LAKE ROE GOLD PROJECT: SUBTERRANEAN FAUNA LEVEL 1 ASSESSMENT

PREPARED FOR **BREAKER RESOURCES**

26 March 2019

Stantec

QUALITY STATEMENT

PROJECT MANAGER	PROJECT TECHNICAL LEAD
Tracy Schwinkowski	Dr Nicholas Stevens

PREPARED BY		
Dr Erin Thomas & Dr Nicholas Stevens	………………………………………………	18/03/2019
CHECKED BY		
Dr Nicholas Stevens	………………………………………………	23/03/2019
REVIEWED BY		
Dr Fiona Taukulis	………………………………………………	25/03/2019
APPROVED FOR ISSUE BY		
Dr Nicholas Stevens	………………………………………………	26/03/2019

PERTH
41 Bishop Street, JOLIMONT, WA 6014
TEL +61 (08) 9388 8799

REVISION SCHEDULE

Rev No.	Date	Description	Signature or Typed Name (documentation on file)			
			Prepared by	Checked by	Reviewed by	Approved by
V0.1	26/03/2019	Draft Report	ET & NS	NS	FT	NS

Executive Summary

Breaker Resources NL (Breaker) are proposing to develop the Lake Roe Gold Project (the Project), which comprises the Bombara gold deposit. The Project is located approximately 100 km east of Kalgoorlie in the eastern Goldfields region of Western Australia and is situated on the south western margin of the Lake Roe salt lake system.

Breaker commissioned a Level 1 subterranean fauna assessment (incorporating a desktop assessment and Level 1 verification (pilot) survey) as part of a suite of environmental and technical invesitgations for the Project, required to inform future regulatory approvals for development. Development of the Project could potentially directly impact subterranean fauna through the physical removal of habitat from mining excavation and groundwater drawdown from dewatering to access the resource.

The main objectives of this assessment were to assess the potential for subterranean fauna to represent an environmental factor, and to determine if a Level 2 Baseline survey of subterranean fauna values would be required. This report presents the findings of the stygofauna and troglofauna desktop assessment and Level 1 verification (pilot) survey of the Project Study Area.

Survey Effort

The pilot survey sampled 23 uncased exploration drill holes (sites) within the Study Area comprising:

- 16 stygofauna net haul samples collected from October 16 to 18, 2018; and
- 15 troglofauna litter traps (deployed for seven weeks from October 16 to December 8, 2018, and 16 scrape samples collected in conjunction with stygofauna sampling in October, 2018.

The survey effort completed fulfilled the recommended survey effort for a Level 1 low sample intensity verification stygofauna and troglofauna survey by the Western Australia EPA Technical Guidance Sampling Methods for Subterranean Fauna Survey. The survey intensity undertaken, in conjunction with the habitat characterisation, was considered more than sufficient to enable a reliable verification of the stygofauna and troglofauna values present in the Study Area in accordance with EPA Technical Guidance Subterranean Fauna Survey.

Subterrnanean Fauna Findings

There were no species of stygofauna or troglofauna collected from the 23 sites sampled within the Study Area. The survey effort conducted is considered to be more than sufficient to provide a reliable verification of the prospectiveness of the habitats sampled for hosting stygofauna and/or troglofauna within the Study Area. he sampling results are consistent with the habitat characterisation that indicated that the Study Area does not provide prospective habitat for subterranean fauna.

Conclusion

The Level 1 subterranean fauna assessment undertaken has demonstrated that the Lake Roe gold deposit in the Study Area does not provide prospective habitat for subterranean fauna and does not host stygofauna or troglofauna values. The sample results confirmed that the clay dominated regolith does not provide the extensive interconnected vugs, voids and open fractures required for subterranean fauna colonisation. The acidic and hypersaline groundwater conditions within the Study Area and surrounding region, in conjunction with the clay-dominated strata restricting of the influx of resources (e.g., nutrients and oxygen), present unfavourable habitat for stygofauna. For troglofauna, the limited unsaturated strata, due to the shallow water table, lacks the interconnected vugs and voids required for troglofauna habitation.

The findings indicate that stygofauna and troglofauna do not represent an environmental factor for future regulatory approvals of the Project in accordance with EPA guidelines, and there is no risk of impacts to subterranean fauna values. Therefore, no further stygofauna or troglofauna assessment is considered necessary to provide further information on the subterranean fauna values of the Study Area. The proposed development of the Project will meet the relevant EPA objectives in that the proposal does not pose a threat to maintaining subterranean fauna representation, diversity, viability and ecological function at the species, population or assemblage level.

Breaker Resources

Lake Roe Gold Project: Subterranean Fauna Level 1 Assessment

CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

1. Introduction

1.1 Project Background

Breaker Resources NL (Breaker) are proposing to develop the Lake Roe Gold Project (the Project), which comprises the Bombara gold deposit. The Project is located approximately 100 km east of Kalgoorlie in the eastern Goldfields region of Western Australia and is situated on the south western margin of the Lake Roe salt lake system (**Figure 1-1**). The Study Area comprises tenement MLA5 (3,749 ha), which includes the proposed development envelope (999 ha) and the proposed pit (55 ha) (**Figure 1-2**).

In August 2018 Stantec Australia Pty Ltd (Stantec) completed a subterranean fauna desktop assessment for Breaker, investigating the environmental and hydrogeological aspects of the Project. Based on the findings and recommendations from the desktop assessment, Stantec was commissioned to undertake a Level 1 subterranean fauna verification survey to inform and support future applications for regulatory approval for the development of the Project.

Development of the Project could potentially directly impact subterranean fauna through the physical removal of habitat from mining excavation and groundwater drawdown from the dewatering required to access the resource. This report presents the findings of the stygofauna and troglofauna desktop assessment and Level 1 verification (pilot) survey of the Project Study Area.

1.2 Scope and Objectives

The overarching aim of the Lake Roe subterranean fauna Level 1 assessment, incorporating both a desktop and pilot survey, was to determine if subterranean fauna would represent an environmental factor that may be impacted by the Project.

The specific objectives of the subterranean fauna Level 1 assessment were:

- evaluate the likelihood of subterranean fauna species existing within the Study Area and adjacent regional area;
- assess whether subterranean fauna will represent an environmental factor; and
- determine if a Level 2 Baseline survey of subterranean fauna values would be required.

To achieve the objectives, the following was completed:

- a desktop assessment involving database searches and literature review;
- evaluation of the prospectiveness of the habitat present to support subterranean fauna within the Study Area; and
- pilot survey for subterranean fauna to verify previous desktop findings.

The principles, objectives and survey methodology are aligned with relevant regulatory guidelines. These include, but are not limited to:

- Environmental Protection Authority (EPA) (2016a) Technical Guidance – Sampling Methods for Subterranean Fauna Survey; and
- EPA (2016b) Technical Guidance – Subterranean Fauna Survey.

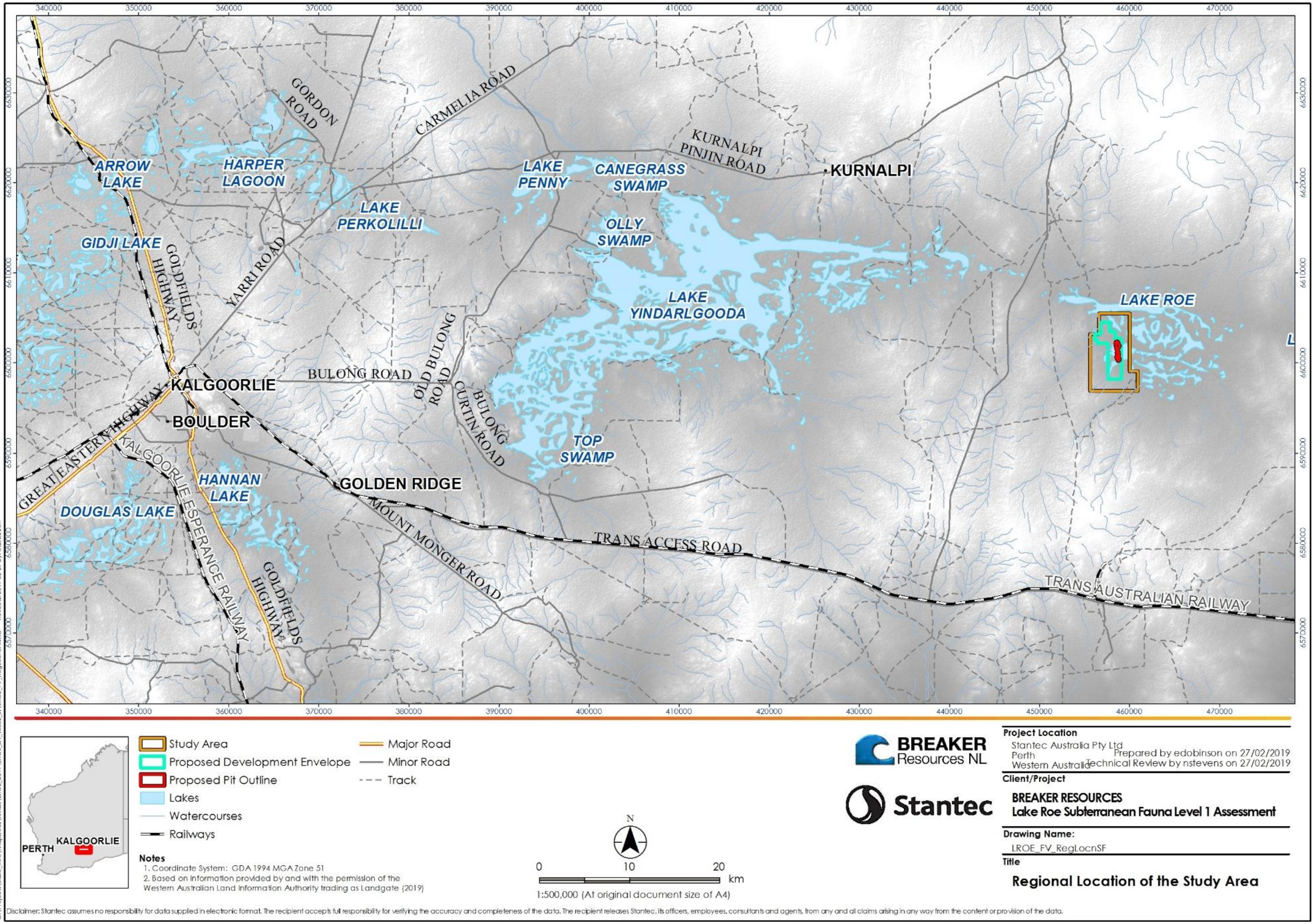

Figure 1-1: Regional location of the Study Area.

