9.2 Subterranean Fauna

9.2.1 EPA Objective

The EPA's objective with regards to subterranean fauna is:

- To maintain representation, diversity, viability and ecological function at the species, population and assemblage level.

9.2.2 Relevant Legislation and Policy

An overview of the legislation and policies applicable to native fauna, including subterranean fauna are discussed in Section 9.3.2.

Guidance specific to subterranean fauna (stygofauna and troglofauna) are provided by the EPA's Environmental Assessment Guideline No. 12 (EAG12) (EPA 2013) and Guidance Statement 54a (GS54a) (EPA 2007). EAG12 supersedes the earlier Guidance Statement 54 (GS54) (EPA 2003) and provides a policy framework outlining how subterranean fauna should be considered in environmental impact assessment. It is designed to promote a more consistent approach to assessment and subsequent approval outcomes. GS54a (a later technical appendix to GS54) provides guidance on sampling methods and survey considerations for assessing subterranean fauna.

Ecological Communities

The Western Australia Minister for the Environment may list an ecological community as being threatened if the community is presumed to be, or at risk of becoming, totally destroyed. The DPaW maintains the list of threatened ecological communities (TECs), which currently contains 376 TECs, of which 25 are also listed under the EPBC Act. There are no TECs within the vicinity of the Project.

Ecological communities with insufficient information available to be considered as TECs, or which are rare but not currently threatened, are placed on a list managed by DPaW and referred to as priority ecological communities (PECs). The Project Area contains PEC No. 49 '*Yeelirrie calcrete groundwater assemblage type on Carey palaeodrainage on Yeelirrie Station*', which is considered to have 'unique assemblages of invertebrates [that] have been identified in the groundwater calcretes' (Figure 9-10). Four categories of PEC are recognised with Priority 1 referring to those considered to be most restricted in occurrence. The Yeelirrie PEC is Priority 1.

Two other Priority 1 PECs ('*Hinkler Well calcrete groundwater assemblage type on Carey palaeodrainage on Lake Way Station*' and '*Kaluwiri calcrete groundwater assemblage type on Raeside palaeodrainage on Kaluwiri Station*') occur in the periphery of the Yeelirrie PEC but do not occur in the study area. A fourth Priority 1 PEC '*Albion Downs calcrete groundwater assemblage type on Carey palaeodrainage on Albion Downs Station*' is located within the Yeelirrie study area but outside of the Development Envelope and predicted area of impact.

9.2.3 Existing Environment

9.2.3.1 Regional context

Recent research has demonstrated that the Yilgarn region of Western Australia, along with the Pilbara, is rich in subterranean fauna (Guzik *et al*. 2011; Humphreys 2001). It has been suggested that subterranean fauna in arid WA have colonised subterranean habitats as the Australian continent moved north and the climate became progressively drier since the late Miocene, some 10 million years ago (Byrne *et al*. 2008; Byrne *et al.* 2011). The richness of stygofauna in the Yilgarn is considered to have arisen from many independent colonisations of former surface species over time into emerging subterranean habitats, followed by subsequent extensive in-situ speciation (Harrison *et al*. 2014; Karanovic *et al*. 2014).

Figure 9-10: Priority ecological communities with the Study Area

9.2.3.2 Stygofauna in the Yilgarn

The calcrete bodies in the palaeovalleys of the Yilgarn are particularly rich in stygofauna beetles, amphipods and some other groups of crustaceans, with species in many taxonomic groups thought to be restricted to single calcretes (Bradford *et al.* 2010; Guzik *et al.* 2008; Leys and Watts 2008) or even small areas within a single calcrete (Karanovic and Cooper 2011). This pattern of species distribution has resulted in the theory that each body of calcrete represents a subterranean 'island'. It has been hypothesised that unfavourable salinities, fine alluvial and clay deposits or other unsuitable habitat between bodies of calcrete represent barriers to species dispersal (Cooper *et al.* 2002). Although stygofauna occur in a range of habitats in the Yilgarn other than palaeovalleys, sampling to date suggests that species richness in other habitats is lower than in calcrete and the associated alluvium and colluvium of palaeovalleys (e.g. Bennelongia 2007, GHD 2010a).

An analysis by Subterranean Ecology (2011) (Appendix F2) of stygofauna records from 68 calcretes in seven palaeodrainage systems in the Yilgarn (Murchison, Moore, Raeside, Carey, Nabberu, Carnegie and Burnside) showed that sampling effort has been highly variable. While patterns of richness must be regarded as uncertain until more sampling has occurred, the calcretes yielding most species to date lie in the Carey and Raeside palaeodrainage systems. Other than Yeelirrie, Subterranean Ecology (2011) considered the most species-rich calcretes to be Hinkler Well (33 species), Urdamurdah (28), Lake Violet (24) and Paroo (21) in the Carey drainage system and Depot Springs (21) in the Raeside drainage system. More recent data from Outback Ecology (2011 and 2012 addendum) appears to suggest that Urdamurdah supports at least 48 species.

Subterranean Ecology (2011) also examined the distribution patterns of individual stygofauna species among calcretes and concluded that about 18% of species were widespread and occurred in well separated calcretes, 12% had ranges extending into neighbouring calcretes and 61% of species were restricted to a single calcrete (the ranges of the remaining species could not be determined).

In second analysis on a more restricted set of calcretes (Hinkler Well, Urdamullah, Lake Violet and Paroo in the headwaters of the Carey system and Depot Springs in the Raeside system), up to 46% of species appeared to have ranges extending into a nearby calcrete. However, this study preceded the detailed genetic and taxonomic work undertaken on some copepod and amphipod genera at Yeelirrie and at Sturt Meadows that showed fine-scale species radiations (Bradford *et al*. 2010; Karanovic and Cooper 2011, 2012, Karanovic *et al*. 2011). If a similar pattern occurs elsewhere in the Carey system, the proportion of species confined to individual calcretes would be higher than estimated by Subterranean Ecology (2011).

9.2.3.3 Troglofauna in the Yilgarn

Troglofauna occur widely, at moderate species richness but low abundance, in mineralised rocks of the Yilgarn (Bennelongia 2009; GHD 2010b). They are less diverse in this habitat in the Yilgarn than in similar habitats in the Pilbara.

Troglofauna may be abundant in the unsaturated zone of calcretes in the Yilgarn (Guzik *et al*. 2011; Humphreys 2008). They may also occur in lower abundance in adjacent coarse alluvium.The groups collected in calcrete include palpigrads (Barranco and Harvey 2008; Giribet *et al*. 2014), pseudoscorpions (Edward and Harvey 2008; Harrison *et al*. 2014), spiders (Baehr *et al*. 2012; Platnick 2008) and isopods (Taiti 2014). The analysis of Yilgarn calcretes by Subterranean Ecology (2011) showed that troglofauna have been recorded from calcretes in the Murchison, Moore, Nabberu and Carey palaeodrainage systems. Other than Yeelirrie, the most species-rich calcretes are Sturt Meadows (17 species) in the Raeside system and Uramurdah (15 species), Lake Violet (8 species), Bubble Well (8 species) and Nambi (7 species) in the Carey system.

Troglofauna species mostly have more restricted ranges than stygofauna (Lamoureux 2004; Halse and Pearson 2014) and, given the calcrete 'island' theory of occurrence, they are expected to be mostly restricted to single calcretes in the Yilgarn.

9.2.3.4 Yeelirrie habitat characterisation

The Yeelirrie palaeochannel is located in the northeastern part of the Archaean Yilgarn craton and comprises five major land forms:

i) breakaways;
ii) wash plains;
iii) sand plains;
iv) playas; and
v) calcretes.

These landforms were further refined within the Project Area by DC Blandford and Associates, 2011 (Section 9.10.4 and Appendix M1).

The average annual rainfall for Yeelirrie is 238 mm, although the frequency and amount of rainfall during any given year is highly variable (URS 2011b). Groundwater recharge in arid areas is mostly dependent upon infrequent, high-intensity rainfall events such as ex-tropical cyclones in summer and frontal storms in winter (URS 2011b).

The term "calcrete" is used here to describe collectively the surficial pedogenic (soil formed calcrete) and the deeper non-pedogenic dolocrete formed at the sub-surface water table interface. Both carbonate types are formed by the in-situ replacement or displacement of the alluvial and colluvial deposits by magnesium and calcium carbonate precipitated from carbonate-saturated groundwater (Mann and Horwitz 1979). Within portions of the calcrete system the surficial calcrete and the non-pedogeneic dolocrete merge into one vertically continuous body which is saturated below the water table and unsaturated above. In other areas the two carbonate types can be developed independently so that a near surface calcrete expression does not necessarily imply underlying saturated dolocrete. There is further complication in that areas of calcrete are rarely uniform;

instead they comprise a variable mixture of calcrete, alluvium/colluvium and clays with carbonate-dominated water chemistry.

The calcrete at Yeelirrie outcrops as a low broad mound along the axis of the palaeochannel. This outcropping is the result of active erosion (wind and ephemeral surficial water flow) of overlying and marginal unconsolidated sediment leaving the carbonate exposed at the surface. Carbonate formation is believed to have begun about 30 million years ago, and has remained in a constant state of re-mobilisation and formation (Mann 1979; Morgan 1993). The continuous dissolution and re-precipitation of carbonate in the system has resulted in high internal structural variability and overall subsurface geometry.

The occurrence of calcrete at Yeelirrie, with associated groundwater conditions in the surrounding alluvium and colluvium, is believed to be the factor that makes Yeelirrie highly suitable habitat for stygofauna and troglofauna. It should also be emphasised that stygofauna and troglofauna are not confined only to calcrete habitat. They also occur in the alluvium and colluvium that is referred to under the broad term "calcrete". Alluvium is the major stygofauna habitat world-wide (Gibert and Deharveng 2002) and alluvium and colluvium around the margin of the calcrete provide important stygofauna habitat (Appendix F1). Alluvium and colluvium may also be used by troglofauna.

