Tronox Pty Ltd

Cooljarloo West Proposal: Subterranean Fauna, Desktop Study and Methods Statement

Final Report

Prepared for
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by Bennelongia Pty Ltd

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Cover photo: nr *Protocrangonyx* sp. from the Swan Coastal Plain

Client – Tronox Pty Ltd

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EXECUTIVE SUMMARY

Tronox Management Pty Ltd (Tronox) (previously Tiwest Pty Ltd) has operated the Cooljarloo mineral sands mine 175 km north of Perth since 1989. The mine was authorised by the WA Minister for the Environment in 1988 (under Ministerial Statement 37). The mine has subsequently been modified by the following expansions:

- Dredge and/or dry mining of ore bodies 27 200 and 28 000 in the southern portions of the tenement (Ministerial Statement 557); and
- Dry mining of Falcon deposit in the northern end of the tenement (Ministerial Statement 790).

The remaining dredge mine life at Cooljarloo is approximately 15 years and Tronox now proposes to develop additional resources to the west of the current operations to extend the Cooljarloo mine life. The additional resources are on exploration leases E70/2345 and E70/2346 and are known as Cooljarloo West (the Proposal). Subterranean fauna (stygofauna and troglofauna) were not assessed under any of the previous environmental impact assessments.

This report assesses the subterranean fauna habitat, requirement for field survey and risk to subterranean fauna associated with the Proposal. The objectives of this desktop study are:

1. To review the current knowledge of subterranean fauna in the region and characterise the local habitat within a regional context to provide;
    a) a basis for gauging the likelihood of significant subterranean fauna assemblages inhabiting the Proposal site and;
    b) the conservation significance of any subterranean fauna species;
2. To identify the potential threats to subterranean fauna species and assess the threat of loss of subterranean fauna species as a result of Proposal development.

A review of the geology and hydrogeology of the Proposal area indicates that there is prospective stygofauna (aquatic subterranean fauna) habitat in the vicinity of the Proposal, particularly in the Superficial Formation aquifer. Based on the extensive nature of both the Superficial and Yarragadee aquifers, it could be expected that the stygofauna habitat would have considerable connectivity beyond the Proposal. Furthermore, this notion aligns with the available information on the distribution of stygofauna, which suggests that most stygofauna species of the Swan Coastal Plain are wide-ranging and mostly have capacity to disperse via surface water. However, it is possible that stygobitic species (i.e. obligate subterranean species) may recognise underground barriers to dispersal barriers in the vicinity of the Proposal. These potential barriers include clay layers that may restrict vertical movement, as well as faults and escarpments that may restrict lateral movement. In addition, potentially isolated stygofauna habitat could be represented in the vicinity of the Proposal by the buried outwash fans and deltaic deposits associated with Mullering Brook and other local water courses.

Although the drawdown associated with mining at the Proposal site is yet to be modelled, the spatial extent is estimated to be in the vicinity of 8,000-10,000 ha. This impact, and others of similar scale already approved in the vicinity of the Proposal, may have the potential to impact on stygofauna species, particularly species that inhabit the shallower component of the Superficial Formation aquifer where the effect of drawdown will be greatest.

In summary, three assumptions about the hydrogeology of the Proposal area suggest there may be a potential threat to stygofauna from the Proposal. It is assumed that:

1. Prospective stygofauna habitat occurs in the vicinity of the Proposal;

2. Potential barriers to dispersal and isolated habitat (habitat discontinuity) occur in the vicinity of the Proposal; and
3. There is potential for the Proposal (and cumulatively, those of other approved impacts nearby) to remove a considerable proportion of the habitat of any highly restricted stygofauna species present.

Consideration of the likelihood of the above assumptions is constrained by the lack of an accurately defined impact footprint (drawdown cone) and by the limited capacity of habitat characterisation to predict the distribution of stygofauna species. Therefore, it is recommended that a pilot-scale field survey is undertaken to define the potential threats to stygofauna more accurately by: a) confirming the presence/absence of stygofauna; and b) exploring the range characteristics of any stygofauna species present. The likely ranges of stygofauna species may then be compared to the extent of groundwater drawdown associated with the Proposal when this is modelled.

Should a significant stygofauna community be recorded, a full-scale sample effort to Environmental Protection Authority guidelines may be required to assess the risk to stygofauna.

Although some troglofauna (air-breathing subterranean fauna) have been collected within the region surrounding the Proposal, it is very unlikely that troglofauna occur within the impact footprint of the Proposal. It may reasonably be expected that the impact footprint as a result of pit excavation will not intersect prospective troglofauna habitat, owing to the high watertable in the vicinity of the Proposal (0-6 m below ground) and the lack of air-spaces within the recent deposits and Bassendean Sand that lie above the watertable. Further assessment of threat to troglofauna species through field survey is therefore not considered necessary.

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1. INTRODUCTION

Tronox Management Pty Ltd (Tronox) (previously Tiwest Pty Ltd) has operated the Cooljarloo mineral sands mine 175 km north of Perth since 1989 (Figure 1.1). The mine was authorised by the WA Minister for the Environment in 1988 (under Ministerial Statement 37). The mine has subsequently been modified by the following expansions:

- Dredge and/or dry mining of ore bodies 27 200 and 28 000 in the southern portions of the tenement (Ministerial Statement 557); and
- Dry mining of Falcon deposit in the northern end of the tenement (Ministerial Statement 790).

The remaining dredge mine life at Cooljarloo is approximately 15 years and Tronox now proposes to develop additional resources to the west of the current operations to extend the Cooljarloo mine life. The additional resources are on exploration leases E70/2345 and E70/2346 and are known as Cooljarloo West (the Proposal). Subterranean fauna were not assessed under any of the previous environmental impact assessments.

