adapted to life between the top soil layers and the watertable. They require high humidity. Both stygofauna and troglofauna have some obvious adaptations to subterranean life that include lack of eyes and little pigmentation and, usually, elongation of limbs and sensory processes.

The arid western half of Australia supports very rich and diverse communities of invertebrate subterranean fauna (Guzik *et al*. 2010). There are very few vertebrate subterranean species in Australia (Aplin 1998; Whitely 1945). Invertebrate stygofauna communities of alluvial and calcrete areas in the Pilbara (Halse et al. 2014) and Yilgarn (Humphreys 2008) are particularly rich, especially in palaeoriver channels. Groundwater salinity in these systems varies from mostly fresh in the Pilbara to brackish or saline in most Yilgarn calcretes, but some stygofauna species occur in hypersaline groundwater (Outback Ecology 2012). Lake Disappointment and the proposed Project borefield lie within the Disappointment Palaeoriver and this old river course may potentially provide suitable habitat for subterranean fauna. The occurrence of subterranean fauna species is relevant to environmental impact assessment because of the highly restricted ranges of some species (Halse and Pearson 2014; Halse *et al*. 2014), which makes them potentially particularly susceptible to habitat removal or habitat alterations. The groundwater abstraction that would occur in any borefield installed by Reward must cause some alteration of subsurface hydrology and this may affect the extent of habitat for any stygofauna species present.

This report provides a summary of the available regional data on subterranean fauna communities in the broad vicinity of Lake Disappointment, with an emphasis on stygofauna. The report does not attempt to assess the likely impact of the borefield and Project on subterranean fauna other than through some general comments on subterranean fauna values.

2. CONSERVATION FRAMEWORK

Protection of native flora and fauna in Western Australia is provided at both state and federal levels. At the federal level, a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places is provided via the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

At the state level, native flora and fauna are protected under the *Wildlife Conservation Act 1950* (in particular Section 14, pp. 8-9). The highest level of protection is given to Schedule 1 species that are considered rare, likely to become extinct, or otherwise in need of special protection. The Department of Parks and Wildlife (DPaW) also maintains a list of priority fauna species that are of conservation importance but, for various reasons, do not meet the criteria for listing as threatened. The current list from November 2015 includes 113 terrestrial invertebrate species: seven insects, 26 arachnids, 22 crustaceans, 22 millipedes, one bristle worm and 35 molluscs (DPaW 2015).

