Bennelongia Environmental Consultants

Gnaweeda Project:

Subterranean Fauna Assessment

Prepared for:

Doray Minerals Ltd

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Short-Range Endemics I Subterranean Fauna

Waterbirds I Wetlands

Gnaweeda Project: Subterranean Fauna

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EXECUTIVE SUMMARY

Doray Minerals Limited (DRM) Andy Well mine are assessing the viability of mining gold at Gnaweeda (the Project), in the Yilgarn region of Western Australia. Excavations and dewatering at the Project may adversely impact subterranean fauna (stygofauna and troglofauna) in the area by removing habitat. This assessment combined desktop review and Level 1 field survey to determine whether the Project will significantly impact the conservation status of subterranean fauna species and communities.

Three main potential habitats exist in and around the Project: detrital deposits, fractured rock (both occur in proposed pits) and regional calcretes. Detrital habitat is widespread and well-connected and species in this habitat will be regionally widespread. Records indicate moderate diversity of stygofauna and depauperate troglofauna in this habitat. Fractured rock typically hosts depauperate, if any, subterranean fauna communities. Most stygofauna species in fractured rock are widespread opportunists. Mafic geologies like the proposed pits usually host depauperate troglofauna assemblages. Fractured rock habitat available to troglofauna is further limited by the shallow depth to groundwater. Fractured rock at the Project is unlikely to host troglofauna and any community will at best be depauperate. Moreover, species will have large distributions associated with detrital deposits overlying fractured rock. Overall, the Project is likely to host a depauperate community of widespread stygofauna species and is unlikely to harbour any troglofauna.

Three calcrete Priority Ecological Communities (PECs) occur in the vicinity, including the Killara calcrete 18–46 km east of the proposed pits whose PEC buffer encompasses the Project. Preliminary modelling of pit dewatering and subsequent drawdown indicate a steep cone of depression with groundwater drawdown of 2 m predicted to occur no more than 2.2 km from the edge of mine pits, suggesting that calcrete aquifers will remain unaffected by pumping. Therefore, it is unlikely that the Project will influence water levels (and the volume of stygofauna habitat) in calcrete aquifers. Excavations will not affect calcretes.

Previous records of subterranean fauna records were compiled for a search area of 10,000 km^2 (100 km x 100 km) surrounding the Project. At least 40 stygofauna species have been recorded in the search area including flatworms, roundworms, rotifers, earthworms, mites, syncarids, amphipods, copepods and beetles. The majority of records are from a previous assessment at the Andy Well mine. Most recorded species are likely to be regionally widespread in association with interconnected detrital habitats. A few species were collected from calcrete aquifers and may be confined. Some targeted stygofauna sampling has occurred close to the Project, however only three specimens from three species have been recorded within 10 km, indicating a depauperate community.

Four troglofauna species have been recorded from the search area including at least two isopod species, a millipede and a symphylan. Other than one isopod that was collected from a cave, all troglofauna are from detrital habitat so are probably moderately widespread. The nearest targeted samples and records of troglofauna to the Project are from Andy Well mine (ca. 20 km northwest) in habitat analogous to the Project. No troglofauna have been recorded in stygofauna samples closer to the Project. Based on desktop review, troglofauna at the Project will be depauperate.

Field survey for subterranean fauna focused on potential impact areas. Ten samples for both stygofauna and troglofauna were taken. Three specimens from two stygofauna species, the cyclopoid copepod *Mesocyclops notius* and the ostracod *Cypretta seurati*, were recorded. Both species are widespread and have been recorded across Australia. The ostracod specimens may belong to a subspecies of *Cypretta seurati*, but considering the extent of habitat will be at least regionally widespread. No troglofauna were recorded. Survey results are consistent with desktop review and demonstrate a depauperate stygofauna community and absence of troglofauna. In combination, results of desktop review and field survey strongly suggest that the Project will not significantly threaten species or communities of subterranean fauna.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Doray Minerals Limited (DRM) are assessing the viability of mining gold at Gnaweeda (the Project), approximately 40 km north-northeast of Meekatharra in the Murchison region of Western Australia, 15 km southeast of DRM's Andy Well mine (Figure 1). Excavations and dewatering to allow dry mining and stable pit slopes at the Project may impact subterranean fauna (stygofauna and troglofauna) in the area by removing potential habitat.

This assessment combines desktop review and Level 1 field survey to determine whether the Project will have significant impacts on the conservation of subterranean fauna species and communities. The specific aims of the assessment are:

- To collate previous records of subterranean fauna within a 100 km x 100 km search area encompassing the Project;
- To assess the prospectivity of potential subterranean fauna habitats in and around the Project;
- To characterise subterranean fauna communities at the Project through field survey; and
- To determine whether the Project will significantly threaten the conservation of subterranean fauna species and communities.

2. BACKGROUND

2.1. Conservation Framework

The Environmental Protection Authority (EPA) recognises the need to conserve subterranean fauna and stipulates their consideration as part of environmental impact assessment process. This is outlined in Environmental Factor Guideline: Subterranean Fauna (EPA 2016a) and the supporting sampling guideline Technical Guidance: Subterranean Fauna Survey (EPA 2016b). The conservation of subterranean can also be viewed in the wider context of state and federal conservation legislation. At the state level, the Wildlife Conservation 1950 and Biodiversity Conservation Act 2016 provide for the listing of species as Threatened by the Minister following recommendations by the Threatened Species Scientific Committee. Threatened species are specially protected because they are under identifiable threat of extinction, are rare, or otherwise in need of protection. Possibly threatened species for which there is not enough information to support listing by the Minister are instead listed by the Department of Parks and Wildlife (Parks and Wildlife) as Priority species. Species may also be listed at the federal level as Threatened under the Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act).

In addition to protecting individual species, ecological communities may be listed to provide protection at both the state and federal levels. At the state level, the Minister may list a community as being a Threatened Ecological Community (TEC) if it is at risk of being totally destroyed. Ecological communities with insufficient information available to be considered as TECs, or which are rare but not currently threatened, are listed by Parks and Wildlife as Priority Ecological Communities (PECs). A number of subterranean communities are listed as either Threatened Ecological Communities (TECs) or PECs.

2.2. Project Description

The Project will comprise two open cut pits (North pit and South pit; Figure 2) that will reach depths of approximately 170 mbgl over a mine life of three years. North and South Pits will cover areas of roughly 18.28 ha and 7.73 ha respectively, with a combined area of approximately 26.01 ha. Water requirements for dust suppression and ablutions are estimated to be 10 L s^{-1} (~0.9 ML d^{-1}) during operations.