This report assesses the subterranean fauna habitat, requirement for field survey and risk to subterranean fauna associated with the Proposal. The defining characteristic of subterranean fauna is that they spend all, or most, of their lifecycle underground and are morphologically adapted to the subterranean environment. Adaptations include pallid colouration, reduction or loss of eyes, elongate body, long slender appendages and well developed sensory setae.

Subterranean fauna have significant scientific value and a high proportion of subterranean species are short-range endemics (SREs), defined by Harvey (2002) as species with ranges of <10,000 km^2. The restricted ranges of most subterranean fauna species means they are particularly vulnerable to extinction from anthropogenic activities and, hence, are a focus for conservation (see Fontaine *et al*. 2007). There are two types of subterranean fauna, stygofauna and troglofauna. Stygofauna occur in groundwater, whereas troglofauna are air-breathing and occur at depth in the various unsaturated soil and rock profiles above the watertable (Gibert and Deharveng 2002). In general terms, stygofauna may be threatened by groundwater drawdown and troglofauna by excavation of soil and rock.

The Proposal site covers about 5700 ha; although the impact footprints within this area are likely to be small relative to the ranges of most subterranean fauna species. However, the planned disturbance associated with the Proposal may potentially threaten highly restricted species of subterranean fauna, if such species exist within the Proposal footprint.

The objectives of this desktop assessment are:

1. To review the current knowledge of subterranean fauna in the region and characterise the local habitat within a regional context to provide;
    a. a basis for gauging the likelihood of significant subterranean fauna assemblages inhabiting the Proposal site and;
    b. the conservation significance of any subterranean fauna species;

2. To identify the potential threats to subterranean fauna species and assess the risk of loss of subterranean fauna species as a result of Proposal development.

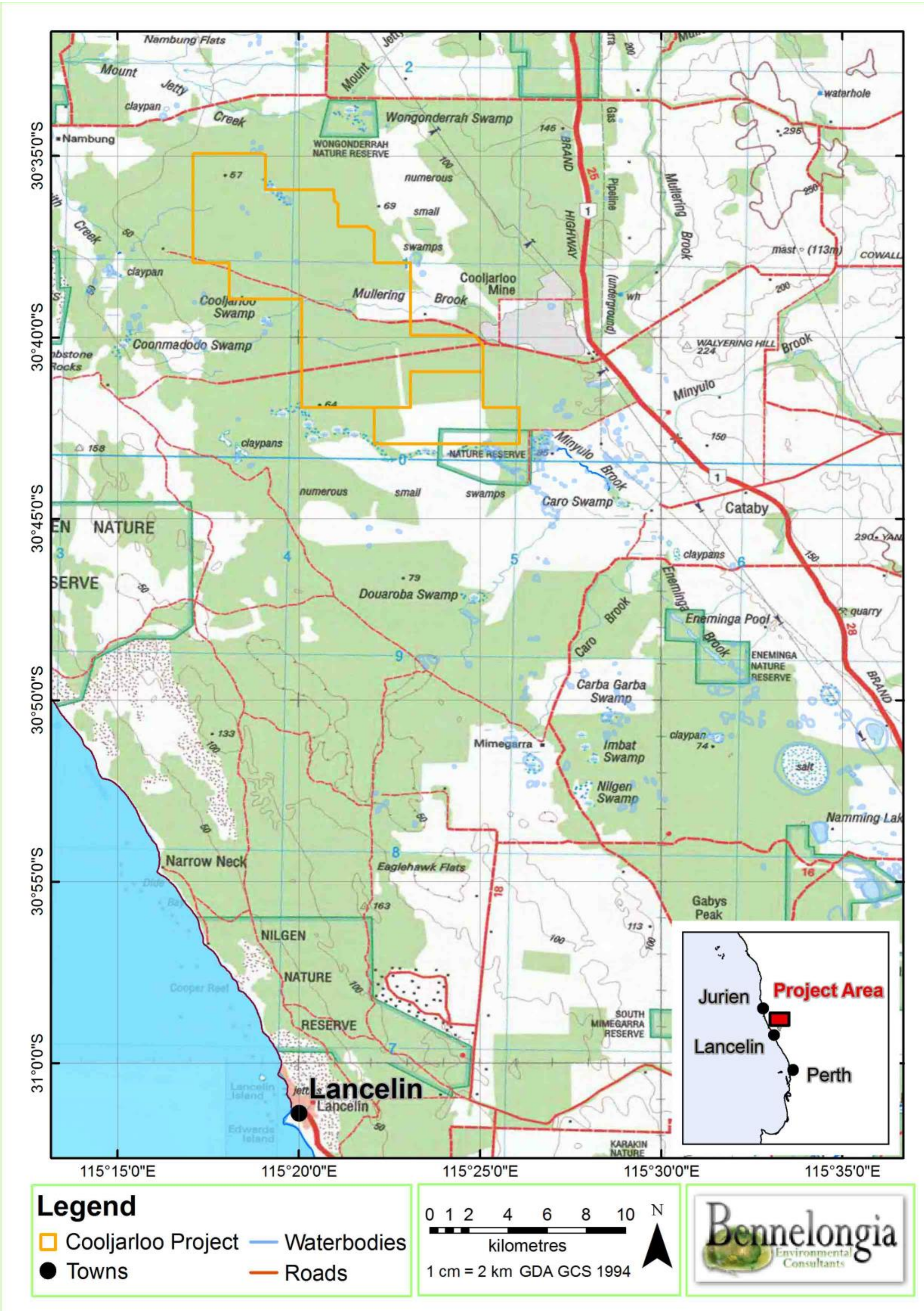

Figure 1.1. Location of the Cooljarloo Project.