The watertable provides the boundary between stygofauna and troglofauna habitats and lies at a depth of about 5 m through most of the Yeelirrie calcrete, although it reaches about 10 m depth to the northwest. Much of the saturated calcrete is 3 to 5 m thick but it is up to 13 m thick in the northwest. It is likely the thickness of saturated calcrete declines towards the margins of the area of calcrete body. The unsaturated calcrete comprising troglofauna habitat is probably 2 to 3 m thick across most of Yeelirrie and thicker in the northwest, where it may be up to 10 m. During periods of flooding, when the watertable rises, the volume of troglofauna habitat is likely to contract and there may be a temporary expansion of the volume of stygofauna habitat.

Several factors combine to create a highly variable, three-dimensional mosaic of subterranean microhabitats at Yeelirrie. Important factors include physical structure (which as described above comprises a complex structure with variable sized voids), chemistry (especially salinity which varies both horizontally and vertically), hydrological processes (annual and seasonal changes in groundwater levels, flows, recharge and discharge) and interaction with the ground surface (e.g. infiltration, availability of vegetation roots and other organic matter, level of nutrients and oxygen).

Groundwater salinity shows an overall gradient within the study area, with average salinities varying from about 1-2 gL^{-1} in the northwest to 10-25 gL^{-1} in the southeast. More challengingly from the viewpoint of habitat characterisation, within these gradients salinities can vary more than an order of magnitude over tens of metres (eg about about 2 gL^{-1} to 33 gL^{-1} within the proposed mine pit). Salinity may also vary vertically by a factor of about three.

9.2.4 Studies and Investigations

9.2.4.1 Environmental assessment surveys

Three main phases of subterranean fauna survey at Yeelirrie can be distinguished:

- i) prior to 2009;
- ii) 2009-2010 as part of the EIA for BHP Billiton's Yeelirrie Project; and
- iii) 2015 as part of the Cameco Yeelirrie Uranium Project.

Prior to 2009 (Phase 1), very little was known about subterranean fauna communities at Yeelirrie because of limited survey effort. The Western Australian Museum did a limited amount of collecting that yielded three species from three bores: Amphipoda indet., the isopod Oniscidea indet., and the copepod *Mesocyclops brooksi*. Sampling of two bores in the neighbouring Albion Downs calcrete also revealed three species: the amphipod Chiltoniidae indet., the copepod Harpacticoida indet., and the syncarid Parabathynellidae indet.

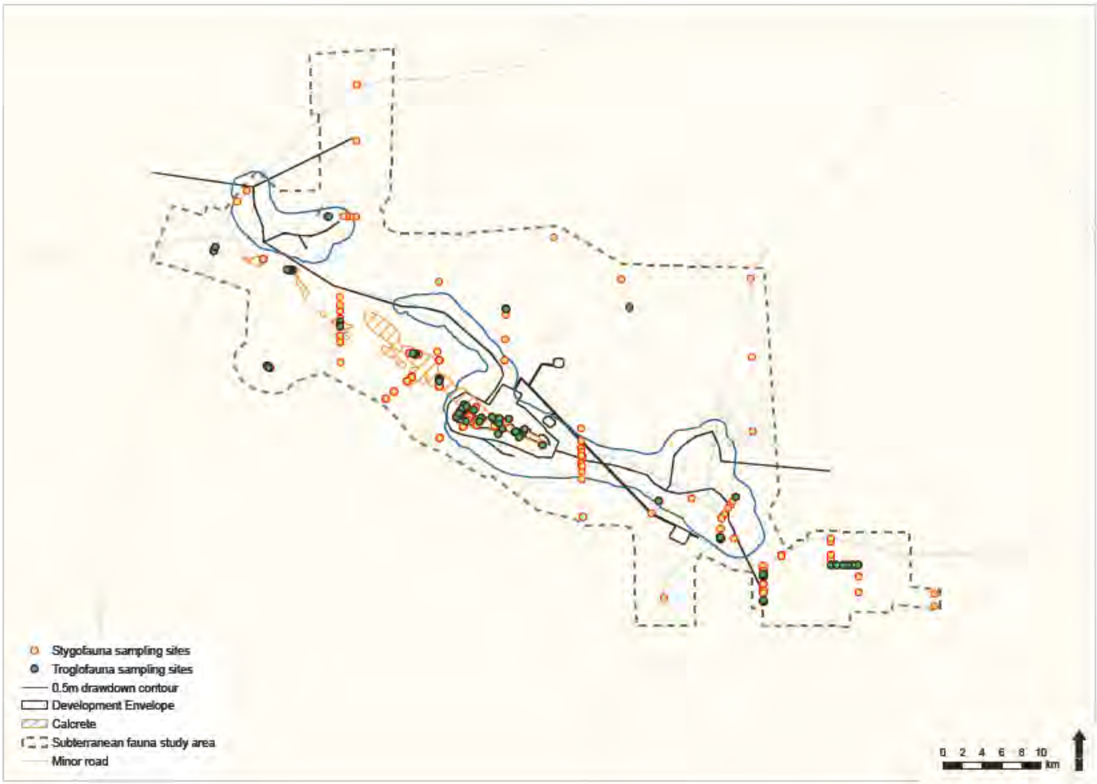


Figure 9-11: Stygofauna and troglofauna sampling locations

Sampling effort increased substantially in Phase 2 when six surveys were conducted by Subterranean Ecology (2011) from March 2009 to September 2010 as part of the EIA for BHP Billiton's Yeelirrie Project (Appendix F2). Altogether, 347 stygofauna samples were collected from 162 bores and 448 troglofauna samples were collected from 100 drill holes, although in many cases the troglofauna samples consisted of complementary 'scrape' and 'trap' samples from the same holes during the same sampling event and may better be regarded as constituting single paired samples (see Table 9-25). Figure 9-11 shows the location of all sampling sites.

In Phase 3 in 2015, Cameco commissioned collection of 66 additional stygofauna samples to improve knowledge of stygofauna distributions (Bennelongia 2015) (Appendix F1).

Genetic analysis was used extensively in the identification processes of Phases 2 and 3 by Subterranean Ecology (2011) and Bennelongia (2015) (Appendices F1 and F2). Sometimes it was the sole means of identifying species (e.g. enchytraeid worms), for some groups it was used to confirm morphological assignments of species (e.g. copepods). In the case of copepods, much of the identification decision process has been documented in the scientific literature as the species were formally described (Karanovic and Cooper 2011, 2012; Karanovic *et al.* 2011). While genetic analysis was an invaluable tool, it did not always provide definitive information about species boundaries and, consequently, it is possible that further collecting and analysis may lead to small changes in the number of species recognised as occurring at Yeelirrie and the distributions of those species (Bennelongia 2015).

In total, 110 species of subterranean fauna were collected in Phase 2 sampling (Appendix F2). This comprised 55 species of stygofauna and 45 species of troglofauna. The 55 stygofauna species consisted of 46 species of aquatic stygofauna and a further nine species of 'amphibious' subterranean fauna that are thought to occur at the interface between groundwater and unsaturated subterranean habitat.

Table 9-25: Stygofauna sampling effort in the study area (2009-2010)

	Area to be affected by the proposed development	Area unaffected by the proposed development	Total
Designated stygofauna samples 2009-2010			
Drill holes	66	96	162
Samples	138	209	347
Designated troglofauna samples			
Drill holes	21	79	100
Paired samples[1]	36	105	141
Single samples	29	137	166

[1] Pairs of samples, each consisting of a scrape and trap sample from the same bore on same trap-set date.

Sampling during Phase 3 collected 15 additional stygofauna species that had not previously been collected at Yeelirrie, bringing the total number of stygofauna species known from the area to 70 species and the total number of subterranean fauna species to 115 species (see Table 9-26) (Bennelongia 2015).

The overall sampling effort at Yeelirrie is much higher than has occurred in the subterranean fauna assessment of any other area of the Yilgarn. While the sampling has been very comprehensive, the occurrence of subterranean fauna below ground makes them inherently difficult to study. There are three major problems with subterranean fauna sampling:

- Sampling can only occur via bores and if there are no existing bores in an area likely to be suitable for a particular species, new bores must be drilled with the attendant cost and environmental damage.
- Identifying occurrences of suitable habitat or microhabitats outside the impact area is usually very difficult because of the high subterranean heterogeneity and the lack of correlation between surface features and underlying habitat. Many species are probably restricted to small patches of a particular microhabitat, defined by salinity.
- Many subterranean species occur at low abundance and are infrequently collected, even when present. Eberhard *et al*. (2009) showed that 12 samples collected at least a month apart are required to collect all the stygofauna species from a high-yielding bore. A further complication is that many bores are either constructed in a way that makes them unsuitable for subterranean fauna or do not intersect appropriate subterranean spaces. These bores never yield, even when adjacent bores consistently do so.

The problems outlined above mean it is often difficult to demonstrate wider occurrence of a species known only from the Project impact area. The difficulties of identifying the number and exact locations of areas containing the species' preferred microhabitat does not only present challenges to sampling. It also means that inferring the distribution of a species based on habitat surrogates can be problematic.

9.2.4.2 Subterranean fauna communities

The 70 stygofauna species at Yeelirrie represent greater stygofauna richness than is known from any other part of the Yilgarn but this is at least partly attributable to the high sampling effort. The community at Yeelirrie is dominated by crustacean groups, namely copepods (49% of species), worms (23%) and syncarids (12%).