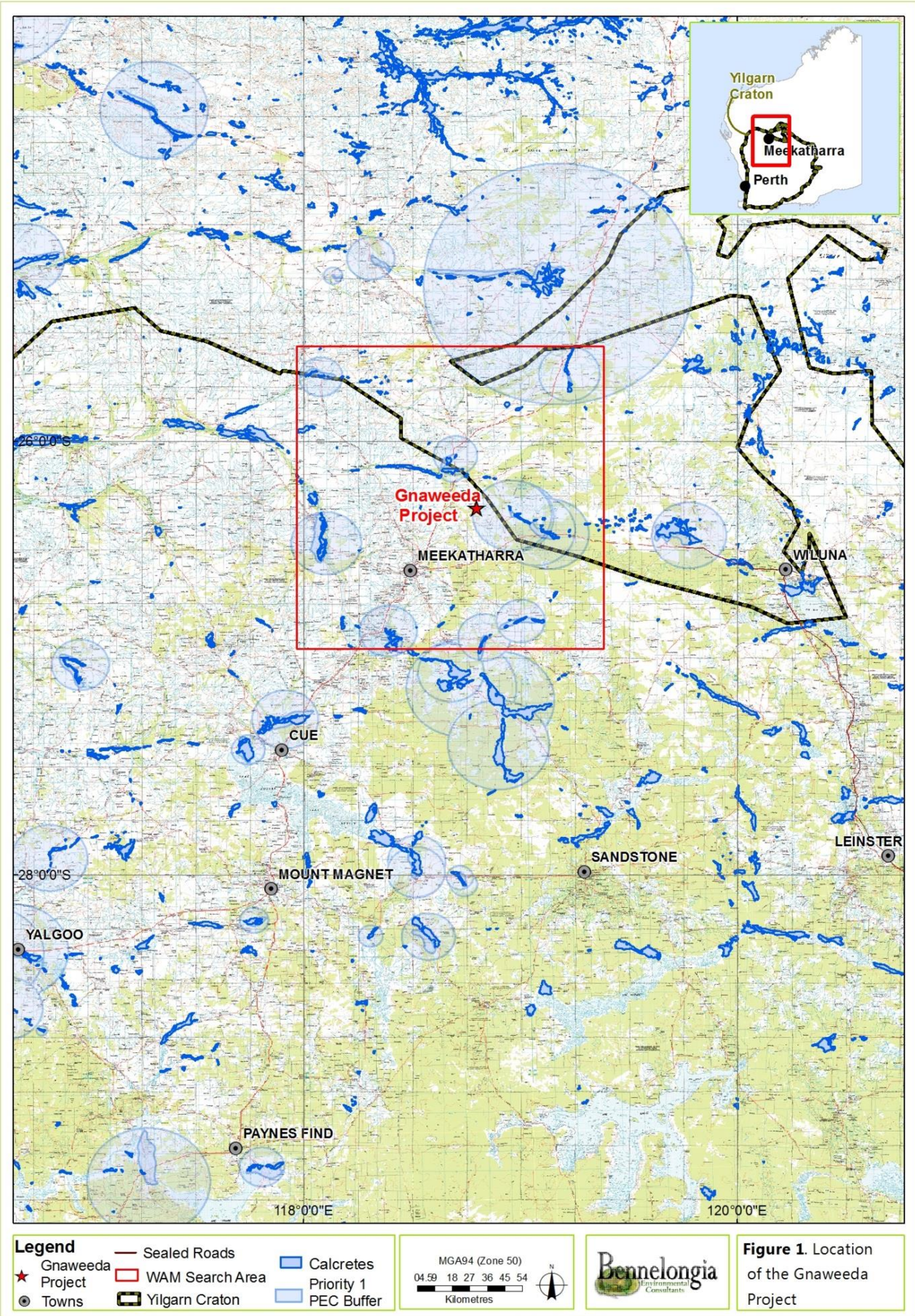

Figure 1. Location of the Gnaweeda Project, area encompassed by desktop review and regional calcrete aquifer PECs.

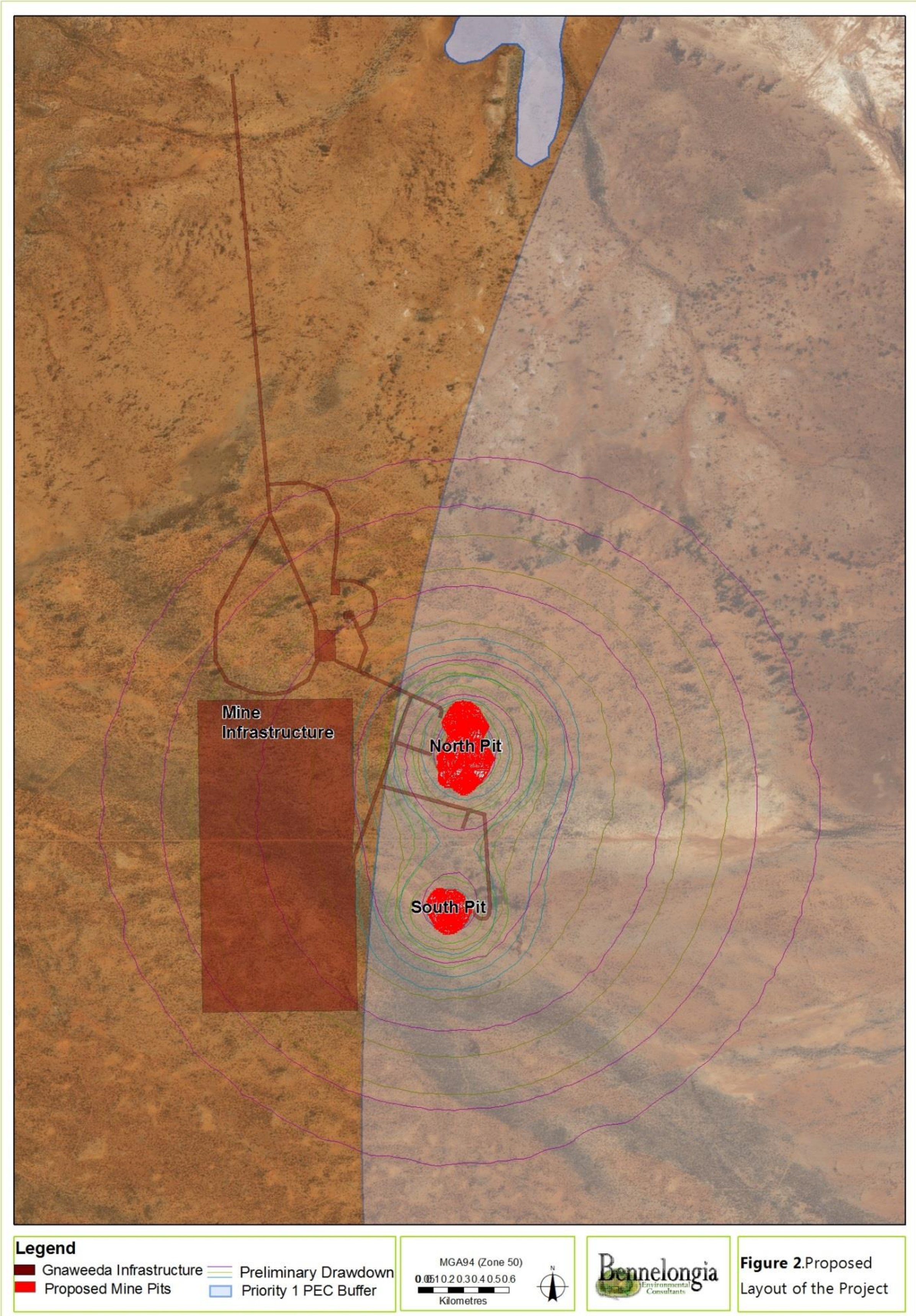

Figure 2. Proposed layout of the Gnaweeda Project.