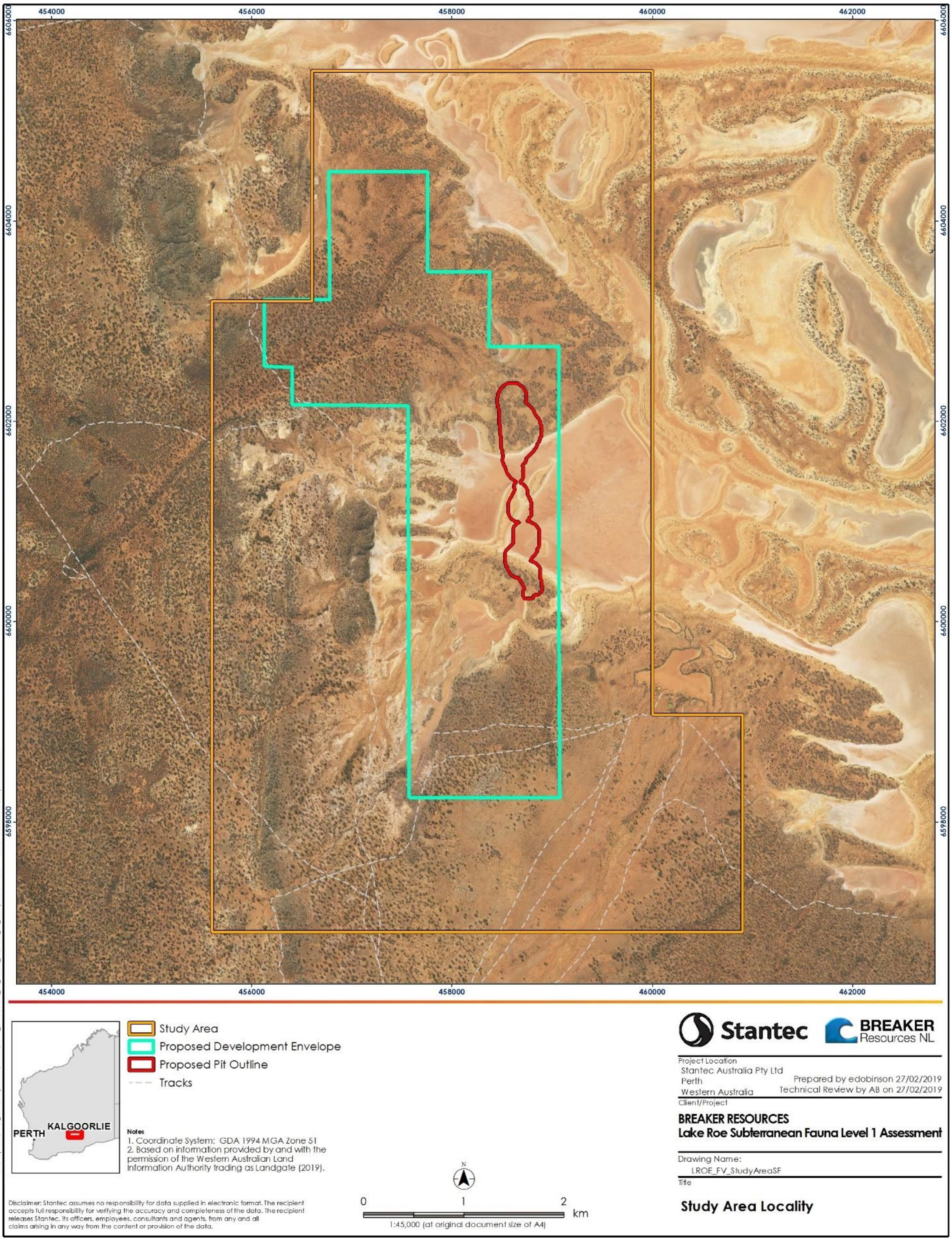

Figure 1-2: Location of the Study Area.

2. Existing Environment

2.1 Biogeographic Location

The Project is located within the Eastern Goldfields (C003) subregion of the Coolgardie bioregion, as defined by the Interim Biogeographic Regionalisation for Australia (IBRA) classification system (Thackway and Cresswell 1995). The Study Area occurs within the Southwestern Interzone (Beard 1979) (Cowan 2001a), within 2 km of the boundary of the East Murchison subregion (MUR01) of the Murchison bioregion (**Figure 2-1**).

The Eastern Goldfields subregion is characterised by gently undulating plains interrupted in the west by low hills and ridges of Archaean greenstones and in the east by a horst of Proterozoic baslic granulite. The underlying strata are eroded and covered with Tertiary sand and gravel soils, scattered exposures of bedrock, and plains of calcareus earths. A series of large salt lakes in the western half of the subregion are the remnants of an ancient major drainage system (Cowan 2001a).

The Project is situated within the upper catchment area of the south-western arm of the extensive Carnegie Palaeodrainage system associated with the Lake Carnegie salt lake basin, more than 200 km east of the Study Area. The northern neighbouring East Murchison subregion also contains extensive saline lakes that are associated with occluded palaeodrainages known to host diverse stygofauna fauna assemblages within the fresh to mesosaline groundwater environments of relatively extensive valley formed calcrete systems (Cooper *et al.* 2002, Humphreys 2008, Outback Ecology 2008b, 2011c, 2012b, c, f, Subterranean Ecology 2011). However, the palaeodrainages systems within the Coolgardie bioregion, south of the Menzies line (29°S), are regarded as generally lacking subterranean values due to hypersaline groundwater conditions and pedogenic calcrete formations (Outback Ecology 2011d, 2012d, Subterranean Ecology 2009).

2.2 Land Use

The primary land uses within the Eastern Goldfields subregion are; Unallocated Crown Land (UCL), Crown Reserves, native grazing pastures, cultivation and conservation reserves (Cowan 2001b). The Study Area also occurs within the Yindi Pastoral Lease (PL N09512) and the Goldfields Groundwater Area GWA21

As the subregion is rich mineral deposits, especially gold and nickel, exploration and mining are prevalent (Kern 1996b). Near the Study Area, the township of Kurnalpi (65 km north-west), was a thriving gold centre from the late 1800's to the early 1900's, however, has since been abandoned.

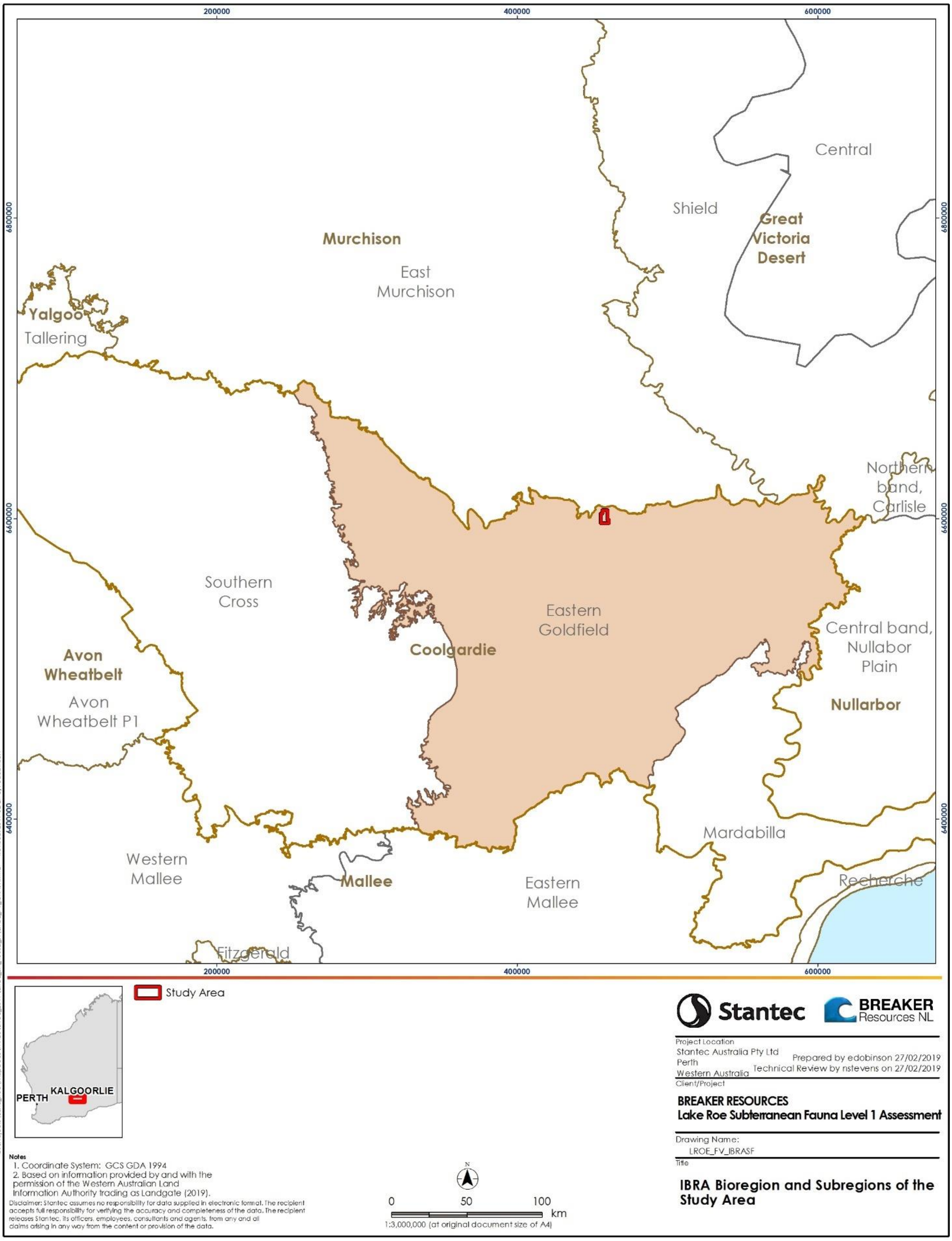

Figure 2-1: Bioregion and subregions associated with the Study Area.

2.3 Climate

The region has an arid climate, characterised by hot summers, with daily maximum temperatures regularly exceeding 30°C, and cool winters, with minimum temperatures often falling below 10°C (Pringle *et al.* 1994) (**Figure 2-2**). The limited annual rainfall that occurs across the region, averaging 268 mm (1939 to 2019), coincides with high evaporation rates (2,400 mm/yr) and is generally characterised by a bimodal distribution (Beard 1976, Johnson *et al.* 1999). Winter rainfall is typically associated with low-pressure frontal systems from the south that tend to be widespread and of variable intensity. Summer rainfall is mainly linked to local thunderstorms or the influence of tropical cyclones to the north (Beard 1990, Pringle *et al.* 1994).