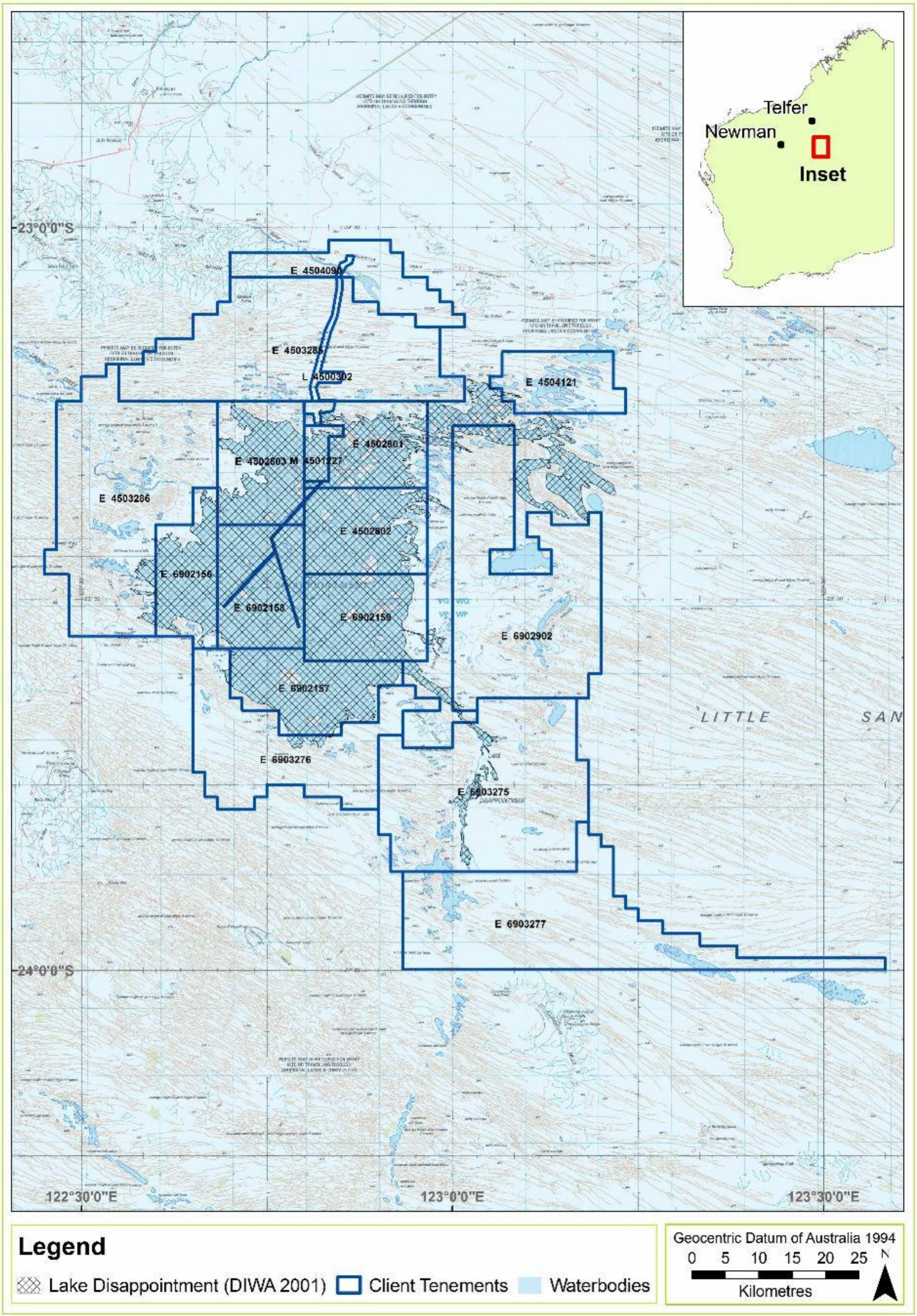

Figure 1. Location of Lake Disappointment and Reward's tenements at the lake.

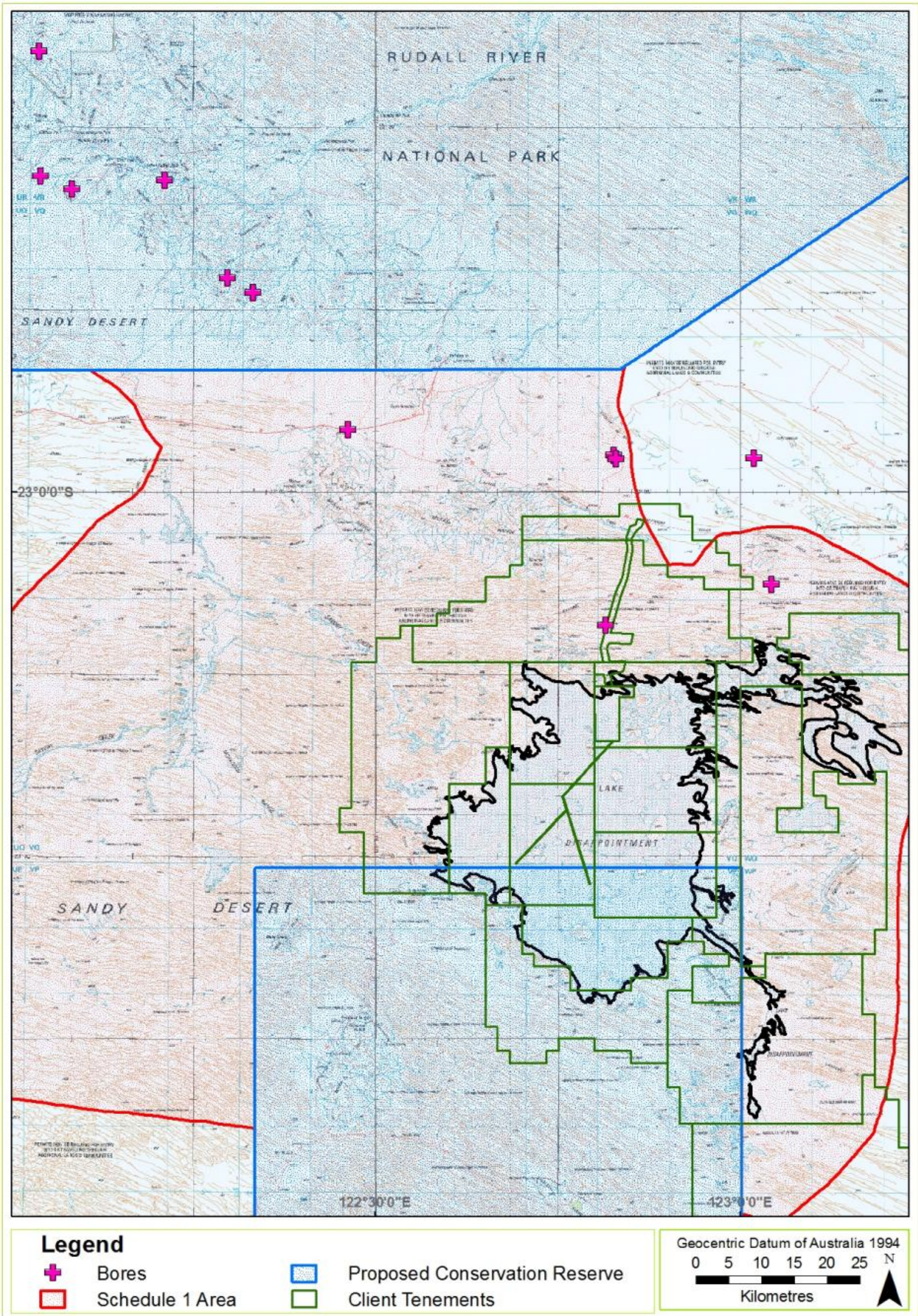

Figure 2. Regional map of Lake Disappointment showing the Proposed Conservation Reserve and extent of the Schedule 1 area.