2.2.1. Pit Dewatering

Significant groundwater inflows to many drill holes across the proposed pits have been observed during exploration drilling in early 2017 (CDM Smith 2017). A hydrogeological drilling and testing program and predictive modelling of mine inflows were subsequently completed. Predicted inflows for the North and South Pits are 0.4–2.5 ML d^{-1} (5–29 l s^{-1}) and 0.8–4.5 ML d^{-1} (9–52 L s^{-1}), respectively.

Preliminary estimates of groundwater drawdown were also modelled. The predicted radius of drawdown (cone of depression) at the end of mining extends 0.5–2.0 km from the pit areas. Groundwater flow at the Project is strongly controlled be geology and the cone of groundwater depression is expected to be more elliptical (elongated north-south) than predicted by modelling (CDM Smith 2017). Based on shapefiles provided by CDM Smith, 5 m drawdown of groundwater after three years of mining may occur up to 2.2 km from the edge of mine pits. The nearest calcrete deposit in the Killara PEC is approximately 18 km east from the edge of mine pits and based on preliminary drawdown modelling it is unlikely that groundwater levels in regional calcretes will be influenced by pumping.

2.3. Subterranean Fauna

Subterranean fauna can be dichotomised into aquatic stygofauna and air-breathing troglofauna. Both groups typically lack eyes and are poorly pigmented due to lack of light. Other characteristic morphological and physiological adaptations such as vermiform bodies, elongate sensory structures, loss of wings, increased lifespan, a shift towards K-selection breeding strategy and decreased metabolism reflect low inputs of carbon and nutrients in subterranean habitats and the requirement to navigate enclosed spaces (Gibert & Deharveng 2002). With the exception of several species of stygofaunal fish, all subterranean fauna in Western Australia are invertebrates.

Geology influences the presence, richness and distribution of subterranean fauna by providing different types of habitat (Eberhard et al. 2005; Hose et al. 2015). Geologies with larger internal spaces support larger assemblages of subterranean fauna, both in terms of abundance and diversity, than consolidated geologies.

Stygofauna communities tend to be richest in calcrete (Humphreys 2001). Detrital aquifers may also host relatively rich assemblages, while less transmissive geologies such as banded iron formations (BIF), saprolite, mafic and ultramafic usually contain depauperate communities (Ecologia 2009; GHD 2009). Stygofauna are usually absent from silt and clay (Korbel and Hose 2011). Both the Pilbara and Yilgarn are particularly rich in stygofauna and a large number of stygofauna PECs in calcretes have been listed from the Yilgarn. Stygofauna occur in varying salinities, but are mostly found in fresh to brackish waters with conductivities of less than 5,000 µS cm^{-1} (approximately 640 mg L^{-1} TDS) and are seldom found in hypoxic groundwater (<0.3 mg O_2 L^{-1}) (Hose et al. 2015).

Troglofauna have been found to occur widely in mineralised iron formations (especially BIF), calcretes and alluvial-detrital deposits in the Pilbara (e.g. Biota 2006; Bennelongia 2008a, b; Edward and Harvey 2010). Troglofauna surveys in Western Australia outside the Pilbara have been limited, but surveys in BIF in the Yilgarn at Koolyanobbing, Mt Jackson and Mt Dimmer have yielded depauperate to moderately rich troglofauna communities (Bennelongia 2008a; Bennelongia 2008b). Significant troglofaunal communities have also been recorded in calcretes of the Yilgarn, with Bennelongia (2015) recording 45 species of troglofauna from the Yeelirrie calcrete, while Outback Ecology (2012) recorded 20 species in calcretes around Lake Way.

Owing to the isolation of prospective subterranean fauna habitats throughout the Western Australian landscape, there is a very high incidence of short-range endemism amongst the Western Australian subterranean fauna.

3. DESKTOP REVIEW

3.1. Previous Records of Subterranean Fauna

Records of subterranean fauna were compiled from Western Australian Museum (WAM) and Bennelongia databases for a search area of 10,000 km^2 (100 km x 100 km) surrounding the Project defined by 25.552°S, 117.979°E and 26.936°S, 119.363°E. Published research papers, environmental assessments and online resources such as the Atlas of Living Australia (ALA 2017) and the Australian Faunal Directory (ABRS 2009) were also reviewed. Higher-order identifications were generally not included in the final list of recorded species unless they belonged to taxonomic units that were otherwise not recorded.

3.1.1. Stygofauna

At least 40 species of stygofauna have been recorded in the search area surrounding the Project (Table 1), including flatworms (Turbellaria), roundworms (Nematoda), rotifers (Rotifera), earthworms (Annelida: Oligochaeta), a mite (Acari), syncarids (Syncarida), amphipods (Amphipoda), three copepod orders (Calanoida, Cyclopoida and Harpacticoida), ostracods (Ostracoda) and beetles (Coleoptera). Some of these taxa have largely unknown ecologies and may be opportunistic rather than obligate stygofauna (roundworms, rotifers, some oligochaetes), whereas other groups represent truly stygal forms.

The majority of records in the search area are from a previous assessment for Andy Well mine (Bennelongia 2011) that predominantly recorded stygofauna from surficial alluvial and colluvial aquifers. Given the wide extent and connectivity of this porous matrix (Section 3.2) and the widely-observed relationship between the ranges of stygofauna species and geology, these species are likely to be moderately widespread.

The assessment at Andy Well mine included some sampling locations very close to the Gnaweeda prospect, with the closest within 1 kilometre of the Project. Yields of stygofauna near the Project were low, with only three specimens from three species recorded within 10 km: the oligochaete *Allonais pectinata*, which is found Australia-wide; and the ostracods *Zonocypris* sp. BOS241 and *Limnocythere* sp. BOS244, both of which are likely to be moderately widespread throughout regional alluvial aquifers. Based on low yields in previous survey the occurrence of other recorded species at the Project is considered unlikely, but will depend on the connectivity of regional detrital aquifers. More importantly, as all these species are likely to be widespread, the Project is not likely to threaten their persistence.

Three species – the syncarid *Billibathynella humphreysi*, the harpacticoid copepod *Kinnecaris barrambie* and the diving beetle Dytiscidae sp. – have been recorded from regional calcrete PECs and are likely to be Short Range Endemics (SREs) confined to individual calcretes. Considering that sampling intensity in these calcretes has been low, it is likely that many more stygofauna species occur but have simply not been collected. Species that are confined to calcrete aquifers are unlikely to occur at the Project, although this will depend on the connectivity of calcrete and surficial aquifers.

Overall, records of stygofauna from the search area suggest a moderate regional diversity of mostly widespread species that utilise extensive surficial aquifers and possibly calcretes. Further sampling in calcretes will reveal greater richness, but the distance between the Project and regional calcretes will mitigate potential threats of groundwater drawdown to confined stygofauna species. The paucity of stygofauna records close to the Project despite some sampling suggests that any communities present will be depauperate. Considering the extent of regional detrital aquifers, any species present are likely to be at least moderately widespread.

