APPENDIX J: SUBTERRANEAN FAUNA SURVEY REPORTS

Bennelongia Environmental Consultants

Lamb Creek Subterranean Fauna Survey Report

Prepared for:

Mineral Resources Limited

December 2021

Final Report

Short-Range Endemics I Subterranean Fauna

Waterbirds I Wetlands

Lamb Creek Subterranean Fauna Survey Report

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EXECUTIVE SUMMARY

The Lamb Creek Iron deposit (the Project), located approximately 90 km northwest of Newman in the Pilbara region of WA, has been the focus of mining interest for a number of years. Recently, Mineral Resources Limited (MRL) commenced exploring options to mine iron at the Project. As a part of the environmental investigations, MRL is investigating the presence of subterranean fauna to build on the knowledge base and assess the potential for impacts from proposed mining operations. Subterranean fauna can be divided into two broad groups: The air-breathing troglofauna that inhabit air filled spaces within the geological matrix between surface soil and groundwater, and the aquatic stygofauna that inhabit equivalent spaces below the water table.

Geology plays an important role in determining the presence or absence of subterranean fauna. Specifically, weathered geologies tend to contain the vugs and voids required to provide habitat for subterranean fauna. Geological data indicate that the Project and surrounding area contain these vugs and voids. This is supported by past surveys that have collected subterranean fauna at the Project area.

An onsite survey for subterranean fauna was conducted during 2021, following the general principles laid out for subterranean fauna sampling by the Environmental Protection Authority (EPA) in *Technical Guidance – subterranean fauna survey*, *Technical Guidance – sampling methods for subterranean fauna*, and the *Environmental Factor Guideline – subterranean fauna*. This involved net hauling for stygofauna and scraping and trapping for troglofauna.

The 2021 survey collected 29 stygofauna specimens belonging to five species, namely two species of amphipod and one species each of copepod, oligochaete worm and nematode worm. Additionally, 21 troglofauna specimens belonging to four species were collected, namely one species each of dipluran, beetle, centipede and millipede.

All of the animals collected during the 2021 survey were either previously collected at Lamb Creek and/or have a distribution extending beyond the perimeter of the Project area, except the troglofaunal centipede Chilenophilidae \`BGE053\`. Examination of historical sampling results revealed that two stygofauna species and four troglofauna species are currently only known from the Project area. These are the syncarid *Brevismobathynella* \`BSY222\`, the harpacticoid copepod *Parastenocaris* sp. B25, the schizomid *Draculoides* \`BSC026\`, the cockroach *Nocticola* sp. B31, the silverfish *Trinemura* sp. B25, and the beetle Zuphiini sp.

The two stygofauna species are believed to have been collected from within Brockman Iron Formation Whaleback Shale member at a location where there will be 12 m of groundwater drawdown. This is half of the thickness of the aquifer.

Block modelling has demonstrated that the main geological unit where troglofauna were mostly collected is the Brockman Iron Formation Dales Gorge D4 sub member, while the deeper Dales Gorge D2 sub member also contains appropriate subterranean spaces. Based on available modelling, these geologies form continuous habitat above the watertable and extending outside of the proposed pit, suggesting that suitable habitat for the troglofauna species known only from within the pit extends into surrounding undisturbed areas.

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1. INTRODUCTION

The Lamb Creek Iron deposit (the Project) located approximately 90 km northwest of Newman in the Pilbara region of WA (Figure 1), has been the focus of mining interest for a number of years. Most recently, Mineral Resources Limited (MRL) commenced exploring options to mine iron at the Project. MRL plans to incorporate production of iron ore from Lamb Creek with other resources in the direct vicinity and to utilise existing infrastructure at Utah Point for export to global markets.

As a part of the environmental investigations, MRL is investigating the presence of subterranean fauna at the Project to build on the knowledge base and assess the potential for impacts from proposed mining operations. Subterranean fauna can be divided into two broad groups: 1) The air-breathing troglofauna that inhabit air filled spaces within the geological matrix, between surface soil layers and groundwater (i.e. the vadose zone), and 2) the aquatic stygofauna that inhabit equivalent spaces below the water table (Moldovan *et al.* 2018). Troglofauna may be impacted by mining through the direct removal of habitat resulting from the excavation of mine pits, while stygofauna can be additionally impacted through groundwater drawdown associated with dewatering to enable dry mining or with the groundwater abstraction necessary to provide processing water. Both troglofauna and stygofauna are scientifically valuable because of their unique biodiversity, high levels of endemism and ancient origins and also provide a variety of ecosystem functions (EPA 2016a).

1.1. Subterranean Fauna Background

Pilbara stygofauna and troglofauna are thought to have colonised their subterranean habitats before and during the aridification of the region over the past 15 million years (Byrne *et al.* 2008). Despite their long history of resilience to the aridification of the Australian biomes, the limited dispersal abilities and thus small ranges of subterranean species result in a great vulnerability to anthropogenic activities that interfere with underground habitats (EPA 2016a).

Understanding of the subterranean fauna in the Pilbara has progressed immensely since the 1990s (Humphreys 1999 Eberhard *et al.* 2005) as a result of sampling that has been mostly driven by the assessments of potential impacts of mining on these formations. The diversity of the region is now estimated to be around 1300 species of stygofauna, and at least another 1500 species of troglofauna (Halse 2018a, Halse 2018b) but reliable estimates are hindered by a developing and sometimes non-existent taxonomic framework for the animal groups encountered. It is, however, well established that the diversity of subterranean fauna is closely linked to the geology of an area because subterranean species can only colonise areas with appropriate spaces for animals to inhabit. This includes interstitial species in alluvium, or fissures, vugs and voids in various chemically deposited or bedrock formations. Geologies supporting rich troglofauna communities include alluvium, a variety of mineralised or weathered iron formations, and calcrete. Stygofauna communities are usually richest in alluvial and calcrete aquifers, especially within palaeochannels (Halse 2018a). As a result of species occurrence being determined by geology and, particularly, the availability and nature of subterranean spaces, the composition and richness of both stygofauna and troglofauna communities often varies significantly over short distances. In order to achieve a reliable estimate of the diversity and composition of the subterranean fauna of an area, knowledge of local geology and hydrogeology needs to be coupled with biological survey.

1.2. Framework

The approach to protection of subterranean fauna is laid out in the Environmental Protection Authority's *Technical guidance: sampling methods for subterranean fauna* (EPA 2016b). Subterranean fauna are also afforded a general level of protection under the Biodiversity Conservation (BC) Act (2016). Special protection is provided to those species or communities listed as endangered, threatened or otherwise in need of special protection and the list of Western Australian threatened species contains many subterranean fauna species, including crustaceans, arachnids and myriapods. Additionally, the Department of Biodiversity, Conservation and Attractions (DBCA) maintains a list of priority fauna species and communities that are of conservation importance, but for various reasons do not meet the criteria for listing as threatened.

2. PREVIOUS SUBTERRANEAN FAUNA SURVEYS

Three surveys for subterranean fauna (one stygofauna and two troglofauna) were conducted at the Project as a part of investigations for a previous proponent (Bennelongia 2013). These surveys encompass a broader area at Lamb Creek than the current survey. The results of these surveys have been revised to include updated taxonomic information and incorporated into Table 3 and Table 4 below, together with the results of the current survey.

Previous surveys in 2011 and 2013 (see Table 3) resulted in the collection of 13 stygofauna species including annelid worms (four species), amphipods (three species), syncarids (two species), copepods (two species), isopods (one species) and nematode worms (not assessed as a part of the EIA process).

A total of 19 species of troglofauna were collected during the 2011/2013 surveys (Table 4). This includes schizomids (three species), diplurans (three species), cockroaches (two species), beetles (two species), silverfish (two species), centipedes (two species), spiders (one species), palpigrads (one species), flies (one species), bugs (one species) and symphylans (one species).

3. GEOLOGY AND HYDROGEOLOGY

Broad scale bedrock data (Government of Western Australia 2021) indicates that the project lies over Banded Iron Formation (BIF), a geology known to contain appropriate vugs and voids for subterranean fauna, particularly troglofauna (ecologia 2009; GHD 2009 Halse 2018b). This is supported by surface geology mapping (Thorne and Tyler 1997), in which BIF is also identified as forming outcropping ranges, with colluvium and alluvium collected in low lying areas such as drainage lines and floodplains (Table 1, Figure 2). Historically, it was believed that weathering of the iron-rich bedrock has produced a widespread regolith profile known as hardcap in the Project area; however more recent work has resulted in a shift in understanding towards this being one of a number of sub members of the Dales Gorge member. This uppermost iron formation layer is variable in depth and contains abundant voids and cavities ranging in size from 10 to 30 mm. There is some infilling with secondary materials such as goethite, quartz, maghemite, clay and opaline silica (Bennelongia 2013). At the time of sampling, the depth to water ranged between 28.5 m to 79 m below ground level (bgl), providing ample space within the vadose zone for the presence of obligate troglofauna species.

Sections of palaeovalleys with high transmissivity are likely to provide good habitat for stygofauna because large interstitial spaces are available. While there are no known palaeovalleys directly underneath the Project area, branches of the Yandicoogina palaeovalley occur relatively close to the north side of the Project (Figure 3). Groundwater in the Project area at the time of sampling had a pH ranging between 4.59 and 7.09 and an Electrical Conductivity of between 97 and 817 µS/cm. This water quality is well within the habitable range of stygofauna. Thus, the likelihood of finding stygofauna at, or near, the Project appears to be high except that depth to water at this site was between 28.5 m to 79 m bgl. Occurrence of stygofauna declines markedly when depth to groundwater is greater than 30 m (Halse *et al.* 2014).

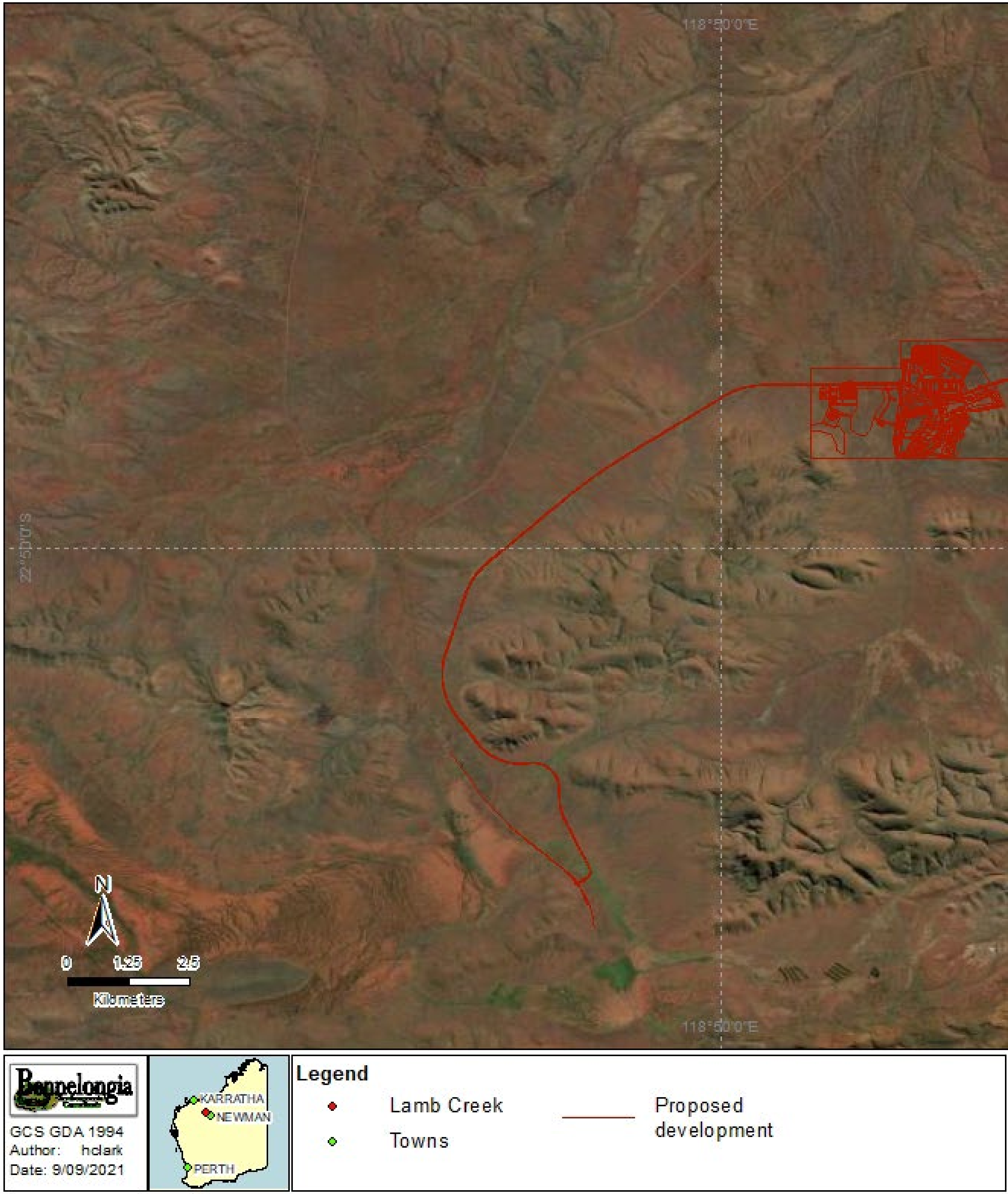
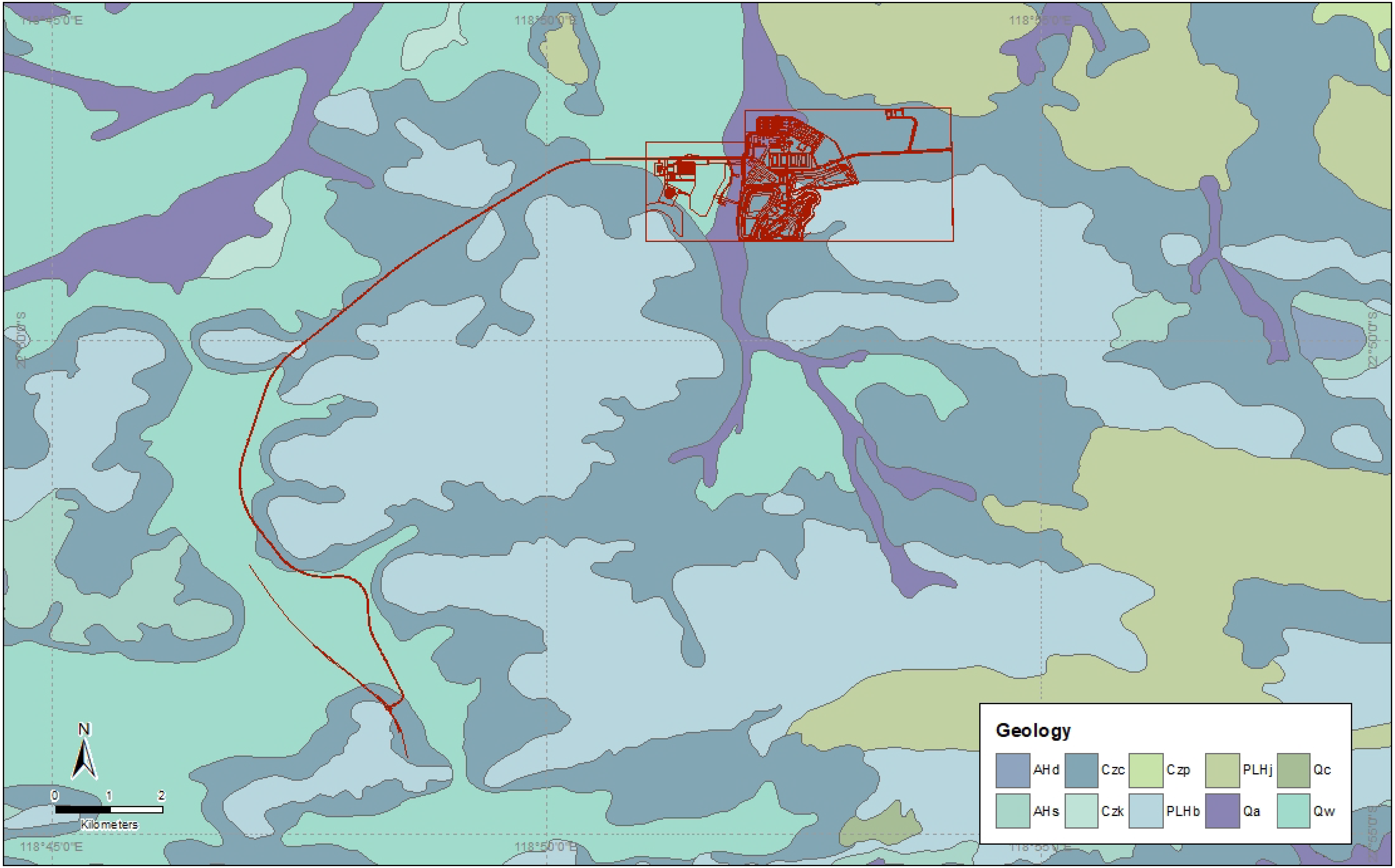


Figure 1. Location of The Project in relation to Newman, Karratha and Perth



Biota
GCS GDA 1994
Author: hclark
Date: 9/09/2021

KARRATHA
NEWMAN
PERTH

Legend

- Lamb Creek
- Towns
- Proposed development

Figure 2. Surface Geology at the Project Area.