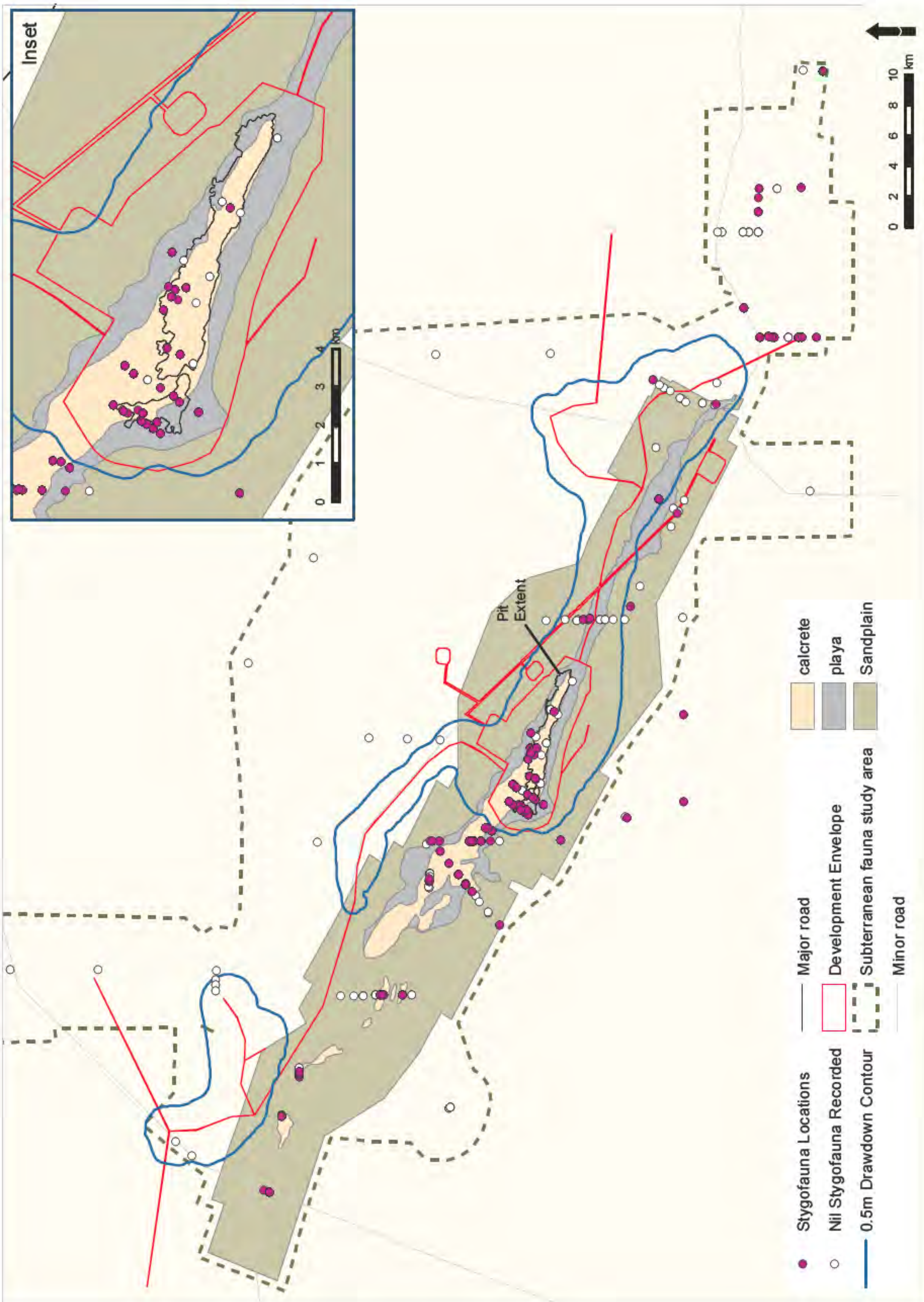


Figure 9-12: Stygofauna locations and major landforms

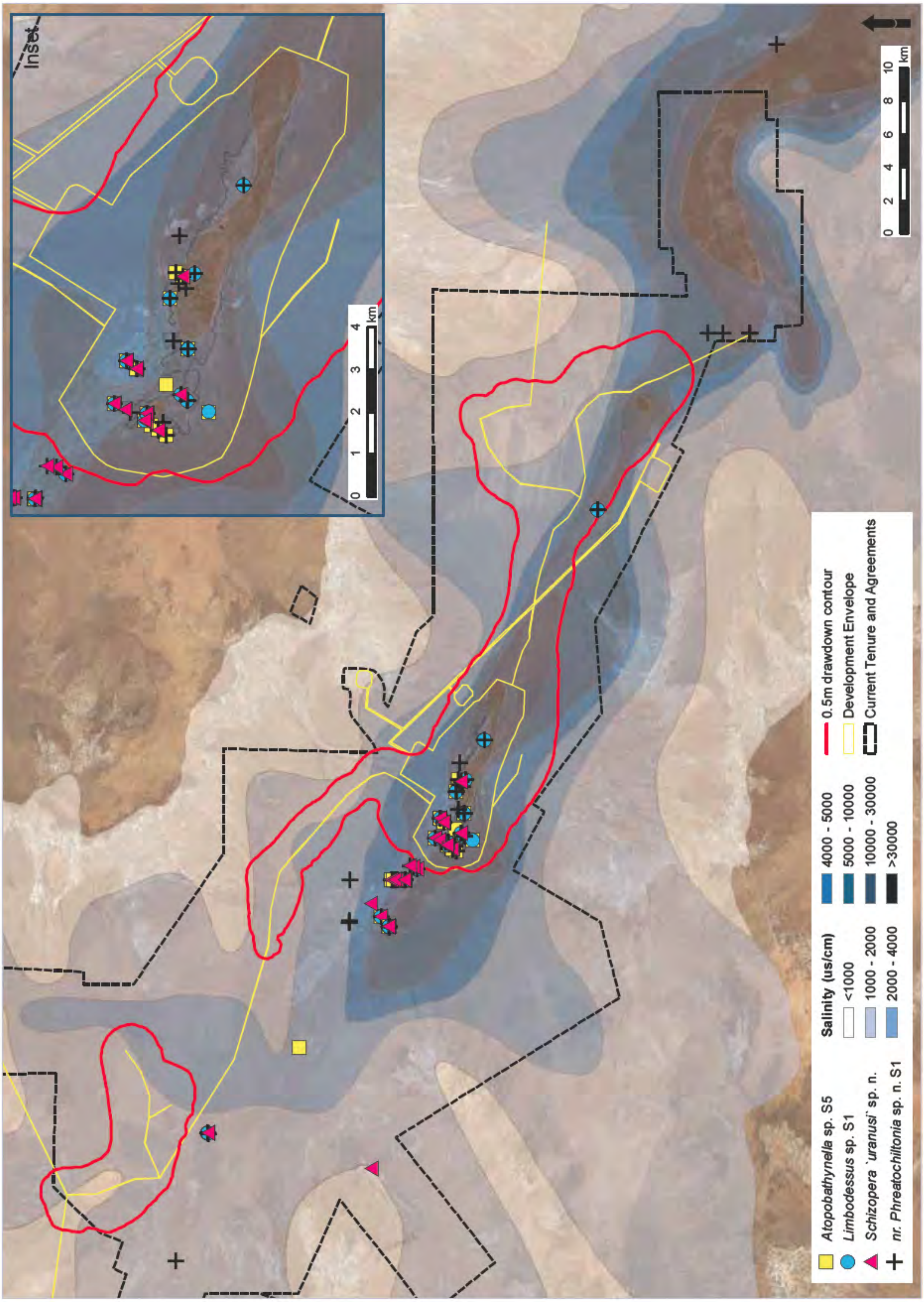


Figure 9-13: Modelled salinity levels and distribution of four widespread stygofauna species

The broad distribution patterns of the stygofauna species at Yeelirrie may be summarised as follows:

- Three species are also known from other calcretes in the Yilgarn region (*Halicyclops kieferi*, *Mesocyclops brooksi*, *Australocamptus hamondi*, and possibly one species of *Halicyclops* cf. *eberhardi*).
- Possibly one of the species of *Halicyclops* cf. *eberhardi* (most likely sp. A) is also known from other calcretes.
- 14 species (20%) have only been found inside the inferred calcrete area.
- 7 species (10%) have only been found inside the inferred playa area.
- 18 species (26%) are common to calcrete and playa areas.
- 27 species (39%) have only been found in the sandplain areas (alluvium and colluvium around the calcrete).

While collecting records suggest many species at Yeelirrie have small ranges and are restricted to narrow bands of salinity, nearly all of the larger species occurring in the calcrete are widespread. This suggests there is no physical barrier to movement, or occurrence, throughout the calcrete. Figure 9-13 illustrates this point by showing the distribution of the four most widespread stygofauna species at Yeelirrie and the modelled salinity levels in which they are found (actual salinities, which are likely to be more variable, were often not recorded). Two large species, the amphipod nr. *Phreatochiltonia* sp. n. S1 and the beetle *Limbodessus* sp. S1 have ranges of >60 km and >40 km, respectively. The small copepod *Schizopera uranusi* and syncarid *Atopobathynella* sp. S5 have ranges of 24 km and 17 km. Based on modelled groundwater salinity, all four species are euryhaline and are found in both fresh and saline groundwater. While Figure 9-13 does not imply that all species at Yeelirrie are widespread, it suggests that the ranges of many species will be greater than currently documented and that ranges within Yeelirrie will be limited by factors other than physical habitat.

Table 9-26: Stygofauna species recorded at Yeelirrie.

Species known only from the predicted area of groundwater drawdown are shaded in blue. Northwest indicates the species occurs west of the mine pit-outside groundwater drawdown, southeast means the species east of the mine pit and outside groundwater drawdown, granite indicates the species occurs in the outer part of the study area, Yeelirrie playa indicates the species occurs west of the mining tenement in the vicinity of Yeelirrie and Albion Downs playas (see Bennelongia 2015 for more detail (Appendix F1)). No species was restricted to the northwest groundwater drawdown.