3.1.2. Troglofauna

Four species of troglofauna have been recorded from the search area, including at least one isopod of the genus *Buddelundia*, one isopod of the genus *Trogloarmadillo*, a lophoproctid millipede and a symphylan (Table 2). One record of the isopod *Buddelundia* sp. comes from a hand-collected cave specimen, however the two remaining congeneric records have insufficient habitat and collection method data to ascertain whether they are actually troglofauna (WAM records). Besides the cave isopod, all records of troglofauna in the search area are from alluvium/colluvium and given extent and connectivity of this geological unit (Section 3.2), species are expected to be moderately widespread.

With the exception of the cave isopod, all regional records of troglofauna are from the previous assessment for Andy Well mine and focused on pit areas at that mine. The nearest targeted troglofauna samples and troglofauna records to the proposed pits at Gnaweeda are from approximately 20 km northwest in alluvium/colluvium. This habitat is analogous to that at the Project.

Considering the prevalence of mostly widespread, well-connected detrital habitat and the paucity of troglofauna records detected in desktop review despite some sampling, assemblages of troglofauna at the Project, if present, are likely to be depauperate and species will be moderately widespread.

Table 1. Previous records of stygofauna fauna in the vicinity of the Project.

Higher Classification	Lowest Identification	No. of records (Abundance)	Comments on Distribution
Platyhelminthes			
Turbellaria	Turbellaria sp.	1	Unknown; not assessed in EIA.
Nematoda	Nematoda sp.	20	Unknown; not assessed in EIA.
Rotifera			
Bdelloidea	Bdelloidea sp. 2:2	7	Unknown; not assessed in EIA.
	Bdelloidea sp. 2:3	1	
	Bdelloidea sp. 6:6	1	
Monogononta			
Brachionidae	*Brachionus urceolaris* s.l.	1	Widespread[1]
Lecanidae	*Lecane ludwigi* form *ichthyoura*	4	
Annelida			
Aphanoneura			
Aeolosomatidae	*Aeolosoma* sp. 1 (PSS)	2	Widespread[2]
Clitellata			
Enchytraeida			
Enchytraeidae	*Enchytraeus* sp. (ex sp. 1 PSS Pilbara)	1	Widespread[2]
	Enchytraeus sp. (ex sp. 2 PSS Pilbara)	11	
Haplotaxida			
Naididae	*Allonais pectinata*	2	Widespread[1]
	Dero (*Dero*) *nivea*	1	Widespread[1]
	Pristina aequiseta	1	Widespread[1]
	Tubificoid Naididae `stygo type 5`	3	Widespread morphospecies [2, 3].
Phreodrilidae	Phreodrilidae spp. `with dissimilar ventral chaetae`	5	Widespread morphospecies [2, 3].
Arthropoda			
Chelicerata			
Arachnida	Acari sp.	2	Unknown – insufficient taxonomy.
Crustacea			
Syncarida			
Parabathynellidae	*Billibathynella* sp. B02	14	Recorded from calcrete and superficial alluvial/colluvial at Andy Well; probably moderately widespread[4].
	Billibathynella humphreysi	5	SRE[5] recorded from calcrete at Mt

Higher Classification	Lowest Identification	No. of records (Abundance)	Comments on Distribution
			Padbury Station.
Malacostraca			
Amphipoda			
Paramelitidae	nr *Kruptus* sp. B09	17	Recorded from calcrete and superficial alluvial/colluvial at Andy Well; probably moderately widespread[4].
	Pilbarus millsi	1	Widespread[2].
Maxillopoda			
Calanoida	Calanoida sp.	3	Unknown.
Cyclopoida			
Cyclopidae	*Diacyclops humphreysi humphreysi*	1	All species widespread[2].
	Fierscyclops fiersi	1	
	Goniocyclops mortoni	1	
	Mesocyclops brooksi	11	
	Mesocyclops notius	5	
	Metacyclops laurentiisae	2	
	Microcyclops varicans	7	
	Paracyclops chiltoni	1	
Harpacticoida			
Canthocamptidae	*Australocamptus* sp. B03	1	Recorded from superficial alluvial/colluvial at Andy Well; probably moderately widespread[4].
Miraciidae	*Schizopera roberiverensis*	1	Widespread[2].
Parastenocarididae	*Parastenocaris* sp. B13	1	Recorded from superficial alluvial/colluvial at Andy Well; probably moderately widespread[4].
	Kinnecaris barrambie	1	SRE confined to calcrete at Cogla Downs[5].
Ostracoda			
Popocopida			
Cyprididae	*Cypretta seurati*	8	Widespread[2].
	Cypridopsis sp. BOS234	2	All species recorded from calcrete and/or superficial alluvial/colluvial near
	Sarscypridopsis sp. BOS247	2	

Higher Classification	Lowest Identification	No. of records (Abundance)	Comments on Distribution
	Zonocypris sp. BOS241	13	Andy Well; all species probably moderately widespread[4].
Limnocytheridae	*Limnocythere* sp. BOS244	2	
	Ostracoda sp. BOS148	1	
Hexapoda			
Insecta			
Coleoptera			
Dytiscidae	Dytiscidae sp.	2	Collected from and likely confined to the Kilara North and/or Kalarundi Calcretes, ca. 24 km northwest of Gnaweeda.

[1]ABRS (2009); [2]Halse et al (2014); [3]Bennelongia unpublished data; [4]Bennelongia 2011; [5]Cho 2011; [6]Karanovic and Cooper (2011).

Table 2. Previous records of troglofauna fauna in the vicinity of the Project.

Higher Classification	Lowest Identification	No. of records	Comments on Distribution
Crustacea			
Malacostraca			
Isopoda			
Armadillidae	*Buddelundia* sp.	3	Insufficient data (taxonomic or habitat) to define likely range.
	Troglarmadillo `ISO011`	4	
Myriapoda			
Diplopoda			
Polyxenida			
Lophoproctidae	Lophoproctidae sp.	1	Recorded from alluvium/colluvium, probably moderately widespread.
Symphyla			
Cephalostigmata			
Scutigerellidae	*Scutigerella* sp. B04	1	Recorded from alluvium/colluvium, probably moderately widespread.

3.2. Geology and Hydrogeology

3.2.1. Regional Scale

The Project is located on the northern part of the Yilgarn Craton that comprises predominantly granitoid Archaean rock crossed by north-northwest trending greenstones belts. Archaean and the overlying Proterozoic strata of the Yilgarn have been extensively oxidised to depths up to 120 m, possibly since the pre-Cretaceous (Morgan 1972), during formation of the Western Australian Plateau. The area has been subjected to a wide range of climates during its history and the regolith has formed a complexly layered structure as a result of leaching of mineral components during wet cycles and precipitation of mineral matter to form ferricrete, silcrete and calcrete during dryer cycles (Morgan 1993). Carbonate deposits (calcretes) are widespread throughout the Yilgarn in association with palaeodrainages.

The Project is in the Murchison River Basin and the East Murchison Groundwater Region. A paleochannel to the northwest features colluvium with quartz and rock fragments and alluvium with unconsolidated sand, silt and gravel, interspersed with calcretes and flanked by deeply weathered lazerite, felsic volcanic rock, felsic tuff, granodiorite and tonalite. Regional groundwaters can be divided into surficial (colluvium, valley-fill alluvium and calcrete), sedimentary and fractured rock aquifers.

