



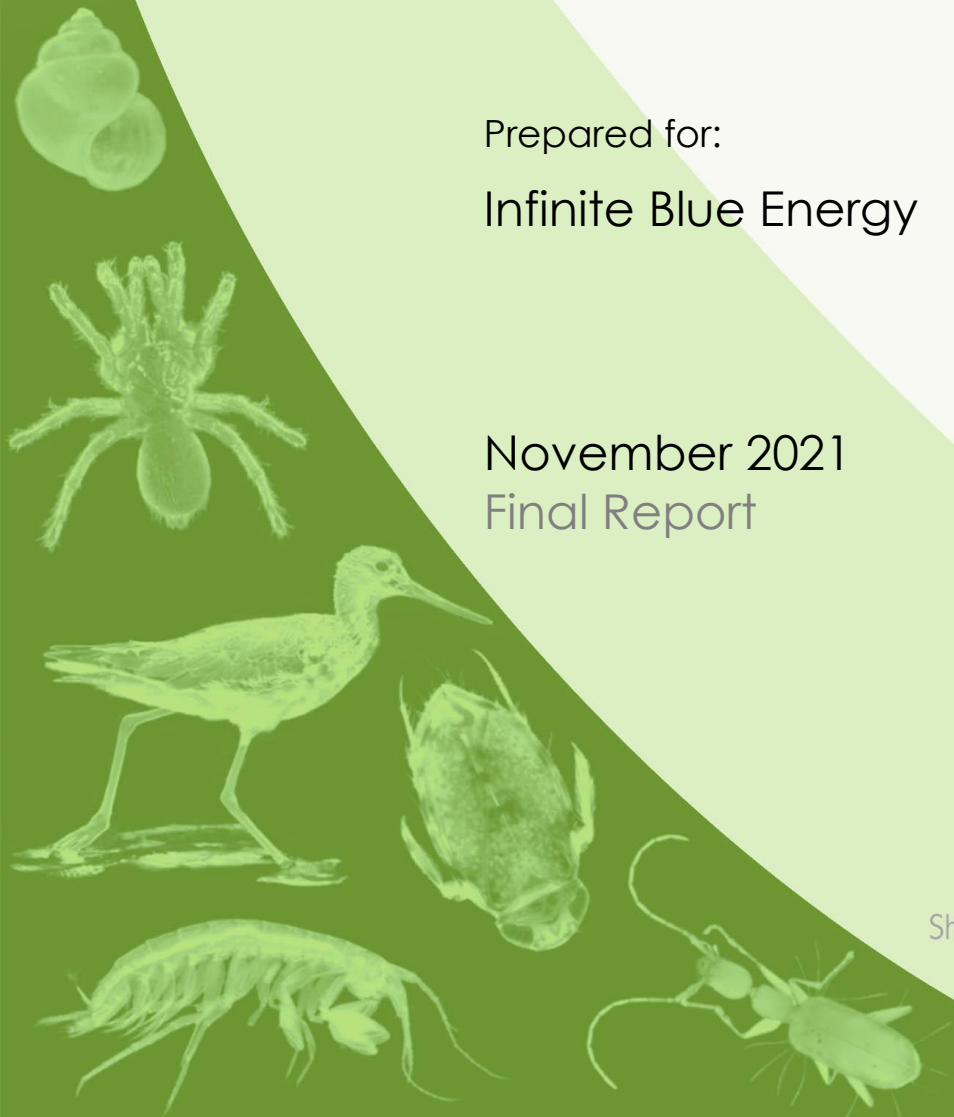
Arrowsmith Hydrogen Project  
Subterranean Fauna Desktop  
Assessment

Prepared for:  
Infinite Blue Energy

November 2021  
Final Report

Short-Range Endemics | Subterranean Fauna

Waterbirds | Wetlands





# Arrowsmith Hydrogen Project Subterranean Fauna Desktop Assessment

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## EXECUTIVE SUMMARY

Infinite Blue Energy proposes to develop the Arrowsmith Hydrogen Project (AHP) 30 km south of Dongara, Western Australia. The proposed AHP is located within Lots 3, 4, 100 and 6110 at Arrowsmith, with a 1929 ha development envelope. The AHP is proposed to produce 45 tonnes of green hydrogen a day by electrolysis using solar, wind energy and water at the site. Hydrogen will be transported offsite by road as cryogenic liquid. Bennelongia has been requested to conduct a desktop review to assess the current knowledge of subterranean fauna values at the AHP with a view to determining the significance of any species and communities present.

Subterranean fauna include aquatic stygofauna in groundwater and air-breathing troglofaunal in the deep soil and rock layers above the watertable. 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 long lifespans and decreased metabolism, also reflect the habitats occupied by subterranean species. With the exception of a few species of fish and snakes, all subterranean fauna species in Western Australia are invertebrates.

Surface geology at the AHP consists of Tamala Limestone as well as low-lying swamp/lacustrine and aeolian deposits associated with Lake Arramall and its drainage. This limestone formation is estimated to be 40-50m thick within the site and features extensive karstic features as a result of dissolution of carbonate. Two named caves occur near Arramall Lake (Arramall Cave and River Cave). Karst formations have long been important to the study of subterranean fauna, providing suitable habitat for both troglofauna and stygofauna, which suggest parts of the AHP might be prospective for subterranean fauna.