2. SITE DESCRIPTION

2.1. Geomorphology

The Proposal sits at the eastern edge of the Swan Coastal Plain, which extends from the Indian Ocean to the Gingin Scarp (Davidson 1995). The Gingin Scarp was formed by marine erosion and separates the Swan Coastal Plain from the Dandaragan Plateau in the southeast and the Arrowsmith Region in the northeast (WorleyParsons 2012). The coastal plain can be divided into two main geomorphic units: the Coastal Belt consisting of calcarenite dunes and beach ridges to the west of the Proposal; and the Bassendean Dunes, in which the Proposal lies, consisting of leached Pleistocene quartz sands (Kern 1989, in WorleyParsons 2012).

2.2. Geology

Regionally, the Proposal is situated in the central part of the northern Perth Basin, which is a sedimentary trough about 950 km long, on the western side of the Precambrian Yilgarn Block. The regional geology is bounded to the east by the Darling Fault which separates the Perth Basin sediments from Archaean crystalline rocks of the Yilgarn Block (Briese 1979, in WorleyParsons 2012).

2.2.1. Recent Deposits

Deposits of alluvium, colluvium and lacustrine sediments form a thin cover over the Quaternary deposits. These deposits vary on local topography and geomorphology (WorleyParsons 2012).

2.2.2. Quaternary and Tertiary Deposits

Tertiary and Quaternary deposits of the Perth Basin are known as Superficial Formations (WorleyParsons 2012). Regionally, these formations consist of laterally and vertically variable sequences, up to 90 m thick, of sand, silt, limestone and clay. Near the coast, calcareous marine sands and coastal limestone (Tamala Limestone and Safety Bay Sand) are present. Inland, variable sequences of fine and medium sand with minor silt and limestone (mainly Bassendean Sand) interfinger with a sequence of clay and clayey sand towards the foothills of the Darling and Gingin scarps (Guildford formation clay) (WorleyParsons 2012).

In the vicinity of the Proposal, the Superficial Formations deposits comprise Bassendean Sand, Guildford Formation (Quaternary), Yoganup Formation and Ascot Formation (Tertiary); and consist of laterally and vertically variable interbedded sequences of sand, gravel, limestone, silt and clay (Parsons Brinkerhoff 2011; WorleyParsons 2012). The general structure of the Superficial Formation sequences is as follows:

1. The Bassendean Sands (0-6 m), consist of loose to medium dense, fine grained sands, with ferruginisation toward the base, commonly forming a ferricrete pebble layer of variable thickness;
2. Guilford Formation (6-20 m) comprises dense clayey and silty fine sand. Several plastic clay layers up to 1 m thick occur in the profile;
3. Guilford Formation (20-35 m) of slightly clayey-silty, fine sand. The sand facies coarsen downward. Close to the base the unit is characterised by fine to medium sands; and
4. Yoganup Formation and Ascot Formation (35-50 m), light sands with heavy minerals, coarsening down until close to the base they become medium-to-coarse, often with flakes of feldspar. A few metres of very coarse gravely sands are often present at the base.

2.2.3. Jurassic Deposits

The Yarragadee formation is largely a fluvial deposit, but thicker shaley sections may represent a lacustrine deposition (Kern 1997, in WorleyParsons 2012). This formation typically comprises interbedded fine-to-coarse feldspathic sandstone, siltstone, and claystone with minor conglomerate and coal (Mory 1995, in WorleyParsons 2012). The Yarragadee Formation has been affected by normal faulting and minor folding. Three major faults with a north-north-westerly trend occur west of the Proposal area (WorleyParsons 2012). These faults include the Beagle, Lesueur and Warradarge Faults (Kern 1989, in WorleyParsons 2012). The Yanchep Syncline occurs west of the Proposal area and the Gingin Anticline occurs to the east. These formations predominantly control the local distribution of the Yarragadee Formation (WorleyParsons 2012).

In the vicinity of the Proposal the Yarragadee Formation occurs from about 50 m. The general structure of the sequence consists of shallow upper profiles characterised by clayey sands, and siltstone. Below the shallow profiles the formation is comprised of coarse sandstones interbedded with siltstone and shale facies (Parsons Brinkerhoff 2011; WorleyParsons 2012).

2.3. Hydrogeology

The Proposal lies over two main regional aquifer systems, the Superficial Formation and the Yarragadee Formation. Based on the reviewed information and field investigations conducted by Parsons Brinckerhoff at the existing mine site (Parsons Brinckerhoff 2011), it is interpreted that the vertical succession of aquifer systems is as follows:

1. Superficial Formation from the ground surface to depths of approximately 18 to 50 m; and
2. Yarragadee Formation from approximately 40 to 50 m depth.

It was also noted that the Superficial Formation and Yarragadee Formation aquifers are considered to be locally interconnected (depending on the presence/thickness of clay layers).

Groundwater at the Cooljarloo mine site is generally of good quality, with pH ranging from slightly acidic to neutral and total dissolved solids (TDS) values generally less than 800 mg/L in both the Superficial and Yarragadee Formations (WorleyParsons 2012).

2.3.1. Superficial Aquifer

The Superficial Formation constitutes a single aquifer system comprised of beds of sands and clays in alternate layers forming a semi-confined to unconfined anisotropic groundwater flow system (Kern 1989, in WorleyParsons 2012). Regionally, groundwater flow is predominantly westward to the Indian Ocean from the limit of Superficial Formations along the Gingin Scarp. Towards the surface, clays can confine the underlying aquifer or support seasonal perched aquifers (Parsons Brinckerhoff 2011; WorleyParsons 2012).

Locally, near Gingin Scarp, the Superficial Formation incorporates outwash fans and deltaic deposits associated with the Mullering Brook and other water courses (Parson Brinckerhoff 2011). These deposits are thought to vary significantly in composition, distribution and form; and include buried sandy riverbed, high-energy channel deposits, and low-transmissivity clayey and silty sand (WorleyParsons 2012). The majority of recharge to the Superficial Formation occurs by direct infiltration of rainfall and recharge in places where Guildford Formation clays are absent; recharge and leakage also occurs from and to the Yarragadee Formation (Parsons Brinckerhoff 2011; WorleyParsons 2012).

