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Level 1 subterranean fauna assessment for the Beyondie Potash Project

Prepared for Kalium Lakes Potash Pty Ltd

June 2017

Draft Report

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Date: 6 June 2017

Submitted to: Phil Scott, Brett Hazelden

Chain of authorship and review			
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EXECUTIVE SUMMARY

Kalium Lakes Potash Pty Ltd (Kalium) proposes to develop the Beyondie Potash Project (the Project). The Project is located approximately 150 km south-southeast of Newman with access to the Great Northern Highway at Kumarina approximately 65 km to the east. The Project spans the border between the Great Sandy Desert and Gascoyne bioregions. It proposes to produce Sulphate of Potash (SOP) by abstraction of hypersaline groundwater brine containing the dissolved product, which is extracted by water evaporation.

Phoenix Environmental Sciences Pty Ltd (Phoenix) was commissioned to conduct a Level 1 subterranean fauna assessment for the Project to support the application for a Programme of Works (PoW) to the Department of Mines and Petroleum (DMP) for the construction and operation of trial ponds for the Project. The study area for this assessment is loosely defined as the exploration leases E69/3309, E69/3346, E69/3347, E69/3351 and E69/3352, with regional sampling conducted outside this area.

The objective of this Level 1 subterranean fauna survey was to assess the likelihood of subterranean fauna to occur in the study area and the wider region by reviewing relevant databases, available technical reports, literature and spatial data. A pilot subterranean fauna survey was conducted from 29–31 March 2017 targeting a total of 15 bores and wells, seven within the study area and eight here considered regional reference sites.

The assessment methodology of this assessment complied with the Environmental Protection Authority's (EPA's) requirements for an environmental impact assessment (EIA) of subterranean invertebrates as outlined in the *Environmental Factor Guideline:* S*ubterranean fauna* and *Technical Guidance: Sampling methods for subterranean fauna*.

Subterranean fauna are animals, predominantly invertebrates, which have evolved to live underground to escape harsh environmental conditions such as extreme heat and dryness of exposed environments. They are classified into two types:

- troglofauna – animals that live in air-filled subterranean networks
- stygofauna – animals that live in water-filled subterranean networks.

Habitats likely to support troglofauna are karstic limestone, channel iron deposits (CIDs; in particular pisolite in inverted landscape geomorphology), groundwater calcretes above the water table, alluvium/colluvium in valley-fill settings, banded iron formations (BIFs) and weathered and fractured sandstone. Stygofauna are likely where there are groundwater voids present, for example in karst limestone, calcretes, alluvial formations and fractured rock.

The Project is just off the south-western edge of the Northwest Officer Basin. Beyondie Lakes and 10 Mile Lake are developed within a palaeochannel system, underlain by bedrock of the Sunbeam Group, consisting mostly of sedimentary sandstones, siltstones, conglomerates and shales. Within the lakes, Quaternary lacustrine deposits are mainly clay, mud and silt which are usually saline and commonly gypsiferous. Surrounding the lakes are expanses of Quaternary Aeolian sand and sand sheets. Longitudinal (seif), chain and net dunes are abundant. Two main calcretes are present consistent with two palaeochannels terminating at the lake system and currently reflected in two surface drainage lines, i.e. Nanyerinny Creek flowing into the Beyondie Lakes from the west and 477 Creek flowing into 10 Mile Lake from the south.

The calcretes that formed in the palaeochannels of the Yilgarn Craton just south-west of the study area belong to the most prospective formations with respect to subterranean fauna diversity, in particular stygofauna, in Western Australia. For example, three calcretes at Lake Way, approximately 230 km south of the study area, up-to-date revealed at least 68 species of stygofauna and up to 20

species of troglofauna, many of which limited to single calcretes. Seventy-seven clacretes of the Midwest and the Goldfields regions have been listed as Priority Ecological Communities by the Department of Parks and Wildlife (DPaW).

Four main aquifers exist in the study area, including upper unconsolidated alluvial and colluvial sediments (< 15 m deep), areas of saturated calcrete, basal palaeochannel sands and areas of weathered or fractured bedrock. Whereas the target process water in the basal palaeochannel sands is a brine of high salinity (70,000 to over 300,000 mg/L TDS) and therefore uninhabitable by stygofauna, the calcrete aquifers and alluvial deposits accommodate freshwater with good potential for stygofauna and troglofauna above the water table.

Database searches identified seven stygofauna species within approximately 100 km of the project area. Three of these are only known from single localities: *Billibathynella ilgarariensis* and *Brevisomabathynella magna* (both Parabathynellidae) and *Pilbaracyclops frustratio* (Cyclopidae). All others are widespread species. No troglofauna was identified in the desktop review area.

The field pilot survey recovered two species of troglofauna, an unidentified spider (Garden Well) and a juvenile meenoplid bug (Hemiptera) (David's Well). Two taxa of stygofauna were recorded, syncarid crustaceans (order Bathynellacea) and amphipods (family Paramelitidae) from Garden Well and Tupee Bore. Molecular identification of both taxa is pending. All subterranean fauna records were from bores in alluvial deposits with considerable distance to Lake Beyondie and 10 Mile Lake. These sample bores are considered references samples, although process water abstraction from the Nanyerinny Creek system was flagged as part of an adaptive water management scheme. There was only limited sampling in and around the calcretes neighbouring 10 Mile Lake where no subterranean fauna was found.

The pilot study as resulted in records on both troglofauna and stygofauna in the alluvial channels west of the Beyondie and 10 Mile lake systems which trigger a Level 2 subterranean survey for the project consistent with EPA guidelines. This proposed survey should include additional bores in the calcretes around 10 Mile Lake.

Impacts on the perched aquifers of the calcretes near 10 Mile Lake due to brine abstraction from the palaeochannel in the lake are currently difficult to assess as it is unclear if and by how much brine abstraction will affect the hydrology of the calcretes, although an impact is thought minimal. Water levels in the calcretes should be monitored during brine abstraction, in particular if subterranean fauna is found during a future Level 2 survey.

Due to the presence of subterranean fauna, freshwater abstraction from Nanyerinny Creek near Garden Bore should, based on current knowledge, be avoided. If water is abstracted, groundwater levels and the presence of stygofauna should be monitored and managed with a subterranean fauna management plan.

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1 INTRODUCTION

Phoenix Environmental Sciences Pty Ltd (Phoenix) was commissioned by Preston Consulting Pty Ltd (Preston) on behalf of Kalium Lakes Potash Pty Ltd (Kalium) to conduct a Level 1 subterranean fauna assessment for the Beyondie Potash Project (the Project), specifically to support a PoW (Programme of Works) application to the Department of Mines and Petroleum (DMP) for the establishment of test bores and construction of trial evaporation ponds as part of the Project.

The Project is located approximately 150 km south-southeast of Newman, with access to the Great Northern Highway at Kumarina approximately 65 km to the east (Figure 1-1). The Project area spans the border between the Great Sandy Desert and Gascoyne bioregions.

1.1 BACKGROUND

Kalium is seeking to develop a sub-surface brine deposit to produce 150–250 ktpa Sulphate of Potash (SOP) product via an evaporation and processing operation within the Project. A concept study completed in April 2015 assessed the mine life of 20 years with considerable upside to extend for many decades.

The study area for the Level 1 subterranean fauna assessment was designed to evaluate the prospectivity of subterranean fauna to occur around the project. It is loosely defined as the exploration leases E69/3309, E69/3346, E69/3347, E69/3351 and E69/3352 (Figure 1-1), but regional surveys in particular along the Nanyerinny Creek system in the west of the study area complemented the assessment. The Beyondie Lakes consist of a western freshwater marsh (outside the study area) connected to two circular salt playas in line in the east. 10 Mile Lake is a large salt playa located about six kilometres to the south. Several claypans are located around the lakes. The Beyondie Lakes salt playas connect with 10 Mile Lake during extreme inundation events.

The Project is based on the extraction of hypersaline groundwater from beneath the salt lake systems. It particularly targets the basal palaeochannel aquifers that are likely to have a significantly higher hydraulic conductivity and specific yield than the other layers in the profile. Thus, the test bores will be established to extract water from the underlying coarser layers.

A number of piezometers will be established around the test bores selected for extended pump testing. These will serve to monitor the propagation of drawdown within the aquifer. It is anticipated that the target aquifer will behave as a confined or semi-confined aquifer. One of the identified risks is that dewatering of the palaeochannel aquifer will lead to increased recharge from any perched systems located higher in the profile. Of particular interest are locations where perched aquifers are likely to exist, such as in calcrete areas and gypsiferous dune areas around the lakes. One of these areas will be targeted to determine whether pumping of the deeper aquifer has any impact on the perched layers above.

The trial will involve the pumping of a 4–6 test bores to supply the trial ponds, with extraction rates ranging from 10–15 L/s, pumped for a period of 12 months (approximately 1.89 x 10^6 m^3/12months) Based on assumed aquifer characteristics, the pressure levels in the lower semi-confined basal sand aquifer would be expected to drop by:

- between 10–15 m within a distance of 250 m from each test bore
- up to 5 m within 500 m from each test bore
- 1 m drop approximately 3 km from each test bore.

Considering that the basal aquifer has a 30–40 m confining head, the drop-in water levels still leaves the aquifer system in a confined state after a year of pumping. Downward leakage from the clays and the silts/sands above the main aquifer would also occur, but with a drop-in water levels far less than in the basal sand aquifer. The impact on the perched aquifers above the clays would be expected to be very limited. Piezometers will be used to monitor the horizontal and vertical propagation of the "cone of depression" during the trial.

The risks associated with potential environmental impacts from drawing on the palaeochannel aquifer are thought to be:

- vegetation stress for any species dependent upon perched fresh water (GDEs)
- impacts on any stygofauna communities within and troglofauna communities above more substantial perched aquifers.

Calcrete aquifers to the south and west of 10 Mile Lake contain fresh water, suitable for domestic consumption. The demand for the operation's potable water supply will be limited as pumping rates of approximately 0.1 L/s are sufficient to supply the expected demand.

Evaporation ponds and other infrastructure will be constructed in the north-east of 10 Mile Lake and cover a total of approximately 750 ha.

Figure 1–1
Location of the Beyondie Potash Project and study area for the Level 1 subterranean fauna assessment

- Tenement E69/3309
- Tenement E69/3346
- Tenement E69/3347
- Tenement E69/3351
- Tenement E69/3352
- Study area (all tenements)
- Principal road
- Secondary road
- Minor road
- Major creeks and rivers
- Lakes
- National Parks, Nature Reserves

0 10 20 40 Kilometres
1:1,250,000

Client: Kalium Lakes Ltd
Project: Beyondie Potash Project

Author: KW
Date: 06-Jun-17

Coordinate System: GDA 1994 MGA Zone 51
Projection: Transverse Mercator
Datum: GDA 1994

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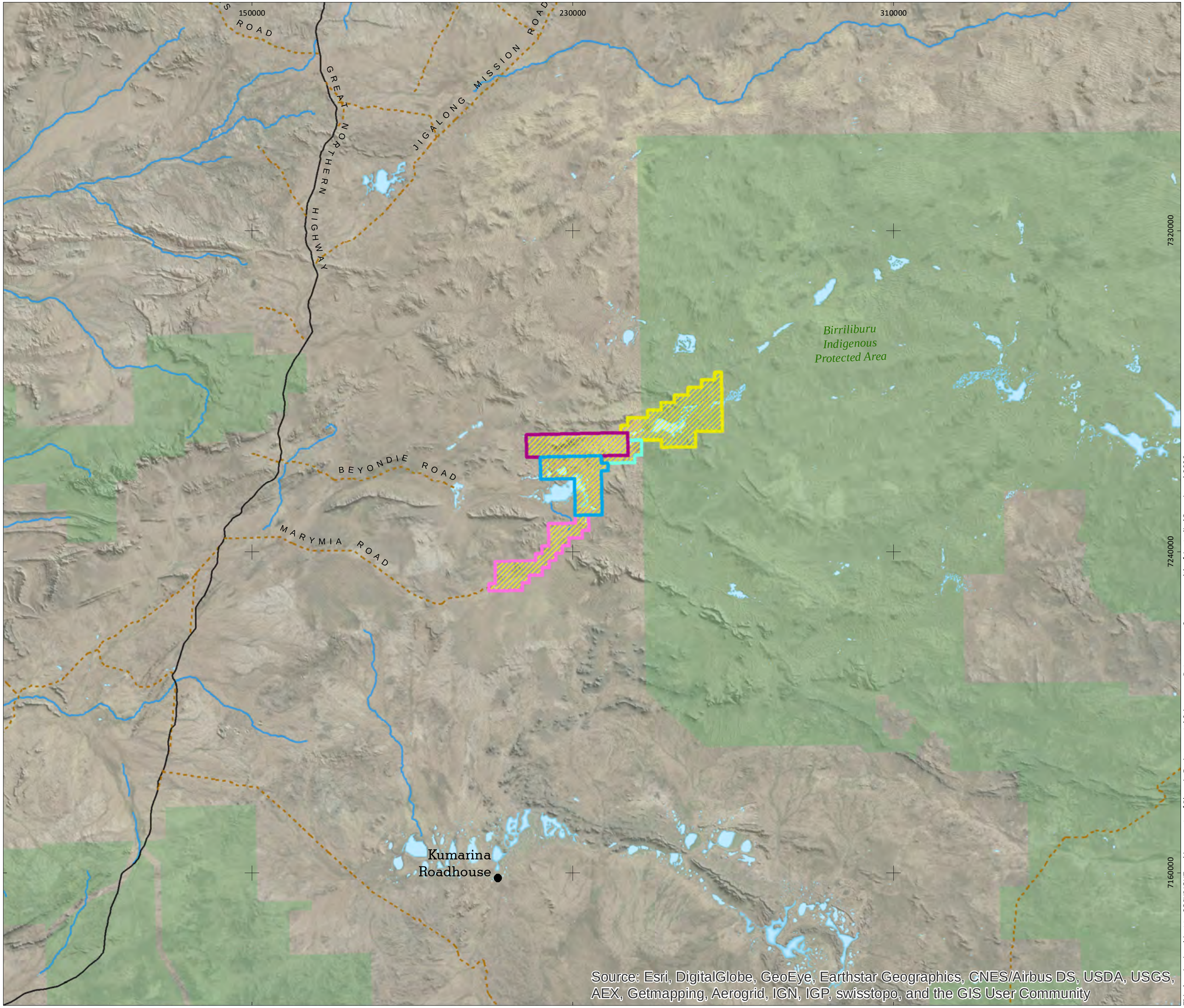

1.2 SURVEY OBJECTIVES AND SCOPE OF WORKS

The objective of the Level 1 subterranean fauna assessment was to identify the likelihood that subterranean fauna are present in the study area and potential impacts by the construction and operation of the trial ponds on these fauna, with particular reference to the abstraction of hypersaline process water (brine) from the underlying aquifer and sourcing of fresh process water from regional alluvial deposits.