A desktop search of subterranean fauna records within an area 100 km x 100 km around the AHP area revealed a depauperate stygofauna community of five species in five families, and a more diverse troglofauna community of up to 54 species from 29 families associated with the caves of the region. The paucity of stygofauna records reflects, at least to some degree, the amount of sampling effort for the region, which has not been surveyed as extensively as the Pilbara or Yilgarn. Nevertheless, considering the low proposed groundwater drawdown, and avoidance of impact to the caves of the AHP, the risk of AHP development to the stygofauna community is considered low.

The troglofauna community in the area around the AHP is potentially rich, with up to 54 species already recorded in caves. These, and other, species may also occur in the karstic habitat of the AHP outside the caves. There is one species, the beetle *Triptenopus occultus*, known only from the AHP in Arramall Cave. It is probably more widespread than this record suggests, however, with the single known location reflecting lack of survey effort.

Threats to troglofauna typically involve the removal of habitat through excavation. No excavation will occur at the AHP, nor will most of the other activities known to impact troglofaunal detrimentally (e.g. altered ventilation, additional light, blasting vibration). Thus, it is unlikely that AHP development will reduce troglofauna conservation values at irrespective of the richness of troglofaunal present and whether *Triptenopus occultus* is restricted to Arramall Cave. Development will be restricted to surface infrastructure and small amounts of groundwater drawdown that are unlikely to affect the quality of troglofauna habitat (especially relative humidity) in either karstic areas or caves.

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## 1. INTRODUCTION

Infinite Blue Energy (IBE) proposes to develop the Arrowsmith Hydrogen Project (AHP) at a site 30 km south of Dongara, Western Australia. The proposed AHP is located within Lots 3, 4, 100 and 6110 in Arrowsmith, with a 1929 ha development envelope (Figure 1). The AHP will produce 45 tonnes of green hydrogen a day by electrolysis using water, as well as solar and wind energy, at the site. Hydrogen will be transported offsite by road as cryogenic liquid.

The scope of this development includes the construction and operation of the AHP and associated infrastructure:

- solar farm (136 MW);
- wind turbines (22 x 6 MW);
- water supply (groundwater);
- processing plant (45 tonnes per day hydrogen); and
- storage and offloading.

The proposed site is former agricultural land and has been grazed by cattle and goats, and the AHP layout has been arranged to avoid wetlands, caves and Carnaby's Black Cockatoo *Zanda latirostris* habitat. Site preparation is planned to commence in 2022, with production commencing in late 2023 subject to approvals and availability of equipment.

Bennelongia has been requested to conduct a desktop review to assess the current knowledge of subterranean fauna values at the AHP with a view to determining the significance of any species and communities present.

## 2. SUBTERRANEAN FAUNA FRAMEWORK

### 2.1. Conservation Legislation

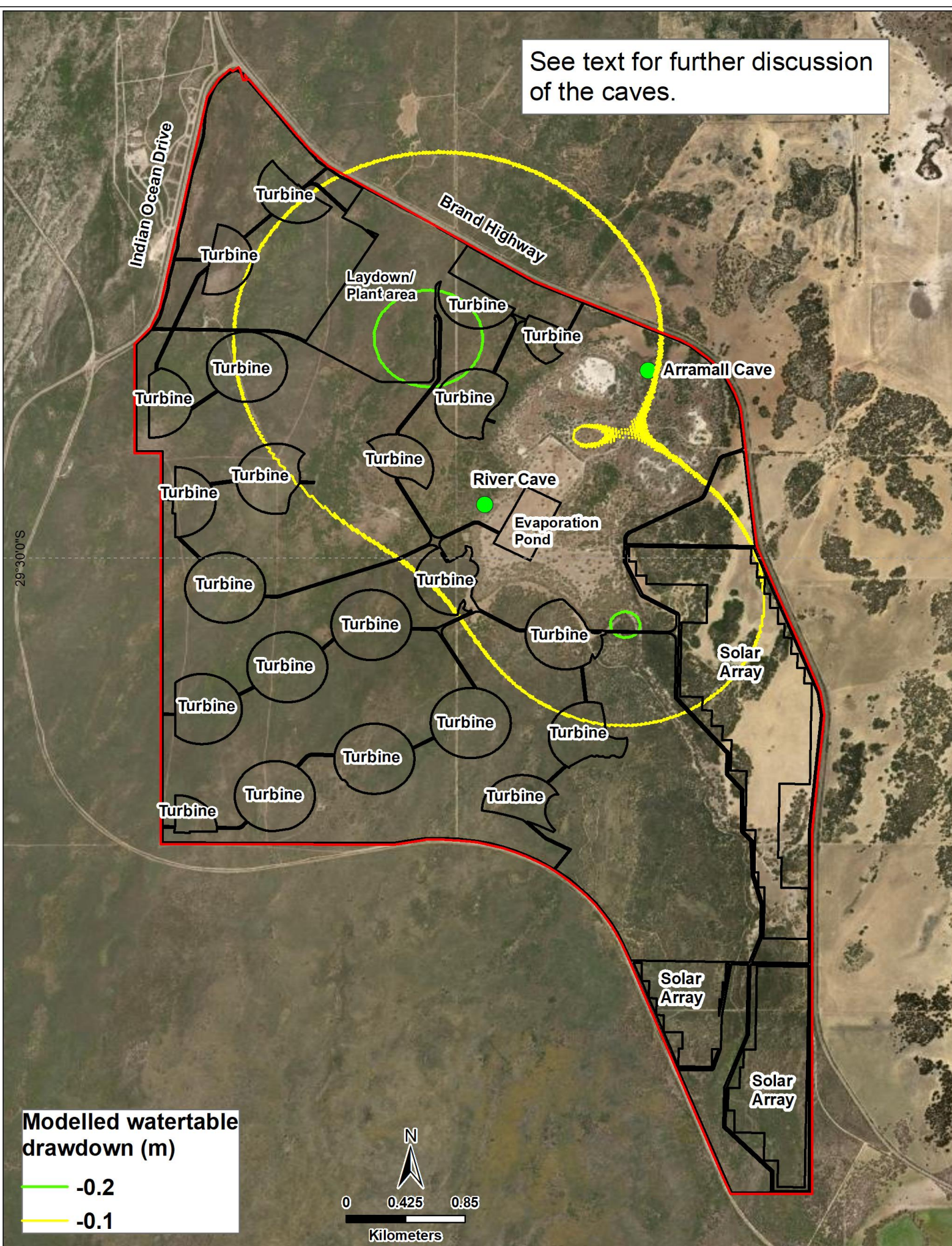
Native flora and fauna in Western Australia are protected at both State and Commonwealth levels. At the state level, the *Biodiversity Conservation Act 2016* (BC Act) provides a legal framework for protection of species, particularly for species listed by the Minister for the Environment as threatened. In addition to the formal list of threatened species under the BC Act, the Department of Biodiversity, Conservation and Attractions (DBCA) also maintains a list of priority fauna species that are of conservation importance but, for various reasons, do not meet the criteria for listing as threatened. The BC Act also provides a framework for the protection of threatened ecological communities (TECs), with DBCA also recognising communities of potential conservation concern, but for which there is little information, as priority ecological communities (PECs). At the national level, the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) provides a similar legal framework to protect and manage nationally and internationally important flora, fauna and ecological communities. However, the threatened fauna lists of the EPBC Act currently do not cover inland subterranean fauna and the list of TECs recognised is smaller than under the BC Act list and has much less focus on subterranean communities.