Table 1: Descriptions of geology found in the region of the Project.

Geological Code	Description
AHd	WITTENOOM FORMATION: thin- to medium-bedded metadolomite, dolomitic pelite, chert, and metamorphosed volcanic sandstone
AHs	MOUNT McRAE SHALE and MOUNT SYLVIA FORMATION: pelite, chert, and banded iron-formation
Czc	Colluvium-partly consolidated quartz and rock fragments in silt and sand matrix; old valley-fill deposits
Czk	Calcrete-sheet carbonate; found along major drainage lines
Czp	ROBE PISOLITE: pisolitic limonite deposits developed along river channels
PLHb	BROCKMAN IRON FORMATION: banded iron-formation, chert, and pelite
PLHj	WEELI WOLLI FORMATION: banded iron-formation (commonly jaspilitic), pelite, and numerous metadolerite sills
Qa	Alluvium_unconsolidated silt, sand, and gravel; in drainage channels and on adjacent floodplains
Qc	Colluvium-unconsolidated quartz and rock fragments in soil; locally derived soil, and scree, and talus deposits
Qw	Alluvium and colluvium-red-brown sandy and clayey soil; on low slopes and sheetwash areas

Figure 3. Palaeovalleys surrounding the Project Area.

4. METHODS

The subterranean fauna surveys reported here were conducted according to the general principles laid out for subterranean fauna sampling by the Environmental Protection Authority (EPA) in *Technical Guidance – subterranean fauna survey* (EPA 2016c), *Technical Guidance – sampling methods for subterranean fauna* (EPA 2016b), and the *Environmental Factor Guideline – subterranean fauna* (EPA 2016a).

4.1. Troglofauna

As far as possible, each troglofauna sample represents the combined results of two different, complementary sampling techniques: scraping and trapping. Previous studies have shown that use of both techniques yields greater diversity of troglofauna than either technique alone. Furthermore, troglofauna occur at low abundance and yields are low, so that use of two techniques contributes significantly to obtaining a representative sample of the troglofauna community in a sampling area (Halse and Pearson 2014):

1. **Scraping** is undertaken prior to setting traps. In each scraping event, a troglofauna net is prepared with a weighted ring net of 150 µm mesh, and a diameter closely matched to 60% of the bore diameter. This net is lowered to the bottom of a bore or to the water table, and subsequently scraped back to the surface at least four times. In each of these *scrapes* a different section of the wall of the hole is targeted (e.g., north, south) to maximize the organisms retrieved. The contents of each scrape are immediately transferred to 100% ethanol for preservation of the sample and its DNA.

2. **Trapping** uses traps of cylindrical PVC (270 x 70 mm) with holes drilled on the side and top to function as entrances and a bait of microwaved leaf litter. Traps are lowered on nylon cord to the end of the bore, or to a few metres above the water table. For most holes, one trap was set near the bottom of the drill hole or just above the water table, which varied between 10 and 60 m. At about one-quarter of holes, a second trap was set approximately halfway between the surface and the first trap. Traps were then left inside bores for seven to 10 weeks, allowing troglofauna enough time to colonize them. During that period, the bores were sealed to minimise movement of surface animals into the troglofauna traps. When traps are retrieved, their contents were transferred to a zip-lock bag and transported alive to the laboratory in Perth.

4.2. Stygofauna

Stygofauna were sampled at each hole using a small, weighted plankton net that was lowered to the bottom of the hole and then agitated vigorously to stir benthic and epibenthic fauna into the water column, where animals were then captured as the net was slowly retrieved. Six separate net hauls were made (three with 50 µm mesh net and three with 150 µm mesh net). The contents of the net were transferred to 100% ethanol for preservation after each haul (EPA 2016b). Contamination between sites was avoided by washing the nets between the sampling of different drill holes.

4.3. Survey Effort

The 2021 subterranean fauna survey comprised 26 stygofauna samples and 35 troglofauna samples (Table 2). Each troglofauna sample comprised the total catch from the scrape and trap sub-samples from that hole, i.e. the number of troglofauna samples is calculated in Table 2 by adding the number of holes scraped to the number with traps set and dividing by two. The full lists of holes visited and samples taken are given in Appendix 1. The distribution of holes sampled for stygofauna and troglofauna can be viewed at Figure 4.

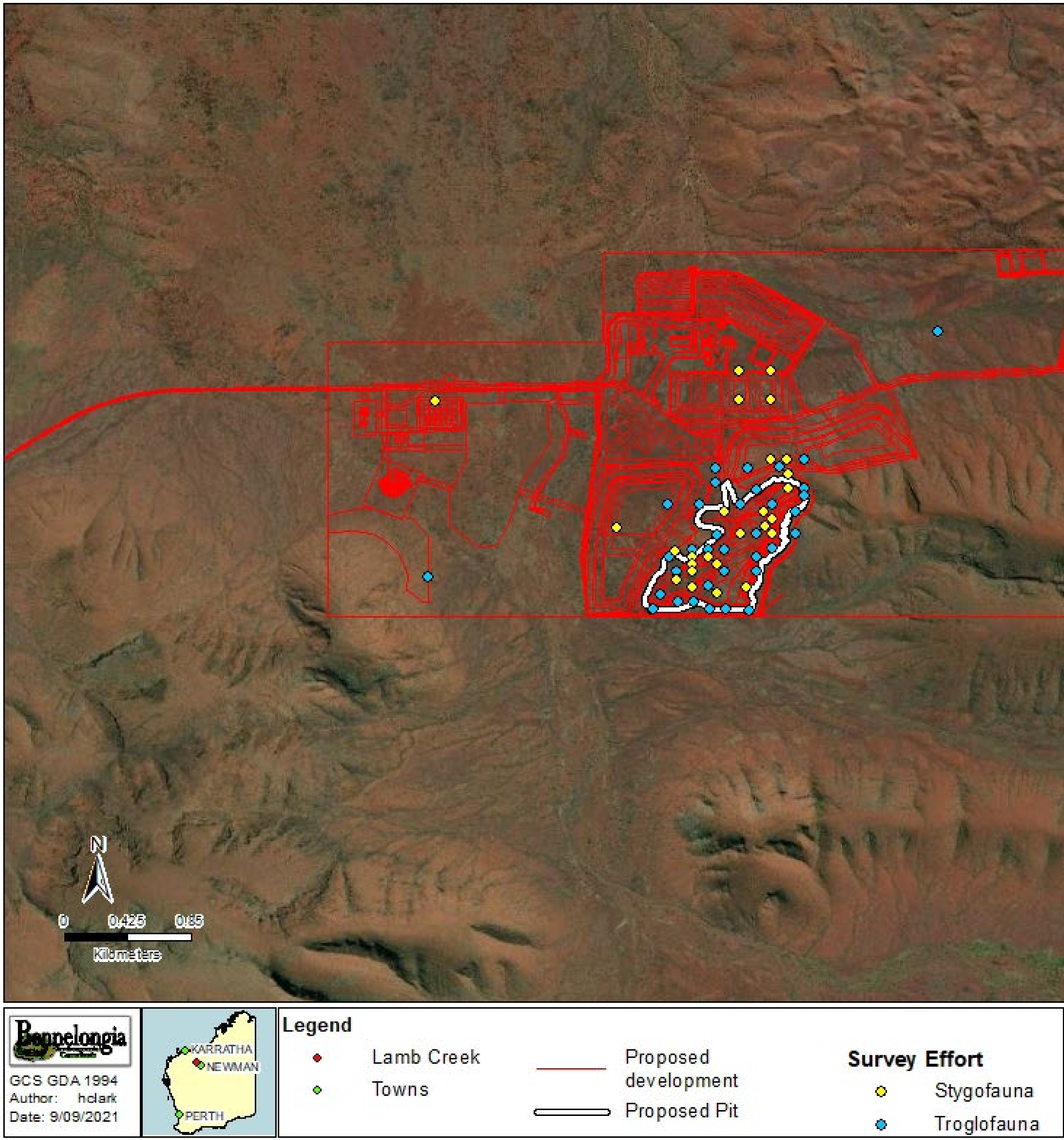


Figure 4. 2021 survey effort at the Project Area.

Table 2: Sample Effort for the 2021 subterranean fauna survey.

Sample Type	No of Net Hauls	No of Scrapes	No of Trap Samples	Total
Stygofauna	26			26
Troglofauna		35	35	35

4.4. Laboratory Processing

All samples were sorted in the laboratory. Leaf litter retrieved from traps was processed in Berlese funnels under halogen lamps for 72 hours, during which time the light and heat drives animals downwards and towards a vial containing 100% ethanol as a preservative. Litter was quickly checked after removal from the funnels to ensure no invertebrates remained.

Samples in ethanol from the Berlese fennels were carefully screened under a dissecting microscope. Troglofauna scrape samples and stygofauna net samples were elutriated to separate animals from sediment and put through sieves to fractionate the contents according to size (53, 90 and 250 μm) to improve searching efficiency prior to screening under a dissecting microscope. All potential subterranean animals were removed from samples during screening for later species or morpho-species level identification. Surface animals were identified to Order level.

Troglofauna and stygofauna identification were made using published, unpublished and informal taxonomic keys, as well as species descriptions in the scientific literature. Morphospecies were established using the characters of existing species keys, and the lowest level of identification possible was reached given the constraints of sex, maturity of the specimens (juveniles and females are often impossible to identity to species level) and possible damage to body parts. During the final phase of identification, dissecting and compound microscopes were used, with the process often requiring dissection of specimens. After the taxonomic assessment was completed, representative animals were lodged with the Western Australian Museum.

4.5. Personnel

Fieldwork was conducted by Jim Cocking, Sam Chidgzey and Melanie Fulcher. Sample sorting was conducted by Melanie Fulcher, Melita Pennifold, Will Fleming, Sam Chidgzey, Heather McLetchie and Monique Moroney. Species identifications were conducted by Jane McRae and Heather McLetchie. Report writing and mapping was conducted by Huon Clark and mapping was conducted by Huon Clark and Melanie Fulcher.

5. RESULTS

5.1. Stygofauna

The 2021 survey resulted in collection of 29 stygofauna specimens belonging to five species (Figure 5 and Table 3), namely two species of amphipod, and one species each of oligochaete worm, copepod and nematode worm (nematodes are not assessed as a part of the EIA process). All of these species were collected in sampling during 2013. All have ranges extending beyond the boundaries of the survey area (Table 3).

Reviewing the results of historical sampling revealed two stygofauna species that are restricted to the survey area (Figure 6). These are the syncarid *Brevismobathynella* `BSY222` and the harpacticoid copepod, *Parastenocaris* sp. B25, both located 1.3km from the nearest edge of the proposed pit (Table 3). These species are discussed in more detail below.

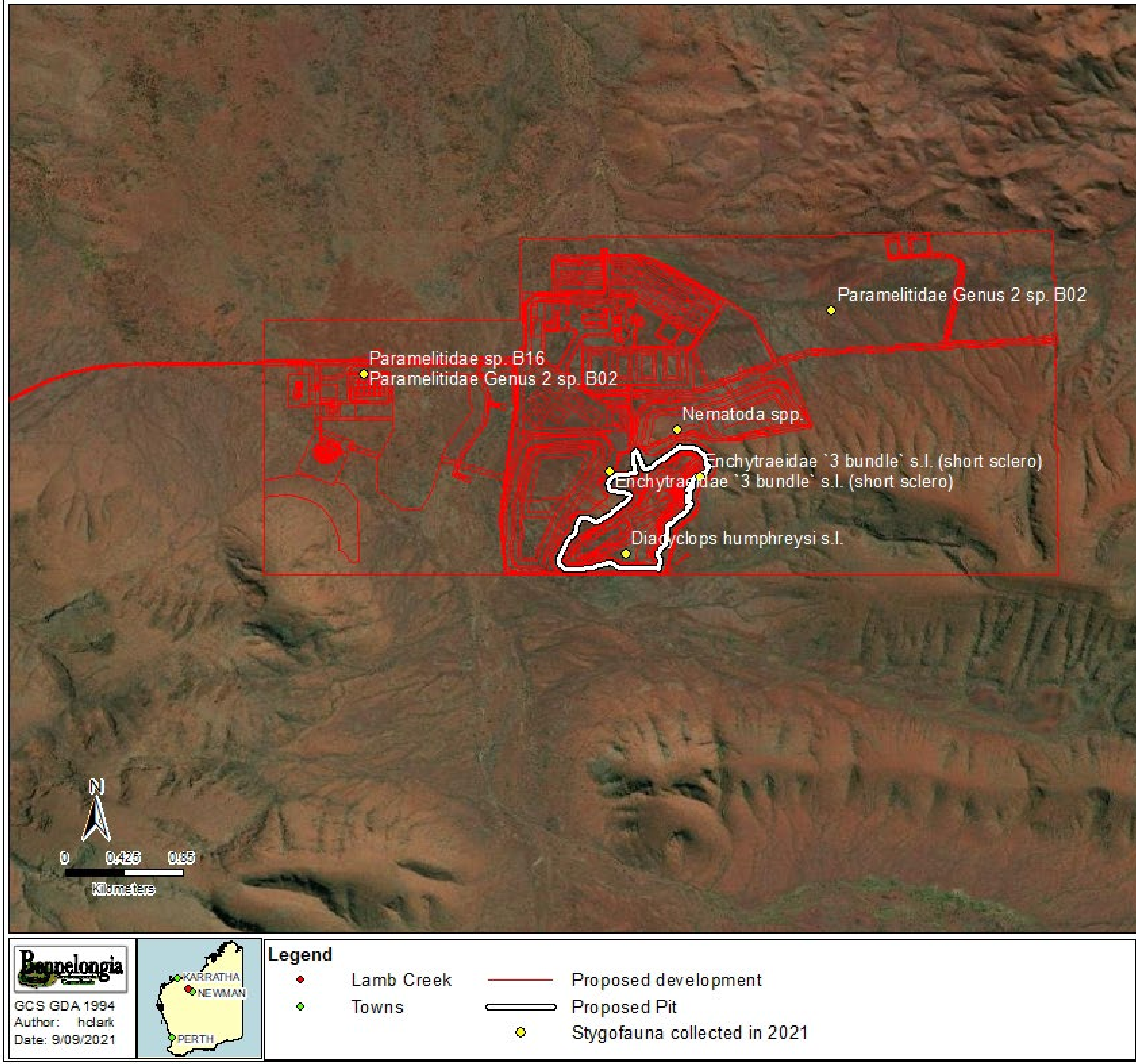


Figure 5. Stygofauna collected during the 2021 survey.