In the context of subterranean fauna, the dominant regional geologies are extensive and interconnected alluvial and colluvial (detrital) deposits overlying deeply-weathered volcanic and sedimentary rocks. Several calcretes in the vicinity are listed as PECs based on subterranean fauna communities. These are the Killara calcrete ca. 18 km to the east and the Killara North and Karalundi calcretes ca. 23–33 km to the north-northwest (Figure 3).

3.2.2. Local Scale

Topography in the Project area is relatively flat to undulating terrain with a mean elevation of ca. 520 mAHD and a maximum elevation of 570 mAHD. Shallow breakaways are present over many granite outcrops. Mineralised deposits occur within the northerly-trending Gnaweeda Greenstone Belt that hosts a mixed succession of mafic, gabbro, siltstone and felsic volcanics. The greenstone is structurally complex due to its multiphase history of ductile and brittle deformation. Mineralised zones are dislocated into three deposits – South, Central and North. Based on drill logs the Project area is overlain by colluvium to approximately 10–20 mbgl.

Intersections of groundwater at the Project during drilling suggest that the main sources of groundwater within deposits are in fractured rock (CDM Smith 2017). Depth to groundwater across the pits is relatively shallow at 9–13 mbgl and water quality is fresh (1,500–2,400 µS cm^{-1}) and slightly alkaline (pH 7.5–8.5).

3.2.3. Habitat Assessment

Three main potential habitats for subterranean fauna exist in and around the Project: detrital deposits, fractured rock in the proposed pits and regional calcretes.

Detrital deposits are regionally widespread and well-connected (Figure 3) and have been the subject of considerable survey effort for stygofauna. Previous results show a moderate diversity of stygofauna in this habitat type and recorded species are known or considered likely to be at least moderately widespread. Targeted sampling for troglofauna has been less extensive and only a small area at Andy Well mine (alluvium/colluvium) has been investigated, although troglofauna have not been recorded in stygofauna net samples elsewhere, which is a reasonably common occurrence. The area in and immediately surrounding the Project has colluvial deposits approximately 10–20 m deep and water chemistry is suitable for stygofauna (159–5,380 µS cm^{-1}). However, prior sampling close to the Project yielded poorly for stygofauna. Therefore, stygofauna may occur in alluvium/colluvium at the Proposal, but any communities are probably depauperate and will probably comprise widespread species. Similarly, alluvium/colluvium at the Project is likely to support only depauperate troglofauna communities, if any, and species are likely to be regionally widespread.

As determined by CDM Smith (2017), fractured rock aquifers in the proposed pits sit at 9–13 mbgl and are fresh (1,500–2,400 µS cm^{-1}), suggesting that water quality and depth will not preclude stygofauna. However, previous surveys in fractured rock (mafic, ultramafic and saprolite) have yielded poorly for stygofauna and these geologies provide poor habitats (Bennelongia 2016a; ecologia 2009; GHD 2009; EPA 2016c). In Western Australia the most common stygal species in fractured rock are cyclopoid copepods, the majority of which are widespread throughout arid and semi-arid north-western central Australia (Karanovic 2004). Troglofauna communities in fractured rock also tend to be modest (Bennelongia 2008a; Bennelongia 2008b) and the richest communities have been recorded in banded ironstone (e.g. Biota 2006), which does not occur at the Project. Mafic geologies comparable to the proposed pits more often than not host depauperate troglofauna assemblages (e.g. Bennelongia 2016b). Suitable fractured rock habitat for troglofauna is further limited by the shallow depth to groundwater. Fractured rock at the Project is unlikely to host troglofauna and any community will at best be depauperate. Species are likely to have large distributions associated with alluvial/colluvial deposits that cover fractured rock.

Regional calcretes, two of which are listed as PECs, are likely to provide prospective stygofauna habitat and may also harbour troglofauna above the water table. Calcretes throughout the Yilgarn support highly speciose communities of stygofauna (e.g. Bennelongia 2015, 2016) and have also been found to be suitable for troglofauna (Bennelongia 2015; Outback Ecology 2012). The nearest calcrete to the Project is the Killara calcrete PEC that runs in a northeast-southeast orientation approximately 18–46 km east of the proposed pits, while the Karalundi and Killara North calcretes occur some 23–33 km to the north (Figure 3). Additionally, a very small calcrete deposit (ca. 74 ha) occurs approximately 4 km from the North Pit, but it is not named or listed and sits outside the PEC buffer for Killara. The Project lies just within the westernmost bound of the Killara calcrete PEC buffer (Figure 3).

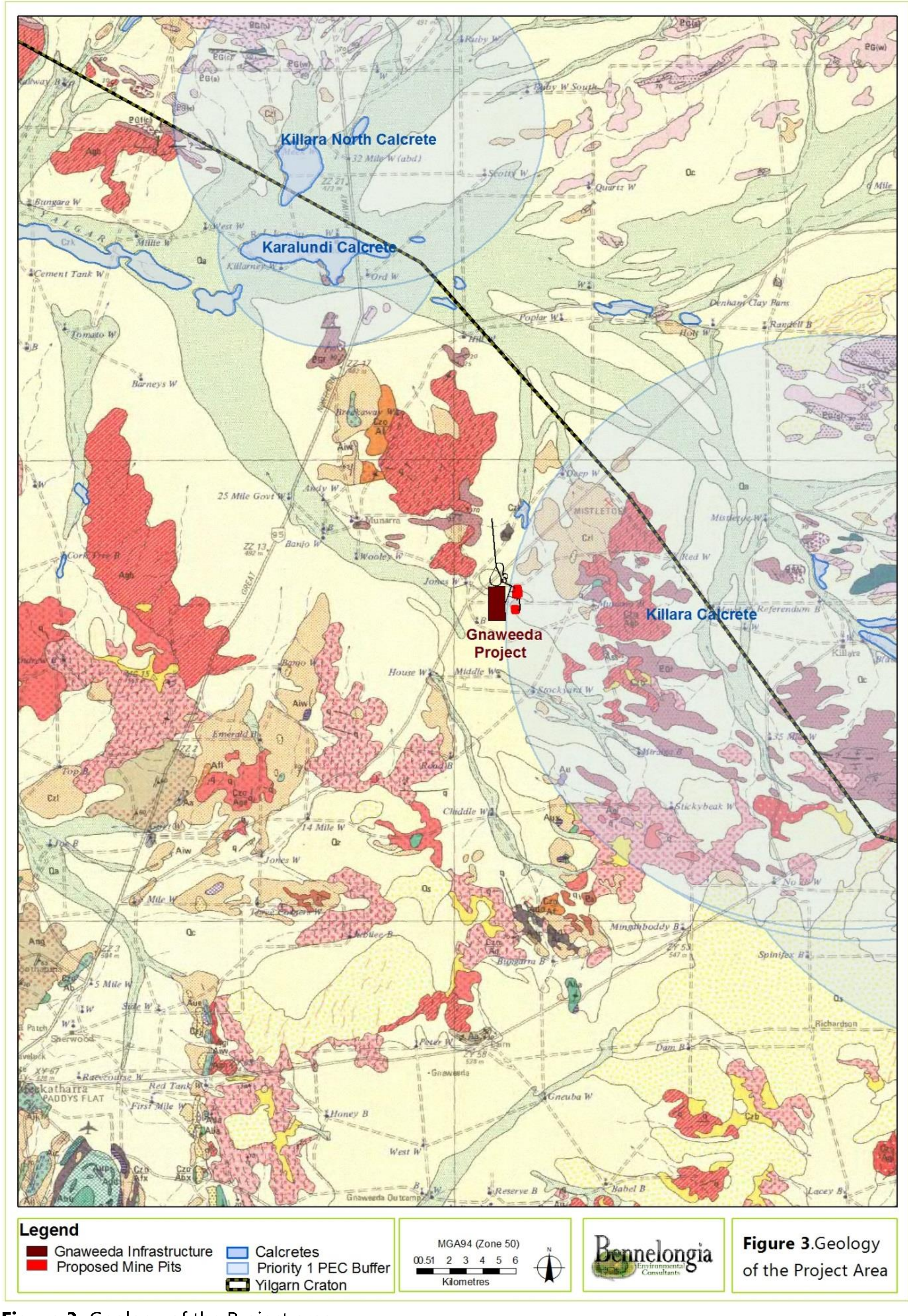

Figure 3. Geology of the Project area.