The nearest Bureau of Meteorology (BOM) weather station to the Project, with reliable long-term (1939 to 2019) and recent climatic data, is at Kalgoorlie-Boulder Airport (Station 12038), approximately 100 km west of the Study Area. The minimum and maximum temperatures recorded in 2018 were largely consistent with the mean temperatures recorded since 1939 (**Figure 2-2**). The total rainfall in 2018 was 60 mm above the average with 328 mm received. January and February received above average rainfalls, with more than twice the average rainfall in February with 65.2 mm falling compared to the average of 31.2 mm. Much drier than average conditions mostly prevailed from March to September with only 1.2 mm rainfall received in May. Well above average winter rainfalls were received in October and November just prior to and during the trap deployment period (**Figure 2-3**).

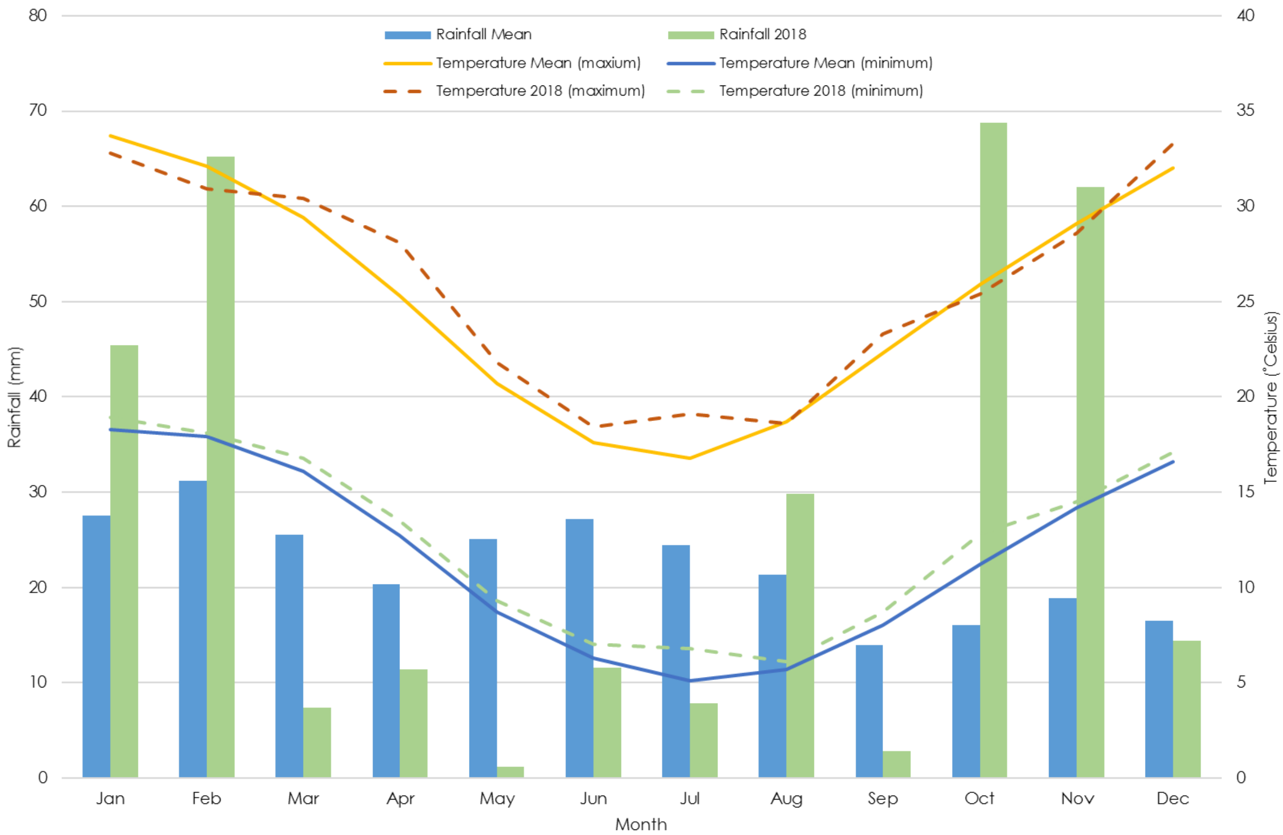

Figure 2-2: Long-term (1939 to 2019) climate data recorded at the Kalgoorlie-Boulder Airport weather station (12038) compared to compared to 2018 data (Bureau of Meteorology 2019).

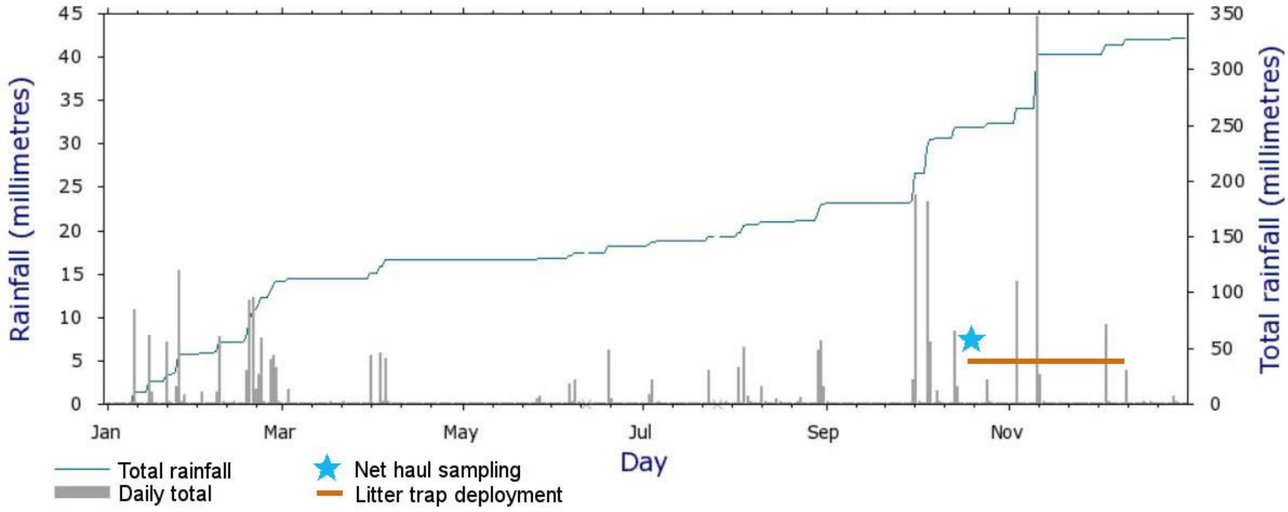

Figure 2-3: Daily rainfall data recorded for 2018 at the Kalgoorlie-Boulder Airport weather station (12038) (Bureau of Meteorology 2018).

2.4 Surface Water and Drainage

The Study Area lies along the south western margin of Lake Roe, which is part of the Roe Palaeodrainage system (Kern 1996a) (**Figure 2-4**). The headwaters of this system are Lake Ballard, with drainage occurring in a south easterly direction to Lake Marmion, Lake Rebecca and Lake Roe, terminating broadly at Lake Yindarlgooda. Due to their extensive size, and the semi-arid climate, these salt lakes remain largely disconnected, with endorheic (internal) drainage patterns (Hammer 1986).

Salt lakes along the drainage system consist of clay, silt and sand, interbedded with evaporite minerals such as gypsum and halite (Campagna 2007). The playas are naturally saline, although are surrounded by numerous, smaller peripheral claypans that are often freshwater. While typically dry, major flood events are known to occur infrequently, associated with intense winter rains or cyclonic events.

The salt lakes can accommodate large inflows, although exhibit substantial fluctuations in water depth and water quality over the course of the hydroperiod. Salinity concentrations tend to range from less than 10,000 mg/L (total dissolved solids) during the initial stages of flooding, to over 300,000 mg/L towards the end of the hydroperiod (Gregory 2007, Williams 1998). The drying cycle of salt lakes can also be rapid, as a result of high evaporation rates (Timms *et al.* 2006).

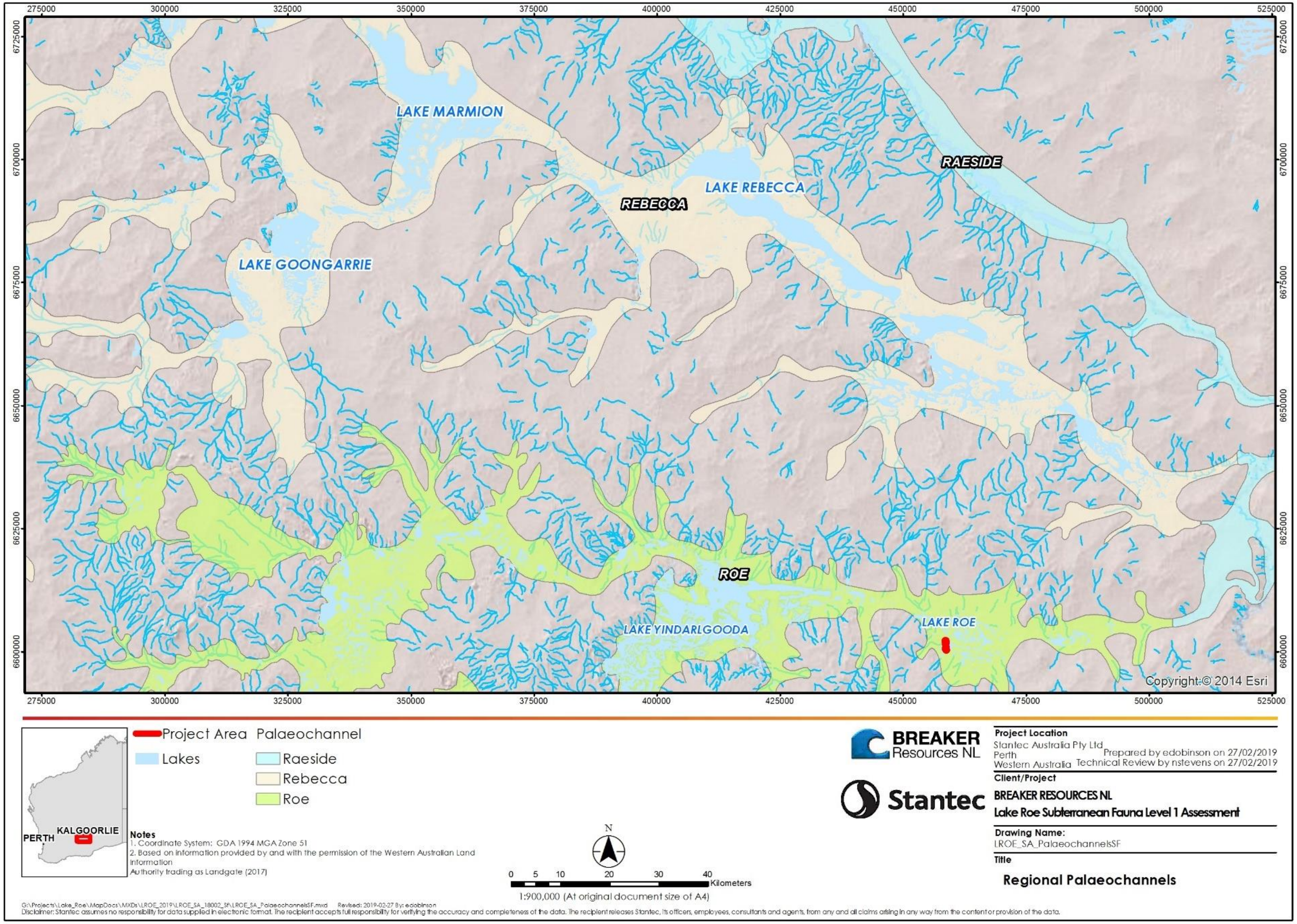

Figure 2-4: Regional palaeochannel drainage systems.