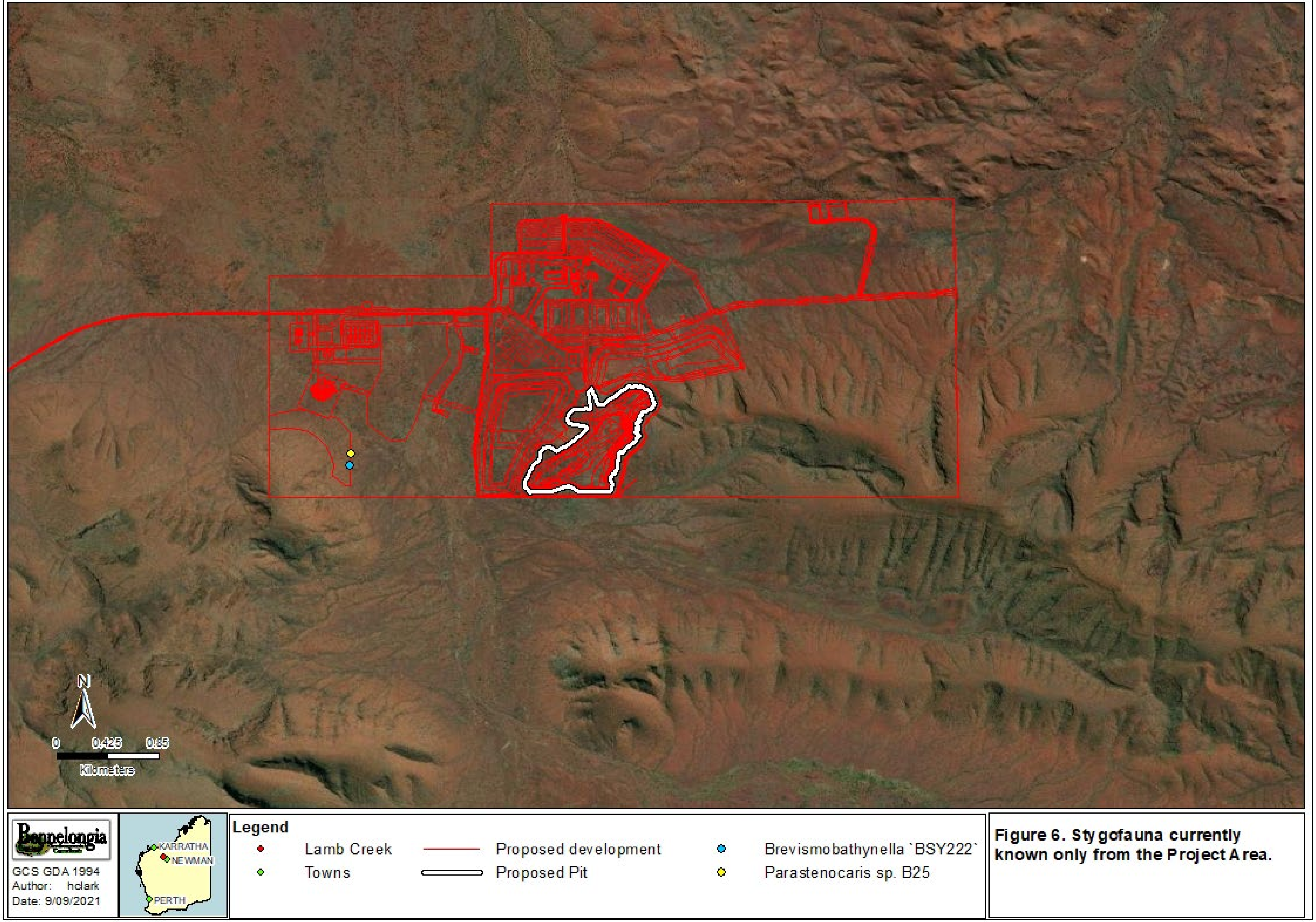


Figure 6. Stygofauna currently known only from the Project Area.

Table 3: Past and present stygofauna survey results at Lamb Creek

Higher Order ID	Lowest Identification	Survey		Distribution	Notes
		2013	2021		
Annelida					
Clitellata					
Oligochaeta					
Enchytraeida					
Enchytraeidae					
Enchytraeus	Enchytraeidae `3 bundle` s.l. (short sclero)	7	2	Widespread	This name represents a morphological alignment of immature animals that may belong to multiple species. Taxonomy of the family is poorly understood
Haplotaxida					
Tubificina					
Phreodrilidae					
Insulodrilus	*Insulodrilus lacustris*	20		Known throughout the Pilbara	
	Phreodrilidae sp. AP DVC s.l.	4		Known throughout the Pilbara	This name represents a morphological alignment of immature animals that may belong to multiple species
	Phreodrilidae sp. AP SVC s.l.	8		Known throughout the Pilbara	This name represents a morphological alignment of immature animals that may belong to multiple species
Arthropoda					
Crustacea					
Malacostraca					
Eumalacostraca					
Amphipoda					
Paramelitidae					
Maarrka	*Maarrka weeliwollii*	4		Known linear range of approx. 90 km	
Paramelitidae Genus 2	Paramelitidae Genus 2 sp. B02	100	8	Known linear range of approx. 70 km	
	Paramelitidae sp. B16	6	8	Known linear range of approx. 50k m	
Isopoda					
Tainisopidae					
Pygolabis	*Pygolabis* sp.	1		higher order identification. Difficult to ascertain distribution	

Higher Order ID	Lowest Identification	Survey		Distribution	Notes
		2013	2021		
Syncarida					
Bathynellaceae					
Parabathynellidae					
Brevismobathynella	*Brevismobathynella* \`BSY222\`	4		Known only from this location	1.3 km from edge of pit
nr Billibathynella	nr *Billibathynella* sp. B02 (=Parabathynellidae sp. S03)	1		Known linear range of approx. 77 km	
Maxillopoda					
Copepoda					
Cyclopoida					
Cyclopidae					
Diacyclops	*Diacyclops humphreysi* s.l.	46	8	Widespread in central Pilbara?	Shown genetically to be species complex but probably widespread outside Project area. Complex occurs throughout Pilbara and beyond
Harpacticoida					
Parastenocarididae					
Parastenocaris	*Parastenocaris* sp. B25	4		Known only from this location	1.3 km from edge of pit
Nematoda	Nematoda sp.	5	3	Not assessed as part of the EIA process	

5.2. Troglofauna

The 2021 survey collected 21 troglofauna specimens belonging to four species (Table 4 and Figure 7). There were single species of dipluran, beetle, centipede and millipede. Two of the species were previously collected at the Project. Of the remaining two, one is widespread in the Pilbara. The other species, the centipede Chilenophilidae \`BGE053\`, is known only from the Project but it was collected outside of the current proposed pit boundaries (Figure 7).

Review of historical sampling found that four of those species are known only from within the proposed pit boundaries (Figure 8). These species are the schizomid *Draculoides* \`BSC026\`, the cockroach *Nocticola* sp. B31, the silverfish *Trinemura* sp. B25 and the higher order beetle identified as Zuphiini sp. (Table 4) and these are discussed in more detail below. Records of higher order identifications that could not be identified to species level but could be members of species listed in Table 4 can be found in Appendix 2.

Table 4: Past and present troglofauna survey results at Lamb Creek

Higher Order Identification	Lowest Identification	Survey			Distribution	Distribution compared to planned pit
		2011	2013	2021		
Arthropoda						
Chelicerata						
Arachnida						
Araneae						
Opisthothelae						
Oonopidae						
Prethopalpus	*Prethopalpus* sp. B27		1		Known only from this site	Outside
Palpigradi	Palpigradi sp. B15		1		Known only from this site	Outside
Schizomida						
Hubbardiidae						
Draculoides	*Draculoides* \`BSC025\`		1		Known only from this site	Outside
	Draculoides \`BSC026\`		1		Known only from this site	Inside
	Draculoides \`BSC027\`		2		Known linear distribution of 11 km	Outside
Hexapoda						
Entognatha						
Diplura						
Japygidae	Japygidae \`BDP157\`		1		Known only from this site	Outside
	Japygidae \`DPL002\` s.l.		1	1	Known linear distance of approx. 330km. This taxon may be made up of multiple species	Outside
	Japygidae sp. B34		1		Known linear distribution of 10.5 km	Outside
Insecta						
Blattodea						
Nocticolidae						
Nocticola	*Nocticola* sp. B10		24		Known Linear distribution of approx. 20 km	Outside
	Nocticola sp. B31	4	4		Only known from Lamb Creek. Known linear distribution of 200 m	Inside
Coleoptera						
Carabidae	Zuphiini sp.		6		Higher order identification. Difficult to ascertain distribution	Inside
Curculionidae						
Curculionidae Genus 1	Curculionidae Genus 1 sp. B02 (=Curculionidae sp. S02)		5	1	Known linear distance of approx. 30km	Inside and outside
Diptera						

Higher Order Identification	Lowest Identification	Survey			Distribution	Distribution compared to planned pit
		2011	2013	2021		
Sciaridae						
Allopnyxia	*Allopnyxia* sp. B01		1		Widespread throughout the Pilbara	Widespread
Hemiptera						
Meenoplidae						
Phaconeura	*Phaconeura* sp. B08		27		Known only from Lamb Creek, known linear distribution of approx. 850m	Outside
Zygentoma						
Nicoletiidae						
Dodecastyla	*Dodecastyla* sp. B02 (=*Atelurodes* sp. S02)		8		Widespread throughout the Pilbara	Widespread
Trinemura	*Trinemura* sp. B25		1		Known only from this site	Inside
Myriapoda						
Chilopoda						
Geophilida						
Chilenophilidae						
Ribautia	*Ribautia* sp. B02		1		Known only from this site	Outside
	Chilenophilidae `BGE053`			1	Known only from this site	Outside
Scolopendrida						
Scolopendridae	Scolopendridae sp. B02		1		Known only from this site	Outside
Diplopoda						
Polyxenida						
Lophoproctidae						
Lophoturus	*Lophoturus madecassus*			18	Widespread throughout Western Australia	Widespread
Symphyla						
Cephalostigmata						
Scutigerellidae						
Hanseniella	*Hanseniella* sp. B21		3		Known only from Lamb Creek. Linear range of approx. 850 m	Outside

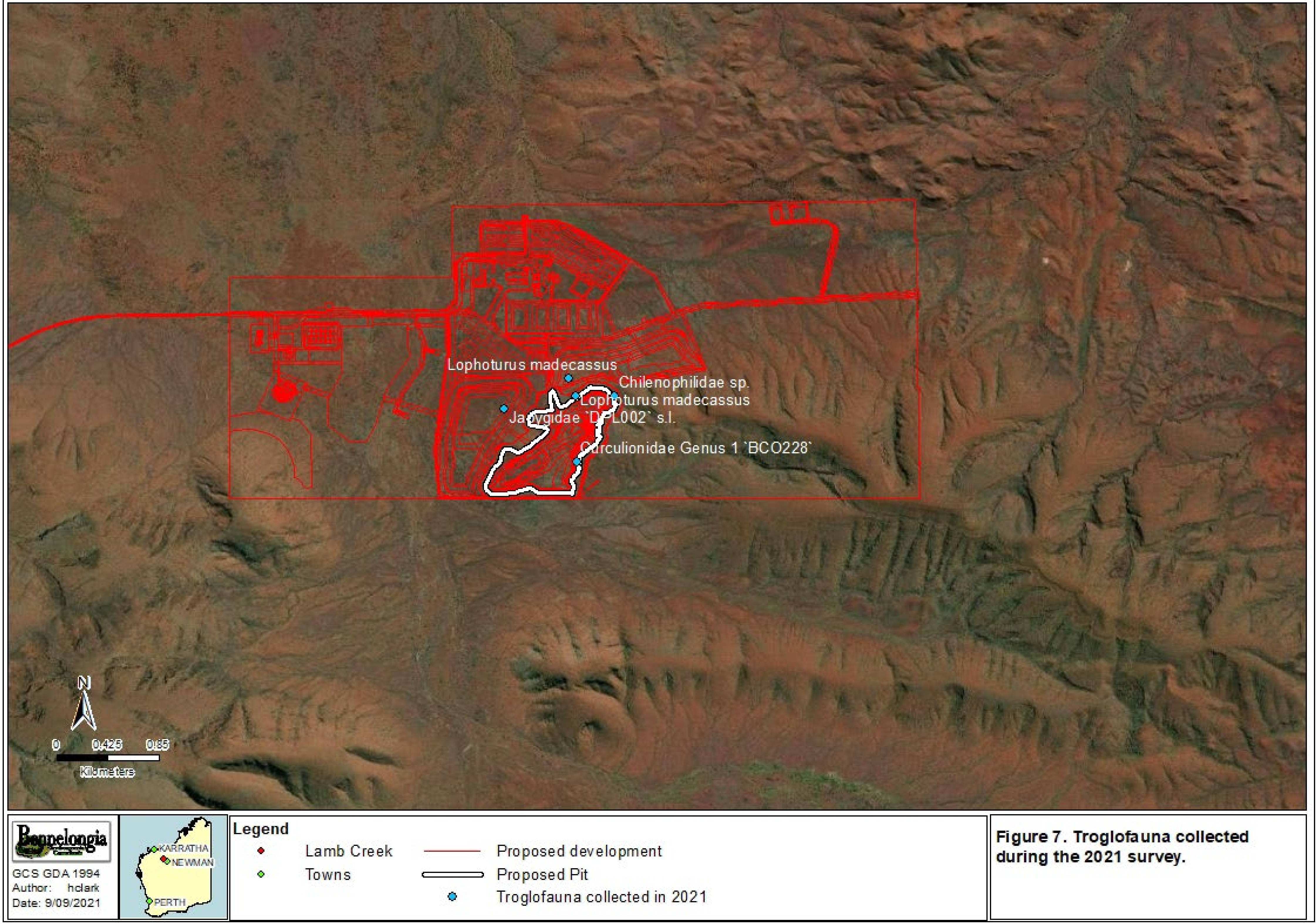
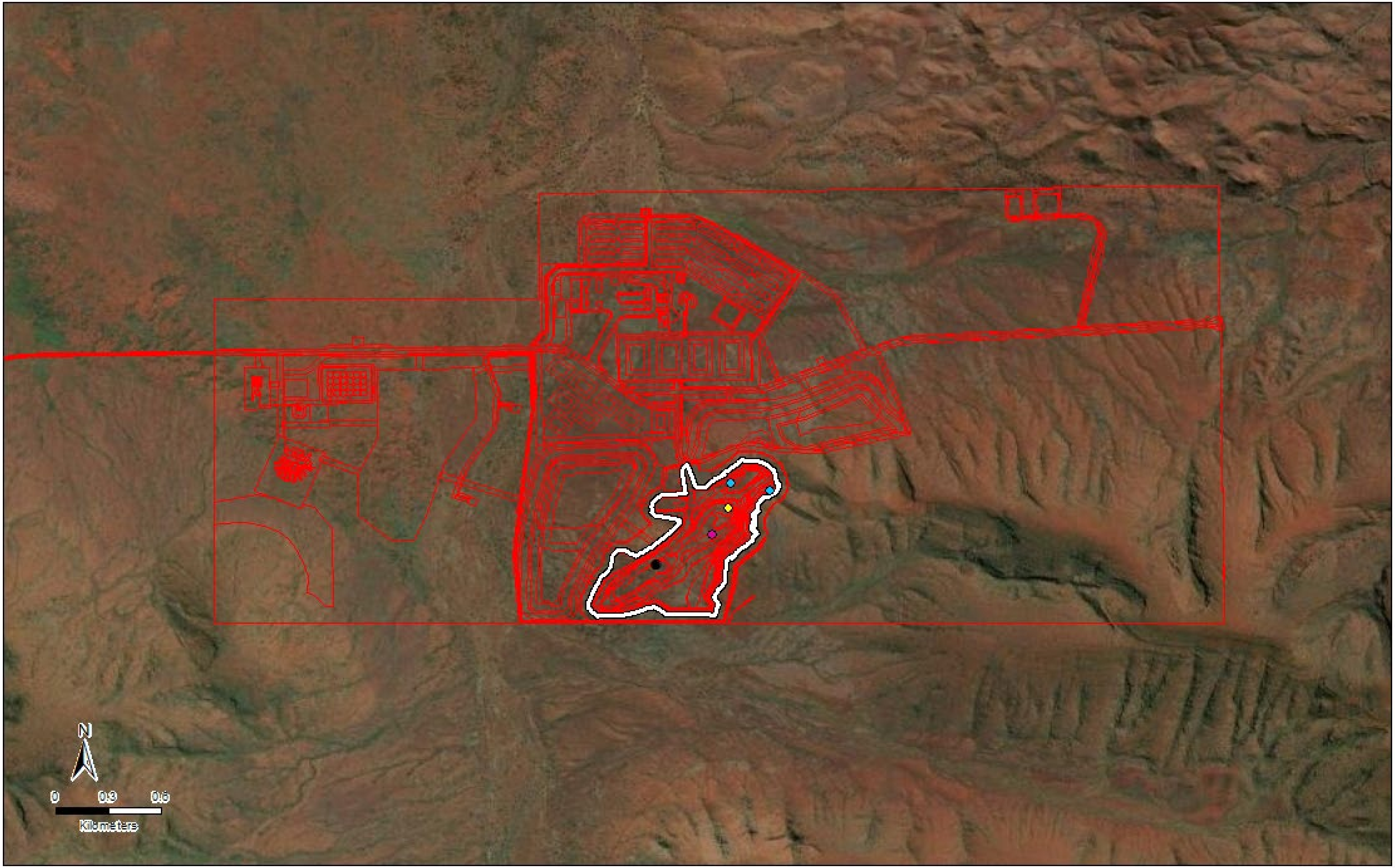


Figure 7. Troglofauna collected during the 2021 survey.



GCS GDA 1994
Author: mfulcher
Date: 16/11/2021

Legend

- Lamb Creek
- Towns
- Proposed development
- Proposed Pit
- Draculoides `BSC026`
- Nocticola sp. B31
- Trinemura sp. B25
- Zuphiini sp.

Figure 8. Troglofauna species currently known only from within the proposed pit.