4. FIELD SURVEY

4.1. Methods

4.1.1. Sampling Effort

A total of 10 drill holes were sampled for both stygofauna and troglofauna. A summary of sampling effort is given in Table 3 and a full description of sampling site characteristics is given as Appendix 2. Due to considerable previous sampling for subterranean fauna in the vicinity of the Project, survey in March 2017 focused on areas in and around proposed pits, i.e. likely impact areas (

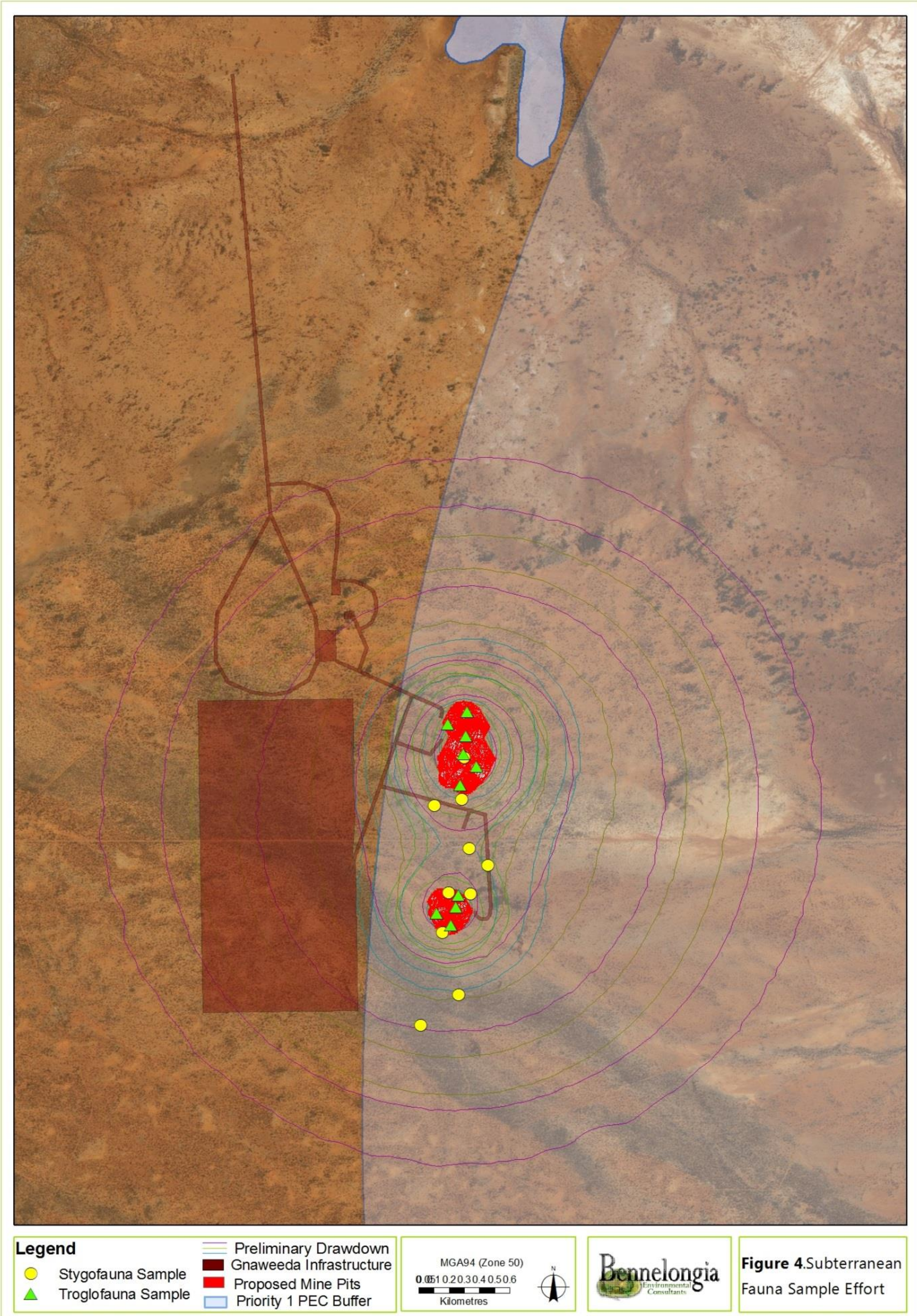

Figure 4).

Table 3. Summary of sampling effort for subterranean fauna during field survey in March 2017.

Target	No. of Sites	Net	Scrape	Single Trap	Double Trap

Stygofauna	10	10	-	-	-
Troglofauna	10	-	10	7	3

4.1.2. Stygofanua

Sampling for stygofauna followed methods prescribed in *Technical Guidance: Subterranean Fauna Survey* (EPA 2016c). Stygofauna were sampled at each bore using weighted plankton nets. Six hauls were taken at each site, three using a 50 µm mesh net and three with a 150 µm mesh net. The net was lowered to the bottom of the hole and jerked up and down to agitate the benthos (increasing the likelihood of collecting benthic species) and then slowly retrieved. Nets were washed between holes to minimise site-to-site contamination. Specimens were flushed and preserved in absolute ethanol and refrigerated.

In situ water quality parameters – temperature, electrical conductance (EC) and pH – were measured at each site with a TPS WP-81 field meter. Static water level (SWL) and total depth of hole were also measured using a Solinst water level meter.

In the laboratory, samples were elutriated to separate out heavy sediment particles and sieved into size fractions using 250, 90 and 53 µm screens. All samples were sorted under a dissecting microscope and stygofauna specimens identified to species where possible using available keys and species descriptions. When necessary for identification, animals were dissected and examined under a differential interference contrast compound microscope. If stygofauna did not represent a described species, they were identified to species/morphospecies using characters from species keys.

4.1.3. Troglofauna

Two sampling techniques were used to collected troglofaunal from drill holes. Cylindrical PVC traps (270 x 70 mm, entrance holes side and top) were baited with moist leaf litter (sterilised by microwaving) and lowered on nylon cord to the most suitable habitat within each drill hole. Holes were covered at the surface while traps were set to minimise the ingress of surface invertebrates. Scrapes were collected immediately prior to setting traps using a troglofauna net (weighted ring net, 150 µm screen, various apertures according to diameter of the hole) that was lowered to the bottom of the hole, or to the watertable, and scraped back to the surface along the walls of the hole. Each scrape comprised four sequences of lowering and retrieving the net. Samples were flushed and preserved in absolute ethanol and refrigerated.