2.5 Geology

The local geology of the Study Area was provided by Breaker in the form of a pit-scale geological map showing the spatial distribution of key lithological and structural elements at 300 mRL (approximately 15 m below ground level) (**Figure 2-5**). The resource is located on the eastern limb of the Bombora Antiform, within differentiated mafic, volcanic and intrusive rocks (principally basalt and dolerite), bounded to the east and west by mafic sediments (black shale) (**Figure 2-6**). An unnamed syenite pluton is located to the east of the deposit, beneath, and extending beyond the extent of Lake Roe.

Structurally, the package that comprises the mine sequence is bounded to the east and west by various splays (branches) of the Claypan Fault, understood to be high strain, ductile features (mylonite to the east) unlikely to provide substantial permeability or groundwater storage. A series of north/south to north northwest/ south southeast striking, vertical shears and thrust faults have been identified within the mineable sequence, along with a series of east northeast/west southwest vertical structures that offset the entire mine sequence (**Figure 2-5**). Towards the southern end of the current pit shell, definition of structure is reasonably dense, while at the northern end of the pit, structural definition appears to be lean. A series of gently northerly dipping quartz reefs/veins occur through the northern half of the current pit shell. Details of the thickness and general character of these reefs are not available.

The depth of weathering in the mafic rocks is quite variable with drillhole logs indicating regolith clays ranging in depths between 2 m and approximately 30 m, with deeper clay profiles likely correlating to increased fracture densities. Drillhole logs indicate the residual clays over the syenite to the east of the pit, may be as deep as 84 m. An enhanced weathering profile over the syenite may geomorphologically be the cause of the topographically low terrain that Lake Roe occupies. The depth of transported material in the vicinity of the Study Area is generally less than 15 m, while the thickness of lake clays associated with the playa, generally range from 2 to 10 m based on interpretation of the available drillhole logs.

2.6 Hydrogeology

A drilling-based study of 22 cross-section lines was undertaken by (Commander *et. al*. (1993), to define the extent of aquifers in palaeovalleys in the Kalgoorlie area. The work indicated the upper (western) parts of the Roe Palaeovalley as being V-shaped and varying from 400 to 700 m wide and 25 to 40 m deep, increasing down gradient (easterly) to 1,000 to 1,500 m wide and 55 to 75 m deep. The easternmost drilled transects are about 60 km west of the Project and the depths of the palaeodrainage feature east of Lake Yindarlgooda (including at Lake Roe), are not available in the literature examined. However, it is not unreasonable to assume the palaeovalley located to the north of the currently defined Bombora resource is at least as deep, if not deeper, than the 75 m recorded 60 km up-gradient to the west.

Given the location of the Project on the western margin of Lake Roe, the key hydrogeological settings that will be likely encountered in the proposed mining area of the Bombora resource from near surface to fresh bedrock are (**Figure 2-8**):

- transported sediments, including those associated with the Roe Palaeodrainage, and the Lake Roe deposits;
- the base of the regolith profile; and
- the fractured rock setting within the otherwise fresh mafic bedrock.

The main truck of the palaeochannel is approximately 3.5 km north of the northern end of the current pit shell. Therefore, it is unlikely that the main high-yielding groundwater palaeochannel sediments (Wollubar Sandstone) will interact directly with mining operations, however, there is a possibility that the transported sediments located in the current pit footprint could be hydraulically linked to the truck palaeochannel. This would need to be evaluated through hydrogeological field work.

The Lake Roe sediments typically comprise clays up to 10 m in thickness, which may provide some degree of storage for groundwater, but are likely to have such low permeability as to be insignificant as a groundwater source at the scale of the pit. The hydrogeological character of the fractured rock setting that constitutes the bulk of the mineable sequence is currently unknown. In this setting, groundwater storage and transmission are governed by the presence of faults, shear zones and joints, and their degree of interconnection, both locally, and more regionally with connectivity to large sources of stored groundwater such as the Wollubar Sandstone. The degree of hydraulic interconnection between the palaeochannel sediments and the fractured rock elements is currently not known.

The groundwater salinity of the aquifer systems present within the main tributary of the Roe Palaeodrainage and the footprint of Lake Roe is hypersaline, in excess of 150,000 mg/L. Groundwaters beyond the playa and main palaeochannel are inferred to range from 30,000 to 150,000 mg/L (**Figure 2-9**).

2.6.1 Hydrogeological Conceptual Model

The current conceptual hydrogeological model for the Study Area places the proposed pit within lake sediment, regolith profile, and fractured rock "aquifer" types. To the north of the pit is the Roe Palaeochannel containing a high yielding Wollubar Sandstone at an estimated depth of between 70 and 100 m, and possibly in hydraulic connection with the mineable sequence via all the aquifer types. Within the fractured rock aquifer, there may be a pronounced north-south oriented permeability ellipsoid, parallel to the overall strike of the structural fabrics.

Recharge to the aquifers is via direct rainfall seepage, throughflow within the aquifer types, and potentially contributions from the Wollubar Sandstone if adjacent aquifers are depressurised. Discharge from the aquifers is likely to be from evapotranspiration from vegetatio n and the land surface, including from the lake when it is holding water, and the lake itself is likely to be the regional groundwater sink, given its low topographic setting. A regional component of throughflow may exist currently, discharging to the east of the Lake Roe. The degree to which mining associated dewatering could impact upon easterly discharge is not known.

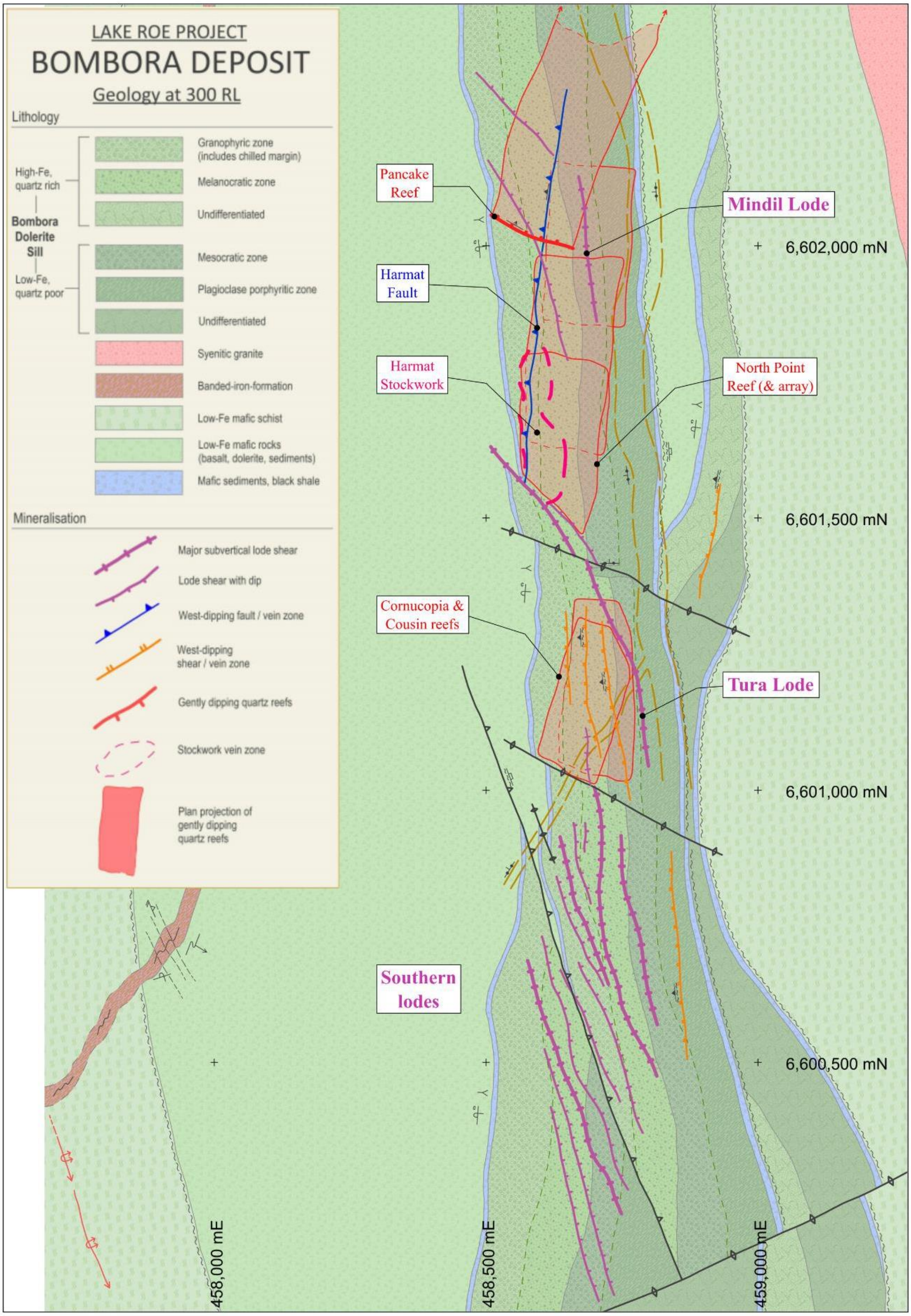

Figure 2-5: Local geology of the Study Area at 300 RL (Breaker Resources NL 2018).