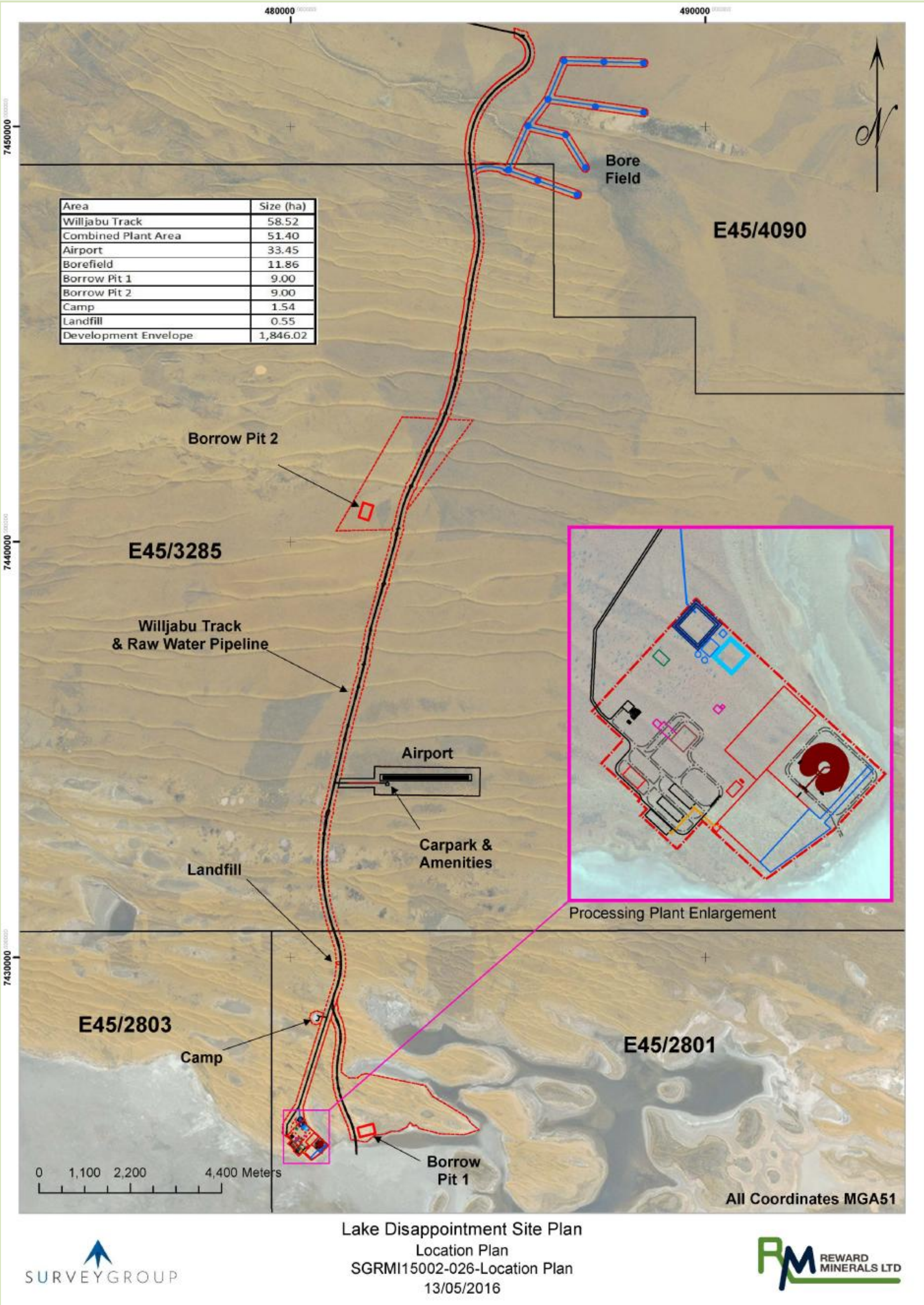

Figure 3. Proposed locations of processing plant and borefield at the Project.

In addition to protection mechanisms for species, the EPBC Act lists Threatened Ecological Communities (TECs) for protection. The WC Act has no provision for listing TECs but the Minister for the Environment has endorsed a list of TECs. Other communities of potential conservation concern, but for which there is little information, are listed informally as Priority Ecological Communities (PECs).

The Western Australian *Environmental Protection Act 1986* considers the conservation of flora and fauna in relation to proposed developments. Three principles outlined in Section 4A of the Act are relevant:

- *The Precautionary Principle*
  Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.
- *The Principle of Intergenerational Equity*
  The present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.
- *The Principle of the Conservation of Biological Diversity and Ecological Integrity*
  The conservation of biological diversity and ecological integrity should be a fundamental consideration.