6. DISCUSSION

The geology of the project and surrounding area is considered to contain suitable habitat for subterranean fauna. Species and communities of both stygofauna and troglofauna have been collected from BIF before and historical sampling at the project has also demonstrated this. The 26 stygofauna samples collected in the 2021 survey yielded 29 stygofauna specimens of five species (Table 3), including members of the amphipods (two species), annelid worms, copepods and nematode worms. Additionally, the 21 troglofauna specimens of four species (Table 4), including diplurans (one species), beetles (one species), centipedes (one species) and millipedes (one species) were collected from 35 samples (Table 2).

6.1. Stygofauna

All of the stygofauna species collected in 2021 have been collected in historical sampling events at the Project Area during sampling in 2013 and have distributions extending well beyond the Project Area. Investigations into historical sampling revealed two species that are currently only known from the project area. These species are the syncarid, *Brevismobathynella* \`BSY222\` and the harpacticoid copepod, *Parastenocaris* sp. B25. Each of these species have been collected from single bores located approximately 1.3 km from the proposed pit (Figure 6).

***Brevismobathynella* \`BSY222\`**

Syncarids are small crustaceans that are almost exclusively groundwater inhabitants. The Western Australian syncarid fauna is significantly diverse (Guzik *et al.* 2008; Perina *et al.* 2018). The ranges of many syncarid species are typically small with many species endemic to single aquifers or sections of regional aquifers (Guzik *et al.* 2008).

While many syncarid species are restricted to specific calcrete aquifers or palaeodrainages, these species are well adapted to life in interstitial spaces through both morphological adaptation (elongate body and reduced appendages) and life history traits such as multiple non-resting larval stages (Cho *et al.* 2006). When interstitial spaces fill up with materials such as clays, movement of syncarids can become restricted (Guzik *et al.* 2008).

A total of four *Brevismobathynella* \`BSY222\` were collected from a single bore (BY072) over two occasions in 2013. The standing water level at the time of sampling was 41.5 m bgl in March 2013 and 34 m bgl in June 2013. The end of hole was at 48 m bgl. Water chemistry recorded at this site is fresh with a recorded electrical conductivity (EC) of between 486 and 547 µS/cm and a neutral pH between 6.88 and 7.19. Unfortunately, stygofauna samples were unable to be taken at this hole in 2021 as the bore could not be accessed past 5 m bgl.

Parastenocaris sp. B25

Harpacticoid species in the Pilbara have variable ranges (Karanovic 2006), with most occupying one or two sub-regions (see Halse *et al*. 2014). A relatively high proportion of the stygal harpacticoid species in the Pilbara and surrounding areas, including Cape Range, have been described (e.g. Karanovic 2006, 2010; Karanovic and Cooper 2012; Karanovic and Hancock 2009; Karanovic and McRae 2013).

Four individuals of *Parastenocaris* sp. B25 were collected in 2013. The depth to water was 40 m bgl and the end of hole was 45 m bgl. This bore was sampled three times in 2013 however *Parastenocaris* sp. B25 was only collected once. Water chemistry was fresh with an EC of between 482 and 516 µS/cm while the pH ranged between 6.98 and 7.23. This bore was not resampled in 2021.

6.2. Habitat and distribution

Hydrogeological modelling of the Project area shows a mine creek catchment area extending north and south of the Project (PSM Consult 2021). Within this, the geology largely determines the transmissivity whereby BIF ranges contain low transmissivities and alluvial/colluvial valleys are areas of preferential flow (PSM Consult 2021). it is within the lower lying areas of preferential flow where dewatering is likely to have the greatest influence.

Both *Brevismobathynella* `BSY222` and *Parastenocaris* sp. B25 were collected from bores approximately 1.4 km from the edge of the pit at the base of a range extending to the south west (Figure 9). Worst case scenario drawdown at the two bores in question is roughly 12 m (Figure 10). The aquifer at this location is a minimum 24 m thick, meaning up to 50 % of the aquifer will be removed at the height of operational drawdown (Mineral Resources Ltd 2021). The aquifer sits within the Brockman Iron Formation Whaleback Shale member, which consists of bands of weathered, partially mineralised supergene Banded Iron Formation (BIF) and a shale unit (Figure 11). This shale unit may act as a low flow hydraulic barrier (Mineral Resources Ltd 2021). This has the potential to provide some protection against drawdown within the stygofauna habitat (Mineral Resources Ltd 2021) however may also restrict movement of stygofauna species throughout the region.

Impacts to stygofauna will be minimised by a short project timeframe and quick groundwater recovery, the majority of which will occur within three years of cessation of groundwater abstraction (PSM Consult 2021).

6.3. Troglofauna

A similar situation has been identified when looking at troglofauna. Three of the four species of troglofauna have distributions extending well beyond the boundaries of the Project Area and/or have been collected in previous sampling in 2011 or 2013 (Table 4). One of the species, the centipede Chilenophilidae `BGE053`, is restricted to the project area but was collected marginally (16 m) outside the proposed pit (Figure 7). Analysis of historical sampling revealed four species that are currently only known from within the proposed pit boundaries. These species are the schizomid *Draculoides* `BSC026`, the cockroach *Nocticola* sp. B31, the silverfish *Trinemura* sp. B25 and the beetle Zuphiini sp. (Figure 8).

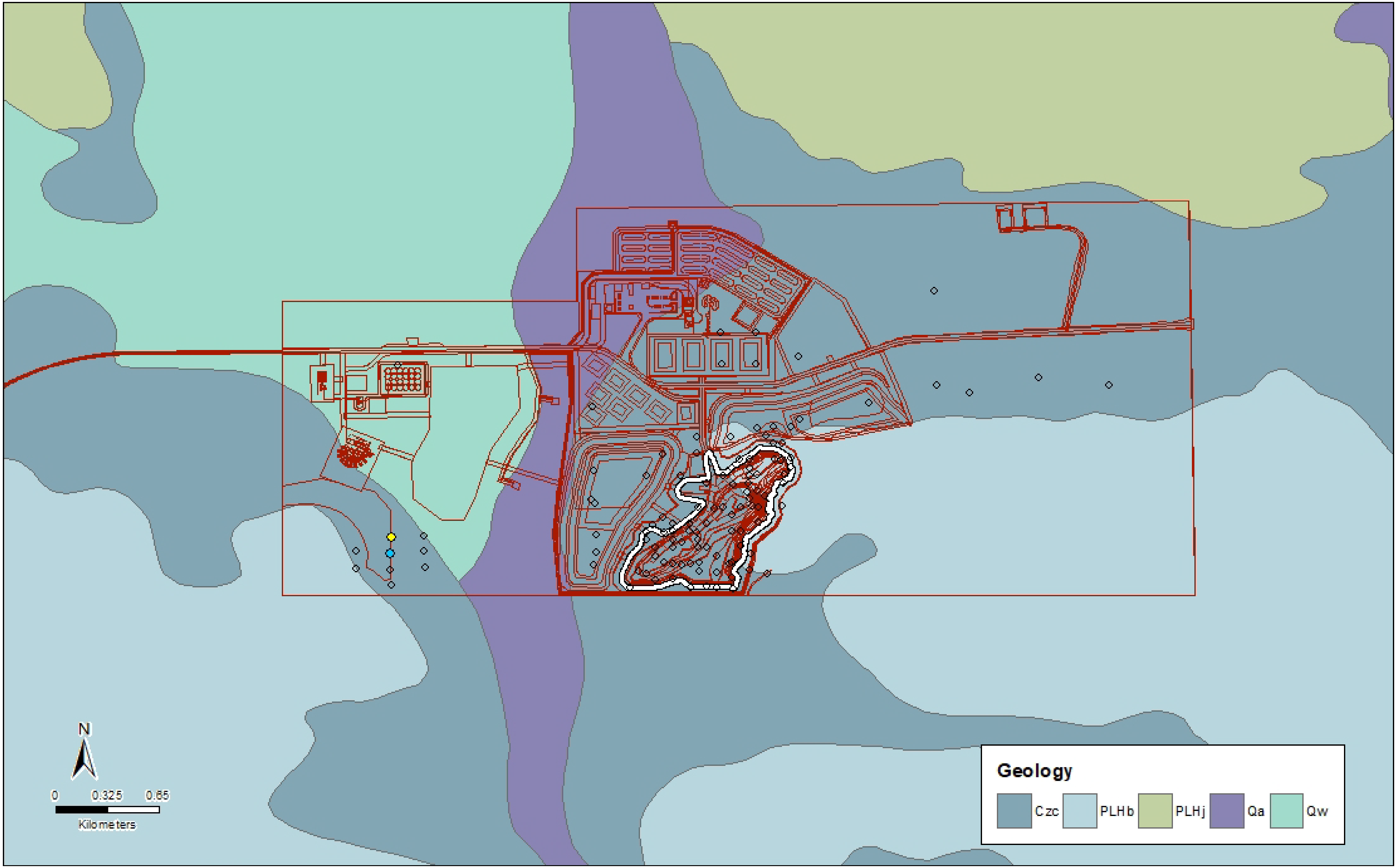
***Draculoides* `BSC026`**

Schizomids (short-tailed whipscorpions) have small ranges (Abrams and Harvey 2015; Abrams *et al.* 2019; Framenau *et al.* 2018; Halse and Pearson 2014; Harms *et al.* 2018; Harvey *et al.* 2008). The median range of schizomids calculated by Halse 2018b was 2.6 km^2. *Draculoides* `BSCO26' was collected in the Project area in 2013 from a drill hole (BY051) that intersected mostly undefined ore geology.

Two other species of schizomid were collected during the 2013 survey: *Draculoides* `BSC025` as a singleton just north of the proposed pit and *Draculoides* `BSC027` as multiple records over a range extending at least 13 km east of the Project area.

***Nocticola* sp. B31**

There is a high proportion of subterranean species within the family Nocticolidae (Trotter *et al.* 2017). Within the Nocticolidae, the genus *Nocticola* is the most speciose (Roth 1988, 2003) and animals of this genus have been regularly collected in vuggy geologies such as BIF throughout the Pilbara (Halse and Pearson 2014). Halse and Pearson (2014) estimate that subterranean cockroaches have a median range of 29 km^2 which can vary between 1 km^2 at the smallest range to 2166 km^2 at their largest.



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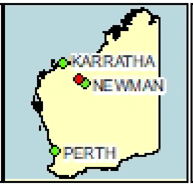
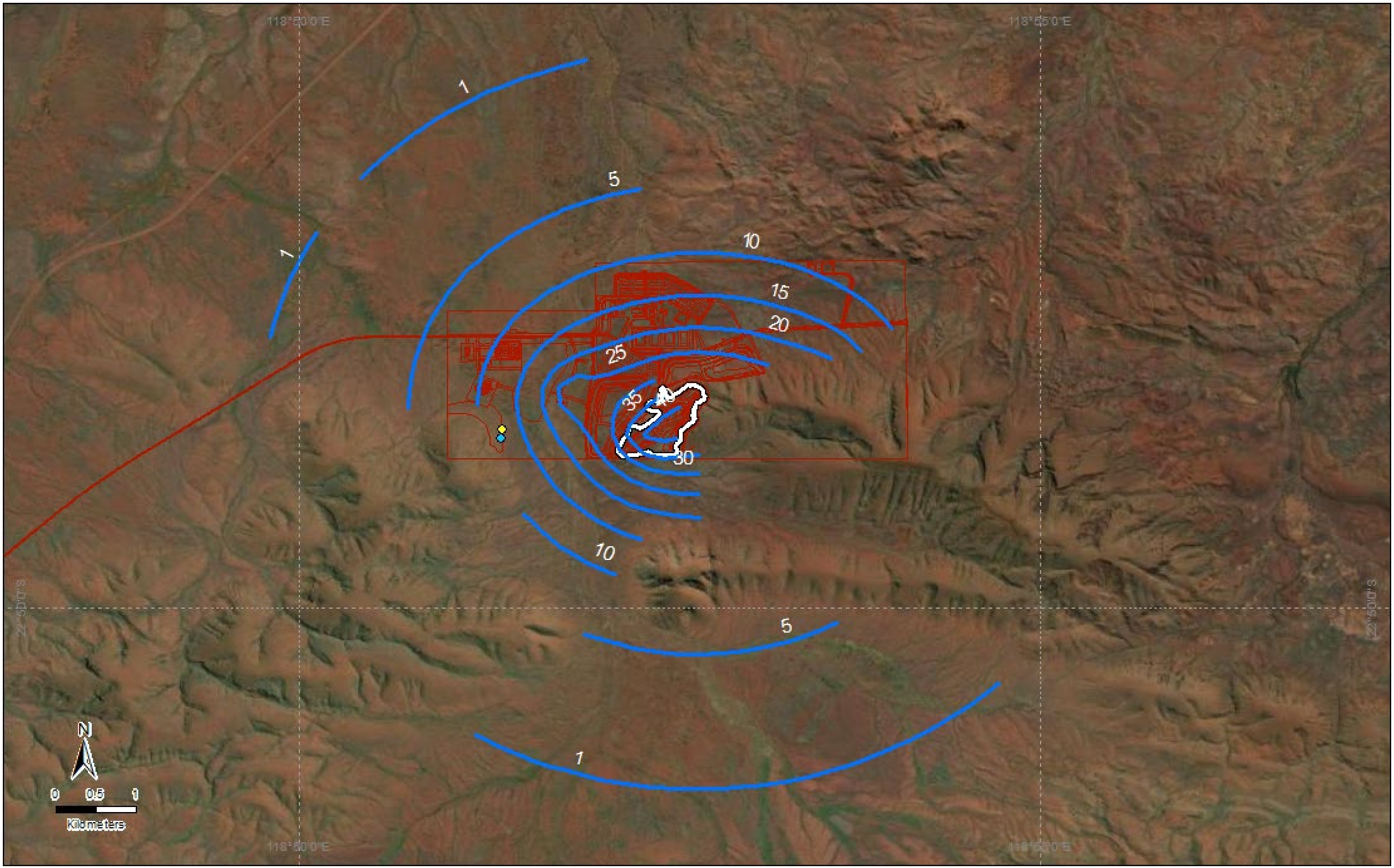


Legend

- Lamb Creek
- Towns
- Proposed development
- Proposed Pit
- Sampled holes
- Brevismobathynella `BSY222`
- Parastenocaris sp. B25

Figure 9. Stygofauna species currently known only from within the Project Area.



Bennelongia

GCS GDA 1994
Author: hclark
Date: 18/11/2021

Legend

- Lamb Creek
- Towns
- Proposed development
- Proposed Pit
- groundwater drawdown model
- Brevismobathynella `BSY222`
- Parastenocaris sp. B25

Figure 10. Stygofauna species with the modelled drawdown

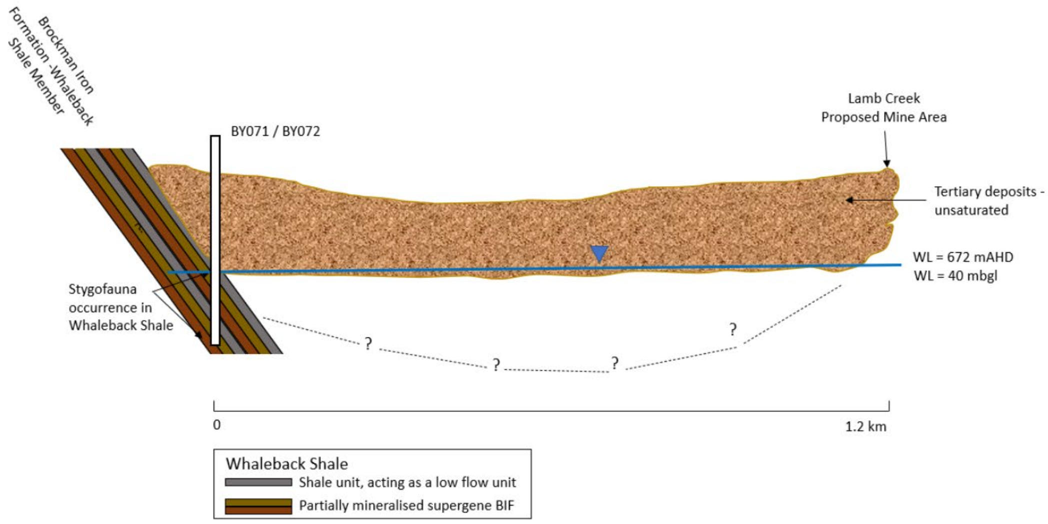


Figure 11: Geology and watertable at stygofauna collection location
Extracted from Mineral Resources Ltd 2021

Eight specimens of *Nocticola* sp. B31 were collected across three sampling events in 2011 and 2013. This species was collected from two bores (BY054 and BY059), 20 m apart. Neither of the bores were resampled in 2021. This species belongs to the *Nocticola cockingi* lineage of troglobionts (see Trotter *et al*. 2017) and would be expected to have a small range.