The scope of work was as follows:

- conduct a desktop review of available technical reports, relevant databases and spatial data to assess the potential for presence of subterranean fauna in the study area
- conduct a pilot survey for subterranean fauna including prospective geologies within the study area (i.e. alluvial deposits and calcretes) and at regional reference sites
- prepare a preliminary desktop report including potential impacts by the construction and operation of the trial ponds, i.e. abstraction of process water from the palaeochannel, abstraction of potable freshwater from the calcrete aquifers and hydrological impacts of the trial ponds.

The assessment methodology complied with the Environmental Protection Authority's (EPA's) requirements for an environmental impact assessment (EIA) of subterranean invertebrates as outlined in Environmental Factor Guideline: *Subterranean fauna* (EPA 2016a) and Technical Guidance: *Sampling methods for subterranean fauna* (EPA 2016c).

2 Legislative context

The protection of fauna in Western Australia (WA) is principally governed by three Acts:

- Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)
- *Wildlife Conservation Act 1950* (WC Act)
- *Environmental Protection Act 1986* (EP Act).

2.1 Commonwealth

Under the EPBC Act, actions that have, or are likely to have, a significant impact on a matter of national environmental significance (NES), require approval from the Australian Government Minister for the Environment.

The EPBC Act provides for the listing of threatened fauna, flora and ecological communities as matters of NES. Conservation categories applicable to threatened fauna, flora and ecological communities under the EPBC Act are:

- Extinct (EX)[1] – there is no reasonable doubt that the last individual has died
- Extinct in the Wild (EW) – taxa known to survive only in captivity
- Critically Endangered (CR) – taxa facing an extremely high risk of extinction in the wild in the immediate future
- Endangered (EN) – taxa facing a very high risk of extinction in the wild in the near future
- Vulnerable (VU) – taxa facing a high risk of extinction in the wild in the medium-term
- Conservation Dependent[1] – taxa whose survival depends upon ongoing conservation measures; without these measures, a conservation dependent taxon would be classified as Vulnerable or more severely threatened.

[1] Species listed as Extinct and Conservation Dependent are not matters of NES and therefore do not trigger the EPBC Act.

2.2 STATE

In WA, the WC Act provides for the listing of native fauna (Threatened Fauna) species which are under identifiable threat of extinction. Threatened Fauna are assigned to one of seven categories under the WC Act (Western Australian Government 2015):

- Schedule 1 – fauna that is rare or is likely to become extinct as critically endangered (CR) fauna
- Schedule 2 – fauna that is rare or is likely to become extinct as endangered (EN) fauna
- Schedule 3 – fauna that is rare or is likely to become extinct as vulnerable (VU) fauna
- Schedule 4 – fauna presumed to be extinct (EX)
- Schedule 5 – Migratory birds protected under an international agreement
- Schedule 6 – fauna that is of special conservation need as conservation dependent fauna
- Schedule 7 – other specially protected (SP) fauna.

Assessments for listing of fauna are based on the International Union for Conservation of Nature (IUCN) threat categories.

The Department of Parks and Wildlife (DPaW) administers the WC Act and also maintains a non-statutory list of Priority fauna species, most recently updated on 3 February 2017 (DPaW 2017). Priority species are still considered to be of conservation significance – that is they may be rare or threatened – but cannot be considered for listing under the WC Act until there is adequate understanding of their threat levels. Species on the Priority fauna lists are assigned to one of five priority (P) categories, P1 (highest) – P5 (lowest), based on level of knowledge/concern.

A total of 23 troglofauna and 20 stygofauna species are currently listed as either Threatened or Priority in Western Australia, with the majority from the Pilbara and Carnarvon IBRA regions (Appendix 1).

The Minister for Environment may also list ecological communities which are at risk of becoming destroyed as 'Threatened'. DPaW maintains a list of ministerially-endorsed Threatened Ecological Communities (TECs) (DPaW 2016a) as well as a non-statutory list of Priority Ecological Communities (PECs) (DPaW 2016b) which are also assigned to one of five categories.

Nine subterranean TECs (Appendix 2) and 86 subterranean PECs (Appendix 3) are listed from Western Australia. Of the 86 PECs, 77 are stygofauna communities in the groundwater of calcretes of the Yilgarn Craton in the Midwest and northern Goldfields regions (i.e. Cooper *et al.* 2008; Guzik *et al.* 2008; Humphreys *et al.* 2009).

3 EXISTING ENVIRONMENT

3.1 INTERIM BIOGEOGRAPHIC REGIONALISATION OF AUSTRALIA

The Interim Biogeographic Regionalisation of Australia (IBRA) defines ‘bioregions’ as large land areas characterised by broad, landscape-scale natural features and environmental processes that influence the functions of entire ecosystems (Department of the Environment 2014b; Thackway & Cresswell 1995). They categorise the large-scale geophysical patterns that occur across the Australian continent that are linked to fauna and flora assemblages and processes at the ecosystem scale (Thackway & Cresswell 1995).

Western Australia contains 26 IBRA bioregions and 53 subregions. The study area is situated on the border to two bioregions; the Gascoyne bioregion and Little Sandy Desert bioregion (Figure 3-1). The study area is situated at the junction of the Augustus subregion (GAS3) of the Gascoyne bioregion and Trainor subregion (LSD2) of the Little Sandy Desert bioregion (Figure 3-1).

The Trainor subregion (LSD2) is characterised by (Cowan & Kendrick 2001):

- red centre desert on Neoproterozoic sedimentary basement (Officer Basin)
- red Quaternary dune fields with abrupt Proterozoic sandstone ranges of Bangemall Basin
- shrub steppe of acacias, *Aluta maisonneuvei* and grevilleas over *Triodia schinzii* on sandy surfaces
- sparse shrub-steppe over *Triodia basedowii* on stony hills
- eucalypt and coolabah communities and bunch grasses on alluvial deposits and drainage lines associated with ranges
- arid climate with episodic summer rainfall.

The Augustus subregion (GAS3) is characterised by (Desmond *et al.* 2001):

- low Proterozoic sedimentary and granite ranges divided by flat broad valleys
- mulga woodland with *Triodia* on shallow stony loams on rises with mulga parkland on shallow earthy loams over hardpan on the plains
- extensive areas of alluvial deposits
- calcrete aquifers of the Carnegie drainage system
- desert climate with bimodal rainfall.

With respect to subterranean fauna, the alluvial deposits and calcrete aquifers as mentioned for, but not limited to, the Augustus subregion are of importance as these geologies are known to support subterranean habitats for both troglofauna and stygofauna (EPA 2016a). The Augustus and Little Sandy Desert bioregions are situated at the north-eastern limit of the Yilgarn Craton, well known for its diverse subterranean fauna (e.g. Cooper *et al.* 2008; Guzik *et al.* 2008; Watts & Humphreys 2001).

Figure 3–1
Location of the Beyondie Potash Project in relation to IBRA regions and subregions

IBRA regions
- Gascoyne
- Little Sandy Desert
- Tenement E69/3309
- Tenement E69/3346
- Tenement E69/3347
- Tenement E69/3351
- Tenement E69/3352
- Study area (all tenements)

0 5 10 20 Kilometres
1:750,000

Client: Kalium Lakes Ltd
Project: Beyondie Potash Project
Author: KW
Date: 06-Jun-17
Coordinate System: GDA 1994 MGA Zone 51
Projection: Transverse Mercator
Datum: GDA 1994

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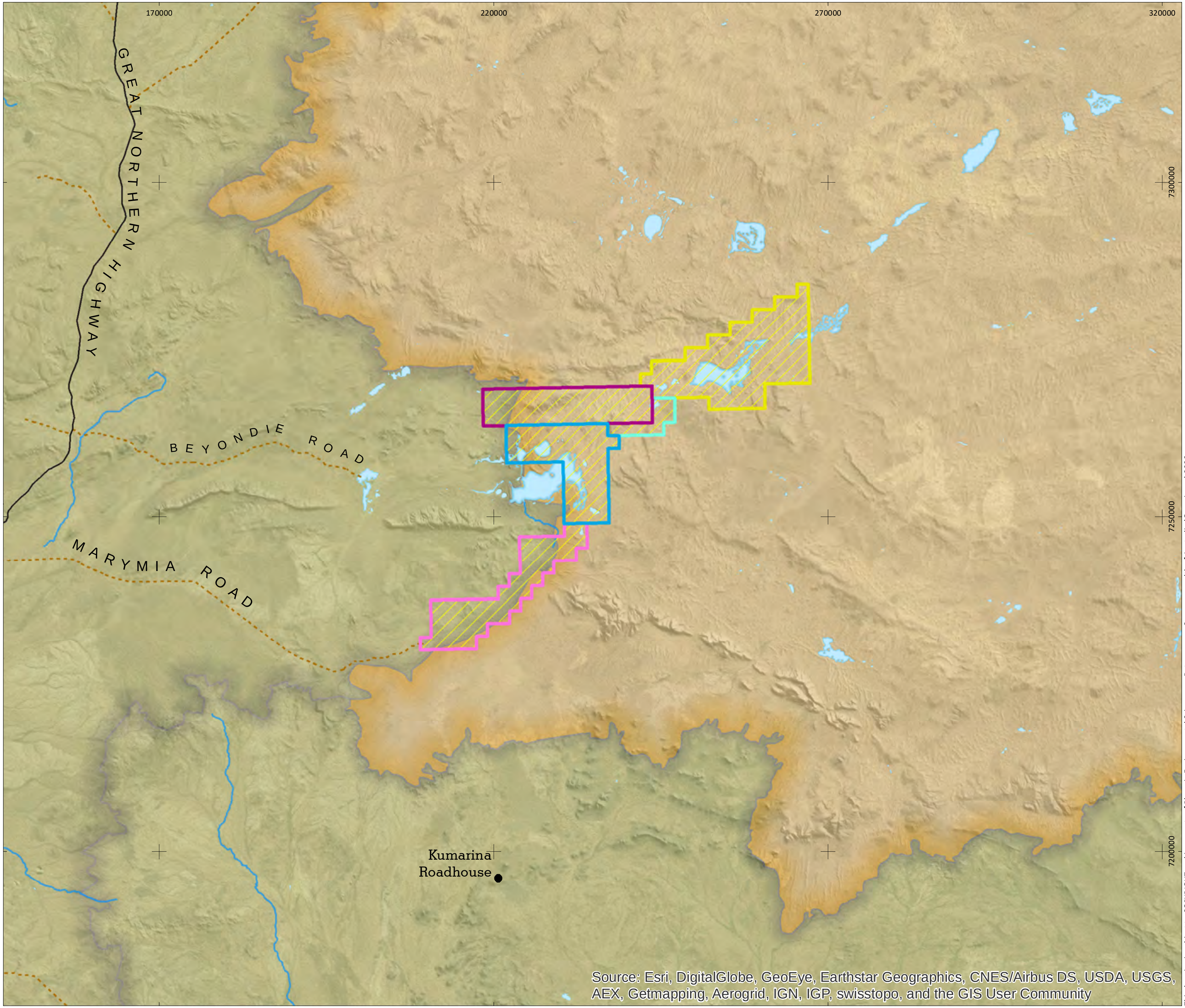


3.2 CLIMATE AND WEATHER

The Gascoyne bioregion has an arid climate with and summer rainfall in the east. Spatially averaged median (1890–2005) rainfall is 202 mm (DEWHA 2008a). The climate of the Little Sandy Desert bioregion is also arid with summer-dominant rainfall. Spatially averaged median (1890–2005) rainfall is 178 mm (DEWHA 2008b). The climate of south-western Little Sandy Desert has also been described as desert tropical with predominant summer rainfall (van Leeuwen 2002).

The nearest Bureau of Meteorology (BOM) weather station with long-term and actual data is Newman Airport (BoM Station 7176; Latitude 23.42°S Longitude 119.80°E), approximately 160 km to the north-west of the study area. Newman records the highest maximum mean monthly temperature (39.1°C) in December and the lowest maximum mean annual temperature (22.8°C) in June. The lowest mean minimum temperature is recorded in July (6.4°C) and the highest in January (24.9°C). Average annual rainfall is 327.7.4 mm with February, January, and March recording the highest monthly averages (71.7, 67.5, and 44.0 mm respectively) (Figure 3-2).

Pan evaporation for the south-western Little Sandy Desert bioregion ranges from 16.1 mm/day in January to 4.5 mm/day in June at an annual daily average of 10.2 mm (van Leeuwen 2002).

The three months prior to the pilot survey recorded overall higher rainfall than average with a total of 359 mm from January to March 2017 providing ideal conditions for subterranean fauna surveys (Figure 3-2). Temperatures were about average in the year preceding the survey, although January 2017 was somewhat colder (Figure 3-2).