The Environmental Protection Authority (EPA) usually requires that risks to any subterranean fauna species ikely to be present are considered when assessing proposed mine developments because subterranean fauna have very small ranges. According to Eberhard *et al.* (2009), about 70% of Pilbara stygofauna species are likely to be short range endemic (SRE) species, with many of them having much smaller ranges than Harvey's criterion for SRE status of 10,000 km^2. Troglofauna species appear to have even smaller ranges than stygofauna (Halse and Pearson 2014; Lamoreux 2004). Therefore, it is likely that most troglofauna species are SREs, with some species perhaps having linear ranges of only a few kilometres. Species with small ranges are vulnerable to extinction through habitat loss and other environmental changes (Fontaine *et al.* 2007; Ponder and Colgan 2002), and are therefore a focus in conservation and environmental impact assessments (EIAs).

3. SUBTERRANEAN FAUNA

Little is known about the stygofauna communities in the Little Sandy Desert although the stygofauna and troglofauna communities of the neighbouring Pilbara region are considered to be of global significance in terms of richness and diversity (Guzik *et al.* 2010; Halse and Pearson 2014; Halse *et al.* 2014)).

3.1. Troglofauna

There have not been any large-scale, general purpose surveys for troglofauna in Western Australia but many troglofauna surveys have been undertaken as part of environmental impact assessments in areas of mining development. Troglofauna have been collected frequently from mineralised iron formations (e.g. Biota 2006, Bennelongia 2008a, b, c; 2009 a, b), as well as from geologies such as calcrete and detrital deposits (Edward and Harvey 2008; Rio Tinto 2008). Troglofauna may occupy interstices, vugs, cavities and fissures within these geologies if relative humidity is close to saturation level (Howarth 1983). If no fissures or voids are present or the atmosphere within the spaces is similar to ambient surface humidity, troglofauna will not occur. Geologies that may limit the continuity of habitat, such as lenses of solid rock or clay, may limit the ranges of troglofauna species.

The invertebrate groups containing troglofauna include pseudoscorpions, spiders, palpigrads, schizomids, harvestmen, isopods, centipedes, millipedes, pauropods, symphylans, diplurans, silverfish, cockroaches, bugs, beetles and fungus-gnats. While diversity and abundance of troglofauna seem to be greatest in the Pilbara, this may reflect sampling intensity. High numbers of troglofauna have been recorded at individual locations in the Yilgarn (Bennelongia 2015) and troglofauna have been collected from the Kimberley (Harvey 2001), Cape Range (Harvey *et al.* 1993), Barrow Island (Biota 2005a), Mid-

West (ecologia Environment 2008), Yilgarn (Bennelongia 2011), South-West (Biota 2005b), and Nullarbor (Moore 1995).

3.2. Stygofauna

Stygofauna surveys of the Pilbara commenced in the 1990s (Humphreys 1999), followed by a rapid increase in knowledge during the last decade as a result of the Pilbara Biodiversity Survey (Halse *et al.* 2014). Calcrete and alluvium are typically considered to be the most productive habitats for stygofauna (Humphreys 2008), although in the Pilbara mafic volcanics may also support rich populations and stygofauna occur in moderate richness in banded iron formations (Halse *et al.* 2014). The Pilbara has been estimated to support between 500 and 550 stygofauna species, with the density of species being relatively uniform across the region (Eberhard *et al.* 2009), although this figure is likely to be a substantial underestimate. Stygofauna communities in the Pilbara are dominated by crustaceans with ostracods, copepods and amphipods contributing most of the animals and species (Eberhard *et al.* 2005; Halse *et al.* 2014).

Very rich stygofauna communities have also been documented from calcrete bodies in the palaeovalleys of the Yilgarn (Bennelongia 2015; MWH 2015) and endemism is generally high, with many species restricted to single calcrete bodies (Guzik etal.2008; Karanovic and Cooper 2011, 2012). The groups commonly occurring in calcrete with high species richness are copepod and syncarid crustaceans (Guzik *et al.* 2008; Karanovic and Cooper 2012; Karanovic *et al.* 2014) and worms, although research has focussed on amphipods and beetles (Leys et al. 2008; Bradford et al. 2013).

4. HABITAT ASSESSMENT

4.1. Geology and hydrogeology

The Little Sandy Desert, which largely corresponds with the Lake Disappointment catchment, is situated at the north-west corner of the Western Shield, and is underlain geologically by the Savory (geological) Basin and the Paterson Orogen, both containing Late Proterozoic rocks (Beard 2005). The Savory Basin mainly comprises gently east dipping, medium to coarse-grained sandstone and pebbly conglomerate. For the most part bedrock is poorly exposed and limited to marginal ranges such as the Robertson Range or to scattered rocky hills such as the Poisonbush Range. The Paterson Orogen consists of a belt of metamorphic and igneous rocks with a long and complex history of multiple deformation and metamorphism which form a series of low rocky ranges trending north-west to south-east (Beard 2005).

The Disappointment Palaeoriver, which contains Lake Disappointment itself, was suggested by Beard (2005) to be a palaeoriver that drained into Rudall River via Savory Creek. The connection to Rudall River was disrupted during the Miocene by one or more factors including tectonic movement, a slight uplift of ridges to the north and sinking of the lake basin. This resulted in Lake Disappointment becoming a terminal basin within an internally draining catchment with a hypersaline brine reservoir under the lake because of prolonged concentration by evaporation (Pendragon 2014).