### 2.2. Subterranean Fauna

Subterranean fauna includes aquatic stygofauna and air-breathing troglafauna. 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 the habitats occupied by subterranean species (Gibert and Deharveng 2002). With the exception of a few species of fish and snakes, all subterranean fauna species in Western Australia are invertebrates.

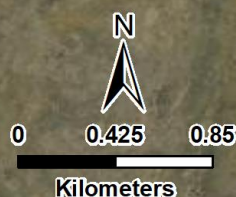


See text for further discussion of the caves.



Modelled watertable drawdown (m)

-0.2  
-0.1



### Legend

- Development envelope
- Disturbance area

Figure 1. Arrowsmith Hydrogen Project area with proposed layout, cave locations, and modelled drawdown.



Although inconspicuous, subterranean fauna contributes markedly to the overall biodiversity of Australia. The Yilgarn and neighbouring Pilbara regions of Western Australia are recognised as hotspots of subterranean faunal biodiversity, with thousands of subterranean species likely to occur (Guzik *et al.* 2010; Halse 2018), the majority of which remain undescribed.

Most subterranean species satisfy Harvey's (2002) criteria for short-range endemism (SRE), namely a total geographic range of less than 10,000 km<sup>2</sup>. In fact, most subterranean fauna have ranges that are at least an order of magnitude less than the SRE threshold (Eberhard *et al.* 2009, Halse and Pearson 2014). Given that species with small ranges are more vulnerable to extinction following habitat degradation than wider ranging species (Ponder and Colgan 2002), it follows that subterranean taxa are highly susceptible to anthropogenic threats, particularly large-scale excavation and groundwater abstraction.

While some subterranean species spend their life cycle in groundwater (stygobites) or subterranean spaces in the vadose zone above the water table (troglobites), others are obligate users of these habitats for most of their life cycle but also move to the surface for a small part of their life cycle. Such animals are referred to as stygophiles and troglaphiles, although the terms are also applied to animals in twilight zones of caves and to species that have both surface and completely subterranean populations. Species with some surface occurrence usually have larger distributions than taxonomically similar stygobites and troglobites because they have greater dispersal opportunities. Finally, stygoxene and troglaxene species may regularly use subterranean environments as refugia but complete their life cycles outside such habitats. It should be noted that some of the animals discussed in this report have been reported in the data sources as troglaphiles but are more likely troglaxenes.

### 2.3. Subterranean Fauna Habitat Requirements

Historically, karst formations have been important to the study of subterranean fauna because caves contain numerous features such as fissures, spaces and even subterranean streams that provide habitat for species both above and below the watertable and the cave systems provide human access to the subterranean environment (EPA 2012). More recently it has become clear that subterranean species also inhabit voids in geologies throughout the landscape matrix beyond the boundaries of cave systems (Eberhard *et al.* 2005a; Halse and Pearson 2014).

Stygofauna communities in aquifers of the broad landscape tend to be richest in areas of calcrete and alluvium (Humphreys 2001), while less transmissive geologies such as banded iron formation (BIF), saprolite, mafic and ultramafic usually contain depauperate communities (ecologia 2009; GHD 2009). It is unusual for silt and clay to support stygofauna because of the lack of interstitial spaces and the associated absence of an aquifer (Korbel and Hose 2011). Geological features such as palaeovalleys as well as the floodplains of modern watercourses are usually prospective habitat for stygofauna (Humphreys 2001; Bagas *et al.* 2004; Bennelongia 2012; Eberhard *et al.* 2005b). Korbel and Hose (2015) found that in alluvium coarser sediments tend to host the greatest numbers of stygofauna, with relatively few animals in silty or clay-rich substrates.