Taxonomic group	Species	Known distribution	Remarks
Rotifera			
	Bdelloidea sp. 2:2	Central calcrete	New in 2015
Nematoda			
	Gen indet., Sp. indet.	Widespread	New in 2015
Platyhelminthes			
	Turbellaria sp.	Northwest	New in 2015, unknown range
Oligochaeta			
Aelosomatidae	*Aeolosoma* sp. S1	Yeelirrie playa	
Enchytraeidae	Enchytraeidae sp. Y1	Yeelirrie playa	
	Enchytraeidae sp. Y2	Northwest	
	Enchytraeidae sp. Y3	Northwest	
	Enchytraeidae sp. Y4	Central drawdown	Known only from impact area

Taxonomic group	Species	Known distribution	Remarks
	Enchytraeidae sp. Y5	Central drawdown	Known only from impact area
	Enchytraeidae sp. Y6	Central drawdown	Known only from impact area
	Enchytraeidae sp. Y7	Northwest	
	Enchytraeidae sp. B03	Northwest	New in 2015
	Enchytraeidae sp. B04	Southeast	New in 2015
	Enchytraeidae sp. B05	Central drawdown	New in 2015
Naididae	Naididae sp. S4	Widespread	
	Naididae sp. S5	Widespread	
Phreodrillidae	Phreodrilidae sp. S8	Widespread	
	Phreodrillidae sp. B06	Northwest	New in 2015
	Phreodrillidae sp. B07	Southeast	New in 2015
Crustacea			
Amphipoda	nr. *Phreatochiltonia* sp. n. S1	Widespread	
Syncarida	*Atopobathynella* sp. 'line K'	Central drawdown	Known only from impact area
	Atopobathynella sp. S4	Northwest	
	Atopobathynella sp. S5	Widespread	
	Atopobathynella sp. Y1	Northwest	
	Atopobathynella sp. Y2	Northwest	
	Atopobathynella sp. Y3	Northwest	
	Bathynellidae sp. S2	Widespread	
	Bathynellidae sp. S4	Yeelirrie playa	
Cyclopoida	*Dussartcyclops* 'dostoyevskyi' sp. n.	Widespread	
	Halicyclops cf. *eberhardi* sp. A	Widespread	Possibly widespread in Yilgarn
	Halicyclops cf. *eberhardi* sp. B	Central drawdown	Known only from impact area
	Halicyclops cf. *eberhardi* sp. C	Yeelirrie playa	
	Halicyclops cf. *eberhardi* sp. D (B01)	Southeast	New in 2015
	Halicyclops kieferi	Assumed widespread	New in 2015, widespread in Yilgarn
	Mesocyclops brooksi	Assumed widespread	Occurs across southern Australia
Harpacticoida	'Dussartstenocaris' 'idioxenos'	Northwest	
	Australocamptus hamondi	Assumed widespread	Widespread in Yilgarn
	Kinnecaris esbe	Yeelirrie playa	
	Kinnecaris linesae	Northwest	

Taxonomic group	Species	Known distribution	Remarks
	Kinnecaris lined	Central drawdown	Known only from impact area
	Kinnecaris linel	Yeelirrie playa	
	Kinnecaris 'linep' sp. n.	Northwest	
	Kinnecaris uranusi	Widespread	
	Nitokra esbe	Yeelirrie playa	
	Nitokra yeelirrie	Widespread	
	Nitokra sp. B03	Southeast	New in 2015
	Novanitocrella 'araia' sp. n.	Central drawdown	Known only from impact area
	Pseudectinosoma 'pentedicos' sp. A	Widespread	
	Pseudectinosoma 'pentedicos' sp. B	Widespread	
	Pseudectinosoma 'pentedicos' sp. C	Widespread	
	Schizopera akation	Widespread	
	Schizopera akolos	Central drawdown	Known only from impact area
	Schizopera analspinulosa	Widespread	
	Schizopera analspinulosa linel	Yeelirrie playa	
	Schizopera emphysema	Central drawdown	Known only from impact area
	Schizopera kronosi	Widespread	
	Schizopera leptafurca	Widespread	
	Schizopera 'linen' sp. n.	Yeelirrie playa	
	Schizopera uranusi	Widespread	
	Schizopera sp. 7439	Central drawdown	Known only from impact area
	Schizopera sp. B16	Southeast	New in 2015
	Schizopera sp. B17	Southeast	New in 2015
Isopoda	Philoscidae sp. n. S1	Yeelirrie playa	
	Philoscidae sp. n. Y2	Central drawdown	Known only from impact area
Ostracoda	*Candonopsis* sp. n. Y1	Widespread	
	Cyprididae sp. indet.	Central	New in 2015
	Strandesia sp. indet.	Central	New in 2015
Insecta			
Coleoptera	*Limbodessus* sp. n. '*yeelirriensis*'	Widespread	
	Limbodessus sp. S1	Widespread	
	Paroster sp. n. '*angustus*'	Widespread	

The 45 troglofauna species documented at Yeelirrie (Table 9-27) also represent greater richness than is known elsewhere in the region. The difference between Yeelirrie and other Yilgarn calcretes is largely attributable to the large sampling effort at Yeelirrie and the fact there has been little extensive sampling of troglofauna in other calcretes of the Yilgarn,. Most previous troglofauna sampling in Yilgarn calcretes did not use the scraping technique, which means yields were substantially reduced (Halse and Pearson 2014).

The distributions of the troglofauna species collected may be summarised as follows (see Figure 9-14):

- 11 species (24%) have only been found inside the inferred calcrete area.
- 3 species (6%) have only been found within the inferred playa area.
- 8 species (17%) are common to both the calcrete and playa areas.
- 19 species (42%) have only been found in the sandplain areas (alluvium and colluvium around the calcrete).
- 3 species (6%) species are common to calcrete and sandplain areas.
- 1 species (2%) is common to playa and sandplain areas.

Figure 9-15 shows the distribution of the more widely abundant troglofauna species across the study area.

Two of the troglofauna species collected at Yeelirrie are likely to be widespread in the Yilgarn. These are the hemipteran Meenoplidae sp. Y1 and millipede Polyxenida sp. S1 (Yeelirrie) (Bennelongia 2015).

Table 9-27: Troglofauna species recorded at Yeelirrie.

Species known only from the proposed mine pit are shaded in blue. See Appendix F1 for explanation of distribution areas.

Taxonomic group	Species	Known distribution
Crustacea		
Isopoda	*Troglarmadillo* sp. n. S12	Yeelirriee playa
	Troglarmadillo sp. n. S13	Widespread
	Troglarmadillo sp. n. S7A	Northwest
	Troglarmadillo sp. n. S7C	Northwest
	Troglarmadillo sp. n. S9	Northwest
	Trichorhina sp. n. F	Mine pit
	Trichorhina sp. n. G	Northwest
	Trichorhina sp. n. H	Northwest
	Trichorhina sp. n. I	Southeast
	Stenoniscidae sp. n. Y1	Yeelirrie playa
Arachnida		
Araneae	*Opopaea* sp. n. Y2	Yeelirrie playa
	Prethopalpus callani	Widespread
	Prethopalpus sp. n. B	Yeelirrie playa
	Desognanops sp.n. Y1	Widespread
Palpigradi	*Eukoenenia* sp. n. S2	Widespread

Taxonomic group	Species	Known distribution
Pseudoscorpiones	*Tyrannochthonius* sp. n. Y1	Mine pit
	Tyrannochthonius sp. n. Y2A	Widespread
	Tyrannochthonius sp. n. Y2C	Yeelirrie playa
	Tyrannochthonius sp. n. Y3	Yeelirrie playa
	Tyrannochthonius sp. n. Y4	Widespread
	Tyrannochthonius sp. n. Y5	Yeelirrie playa
	Austrohorus sp. n. Y1	Mine pit
	Austrohorus sp. n. Y2	Yeelirrie playa
Myriapoda		
Chilopoda	Geophilidae sp. Y1	Widespread
	Cryptops sp.Y1	Widespread
Diplopoda	Polyxenida sp. S1 (Yeelirrie)	Widespread
Pauropoda	Pauropoda sp. S6A	Northwest
	Pauropoda sp. S6B	Mine pit
	Pauropoda sp. Y1	Northwest
	Pauropoda sp. Y2	Northwest
	Pauropoda sp. Y3	Yeelirrie playa
Symphyla	Symphyla sp. Y1	Northwest
	Symphyla sp. Y2	Northwest
	Symphyla sp. Y3	Northwest
	Symphyla sp. Y4	Northwest
	Symphyla sp. Y5	Yeelirrie playa
	Symphyla sp. Y6	Yeelirrie playa
	Symphyla sp. Y7	Mine pit
Hexapoda		
Diplura	Japygidae sp. Y3	Widespread
	Parajapygidae sp. Y1	Widespread
	Projapygidae sp Y2	Widespread
Hemiptera	Enicocephalidae sp. Y1	Yeelirrie playa
	Meenoplidae sp. Y1	Widespread
Thysanura	Atopatelurini sp. n. Y2	Southeast
	Hemitrinemura sp. n. Y1	Widespread

9.2.4.3 Taxonomy

Sixteen of the stygofaunal copepod species and one of troglofaunal spider species from Yeelirrie have been formally described since 2011. They are the copepod *Dussartstenocaris idioxenos*, *Kinnecaris esbe*, *K. linesae*, *K. lined*, *K. uranusi*, *Nitokra esbe*, *N. yeelirrie*, *Schizopera akation*, *S. akolos*, *S. analspinulosa*, *S. analspinulosa linel*, *S. emphysema*, *S. kronosi*, *S. leptafurca*, and *S. uranusi*, and the