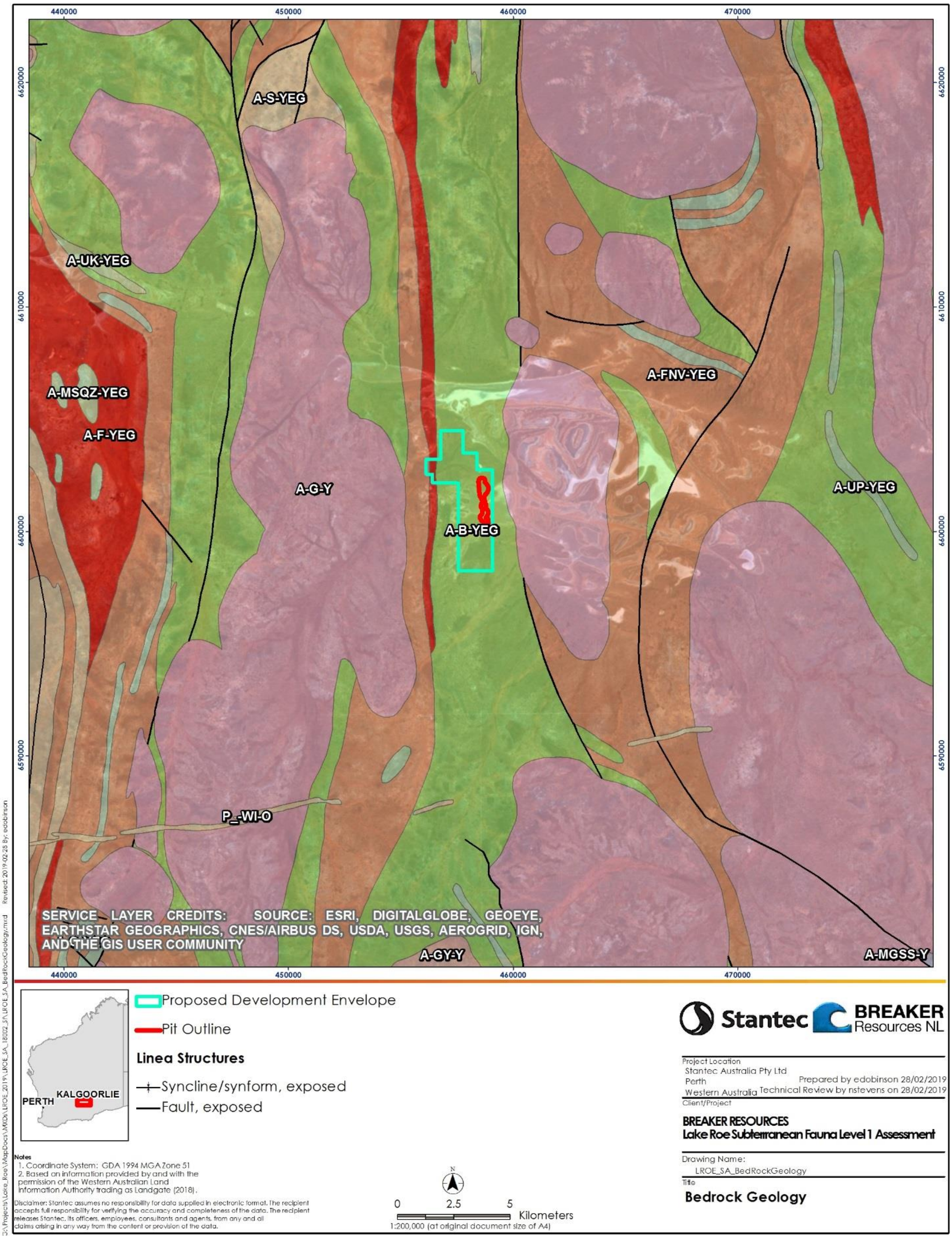

Figure 2-6: Bedrock geology setting of the Study Area.

Bedrock Geology

- A-b-YEG; Eastern Goldfields Superterrane greenstones; Fine to very fine grained mafic rock with minor ultramafic rock, undivided; metamorphosed
- A-f-YEG; Eastern Goldfields Superterrane greenstones; Volcanic and volcaniclastic felsic rocks, undivided; andesite to rhyolite, minor basaltic andesite; local fragmental textures; metamorphosed
- A-fnv-YEG; Eastern Goldfields Superterrane greenstones; Volcanogenic sedimentary rocks derived from felsic volcanic rocks; local felsic lava and volcaniclastic sandstone
- A-g-Y; Yilgarn Craton granites; Granitic rock, undivided; metamorphosed
- A-gy-Y; Yilgarn Craton granites; Syenite and alkali feldspar syenite; locally porphyritic; metamorphosed
- A-mgss-Y; Yilgarn Craton granites; Foliated metagranite, locally gneissic; may include amphibolite lenses; includes deeply weathered rock
- A-msqz-YEG; Eastern Goldfields Superterrane greenstones; Quartz--aluminosilicate rock within felsic volcanic sequences, commonly schistose; abundant andalusite poikiloblasts; local minor kyanite or chloritoid
- A-o-YEG; Eastern Goldfields Superterrane greenstones; Mafic intrusive rock dominant; metamorphosed
- A-s-YEG; Eastern Goldfields Superterrane greenstones; Siliciclastic sedimentary rock, undivided; includes sandstone, siltstone, shale, and chert; metamorphosed
- A-uk-YEG; Eastern Goldfields Superterrane greenstones; Komatiite and komatiite flow units; olivine spinifex texture and locally well developed cumulate zones; metamorphosed; silicified or weathered
- A-up-YEG; Eastern Goldfields Superterrane greenstones; Peridotite; metamorphosed; with relict olivine cumulate texture; minor metapyroxenite; commonly serpentinitized and locally rodingitized or silicified
- P_-WI-o; Widgiemooltha Supersuite; Dolerite and gabbro; includes cumulate and granophyric differentiates

Figure 2-7: Bedrock geology legend.

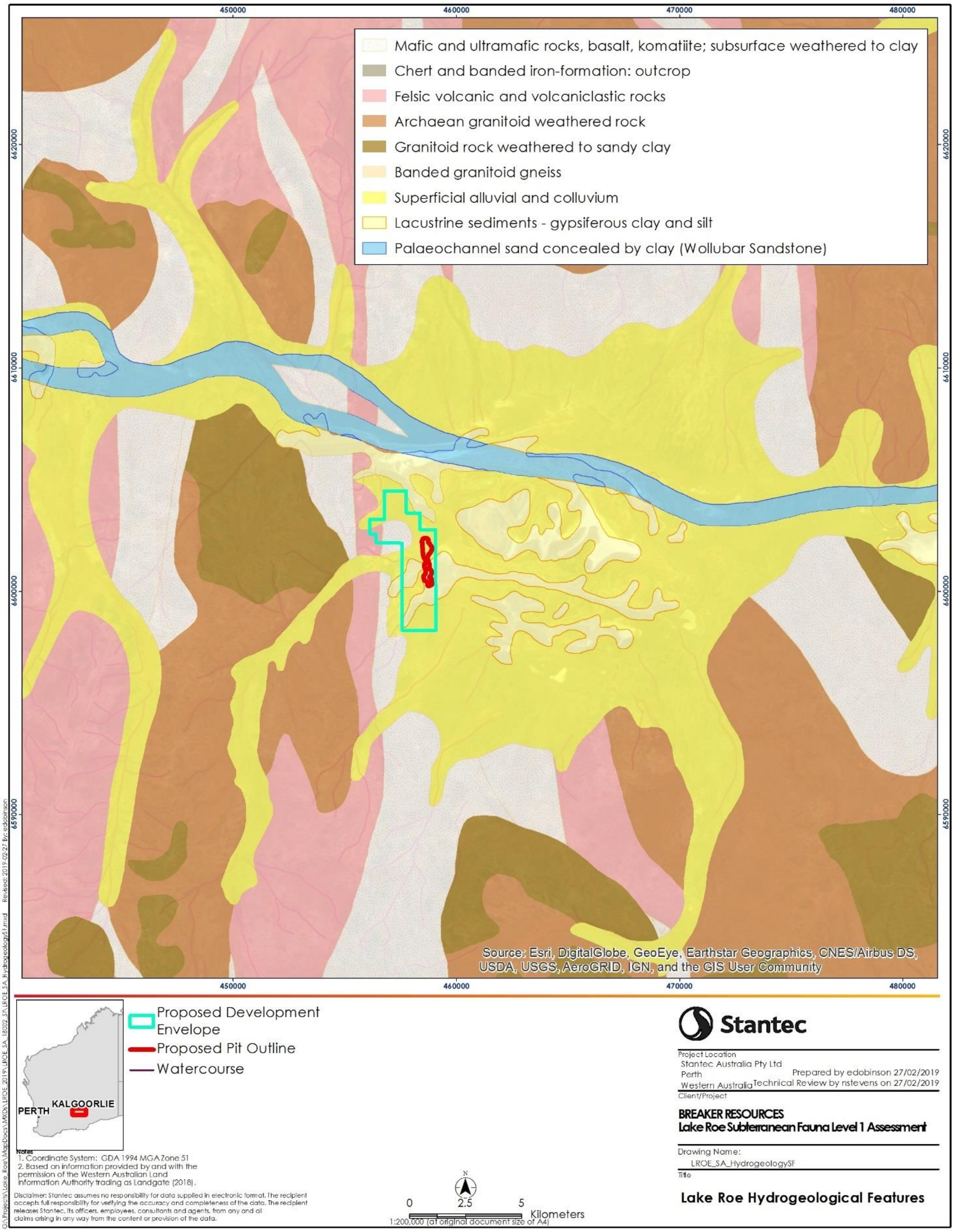

Figure 2-8: Regional hydrogeological features.