***Trinemura* sp. B25**

Silverfish of the family Nicoletiidae lack pigment and eyes and can be found in both soil and subterranean environments (Smith and McRae 2016). This can make distinguishing between surface and subterranean species challenging. However, recent work conducted on this group has identified subterranean fauna species that are considered to have narrow ranges (Smith *et al.* 2012).

Trinemura sp. B25 was collected once in 2013 as by-catch in a stygofauna net haul in an un-named bore (expected historical bore from previous drilling). This species has not been collected since and this bore was not resampled in 2021.

Zuphiini sp.

Six specimens of carabid beetle tribe Zuphiini sp. were collected from a single hole (BY086) within the pit at Lamb Creek in 2013. Due to these specimens being entirely made up of fragments rather than whole animals, making further determination on identification of these animals challenging. Three species of subterranean Zuphiini sp. have been described in 2014 by Baehr (2014). These three species have known linear distributions ranging from a single site to 30 km.

The desktop search identified a further 34 specimens from the Zuphiini tribe within 51 km of the Project. This includes two described species (Baehr 2014) and seven undescribed morphospecies. The nearest record is approximately 13 km to the south east of the Project and is the Holotype of the described species *Typhlozuphium longipenne* (Baehr 2014). The fragments from bore BY086 were also sent to Germany, however, no description ever arose from these specimens.

6.4. Habitat and distribution

All of the troglofauna specimens discussed, including Chillenophilidae `BGE053`, have a close affinity with the mapped BIF (Figure 12 and Table **1**) identified within the Project Area. BIF is a geology which is regularly prospective for troglofauna (ecologia 2009; GHD 2009 Halse 2018b), and as such, the collection of the majority of these animals within this geology type is not surprising. While the surface geology mapped in Figure 12 depicts the collection of *Trinemura* sp. B25 outside of this habitat type, it is expected that BIF extends underneath the mapped colluvial surface geologies. The BIF also extends along the range toward the east, indicating possible habitat connectivity throughout this geology (Figure 12).

In an earlier report, Bennelongia (2013) concluded that each of these species are likely to have habitat extend beyond the proposed pit. This was based on information at the time indicating weathered and porous hardcap throughout the area, and it was determined this was the most likely source of habitat for troglofauna species (Bennelongia 2013).

More recently, MRL has conducted further drilling and developed a block model of the area (Figure 13). This has resulted in a shift in understanding of the geology. Generally speaking, the subterranean geology is made up of the Dales Gorge member of the Brockman Iron formation. The Dales Gorge member has been divided into four sub members; D1, D2, D3 and D4 (Figure 13). These sub members show varying degrees of habitat prospectivity as defined in Table 5 and b)
Figure 14.

Figure 14 shows two examples of cores taken from within the pit at Lamb Creek. Figure 14 a) shows vugs and voids which are considered to be appropriate habitat for troglofauna. This section of core was taken from the Dales Gorge D4 sub member. Figure 14 b) shows the more clay and silty Dales Gorge D3 sub member, lacking in appropriate subterranean spaces.

Table 5: Description of Dales Gorge sub members and presence of troglofauna habitat

Sub member	Description	Available Vugs and voids	Troglofauna Prospective Geology
D1	Soft rock, with high fine silt and clay content primarily below the water table	No	No
D2	Hard rock, well weathered geology with large vugs and voids. Some areas sit above the water table	Yes	Yes
D3	Soft rock, with high fine silt and clay content primarily below the water table	No	No
D4	Hard rock, well weathered geology with large vugs and voids. Some areas sit above the water table	Yes	Yes

Based on this information provided by MRL, it is believed that the Dales Gorge D4 sub member is the most likely geology from which troglofauna were collected.

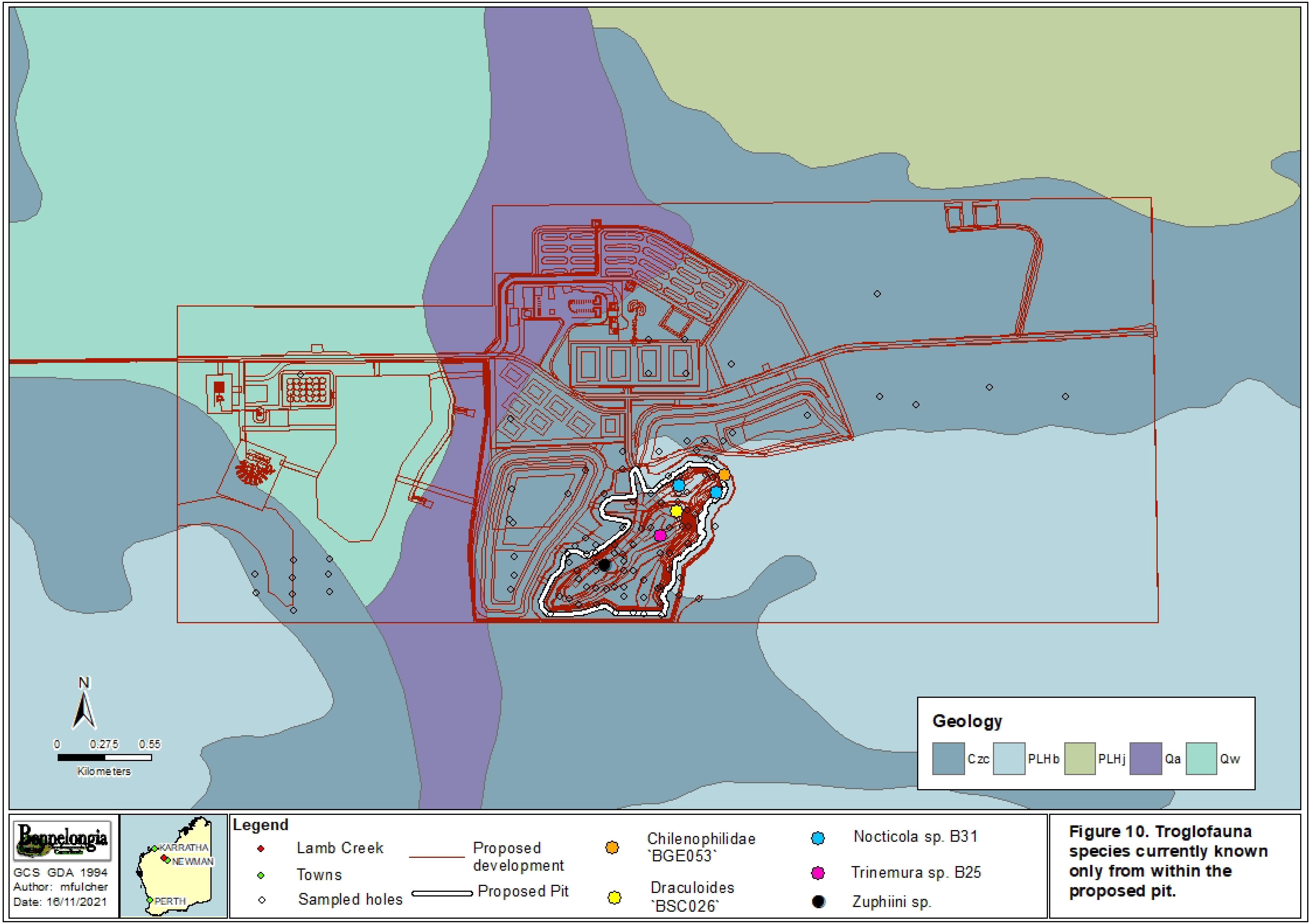


Figure 10. Troglofauna species currently known only from within the proposed pit.

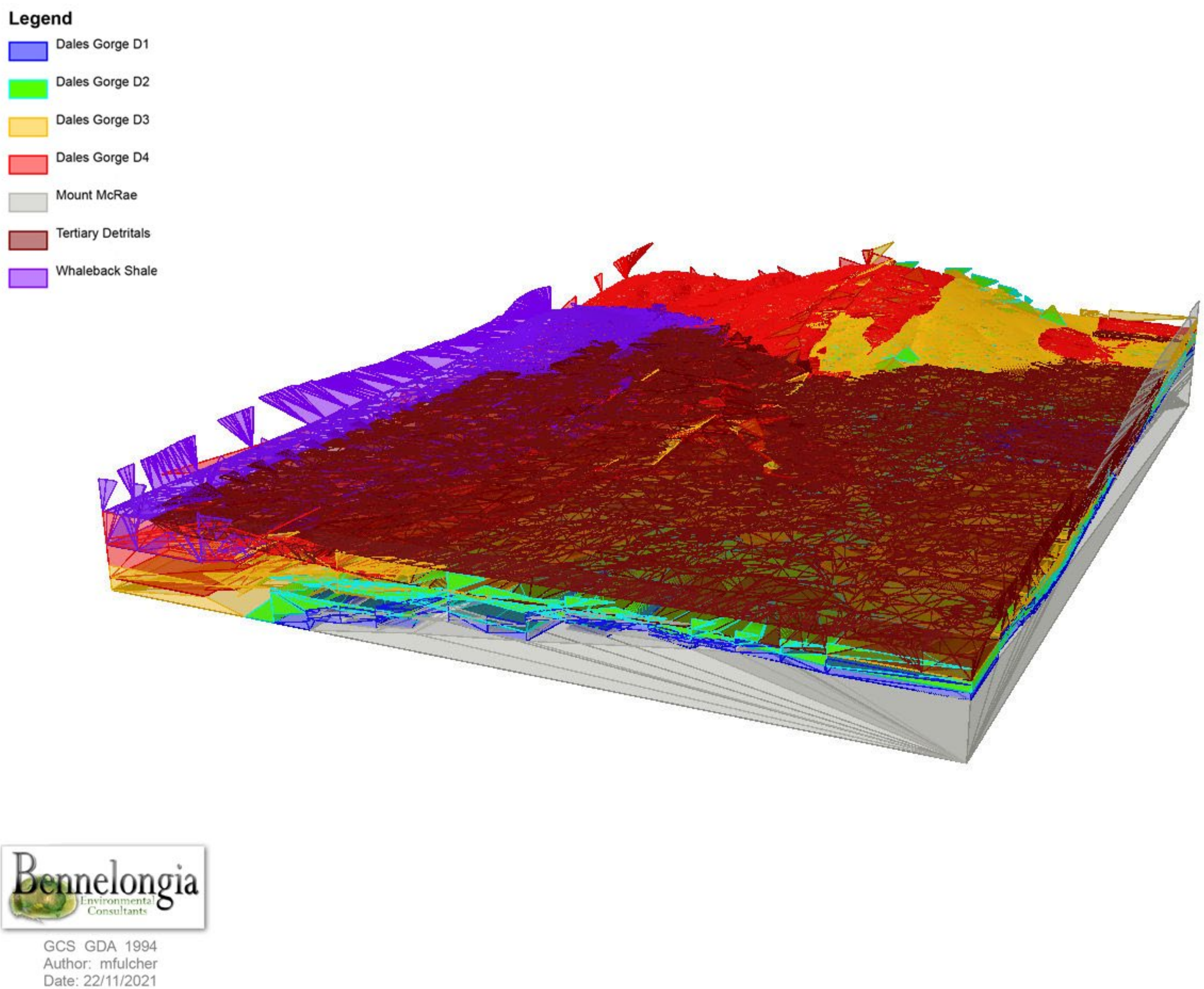


Figure 13: Geological block model for the Project

a)

b)

Figure 14: a) core from D4 Dales gorge sub member demonstrating weathering and subterranean spaces and b) core from D3 dales gorge sub member show clay and a lack of subterranean spaces.

***Draculoides* `BSC026` (Bore BY051)**

At the time of sampling, the water table in Bore BY051 was recorded as 54.59 m bgl (below ground level). The block model indicated that the groundwater surface is approximately 53 m bgl. The groundwater at the location is within the D3 sub member meaning that the D2 sub member is below the groundwater level and therefore not suitable for troglofauna. The schizomid *Draculoides* `BSC026` collected from this hole was caught as by-catch from stygofauna sampling making a determination on depth of collection difficult, However, based on the knowledge of the geology at this location and the depth to groundwater, we can safely assume that it was collected from within the Dales Gorge D4 sub member.

The Dales Gorge D4 sub member is approximately 24 m thick, extending from approximetly16 m bgl to approximately 40 m bgl according to the block modelling. The Dales Gorge D4 sub member above the water table has limited extension both to the north and south however this geological unit extends outside of the pit in both an east and west direction (Figure 15). In particular, the range to the east of the pit contains considerable areas of the Dales Gorge D4 sub member including surface outcropping (Figure 13). The closest edge of the pit where continuous habitat occurs approximately 120 to 140 m away in an east and slightly southerly direction.

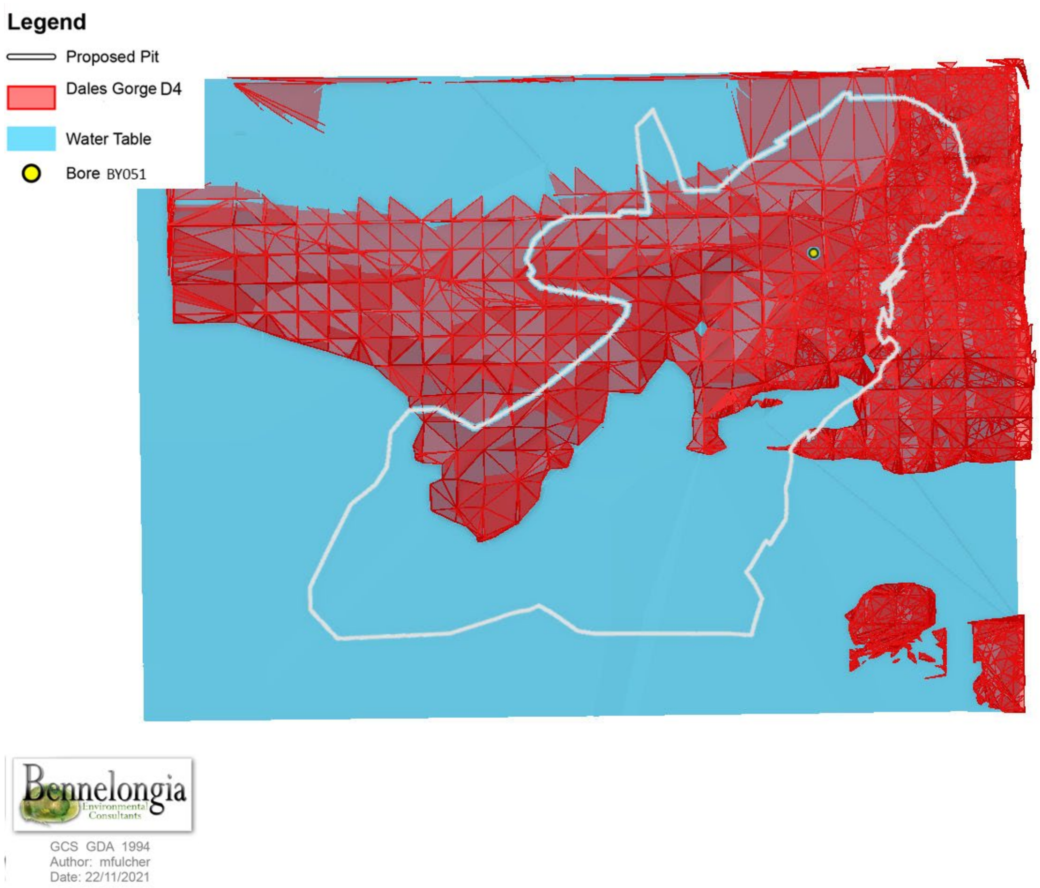


Figure 15: Modelled Dales Gorge D4 sub member above the watertable showing bore BY051

Schizomids are known to have small ranges and this is true for schizomid species in the Hamersley ranges (Abrams and Harvey 2015; Abrams *et al.* 2019; Framenau *et al.* 2018; Halse and Pearson 2014; Harms *et al.* 2018; Harvey *et al.* 2008). However, the median range of shizomids is 2.6 km^2 (Halse 2018b). Given this, the available continuous habitat and the close proximity of this species collection location to the edge of the pit, it is reasonable to expect this species known range extends beyond the edge of the pit.

***Nocticola* sp. B31 (Bore BY054 and BY059)**

Nocticola sp. B31 was collected in two bores BY054 and BY059. The focus of this discussion will be on BY059 for two reasons. 1) the close proximity of this bore to the edge of the pit makes it the most likely location to demonstrate habitat connectivity outside of the pit and 2) the animal in question from this hole was collected in a trap set at 30 m bgl giving us more confidence in the geology in which it was collected.

The water table at bore BY059 at the time of sampling was below the end of the hole (EOH = 48 m bgl). This is confirmed by the modelling which indicates the water table is approximately 65 m bgl. The geology at this depth is Dales Gorge D3 sub member which is not prospective to troglofauna. Therefore, the only suitable habitat at this location is the Dales Gorge D4 sub member. This geological unit is approximately 34 m thick, ranging from the surface to approximately 34 m bgl.