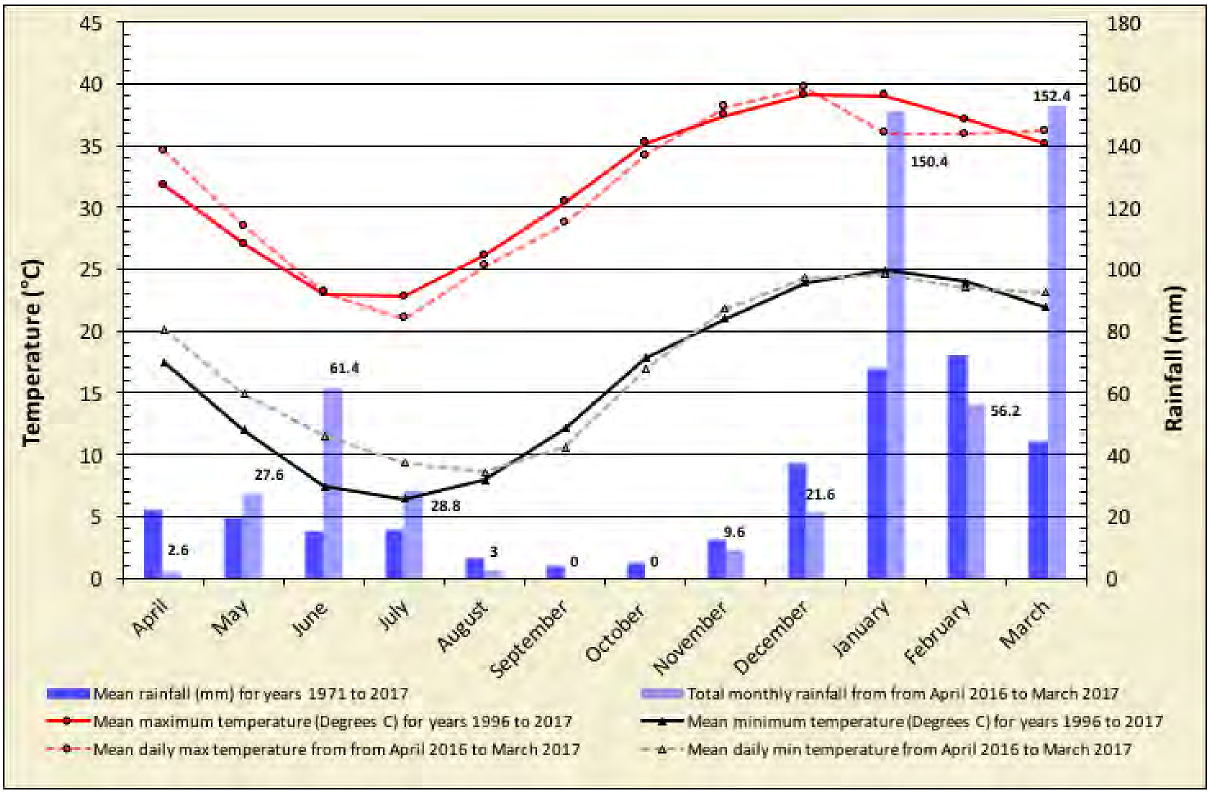


Figure 3-2 Average monthly temperatures and rainfall for Newman (BoM 2017)

3.3 GEOLOGY

The Project is located just off the south-western edge of the Northwest Officer Basin (previously named Savory Basin). Beyondie Lakes and 10 Mile Lake are developed within a palaeochannel system, underlain by bedrock of the Sunbeam Group, consisting mostly of sedimentary sandstones, siltstones, conglomerates and shales (Grey *et al.* 2005).

The formations making up the Sunbeam Group are (Grey *et al.* 2005):

- **Watch Point Formation**: brown to grey, fine- to medium-grained sandstone interbedded with grey to olive-green siltstone and silty sandstone, and brown to blue-grey shale. Some fine-grained sandstone is glauconitic.
- **Coondra Formation**: coarse-grained sandstone interbedded with pebble to boulder conglomerate, in part matrix supported
- **Spearhole Formation**: coarse- to medium-grained sandstone, pebbly sandstone and conglomerate lenses.
- **Mundadjini Formation**: fine- to coarse-grained sandstone, conglomerate, siltstone, minor shale, mudstone, dolomite (some stromatolitic) and evaporites.
- **Skates Hill Formation**: contains dolomite, commonly stromatolitic, medium- to fine-grained sandstone, siltstone, and thick, discontinuous basal conglomerates.
- **Boondawari Formation**: diamictite, fine- to coarse grained sandstone, conglomerate, siltstone, mudstone, dolomitic siltstone, and dolomite, in part stromatolitic.

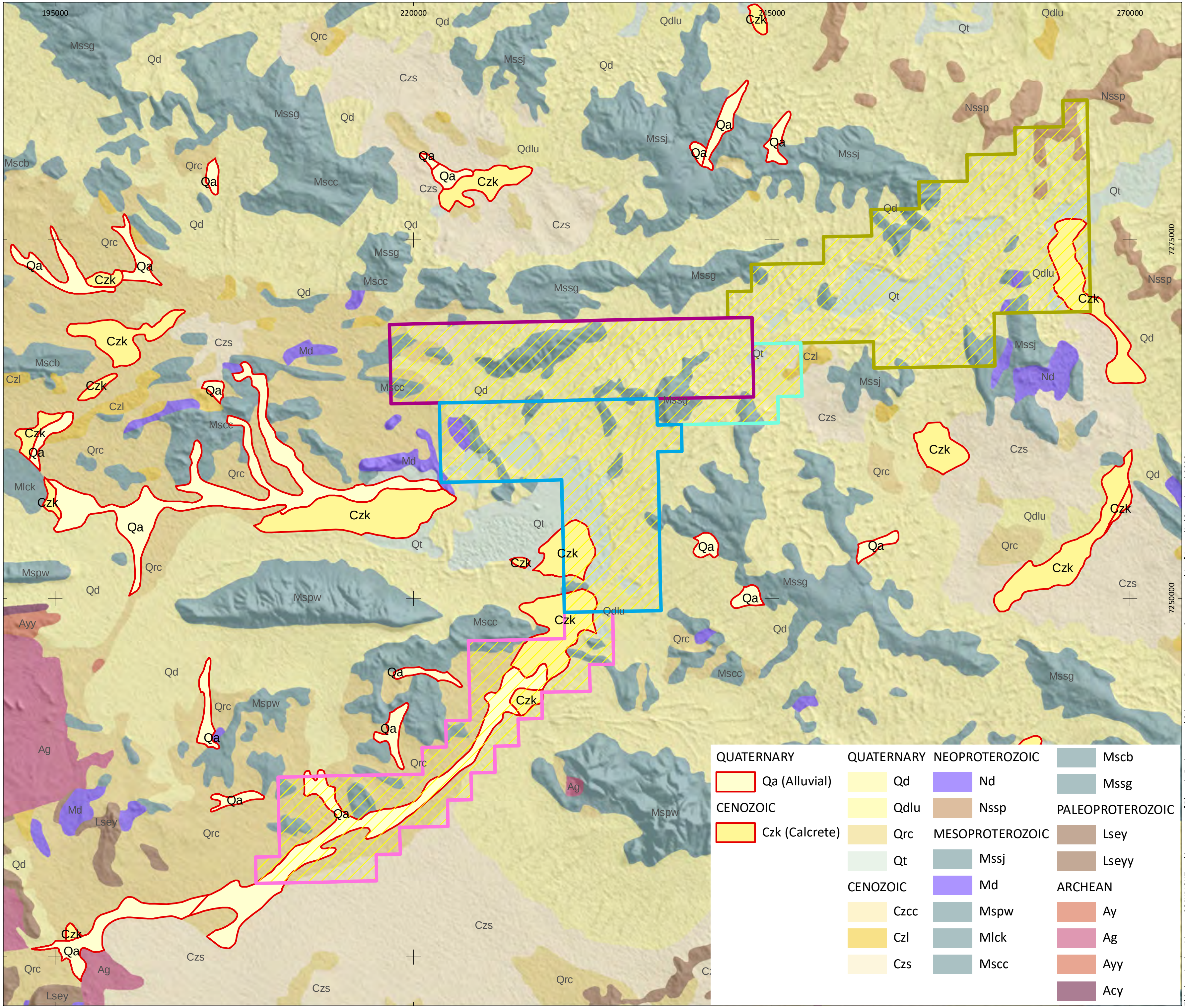
Intruded into the bedrock are dolerite intrusions (dykes and sills – Nd), for example expressed in the north-western part of the study area between the Beyondie freshwater marsh (just outside the study area) and eastern and western salt pan (Figure 3-3). Palaeochannels have been incised into the bedrock. Within the lakes, Quaternary lacustrine deposits (Qt) are mainly clay, mud and silt which are usually saline and commonly gypsiferous. Surrounding the lakes are expanses of Quaternary Aeolian sand and sand sheets (Qd) (Figure 3-3). Longitudinal (seif), chain and net dunes are abundant and there are some areas of ironstone pebble veneer. Two main calcretes (Czk) are present west and south (here fragmented) of 10 Mile Lake consistent with two palaeochannels terminating at the lake system and currently reflected in two surface drainage lines, i.e. Nanyerinny Creek flowing into the Beyondie Lakes from the west and 477 Creek flowing into 10 Mile Lake from the south. However, the western calcrete is outside the study area and almost 5 km to the west of potential test bore locations (Figure 3-3). A further large calcrete body is also present east of Sunshine Lake. Whilst the surface expression of these calcretes has been mapped (Figure 3-3), it is unclear how far these extend into the neighbouring Quaternary deposits. Alluvial deposits (Qa) are generally found in the Nanyerinny Creek and 477 Creek systems (Figure 3-3).

Recent drilling within the palaeochannel systems has identified an upper layer of sands and silts, underlain by 20–40 m of clays, in turn underlain by a basal palaeochannel sand (where present), or solid bedrock (J. Jolly, pers. comm. to V.W. Framenau, 5 August 2015).

The most prospective geologies for subterranean fauna are those of Quaternary alluvials and calcretes as identified in Figure 3-3.

Figure 3–3
Surface geology of the Beyondie Potash Project

- Tenement E69/3309
- Tenement E69/3346
- Tenement E69/3347
- Tenement E69/3351
- Tenement E69/3352
- Study area (all tenements)



0 2.75 5.5 11 Kilometres
1:350,000

Client: Kalium Lakes Ltd
Project: Beyondie Potash Project

Author: KW
Date: 06-Jun-17

Coordinate System: GDA 1994 MGA Zone 51
Projection: Transverse Mercator
Datum: GDA 1994

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3.4 HYDROLOGY

10 Mile Lake is a large salt playa and forms the western end of a chain of ephemeral salt lakes which extend eastwards and include Lake Sunshine, Yanneri Lake and Terminal Lake. This suite of lakes do not hydrologically connect above ground but they form part of the Ilgarari palaeoriver which is a remnant of an extensive river system from the tertiary period (Gentilli 1979). The Ilgarari palaeoriver is a tributary of the Disappointment palaeoriver, that includes Lake Disappointment (Beard 2005). The catchment for Lake Disappointment is largely the Little Sandy Desert bioregion (Beard 2005). These salt lakes are dry most of the year but become seasonally inundated during the wet season if there is sufficient rainfall.

The four main aquifers that exist in the area are (Advisian 2017; AQ2 2016) :

- basal sands in the thalweg of the palaeochannel (target of the resource assessment for SOP production)
- upper unconsolidated sediments in the palaeochannels (<10 m deep); i.e. alluvial (heterogenous, coarse) and lacustrine (gypsiferous, sand, silts, clays) deposits
- areas of saturated calcrete (especially to the west and south of 10 Mile Lake)
- areas of weathered or fractured bedrock.

The relationship between the existing salt lakes (playa lakes) and the palaeochannel is important, as it influences the future abstraction of brine from the palaeochannel system. There are four potential relationships between groundwater flow in the palaeochannels and the playa lake development:

- a groundwater through-flow system, with flow below the lakebed and limited interaction with the playa.
- recharge takes place from the lake to the underlying groundwater system, with limited evaporation taking place and minor development of evaporites.
- groundwater inflow to the lakebed, with evaporation and evaporite minerals development
- groundwater inflow to the lake, with the groundwater table being above the surface of the deepest part of a playa lake, so that groundwater input is constant and subaqueous evaporites accumulate.

In the case of the Beyondie Lakes and 10 Mile Lake, the third case is likely, with flow down the palaeochannel being controlled (on a local playa scale) by evaporative discharge (AQ2 2016). Deflation of exposed lakebeds along palaeovalley results in the lowering of the topographic elevation of lakebeds, thereby effectively bringing the groundwater level closer to the surface, promoting evaporation (AQ2 2016). The evaporative “pumping” increases groundwater discharge at the lake site, thus promoting groundwater flow towards the playa lakes. The evaporative pumping, together with the development of dense brines below the evaporative surface, results in the development of density driven flow circulation of groundwater around the lakes. Evaporation at the phreatic surface increases the brine density causing it to sink through the aquifer.

On a regional scale, it is expected that some downgradient flow of groundwater occurs within the regional palaeochannel system, with the expectation that some of the brines developed below the lakes, will move downgradient away from the lake surface.

The total volume of the groundwater resource in the palaeochannel system of the Beyondie Lakes and 10 Mile Lake, including an area approximately 5 km to the east of 10 Mile Lake, is estimated at 3,940 x 10^6 m^3 (J. Jolly, email to V.W. Framenau, 5 August 2015).

Drawdown experiments suggest that after one year of pumping brine at three bores at 13.5 L/s each, the piezometric level in the basal sand aquifer adjacent to these bores is predicted to be about 32 m, with the cone of depressurisation along the palaeochannel extending to approximately 14 km (AQ2 2016).

Pumping of water from the basal sand aquifer may induce changes in the hydrostatic-heads within the different aquifer horizons and potentially induce flow from adjacent, i.e. sedimentary and calcrete aquifers ((AQ2 2016).

3.5 BIOLOGICAL CONTEXT

Subterranean fauna live within air- or water-filled underground networks. They are predominantly invertebrates. Organisms specialised for living in air-filled subterranean networks are referred to as troglofauna, while those inhabiting water-filled subterranean networks are referred to as stygofauna (Howarth 1983; Humphreys 2000).

Subterranean habitats are perpetually dark, are extremely constant in temperature and humidity (air-filled networks) and very low in nutrients and energy (Howarth 1993). Evolution under such conditions has resulted in much specialised organisms that are restricted to the void networks (Harvey 2002; Holsinger 2000; Howarth 1993; Ponder & Colgan 2002). Such species are obligated to living in subterranean networks and cannot live in epigean (surface) environments.