2.3.2. Yarragadee Aquifer

The Yarragadee Formation forms the deepest and most extensive aquifer system in the northern Perth Basin. It extends westwards to the Warradarge Fault, eastwards to the Yilgarn Block and to the north and south throughout the Dandaragan Trough. Regionally, the Yarragadee aquifer is unconfined west of the Dandaragan Scarp but is confined beneath the thick Otorowiri Siltstone Member to the east. Recharge to the Yarragadee aquifer is via infiltration of rainfall into the overlying weathered sediments and by vertical leakage from the overlying Bassendean Sand (WorleyParsons 2012).

3. PROJECT DESCRIPTION AND POTENTIAL IMPACTS

3.1. Mining Activities Relevant to Subterranean Fauna

The Proposal comprises three additional orebodies west of the existing mine site; namely Harrier, Kestrel and Woolka, covering 273, 149 and 385 ha respectively (Figure 3.1). It is proposed that all three orebodies will be dredge mined. Key mining components and activities of the dredge mining include:

- Dredging (ore excavation) in an artificial pond and pumping ore in slurry form to a floating concentrator.
- Washing and separating the heavy mineral sands from tailings via specific gravity.
- Progressively backfilling of tailings into mined-out areas to create the final post-mining landform.
- Obtaining process water from local groundwater causing drawdown cones around production bores.

Other major activities of the Proposal will involve relocating the existing dredge, and there is the potential that ore processing plant will be also moved from the Cooljarloo mine to Cooljarloo West and back again. Relocation of the dredge between the two mines will be achieved by floating the dredge along a 6 km channel. This will require a corridor about 100 m wide for the construction of the channel, a power line, a pipeline and an access road. Collectively this will occupy about 153 ha (Figure 3.1).

3.2. Potential Impacts on Subterranean Fauna

Two types of mine-related impacts are recognised in this report: 1) *Primary Impacts* from proposed mining that have the potential to threaten the persistence of subterranean fauna through direct removal of habitat; and 2) *Secondary Impacts* that reduce population densities rather than threatening species persistence. Reduction in the quality of subterranean fauna habitat as a result of increased turbidity of water from dredging is an example of secondary impact.

When assessing the threat to subterranean fauna species from the proposed Project, only primary impacts were taken into consideration, although it is recognised that the cumulative effect of secondary impacts may also detrimental. Background on factors causing secondary impact is given in Appendix 1.

3.2.1. Impacts of the Proposal: Stygofauna

Groundwater drawdown of aquifers during the process of dredge mining may lead to significant threat to restricted stygofauna species through loss of habitat. For the purpose of impact assessment, modelled drawdown >2 m from natural fluctuations is the most commonly used criterion to define the area of habitat loss (Bennelongia 2008; Bennelongia 2009a; Bennelongia 2010). In some cases this level