The edge of the Pit is only approximately 25 m east of bore BY059 and the Dales Gorge D4 sub member extends well beyond this into the range in an easterly direction (Figure 16).

There are three described species of subterranean cockroaches in the Pilbara which have known linear ranges of 31, 12 and 10 km respectively (Trotter *et al.* 2017). Commonly, subterranean cockroaches have linear ranges of between 5 and 15 km (Bennelongia 2013). Due to the available habitat and one of the collection locations being within 25 m of the edge of the pit, it is considered highly probable that this species range extends beyond the pit.

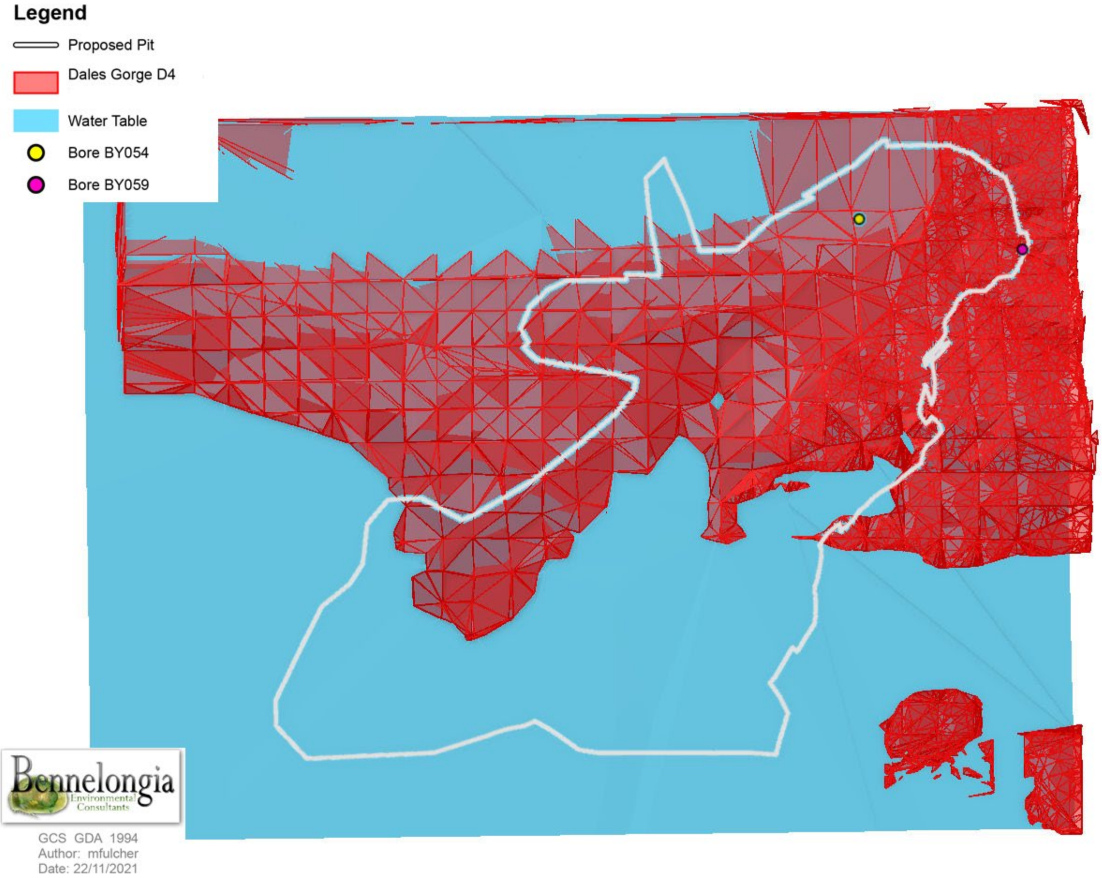


Figure 16: Modelled Dales Gorge D4 sub member above the watertable showing bores BY054 and BY059

***Trinemura* sp. B25 (Un-named bore)**

Trinemura sp. B25 was collected as by-catch during a stygofauna net haul and as a result, a determination on collection depth cannot be made. At the time of sampling, the water table was recorded as approximately 55 m bgl which closely mirrors the modelled groundwater depth at this location. The geology at this depth is Dales Gorge D2 sub member which extends approximately 10 m above the water table (ignoring any fluctuations in depth to water). This geology is considered to be hard rock with appropriate subterranean spaces for troglofauna. Above this, there is a 27 m thick layer of the soft and clay filled Dales Gorge D3 sub member. A 15 m layer of vuggy Dales Gorge D4 sub member sits between 2 m bgl and 17 m bgl and is the most likely geology from which *Trinemura* sp. B25 was collected.

Not far to the north of this un-named bore, the D2 sub member ducks below the water table however extends well beyond the pit in both the east and west directions up into the ranges (Figure 17). This demonstrates the possibility of habitat connectivity in this geology above the water table. Similarly, available habitat in the D4 sub member also extends outside of the proposed pit in both the east and west directions (Figure 18). The D4 sub member extends well in the range to the east where this geology can be seen at the surface as outcropping.

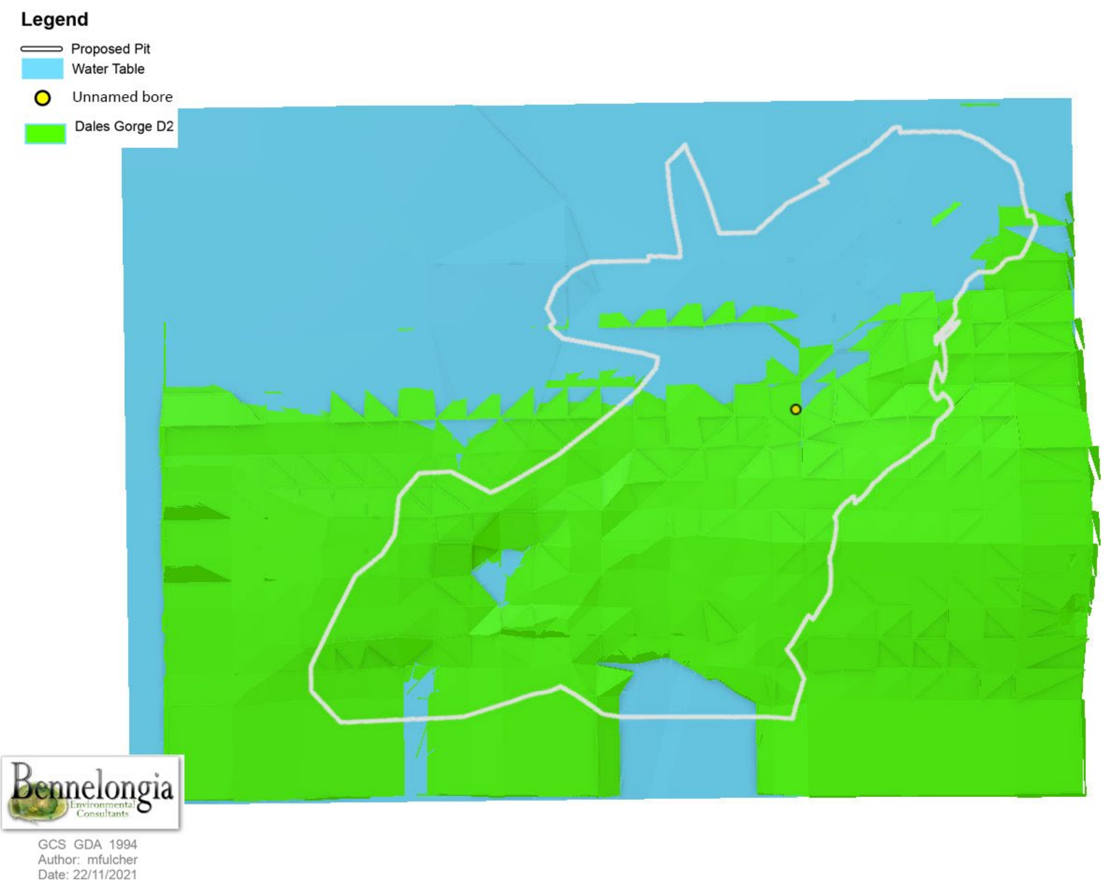


Figure 17: Modelled Dales Gorge D2 sub member above the watertable showing the un-named bore

The un-named bore in which *Trinemura* sp. B25 was collected is roughly in the middle of the pit (Figure 8). The smallest direct line to the edge of the pit from this hole is only roughly 160 m south east. There is continuous habitat in this direction when looking at the Dales Gorge D2 sub member (Figure 17) however this is not the case for the Dales Gorge D4 sub member (Figure 18). The closest direct line of continuous habitat for the Dales Gorge D4 sub member is approximately 190 m west however there is also continuous habitat approximately 200 m east leading up into the range.

Given that Trinemura sp. commonly have linear ranges of up to 45 km (Bennelongia 2013), it is considered likely that *Trinemura* sp. B25 extends beyond the boundaries of the pit.

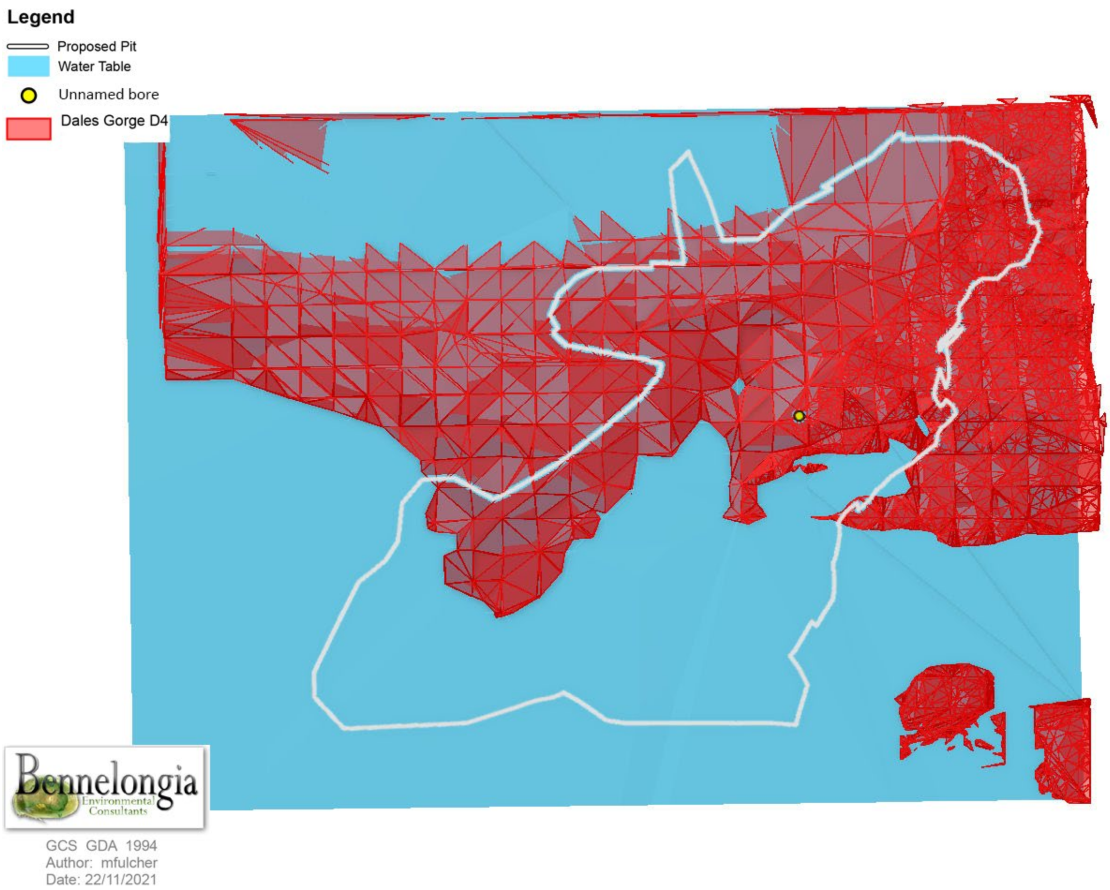


Figure 18: Modelled Dales Gorge D4 sub member above the watertable showing the un-named bore

Zuphiini sp. (Bore BY086)

Bore BY086 was constructed to a depth of approximately 94 m bgl and intersected water at the time of sampling at approximately 47.5 m bgl. This is similar to the indicated water depths provided by the geological modelling of approximately 53 m bgl. This then becomes the lower limit of habitat and collection of the Zuphiini sp. specimens. These specimens were collected as by-catch during stygofauna sampling so no conclusions can be made about a depth at which these specimens were collected.

According to the geological block model, Bore BY086 intersects four geological types before striking groundwater. The top nine meters (approximately) are Tertiary Detritals before intersecting a three meter section of Dales Gorge D4 sub member. Below this is a 16 m section of Dales Gorge D3 sub member followed by a 25 m section of Dales Gorge D2 sub member down to the water table.

Located in the south-western corner of the pit (Figure 8), this bore intersects the very edge of the available habitat provided by the D4 sub member (Figure 19). The only direction in which D4 sub member habitat continues in a direct line outside of the pit is in a northwest direction, approximately 90 m from Bore BY086. The D4 sub member forms a continuous layer spanning the pit to the north of Bore BY086 providing continuous habitat both to the east and to the west of the pit (Figure 19).

At a greater depth, between approximately 28 m bgl and the water table at 53 m bgl, lies the D2 sub member, which also holds appropriate vugginess for troglofauna. The Dales Gorge D2 sub member extends extensively above the water table both to the east and the west well beyond the boundary of the pit (Figure 20). Similarly to the D4 sub member, the closest direct line of continuous habitat for the D2 member is 90 m to the northwest.

The three species of subterranean Zuphiini described by Baehr (2014) have linear ranges from a single site to 30 km. The availability of continuous habitat together with the relatively small size of the pit (approx. 45 ha), indicates a likelihood this species would have ranges extending beyond the impact of the pit.

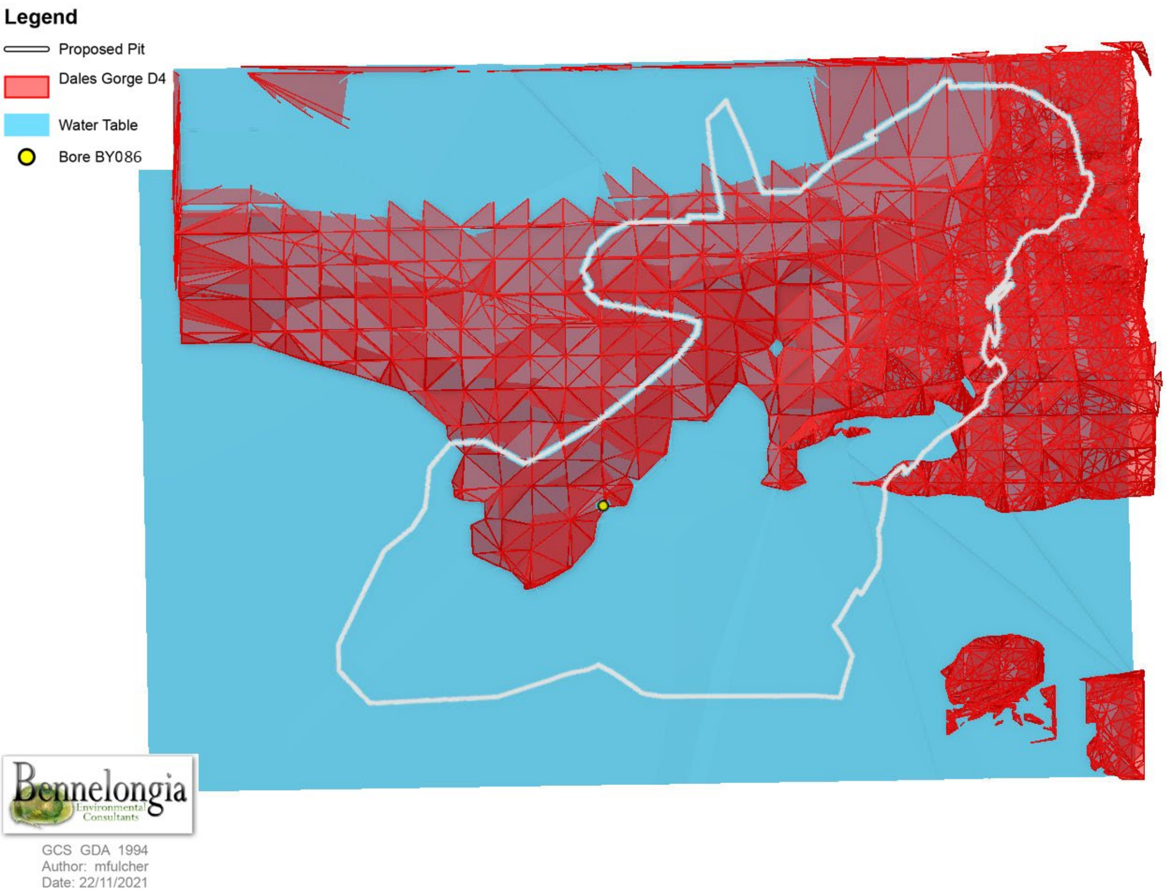


Figure 19: Modelled Dales Gorge D4 sub member above the watertable showing the bore BY086

7. CONCLUSION

The 2021 survey resulted in the collection of 29 stygofauna specimens of five species (Table 3). Species collected were two species of amphipod and single species of oligochate worm, copepod and nematode worm. This is a relatively low number of animals and species in contrast to other surveys throughout the Pilbara. It reflects, however, the results of previous surveys that were conducted at the Project area in 2011 and 2013 by Bennelongia. While these surveys collected more species, the area covered was greater and the sample effort was higher (Bennelongia 2013).