Little detailed information on the hydrogeology of the Disappointment Palaeoriver, or the surrounding area, is available.

4.2. Habitat Requirements for Troglofauna

The occurrence of troglofauna is dependent on the existence of suitable geology, humidity and energy sources. If no fissures or voids are present below ground, it is unlikely that troglofauna will be present. Similarly, relative humidity must be close to saturation and animals must have a food source. The most likely food source is carbon input from the surface during high intensity rainfall events (Humphreys 1991; Simon *et al.* 2007)).

If suitable habitat is present in the form of subterranean spaces, the pattern of their occurrence will largely determine the abundance and distribution of troglofauna. Vertical connectivity with the surface is important for supplying carbon (and nutrients) and plant roots may provide this connection, while lateral connectivity of voids is crucial to underground dispersal of species.

4.3. Habitat Requirements of Stygofauna

Stygofauna occur in an array of different groundwater habitats including porous, karstic and fractured-rock aquifers, springs and the hyporheos of streams (Eberhard *et al.* 2005). Stygofauna inhabit the interstitial spaces, fissures and voids in groundwater within these aquifer types. Lateral connectivity of these spaces is important because it enables animals to move about underground, while vertical connectivity through to the surface is important for supplying carbon and nutrients. Geological features such as dykes and lenses of clay may act as barriers to dispersal of stygofauna below-ground and lead to species having highly patchy, or restricted, ranges.

Apart from salinity, the physiochemical tolerance of stygofauna has not been well defined (Humphreys 2008). Furthermore it should be noted that for the vast majority of stygofauna studies, physiochemical parameters have been recorded in the first metre of the upper aquifer and, therefore, relationships with stygofauna that inhabit the deeper aquifers cannot be established.

Stygofauna have mostly been recorded from fresh to brackish groundwater but recently species have been found in salinities of up to 100,000 mg/L TDS or more (Outback Ecology 2012). Stygofauna are known to be rich in calcareous systems where the pH is typically between 7.2 and 8.2 (Humphreys 2001), although their pH tolerance is likely to be considerably greater than this suggests. Biota (2008) reported a mean pH of 6.7 for 15 bores that contained stygofauna at various locations in the Pilbara. Stygofauna are known to be tolerant of low concentrations of dissolved oxygen; e.g. Biota (2008) reported a mean DO of 38.2% saturation for the 15 bores mentioned above.

4.4. Likelihood of Occurrence

The only impacts to subterranean fauna likely to arise from the Project will be associated with groundwater drawdown. While the reasoning is not widely documented, it is considered unlikely that groundwater drawdown will alter humidity in the overlying troglofauna habitat. This is because in the (relatively) closed subterranean environment groundwater at any depth can maintain a saturated atmosphere in the deeper strata until the point below the surface where root/soil moisture interactions and surface evaporation become more important than groundwater influence. This point is determined by vegetation and soil type rather than depth to groundwater.

Groundwater drawdown is unlikely to adversely affect troglofauna (in fact, it may even increase troglofauna habitat). Accordingly, troglofauna are not considered further in this assessment, which focusses on stygofauna.

5. STYGOFAUNA IN THE VICINITY OF THE PROJECT

Six bores/wells were being explored by Reward as possible sources of groundwater for mine processing at the time of compiling this review. Depth to the water table at these wells ranges from 15-30 m although little is known regarding the specific site geology. The connection between groundwater and the surface is considered to be adequate in most situations for stygofauna to occur in abundance until the watertable is more than 30 m below ground surface (Halse *et al.* 2014).

It can be further hypothesised that if the wells produce sufficient volumes of water to be considered as groundwater production sites, the aquifers surrounding them must be transmissive. This would indicate that the physical structure within the aquifer provides suitable habitat for stygofauna.

Given the wide range of salinities in which stygofauna are known to occur, salinity (although currently unknown) would not be expected to preclude stygofauna occurrence, although high salinity may reduce the number of stygofauna species present.

5.1. Database and Literature Searches

The likelihood of subterranean fauna occurring in the Project area was assessed using a search of the Western Australian Museum (WAM) database for an area of 100 by 100 km around the Project (defined by -22.467S; 121.612 E and -24.748; 124.101 E). This search retrieved no results.

The search area was then extended and the nearest known communities for stygofauna were identified from published research papers and publically available environmental reports. The nearest known locations with stygofauna are Kintyre, 130 km north-west., a sub-selection of sites from the eastern part of the Pilbara Biodiversity Survey (140-300 km north-west), Telfer Gold Mine 190 km north, Davidson Creek 210 km west and Lake Carnegie 240 km south (Table 1).

Table 1. Reports included in the desktop assessment.