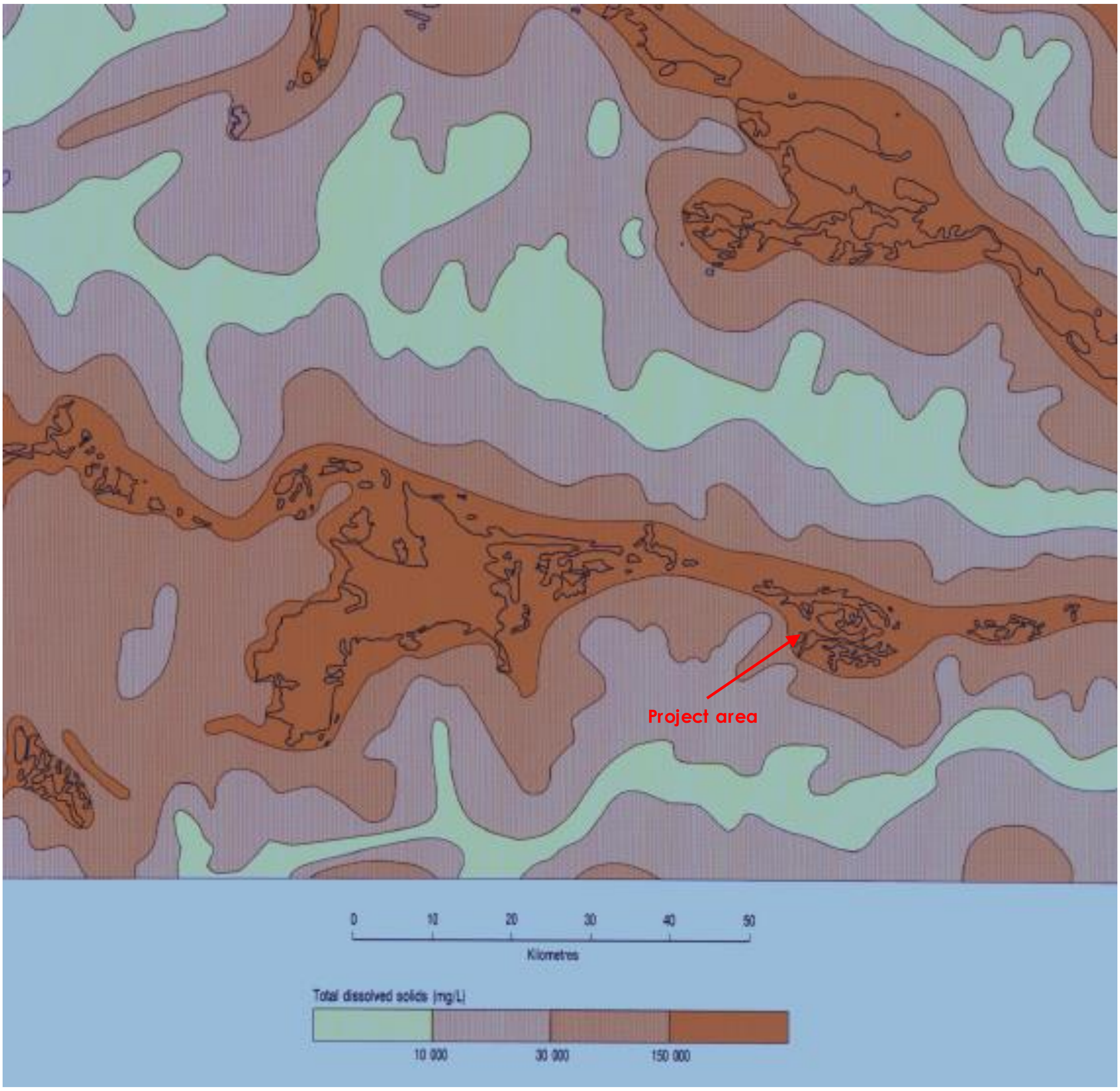

Figure 2-9: Groundwater salinity in the vicinity of the Project (Kern 1995).

3. Subterranean Fauna

3.1 Habitat

The prospective habitat for subterranean fauna (stygofauna and troglofauna) is dependent on the presence of voids of suitable size and connectivity to satisfy biological requirements. Subterranean fauna were previously believed to be mostly restricted to karst landscapes that provide a relatively high degree of secondary porosity, but in more recent times have been found to occur in various types of non-karstic geologies and aquifer systems that exhibit suitable voids for colonisation (Humphreys 2008).

Stygofauna are now known to occur in non-karstic aquifers in coarse alluvial sediments, fractured rock, pisolites and thin rocky regoliths (Halse *et al.* 2014, Humphreys 2006, 2008, MWH 2016, Outback Ecology 2014). Likewise, recent surveys have identified troglofauna from non-karstic geologies such as vuggy pisolite ore beds, and fractured and weathered rock formations in the Pilbara and Yilgarn regions (Barranco and Harvey 2008, Bennelongia 2009, Halse *et al.* 2002, MWH 2015, Outback Ecology 2011c, Subterranean Ecology 2008b).

The extent of subterranean fauna habitat is dependent on the interconnection of sub-surface crevices, fractures and voids, within suitable geological and hydrogeological units and aquifer systems. In addition to allowing for the movement of subterranean fauna, adequate interconnected void spaces and associated high permeability can provide pathways for infiltration (vertical or lateral) of resources such as oxygen and nutrients, key factors influencing subterranean fauna persistence and distribution (Humphreys 2008, Strayer 1994). Geological, hydrological, and hydrogeological studies can give an indication of the extent of subterranean fauna habitat present by providing information on the geological units and structures present, as well as recharge zones, groundwater flow or aquifer characteristics.

3.2 Stygofauna

Stygofauna (groundwater fauna) are predominantly comprised of invertebrates, particularly crustaceans. Other invertebrate stygofauna groups can include gastropods, insects, water mites and worms. In Western Australia, studies have shown that the calcrete and alluvial aquifers associated with palaeodrainage channels of the arid and semi-arid zones can contain rich stygofauna communities. The Pilbara and to a lesser extent the Yilgarn, stand out as global hotspots for stygofauna diversity (Halse *et al.* 2014, Humphreys 2008). Stygofauna can be further classified according to their level of dependency on the subterranean environment:

- stygoxenes are animals that enter groundwaters passively or accidentally;
- stygophiles inhabit groundwaters on a permanent or temporary basis; and
- stygobites are obligate groundwater dwellers and the focus of the stygofauna component of this assessment.

Stygobites are restricted to their subterranean environment and as such are often classified as short range endemics. Short-range endemic species (SRE's) have geographically restricted ranges of less than 10,000 km^2 and are considered more vulnerable to extinction because of their limited distribution range (Harvey et al. 2011, Harvey 2002). Stygobites can often be distinguished from surface or soil dwelling animals by morphological characteristics typical of a subterranean existence, such as a reduction or absence of pigmentation, absence or reduction of eyes, and the presence of extended locomotory and sensory appendages (Humphreys 2008). They can also be defined by ecological parameters such as longer life history stages, and lower rates of metabolism and fecundity (Cooper et al. 2002, Danielopol and Pospisil 2000).

Ecologically, there are many factors that influence the persistence and distribution of stygofauna at a range of habitat and temporal scales (Boulton 2000). Some of the more influential factors at the microhabitat (sediment) scale include suitable interstitial pore size (i.e. provision of connected network of habitable cavities), hydrological exchange inflow rates of resources (e.g. dissolved oxygen, organic carbon, biofilm growth, prey), and water quality parameters such as temperature, pH, dissolved oxygen and organic carbon levels. At the mesohabitat (catchment) scale, factors include surface water flow patterns influencing infiltration zones and hydrological exchange influx rates into the groundwater systems of energy resources or dissolved oxygen according to geomorphological features, as well as interactions with riparian vegetation and parafluvial sediments (Boulton *et al.* 1998, Schmidt *et al.* 2007).

3.3 Troglofauna

Troglofauna (air-breathing subterranean fauna) are often relictual forms related to surface dwelling (epigean) groups and can be distinguished by characteristics associated with a below-ground existence (Humphreys 2000b). Troglofauna can be divided into:

- troglophiles, which carry out most of their lifecycle underground but are able to survive in epigean habitats;
- trogloxenes, which can enter subsurface habitats passively or incidentally; and
- troglobites are obligate or permanent subterranean inhabitants (Thurgate et al. 2001) that generally lack pigmentation, are blind (or have reduced eyes), have elongated limbs and may possess enhanced non-visual sensory adaptations (Culver and Sket 2000), and ae the focus of the troglofauna component of this assessment.

Troglofauna are found worldwide and historically had been generally classified as cave organisms (Culver and Sket 2000). However, the discovery of diverse troglofauna communities inhabiting sub-surface rock fractures in non-karst areas in Europe in the 1980s prompted broader consideration of potential habitat (Juberthie 2000). The most common environments in which troglofauna occur are those that support suitably sized and extensively connected crevices, small cavities or vugs associated with secondary porosity from erosion, fractures and shears zones, that remain relatively humid, an important condition considered to be a key requirement for troglofauna existence (EPA 2003). Like stygofauna, troglobites are restricted to their subterranean environment and often have locally-restricted distributions so most species are considered to be SRE's that are more vulnerable to extinction because of their limited distribution range (Harvey *et al.* 2011, Harvey 2002).

The most researched areas in Western Australia are the Cape Range and Barrow Island karst cave systems where large, diverse communities have been discovered(Hamilton-Smith and Eberhard 2000, Humphreys 1991, 2000a). However, extensive sampling in areas of the Pilbara Craton has identified diverse troglofauna assemblages from non-karstic geologies such as vuggy pisolite ore beds (Biota 2006, MWH 2014a, b). Diverse troglofauna assemblages are commonly collected from groundwater associated calcrete (i.e. non-pedogenic calcrete) and alluvial/colluvial geologies within palaeodrainage channels of the arid and semi-arid zones, particularly in the Pilbara and Yilgarn regions (Harrison *et al.* 2014, MWH 2015, Outback Ecology 2011c, 2012a, c, Platnick 2008), but less so in the more arid interior of Australia (Outback Ecology 2011d). Less diverse troglofauna assemblages have also been recorded from weathered fractured rock (Outback Ecology 2011a, 2014) and metamorphic mafic rock systems (Bennelongia Environmental Consultants 2009).

Continued studies are likely to increase the understanding of prospective troglofauna habitat in Western Australia. It is only recently that troglofauna have become a focus of environmental assessment in Western Australia, and there is still relatively little information on their distribution compared to stygofauna (Eberhard *et al.* 2007, Environmental Protection Authority 2016a).

3.4 Risk and Relevant Legislation

Development and operation of mines in Western Australia pose risks to subterranean fauna and their habitat, which include:

- direct removal of, or disturbance to, habitats through mining excavation;
- lowering the groundwater table through groundwater abstraction for pit dewatering and supply; and
- altering water quality parameters, to levels which may exceed species tolerance limits.

Subterranean fauna are protected under State and Federal legislation, governed by three Acts:

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

With this legislation in mind, the EPA developed the *Technical Guidance Subterranean Fauna Survey* (2016b)(equivalent to EPA (2013) EAG 12 *Environmental Assessment Guideline for Consideration of Subterranean Fauna in Environmental Impact Assessment in Western Australia*) and the *Technical Guidance Sampling Methods for Subterranean Fauna Survey* (2016a)(equivalent to EPA (2007) *Guidance*

Statement No. 54A Sampling Methods and Survey Considerations for Subterranean Fauna in Western Australia) which outline considerations and sampling methods for subterranean fauna in Western Australia. These documents provide advice to proponents and the public on the requirements for environmental impact assessment (EIA) and management of subterranean fauna. The assessment reported here was designed in accordance with both the EPA (2016a, b) guidance documents.