Upon return to the laboratory, troglofauna were extracted from the leaf litter in traps using Tullgren® funnels under incandescent lamps. The light and heat drives the troglofauna and other invertebrates out of the litter into the base of the funnel containing 100% ethanol which acts as a preservative. After about 72 hours, the ethanol and its contents were removed and sorted under a dissecting microscope. Litter from each funnel was also examined under a microscope for any remaining live or dead animals. Preserved scrapes were elutriated in the laboratory to separate animals from heavier sediment and screened into size fractions (250 and 90 µm) to remove debris and improve searching efficiency. Samples were then sorted under a dissecting microscope.

All fauna picked from scrapes or extracted from bait were examined for troglomorphic characteristics (lack of eyes and pigmentation, well developed sensory organs, slender appendages, vermiform body). Troglofauna specimens were identified to species/morphospecies where possible using the same techniques employed for stygofauna.

4.1.4. Personnel

Field sampling was done by Jim Cocking. Samples were sorted by Jim Cocking and Mike Scanlon and specimens identified by Jane McRae. Reporting was done by Anton Mittra and maps were compiled by Mike Scanlon.

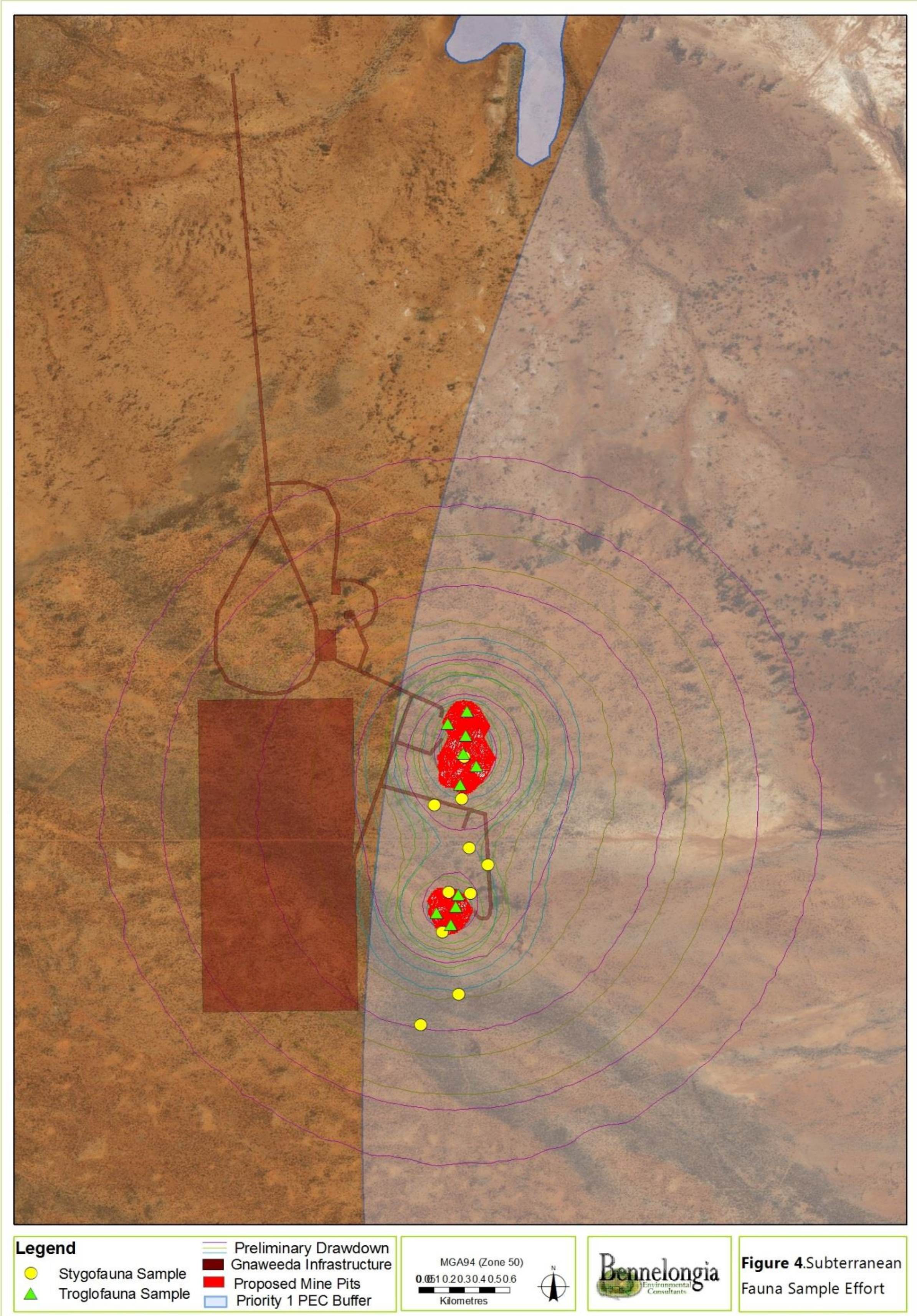

Figure 4. Sampling effort during subterranean fauna survey in March 2017.

4.2. Results

4.2.1. Stygofauna

Yields of stygofauna in the Project area were very small, with only three specimens from two species recorded (Table 3). This result demonstrates that the Project area does not provide good stygofauna habitat and harbours a depauperate stygofauna community, consistent with previous sampling in the vicinity that also recorded low numbers of specimens and species (Section 3.1.1).

The recorded species were the cyclopoid copepod *Mesocyclops notius* and the ostracod *Cypretta seurati*. *Mesocyclops notius* is a widespread habitat generalist that has been recorded across Australia in both stygofauna and surface water samples (ABRS 2009).

Cypretta seurati is a very widespread species (ALA 2017; Halse et al. 2014), although may contain distinct subspecies with somewhat smaller distributions (S. Halse, pers. comm., June 2017). It was recorded at the Project in hole TBMB002 in the centre of North Pit. Static water level in this hole was 11.76 mbgl and the depth of colluvial overburden at nearby TBRC141 (the closest hole for which drill logs are available, 25 m away) is approximately 20 m. If in fact the recorded specimens of *Cypretta seurati* at the Project belong to a subspecies, it is nevertheless highly likely to be at least moderately widespread due to the extent and connectivity of the detrital aquifer.

Table 4. Stygofauna recorded during field survey at the Project in March 2017.

Higher Classification	Lowest Identification	Site		
		TBMB001	TBMB002	TBMB006
Maxillopoda				
Cyclopoida	*Mesocyclops notius*	1		1
Ostracoda	*Cypretta seurati*		1	

4.2.2. Troglofauna

No troglofauna was recorded from 10 samples at the Project in March 2017. This result is consistent with the predictions based on desktop review that any troglofauna community in the vicinity of the Project would be depauperate. The Proposal does not appear to contain good habitat for troglofauna.

5. RISK ASSESSMENT

The effects of mine development and operations on subterranean fauna communities can be broadly divided into two categories:

1. Primary impacts – possible extinction, or threat to the persistence of local populations, of subterranean fauna through the direct removal of habitat; and
2. Secondary impacts – reduction of population densities of subterranean fauna through a range of environmental factors, for example pollutants and increased turbidity (Appendix 3).