Organisms specialised to live in subterranean networks are likely to represent short-range endemics (SREs) with extremely limited capabilities of dispersal (Harvey 2002; Ponder & Colgan 2002; Volschenk & Prendini 2008). Short-range endemics are species with naturally small distributions, nominally less than 10,000 km^2, although species restricted to subterranean void systems may have considerably smaller distributions and therefore represent extreme SREs (Harvey 2002). It is these subterranean species that are considered to be of conservation significance because they are at greatest risk of extinction from project developments.

In Western Australia, and particularly in the Pilbara and Midwest region, there has been a recent renaissance in the study of subterranean biodiversity (Humphreys 2008) driven by the growth of the mineral resources industry and mining environmental impact assessment (EPA 2016a, c). However, the biology, diversity and distributions of most of Western Australia’s subterranean fauna are still poorly understood.

3.5.1 Stygofauna

Stygofauna represent the fauna living within subterranean water bodies or aquifers (Humphreys 2000). They typically show similar traits to troglobites in their specialisation to subterranean life, including loss of body pigment, eyes and heightened mechano-sensory systems. Stygofauna can be distinguished by their propensity for subterranean life (Humphreys 2008):

- stygobites — restricted to subterranean habitats and usually perish on exposure to the surface environment
- stygophiles — facultatively use subterranean habitats but are not reliant on them for survival
- stygoxenes — inhabitant of surface water which may also be able to freely move from surface to subterranean systems and back.

Short-range endemic stygofauna are only represented by stygobitic species.

3.5.2 Troglofauna

Troglofauna are typically divided into three categories of specialisation to subterranean life (Barr 1968; Howarth 1983; Humphreys 2000):

- troglobites — restricted to subterranean habitats and usually perish on exposure to the surface environment
- troglophiles — facultatively use subterranean habitats but are not reliant on them for survival
- trogloxenes —use subterranean systems for specific purposes, such as roosts for reproduction (e.g. bats and swiftlets).

Both troglobites and troglophiles may be SREs and are therefore conservation significant.

Stygobites and troglobites are often characterised by specialised adaptations to subterranean life that allows them to exploit the dark, often nutrient-poor subterranean void networks, such as (Howarth 1983, 1993; Humphreys 2000; Poulson & Lavoie 2000):

- lack or reduction of eyes
- elongated limbs, but lack or reduction of wings (for species that are normally winged)
- lack or reduction of body pigmentation
- heightened chemosensory and mechano-sensory systems
- loss of circadian rhythms
- very low metabolic rate.

3.5.3 Threatening processes

Impacts to subterranean fauna can be classed as either:

- **primary impacts** – impacts that physically destroy the subterranean void networks
- **secondary impacts** – impacts that change the subterranean habitat without physically destroying the void networks.

Primary impacts are obvious, whereas secondary impacts tend to be cumulative and may affect a far greater area than that being developed (Hamilton-Smith & Eberhard 2000). There are commonly two key threatening processes from mining activities that impact subterranean fauna through the direct loss of habitat:

- **Development of mine pits** – the most obvious primary impact to subterranean habitats occurs as a result of their physical removal during mining. Troglofauna require air-filled void networks and most of this habitat exists in the overburden, which is typically destroyed during pit construction/excavation. Similarly, direct loss of stygofauna habitat may be caused by the removal of geological formations if any aquifers are associated with these formations.
- **Depletion of an aquifer leading to loss of stygofauna habitat** – depletion of an aquifer that is identified as suitable for stygofauna represents a direct loss of stygofauna habitat. The significance of the impact is dependent on the depth of drawdown, the size and extent of the aquifer and the connectivity of the aquifer with adjacent habitat for stygofauna.

Secondary impacts are those that affect the physicochemical properties of subterranean habitats. The nature of these changes can be difficult to measure and there is limited empirical evidence to support or refute these putative impacts. There are four secondary impacts that may be relevant to the Project:

- **Depletion of an aquifer leading to altered relative humidity** – troglofauna are dependent on high relative humidity (Barr 1968; Humphreys 1991; Humphreys 2000). Dewatering may impact troglofauna habitat in unsaturated strata above the water table by lowering relative humidity.
- **Nutrient starvation** – surface vegetation is the primary source of nutrients entering subterranean systems. Large-scale clearing of vegetation may result in the localised nutrient starvation of underlying subterranean habitat. Smothering of these nutrient sources on which subterranean systems depend, in the form of waste and overburden stockpiles and tailings ponds, may reduce inflow of nutrients to subterranean systems and lead to nutrient deficient habitats (Howarth 1993; Humphreys 2000; Poulson & Lavoie 2000).
- **Vibration** – shock waves through subterranean strata from blasting or heavy vehicle traffic may result in the collapse of less-consolidated void spaces and also impact physically on subterranean fauna. There is little data to challenge or corroborate these observations and impacts may generally be localised rather than critically threatening.
- **Contamination:** contamination of subterranean habitats from spills, such as diesel fuel, may degrade the quality of subterranean habitats. Such impacts would generally be highly localised and minor in scale; however, major contamination of subterranean habitats may have significant impacts.

3.5.4 Calcretes as subterranean fauna habitat

In Western Australia, the types of geology known to support stygofauna include calcretes, alluvial formations particularly when associated with alluvial or palaeochannel aquifers, fractured rock aquifers and karst limestone; troglofauna are likely to be present in karst, channel iron deposits (CID), banded iron formations (BIF), alluvium/colluviums in valley-fill areas, and weathered or fractured sandstone (EPA 2016a). Of these, calcretes are most prominent within the study area (Figure 3-3).

Calcretes are carbonate deposits that formed near the water table in arid lands as a result of concentration processes by near-surface evaporation. The calcretes are mainly associated with the palaeodrainage channels of the Pilbara and Yilgarn cratons and their associated orogens which together form the Western Shield of Australia (Beard 1998). Calcrete deposits of the Yilgarn region of central Western Australia are believed to have formed from the groundwater flow between 30–10 Mya when continued aridity produced salt lakes, extensive alluvial fans and dunes which assisted in fragmenting the river valleys into isolated ponds (Morgan 1993). In the northern river valleys of the Western Shield calcretes concentrated on the upstream side of the salt lakes (Morgan 1993).

Over 200 major calcretes are found in the Yilgarn and they provide habitat for a diversity of subterranean fauna (both stygo- and troglofauna), such as diving beetles (Dytiscidae) and a variety of crustaceans, including amphipods (Amphipoda), slaters (Isopoda), syncarids (Bathynellacea) and copepods (Copepoda) (Bradford *et al.* 2013; Cooper *et al.* 2008; Guzik *et al.* 2008; Humphreys 2001; Javidkar *et al.* 2015; Javidkar *et al.* 2016; Javidkar *et al.* 2017; Watts & Humphreys 2004). The calcretes are generally shallow (approximately up to 10 m deep), but may reach depths of up to 30 m (Humphreys *et al.* 2009).

The calcretes of the Western Shield that occur near salt lakes have recently been flagged as 'groundwater estuaries' of potentially high biodiversity value (Humphreys *et al.* 2009). Their groundwater profiles can be compared to the anchialine systems near ocean estuaries, where saline water intrudes under the freshwater fan of the river mouth. The complex interplay of fresh and saline water creates steep biogeochemical gradients to potentially support cascades of microbiological and micro- and macroinvertebrate communities (Humphreys *et al.* 2009).

The high endemicity of the groundwater stygofauna of calcrete deposits in the Yilgarn Craton has resulted in the listing of 77 Priority Ecological Communities for the Midwest and the Goldfields regions of Western Australia (DPaW 2016b) (Appendix 3).

3.5.5 Salinity

Globally, stygofauna are generally restricted to freshwater and rarely occur in mildly brackish waters, except in the special case of anchialine ecosystems (Bradbury & Williams 1996b; Humphreys 1999). However, the Western Shield of contains a diverse assemblage of near-marine and ancient freshwater lineages inhabiting groundwater with salinity values that may reach marine conditions (Humphreys 2008). At Lake Way, Watts and Humphreys (2004) recorded a diverse stygal assemblage in a bore with surface salinity near seawater (30,000 mg/L) and a strong salinity gradient increasing to 69,000 mg/L at 6 m depth. The finer scale vertical distribution of stygofauna inhabiting groundwater in Western Australia, which may be strongly stratified with steep gradients in salinity at micro/meso-scales, remains largely unknown (Humphreys *et al.* 2009; Subterranean Ecology 2010b).

4 METHODS

4.1 DESKTOP REVIEW

This assessment followed EPA guidelines which state that desktop reviews for subterranean fauna should (EPA 2016a):

- search regional and project/site specific habitat data, including geological and hydrological information, previous studies of the area (published and unpublished), site photographs and databases including fauna records
- place the project area into a regional context
- make conclusions about whether the area is likely to provide habitat for subterranean fauna and consider impacts of the proposal.

4.1.1 Database searches

Database searches and literature reviews of relevant publications were undertaken to compile a list of conservation significant subterranean species that may occur within the study area based on the proximity of previous records.

The following database searches were undertaken for a quadrat of approximate 100 km length with the diagonal coordinates of -24.31222°S, 119.78444°E (NW point) and -25.23472°S, 120.7808°E (SE point):

- EPBC Act Protected Matters Search Tool (Department of the Environment 2015)
- DPaW/WA Museum NatureMap (DPaW 2015a)
- DPaW Threatened Flora, Fauna and Ecological Communities databases (DPaW 2015c).

In addition, the WA Museum Arachnology/Myriapodology, Crustacea and Mollusca databases were undertaken for a quadrat of approximate 200 km length, consistent with the nominal range of short-range endemic invertebrates (EPA 2016d), with the diagonal coordinates of -23.86°S, 119.30°E (NW point) and -25.67°S, 121.27°E (SE point).

4.1.2 Literature review

A number of subterranean fauna surveys or desktop reviews in the vicinity of salt lakes were consulted to provide context of biodiversity for large inland salt lakes in Western Australia, including Lake Disappointment, Lake Way and Lake Lefroy (Table 4-1). It is recognised that these lakes are in considerable distance from the study area; however, any salt lake in the state can provide background data to interpret the results from the survey in the study area. All of these salt lakes are also under some impact from mining activities.

Table 4-1 Selected aquatic invertebrate surveys of salt lakes in Western Australia

Project	Author	Remarks
Lake Way	Toro Energy (2011, 2012)	Closest to study area and similar geology (calcrete near salt lakes), very comprehensive survey program over a number of years
Lake Disappointment	Phoenix (2014)	Subterranean desktop assessment only
Lake Lefroy	Subterranean Ecology (2010a, b)	Separate troglofauna and stygofauna assessments

4.2 FIELD SURVEY

4.2.1 Survey

A total for 15 bores were surveyed for subterranean fauna including seven within the exploration tenements and eight regional reference sites (Table 4-2;

Figure 4-1) between 29–31 March 2017.

Table 4-2 Location and details of bores sampled during field survey

Bore	Latitude (GDA94)	Longitude (GDA94)	Depth (m)	Depth to water (m)
David's Well	-25.030062	120.007066	21	6
No.77 East Well	-24.975719	120.189032	10	1
Broken Leg Bore	-24.997021	120.056049	42	16
Garden Well	-24.782386	120.061737	22	11
Beyondie Bore	-24.782565	120.043510	24	11
Tupee Well	-24.660603	120.054702	13	9
12 Mile Well	-24.731820	120.224108	11	5
Unnamed Bore	-24.769961	120.111655	20	4
WM05MBS	-24.732438	120.326538	53	3
WB14 (= Beyondie West)	-24.784564	120.036625	>100	11
WB25	-24.767690	120.384670	29	7
WB09MB5	-24.792840	120.333731	31	3
TMAC23	-24.809518	120.338262	12	3
WB12MB1	-24.796494	120.367315	34	1
WB10TB1	-24.766475	120.363892	74	7

Figure 4-1
Location of bores sampled during field survey

- ● Bores
- Tenement E69/3309
- Tenement E69/3346
- Tenement E69/3347
- Tenement E69/3351
- Tenement E69/3352
- Study area (all tenements)

0 2.75 5.5 11 Kilometres
1:350,000

Client: Kalium Lakes Ltd
Project: Beyondie Potash Project

Author: KW
Date: 06-Jun-17

Coordinate System: GDA 1994 MGA Zone 51
Projection: Transverse Mercator
Datum: GDA 1994

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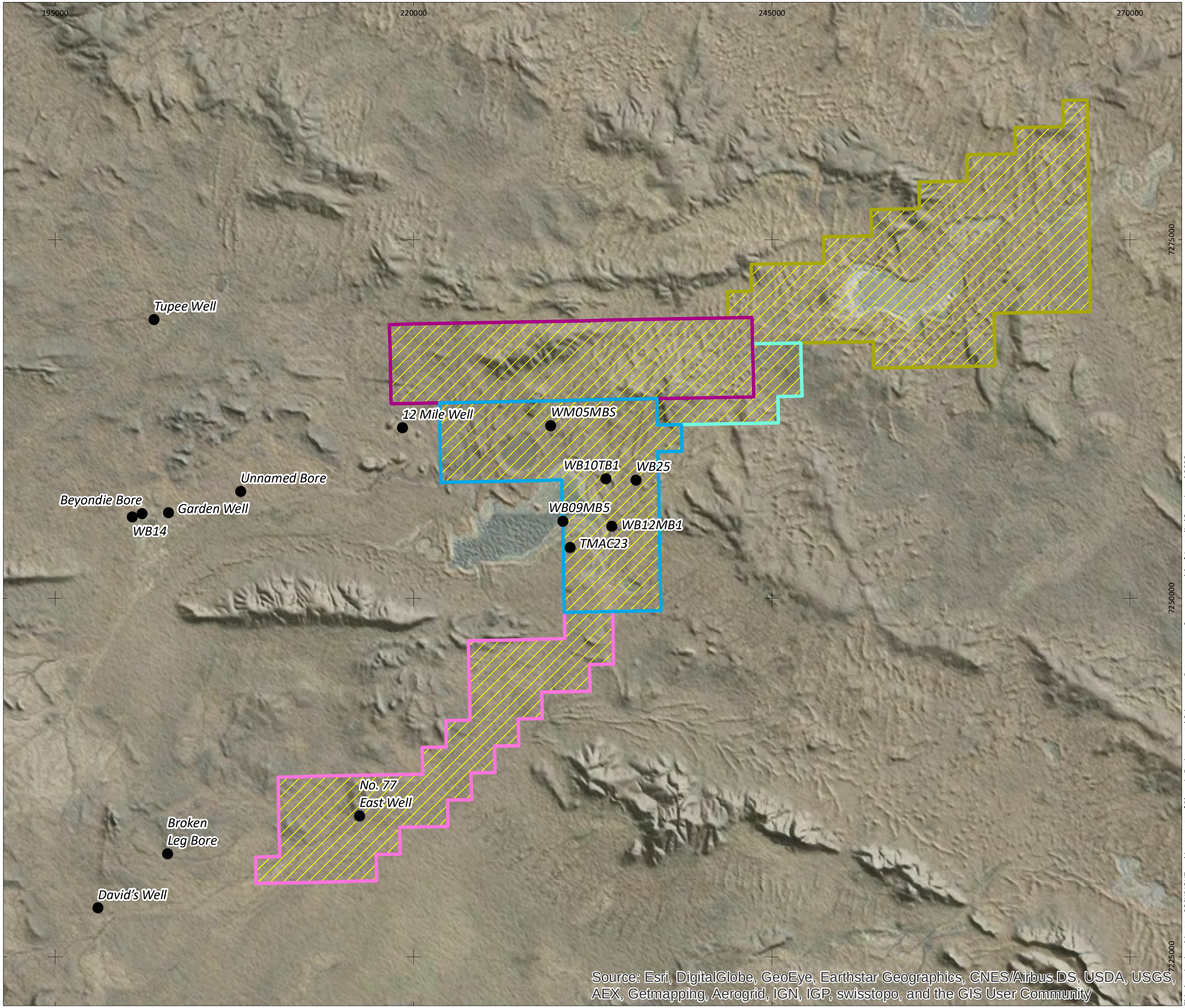