The situation is similar for the troglofauna survey with 21 troglofauna specimens of 4 species collected (Table 4), including one species each of dipluran, beetle, centipede and millipede.

Of the animals collected in 2021, only the centipede Chilenophilidae \`BGE053\` has a known range limited to the Project area but it was found outside the proposed pit and so is not considered to be at risk from mining operations. Two stygofauna species and four troglofauna species from historical sampling are currently only known from the Project area. These are the stygofaunal *Brevismobathynella* \`BSY222\` and *Parastenocaris* sp. B25, and the troglofaunal *Draculoides* \`BSC025\`, *Nocticola* sp. B31, *Trinemura* sp. B25 and Zuphiini sp.

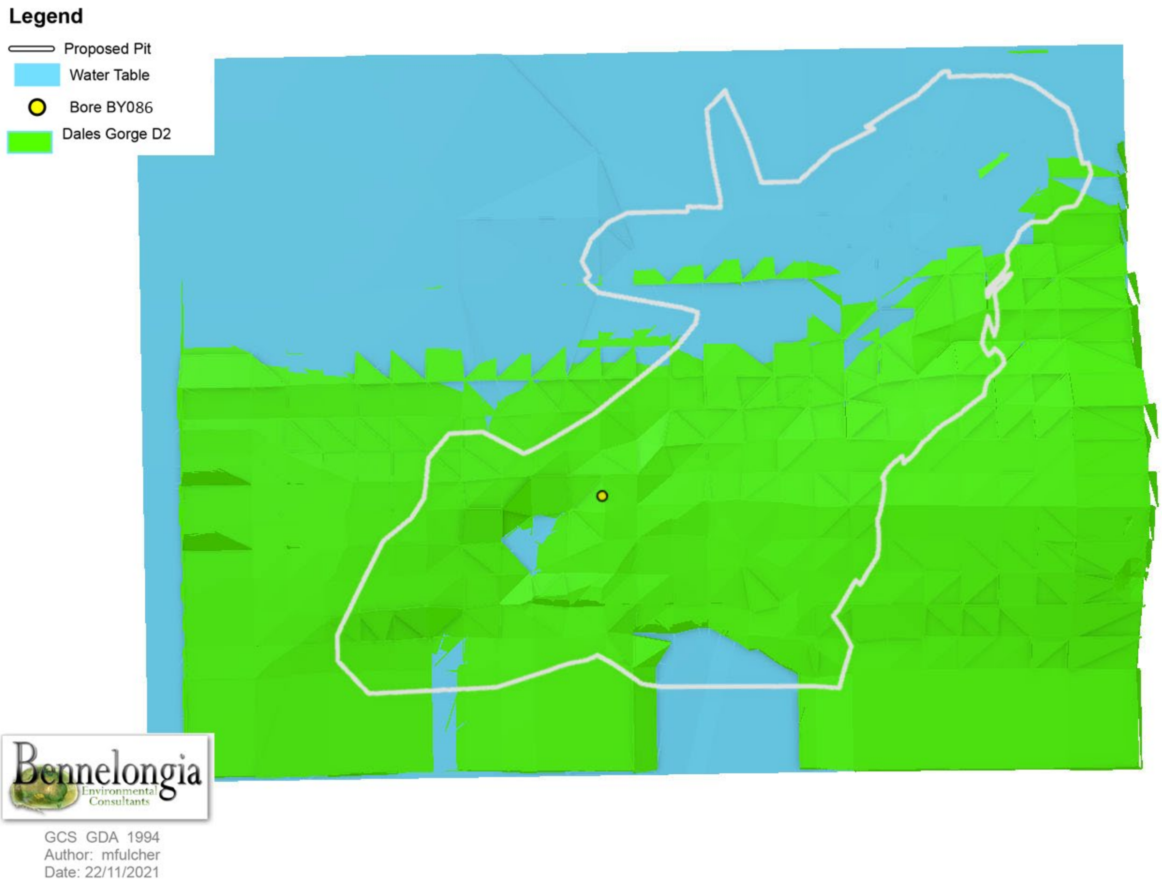


Figure 20: Modelled Dales Gorge D2 sub member above the watertable showing the bore BY086

At the height of operational water extraction, the drawdown cone (1 m) extends approximately 4.5 km from the edge of the pit (Figure 10). At the site where the two restricted stygofauna, *Brevismobathynella* `BSY222` and *Parastenocaris* sp. B25, were collected, water drawdown at it's height would be approximately 12 m (Figure 10) which is up to half of the aquifer (Mineral Resources Ltd 2021). The water table at these sites sits at the top of the Brockman Iron Formation Whaleback Shale member, indicating the likely habitat these animals were collected from is the bands of weathered, partially mineralised supergene BIF which exists in bands in this unit (Figure 11). The bands of more resistant shale may act as a hydraulic barrier (Mineral Resources Ltd 2021), providing some protection against drawdown but could also limit animal movement throughout the landscape.

All four species of troglofauna currently known only from within the proposed pit at the Project area belong to groups that are known to have a high proportion of small-range species. These are the schizomid *Draculoides* `BSC025`, the cockroach *Nocticola* sp. B31, the silverfish *Trinemura* sp. B25 and the beetle Zuphiini sp. Block modelling of the area has been conducted and it is believed the most likely geological unit to harbour troglofauna is the Dales Gorge D4 sub member. The deeper Dales Gorge D2 sub member also contains appropriate subterranean spaces considered appropriate habitat for troglofauna. The block model, as demonstrated in Figure 13 through Figure 20 shows connected habitat available extending outside of the proposed pit for all likely habitats from each of the collection locations for the four species currently only known from the pit. This is also aided by the relatively small size of the pit (~45 ha).

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Appendix 1 – Sites visited/sampled and fauna collected in 2021

Field	Latitude	Longitude	Target Fauna	Species Collected
LCK20RC052	-22.8077	118.8755	Troglofauna	Lophoturus madecassus
LCK20RC085	-22.809	118.876	Troglofauna	Lophoturus madecassus
LCK20RC047	-22.8086	118.8736	Troglofauna	
LCK20RC049	-22.8099	118.8726	Troglofauna	Enchytraeidae `3 bundle` s.l. (short sclero)
LCK20RC118	-22.8071	118.8789	Troglofauna	
LCK20RC120	-22.8076	118.8775	Troglofauna	
LCK20RC113	-22.8089	118.8789	Troglofauna	Chilenophilidae `BGE053`
LCK20RC105	-22.8116	118.8784	Troglofauna	
LCK20RC111	-22.8094	118.8789	Troglofauna	
LCK20RC136	-22.8126	118.877	Troglofauna	
LCK20RC133	-22.8117	118.876	Troglofauna	
LCK20RC103	-22.8139	118.8761	Troglofauna	Curculionidae Genus 1 sp. B02
LCK20RC100	-22.8163	118.8756	Troglofauna	
LCK20RC071	-22.8162	118.8742	Troglofauna	
LCK20RC045	-22.8162	118.8732	Troglofauna	
LCK20RC032	-22.8158	118.8722	Troglofauna	
LCK20RC020	-22.8158	118.8712	Troglofauna	
LCK20RC021	-22.8163	118.8698	Troglofauna	
LCK20RC009	-22.8131	118.8707	Troglofauna	
LCK20RC006	-22.8099	118.8707	Troglofauna	Japygidae `DPL002` s.l.
LCK20RC025	-22.8126	118.8722	Troglofauna	
LCK20RC037	-22.8126	118.8731	Troglofauna	
LCK20RC066	-22.814	118.8741	Troglofauna	
LCK20RC063	-22.8126	118.8741	Troglofauna	
BY019	-22.7994	118.8871	Troglofauna	Paramelitidae Genus 2 sp. B02
LCK20RC046	-22.8077	118.8736	Troglofauna	
LCK20RC079	-22.8099	118.875	Troglofauna	
LCK20RC089	-22.8099	118.877	Troglofauna	
LCK20RC107	-22.8103	118.8785	Troglofauna	Enchytraeidae `3 bundle` s.l. (short sclero)
LCK20RC128	-22.813	118.8761	Troglofauna	
LCK20RC151	-22.8035	118.8769	Stygofauna	
LCK20RC152	-22.8017	118.8769	Stygofauna	
LCK20RC149	-22.8036	118.875	Stygofauna	
LCK20RC121	-22.8071	118.877	Stygofauna	Nematoda spp.
LCK20RC116	-22.808	118.8779	Stygofauna	
LCK20RC112	-22.8089	118.878	Stygofauna	
LCK20RC053	-22.8117	118.8736	Troglofauna	
BY072	-22.8143	118.8561	Troglofauna	
LCK20RC042	-22.8149	118.8732	Troglofauna	
LCK20RC016	-22.814	118.8712	Troglofauna	
LCK20RC003	-22.8154	118.8703	Troglofauna	

Field	Latitude	Longitude	Target Fauna	Species Collected
RCD7	-22.8036	118.8565	Stygofauna	Paramelitidae Genus 2 sp. B02
				Paramelitidae sp. B16
LCK20WB001	-22.8103	118.8741	Stygofauna	
LCK20WB002	-22.8127	118.8711	Stygofauna	
LCK20RC026	-22.8131	118.8722	Stygofauna	
LCK20RC038	-22.8131	118.8731	Stygofauna	
LCK20RC057	-22.8153	118.8737	Stygofauna	Diacyclops humphreysi s.l.
LCK20RC055	-22.8135	118.8736	Stygofauna	
TH19	-22.8149	118.8754	Stygofauna	
LCK20RC138	-22.8103	118.8765	Stygofauna	
LCK20RC139	-22.8112	118.8765	Stygofauna	
LCK20RC141	-22.8117	118.877	Stygofauna	
LCK20RC027	-22.8135	118.8722	Stygofauna	
LCK20RC030	-22.8149	118.8722	Stygofauna	
LCK20RC083	-22.8117	118.8751	Stygofauna	
LCK20RC117	-22.8071	118.8779	Stygofauna	
LCK20RC142	-22.8108	118.877	Stygofauna	
LCK20RC150	-22.8018	118.8749	Stygofauna	
LCK20RC017	-22.8144	118.8712	Stygofauna	
LCKUNKWB001	-22.8113	118.8676	Stygofauna	
LCK20RC028	-22.814	118.8722	Stygofauna	

Appendix 2 – Higher Order Identifications from historic sampling

Higher Order Identification	Lowest Possible Identification	2011	2013
Arthropoda			
Chelicerata			
Arachnida			
Araneae			
Opisthothelae			
Oonopidae			
Prethopalpus	Prethopalpus sp.		1
Hexapoda			
Entognatha			
Diplura	Diplura sp.		1
Insecta			
Blattodea			
Nocticolidae			
Nocticola	Nocticola sp.		10
Hemiptera			
Meenoplidae			
Phaconeura	Phaconeura sp.	1	8
Zygentoma			
Nicoletiidae	Nicoletiinae sp.		1

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Rev B

Hydrogeological Assessment of Stygofauna Sites at the Proposed Lamb Creek Mine

Background

Results from a recent stygofauna study for the Lamb Creek proposed mine (Bennelongia, 2021), showed two historical stygofauna occurrences located approximately 1.2 km west of the proposed mining area. The two stygofauna species are namely the syncarid *Brevismobathynella* BSY222 and the harpacticoid copepod *Parastenocaris sp.* B25, both of which have only been known to occur in the vicinity of the proposed mining area.

An analytical model was completed to estimate drawdown extents during the dewatering phase, and for recovery duration in the post-mining phase. Backfilling of the pit (post-mining) is planned, however as the analytical model assumes no backfilling, the results are considered conservative.

The following provides a summary of key aspects that pertain to understanding water level response at the two relevant stygofauna sites and the effect on their habitat.

Pit Backfilling

MRL plan to backfill the pit by up to a minimum of 1 m above pre-mining water level of 672 mAHD i.e., minimum 673 mAHD. If a pit is backfilled above pre-mining water levels such that there is no open water body, evaporative processes from the pit area are significantly reduced, if not completely eliminated; *Rose etal*. (2005) found that at a depth of 700 mm below surface, evaporation rates were 0.3 mm/day. With this, if the pit is backfilled and evaporative processes are eliminated, post-mining residual drawdown will only occur during the groundwater recovery phase.

Habitat of the Identified Stygofauna

The stygofauna sampling was conducted from two historical RC holes with lithological logs recording Tertiary deposits between 0-34 mbgl and the Whaleback Shale from 34-64 mbgl. Water levels from these two RC holes (at the time of sampling) were recorded in Bennelongia (2021), as being 40 and 41.5 mbgl. This provides evidence that the water level is in fact lower than the base of the Tertiary deposits and that therefore, the stygofauna habitat is within the Whaleback Shale (**Figure 1**).

The estimated minimum aquifer thickness in the Whaleback Shale is +/-24 m with the potential for a further 7.5 m in the winter season; it was noted in Bennelongia (2021) that there was a water level increase to 34 mbgl (increase of 7.5 m) between sampling rounds in March and June 2013.

The Whaleback Shale Member of the Brockman Iron Formation has been described as follows:

> "**Approximately 50 m thick consisting of thinly bedded shales with thicker chert or BIF bands, weathered with supergene enrichment of BIF bands**"

As the two stygofauna occurrences appear to occur in the Whaleback Shale, it is likely that their habitat in this area is in the weathered and supergene enriched sections of the BIF where porosity is higher. Furthermore, the thin shale beds would act as low flow hydraulic barriers. Such a scenario would likely reduce/delay drawdown in the stygofauna habitat of the Whaleback Shale during the dewatering phase.

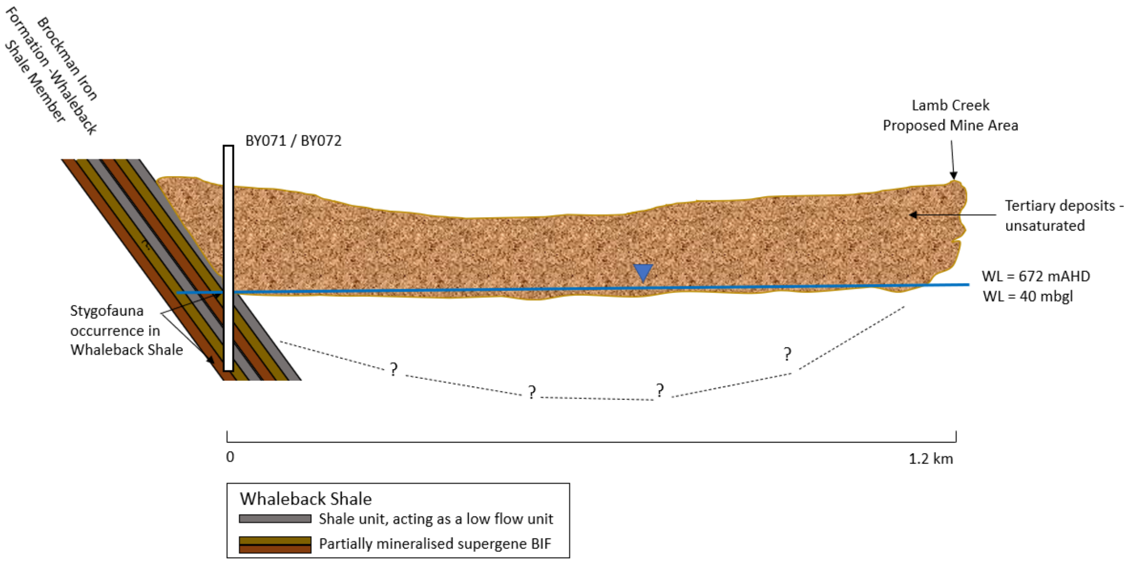


Figure 1 - Conceptual hydrogeology around the stygofauna occurrences

<u>Analytical Model</u>

The analytical model included surface and subsurface inflow and outflow relevant to the pit and pit catchment area (**Figure 2**). The main limitations of the model include, 1) assumed no post-mining backfilling and, 2) it did not include upstream groundwater inflow into the system. With such limitations, the dewatering drawdown contours, residual drawdown contours, and duration for groundwater recovery are considered conservative; the results of these are discussed below.