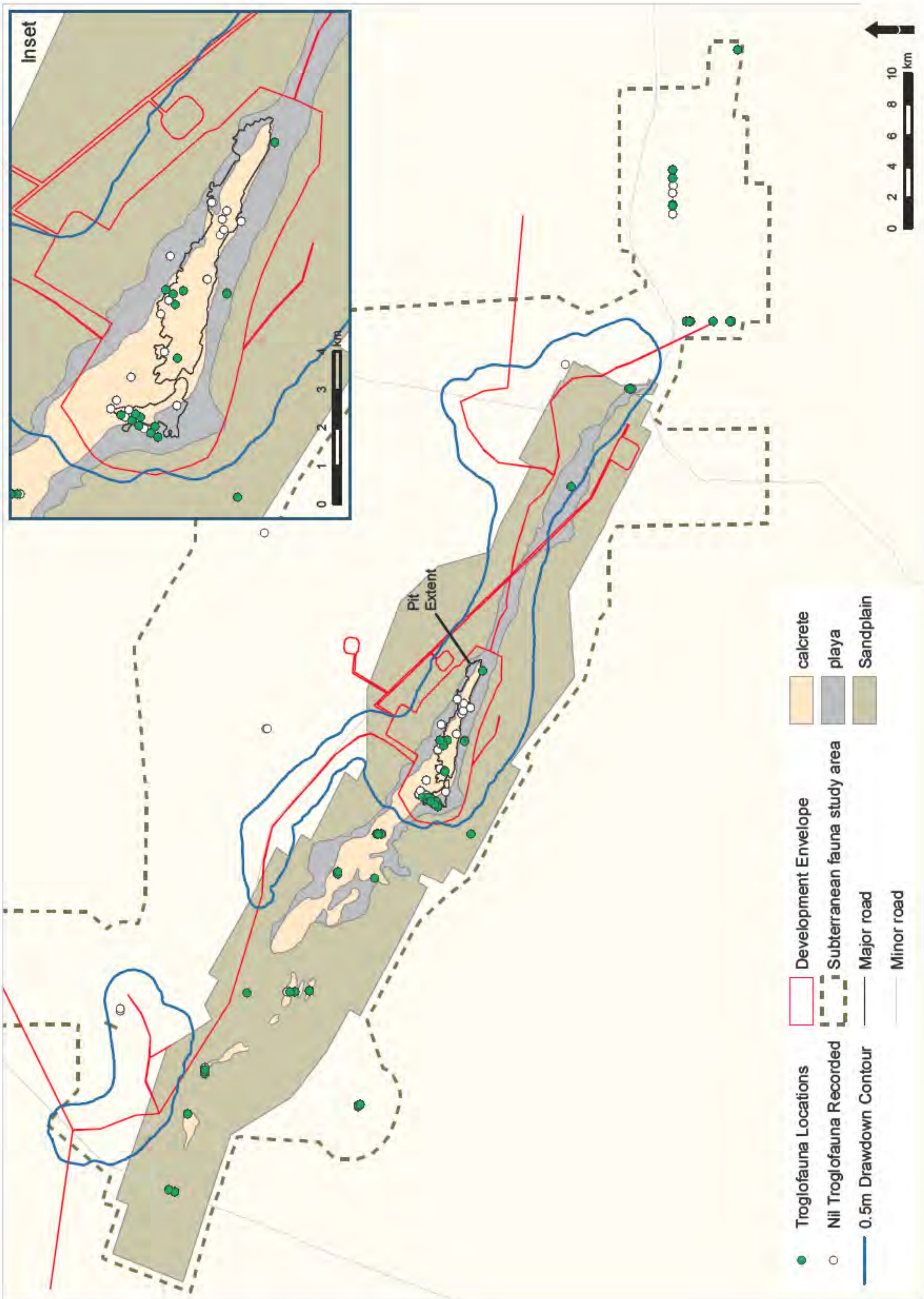


Figure 9-14: Troglofauna locations and major landforms

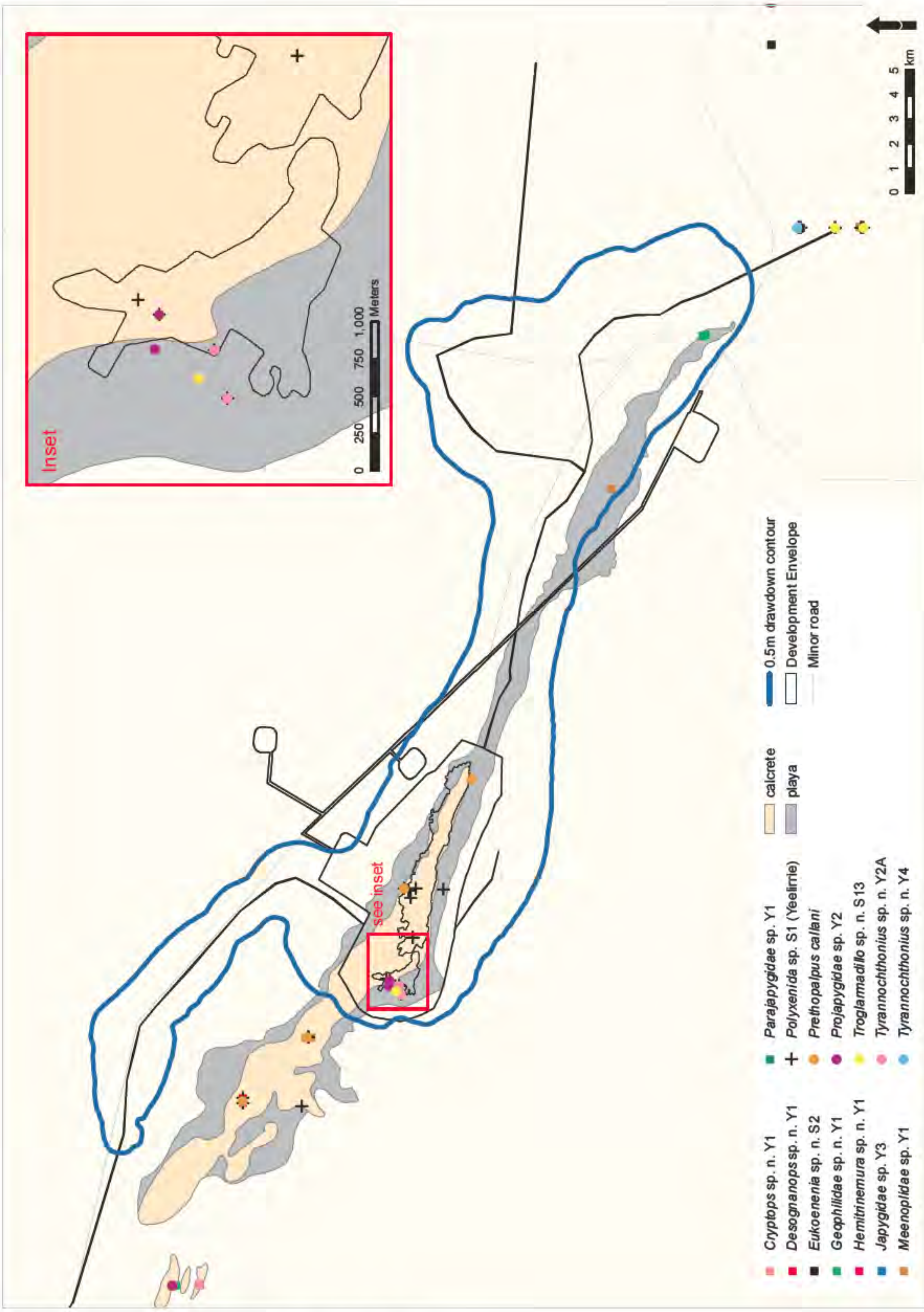


Figure 9-15: Widely abundant troglofauna species

goblin spider *Prethopalpus callani* (Baehr *et al*. 2012; Karanovic and Cooper 2011 a, b; Karanovic and Cooper 2012; Karanovic et al. 2014).

9.2.5 Potential Impacts on Subterranean Fauna

Habitat loss represents the most significant potential threat to subterranean fauna and is considered here as the principal threatening process. Loss of relatively small areas of subterranean habitat may have the potential to threaten the persistence of some subterranean fauna species because of the very small ranges of some species (less than 100 ha for some troglofauna species; see Halse and Pearson 2014).

Loss of stygofauna habitat at Yeelirrie will occur mainly through groundwater drawdown although the area excavated for the mine pit (which is contained within the area of groundwater drawdown) will also represent lost habitat. Although annual changes of 2 m occur at Lake Way to the north (Mann and Horwitz 1979), natural annual fluctuations of groundwater levels at Yeelirrie are probably <1 m. Given that the thickness of saturated calcrete, which is considered to be the main stygofauna habitat at Yeelirrie, is only 2 to 3 m across much of Yeelirrie, substantial drawdowns are likely to fully dewater the calcrete and cause major habitat loss for stygofauna. Smaller drawdowns may result in significant changes to groundwater salinities within calcretes because of the natural vertical salinity gradient.

It is common practice when examining relatively deep and uniform aquifers to assume that only drawdowns of >2 m over and above natural fluctuations will have significant conservation impacts on stygofauna. On account of the relative thinness of the saturated calcrete in most of the drawdown area at Yeelirrie, a more precautionary threshold of >0.5 m was identified as the point when groundwater drawdown may result in enough loss of stygofauna habitat to have significant conservation effects.

Loss of troglofauna habitat at Yeelirrie will occur through excavation for the mine pit. In addition there may be a small area around the mine pit (extending only a few metres) in which drying of habitat and the effects of mine pit activities will reduce habitat quality sufficiently to have conservation effects. Outside the proposed mine pit and this narrow buffer, there should be no significant loss of habitat.

9.2.6 Subterranean Fauna Assessment

9.2.6.1 Impacts on the Yeelirrie PEC

The Yeelirrie Priority 1 PEC represents a conservation significant community. It is currently defined spatially as a buffered area (Figure 9-10), without any delineation of the core area containing the ecological community of interest from the surrounding buffer, although the Yeelirrie calcrete is the focus of the listing. At the time the PEC was first listed, only three stygofauna species were known to occur at the calcrete and the compositional characteristics of the community were not defined. Following Phase 2 and 3 sampling, it has been shown that the study area supports 115 subterranean fauna species, of which 70 are stygofauna.

Figure 9-16 illustrates the modelled maximum drawdown impacts throughout the entire length of the palaeochannel around Yeelirrie. The figure utilises known bore information to show lithological units, depth of groundwater and aquifer thickness. As illustrated in the figure, there are large areas that experience a drawdown of > 0.5 m, however a significant percentage of the aquifer remains as stygofauna habitat.

Given that the amount of drawdown varies along the palaeochannel, as well as between landscape units, it is difficult to assess potential impacts on the PEC without clear definition of its extent and species composition. Furthermore, there is no widely accepted framework for determining what represents an unacceptable loss of area from an ecological community, especially when it occurs within a single area. Most proposed schemes are based on communities that have multiple occurrences across the landscape (e.g. Rodriguez et al. 2011).