4.2.2 Fauna sampling

The subterranean fauna survey was conducted using six stygofauna hauls, three with a 250 µm and three with a 50 µm weighted nets (diameter 90 mm). After the net was lowered to the bottom of each bore, it was used to briefly stir up sediments and their benthic inhabitants. All nets were equipped with nylon 'ticklers' to collect any troglofauna animals moving along the sides of the bores. The nets were scraped back up the bore wall with each scrape covering a different part of the bore wall.

After each haul/scrape, the strained content was rinsed into a 120 ml plastic vial by squirting 100% ethanol down the sides of the net and around the rim of the weight, washing the sample contents into the vial. If not already full, the sample vial was topped up with 100% ethanol.

The net was thoroughly rinsed in freshwater after each sample to avoid cross-contamination of samples.

At conclusion of the survey, samples were stored in a refrigerator in the laboratory, where they were sorted and specimens identified using high-magnification stereo-microscopes.

4.2.3 Bore and water quality data

At each bore, depth and depth to groundwater were measured (see Table 4-2). Water quality parameters were measured in-situ with a YSP multiprobe in a water sample bailed up from the bore and included:

- temperature (°C)
- dissolved Oxygen (%)
- dissolved Oxygen (mg/L)
- conductivity (µs/cm)
- salinity (ppt)
- pH
- oxygen reduction potential (mV).

4.2.4 Morphological species identifications

Phoenix has considerable in-house expertise in the identification of SRE target groups. Senior staff involved in identifications are also Research Associates with a longstanding taxonomic research history at the WA Museum. For some groups, eternal experts were consulted (Table 4-3).

4.2.5 Molecular identifications

The identification of species based on comparisons between DNA sequences is referred to as DNA barcoding and is an expected idenfication tool in survey of subterranean fauna (EPA 2016a). Any gene can be used for barcoding purposes; however, the primary gene targeted by researchers is Cytochrome Oxidase Subunit I (COI) (Hebert *et al.* 2003).

Molecular identifications were conducted by staff of Helix Molecular Solutions, based at the School of Biological Sciences, University of Western Australia (Table 4-3).

4.3 PROJECT PERSONNEL

The personnel involved in the survey are presented (Table 4-3).

Table 4-3 Project team

Name	Qualifications	Role/s
Dr Volker Framenau	B.Eng. (Chem. Eng.), M.Sc. (Cons. Biol.), Ph.D. (Zool.)	Project manager, taxonomy (Araneae, Hemiptera), report writing
Mr Jarrad Clark	B.Sc. (Env. Sci.)	Field survey
Ms Karen Crews	B.Sc. (Env. Sci.) (Hons)	Report review
Mrs Kathryn Wyatt	BIS. (GIS), Grad. Cert. (GIS)	GIS
Ms Jane McRae[1]		Taxonomy (Copepoda, Cladocera, Conchostraca)
Ms Yvette Hitchen[2]		Molecular analyses (laboratory)
Dr Terrie Finston[2]		Molecular analyses (analyses, report writing)

1 – Bennelongia; 2 – Helix Molecular Solutions

5 RESULTS

5.1 DESKTOP REVIEW

5.1.1 Database searches

The database searches did not return any subterranean records from the study area, but returned seven species of stygofauna in three orders of crustaceans (Bathynellacea, Cyclopoidea, Podocopida) from within approximately 100 km of the Project (Table 5-1; Figure 5-1). Three of these species are currently known from single localities and the remaining four species are known to be widespread (see section 5.2).

No troglofauna records were returned in the database searches.

5.1.2 Threatened and priority species or ecological communities

No Western Australian subterranean fauna or ecological communities are listed as matters of NES (Department of the Environment 2014a).

No Threatened or Priority subterranean fauna species or ecological communities are listed from the Little Sandy Desert (DPaW 2016a, b, 2017) (see also Appendices 1–3). A large number of subterranean stygofauna communities are listed as PECs from calcretes of the Yilgarn Craton; however, none of these occur in the Little Sandy Desert.

5.1.3 Literature review

Stygofauna and troglofauna were recorded for the Wiluna Uranium Project situated at Lake Way, a large inland salt lake in the Murchison region of WA approximately 230 km south-west of the study area Toro Energy (2011, 2012). At least 67 stygofauna but only up to 20 troglofauna species were recorded from the surveys encompassing the Hinkler Well, Lake Violet and Uramurdah calcretes groundwater systems, all listed as Priority Ecological Communities (DPaW 2015b). The salinity levels in the upper strata of the bores where some of these species were recorded were up to 141,200 µS/cm (hypersaline). A number of the species recorded were found in more than one calcrete system challenging the notion that calcretes are isolates subterranean islands. No subterranean samples were collected from the playa of Lake Way.

A subterranean desktop study for a proposed Potash mine at Lake Disappointment (280 km north-east of the study area) concluded that there was low likelihood of subterranean fauna to be present under the lake playa due to high salinity levels and low porosity lacustrine sediments (Phoenix 2014). However, calcrete formations to the west of Lake Disappointment were considered as subterranean fauna habitat and surveys were recommended if these calcretes were likely to be affected by the development.

Detailed desktop studies for subterranean fauna at Lake Lefroy identified variable likelihoods of stygo- and troglofauna to occur based on geology (porosity/permeability of the sediment) and, for stygofauna, salinity (Subterranean Ecology 2010a, b). Overall, the likelihood of stygofauna (Subterranean Ecology 2010a) or troglofauna (Subterranean Ecology 2010a) to occur was low; however, the Goldfields region lacks the calcrete deposits typical for the Yilgarn.

Table 5-1 Subterranean fauna recorded in the desktop review

Family	Genus and species	Troglofauna/ stygofauna	SRE rating	Locality	Latitude (GDA94)	Longitude (GDA94)
Syncarida – Bathynellacea						
Parabathynellidae	*Billibathynella ilgarariensis*	Stygofauna	SRE	Bulloo Downs Station, Ilgarari Creek, Yanneri Well	-24.439444	119.7575
	Brevisomabathynella magna	Stygofauna	SRE	Cunyu Station, Sweetwaters Well, Nabberu Palaeodrainage	-25.610556	120.3725
Copepoda – Cyclopoidea						
Cyclopidae	*Pilbaracyclops frustratio*	Stygofauna	SRE	Yanneri Well, Bulloo Downs Station, Ilgarari Creek, Lake Disappointment	-24.439722	119.7575
	Mesocyclops brooksi	Stygofauna/ stygophile	Widespread	No. 37 Government Well, Bulloo Downs Station, Ilgarari Creek	-24.313611	119.6975
				Well (Site 31), Bulloo Downs Station, Ilgarari Creek	-24.327778	119.672778
				Old Ilgarari Well, Bulloo Downs Station, Ilgarari Creek	-24.334167	119.68
	Microcyclops varicans	Stygofauna	Widespread	No. 37 Government Well, Bulloo Downs Station, Ilgarari Creek	24.313611	119.6975
Ostracoda – Podocopida						
Candonidae	*Deminutiocandona quasimica*	Stygofauna	Widespread	Bulloo Well, Bds001, Pilbara Region	-24.008333	119.575
Cyprididae	*Cyprinotus cingalensis*	Stygofauna/ surface	Widespread	Government Well #40, Savory 2, Pilbara Region	-23.863611	120.150667

Figure 5-1
Subterranean fauna records from the desktop review

Desktop records

- SRE
- Widespread
- Tenement E69/3309
- Tenement E69/3346
- Tenement E69/3347
- Tenement E69/3351
- Tenement E69/3352
- Study area (all tenements)

0 5 10 20 Kilometres
1:1,100,000

Client: Kalium Lakes Ltd
Project: Beyondie Potash Project

Author: KW
Date: 06-Jun-17

Coordinate System: GDA 1994 MGA Zone 51
Projection: Transverse Mercator
Datum: GDA 1994

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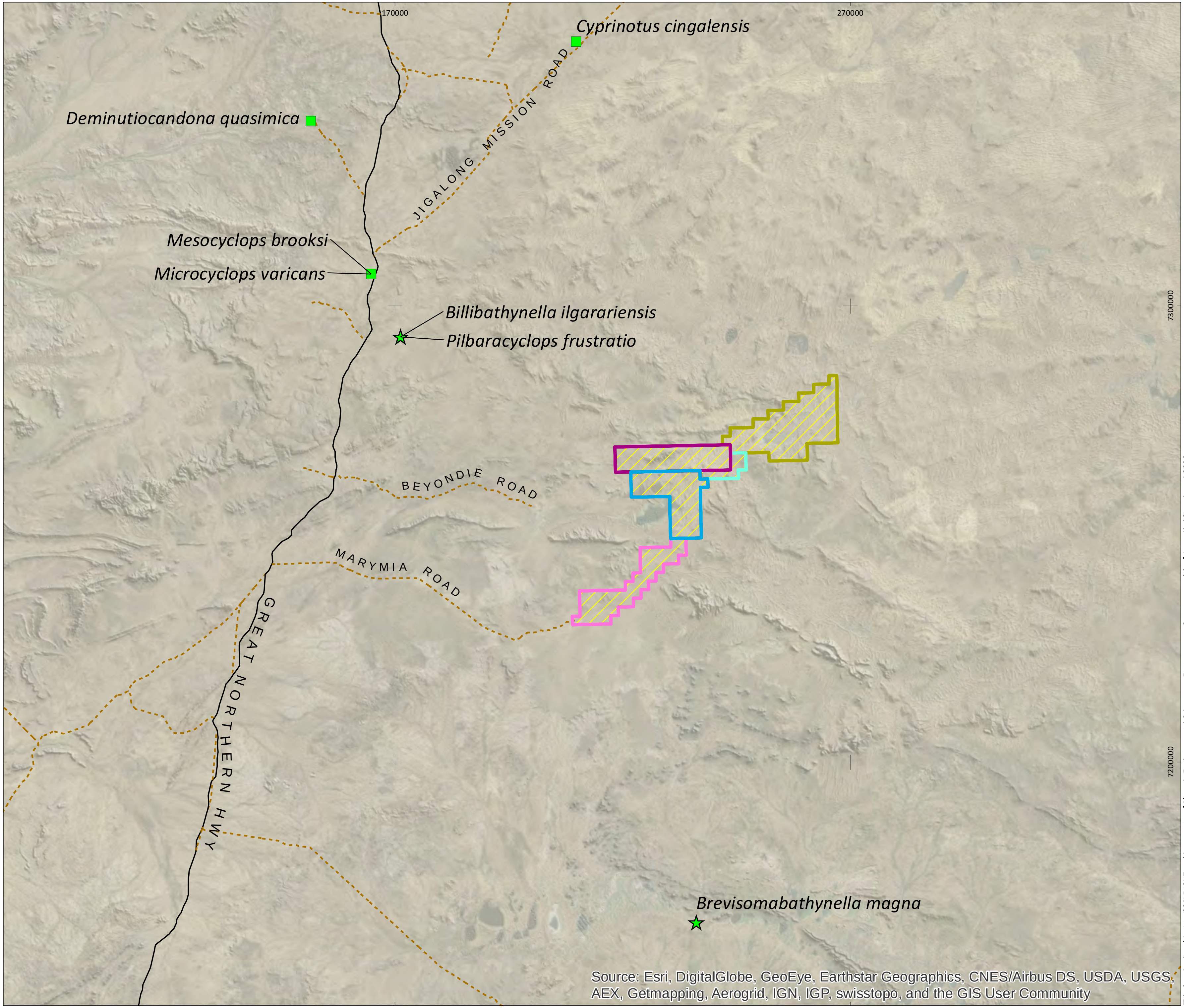

5.2 FIELD SURVEY

5.2.1 Water quality

Water quality parameters varied greatly between bores, in particular with respect to salinity

Table 5-2). Five bores had freshwater, four were subsaline, one hyposaline, one mesosaline and four contained hypersaline water. Water in most bores was slight alkaline, with the exception of Broken Leg Bore, which was very slightly acidic

Table 5-2).