Author	Year	Report Name/ Location	Produced for	Distance from the Project
BEC	2012	Subterranean fauna assessment of the Kintyre Uranium Deposit	Cameco Australia Pty Ltd	130 km NNW
BEC	2014	10 Years of stygofauna monitoring at Telfer Gold Mine	Newcrest Mining Ltd	190 km NNW
DPaW	2002-2007	Biodiversity survey of the Pilbara	Department of Parks and Wildlife	140-300 km NW
Phoenix	2009	Davidson Creek Iron Ore Project subterranean survey	FerrAus Ltd	210 km W
DPaW	Unpub.	Lake Carnegie	Ad hoc survey	240 km S

The Kintyre Project area was surveyed by Bennelongia (2012) for stygofauna in 2012 and 15 species of stygofauna from seven higher level groups were collected (Table 2), which represents a moderately sparse stygofauna community containing all commonly collected higher groups of stygofauna other than ostracods. Monitoring of stygofauna at the Newcrest Telfer gold mine over a 10 year period identified a total of 39 stygofauna representing a relatively rich stygofaunal community. Nearly all of the species occurred in calcrete (Bennelongia 2013). Phoenix (2009) sampled 57 bores from Davidson Creek for the FerrAus Pilbara Project and recorded 23 species, although many of these were higher level identifications and may represent multiple species. Sampling of a small number of wells at Lake Carnegie by Harley Barron of DPaW identified seven stygofauna species.

Halse *et al.* (2014) undertook a regional survey of stygofauna in the Pilbara from 2002 - 2007. A subset of the sites sampled (30 bores in five different areas closest to Lake Disappointment) contained 56 species (Table 2). These Pilbara bores were spread out over a distance of 300 km and do not represent a single community, rather they highlight the species that have been recorded in proximity to Lake Disappointment.

Overall, crustaceans were the most commonly collected group in the expanded search area with at least 75 species recorded, including 17 ostracods, 36 copepods five syncarids, 13 amphipods and three isopods. Nineteen species of worms were recorded, followed by four insects, three rotifers, one snail and one nematode (Table 2).

Three of the four insect species were collected by Phoenix (2009). Two of them were dipterans and have questionable status as stygofauna; they are more likely to be surface species that utilise some groundwater environments. This also applies to one or two of the ostracod species collected at Davidson Creek.

Table 2. Stygofauna species identified to occur in the vicinity of the Project.

Taxonomy	Kintyre	Telfer	Davidson Creek (Phoenix)	Eastern Pilbara	Carnegie
4					
Nematoda sp.	X	X		X	
Rotifera					
Bdelloidea sp.				X	
Bdelloidea sp. 3:2		X			
Dissotrocha sp.				X	
Filinia sp.	X				
Mollusca					
Gastropoda					
Hydrobiidae sp. B02		X			
Annelida					
Aphanoneura					
Aeolosoma sp. 1 (PSS)				X	
Aeolosoma sp. 2 (PSS)				X	
Polychaeta					
Namanereis sp. B01		X			
Namanereis pilbarensis				X	
Clitellata					
Oligochaeta					
Oligochaeta sp.				X	
Pristina aequiseta			X	X	
Pristina longiseta			X	X	
Enchytraeidae sp.		X	X	X	
Enchytraeidae sp. 3 (PSW) Pilbara			X		
Enchytraeus sp. 1 (PSS) Pilbara			X		
Enchytraeus sp. 2 (PSS) Pilbara			X		
Insulodrilus sp.		X			
Phreodrilid with dissimilar ventral chaetae		X	X	X	
Phreodrilid with similar ventral chaetae		X	X		
Tubificidae sp. stygo morphotype 2 (PSS)				X	
Tubificidae sp. stygo type 1 (imm Ainudrilus ?WA25/26) (PSS)				X	
Tubificidae sp. stygo type 4				X	
Tubificidae stygo type 1 (imm. *Ainudrilus* WA25/26?) (PSS)		X			
Tubificidae stygo type 5	X				
Tubificoid Naididae stygo type 5			X		
Arthropoda					
Crustacea					
Ostracoda					
?Candoninae sp.				X	
Areacandona iuno				X	
Areacandona scanlonii				X	
Candonopsis `tuccamunna`				X	
Candonopsis cf. *tenuis*				X	
Candonopsis dedeckkeri				X	
Humphreyscandona `yandagoogeae`				X	
Leicacandona jula		X			
Leicacandona n. sp. (IK)		X			
Leicacandona pinkajartinyi		X			