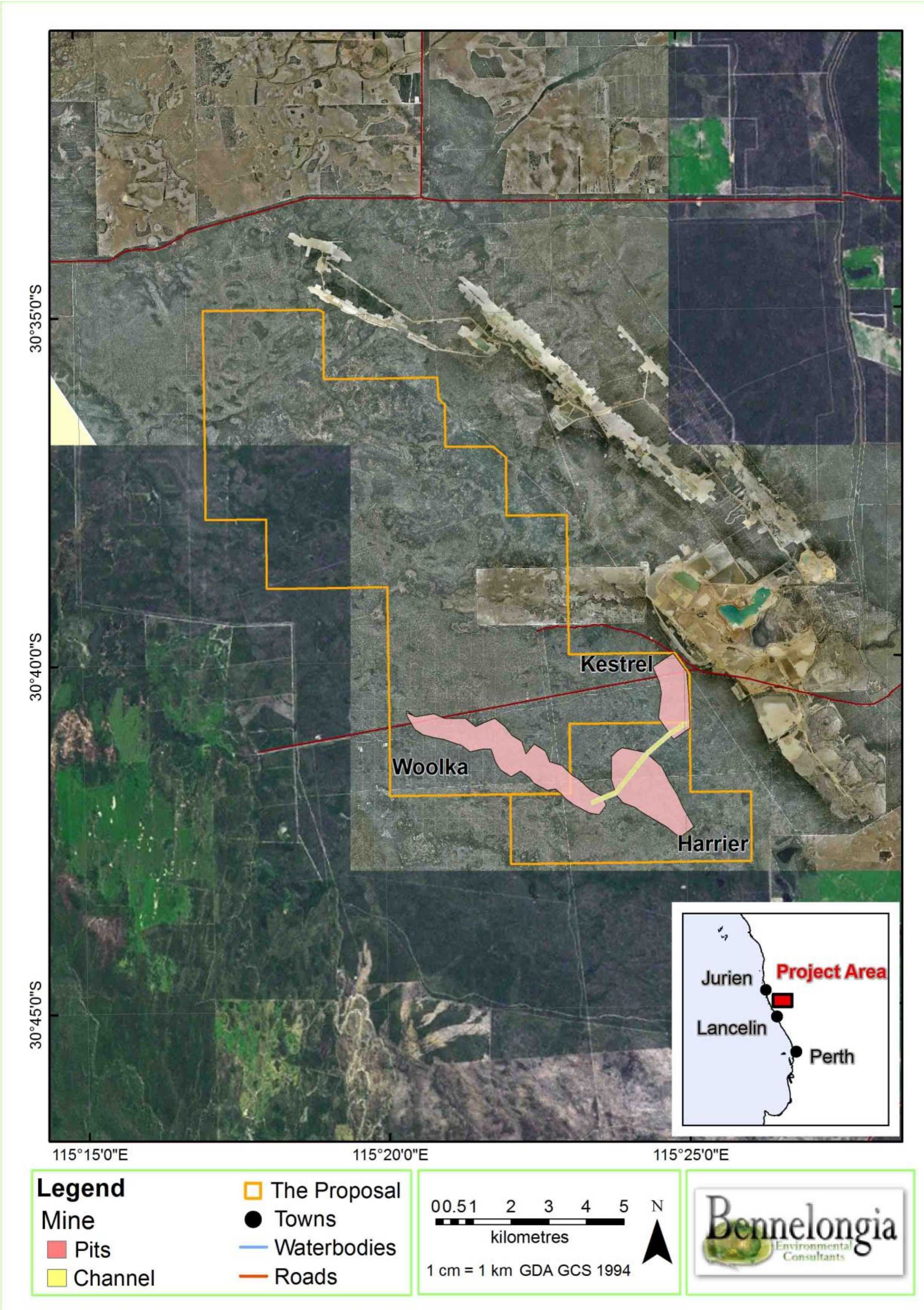

Figure 3.1. Proposal impacts.

of drawdown probably represents a conservative approach to assessment, such as when a deep uniform aquifer is being de-watered. Drawdowns much greater than 2 m may will have little effect on the available volume of stygofauna habitat and, therefore, little impact on conservation values. However, for many aquifers it is difficult determine how uniform the aquifer is and what vertical space is occupied by different species. Hence, drawdown >2 m from natural fluctuations provides a convenient and easily interpreted criterion for determining the area of drawdown that potentially has biological importance.

In the case of the Proposal, groundwater drawdown has not yet been modelled but estimates drawn from Golder Associates (2012) indicate that the spatial extent of drawdown of >2 m is expected to be in the general vicinity of 8,000-10,000 ha.

3.2.2. Impacts from the Proposal: Troglofauna

Of all the mining activities at the Project, only *pit excavation* and *channel excavation* will represent significant habitat loss. All excavations at the Project are considered Primary Impact (Figure 3.1). This totals an area of 961 ha.

3.3. Cumulative Impact

Cumulative impact is defined here as an additional threat to the conservation of subterranean fauna species beyond the threat from the Proposal alone. It results from the combination of the impact of the Proposal with the impact of other (usually previously approved) developments in nearby areas. In addition to the current mining operations at Cooljarloo, there is one other approved mineral sands mine to the south of Cooljarloo (Iluka Resource Limited's Cataby Mineral Sands Project) undertaking pit excavation and groundwater extraction; and further to the south, a turf farm (Superior Lawns) that extracts significant amounts of groundwater.

The concept of cumulative impact is straightforward but on-ground examples of cumulative impacts are often more elusive (e.g. Cooper and Sheate 2002). One scenario in which the Proposal may result in significant cumulative impact is if a species is known only from an approved impact area and also the Proposal footprint.

With respect to the Proposal, there is little scope to assess cumulative impact given that there was no assessment of subterranean fauna at nearby operationsHowever, the combined area of impact footprints of all operations and proposed projects may provide a guide to whether impacts on subterranean fauna are likely.

4. SUBTERRANEAN FAUNA OCCURRENCE

4.1. Stygofauna

4.1.1. Habitats

Stygofauna occur in an array of different groundwater habitats including porous, karstic and fractured-rock aquifers, springs and the hyporheos of streams (Eberhard *et al*. 2005). Stygofauna inhabit subterranean spaces (fissures and voids). In general terms, the likelihood of stygofauna occurring in an aquifer is directly related to its transmissivity because stygofauna require interstitial spaces, voids and channels in which to live (Gibert and Deharveng 2002). The physiochemical tolerances of stygofauna have not been well defined, although some information is available on salinity tolerances. Stygofauna have mostly been recorded in fresh to brackish groundwater but may occur in salinities up to 60,000 mg/L TDS (Watts and Humphreys 2006; Reeves *et al*., 2007; Ecologia 2009).

4.1.2. Prospective Stygofauna Habitat in the Vicinity of the Proposal

The main lithology representing prospective stygofauna habitat at the Proposal is the Tertiary and Quaternary deposits (where non-cemented). Within the Bassendean Sands this is represented by the ferricrete pebble layer at about 6 m below ground. The sands of the Guilford Formation (6-35 m below ground) are less prospective for stygofauna as they are often clayey, but sand substrates can harbor smaller stygofauna like copepods and syncarids.

The deeper Yoganup Formation and Ascot Formation also contain strata that are prospective for stygofauna in terms of likely voids and interstitial spaces, particularly towards the base of these sequences where a layer of very coarse gravel is present. The Yarragadee Formation is less prospective stygofauna habitat owing to the greater depth and mostly confined nature of this aquifer. However, it is possible that the coarse sandstones of this unit may be prospective for stygofauna.

4.1.2.1. Habitat Continuity

The continuity of prospective stygofauna habitat in the vicinity of the Proposal is difficult to determine. While both the Superficial and Yarragadee aquifers are considered very extensive, it is possible that stygofauna recognise habitat units within these regional aquifers. The barriers limiting the geographic occurrence of stygofauna species are not well understood. It is almost certain that some stygofauna species that occur in Superficial and Yarragadee aquifers are widespread but it is possible that such species occur in a pattern that reflects the distribution of patches of their preferred habitat. Predicting the occurrence of stygofauna species is difficult if the patches of preferred habitat are smaller than the scale at which geological/hydrological mapping has occurred.

Potential barriers to stygofauna in the vicinity of the Proposal include clay layers that may restrict vertical movement, as well as faults and escarpments that may restrict lateral movement. Although unlikely, potentially isolated stygofauna habitat could be represented by the outwash fans and deltaic deposits associated with the Mullering Brook and other local water courses. These deposits include buried sandy riverbed, high-energy channel deposits, and low-transmissivity clayey and silty sand (see Section 2.2.5).