Table 5-2 Water quality data for sampled bores

Bore	Temperature (°C)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Conductivity (µs/cm)	Salinity (ppt)	pH	Oxygen Reduction Potential (mV)
David's Well	28.5	80.6	5.7	724	0.34	7.37	131
No. 77 East Well	24.3	10	0.74	149.9	0.07	8.32	113.2
Broken Leg Bore	27.3	5	0.34	1,016	0.48	6.97	-166
Garden Well	25.5	54	4.16	804	0.38	7.5	23.8
Beyondie Bore	26.1	34.7	2.52	577	0.27	7.87	47.4
Tupee Well	26.1	14.3	1.06	5,980	3.0	7.51	110
12 Mile Well	28.8	89.2	6.21	3,238	1.62	7.92	82
Unnamed Bore	28.2	24.7	1.79	3,257	1.63	7.49	89.7
WM05MBS	28.8	26.6	1.34	95,128	65.45	6.83	197
WB14 (= Beyondie West)	26.4	59.6	4.52	1,593	0.77	8.22	91.7
WB25	27.3	20.4	1.37	26,650	15.62	7.35	137.7
WB09MBS	26	6.4	0.31	96,105	66.25	7.26	170.7
TMAC23	27.1	32.8	2.3	11,061	6.01	7.84	103.9
WB12MB1	28.5	9.2	0.35	144,185	108.47	7.06	149.7
WB10TB1	27.6	15.8	0.51	150,500	114.51	7.71	134.8

1 – Salinity (Hammer 1986): <0.5 – freshwater; 0.5–3 ppt – subsaline; 3–20 ppt – hyposaline; 20–50 ppt – mesosaline; >50 ppt - hypersaline

5.2.2 Subterranean fauna

A total of 17 specimens of potential troglofauna where collected, but only an unidentified spider from Garden Well and a meenoplid bug from David's Well are here considered to be troglobitic (Table 5-3). The reminder, mites and springtails, potentially belong to the edaphic (soil) fauna and are not further considered here.

Table 5-3 Potential troglofauna fauna collected during field survey

Higher order	Genus and species	No. of specimens	Bores	Ecotype
Acari (mites)				
Acari fam. indet.	Acari sp. indet.	13	Garden Well, Broken Leg, W12MBI	Troglophiles/edaphic; not considered in subterranean studies
Araneae (spiders)				
Araneomorphae fam. indet.	Araneomorphae sp. indet.	1	Garden Well	**Troglobitic**; poor condition, family identification not possible
Hemiptera (bugs)				
Meenoplidae	Meenoplidae sp. indet.	1	David's Well	**Troglobitic**; immature larvae
Collembola (springtails)				
Collembola fam. indet.	Collembola sp. indet	2	Beyondie Bore, WB09MDB	Troglophiles/edaphic; not considered in subterranean studies

A total of 11 taxa of potential stygofauna were recorded from the field survey, some in considerable numbers (Table 5-4). Only two of the aquatic invertebrates are considered stygobites, paramelitid amphipods from Garden Well and Tupee, and syncarid crustaceans (order Bathenallacea) from Garden Well. The copepod *Mesocyclops brooksi* has initially been described from groundwater, but has subsequently been found mainly in wells and is now considered a stygophile rather than a stygobite (Karanovic 2006).

All other aquatic organisms are widespread and often found in surface lentic (still water) systems (Table 5-4).

Table 5-4 Potential stygofauna fauna collected during field survey

Higher order	Genus and species	No. of specimens	Bores	Ecotype
Amphipoda (amphipods)				
Amphipoda fam. indet.	Paramelitidae sp. indet.	8	Garden Well, Tupee	**Stygobitic**; molecular analyses pending
Syncarida (syncarids)				
Bathynellacea fam. indet.	Bathynellacea sp. indet.	6	Garden Well	**Stygobitic**; molecular analyses pending
Cladocera (water fleas)				
Daphniidae	*Ceriodaphnia quadrungula* s. l.	>100	No 77 East Well	Surface
Macrothricidae	*Macrrothrix capensis*	1	Beyondie Bore	Surface
Moinidae	*Moina micrura* s. l.	>100	No. 77 East Well	Surface
Conchostraca				
Leptestheriidae	*Leptestheria* 'B01'	6	No. 77 East Well	Surface
Copepoda				
Cyclopidae	*Mesocyclops brooksi*	>100	Beyondie Bore, No. 77 East Well	**Stygophile**; widespread
	Mesocyclops sp. indet.	2	No. 77 East Well, Tupee	Unknown; immature specimens
	Thermocyclops decipiens	>100	Beyondie Bore, No. 77 East Well	Surface; widespread
Diptera (flies)				
Chironomidae	Chironomidae sp. indet.	1	Beyondie Bore	Surface; not further identified as irrelevant to study
Oligochaeta (worms)				
Oligochaeta fam. indet.	Oligochaeta sp. indet.	2	Broken Leg	Unknown

Figure 5-2
Subterranean fauna collected during field survey

- Stygofauna records
- Troglofauna records
- Tenement E69/3309
- Tenement E69/3346
- Tenement E69/3347
- Tenement E69/3351
- Tenement E69/3352
- Study area (all tenements)

0 2.75 5.5 11 Kilometres
1:350,000

Client: Kalium Lakes Ltd
Project: Beyondie Potash Project

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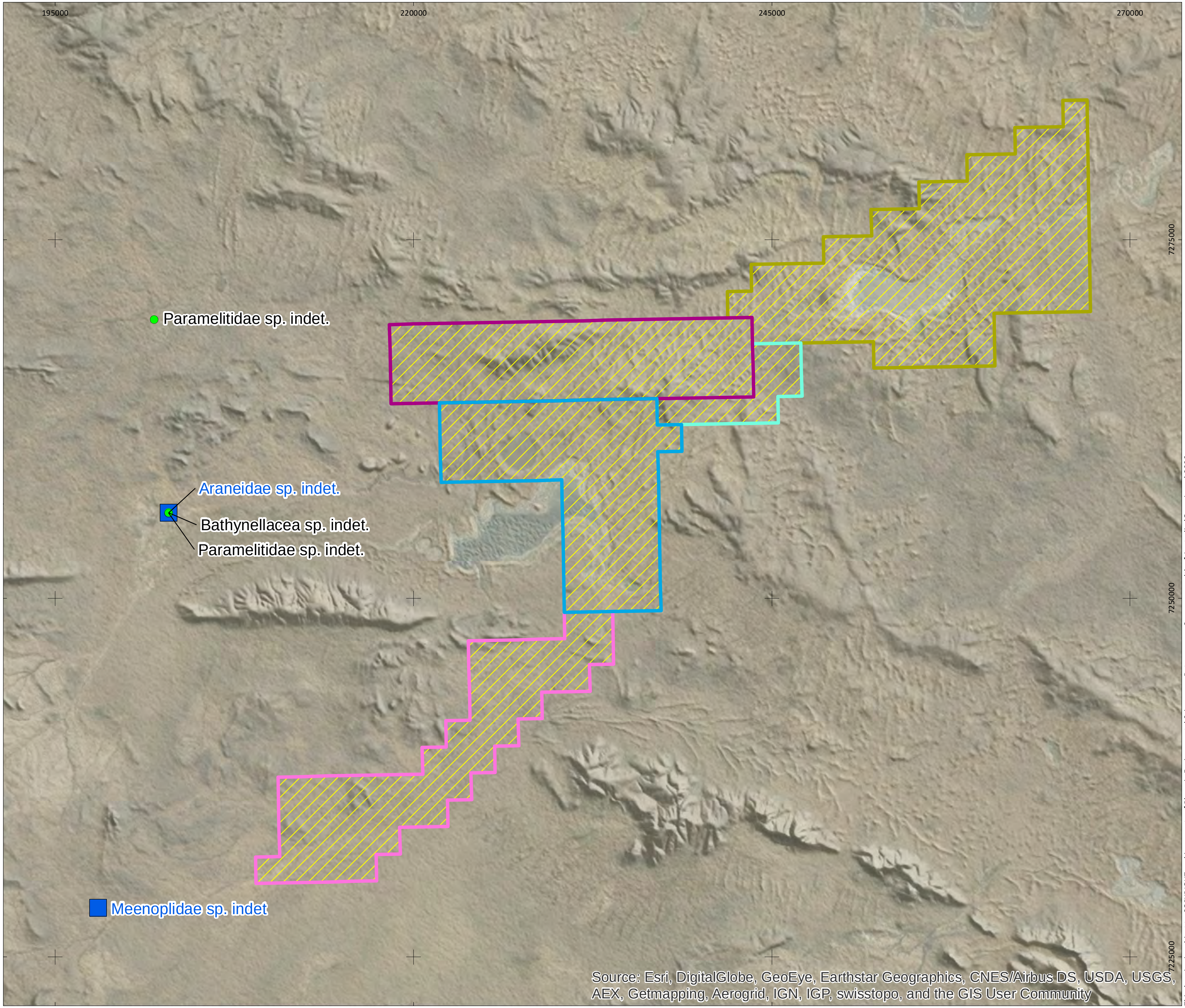

5.2.3 Subterranean fauna

5.2.3.1 Araneae (spiders)

Spiders include a considerable number of subterranean forms in a number of families, in Australia represented by, amongst others, Trochanteriidae (Platnick 2008), Oonopidae (Baehr *et al.* 2012), Tetrablemmidae (Burger *et al.* 2010), Symphytognathidae (Harvey 2001b), Gnaphosidae (Phoenix, unpublished data) and others (Harvey *et al.* 1993). Currently, all known species of troglobitic spiders have a very narrow distribution and are often known from single bores or caves.

A poorly preserved, likely troglobitic small juvenile spider was recovered from Garden Well and is here considered to represent a troglobitic form due to colouration and lack of eyes (Table 5-3). It mostly resembles a symphytognathid spider, but accurate identification even at family level is not possible.

5.2.3.2 Hemiptera (bugs)

A single specimen of immature Meenoplidae was collected at David's Well (Table 5-3). It was classified as troglofauna as it is eyeless and troglobitic forms in the family are known from Western Australia (Hoch 1993). However, the life cycles of species in the family are poorly known and it is possible that eyeless larvae have surface dispersal stages (Bennelongia 2012). The specimen was found in considerable distance south-west of 10 Mile Lake at a reference bore and is not considered for the impact assessment of the Project.

5.2.3.3 Amphipoda (amphipods)

There is a considerable diversity of subterranean amphipods world-wide (Holsinger 1993). The Western Australian fauna includes members of a number of families, such as Melitidae, Neoniphargidae, Paramelitidae, Bogidiellidae and others (Bradbury 2002; Bradbury & Williams 1997). Calcrete aquifers of the Yilgarn host a highly diverse amphipod fauna within the Hyalidae and Paramelitidae (Cooper *et al.* 2007).

Stygobitic amphipods in the family Paramelitidae were collected from Garden Well and Tupee Bore (Table 5-4). They were submitted for molecular analyses (results pending). It is not clear if they represent the same species which would suggest a connection of the underlying alluvial aquifer of both bores.

5.2.3.4 Syncarida (syncarids)

Syncarid crustaceans are often confined to subterranean environments. They are considered rare and difficult to collect and therefore very little is known about the biology and relationships (Abrams *et al.* 2013). They are regularly collected in calcretes of the Yilgarn and Pilbara cratons (Cho & Humphreys 2010; Guzik *et al.* 2008).

Two parabathynellids were recorded in the desktop review, *Billibathynella ilgarariensis* and *Brevisobathynella magna* (Table 5-1; Figure 5-1). Both are currently only known only known from type localities, ca. 65 km north-west and approximately 95 km south of the study area (Figure 5-1) (Cho & Humphreys 2010; Hong & Cho 2009).

Six specimens of syncarids were collected from Garden Well. A subsample was submitted for molecular analysis, but results and therefore genus- and species-level identification are still pending.

5.2.3.5 Copepoda (copepods)

Copepods are microscopic teardrop-shaped crustaceans that are common in freshwater and saline wetlands (Maly *et al.* 1997; Stoch 2001). The also from a considerable element of subterranean stygofauna in Western Australia (Karanovic 2006).

Three subterranean species of copepods were identified in the desktop review, including one species only known from a single locality, *Pilbaracyclops frustratio* from approximately 65 km north-west of the study area (Table 5-1; Figure 5-1).

Only one of the copepod species identified from the desktop review was collected during the field survey, *Mesocyclops brooksi*. This species was described from ground waters of the Cape Range karsts (Pesce *et al.* 1996), but records have been forthcoming from the south-west of WA and interstate (Karanovic 2006). The species is considered a stygophiles rather than stygobite due to its common presence in open wells rather than bores (Karanovic 2006). The species were collected at Beyondie Bore and No. 77 East Well (Table 5-1; Figure 5-1).

5.3 SURVEY LIMITATIONS

The EPA *Technical Guide: Terrestrial fauna surveys* (EPA 2016e) identifies potential limitations that may be encountered during terrestrial fauna surveys. These were applied here as no equivalent guidance with respect to subterranean fauna exists (Table 5-5). With respect to this survey, limited contextual information from around the study area was identified as main limitation.

Table 5-5 Survey limitations based on EPA Technical Guide: Terrestrial fauna surveys (EPA 2016e)

Limitations	Limitation for this survey?	Comments
Competency/experience of survey personnel, including taxonomy	No	The field and laboratory teams and report authors have extensive experience in survey of subterranean systems in WA. Taxonomically poorly known groups were identified by molecular methods.
Scope and completeness - were all planned survey methods implemented successfully, was the study area fully surveyed	No	Suitable collecting methods were used based on comparable surveys in WA and consistent with subterranean pilot surveys conducted in WA.
Intensity - in retrospect, was the intensity adequate	No	The survey intensity of 15 bores was appropriate for a pilot subterranean fauna survey within the study area.
Proportion of fauna identified, recorded and/or collected.	No	Fauna specimens collected match geological and hydrological conditions (i.e. no stygofauna in hypersaline water). All fauna specimens were identified to lowest possible taxonomic level.
Availability of adequate contextual information	Yes	There is good regional contextual information in relation to subterranean surveys in the Goldfields, in particular with respect to the Yilgarn. However, little information was available in the vicinity of the study area as evidenced by the results of the desktop review.
Timing, weather, season, cycle	No	The survey was conducted at a suitable time of the year and more than average rainfall.
Disturbances which affected the results of the survey	No	No disturbances occurring during the period of the field survey are considered to have impacted the results.
Remoteness and/or access problems	No	There were no access problems in the study area.

6 DISCUSSION

The EPA's objective for subterranean fauna is its protection so that biological diversity and ecological integrity are maintained (EPA 2016b). Subterranean communities are often restricted to very small areas based on the limited dispersal capabilities of the fauna with short-range endemism interpreted at a much smaller scales than in terrestrial systems (Eberhard *et al.* 2009). There, activities that may impact on subterranean assemblages require attention at a much smaller scale.