Taxonomy	Kintyre	Telfer	Davidson Creek (Phoenix)	Eastern Pilbara	Carnegie
Leicacandona quasihalsei				X	
Cypretta seurati		X		X	
Cyprinotus kimberleyensis				X	
Sarscypridopsis ochracea					X
Stenocypris bolieki				X	
Gomphodella sp. BOS354		X			
Darwinulidae *sp.*				X	
Maxillopoda					
Copepoda					
Calanoida					
Eudiaptomus lumholtzi	X				
Cyclopoida					
'*Bryocyclops*' sp. 1 (PSS)		X			
Diacyclops cockingi		X		X	
Diacyclops humphreysi humphreysi		X	X	X	
Diacyclops scanloni		X		X	
Diacyclops sobeprolatus				X	
Diacyclops sp.				X	
Fierscyclops (*Fierscyclops*) sp. B04			X		
Goniocyclops sp. B07			X		
Halicyclops calm				X	
Halicyclops kieferi		X			
Halicyclops sp.					X
Metacyclops sp.					X
Metacyclops sp.				X	
Mesocyclops brooksi				X	
Mesocyclops sp.		X			
Microcyclops varicans		X	X	X	X
Orbuscyclops westaustraliensis	X				
Pescecyclops sp. B02 (nr kimberleyi)			X		
Pilbaracyclops frustratio		X		X	
Cyclopoida sp.	X				X
Harpacticoida					
Harpacticoida sp.				X	
Harpacticoida sp. B01	X				
Abnitocrella sp. 1 (TOK)		X			
Abnitocrella sp. B02 (nr *obesa*)*		X			
Megastygonitocrella bispinosa				X	
Megastygonitocrella sp. B03 (nr *ecowisei*)		X			
Megastygonitocrella unispinosa				X	
Nitocrella sp. B03 (nr *trajani)**		X			
Nitocrella sp. B04 (nr *obesa*)	X				
Nitocrella sp. B05	X				
Ameridae (nr *Gordonnitocrella*) sp. B01		X			
Australocamptus sp. B02			X		
Elaphoidella humphreysi				X	
Canthocamptidae sp.				X	X
Parastenocaris sp.			X	X	
Parastenocaris sp. B07	X	X			

Taxonomy	Kintyre	Telfer	Davidson Creek (Phoenix)	Eastern Pilbara	Carnegie
Parastenocaris sp. B09			X		
Parastenocaris sp. B10			X		
Parastenocaris sp. B11			X		
Parastenocaris sp. B12			X		
Parastenocaris sp. B20	X				
Malacostraca					
Eumalacostraca					
Syncarida					
Atopobathynella sp.	X	X			
nr *Billibathynella (Brevisomabathynella)* sp. B08		X			
Hexabathynella sp. A (PSS)				X	
Notobathynella sp. B06	X				
Parabathynellidae sp.				X	
Amphipoda					
Bogidiellidae sp.				X	
Bogidiellidae sp. 1 (PSS)				X	
Bogidiellidae sp. B02	X	X			
Melitidae sp.		X			
Chydaekata sp.				X	
Molina cf. *pleobranchos* (PSS)				X	
Paramelitidae sp.				X	
Paramelitidae sp. 2 (PSS)				X	
Paramelitidae sp. B06		X		X	
Paramelitidae sp. B07	X			X	
Paramelitidae sp. B10		X			
Paramelitidae sp. B11		X			
Paramelitidae sp. B28		X			
Paramelitidae sp. B30		X			
Pilbarus sp.				X	
Pilbarus sp. S01 (PSS)				X	
Isopoda					
Microcerberidae sp.		X		X	
Microcerberidae sp. B04	X				
Adoniscus sp. B01		X			
Pygolabis weeliwolli				X	
Hexapoda					
Insecta					
Insecta sp.			X		
Diptera					
Tanypodinae sp.			X		
Diptera sp.			X		
Coleoptera					
Limbodessus harleyi					X

Phylum, sub-phylum, class, sub-class and order are indicated by orange, green, purple blue and brown shading respectively.

Given that groundwater in the Lake Disappointment Palaeoriver is likely to be saline, it is reiterated that recent surveys in the Yilgarn have extended the documented salinity tolerances of various crustacean groups, including syncarids (108,600µS cm^{-1}) and copepods (141,200µS cm^{-1}) (Outback Ecology 2102). While this level of salinity tolerance is surprising in the low energy environment of groundwater, it suggests that the occurrence of stygofauna in arid parts of Western Australia can rarely be ruled out on the basis of high salinity.

5.1.1. Listed Species and Threatened/Priority Communities

No subterranean invertebrate species from the extended search area around the Project is listed under the WC Act. Furthermore, there are no PECs or TECs for subterranean fauna listed in the vicinity of the Project.

5.2. Potential Impacts on Subterranean Fauna

It has already been indicated that groundwater drawdown within the proposed borefield is considered to be the only likely impact on subterranean fauna and that this will affect only stygofauna. However, in a more general framework, two types of impacts are recognised. These are: 1) *Primary Impacts* that have the potential to threaten the persistence of subterranean fauna through direct removal of habitat; and 2) *Secondary Impacts* that reduce population densities rather than threatening species persistence. Loss of aquifer habitat through dewatering or mine pit excavation are examples of primary impacts, while reduction in the habitat quality of as a result of nutrient enrichment through increased surface inputs from sewerage or the increased turbidity from mine blasting are examples of secondary impacts (Masciopinto *et al.* 2006; Scarsbrook and Fenwick 2003).

Detailed information on factors causing secondary impact is given in Appendix 1.

5.2.1. Project Impacts

The proposed location of the borefield to support the Project is approximately 20 km north of Lake Disappointment in the Disappointment Palaeoriver. Characteristics of the aquifers to be abstracted are still being investigated and pumping rates are yet to be determined, so that the extent of groundwater drawdown and the resultant potential loss of stygofauna habitat are unknown. However, for the purpose of this review it is considered that groundwater drawdown from the Project has the potential to impact any stygofauna community present in the proposed borefield.