Stygofauna occur in varying salinities but are mostly found in fresh to moderately saline waters with conductivities of less than 40,000 µS/cm. While oxygen levels are typically not measured during stygofauna surveys for environmental impact assessments in Western Australia, stygofauna are reported to be uncommon in hypoxic groundwater (<0.3 mg O<sub>2</sub>/L; Hose *et al.* 2015; Halse 2018).

Troglofauna have been found to occur widely in mineralised iron formations, calcretes and detrital deposits in the Pilbara (Halse 2018). Troglofauna surveys in Western Australia outside the Pilbara have been limited but surveys in ironstone ranges in the Yilgarn at Koolyanobbing, Mt Jackson and Mt Dimmer have yielded depauperate to moderately rich troglofauna communities (Bennelongia 2008a, b), while significant communities have been recorded in calcretes of the Yilgarn. Records of the occurrence



of troglafauna in more coastal areas of south-western Australia are few and mostly from caves (English *et al.* 2003; Knott *et al.* 2007; Knott *et al.* 2008; Knott *et al.* 2009; Moulds 2007b; Tang and Knott 2009).

### 3. REGIONAL SETTING

#### 3.1. Geology

Surface geology at the AHP consists mostly of Tamala Limestone, comprising calcarenite/sand deposit, as well as low-lying swamp/lacustrine and aeolian deposits associated with Lake Arramall and its drainage (Figure 2).

Tamala limestone extends along the coast of Western Australia from Albany in the south to Shark Bay in the North. It is a karstic geology and well-known caves in this formation occur from Augusta to Eneabba. The limestone in the AHP is estimated to be 40-50m thick and contains extensive karstic features as a result of dissolution of carbonate, as well as two named caves (Arramall Cave and River Cave). Other karstic features in the area include vertical solution channels, pipes, and cavities, which are most common near the watertable and are frequently filled with sand (AQ2 2021).

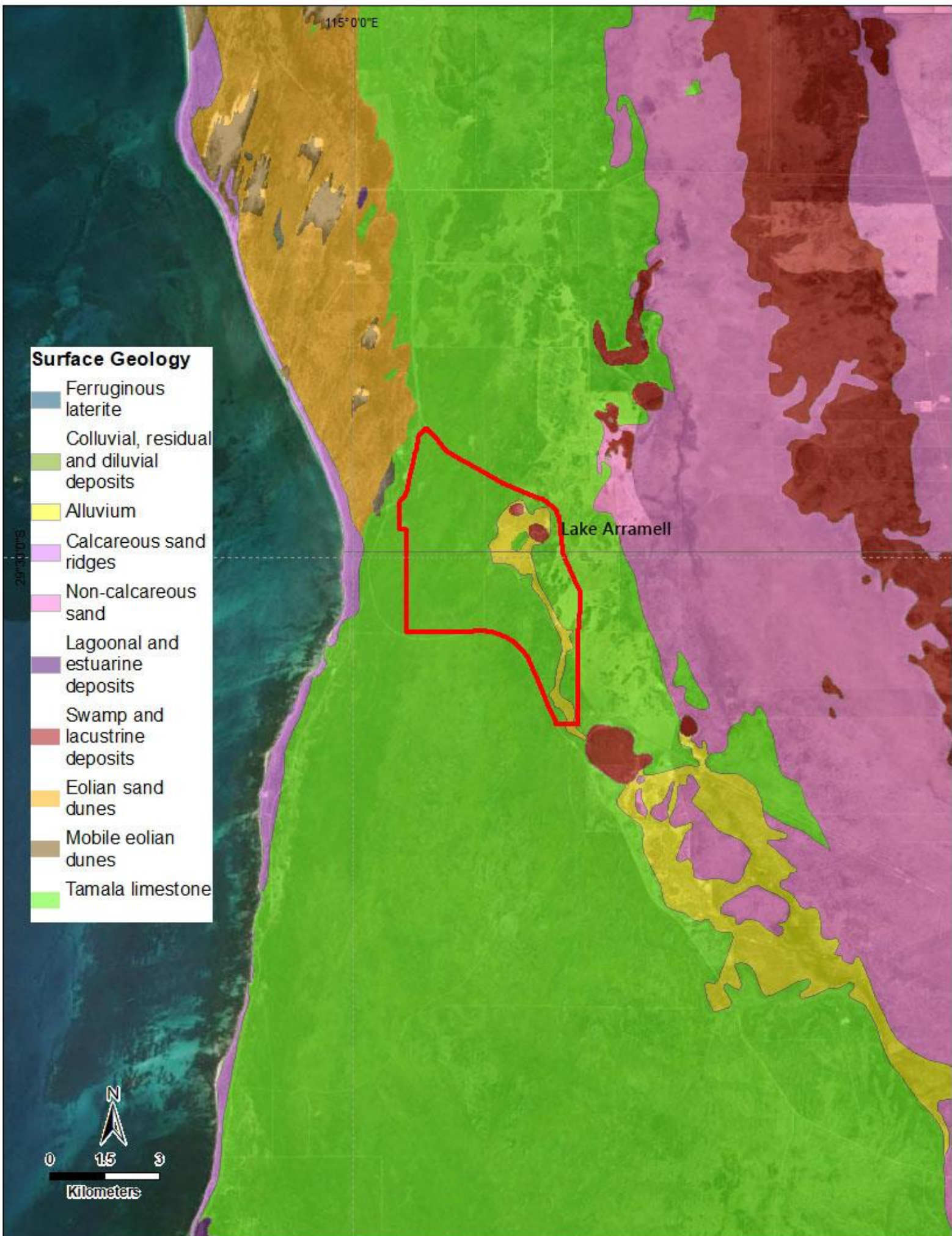
Both Arramall and River Caves were formed via overflow of Lake Arramall. Arramall Cave is thought to be approximately 2 km in length and extends north of Brand Highway (under the road). It is incompletely mapped but contains the larger chambers than River Cave. These chambers were formed by roof collapses (Western Australian Speleological Group 1990). River Cave has a length of about 1.8 km. The floors of both caves are sandy as a result of caves largely filling with sand when Lake Arramall overflows into them.