A Level 1 desktop review represents the initial assessment on the likelihood of subterranean fauna to occur in an area of future development. A reconnaissance survey, generally aimed at investigating local geological features (i.e. presence of surface expressions of calcretes), may include or may be followed by a low intensity (Level 1) pilot survey to further evaluate if subterranean fauna are present and therefore if a Level 2 survey is required.

The two categories of a Level 2 survey are (EPA 2016a):

- **comprehensive**, i.e. it should provide detailed information to allow an understanding of the subterranean faunal values of an area and to place it into appropriate context; it requires repeated sampling
- **targeted**, i.e. to provide answers to specific questions building on existing information.

EPA Technical Guidance: Sampling methods for subterranean fauna (EPA 2016c) elaborates on the sampling methods for subterranean fauna, in particular the minimum number of samples required for a particular survey and where these should be located in relation to the project impact. The key requirements for a Level 2 survey are:

- **stygofauna**: a minimum of 40 samples taken from at least 10 bores within the impact zone, with the impact zone including those parts of the aquifer where significant drawdown occurs
- **troglofauna**: at least 60 samples from areas that from areas that are likely to have significant troglofauna values.

For both, stygofauna and troglofauna, sampling in two seasons is recommended. For stygofauna, bores must be at least six months old to allow recolonisation. If they are less than three months old, sampling must occur over two seasons (EPA 2016c).

The study area is situated in a poorly surveyed area where the eastern Gascoyne and southwestern Little Sandy Desert bioregions intercept and where limited contextual information exists (van Leeuwen 2002). This was evident in the poor return from the desktop review that only revealed records of seven species of stygofauna and no troglofauna records.

6.1 LIKELIHOOD OF SUBTERRANEAN FAUNA OCCURRENCE

A number of factors need to be considered in assessing the likelihood of subterranean fauna to occur, in particular the geological and hydrological setting of the Project, if there was subterranean fauna previously recorded in the vicinity of the Project and the results of surveys in similar conditions, i.e. alluvial and calcrete deposits near salt lakes in palaeovalleys in Western Australia.

It is clear that there is a high likelihood of subterranean fauna to occur in the study area. Calcretes of the Yilgarn belong to the hotspots of subterranean biodiversity in Western Australia, in particular with respect to stygofauna (Cooper *et al.* 2008; Watts & Humphreys 2001). The study area is situated at the border of the Yilgarn Craton and the Officer Basin, where similar geological conditions occur with the formation of alluvial deposits and calcrete expressions in ancient palaeochannels. Based on geology and hydrology, it is much less likely that subterranean fauna is present within the sediments of the Beyondie Lakes and 10 Mile Lake, which are characterised by lacustrine deposits of possibly low porosity, including clay, mud and silt. However, the depth and the extend of the calcretes, the most prospective formation in relation to subterranean fauna, below the surrounding Quaternary sediments is currently unknown and it is possible that there is potential habitat beyond the current surface expressions. Similarly, neighbouring calcretes are thought to be connected at Lake Way, supported by a distinct overlap in stygofauna communities (Toro Energy 2011).

Salinity is one of the important determinants of stygofauna occurrence. Stygofauna are less likely to occur at salinity levels that exceeds marine levels (EPA 2016a), although stygofauna has been found in up to 69,000 mg/L TDS (Watts & Humphreys 2004). The perched aquifers of the alluvial deposits and calcretes in the study area and at regional sites consists of freshwater (see Table 5-2) and are therefore very suitable to host stygofauna. In contrast, analyses of the targeted process water resulted in salinities in the brine in excess of 70,000 mg/L TDS, with levels consistently around 200,000 mg/L and sometimes in excess of 300,000 mg/L (up to 114.1 ppt in the sampled bores; see Table 5-2). These salinities are uninhabitable for stygofauna.

Our pilot survey recovered troglofauna and stygofauna from the alluvial deposits of the Nanyerinny Creek system west of Beyondie Lakes at Garden Well (freshwater), and Tupee Bore (subsaline) and in a south-western reference bore, David's Well (freshwater). It is possible that the alluvial aquifer between Garden Well and Tupee Bore is connected, which would be supported if the amphipods found at both sites represent the same species (molecular analyses pending). Stygofauna fauna records from the desktop review were also from the alluvial deposits, approximately 65 km north-west of the study area. It could so for not be established if the syncarids from the desktop review are the same as those from the field survey (molecular analyses pending). Only one species, the widespread stygophile copepod *Mesocyclops brooksi* were both present in both desktop review and field survey.

No subterranean fauna was recovered from bores surrounding 10 Mile Lake, most of which contain hypersaline water. However, subterranean fauna sampling in calcretes, the most prospected subterranean habitat in the study area, was limited to a single bore (TMAC23). Although salinity was subsaline there and therefore provided conditions for stygofauna to occur, not subterranean fauna was collected from this bore. However, a single sample is not sufficient to evaluate the occurrence of subterranean fauna in this calcrete and further sampling should be conducted.

6.2 PRELIMINARY IMPACT ASSESSMENT

6.2.1 Brine abstraction

The abstraction of brine is the key factor that should be considered when assessing the impacts of the construction and operation of the trial ponds on subterranean fauna in the study area. Total abstraction over 12 months is 1.89 x 10^6 m^3 which only represents 0.0004% of the estimated aquifer of the Project (3,940 x 10^6 m^3). The drawdown of the brine will potentially effect perched aquifers (i.e. stygofauna habitat and possibly troglofauna habitat above), if these aquifers drain into the lower groundwater reservoir and therefore the size of available habitat is reduced, or humidity for troglofauna potentially present above water level in the calcretes is altered. However, the calcretes extend a considerable distance, between 15–20 km from the trial bores. With a drawdown of the brine of less than 1 m at 3 km from the test bores (AQ2 2016), a secondary impact on perched aquifers at 15 km distance should be considered minimal.

In addition, permeability of the lacustrine deposits in the palaeochannel at the lakes and therefore the connectivity between abstracted brine and perched aquifers is low, limiting the effects of water abstraction. For the western calcrete situated outside the study area, this effect is amplified by the presence of a dolerite intrusion that appears to form a dyke potentially interrupting the ground water flow between the calcrete and Beyondie freshwater marsh in the west and the Beyondie salt lakes in the east.

A more detailed assessment with estimates of how much of the subterranean habitat may be affected will require both more detailed geological investigations to calculate the actual size of the calcretes (and therefore subterranean habitat), but also further hydrological modelling to quantitatively assess how continuous process water abstraction beyond 12 months will impact on the perched aquifers (AQ2 2016).

6.2.2 Potable water abstraction

Kalium is pursuing an adaptive water abstraction strategy and a final decision on potable/process water abstraction has not been made (Advisian 2017). Alluvial aquifers and the calcrete south of 10 Mile Lake are options. Stygofauna and troglofauna have been found at Garden Well and the presence of potentially conservation significant species must be managed. Similarly, water abstraction from the calcrete should be accompanied by water level and quality monitoring, and potentially monitoring of subterranean fauna, if present.

6.2.3 Evaporation ponds

The evaporation ponds north-west of 10 Mile Lake cover approximately 740 ha, in addition to 21 ha of other infrastructure (Figure 3-3). Potential secondary impacts of this infrastructure on subterranean fauna include leakage of brine from the ponds into a perched aquifer. However, at a distance of more than 4 km to the southern calcrete, any secondary impacts are unlikely and buffered by 10 Mile Lake.

6.3 RECOMMENDATION

The survey confirmed the presence of subterranean fauna in the vicinity of the project and therefore it is recommended that the survey effort is increased to Level 2 consistent with EPA (2016a). This expanded survey should particularly aim to survey further bores in the calcretes around 10 Mile Lake, as only a single bore within this geology was sampled during the pilot study.

Sourcing of large amounts of freshwater around Garden Well should be avoided, although it is currently unknown if the subterranean fauna recorded at the well is endemic and therefore of conservation significance. If water is abstracted from the aquifer around Garden Well, water levels and the presence of stygofauna should be monitored based on a subterranean fauna management plan.

Impacts on the perched aquifers of the calcretes near 10 Mile Lake due to brine abstraction from the palaeochannel in the lake are currently difficult to assess as it is unclear if and by how much brine abstraction will affect the hydrology of the calcretes, althouth impact is currently considered minimal. Water levels in the calcretes should be monitored during brine abstraction, in particular if subterranean fauna is found during future surveys. If subterranean fauna is present, brine abstraction should be accompanied by monitoring basd on a subterranean fauna management plan.

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Appendix 1 Conservation significant subterranean fauna in Western Australia (DPaW 2017)

Genus and species	Common name	Troglo-/ stygofauna	Conservation rating (DPaW 2017)	Distribution (DPaW 2017)	Currently known records
Arachnida					
Araneae (spiders)					
Tartarus mullamullangensis	Mullamullalang Cave spider	T	VU	South Coast	Mullamullang Cave, Nullarbor Plain (Gray 1992)
Tartarus murdochensis	Murdoch Sink cave spider	T	VU	South Coast	Phyllistine Flattener Cave and Murdoch Sink, Nullarbor Plain (Gray 1992)
Tartarus nurinensis	Nurina Cave spider	T	VU	South Coast	Nurina Cave, Roe Plains (Gray 1992)
Tartarus thampannensis	Thampanna Cave spider	T	VU	South Coast	Thampanna Cave, Nullarbor Plain (Gray 1992)
Troglodiplura lowryi	Nullarbor cave trapdoor spider	T	VU	South Coast	Roaches Rest Cave and Cave NR. 6 Bore, Nullarbor Plain (Main & Gray 1985)
Pseudoscorpiones					
Ideoblothrus linnaei		T	P1	Pilbara	Mesa A (Harvey & Leng 2008)
Ideoblothrus sp. Mesa A (WAM T81374)		T	P1	Pilbara	Mesa A (Harvey & Edward 2007)
Indohya damocles	Cameron's Cave pseudoscorpion	T	CR	Pilbara	Cameron's Cave, Cape Range (Harvey & Volschenk 2007)
Lagynochthonius asema		T	P1	Pilbara	Mesa A (Edward & Harvey 2008)

Genus and species	Common name	Troglo-/ stygofauna	Conservation rating (DPaW 2017)	Distribution (DPaW 2017)	Currently known records
Tyrannochthonius sp. Mesa A (WAM T81480)					Mesa A
Schizomida					
Bamazomus subsolans	Eastern Cape Range bamazomus	T	EN	Pilbara	Unnamed limestone quarry, Cape Range (Harvey 2001a)
Bamazomus vespertinus	western Cape Range bamazomus	T	EN	Pilbara	Cave C-215, Cape Range Peninsula (Harvey 2001a)
Draculoides bramstokeri	Barrow Island draculoides	T	VU	Pilbara	Barrow Island (Harvey & Humphreys 1995)
Draculoides brooksi	northern Cape Range draculoides	T	EN	Pilbara	North-eastern Cape Range Peninsula (Harvey *et al.* 2008)
Draculoides julianneae	western Cape Range draculoides	T	EN	Pilbara	Caves C-111 and C-215, Cape Range Peninsula (Harvey *et al.* 2008)
Draculoides mesozeirus	Middle Robe draculoides	T	VU	Pilbara	Middle Robe (Harvey *et al.* 2008)
Draculoides vinei	Cape Range Draculoides	T	P4	Pilbara	Caves within Tulki limestone of Cape Range (Harvey 2001a; Harvey *et al.* 2008)
Paradraculoides anachoretus	Mesa A paradraculoides	T	VU	Pilbara	Mesa A (Harvey *et al.* 2008)
Paradraculoides bythius	Mesa B/C paradraculoides	T	VU	Pilbara	Mesa B and Mesa C (Harvey *et al.* 2008)
Paradraculoides gnophicola	Mesa G paradraculoides	T	VU	Pilbara	Mesa G (Harvey *et al.* 2008)
Paradraculoides kryptus	Mesa K paradraculoides	T	VU	Pilbara	Mesa K (Harvey *et al.* 2008)

Genus and species	Common name	Troglo-/ stygofauna	Conservation rating (DPaW 2017)	Distribution (DPaW 2017)	Currently known records
Myriapoda					
Speleostrophus nesiotes	Barrow Island millipede	T	VU	Pilbara	Barrow Island (Car *et al.* 2013; Hoffman 1994)
Stygiochiropus peculiaris	Cameron's Cave millipede	T	CR	Pilbara	Camerons Cave, Cape Range Peninsula (Shear & Humphreys 1996)
Stygiochiropus isolatus	Millipede	T	VU	Pilbara	Cave C-222, Cape Range Peninsula (Humphreys & Shear 1993)
Stygiochiropus sympatricus	Millipede	T	VU	Pilbara	Cave C-111, Cape Range Peninsula (Humphreys & Shear 1993)
Crustacea					
Amphipoda					
Bogidomma australis	Barrow Island bogidomma amphipod	S	VU	Pilbara	Barrow Island (Bradbury & Williams 1996a)
Hurleya sp. (WAM 642–97)	Crystal Cave crangonyctoid amphipod	S	CR	Swan	Crystal Cave, Yanchep
Liagoceradocus branchialis	Cape Range liagoceradocus amphipod	S	EN	Pilbara	Bundera Sinkhole, Cape Range Peninsula (Bradbury & Williams 1996b)
Liagoceradocus subthalassicus	Barrow Island liagoceradocus amphipod	S	VU	Pilbara	Ledge Cave B-1, Barrow Island (Bradbury & Williams 1996b)
Nedsia fragilis	Freshwater amphipod	S	VU	Pilbara	Barrow Island (Bradbury & Williams 1996a)