4.1.3. Stygofauna of the Swan Coastal Plain

There has been less stygofauna research in the South-West than in central and northern Western Australia and few species have been described. Most of the stygofauna studies on the Swan Coastal Plain of the South-West have occurred in caves, with works conducted by the Western Australian Museum (WAM), Department of Environment and Conservation, University of Western Australia and Murdoch University (e.g. Eberhard 2004; Pinder *et al*. 2006; Tang and Knott 2009).

Though little systematic survey has been completed, knowledge to date suggests that the subterranean fauna of the Swan Coastal Plain is relatively depauperate in comparison to other regions of Western Australia (e.g. Table 3.1 in EPA 2007). For example, Schmidt (2005) found relatively few species in groundwater associated with Marbling Brook on the eastern edge of the Darling Scarp in the Chittering catchment, 60 km north-east of Perth. The total yield from seven groundwater bores sampled 12 times was about 21 species, with most being copepods. All animals collected were very small, with the exception of two species of amphipod, and only two of the 21 species were considered to be stygobionts.

Biota (2005) sampled about 35 bores (a total of 50 samples) on the Swan Coastal Plain near Ludlow, south of Perth and recorded Amphipoda, Isopoda, Ostracoda and Copepoda. Species identification was attempted only for the single species of amphipod collected, which was a new, undescribed species. However, the other taxa are unlikely to have represented many species and the proportion of likely stygobiont species is unclear.

Tang and Knott (2009) reported 15 copepod species of the Gnangara groundwater system, four of them new species; namely *Eucyclops edytae, Paracyclops intermedius, Mixocyclops mortoni,* and *Paranitocrella bastiani*. Fourteen of the 15 species are also known from surface water systems or from springs. Only one species, *P. bastiani*, is restricted to cave groundwater and for many species there was little evidence of occurrence outside the hyporheos (i.e. they are not deep groundwater stygofauna).

Bennelongia (2009b) sampled 19 bores at Point Grey peninsula in the Harvey Estuary, south-east of Mandurah, collecting 18 species of stygofauna. Copepods, amphipods, syncarids, ostracods, oligochaetes, nematodes, mites and rotifers were recorded. Many of the species collected are widely known in surface and groundwater from the Swan Coastal Plain and surrounds, however few species were considered likely to be stygobionts.

4.1.4. Stygofauna in the Vicinity of the Proposal

A literature review was used to assess the likelihood of stygofauna occurring at the Proposal. Records of stygofauna were compiled from previous environmental impact assessments, records WAM and primary literature. All available data within a 50 by 50 km Search Area surrounding Cooljarloo (30.1683°S to 31.0809°S, 115.0272°E to 116.0737°E; Appendix 2) were reviewed.

At least five, and possibly seven, species of stygofauna have been collected in the Search Area (Table 4.1) with all but one record being from a cave. Up to three amphipods species of the genus *Hurleya* may be represented in separate records from Tombstone Rocks Cave, Brown Bone Cave and a bore near Wedge Island. One undescribed species of oligochaete of the genus *Aktedrilus* has been recorded at Tombstone Rocks Cave, along an unidentified ostracod and a copepod; and an unidentified turbellarian was recorded at Tick Cave (Table 4.1).

Table 4.1. Stygofauna species collected in the Proposal Search Area.

Higher Groups		Species	Comments on Range
Turbellaria			
	Tricladida		
		Tricladida sp.	Uncertain due to low taxonomic resolution
Tubificida			
	Oligochaeta		
		Aktedrilus n. sp 1	Only known from Tombstone Rocks Cave
Malacostraca			
	Ostracoda		
		Ostracoda sp.	Uncertain due to low taxonomic resolution
	Copepoda		
		Copepoda sp.	Uncertain due to low taxonomic resolution
	Amphipoda		
		Hurleya spp.	May represent three species, with records from Tombstone Rocks Cave, Brown Bone Cave and a bore near Wedge Island. There is a minimum of 14 km between records.

The relatively low number of stygofauna recorded around the Proposal Search Area is likely to reflect the lack of designated stygofauna surveys, rather than an absence of stygofauna. Although there are a number of cave systems in the Search Area, which have undergone considerable ad-hoc survey from speleologists, it is likely that the focus of these surveys was on troglofauna rather than stygofauna. Survey of non-karstic groundwater has apparently been very limited.

4.2. Troglofauna

4.2.1. Habitats

Troglofauna habitat is usually considered to occur between the lower layers of loose soil and sand (starting about 4 m below the ground surface) and the interface with the groundwater (see Juberthie *et al*. 1981). Troglofauna presence is dependent on the structure of subterranean habitat and, as with stygofauna, if no fissures or voids are present in the subterranean strata no troglofauna will occur. If subterranean spaces are present, the pattern of their occurrence will largely determine the density and distribution of troglofauna. Lateral connectivity of spaces is crucial to underground dispersal. Geological features such as major faults and dykes that block the continuity of habitat may act as barriers to dispersal, leading to species having highly restricted ranges.

Most troglofauna surveys for environmental assessment have been undertaken in areas of pisolite or BIF and it is been demonstrated in many surveys that these habitats are suitable for troglofauna. Information about the occurrence of troglofauna outside mineralized habitats is limited because mine development has been the primary reason for most of the surveys. However, troglofauna have also been collected from calcrete and alluvium in the Yilgarn and from karsts in the Swan Coastal Plain (Barranco and Harvey 2008; Platnick 2008; Bennelongia 2008a, b; Bennelongia 2009c).

4.2.2. Troglofauna of the Swan Coastal Plain

Studies on cave systems within Yanchep National Park by WAM arachnid researchers have collected one species of pseudoscorpion that has been described as troglobitic, *Protochelifer cavernarum,* along with two troglobitic species of spider, *Chasmocephalon* sp. and *Pholcomma* sp. A further three species of spider have been classified as troglophilic: *Troglonata* sp., *Tasmanoonops* sp. and *Baalzebub* sp. (see Table 3.3 in Bennelongia 2009d). Troglofauna are also known from alluvium at Ludlow (Biota 2003); and ad-hoc surveys by various groups have been conducted in the caves of the Nambung National Park (see Section 4.2.4).