#### 3.2. Hydrogeology

There are two aquifers at the AHP, the surficial Tamala Limestone aquifer and the underlying Yarragadee aquifer (AQ2 2021). The Yarragadee is the largest aquifer in the northern Perth Basin, and water levels have generally increased in recent decades due to land clearing (Department of Water 2017). At Arrowsmith this aquifer lies within a thick sandstone unit that also contains a lot of sand, which is mostly unconsolidated.

Groundwater level in the surficial limestone aquifer is estimated to be 5-10m below surface near Arramall Lake. Water tested in two existing bores was subsaline, with values of 3,400 and 1,800  $\mu\text{S}/\text{cm}$  (AQ2 2021).

IBE proposes to abstract 854 ML/y of groundwater from two Yarragadee Aquifer bores, which is estimated to produce groundwater drawdown of 0.2 m in the surficial Tamala limestone aquifer over an area of about 400 m around the northern production bore and 60 m around the southern bore (Figure 1). The radius from the bores to zero drawdown is estimated to be approximately 9 km, with the distance to the 0.1 m drawdown contour being approximately 1.5 km (Figure 3; Cardno 2021)..



## 4. DESKTOP REVIEW

Records of subterranean fauna were compiled from Western Australian Museum (WAM) and Bennelongia databases for a square search area of approximately 10,000 km<sup>2</sup> surrounding the AHP (Figure 3). Published research papers, available environmental reports, and online resources such as the Atlas of Living Australia were also reviewed.

### 4.1. Stygofauna

The desktop search returned a depauperate stygofauna community, with five species belonging to five families. These include one species each from the following groups: syncarid, copepod and ostracod crustaceans, and nematode and annelid worms.

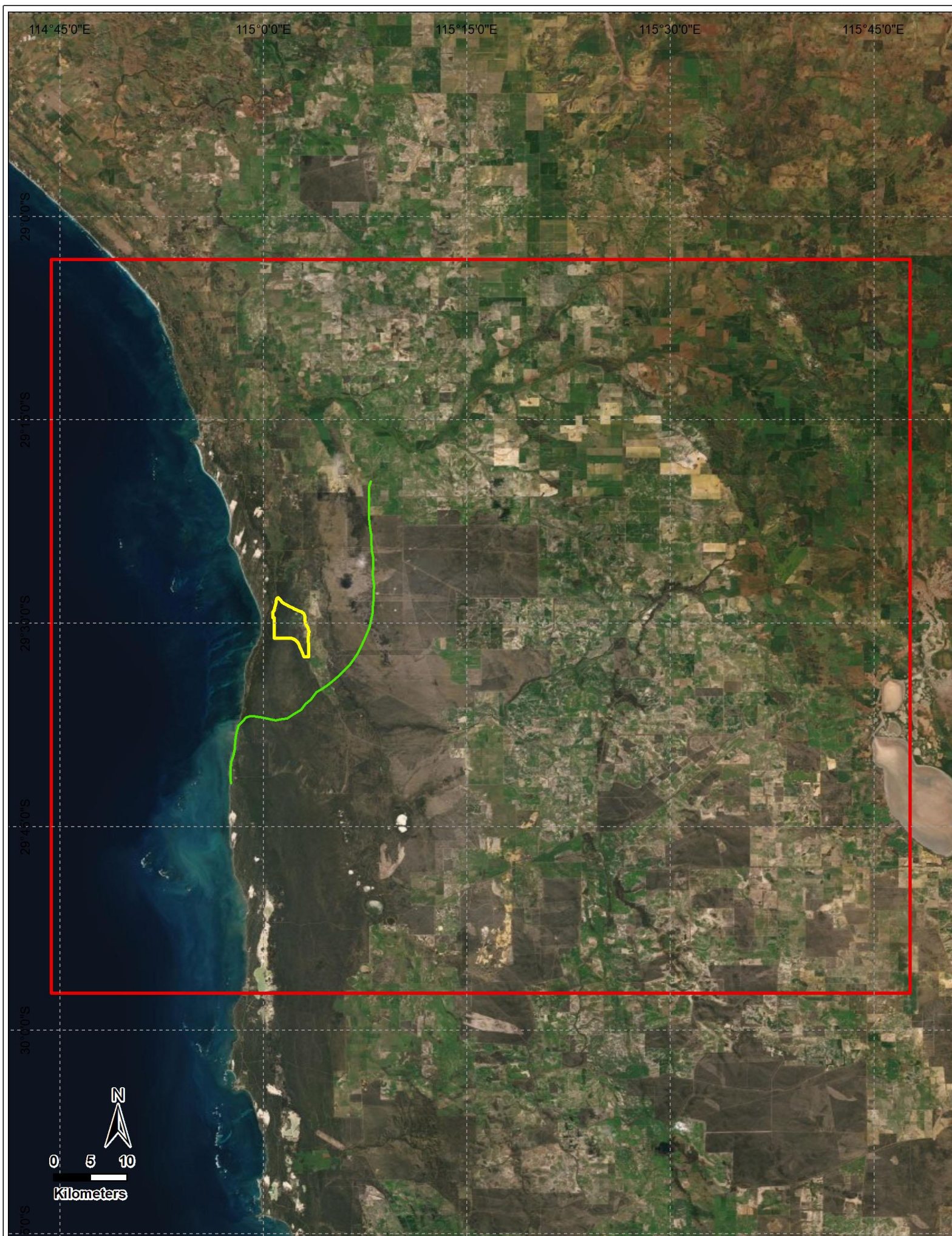
**Table 1:** Stygofauna from the desktop search.