Mining proposals that will potentially impact on groundwater, or hypogean habitats that support subterranean fauna, require a risk assessment to ensure mining operations do not threaten the viability of important species or communities. Proponents must demonstrate that any species existing within potential mine-related impact zones also occur outside this area. For taxa restricted to impact zones, a suitable management plan must be developed, which includes ongoing monitoring of subterranean fauna to ensure the persistence of the species.

3.5 Regulatory Survey Adequacy Guidelines

The EPA (2016a) stipulates that the appropriate level of survey depends on the likely presence of subterranean fauna, the degree of impact proposed, and adequacy to reliably inform decisions as part of the EIA process as to whether a proposal meets the EPA's objective and is tailored to the circumstances of the proposal.

For Level 1 low intensity (pilot) surveys the recommended survey intensity considered to provide a reliable indication of the habitat present hosting subterranean fauna is:

- Troglofauna — 10 to 15 samples; and
- Stygofauna — 6 to 10 samples.

If the findings from a desktop assessment and pilot survey indicate that a study area is not prospective for subterranean fauna then no further survey would be required. If a pilot survey does collect stygofauna and / or troglofauna species, thereby demonstrating that subterranean fauna are a potential environmental factor, then a Level 2 (baseline or comprehensive) survey would be required.

The EPA (2016b) recommends that for Level 2 (baseline) stygofauna surveys in areas that have been demonstrated to host a stygofauna assemblage, a minimum of 40 net haul samples are to be collected over at least two survey seasons from within proposed impact areas. The minimum survey effort is considered to relate to proposed impacts across an interconnected habitat, not a collated impact survey effort of separate habitats that are each likely to host distinct stygofauna assemblages with no, or restricted, gene flow occurring among each system.

For Level 2 (baseline) troglofauna surveys in areas that are likely to host 'significant troglofaunal values', a minimum of 60 litter trap samples deployed over two rounds for a minimum of six weeks each are recommended (EPA 2016b). The definition of 'significant values' is not specified or quantified but has been interpreted to relate to the presence of a relatively diverse troglofauna assemblage in or associated with the proposed development area.

4. Methods

4.1 Database Searches and Lists

Searches of both federal and state databases were undertaken as part of the desktop review for stygofauna or troglofauna taxa records from within or near the Study Area, and to identify threatened or priority ecological communities (TEC's and PEC's). Search areas were from the central point of the Study Area (**Table 4-1**). Database and internet information sources included:

- Department of Biodiversity, Conservation and Attractions (DBCA) TEC/PEC database was searched for TEC's and PEC's occurring within a 75 km radius of the Study Area;
- Western Australian Museum's (WAM) arachnid, crustacean, myriapod and oligochaete collection databases were searched for subterranean fauna;
- Atlas of Living Australia (ALA);
- Nature Map of Western Australia; and
- Stantec's Biolink Subterranean Fauna Database (SBSFD).

The following Federal and State government lists were also checked against the database results, to identify any threatened or priority subterranean fauna that may occur within the search area:

- WC Act Schedule Species List;
- EPBC Act TEC List; and
- EPBC Act Threatened Fauna List.

Table 4-1: Defined search parameters of database and internet sources.

Data Source	Search Area	Co-ordinates
DBCA TEC/PEC	75 km radius	Central point @ 30.721952 S, 122.566144°E
Nature Map		
Literature Review		
WAM Collections		
ALA		
SBSFD		

4.2 Literature Review

A literature review was conducted to gather existing information on subterranean fauna from within the vicinity of the Study Area. The review included technical reports, scientific journal articles and government publications. The areas of focus for the literature review were drainage and palaeochannel systems associated with and/or near to the Project within approximately 75 km of the Study Area.

4.3 Field Personnel and Licences

The field survey methods and sampling effort employed for the Lake Roe subterranean fauna verification survey followed both the EPA (2016a, b) technical documents. Regulation 17 licence to take fauna for scientific purposes (*Wildlife Conservation Act 1950*, Regulation 17) was obtained from the DBCA prior to survey: Licence Number 08-002978-1. Stantec personnel involved in the field sampling were Dr Nicholas Stevens and Emma Dobinson.

4.4 Groundwater Properties

Groundwater properties can have an important influence on the occurrence and distribution of stygofauna and their habitat. A number of basic groundwater physicochemical parameters (electrical conductivity (EC), pH, water temperature, dissolved oxygen (DO), and reduction-oxidation potential (Redox)) were recorded in the field from a water sample collected by a bailer from the upper one to two metres of the bore column using a calibrated YSI water quality meter.

Standing water level (SWL) was measured as metres below ground level (m bgl) using a Solinst 101 water level meter. The end of hole depth (EoH) was calculated from the number of rotations of the stygofauna sampling winch reel required to retrieve stygofauna nets.

4.5 Stygofauna Assessment

4.5.1 Net Haul Sampling

Stygofauna samples were taken from exploration drill holes (referred to henceforth as sites) using haul nets, which have been found to be the most efficient retrieval method (Allford *et al.* 2008). The details of sites sampled are presented in **Appendix A,** including representative site photos (**Figure A-1**). Sampling was consistent with the procedures outlined by the EPA (2016b). The sampling method was as follows:

- samples were collected using two weighted haul nets with mesh sizes of 150 µm and 50 µm. Each net was fitted with a collection vial with a base mesh of 50 µm;
- the 150 µm net was lowered first, to near the bottom of the site;
- once at the bottom, the net was gently raised up and down to agitate the sediments;
- the net was then raised slowly, to minimise the 'bow wave' effect that may result in the loss of specimens, filtering the stygofauna from the water column on retrieval;
- once retrieved, the collection vial was removed, the contents emptied into a 250 ml polycarbonate vial, and preserved with 100% undenatured ethanol;
- this process was repeated three times alternating with three samples with the 50 µm net;
- to prevent cross-contamination, all sampling equipment was washed thoroughly with Decon 90 (2 to 5% concentration) and rinsed with potable water after each site;
- in the field, samples were placed into eskies with ice bricks prior to being transferred into a refrigerated environment on-site at the end of each survey day; and
- samples were couriered back to the Stantec laboratory in Perth, where they were stored in 100% ethanol and refrigerated at approximately minus 20°C.

4.5.2 Stygofauna Survey Effort

A total of 16 stygofauna net haul samples were collected from 16 sites across the Study Area from October 16 to 18, 2018 (**Appendix A**). The survey effort undertaken exceeded the recommended number of six to ten samples for a Level 1 low intensity (pilot/verification) stygofauna survey by EPA (2016a). The survey intensity undertaken, in conjunction with the habitat present, is considered to be sufficient to enable a reliable verification to be made of the stygofauna values present in the Study Area in accordance with the EPA (2016b).

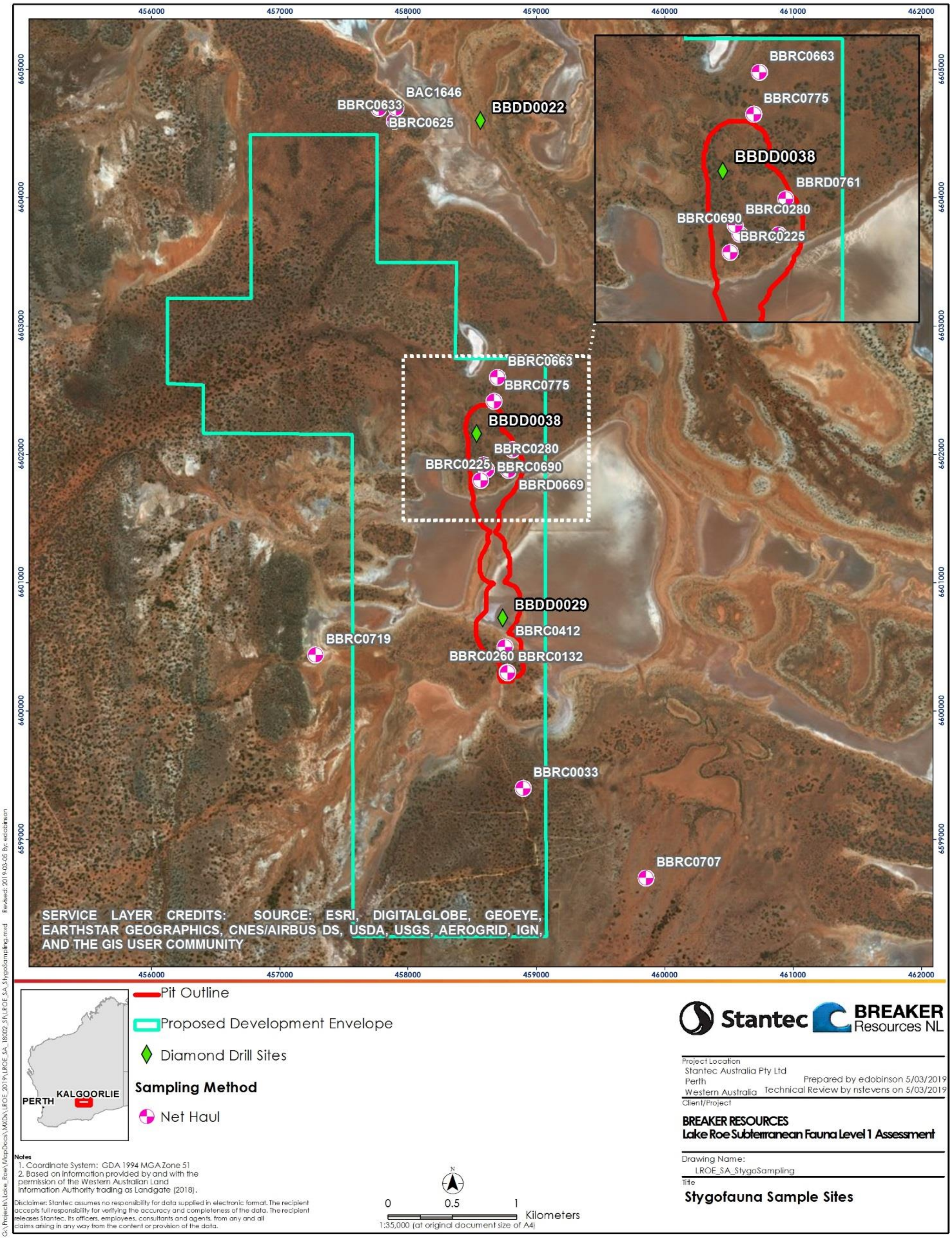

Figure 4-1: Stygofauna sample sites.