4.2.3. Prospective Troglofauna Habitat in the Vicinity of the Proposal

Owing to the high watertable in the vicinity of the Proposal (0-6 m below ground) and the lack of air-spaces within the recent deposits and Bassendean Sand above the watertable, it is considered unlikely that prospective troglofauna habitat occurs in the vicinity of the Proposal. This includes the area in and around the proposed mine pits and the dredge channel.

4.2.4. Troglofauna in the Vicinity of the Proposal

A literature review was used to assess the likelihood of troglofauna occurring at the Proposal. Records of troglofauna were compiled from previous environmental impact assessments, records of the Western Australian Museum (WAM) and primary literature. All available data within a 50 by 50 km Search Area surrounding Cooljarloo (30.1683°S to 31.0809°S, 115.0272°E to 116.0737°E; Appendix 2) were reviewed.

At least 13 species of troglofauna have been collected in the Search Area (Table 4.2), with all but the hemipterans collected from caves. At least five species of spiders have been collected, with the genus *Pholcomma* potentially represented by multiple species. One species of pseudoscorpion has been recorded that is considered to be widespread. Similarly to the spider genus *Pholcomma*, the isopod genus, *Laevophiloscia* is possibly represented by multiple species unique to individual cave systems (Table 4.2). Myriapoda and Hexapoda (Entognatha and Insecta) are represented by at least six species, but apart from the hemipteran, *Phaconeura* sp., none of the species has been indentified above family level and little can be said of the likely range of these species other than troglofaunal hemipterans are typically very widespread.

Table 4.2. Troglofauna species recorded in the Proposal Search Area.

Higher Groups		Species	Comments on Range
Arachnida			
	Pseudoscorpionida		
		Protochelifer cavernarum	Widespread species occurs in WA, SA and NSW
	Araneae		
		cf. *Icona* ('*Austrotheridion*' gen. nov.)	Potentially restricted to Quandong Cave, Nambung National Park
		Baazelbub sp.	Possibly restricted to unnamed cave, Nambung National Park
		Desidae sp.	Possibly restricted to unnamed cave, Nambung National Park
		Tasmanoonops sp.	Possibly restricted Cadda Cave, Nambung National Park
		Pholcomma spp.	Blind and eye-reduced records at multiple caves at Nambung National Park. If troglobitic, species possibly restricted to single cave systems.
Malacostraca			
	Isopoda		
		Laevophiloscia spp.	Blind and eye-reduced records at multiple caves at Nambung National Park. If troglobitic, species possibly restricted to single cave systems.
Chilopoda			
	Scolopendrida		
Entognatha			
		Cryptopidae sp.	Singleton record, uncertain range due to low taxonomic resolution
	Diplura		
		Campodeidae sp.	Uncertain due to low taxonomic resolution
		Japygidae sp.	Uncertain due to low taxonomic resolution
Insecta	**Blattodea**		
		Blattodea sp.	Blind and eye-reduced records at multiple caves at Nambung National Park. If troglobitic, species possibly restricted to single cave systems.
	Hemiptera		
		Meenoplidae/*Phaconeura* sp.	Recorded at a number of caves in Nambung National Park in addition to bores at Cataby. May represent multiple species, but troglofaunal hemipterans do not typically have restricted ranges
	Coleoptera		
		Carabidae sp.	Singleton record, uncertain range due to low taxonomic resolution

5. CONCLUSION AND RECOMMDATIONS

5.1. Stygofauna

The review of the geology and hydrogeology indicates that there is prospective stygofauna habitat in the vicinity of the Proposal, particularly in the Superficial Formation aquifer. Based on the extensive nature of both the Superficial and Yarragadee aquifers, it could be expected that the stygofauna habitat would have considerable connectivity beyond the Proposal. Further, this notion aligns with the available information on stygofauna distributions, which suggests that most stygofauna species of the Swan Coastal Plain are wide-ranging. However, it is possible that stygobitic species may recognise dispersal barriers in the vicinity of the Proposal. These potential barriers include clay layers that may restrict vertical movement, as well as faults and escarpments that may restrict lateral movement. In addition, potentially isolated stygofauna habitat could be represented in the vicinity of the Proposal by the buried outwash fans and deltaic deposits associated with Mullering Brook and other local water courses.

Although the drawdown associated with mining at the Proposal site is yet to be modelled, the spatial extent is estimated to be in the vicinity of 8,000-10,000 ha. This impact, and others already approved of a similar nature in the vicinity of the Proposal, may have the potential to impact to stygofauna species; particularly species that inhabit the shallower component of the Superficial Formation aquifer where the effect of drawdown will be greatest.

In summary, three assumptions about the hydrogeology of the Proposal area suggest there may be a potential threat to stygofauna from the Proposal. It is assumed that:

1. Prospective stygofauna habitat occurs in the vicinity of the Proposal;
2. Potential barriers to dispersal and isolated habitat (habitat discontinuity) occur in the vicinity of the Proposal; and
3. There is potential for the Proposal (and cumulatively, those of other approved impacts nearby) to remove a considerable proportion of the habitat of any highly restricted stygofauna species present.

Consideration of the likelihood of the above assumptions is constrained by the lack of an accurately defined impact footprint (drawdown cone) and by the limited capacity of habitat characterisation to predict the distribution of stygofauna species. Therefore, it is recommended that a pilot-scale field survey is undertaken to define the potential threats to stygofauna more accurately by: a) confirming the presence/absence of stygofauna; and b) exploring the range characteristics of any stygofauna species present. The likely ranges of stygofauna species may then be compared to the extent of groundwater drawdown associated with the Proposal when this is modelled.