6. CONCLUSIONS

Groundwater drawdown has a minimal impact on troglofauna and any troglofauna community present in the proposed borefield is not expected to be impacted by the borefield and Project. However, stygofauna that inhabit the aquifers proposed for pumping may be impacted.

A search of the WAM database an area of 100 by 100 km around the Project retrieved no results. However, stygofauna have been recorded within an extended search area that included locations 130-240 km from Lake Disappointment. These results are interpreted to indicate that arid areas with similar landscapes to that of Lake Disappoitment have the capacity to host rich to moderately rich stygofauna communities. In particular, stygofauna are often abundant in palaeorivers and, depending on salinity and the pore space sizes of its upper aquifers, the Disappointment Palaeoriver appears likely to support at least some stygofauna. Any areas of calcrete within the Disappointment Palaeoriver are likely to support rich stygofauna communities.

In the absence of site data on stygofauna, another approach to assessing the likelihood of stygofauna occurrence is to examine transmissivity. Stygofauna occur in nearly all transmissve aquifers with adequate hydraulic connections to the surface for carbon and nutrient input. Borefields need to be in transmissive aquifers to provide adequate yields and this alone suggests that stygofauna are likely to be present within the proposed Project borefield unless the watertable is deep (i.e. >40 m below surface). High salinity levels may reduce the number of stygofauna species present but some stygofauna species tolerate truly hypersaline conditions.

It is sometimes suggested that even if stygofauna are present in the shallow overlying aquifers, there will be no impacts of drawing groundwater from deeper aquifers below confining layers such as aquitards. However, in most situations water cannot be pumped from below an aquitard unless there is some downward leakage from the overlying aquifers and stygofauna may potentially ne impacted .

For the reasons outlined below, a Level 1 stygofauna survey is recommended to characterise the stygofauna community of Lake Disappointment:

- There is a lack of knowledge of stygofauna communities in the region, with WAM database search results retuning no results;
- Further afield, rich to moderately rich communities have been recorded;
- There is some calcrete in the region and calcretes have previously been recorded to host rich stygofauna communities in other regions;
- Salinity levels in the aquifers of the palaeoriver are not well documented, including the extent to which the upper layer of groundwater is less saline; and
- The project may have impact on stygofauna communities, if present, through groundwater drawdown and the likely significance of this impact cannot be assessed without data about the stygofauna community present.

Depending on results of the Level 1 survey, there may be need for additional survey.

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Appendix 1 - Secondary Impact of Mining on Subterranean Fauna

Mining activities that may result in secondary impacts to subterranean fauna include:

1. *De-watering below troglofauna habitat*. The impact of a lowered water table on subterranean humidity and, therefore, the quality of troglofauna habitat is poorly studied but it may represent risk to troglofauna species in some cases. The extent to which humidity of the vadose zone is affected by depth to the watertable is unclear. Given that pockets of residual water probably remain trapped throughout de-watered areas and keep the overlying substrate saturated with water vapour, de-watering may have minimal impact on the humidity in the unsaturated zone. In addition, troglofauna may be able to avoid undesirable effects of a habitat drying out by moving deeper into the substrate if suitable habitat exists at depth. Overall, de-watering outside the proposed mine pits is not considered to be a significant risk to troglofauna.
2. *Percussion from blasting*. Impacts on both stygofauna and troglofauna may occur through the physical effect of explosions. Blasting may also have indirect detrimental effects through altering underground structure (usually rock fragmentation and collapse of voids) and transient increases in groundwater turbidity. The effects of blasting are often referred to in grey literature but are poorly quantified and have not been related to ecological impacts. Any effects of blasting are likely to dissipate rapidly with distance from the pit and are not considered to be a significant risk to either stygofauna or troglofauna outside the proposed mine pits.
3. *Overburden stockpiles and waste dumps*. These artificial landforms may cause localised reduction in rainfall recharge and associated inflow of dissolved organic matter and nutrients because water runs off stockpiles rather than infiltrating through them and into the underlying ground. The effects of reduced carbon and nutrient input are likely to be expressed over many years and are likely to be greater for troglofauna than stygofauna (because lateral movement of groundwater should bring in carbon and nutrients). The extent of impacts on troglofauna will largely depend on the importance of chemoautotrophy in driving the subterranean system compared with infiltration-transported surface energy and nutrients. Stockpiles are unlikely to cause species extinctions, although population densities of species may decrease under them.
4. *Aquifer recharge with poor quality water*. It has been observed that the quality of recharge water declines during, and after, mining operations as a result of rock break up and soil disturbance (i.e. Gajowiec 1993; McAuley and Kozar 2006). Impacts can be minimised through management of surface water and installing drainage channels, sumps and pump in the pit to prevent of recharge though the pit floor.
5. *Contamination of groundwater by hydrocarbons*. Any contamination is likely to be localised and may be minimised by engineering and management practices to ensure the containment of hydrocarbon products.