Higher Order	Lowest Identification	Comment/Distribution
Crustacea		
Malacostraca		
<b>Bathynellacea</b>		
Parabathynellidae	<i>Hexabathynella</i> sp.	Higher level identification
Hexanauplia		
<b>Cyclopoida</b>		
Cyclopidae	<i>Pilbaracyclops fiersi</i>	Widespread in Mid-West
Ostracoda		
<b>Podocopida</b>		
Candonidae	<i>Candonopsis tenuis</i>	Australia-wide
<b>Nematoda</b>	Nematoda spp.	Higher level identification
<b>Annelida</b>		
<b>Clitellata</b>		
Haplotaxida		
<b>Phreodrilidae</b>	<i>Antarctodrilus</i> sp. WA3	Swan Coastal Plain

The lack of stygofauna records within the search area is likely to reflect, at least in part, a lack of sampling effort in the region. Similar locations in southwestern Australia where there has been more sampling effort often show more diverse communities. These include stygofauna surveys in coastal plain aquifers to the south in the Gnangara Mound (Tang and Knott 2009), Bassendean Sand at Kensington in Perth (Bennelongia 2015), limestone sands at Pt Grey beside the Harvey Estuary near Mandurah (Bennelongia 2009). Mineral sands at Cooljarloo, south-east of The Pinnacles, contained no stygofauna, however (Bennelongia 2013). Caves on the coastal plain are also known to support stygofauna (e.g. Karanovic 2003; Karanovic 2005; Knott *et al.* 2007; Knott *et al.* 2008; Knott *et al.* 2009), while Pinder *et al.* (2006) documented stygofaunal oligochaetes in karst caves and aquifers along the west coast of Australia from Cape Range in the north to the Leeuwin-Naturaliste Ridge in the south.


The Department of Water and Environmental Regulation has conducted environmental monitoring of stygofauna in the Yanchep caves to the south of the AHP, near the Gnangara Mound (English *et al.* 2003; Knott *et al.* 2007; Knott *et al.* 2008; Knott *et al.* 2009). Exploration of 11 caves and 2 springs has yielded 68 species of that were regarded as potential stygofauna. Groups collected include copepods (23 species), oligochaete worms (17 species), ostracods (nine species), polychaete worms (five species), amphipods (five species), flatworms (one species) isopods (one species), mites (one species), snails (one species), rotifers (one species), and nematode worms (rotifers and nematodes are not included in EIA assessments).






#### Legend

 AHP Boundary

 Desktop Search Area

 Drawdown Extent

**Figure 3: Arrowsmith Hydrogen Project desktop search area and modelled drawdown extent.**



## 4.2. Troglafauna

The Western Australian Museum database, largely based on the collecting of Moulds (2007a), returned records of 53 species of potential troglafauna belonging to at least 29 families from caves in the search area. No other habitat supported troglafauna.

Most of the species in the search area occur in Arramall or River Caves, which lie within the AHP. In addition to species from the Museum search, the website of the Western Australian Speleological Group (<https://wasg.org.au/index.php/2015-09-05-08-05-32/eneabba/eneabba-description>) and Susac (2007) provide records of another eight troglafaunal species in Arramall or River Caves. Susac (2007) states that 83 invertebrate species have been recorded in Arramall Cave and 26 cavernicolous invertebrate species in River Cave. Sixty-one species from these caves and the wider search area are listed in Table 2. Many of the other species found regularly in the caves appear to be surface taxa and so are not listed in Table 2. Many of the species in Table 2 that were classed as troglaphiles by collectors should probably be classed as troglaxenes.

The species regarded by collectors as having strong subterranean affinity include: three species of snail, six species of mite, 11 species of spider, two species of harvestman, two species of scorpion, 12 species of isopod, two species of collembola, two species of cockroach, six species of beetle, four species of true bug, two species of moth, two species of booklice, three species of silverfish, five species of centipede, and one harvestmen (Table 2). Both mites and collembola are usually excluded from environmental impact assessment reporting but they do contain troglafaunal species.

Nearly all species in Table 2 are known to be widespread. There are no species that are obviously troglabites. Consequently, the richness of the troglafauna list is much larger than the likely list of species in the karstic areas around the caves, which would contain essentially only troglabitic species or troglaphiles that spend most of their life cycles in dark, enclosed underground habitat.

### 4.2.1. Comments on Records of Some Identified Species

The mite *Kleemannia plumosa* was recently synonymized with *Ameroseius dubitatus*, which is found throughout Europe (Masan 2017), hence the species is considered cosmopolitan.