Drawdown of >0.5 m at Yeelirrie will impact on approximately 37% and 60% of the areas of inferred calcrete and playa, respectively (Figure 9-12). The proportion of sandplain impacted will be small because it is an extensive landscape unit. Twenty per cent of stygofauna species are currently known only from the inferred calcrete, a further 36% of species are known only from the inferred calcrete and playa, and 44% of species occur in the sandplain or are probably widely distributed in the Yilgarn.

When assessing the impact of the Project on conservation values of the PEC, it should be recognised that there will not be total loss of stygofauna habitat in all areas where groundwater drawdown is >0.5 m (Figure 9-11). In fact at bore YYHC0075 (Figure 9-16), which is approximately 3 km south east of the pit, drawdown is predicted to be 4.4 m and below this 16.7 m (79%) of the aquifer will remain intact. In much of the area of inferred calcrete, some calcrete and the underlying alluvium will remain saturated. It is expected that the overall ecological character of the PEC will show little change in terms of species richness and composition as a result of Project development because most species have part of their populations outside the area of groundwater drawdown.

9.2.6.2 Listed Species

None of the 115 subterranean fauna species from Yeelirrie is currently listed for special protection under the State WC Act or Commonwealth EPBC Act.

9.2.6.3 Stygofauna

Seventy stygofauna species have been recorded from the Project Area, with populations of 86% of these species found outside the mapped extent of groundwater drawdown.

Ten species are currently known only from the mine pit and associated areas of predicted groundwater drawdown (Figure 9-17). Nine of the species are known from single bores and the other species is known from two bores. No restricted species have been recorded only from the northwest area of groundwater drawdown (Figure 9-12), which is associated with additional groundwater abstraction for processing water.

Discussion of the distributions of the ten stygofauna species known only from the predicted area of groundwater drawdown is provided below (also see Appendix F1).

Enchytraeidae sp. Y4

In total, 1133 enchytraeid worms were collected throughout the Yeelirrie calcrete and the Yeelirrie Playa and only a handful of specimens were DNA sequenced to show that nine species are present. Subterranean oligochaetes, including enchytraeids, are thought to be moderately widespread (Pinder 2008), so that the pattern of localised occurrence at Yeelirrie that may be inferred from DNA results would be unusual. It is more likely that Enchytraeidae sp. Y4, which was detected genetically from a single animal occurs more widely at Yeelirrie (the other 37 enchytraeids in the sample were assumed to be Enchytraeidae sp. Y4).

Subterranean Ecology (2011) examined many specimens from many samples genetically and, to contain costs, mostly analysed only one animal of each morphotype. In the case of enchytraeid worms, few species were expected and there was no attempt to identify morphotypes. Therefore, it was assumed all specimens in a sample belonged to the same species as defined by DNA sequencing.

Enchytraeidae sp. Y6

This amphibious species was collected at a single bore hole within the proposed mine pit. Identification was based on a single animal and the other three enchytaeid worms in the same bore sample were assumed to be Enchytraeidae sp. Y6. Based on the belief that enchytraeid species are usually moderately widespread, it is considered to be likely that Enchytraeidae sp. Y6 occurs more widely at Yeelirrie.

Atopobathynella sp. 'line K'

This syncarid species was collected from a single bore hole in the southeastern part of the groundwater drawdown. Syncarids are conventionally considered to have small ranges. However, *Atopobathynella* sp. 'line K' is one of six species of *Atopobathynella* collected in the study area and two of the three species collected from multiple bores were widespread (Table 9-26). The most numerous species (*Atopobathynella* sp. S5) has a known linear range of 20 km (Figure 9-13). This suggests further sampling may show *Atopobathynella* sp. 'line K' occurs outside the area of groundwater drawdown.

Halicyclops cf. *eberhardi* sp. B

The copepod *Halicyclops* cf. *eberhardi* sp. B was collected as 372 specimens in four samples from a single bore on the periphery of the proposed mine pit and within the area of groundwater drawdown. The closely related *H.* cf. *eberhardi* sp. A is more widely distributed in the Yeelirrie calcrete and, perhaps, regionally. Another closely related species, *H.* cf. *eberhardi* sp. C, was collected at Yeelirrie playa. Little can currently be said about the likely range of *H.* cf. *eberhardi* sp. B other than it must be larger than currently documented. Copepods are often are abundant in particular microhabitats (Galassi *et al*. 2009) and the large number of specimens collected from a single bore suggests this applies to *H.* cf. *eberhardi* sp. A.

Collection of a species in large numbers from only one hole also suggests that sampling stochasticity is not a likely reasons that *H.* cf. *eberhardi* sp. A was collected from only one bore. A more likely explanation is that the species occurs in microhabitat with a patchy, and probably infrequent, occurrence. Such a microhabitat might be quite widespread, at least subregionally, and delineated by a particular factor such as salinity, or a combination of salinity and other factors (see Section 9.2.2.4). However, identifying the locations of particular habitats in a heterogeneous area such as Yeelirrie is difficult.

Kinnecaris lined

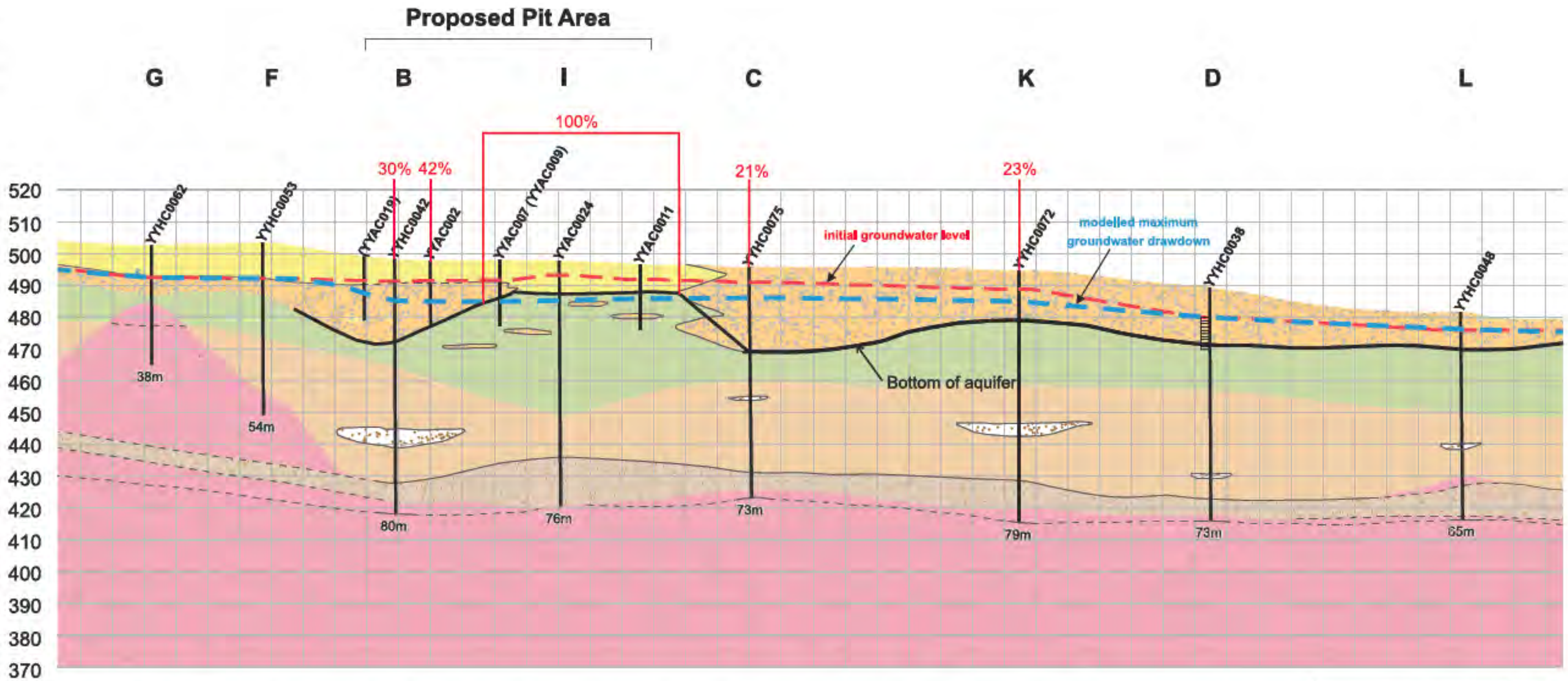
One hundred specimens of the copepod *Kinnecaris lined* were collected from a single bore in the southeastern part of the central groundwater drawdown. The identification was based on DNA sequence data and morphology (Karanovic and Cooper 2011). Given that six species of *Kinnecaris* occur in the study area, with all species other than *K. uranusi* having restricted known ranges, it is likely most of species of *Kinnecaris* at Yeelirrie occupy specific microhabitats within the study area. Little can be said currently about the likely distribution of *K. lined* but further sampling may show it occurs outside the area of groundwater drawdown.

Novanitocrella 'araia' sp. n.

The copepod *Novanitocrella* 'araia' sp. n. is known only from a single animal in a sample from within the proposed mine pit. The species is defined morphologically and a further 123 animals belonging to a subspecies *Novanitocrella* 'araia linec' ssp. n. are known from the east of the mine pit within the area of groundwater drawdown. The species and subspecies are treated here as a single taxonomic unit with a known range of 11 km. The only other species of the genus, *N. aboriginesi*, has a known linear range of about 20 km (Karanovic 2004) and it is likely that further sampling will show *Novanitocrella* 'araia' sp. n. occurs outside the area of groundwater drawdown.