The consideration of secondary impacts requires detailed information about mine operations and typically does not form part of subterranean fauna assessments. Some background on factors causing secondary impacts is given in Appendix 3.

5.1.1. Potential Impacts on Stygofauna

Open cut mining at the Project will require a dewatering program to enable dry mining and stable pit walls. Abstracted groundwater is typically used in ore processing, ablutions and dust suppressions. Subsequent drawdown of aquifers poses a primary threat to stygofauna communities that occur within the dewatering footprint. In particular, species restricted to the impact footprint face possible extinction. Besides dewatering, the excavation of the pit itself cause complete loss of potential stygofauna habitat within the pit area, while construction of other infrastructure such as tunnels, drainage and tailing dams may degrade or remove networks of suitable habitat within the mine area, or could disrupt connectivity between populations on either side of the disturbance.

5.1.2. Potential Impacts on Troglofauna

Direct habitat loss through mine pit excavation is the primary mine-related threat to troglofauna. The extent of habitat loss will depend on the area and depth of mine pits and other excavations, as well as the occurrence and connectivity of suitable habitat outside the impact zone. Animals utilising small isolated pockets of habitat are more vulnerable to significant primary impacts than those inhabiting more extensive geologies.

5.1.3. Potential Impacts of the Project

Consistent with regional records collated in desktop review, results of field survey for subterranean fauna at the Project in March 2017 indicate that the area hosts a very depauperate stygofauna and there is no evidence of troglofauna. Habitats at the Project sampled during field survey included fractured rock and overlying colluvium. Previous records of stygofauna and troglofauna in the search area covered by desktop review have predominantly come from detrital habitats (alluvium/colluvium) that are regionally widespread and interconnected. Species recorded in this habitat are probably at least moderately widespread due to the extent and connectivity of this geology.

Based on the paucity of both stygofauna and troglofauna and the fact that the few recorded species are widespread, the Project is unlikely to threaten subterranean fauna in fractured rock and detrital habitats.

Several species of stygofauna have been recorded from regional calcrete PECs and further sampling in those formations may reveal significant richness. Depending on the degree of continuity between calcretes and surrounding detrital deposits, species recorded in calcretes are likely to have confined distributions. Troglofauna may also occur in calcretes but will not be threatened by the Project, given the limited extent of proposed excavations.

The nearest calcretes to the proposed pits form the Killara PEC approximately 18 km to the east. The Project lies on within the outer limits of the PEC buffer. Preliminary modelling of pit dewatering and subsequent drawdown indicate a relatively steep cone of depression (CDM Smith 2017), with groundwater drawdown of 2 m predicted to occur no more than 2.2 km from the edge of mine pits. Based on this model, drawdown will be negligible several kilometres from the mine pits. This suggests that calcrete aquifers will remain unaffected by pumping and, therefore, it is considered unlikely that the Project will influence water levels (and the volume of stygofauna habitat) in regional calcrete aquifers.

6. CONCLUSIONS

This assessment combined desktop review and Level 1 field survey to determine the likelihood that proposed gold mining at Gnaweeda will significantly threaten the conservation of subterranean fauna species or communities.

A moderate diversity of stygofauna and a depauperate troglofauna have been recorded in the vicinity of the Project. Most recorded species are from alluvium/colluvium and are likely to be at least moderately widespread.

Three main potential subterranean habitats occur at the Project – fractured rock in proposed pits, overlying detrital and regional calcretes. The former two habitats are of low prospectivity for subterranean fauna. Calcretes may harbour considerable richness but are at least 18 km from the proposed operations.

Survey results suggest that the Project hosts a depauperate stygofauna and no troglofauna. Considering the low prospectivity and at most depauperate assemblages of both stygofauna and troglofauna, species of which are likely to be widespread, the Project poses negligible threat to subterranean fauna species and communities. Based on preliminary drawdown modelling, groundwater abstraction will not affect water levels in regional calcretes and therefore will not cause stygofauna habitat loss. Calcrete aquifers will not be affected by excavations and therefore any troglofauna in calcretes will not be threatened.

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8. APPENDICES

Appendix 1. Higher-order omissions from the desktop review species list.

Stygofauna

Higher Classification	Lowest Identification	Number of records (Abundance)
Rotifera	Rotifera sp.	1
Eurotatoria		
Bdelloidea	Bdelloidea sp.	1
Crustacea		
Diplostraca	Diplostraca sp.	1
Maxillopoda	Copepoda sp.	13
Cyclopoida		
Cyclopoidae	Cyclopoidae sp.	2
	Cyclopoida sp.	7
Harpacticoida	Harpacticoida sp.	6
Popocopida		
Cyprididae	Cypretta sp.	1
Ostracoda	Ostracoda sp.	1
	Ostracoda sp. unident.	20
Annelida	Oligochaeta sp.	13
Haplotaxida		
Naididae	Pristina sp.	1

Troglofauna

Higher Classification	Lowest Identification	Number of records (Abundance)
Crustacea		
Malacostraca		
Isopoda	Isopoda sp.	3

Appendix 2. Characteristics of holes sampled during survey in March 2017.

Stygofauna							
Hole	**Latitude**	**Longitude**	**EC (µS cm^{-1})**	**pH**	**SWL (m)**	**Groundwater Depth (m)**	**End of Hole (m)**
TBMB001	-26.32865564	118.7855085	589	6.34	10.57	10.57	50
TBMB002	-26.32059914	118.7851545	1,191	6.56	11.16	11.16	51
TBMB003	-26.32307449	118.7849921	1,084	6.41	10.85	10.85	57
TBMB006	-26.3259663	118.7854572	1,049	6.28	10.24	10.24	57
TBMB009	-26.3285809	118.7842552	1,260	6.89	10.91	10.91	57
TBMB010	-26.3309598	118.7838709	1,168	6.53	10.2	10.2	57
TBMB011	-26.33460385	118.7848184	1,167	6.62	10.11	10.11	57
TBMB019	-26.32345544	118.7833953	1,076	6.58	10.34	10.34	57
TBMB022	-26.33642814	118.7825723	1,456	6.2	10.32	10.32	57
TBMB023	-26.32698193	118.7865346	1,111	6.51	10.64	10.64	21

Troglofauna					
Hole	**Sum of Latitude**	**Sum of Longitude**	**SWL (m)**	**Scrape**	**Trap depth (m)**
TBDD001	-26.32875437	118.7848288	11	Yes	9
TBRC076	-26.32945142	118.7846692	11	Yes	8
TBRC083	-26.32981736	118.7835529	11	Yes	5, 9
TBRC085	-26.33051097	118.784395	11	Yes	8
TBRC091	-26.32113153	118.7858939	12	Yes	6, 10
TBRC131	-26.32223591	118.7849192	12	Yes	10
TBRC141	-26.32040108	118.7851114	12	Yes	10
TBRC149	-26.31931583	118.7852751	12	Yes	10
TBRC157	-26.31862534	118.7841827	12	Yes	5, 10
TBRC166	-26.3178796	118.7853532	12	Yes	10

Appendix 3. 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 water table 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. 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.