The mite *Caligonella humilis* is represented in the search area by a single record from Arramall cave. However, it is a cosmopolitan species and not typically associated with subterranean habitats.

The pseudoscorpion *Protochelifer cavernarum* is associated with cave guano deposits and is found from southern Australia north along the east coast, though molecular investigations showed that the species is actually a complex with distinct species among different caves (Moulds *et al.* 2007). Moulds (2007a) speculated that the possibility exists that populations from caves of the Eneabba and Jurien Karst areas are distinct and locally endemic.

*Neotemnopteryx douglasi* is a troglaphilic cockroach with two distinct populations, with records from both the east and west coasts of Australia. According to Moulds (2007a) the populations should be considered distinct species or possibly even genera, though this requires further genetic work to confirm. This species is found in multiple caves in the AHP area, including healthy populations in Weelawadji outside the AHP.

The beetle *Triptenopus occultatus* is known from a single collection of two individuals made in 1969 in Arramall cave, with no additional records since. These individuals were eyeless, though pigmented and lacking some other characters common to troglabites such as elongated appendages, suggesting the loss of eyes may have come prior to its cave habit (Britton 1974). This species appears to be very rare.

**Table 2:** Troglafauna records from the search area.

Higher order classification	Lowest Identification	AHP Caves		Comment
		E22: Arramall	E23: River	
Gastropoda				
Bithyniidae	<i>Gabbia kendricki</i>	x		Widespread
Bothriembryontidae	<i>Bothriembryon perobesus</i>			Possible troglaxene, P1 species P1
Succineidae	<i>Succinea</i> sp.	x		Higher level identification
Arachnida				
<b>Acari</b>				
Ameroseiidae	<i>Kleemannia plumosa</i>			Cosmopolitan
Cheyletidae	<i>Calligomella humilis</i>	x		Cosmopolitan
Cunaxidae	<i>Cunaxa setirostris</i>			Widespread
	Cunaxidae sp2			In Eneabba, Jurien, and Nambung caves
Ichthyostomatogasteridae	<i>Asternolaelaps australis</i>			Widespread
Trombidiidae	Trombidiidae sp1		x	Also in Nambung caves
<b>Araneae</b>	Araneae sp1	x	x	Also in Jurien and Nambung caves
	Araneae sp2		x	Also in Jurien and Nambung caves
	Araneae sp3		x	Also in Jurien and Nambung caves
	Araneae sp4		x	Also in Nambung caves
	Araneae sp5		x	Also in Nambung caves
	Araneae sp6		x	Also in Nambung caves
	Araneae sp7			In Weelawadji Cave E24
Theridiidae	Theridiidae sp1		x	Also in Jurien caves
Linyphiidae	<i>Laetesia</i> sp.	x		Troglomorphic: blind, depigmented
Desidae	<i>Baiami tegerarioides</i>	x		Widespread in WA
	<i>Baiami volucris</i>	x	x	Widespread in WA
<b>Opiliona</b>				
Cheliferidae	Opiliona sp1	x	x	Troglophile; also in Jurien caves
<b>Pseudoscorpiones</b>				
Cheliferidae	<i>Protochelifer cavernarum</i>	x	x	Troglophile; widespread, though see discussion
Chthoniidae	<i>Austrochthonius australis</i>	x		widespread

Higher order classification	Lowest Identification	AHP Caves		Comment
		E22: Arramall	E23: River	
Crustacea				
Malacostraca				
<b>Isopoda</b>	Isopoda sp1			Stockyard Tunnel E1
Armadillidae	Armadillidae sp1		x	Also in Thousand Man (SH7), Pretty (SH9) caves
	<i>Pseudodiploexochus australiensis</i>	x	x	Troglophile, blind and depigmented
Philosciidae	Armadillidae sp2			Trogloxene
	<i>Laevophiloscia richardsae</i>	x	x	Troglophile
	<i>Laevophiloscia</i> sp. 3			Troglophile
	<i>Laevophiloscia</i> sp1	x		Troglophile; also in Jurien caves
	<i>Laevophiloscia</i> sp2	x		Troglophile; also in Jurien caves
	Philosciidae sp1			In Eneabba and Jurien caves
	<i>Laevophiloscia yalgoonesis</i>	x	x	WA and SA
	<i>Laevophiloscia unidentata</i>	x	x	Troglophile, type specimen from Yallingup cave
Oniscidae	Oniscidae sp.			Higher level identification
Hexapoda				
<b>Collembola</b>				
Entomobryidae	Entomobryidae sp1		x	Troglophile; also in Stockyard Tunnel E1
	<i>Pseudosinella</i> sp.		x	Higher level identification
Insecta				
<b>Blattodea</b>				
Blattellidae	<i>Neotemnopteryx douglasi</i>	x		Troglophile; distribution along SW coast
?Nocticolidae	?Nocticolidae sp.	x	x	Troglophile: depigmented
<b>Coleoptera</b>				
Staphylinidae	<i>Tripectenopus occultus</i>	x		Known only from Arramall Cave
Carabidae	<i>Lecanomerus flavocinctus</i>	x	x	Widespread
	<i>Speotarus lucifugus</i>	x		Troglophile; widespread
Anobiidae	<i>Ptinus exulans</i>			Troglophile; widespread
Tenebrionidae	<i>Brises acuticornis duboulayi</i>			Troglophile; widespread
Dermestidae?	Dermestidae? sp1	x		Troglophile?; larvae