Should a significant stygofauna community be recorded, a full-scale sample effort to EPA guidelines may be required to assess the risk to stygofauna.

5.2. Troglofauna

Although some troglofauna have been collected within the Proposal Search Area (almost all from caves), it is very unlikely that troglofauna occur within the impact footprint of the Proposal. It may reasonably be expected that the impact footprint as a result of pits excavation will not intersect prospective troglofauna habitat due to the high watertable in the vicinity of the Proposal (0-6 m below ground) and the likely lack of air-spaces within the recent deposits and Bassendean Sand that remain unsaturated.

Hence, it is considered almost certain that there is no threat to troglofauna species from the Proposal and further assessment including field survey is unwarranted.

6. METHODS STATEMENT FOR PILOT-SCALE STYGOFAUNA SURVEY

6.1. Survey Rationale and Sample Effort

The recommended pilot-scale stygofauna survey of the Proposal impact footprint will be conducted according to the general principles laid out in EPA Guidance Statements Nos 54 and 54A (EPA 2003, 2007).

It is proposed that the pilot-scale survey within the groundwater drawdown (the Proposal impact footprint) collect 20 samples; equating to half the full-scale sample effort according to EPA guidelines (which recommends 40 samples over two seasons). With this approach, in the event that a significant stygofauna community be recorded, it would be feasible to meet the EPA guidelines with one additional round (and season) of sampling. Sampling of bores in reference areas that have not been subject to previous groundwater drawdown is also proposed, with 10 samples to be collected from bores intersecting similar geology to those sampled in the impact footprint.

6.2. Survey Timing

It is recommended that the pilot-scale survey commence in spring, and should further work be required based of the findings of the pilot a second round of sampling should be conducted in summer or autumn. This would constitute two round of sampling over two seasons as recommended by the EPA guidelines.

6.3. Sampling Methods

Stygofauna sampling will follow the methods outlined in Eberhard *et al*. (2005) and recommended by the EPA (2007). At each bore, six net hauls will be collected using a plankton net (weighted), with three hauls with 50 µm mesh net and three hauls with 150 µm mesh net. After the net is lowered to the bottom of the bore it will be oscillated up and down briefly to agitate sediments at the base of the bore prior to a slow retrieve of the net. Contents of the net will be transferred to a 125 ml polycarbonate vial after each haul and preserved in 100% ethanol. Nets will be washed after each sample to minimise contamination between sites. Electrical conductivity (used to infer salinity), pH, and temperature will be measured at each bore.

6.4. Species Sorting and Identification

In the laboratory, samples will be elutriated to separate out heavy sediment particles and sieved into size fractions using 250, 90 and 53 µm screens. All samples will sorted under a dissecting microscope. Sorted animals will be identified to species or morphospecies using available keys and species descriptions. Where necessary, animals will be dissected and examined under a compound microscope.

Representative specimens will be lodged at the Western Australian Museum when any assessment report is submitted to the EPA.

6.5. Genetic Characterisation of Species

It is common for specimens to be collected in a condition that is not amenable for species level identification based on morphology, i.e. the specimens are juvenile, the wrong gender or damaged. In some cases, to understand species boundaries and determine the ranges of potentially conservation significant species, DNA analysis is required. Typically, Bennelongia engages either the South Australian Museum or Helix Molecular Solutions to conduct such analysis.

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8. APPENDICES

Appendix 1: Secondary Impacts of Mining on Subterranean Fauna.

De-watering below Troglofauna Habitat

The impact of a lowered watertable on subterranean humidity and, therefore, the quality of troglofauna habitat is poorly studied, but it may represent risk to troglofauna species in some cases. The extent to which humidity of the vadose zone is affected by depth to the watertable is unclear. Given that pockets of residual water probably remain trapped throughout de-watered areas and keep the overlying substrate saturated with water vapour, de-watering may have minimal impact on the humidity in the unsaturated zone. In addition, troglofauna may be able to avoid undesirable effects of a habitat drying out by moving deeper into the substrate if suitable habitat exists at depth. Overall, de-watering outside the proposed mine pits is not considered to be a significant risk to troglofauna.

Percussion from Blasting

Impacts on both stygofauna and troglofauna may occur through the physical effect of explosions. Blasting may also have indirect detrimental effects through altering underground structure (usually rock fragmentation and collapse of voids) and transient increases in groundwater turbidity. The effects of blasting are often referred to in grey literature but are poorly quantified and have not been related to ecological impacts. Any effects of blasting are likely to dissipate rapidly with distance from the pit and are not considered to be a significant threats to either stygofauna or troglofauna outside the proposed mine pits.

Overburden Stockpiles and Waste Dumps

These artificial landforms may cause localised reduction in rainfall recharge and associated entry of dissolved organic matter and nutrients because water runs off stockpiles rather than infiltrating through them and into the underlying ground. The effects of reduced carbon and nutrient input are likely to be expressed over many years and are likely to be greater for troglofauna than stygofauna (because lateral movement of groundwater should bring in carbon and nutrients). The extent of impacts on troglofauna will largely depend on the importance of chemoautotrophy in driving the subterranean system compared with infiltration-transported surface energy and nutrients. Stockpiles are unlikely to cause species extinctions, although population densities of species may decrease.

Aquifer Recharge with Poor Quality Water

Quality of recharge water declines during, and after, mining operations as a result of rock break up and soil disturbance (i.e. Gajowiec 1993; McAuley and Kozar 2006). Impacts can be minimised through management of surface water and installing drainage channels, sumps and pump in pits to prevent of recharge though the pit floor.

Contamination of Groundwater by Hydrocarbons

Any contamination is likely to be localised and may be minimised by engineering and management practices to ensure containment.

Appendix 2. Proposal Search Area