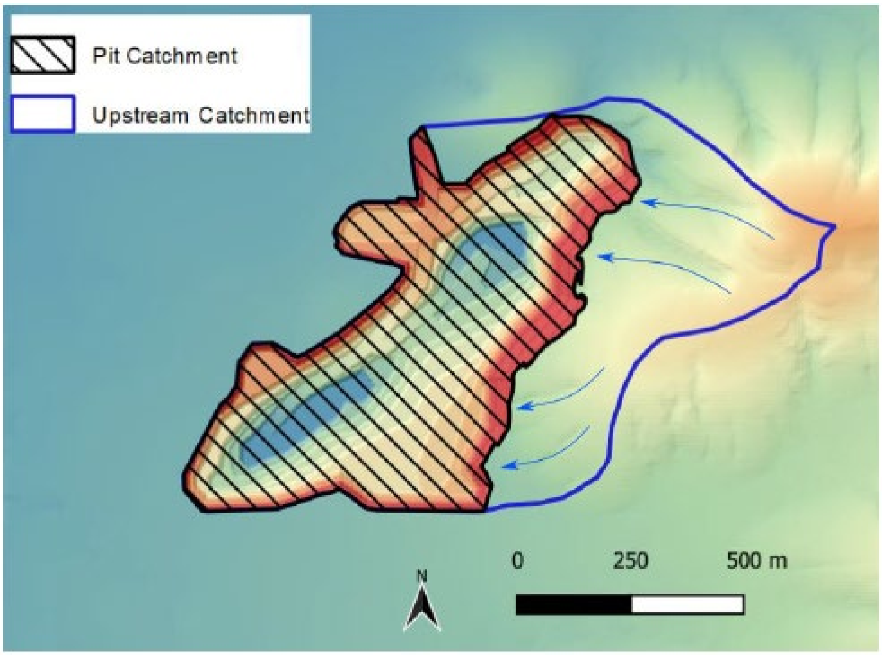


Figure 2 – Pit and Catchment Area

Dewatering Drawdown at Stygofauna Sites - Percentage of Aquifer Affected

The worst-case modelled drawdown due to **dewatering** reached 12 m at the site of stygofauna occurrences (**Figure 3**). Assuming the stygofauna habitat does not extend beyond the drawdown zone, with an estimated aquifer thickness of 24 m and a drawdown of 12 m, the percentage of stygofauna habitat affected by drawdown during the short-term mining is estimated to be **50%.**

This scenario is conservative as it assumes the stygofauna habitat is limited to the two identified occurrences only.

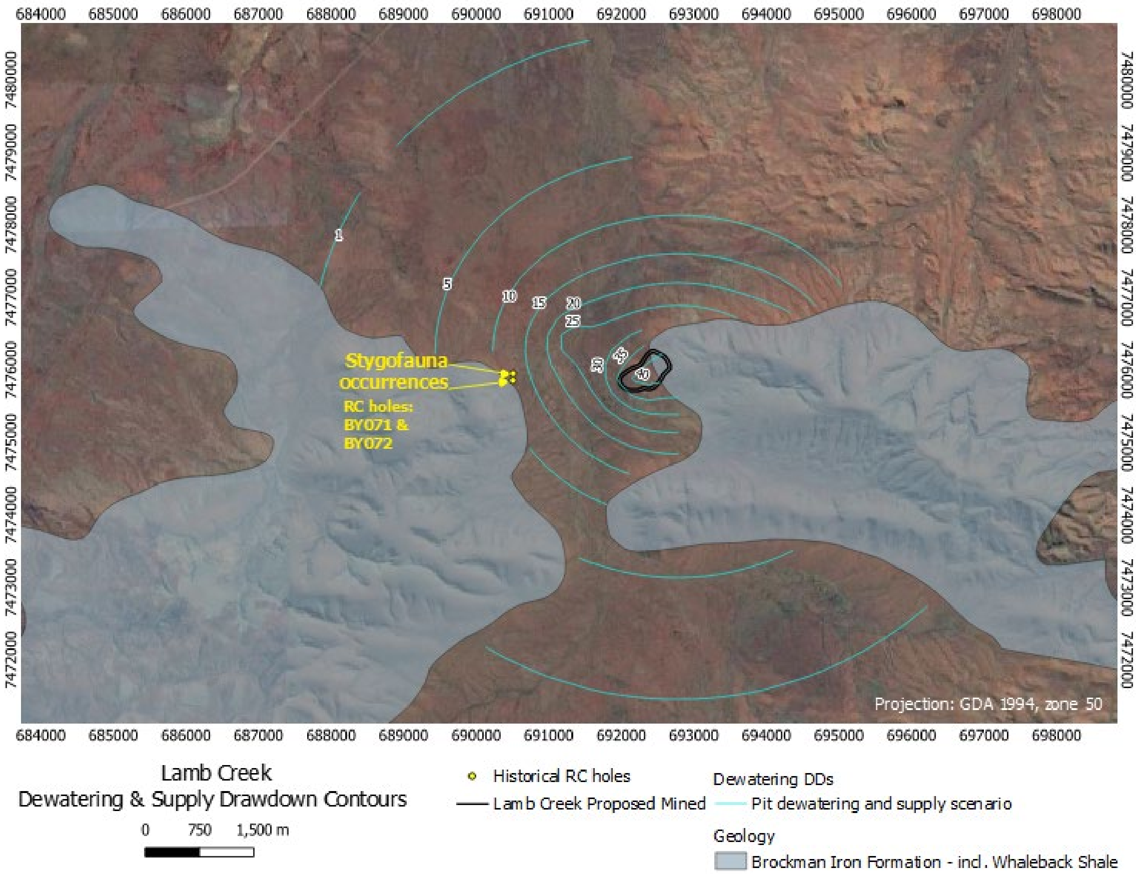


Figure 3 - Drawdown contours during dewatering and supply phase

Residual Drawdown at Stygofauna Sites – Percentage of Aquifer Affected

This scenario does not consider post-mining backfilling of the pit and therefore assumes that a full groundwater recovery will not occur.

The worst-case **residual** drawdown at the site of the stygofauna occurrences was modelled to be 2.25 m (**Figure 4**). Assuming the stygofauna habitat is entirely within the residual drawdown zone, with an estimated aquifer thickness of 24 m and a residual drawdown of 2.25 m, the percentage of stygofauna habitat affected by residual drawdown is estimated to be **9%.**

This scenario is considered unlikely as MRL plan to backfill the pit.

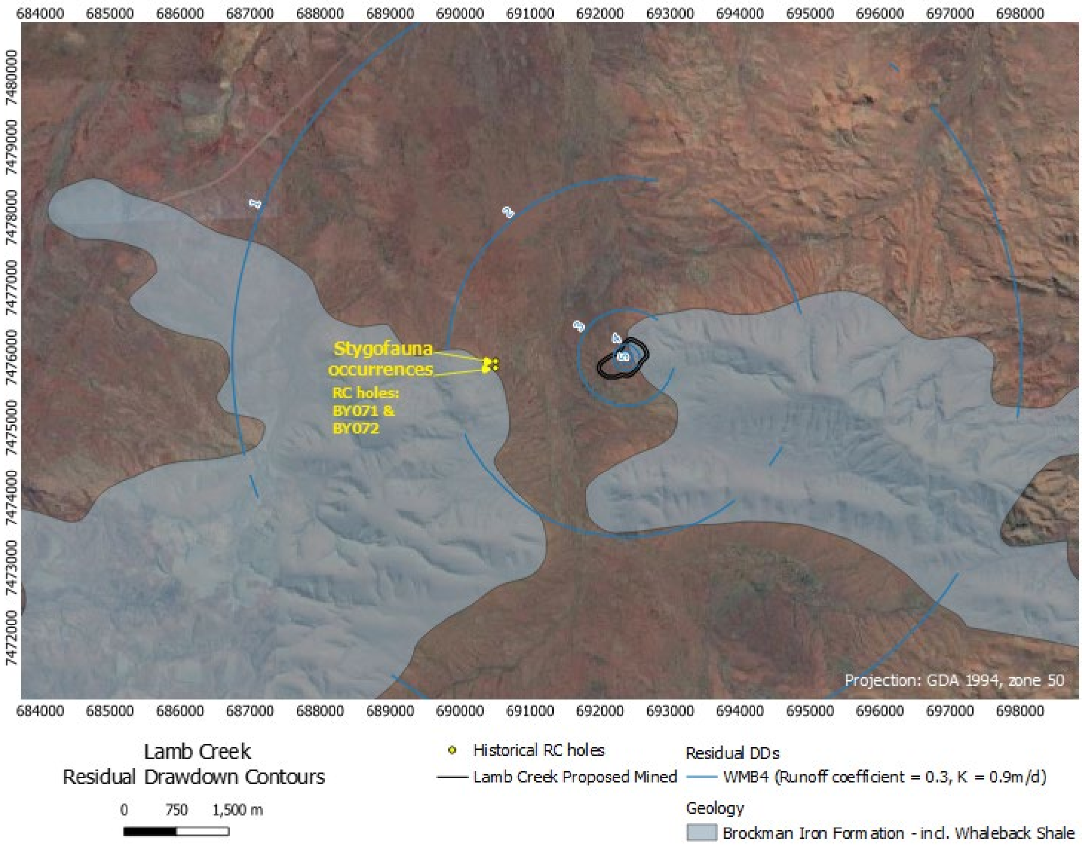


Figure 4 - Residual drawdown contours (WMB4) with stygofauna habitat Brockman Iron Formation. WMB4 results were inclusive of 'pit and upstream catchment' areas but no pit backfilling

Post-Mining Groundwater Recovery within the Pit – Sensitivity Analysis

'Post-mining groundwater recovery invariably dictates residual drawdown'.

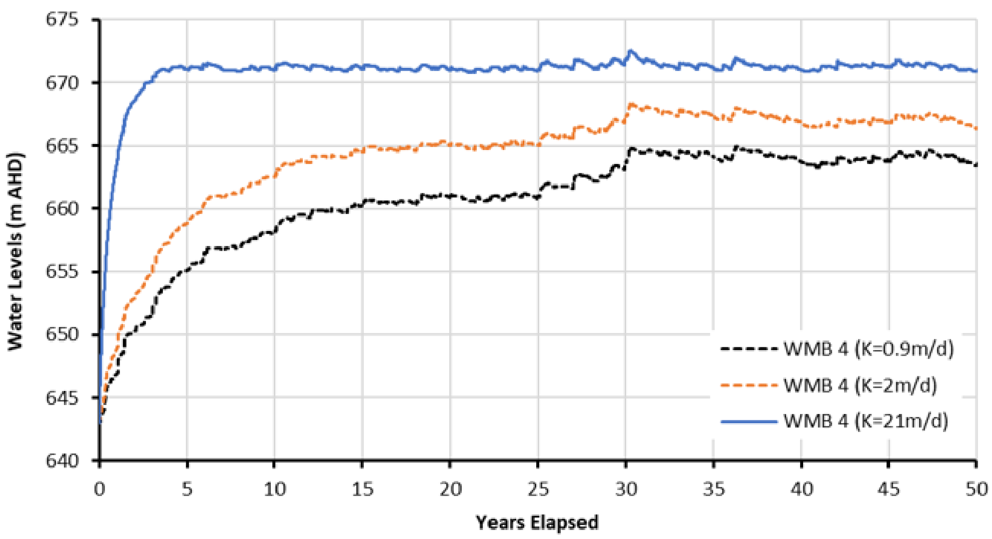
Backfilling the pit is expected to eliminate residual post-mining drawdown after full groundwater recovery has been attained. Nevertheless, to assess potential scenarios for groundwater recovery duration, a sensitivity analysis was completed to test different hydraulic conductivity values (K=0.9, 2 & 21 m/d; actual results from slug tests) against different run-off coefficients of 0.3 and 0.7.

The results of the sensitivity analysis are summarized in **Table 1** and graphically in **Figure 5.** Reference to **Table 1** shows that with a high run-off coefficient and high hydraulic conductivity, full recovery can be attained after 5-years, after which time no residual drawdown would occur (**Figure 5**); this scenario is considered to reflect post-mining pit backfilling of which is planned by MRL.

A worst-case scenario is shown as 'Slow Recovery' in **Table 1**, reflecting the case for no pit backfill. This scenario shows that groundwater level within the pit will recover to 55% of pre-mining groundwater levels after 10 years and 73% after 30 years. This worst-case scenario assumes a very low run-off coefficient and low hydraulic conductivity, values of which are considered unlikely to be representative.

Table 1 - Pit Void Groundwater Recovery Analysis

	Location: Pit Void (no backfill) Analytical Model Results for Post Mining Groundwater Recovery		
	Full Recovery	**Moderate Recovery**	**Slow Recovery**
	WMB 2 runoff coeff. = 0.7 k = 21 m/d	WMB 4 runoff coeff. = 0.3 k = 2.0 m/d	WMB 4 runoff coeff. = 0.3 k = 0.9 m/d
Time post operations	% Recovery to Pre-mining Groundwater Levels		
2 years	80	30	25
5 years	100	60	48
10 years	recovered	70	55
20 years	recovered	75	64
30 years	recovered	80	73



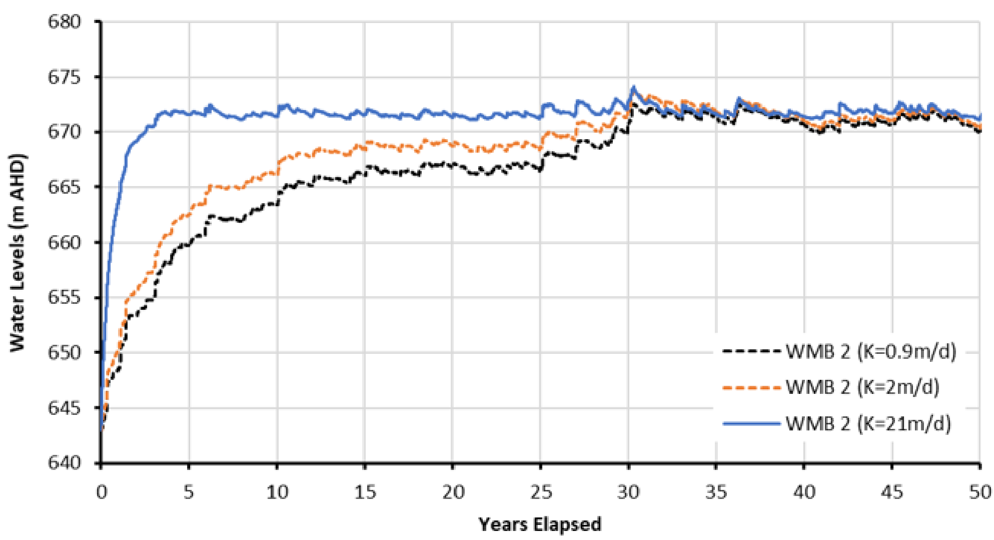


Figure 5 - Sensitivity analysis on K value for aquifer recovery; WMB4 runoff-coefficient = 0.3; WMB2 run-off coefficient = 0.7

Concluding Summary

The habitat of the two relevant stygofauna species is within the Whaleback Shale which may be partially disconnected from other parts of the groundwater system by the low-flow shale units of the Whaleback Shale. Drawdown at the stygofauna sites due to dewatering is therefore likely to be reduced and/or delayed.

Post-mining, MRL plan to backfill the Lamb Creek proposed pit to at least 1 m above pre-mining water level, resulting in no pit lake or evaporative processes. As such, once full groundwater recovey has been attained, it is expected that there will be no residual drawdown. For completeness however, drawdown contours were modelled to assess residual drawdown effects with no pit backfilling.

Drawdown contours were modelled in an analytical model for the dewatering and post-mining phases. During the short-term dewatering phase, the two stygofauna sites were modelled to be within the 12 m drawdown contours where **50%** of their immediate habitat is estimated to be affected. For the post-mining phase, if the pit is not backfilled, the stygofauna sites were within the 2.25 m residual drawdown contours where **9%** of their habitiat is estimated to be affected; pit backfilling is however planned by MRL.

For groundwater recovery within the pit (which invariably dictates residual drawdown), a sensitivity analysis on the hydraulic conductivity and run-off coefficients showed that a full groundwater recovery could be attained after 5-years, even without considering pit backfilling. As a worst-case and conservative scenario, the sensitivity analysis showed that with no pit backfilling and with low hydraulic and run-off coefficient values, groundwater levels would return to 73% of pre-mining levels after 30-years.

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