Schizopera akolos

In total, nine species and one subspecies of the copepod *Schizopera* have been collected from Yeelirrie, with all four species recorded from multiple bores being widespread (Table 9-26). *Schizopera akolos* was collected as four animals in two samples from a single bore at the western end of the proposed mine pit. It is likely that *Schizopera akolos* occupies a relatively rare microhabitat



Hole name	top aquifer	bottom aquifer	initial water table	elevation drawdown	thickness aquifer	WL change	%
YYHC0042	492.29	473	492.29	486.56	19.29	5.73	30
YYHC002	491.5	477	491.42	485.39	14.5	6.03	42
YYHC0075	490.46	469	490.43	486	21.46	4.431	21
YYHC0072	486.35	479	486.35	484.65	7.354	1.704	23
YYHC0038	479.63	471	479.63	480.14	8.634	-0.506	0
YYHC0048	475.98	470	475.98	476.66	5.978	-0.682	0

Figure 9-16: Longitudinal cross-section

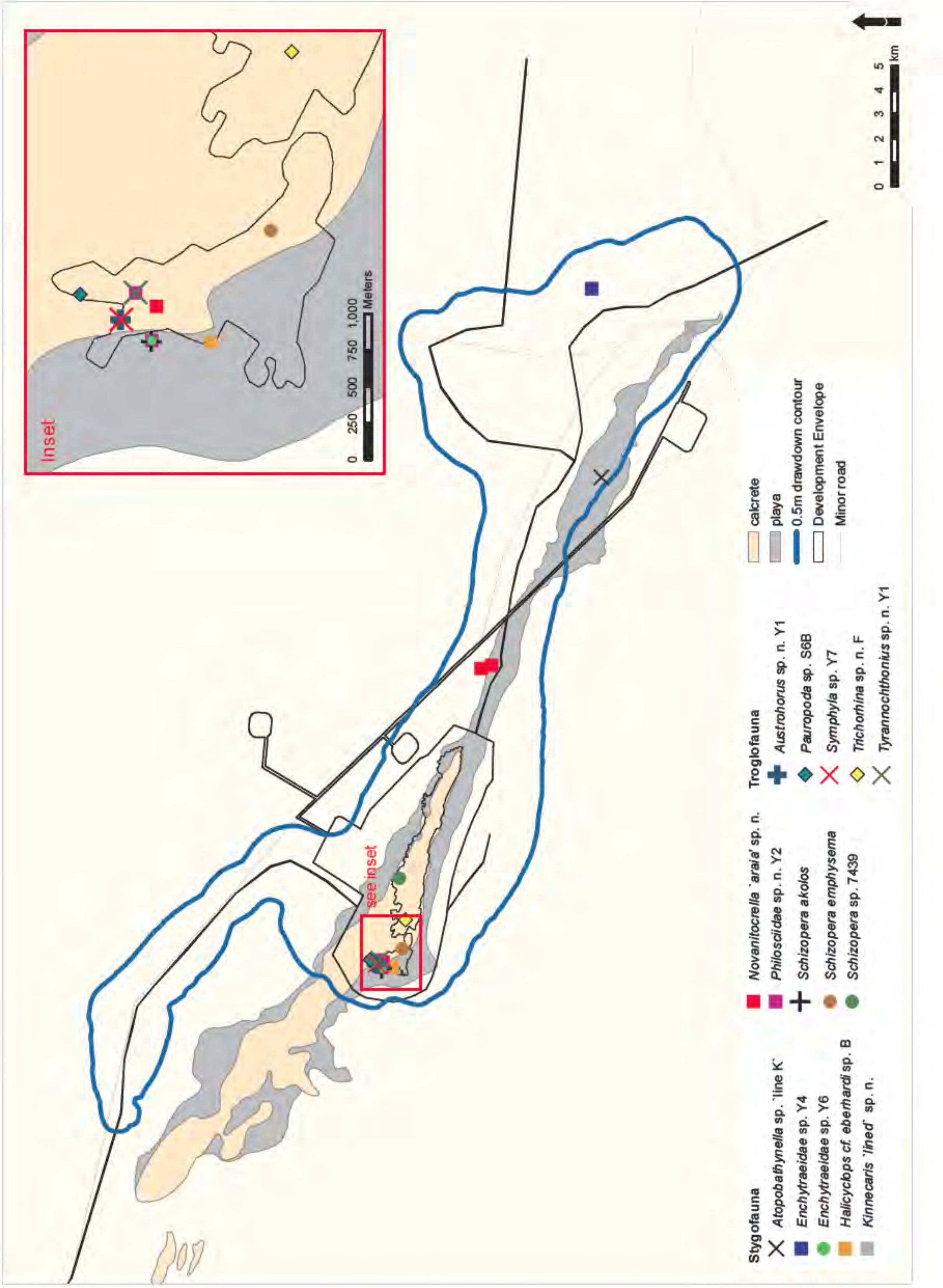


Figure 9-17: Subterranean fauna species known only from within predicted area of drawdown

(see Bradford 2010). Genetic data suggest the high richness of *Schizopera* species at Yeelirrie is the result of multiple invasions of surface species, as well as local speciation (Karanovic and Cooper 2012). DNA data suggest one of the invading species was *Schizopera akolos* and a wide range at Yeelirrie might be expected for such a species. Thus, while the likely range of *Schizopera akolos* is uncertain, it certainly larger than currently documented and further sampling may show *Schizopera akolos* occurs outside the area of groundwater drawdown.

Schizopera emphysema

Eight animals of *Schizopera emphysema* were collected in four samples from one bore within the proposed mine pit. As with *S. akolos*, this species probably occupies a discrete microhabitat within the study area because it was not collected from any of the three bores a few metres away (Karanovic and Cooper 2012). Like *Schizopera akolos*, *S. emphysema* belongs to a clade of surface-invading species that might be expected to be widespread and it is considered likely the species has a patchy occurrence at Yeelirrie corresponding with occurrences of its preferred microhabitat. Further sampling may show *Schizopera emphsema* occurs outside the area of groundwater drawdown at Yeelirrie.

Schizopera sp. 7439

Schizopera sp. 7439, which was identified by genetic analysis of a single animal, was collected in one sample of five animals from one bore within the proposed mine pit. It was not recognised morphologically prior to DNA analysis and therefore may have occurred in other samples without being recognised and recorded. As this species is known from a single sample, with identification based on a single individual, the probability that collection of additional specimens will increase its range is high but little can be concluded currently about its likely distribution.

Philosciidae sp. n. Y2

This amphibious isopod species was collected as five specimens in four samples from two bore holes within the proposed mine pit. Terrestrial isopods often have restricted ranges (Judd *et al*. 2003) and other subterranean philosciids have sometimes been shown to be restricted to single calcretes or to have mine-scale distributions (Cooper *et al*. 2008; Taiti and Humphreys 2001). Little can be said about the likely range of *Philosciidae* sp. Y2 but further sampling may show *Philosciidae* sp. Y2 occurs outside the area of groundwater drawdown.

9.2.6.4 Troglofauna

Forty-five troglofauna species have been recorded from the Project Area, with the populations of 89% of these species found outside the proposed mine pit.

Discussion of the distributions of the five troglofauna species known only from the area of the proposed mine pit is provided below (Figure 9-17; see also Appendix F1).

Trichorhina sp. n. F

Three of the four species of the isopod *Trichorhina* collected in the study area are known from single bores, with *Trichorhina* sp. n. F being represented by a single animal within the proposed mine pit. The fourth species, *Trichorhina* sp. n. G, occurs in multiple bores with a linear range of about 14 km but is restricted to the northwestern part of the Yeelirrie calcrete. It is likely *Trichorhina* sp. n. F will have a small range but further sampling may show it occurs outside the mine pit.

Tyrannochthonius sp. n. Y1

Three of the six species of the pseudoscorpion *Tyrannochthonius* at Yeelirrie were collected from two or three bores. As a result, both *Tyrannochthonius* sp. n. Y2A and *Tyrannochthonius* sp. n. Y4 showed relatively wide distributions (13 and 26 km, respectively). Most subterranean pseudoscorpions have similar ranges (Harvey and Edward 2007; Harvey and Leng 2008) and it appears that the restricted range of *Tyrannochthonius* sp. n. Y1 is the result of a single animal being collected. Further sampling is likely to show that *Tyrannochthonius* sp. n. Y1 is more widespread.

Austrohorus sp. n. Y1

Both species of the pseudoscorpion *Austrohorus* collected in the study area came from single bore holes. *Austrohorus* sp. n Y1 was represented by a single animal collected approximately 220 m from the edge of the proposed mine pit. Little can be said about its likely range other than that most pseudoscorpions have linear ranges that are at least an order of magnitude greater than this (Harvey and Edward 2007; Harvey and Leng 2008). Further sampling may show that *Austrohorus* sp. n Y1 is more widespread.

Pauropoda sp. S6B

All five pauropod species collected at Yeelirrie have apparently restricted distributions, although in some cases it was because single animals were collected. Pauropoda sp. S6B was collected in one sample containing three animals, only one of which was analysed genetically. Recent taxonomic work on surface pauropods in Australia suggests that Western Australia has many endemic species but range information is limited because there has been little collecting (Scheller 2010; Scheller 2013). Collections of troglofaunal pauropods in the Pilbara suggest they have similar ranges to pseudoscorpions and are less tightly restricted than many troglofauna species (Halse and Pearson 2014). It is considered to be likely that the range of Pauropoda sp. S6B extends beyond the proposed mine pit, especially considering the proximity of the one record to the edge of the mine pit.

Symphyla sp. Y7

All seven symphylan species collected from Yeelirrie have apparently restricted distributions, although as with pauropods this is often the result of single animals being collected. Symphyla sp. Y7 was represented by a single specimen and little can be said about its likely range because of the poor taxonomic framework for this group in Australia and the resultant lack of species level identifications and range information. Thus, it must be considered possible that Symphyla sp. Y7 is restricted to the proposed mine pit, although the proximity of the one record to the edge of the mine pit indicates that, on balance, the species' range is more likely to extend outside.

9.2.6.5 Impacts on Species

A comprehensive subterranean fauna sampling program at Yeelirrie has documented most of the species in the area and provided information on their distributions in relation to Project impacts. It is clear that the conservation status of most species known from the PEC will not be affected by mining and groundwater drawdown, although 10 species of stygofauna and five species of troglofauna are currently known only from areas proposed to be impacted by mining or de-watering.