Genus and species	Common name	Troglo-/ stygofauna	Conservation rating (DPaW 2017)	Distribution (DPaW 2017)	Currently known records
Nedsia humphreysi	Freshwater amphipod	S	VU	Pilbara	Barrow Island (Bradbury & Williams 1996a)
Nedsia hurlberti	Freshwater amphipod	S	VU	Pilbara	Barrow Island (Bradbury & Williams 1996a)
Nedsia macrosculptilis	Freshwater amphipod	S	VU	Pilbara	Barrow Island (Bradbury & Williams 1996a)
Nedsia sculptilis	Freshwater amphipod	S	VU	Pilbara	Barrow Island (Bradbury & Williams 1996a)
Nedsia straskraba	Freshwater amphipod	S	VU	Pilbara	Barrow Island (Bradbury & Williams 1996a)
Nedsia urifimbriata	Freshwater amphipod	S	VU	Pilbara	Barrow Island (Bradbury & Williams 1996a)
Nedsia chevronia	Freshwater amphipod	S	P2	Pilbara	Barrow Island (Bradbury 2002)
Copepoda					
Bunderia misophaga	Copepod	S	CR	Pilbara	Bundera Sinkhole, Cape Range Peninsula (Jaume & Humphreys 2001)
Speleophria bunderae	Copepod	S	CR	Pilbara	Bundera Sinkhole, Cape Range Peninsula (Jaume *et al.* 2001)
Stygocyclopia australis	Copepod	S	CR	Pilbara	Bundera Sinkhole, Cape Range Peninsula (Jaume *et al.* 2001)
Decapoda					
Stygiocaris lancifera	Lance-beaked cave shrimp	S	VU	Pilbara	Cape Range Peninsula (Knott 1993)
Stygiocaris stylifera	Spear-beaked Cave Shrimp	S	P4	Pilbara	Cape Range Peninsula (Knott 1993)
Isopoda					

Genus and species	Common name	Troglo-/ stygofauna	Conservation rating (DPaW 2017)	Distribution (DPaW 2017)	Currently known records
Abebaioscia troglodytes	Pannikin Plain Cave isopod	T	VU	South Coast	Pannikin Plain Cave, Nullarbor Plain (Vandel 1974 [imprint date 1973])
Paraplatyarthrus subterraneus	Poseidon slater	T	P1		Pilbara (Javidkar & King 2015)
Ostracoda					
Welesina kornickeri	Ostracod	S	CR	Pilbara	Bundera Sinkhole, Cape Range Peninsula (Danielopol *et al.* 2000)
Remipedia					
Kumonga exleyi	Cape Range remiped	S	CR	Pilbara	Bundera Sinkhole, Cape Range Peninsula (Yager & Humphreys 1996)
Polychaeta					
Prionospio thalanji	Bristle worm	S	CR	Pilbara	Bundera Sinkhole, Cape Range Peninsula (Wilson & Humphreys 2001)
Insecta					
Blattaria					
Nocticola flabella	Cape Range Blind Cockroach	T	P2	Pilbara	Cape Range Peninsula (Roth 1991)

Appendix 2: Subterranean Threatened Ecological Communities in Western Australia (DPaW 2016a)

Name of community	Description	Category of Threat and criteria met under WA criteria	Conservation Rating (EPBC Act 1999)	
Caves SP01	Aquatic Root Mat Community Number 1 of Caves of the Swan Coastal Plain	CR B) i), CR B) ii)	EN	Swan Coastal Plain
Caves Leeuwin01	Aquatic Root Mat Community Number 1 of Caves of the Leeuwin Naturaliste Ridge	CR B) i), CR B) ii)	EN	Warren
Caves Leeuwin02	Aquatic Root Mat Community Number 2 of Caves of the Leeuwin Naturaliste Ridge	CR B) i), CR B) ii)	EN	Warren
Caves Leeuwin03	Aquatic Root Mat Community Number 3 of Caves of the Leeuwin Naturaliste Ridge	CR B) i), CR B) ii)	EN	Warren
Caves Leeuwin04	Aquatic Root Mat Community Number 4 of Caves of the Leeuwin Naturaliste Ridge	CR B) i), CR B) ii)	EN	Warren
Cameron’s	Cameron’s Cave Troglobitic Community	CR B) i), CR B) ii)		Carnarvon Basin
Bundera	Cape Range Remiped Community	CR B) ii)		Carnarvon Basin
Ethel Gorge	Ethel Gorge aquifer stygobiont community	EN B) ii)		Pilbara
Depot Springs	Depot Springs stygofauna community	VU B)		Goldfields Region, Murchison Bioregion

Appendix 3: Priority Ecological Communities (DPaW 2016b)

Name of community	Description	Threats	Category (WA)
Pilbara			
Barrow Island subterranean fauna	Barrow Island stygofauna and troglofauna	Mining and industrial development	Priority 1
Subterranean invertebrate communities of mesas in the Robe Valley region	A series of isolated mesas occur in the Robe Valley in the state's Pilbara Region. The mesas are remnants of old valley infill deposits of the palaeo Robe River. The troglobitic faunal communities occur in an extremely specialised habitat and appear to require the particular structure and hydrogeology associated with mesas to provide a suitable humid habitat. Short range endemism is common in the fauna. The habitat is the humidified pisolitic strata	Mining	Priority 1
Subterranean invertebrate community of pisolitic hills in the Pilbara	A series of isolated low undulating hills occur in the state's Pilbara region. The troglofauna are being identified as having very short-range distributions	Mining	Priority 1
Mingah Springs calcrete groundwater assemblage type on Gascoyne palaeodrainage on Mingah Spring Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Stygofaunal community of the Bungaroo Aquifer	A unique assemblage of aquatic subterranean fauna including eels, snails and other stygofauna	Groundwater drawdown, mining	Priority 1
Stygofaunal communities of the Western Fortescue Plains freshwater aquifer	A unique assemblage of subterranean invertebrate fauna	Groundwater drawdown and salinisation	Priority 4(ii)
Kimberley			
Invertebrate community of Napier Range Cave	On Old Napier Downs, Karst No. KNI	Mine close by and tourist visitation	Priority 1
Midwest			
Badja calcrete groundwater assemblage type on Moore palaeodrainage on Badja Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1

Name of community	Description	Threats	Category (WA)
Belele calcrete groundwater assemblage type on Murchison palaeodrainage on Belele Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Beringarra calcrete groundwater assemblage type on Murchison palaeodrainage on Beringarra Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Black Range South and Windsor groundwater calcrete assemblage type on Raeside and Murchison palaeodrainage on Lake Mason and Windsor Stations	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Bunnawarra calcrete groundwater assemblage type on Moore palaeodrainage on Bunnawarra Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Byro Central and Byro HS calcrete groundwater assemblage types on Murchison palaeodrainage on Byro Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Challa, Challa North and Wondinong calcrete groundwater assemblage type on Murchison palaeodrainage on Challa and Wondinong Stations	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Cogla Downs calcrete groundwater assemblage type on Murchison palaeodrainage on Yarrabubba Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Curbur calcrete groundwater assemblage type on Gascoyne palaeodrainage on Curbur Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Dalgety and Landor calcrete groundwater assemblage type on Gascoyne palaeodrainage on Dalgety Downs and Landor Stations	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Doolgunna calcrete groundwater assemblage type on Gascoyne palaeodrainage on Doolgunna Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Gabyon calcrete groundwater assemblage type on Moore palaeodrainage on Gabyon Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Gifford Creek, Mangaroon, Wanna calcrete groundwater assemblage type on Lyons palaeodrainage on Gifford Creek, Lyons and Wanna Stations	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Hillview calcrete groundwater assemblage type on Murchison palaeodrainage on Hillview Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1

Name of community	Description	Threats	Category (WA)
Innouendy calcrete groundwater assemblage type on Murchison palaeodrainage on Innouendy Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Karalundi calcrete groundwater assemblage type on Murchison palaeodrainage on Karalundi Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Killara calcrete groundwater assemblage types on Murchison palaeodrainage on Killara Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Killara North calcrete groundwater assemblage types on Murchison palaeodrainage on Killara Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Lake Austin calcrete groundwater assemblage type on Murchison palaeodrainage on Austin Downs Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Maranalgo west calcrete assemblage type on Moore palaeodrainage on Maranalgo Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Meeberrie calcrete groundwater assemblage type on Murchison palaeodrainage on Meeberrie Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Meka calcrete groundwater assemblage type on Murchison palaeodrainage on Meka Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Milgun central calcrete groundwater assemblage types on Gascoyne palaeodrainage on Milgun Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Milgun south calcrete groundwater assemblage types on Gascoyne palaeodrainage on Milgun Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Milly Milly calcrete groundwater assemblage type on Murchison palaeodrainage on Milly Milly Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Mount Augustus calcrete groundwater assemblage type on Lyons palaeodrainage on Mount Augustus Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Mt Clere calcrete groundwater assemblage type on Gascoyne palaeodrainage on Mt Clere Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Mount Narryer calcrete groundwater assemblage type on Murchison palaeodrainage on Mount Narryer Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Mount Padbury calcrete groundwater assemblage type on Murchison palaeodrainage on Mount Padbury Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1

Name of community	Description	Threats	Category (WA)
Muralgarra calcrete groundwater assemblage type on Murchison palaeodrainage on Muralgarra Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Murchison Downs calcrete groundwater assemblage type on Murchison palaeodrainage on Murchison Downs Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Ninghan calcrete groundwater assemblage type on Moore palaeodrainage on Ninghan Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Nowthanna Hill calcrete groundwater assemblage type on Murchison palaeodrainage on Yarrabubba Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Paroo calcrete groundwater assemblage type on Carey palaeodrainage on Paroo Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Polelle calcrete groundwater assemblage type on Murchison palaeodrainage on Polelle Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Taincrow calcrete groundwater assemblage type on Murchison palaeodrainage on Taincrow Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Three Rivers calcrete groundwater assemblage types on Gascoyne palaeodrainage on Three Rivers Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Three Rivers Plutonic calcrete groundwater assemblage types on Gascoyne palaeodrainage on Three Rivers Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Wagga Wagga and Yalgoo calcrete groundwater assemblage type on Yalgoo and Moore palaeodrainage on Wagga Wagga and Bunnawarra Stations	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Windimurra calcrete groundwater assemblage type on Murchison palaeodrainage on Windimurra Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Wooramel calcrete groundwater assemblage type on Wooramel palaeodrainage on Innouendy Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Yarrabubba east calcrete groundwater assemblage types on Murchison palaeodrainage on Yarrabubba Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Yarrabubba west calcrete groundwater assemblage types on Murchison palaeodrainage on Yarrabubba Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1

Name of community	Description	Threats	Category (WA)
Yoweragabbie calcrete groundwater assemblage type on Moore palaeodrainage on Yoweragabbie Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Goldfields			
Albion Downs calcrete groundwater assemblage type on Carey palaeodrainage on Albion Downs Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Banjawarn and Melrose (Lake Darlot) calcrete groundwater assemblage type on Carey palaeodrainage on Banjawarn and Melrose Stations	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Barwidgee calcrete groundwater assemblage type on Carey palaeodrainage on Barwidgee Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Black Range North calcrete groundwater assemblage type on Raeside palaeodrainage on Lake Mason Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Cunyu SBF and Cunyu Sweetwater calcrete groundwater assemblage types on Nabberu palaeodrainage on Cunyu Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Dandaraga calcrete groundwater assemblage type on Raeside palaeodrainage on Dandaraga Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Glenayle and Carnegie Downs calcrete groundwater assemblage type on Burnside palaeodrainage on Glenayle Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Hinkler Well calcrete groundwater assemblage type on Carey palaeodrainage on Lake Way Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Lake Way South calcrete groundwater assemblage type on Carey palaeodrainage on Lake Way Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Jundee Homestead calcrete groundwater assemblage type on Carnegie palaeodrainage on Jundee Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Jundee South Hill calcrete groundwater assemblage type on Carnegie palaeodrainage on Jundee Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1

Name of community	Description	Threats	Category (WA)
Kaluwiri calcrete groundwater assemblage type on Raeside palaeodrainage on Kaluwiri Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Lake Mason calcrete groundwater assemblage type on Raeside palaeodrainage on Lake Mason Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Lake Miranda east calcrete groundwater assemblage types on Carey palaeodrainage on Yakabindie Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Lake Miranda west calcrete groundwater assemblage types on Carey palaeodrainage on Yakabindie Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Lake Violet south and Lake Violet calcrete groundwater assemblage types on Carey palaeodrainage on Millbillillie Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Laverton Downs calcrete groundwater assemblage type on Carey palaeodrainage on Laverton Downs Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Lorna Glen calcrete groundwater assemblage type on Carnegie palaeodrainage on Lorna Glen Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Melita calcrete groundwater assemblage type on Raeside palaeodrainage on Melita Station (Sons of Gwalia)	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Millbillillie: Bubble calcrete groundwater assemblage type on Carey palaeodrainage on Millbillillie Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Mount Morgan calcrete groundwater assemblage type on Carey palaeodrainage on Mount Weld Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Nambi calcrete groundwater assemblage type on Carey palaeodrainage on Nambi Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Old Cunya calcrete groundwater assemblage type on Nabberu palaeodrainage on Cunyu Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Perrinvale (Pine Well) calcrete groundwater assemblage type on Raeside palaeodrainage on Perrinvale Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Pinnacles calcrete groundwater assemblage type on Raeside palaeodrainage on Pinnacles Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1

Name of community	**Description**	**Threats**	**Category (WA)**
Sturt Meadows calcrete groundwater assemblage type on Raeside palaeodrainage on Sturt Meadows Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Uramurdah Lake calcrete groundwater assemblage type on Carey palaeodrainage on Millbillillie Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Wiluna BF calcrete groundwater assemblage type on Carey palaeodrainage on Millbillillie Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Windidda calcrete groundwater assemblage type on Carnegie palaeodrainage on Windidda Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Yakabindie calcrete groundwater assemblage type on Carey palaeodrainage on Yakabindie Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Yandal calcrete groundwater assemblage type on Carey palaeodrainage on Yandal Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Yeelirrie calcrete groundwater assemblage type on Carey palaeodrainage on Yeelirrie Stration	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Yuinmery calcrete groundwater assemblage types on Raeside palaeodrainage on Yuinmery Station	Unique assemblages of invertebrates have been identified in the groundwater calcretes	Mining	Priority 1
Warren			
Microbial mantles of Nullarbor caves (especially Weebubbie Cave)	Significant microbial communities in underwater sections of cave	Uncontrolled access	Priority 1
Subterranean faunal ecosystems of Nullarbor caves (known from Nurina Cave, Olwolgin Cave, Burnabbie Cave, N327, N1327)	The caves contain communities of invertebrates, other fauna and sensitive habitats including tree roots. Caves included in this community contain at least four troglobitic taxa.	Uncontrolled access	Priority 3(i)