Higher order classification	Lowest Identification	AHP Caves		Comment
		E22: Arramall	E23: River	
<b>Hemiptera</b>				
Meenoplidae	Meenoplidae sp.	x		Troglophile, unpigmented
Reduviidae	Emesinae sp1			Troglophile
	Harpactorinae sp1			Troglophile
	Harpactorinae sp3		x	Troglophile
<b>Lepidoptera</b>				
Teneidae	<i>Monopis crocicapitella?</i>	x		Troglophile; widespread
Erebidae	<i>Dasypodia selenophora</i>	x		Troglophile; Nambung Eneabba caves
<b>Pscoptera</b>				
Trogiidae	Trogiidae sp1	x		Troglophile; also Jurien caves
	Trogiidae sp2		x	Troglophile
<b>Zygentoma</b>				
Lepismatidae	Lepismatidae sp1			Troglophile
Nicoletiidae	<i>Trinemura ?novaehollandiae</i>			
	<i>Trinemura</i> sp1			Troglophile
<b>Myriapoda</b>				
Chilopoda				
<b>Scolendropmorpha</b>	Scolendropmorpha spp.	x		Troglomorphic; one or more species
<b>Symphyla</b>	Symphyla sp.	x		Higher level identification
<b>Scutigerida</b>				
Scutigeridae	Scutigeridae sp1			Troglophile
	<i>Allothureua lesueurii</i>	x		Troglophile, widespread
	<i>Thereuopodina</i> sp.			Higher level identification



The silverfish *Trinemura novaehollandiae* was tentatively identified from the Stockyard Tunnel of the Eneabba karst region. This species was recently redescribed, and is known from locations south of the AHP with additional specimens collected from Mundaring Weir (Smith 1998).

### 4.3. Threatened and Listed Species

The only listed species from the caves is the snail *Bothriembryon perobesus*, which is listed as Priority 1 by DBCA. The cave-associated record is from Weelawadj cave. This species has additional surface records from the west and south coasts of WA, and live specimens were collected from two sites in 2014 and 2016 (Whisson 2019). These sites represented diverse habitats, the first being in Moore River National Park, with individuals collected from sandy soils among *Banksia* and eucalypt woodland, and the second site was a limestone escarpment north of Leeman. This and previous data indicate that this species is likely to be a troglonexene or opportunistic, utilizing the cave environment only for its relatively stable and moist conditions.

### 4.4. Cave Habitat

Arramall and River Caves were first explored by speleologists in 1960. Arramall Cave was mapped in 1973, with further mapping in the 1990s. River Cave has not been mapped but it has stronger surface connections, allowing for more even input of organic matter but also more drying in summer and autumn (Susac 2007). Thus, Arramall Cave is likely to be more important troglofaunal habitat than River Cave.

Compared with other caves in Tamala limestone in the broad Eneabba area, the numbers of species in Arramall Cave (83 species) and River Cave (26 cavernicolous species) are very similar to the number of species in Weelawadj Cave (83 species) and Beekeepers Cave (29 cavernicolous species) in Beekeepers National Park, more than in Drovers Cave (14 species) in Drovers Cave National Park near Jurien, and substantially fewer than in the large Stockyard Cave (62 cavernicolous species) near Leeman.

## 5. CONCLUSIONS

Surface geology at the AHP consists of Tamala Limestone, as well as low-lying swamp/lacustrine and aeolian deposits associated with Lake Arramall and its drainage. Karst formations have long been important to the study of subterranean fauna because caves provide access to the subterranean environment. With the slightly brackish groundwater salinities observed at the AHP, habitat is considered suitable for subterranean fauna.

The desktop search of 100 km x 100 km around the AHP area found a depauperate stygofauna community of five species, and a much more diverse troglofauna community of up to 61 species. These troglofauna species were all associated with the caves of the region but probably none of them is troglobitic.

Threats to stygofauna from development primarily arise where there is significant dewatering or salinization of groundwater. These changes can threaten composition or persistence of isolated communities in certain circumstances. Considering the small drawdown predicted (no more than 0.2 m) from Project-associated groundwater extraction the threat to stygofauna conservation values is considered low, irrespective of what stygofauna is present. This conclusion of no conservation impact is reinforced, however, by the apparently depauperate nature of stygofauna communities in the region.

The troglofauna community in the AHP is rich. All 61 species recorded in the caves of the AHP or surrounding areas have potential to occur in the AHP. However, it is likely there has been a bias towards assigning species in caves to subterranean status. Many of the species listed in Table 2 as troglophiles are probably troglonexenes. A substantial proportion of the species without designated subterranean status are probably species collected at the front of caves. Few, if any, of the species in the desktop search have the potential to occur in subterranean habitat of the AHP other than caves. Nearly all named

species recorded in the AHP are widespread. There is, however, one species, the beetle *Triptenopus occultus*, known currently only Arramall Cave.

Threats to troglofauna typically involve the removal of habitat through excavation. No excavation will occur at the AHP but cave fauna can also be impacted in other ways, including reduced humidity through altered ventilation, removal of standing waterbodies or, possibly, more general groundwater drawdown. It is unlikely the small drawdown proposed at the AHP will affect cave humidity. Other aspects of project development are also unlikely to affect cave fauna. Thus, despite *Triptenopus occultus* being known to date only from Arramall Cave, it is unlikely that proposed development will reduce troglofauna conservation values at the AHP.

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