Some additional sampling was undertaken, both in 2009-2010 and 2015 to attempt to show wider occurrence of these 15 species. However, the fine-scale heterogeneity of salinity and other habitat characteristics of the subterranean environment at Yeelirrie make it difficult to design an appropriate sampling program. This was highlighted by the considerable mis-match between the modelled salinity of bores used for targeted sampling in 2015 and the actual values recorded in those bores during when sampling. Seven of the eight restricted species for which salinity information was available had been recorded in the impact area at salinities of 10-25 gL^{-1}. However, 67% of the bores sampled outside the impact area to show wider occurrence of apparently restricted species were in groundwater of <5gL^{-1}, despite modelling suggesting salinities would be mostly 15-20 gL^{-1} (Appendix F1).

For nine of the 15 species currently known only from the proposed mine pit or groundwater drawdown area, it is considered there is sufficient surrogate evidence from related species to indicate the species are likely to occur outside these impact areas. These species are:

- Enchytraeidae sp. Y4, Enchytraeidae sp. Y6. It is likely these species were apparently restricted because there were DNA identifications of only a very small proportion of the animals collected. Enchytraeidae sp. Y5, which also appeared to be restricted on the basis on sampling results from 2009-2010, was shown in 2015 to be more widespread (see below).

- *Atopobathynella* sp. 'line K'. Species of *Atopobathynella* that were collected from multiple bores are mostly widespread at Yeelirrie.
- *Schizopera akolos*, *Schizopera emphysema*. All species of *Schizopera* collected from multiple bores are widespread at Yeelirrie. Phylogenetic evidence suggests these two species are have colonised from the surface and, therefore, are likely to have a moderately wide range at Yeelirrie.
- *Tyrannochthonius* sp. n. Y1, *Austrohorus* sp. n. Y1. Troglofaunal pseudoscorpions are usually moderately widespread.
- Pauropoda sp. S6B, Symphyla sp. Y7. These species occur so close to edge of proposed mine pit that their ranges will extend outside. In addition, pauropods are mostly moderately widespread.

There is not strong surrogate evidence of wider range for six of the 15 species. However, five species require only small range extensions to occur outside the impact areas. These range extensions are well within the probable magnitude of the species ranges:

- *Halicyclops* cf. *eberhardi* sp. B. This genus has shown considerable speciation at Yeelirrie. Although the species probably has a small range, it was found close to the boundary of groundwater drawdown and probably occurs outside.
- *Kinnecaris lined*. This genus has shown considerable speciation at Yeelirrie. Although the species probably has a small range, it was found close to the boundary of groundwater drawdown and probably occurs outside.
- *Novanitocrell*a 'araia' sp. n. The taxonomy of this species is complex and it may in fact consist of two species but Novanitocrella 'araia' sp. n. has a smaller range than the only described species of the genus and occurs near the western boundary of groundwater drawdown. With a small range extension the species would occur outside the proposed impacted area.
- *Philosciidae* sp. n. Y2. With a small westward range extension, the species would occur outside the area of proposed groundwater drawdown.
- *Trichorhina* sp. n. F. This is the species of troglofauna most likely to be restricted to the mine pit on the basis of existing information but, with a range extension of <1 km, it would extend beyond the mine pit.

One of the 15 species should be treated as having uncertain taxonomic, as well as conservation, status because of the way it was identified:

- *Schizopera* sp. 7439. This specimen was identified genetically during the 2009-2010 sampling (Subterranean Ecology 2011) and then subjected to further analysis by Karanovic and Cooper (2010). In the latter publication, it is unclear whether they consider *Schizopera* sp. 7439 to be a cryptic species that looks like *Schizopera uranusi* or the result of contamination during analysis. It is considered that further verification of the validity of the specimen as a valid taxonomic unit is required before it is treated as being restricted to the impact area.

While evidence is presented above to suggest wider occurrence of 14 species and taxonomic uncertainty about an additional 15th species, it is emphasised again that predicting the true ranges of these 15 species through both field sampling and surrogate analysis is difficult without good understanding of the factors driving habitat selection by the individual species. Accurate determinations, and even predictions, of ranges usually require that animals have been collected from 25-30 sites with a sampling regime that is spatially unconstrained (Wisz *et al*. 2008). It is unlikely that anywhere near this number of records can be collected for subterranean fauna species occurring in rare microhabitats because of the inability to target specific habitats when sampling as discussed in Section 9.2.4.1.

In some cases, however, small numbers of samples will show that species ranges extend beyond the impact area. The collection of two additional specimens of Enchytaeidae sp. Y5 during a targeted sampling program in 2015 showed that this species has a linear range of at least 23 km and occurs outside the proposed mine pit. Previously, this genetically identified enchytraeid was known only from two bores in the mine pit (Appendix F1).

In summary, the sampling for subterranean fauna at Yeelirrie has been the most comprehensive of any subterranean fauna survey in the Yilgarn and the results confirm some of the research related theories about stygofauna habitat, including that calcrete areas are productive habitats hosting significant species richness. Geological work and the subterranean fauna sampling results also show, however, that calcrete habitat is not easily defined and subterranean fauna species are not limited to areas described as calcrete.

9.2.7 Management

Management options to protect subterranean fauna are difficult especially considering the uncertainty and limitations of the study and impact assessment. Cameco has investigated numerous management strategies to reduce its impact on subterranean sauna, including:

- **Sterilisation of the economic orebody**: this strategy will have a significant impact on the economics of the project. The strategy could potentially be effective to reduce the impact to troglofauna species currently only known from the pit as four of the troglofauna species (*Tyrannochthonius* sp. n. Y1, *Austrohorus* sp. n. Y1, Pauropoda sp. S6B and Symphyla sp. Y7) are only known from the northwestern corner of the pit. However as discussed in Section 9.2.5.4, given the close proximity of all four species to the edge of the pit, the range of these species is likely to extend outside the pit and impact zone. This management strategy will not have a net benefit to restricted stygofauna species because of the requirement for dewatering. This strategy is not being proposed because it offers no net benefit to any likely restricted species and the overall impact to the economics of the project is significant.
- **Dewatering strategy and location of production supply well fields**: The groundwater model is currently conceptual in nature, however given the long history of the Albion Downs Wellfield and the historical work by WMC, Cameco has a high level of confidence that water can be sourced from the palaeochannel. Less confidence and more uncertainty of impacts is present for the Western Brackish Wellfield, Northern Brackish Wellfield and Eastern Brackish Wellfield (as described in Appendix I1), however these areas do not contain preferred subterranean fauna habitat. During the water modelling process Cameco has implemented the following in order to reduce impact to stygofauna:
  - No abstraction wells have been located within the palaeochannel to the northwest of the proposed mine pit. While this area is potentially an excellent source of groundwater, it also supports many stygofauna species and is the location of likely range extension for the species currently only known from impact area. Cameco has deliberately not located any abstraction wells in this area in order to reduce impact to stygofauna species and maintain a significant amount of calcrete habitat within the palaeochannel.
  - No abstraction wells have been placed within the mine pit. This has reduced the drawdown impact to the northwest, and area that supports many stygofauna species and is the location of likely range extension for the species currently only known from impact area.
  - Despite not having a benefit to species currently only known from the area of impact Cameco has also removed a number of planned abstraction wells from the palaeochannel in the Western Brackish Wellfield. This has resulted in a reduced impact to the palaeochannel and suitable habitat in the area (a number of species have been collected from this area).

More work can still be undertaken in this area to further reduce the impact to habitat and the species currently only known from the area of impact. However Cameco is currently unable to progress this further given the current knowledge (Western Brackish Wellfield, Northern Brackish Wellfield and Eastern Brackish Wellfield) and the need to have high level of confidence in water supply at this stage of the Project. Cameco is committed to undertaking further testing of the wellfields during a Definitive Feasibility Study (DFS). This information will allow Cameco to further refine the groundwater model and look for opportunities to relocate abstraction wells from the palaeochannel.

- **Consideration of a groundwater barrier wall**: As discussed and presented in Appendix I1 (Section 5.7) Cameco also considered installation of a bentonite slurry wall in order to reduce the drawdown impact up gradient of the wall. Modelling indicates that a barrier wall would have a limiting drawdown effect on water table and would currently not provide a net benefit to species only known from the area of impact. Given this and the fact that installation of a slurry wall would come at a significant cost and result in additional vegetation clearing, this management option is currently not considered feasible.

Of the management strategies considered, the only feasible and effective option to reduce impact is through the implementation of a dewatering strategy and strategically located production supply wells. This strategy will be further refined and investigated prior to the commencement of the Project during a DFS study when further testing of the groundwater supply areas will occur. Potential options include:

- locating well fields in the alluvium/weathered bedrock aquifers in the areas north of the valley floor and north of the proposed pit; and
- investigating additional water sources outside the palaeochannel and not in preferred stygofauna habitat, with the potentially of relocating entire well fields.

Prior to Project commencement Cameco will develop a Subterranean Fauna Management Plan, which will be closely integrated with the Groundwater Management Plan (Section 9.5.6). The plan will detail the results of the DFS investigation and include the following at a minimum:

- Develop subterranean fauna monitoring program.
- Set trigger criteria and contingency actions.
- Outline reporting requirements.

In summary, Cameco has utilised the hierarchy of control to manage the impact of the Project on stygofauna. This includes the following:

- **Avoid.** No abstraction wells have been located within the palaeochannel to the northwest of the pit. While this area is potentially an excellent source of groundwater, it also supports many stygofauna species.
- **Minimise.** Abstraction wells will be relocated throughout the supply area to reduce the groundwater impact where possible. Cameco believes that there are number of opportunities to continue to minimise this impact and these opportunities will be explored during a DFS.

9.2.8 Commitments

Cameco will develop and implement a Subterranean Fauna Management Plan, which will be closely integrated with the Groundwater Management Plan. Cameco is also committed to having further discussions with the OEPA and DPaW to determine a suitable offset.

9.2.9 Outcomes

Residual impacts on subterranean fauna are predicted to occur as a result of implementation of the Project and therefore offsets are proposed (Section 12.4). Cameco will have further conversations with OEPA and DPaW to determine suitable offsets.

Taking into account Project design, the proposed management measures, and the proposed offsets strategy of ongoing investigations to expand the range of species currently considered restricted, Cameco believes that the proposal will meet the EPA objective of maintaining the representation, diversity, viability and ecological function at the species, population and assemblage level.