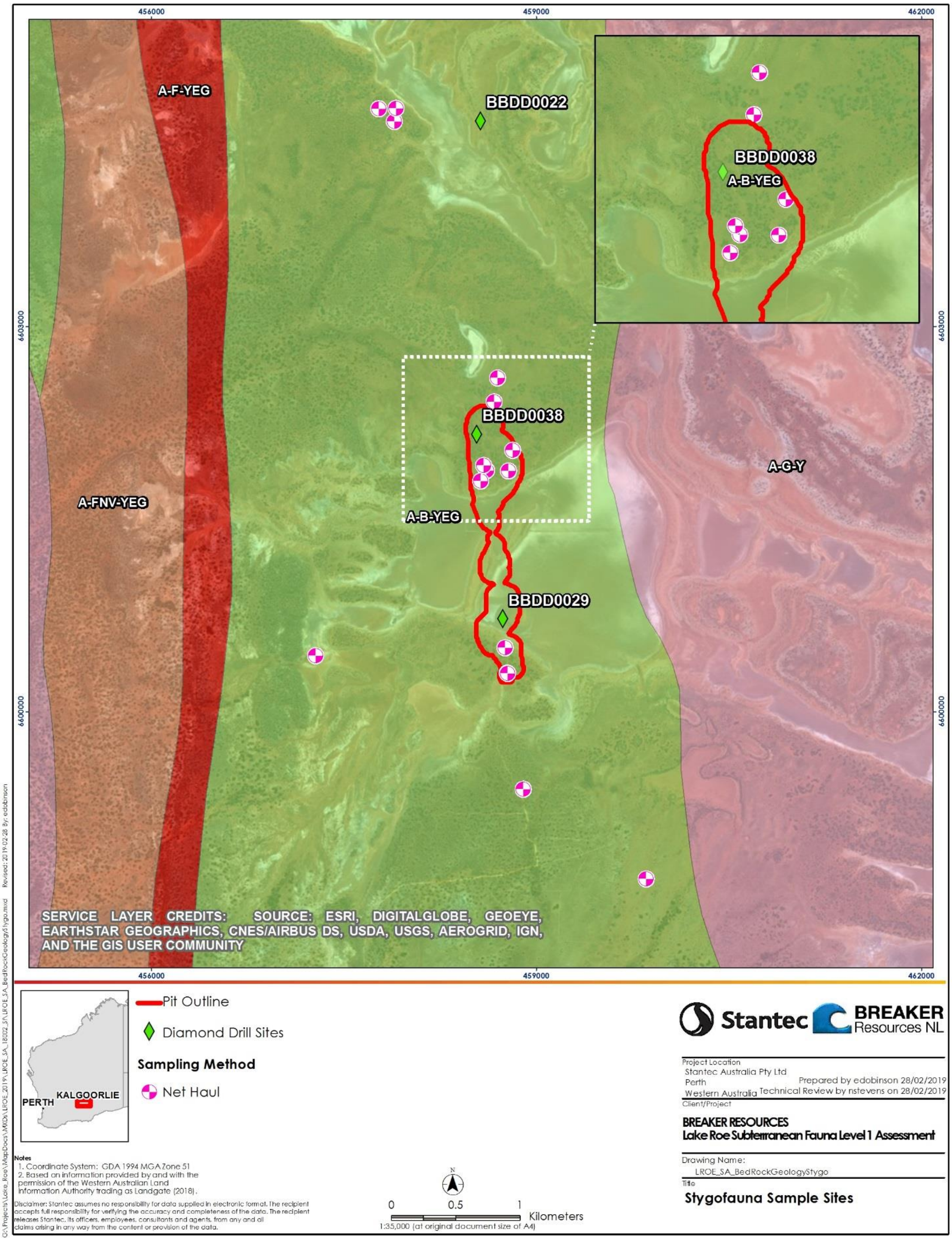

Figure 4-2: Stygofauna sample sites in relation to sub-surface geology (refer to Figure 2-7 for legend).

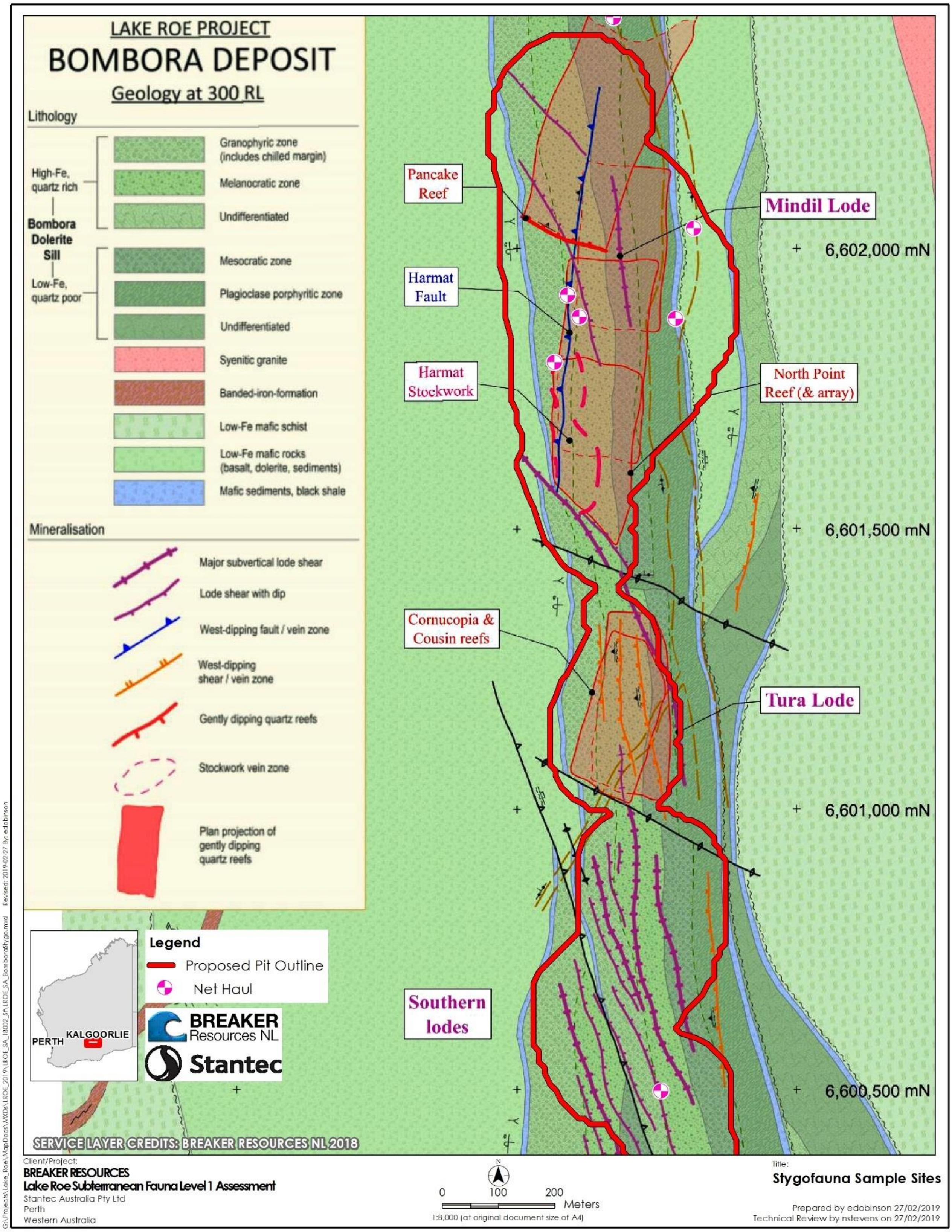

Figure 4-3: Stygofauna sample sites in relation to bedrock geology and geological structures (adapted from (Breaker Resources NL 2018).

4.6 Troglofauna Survey

Troglofauna samples were taken from exploration drill holes (sites) using litter traps and net haul scrapes. The details of sites sampled are presented in **Appendix A.**

4.6.1 Litter Traps

Troglofauna were sampled using litter traps as follows:

- litter traps were packed with sterilised organic material and sealed to maintain moist, sterile conditions prior to field deployment;
- traps were then moistened with water prior to deployment in sites;
- once installed in the sites, traps were left in place for eight weeks to allow adequate time for colonisation by troglofauna; and
- on retrieval, traps were sealed in zip lock bags, labelled, and couriered to the Stantec laboratory in Perth for sorting and identification.

In the laboratory, troglofauna specimens were extracted from the litter using Tullgren funnels. Litter was placed into funnels, and light and low heat was applied from overhead lamps to create a temperature gradient of approximately 14°C in the litter (**Figure 4-4**). This method was applied to encourage any troglofauna, which are light sensitive and prefer humid conditions, to migrate down through the litter as it dried. Troglofauna specimens then fall through a mesh layer into collection vials at the base of the funnels, containing 100% ethanol. After collection of troglofauna in the vials, the litter was removed from the funnels and manually searched under magnification for any troglofauna specimens that might be remaining.

Figure 4-4: Troglofauna collection and extraction methods: A) Litter trap; B) Tullgren funnels.

4.6.2 Net Haul Scraping

Net haul scraping has been found to be an efficient method for sampling for troglofauna that compliments troglofauna trapping (Halse and Pearson 2014, MWH 2014a, Outback Ecology 2011c, Stantec 2017a, Subterranean Ecology 2008a). Net haul scraping involves the following:

- lowering of a stygofauna net to the bottom of a dry site or at least 1 m below the standing water level if groundwater is present.
- scraping the net up along the uncased wall surface of the site on retrieval with the aim of dislodging and collecting any invertebrates that may be present.
- this process is repeated four times per site with each scrape sampling a different side of the wall surface of the site.

Scraping for troglofauna can also be conducted simultaneously when sampling uncased bores with water present for stygofauna so that the stygofauna sample also counts as a troglofauna scrape sample. The only difference is the sample effort is greater with six net hauls taken per sample rather than four. Stygofauna sampling of fully-cased bores are not regarded as net haul scrape samples, regardless of whether potential troglofauna taxa may have been collected.

All haul samples were preserved in 100% ethanol prior to shipment back to the Stantec laboratory in Perth for processing. To enhance preservation of specimens and their DNA, samples were kept cool onsite in eskies with ice bricks then refrigerated at the end of each survey day. All samples were then shipped back to Perth in eskies with ice bricks then placed in freezers (at minus 20 Celsius) to further promote fixation of DNA.

4.6.3 Troglofauna Survey Effort

A total of 15 litter trap samples and 16 scrape samples were collected from 23 sites (**Appendix A**). All troglofauna litter traps were deployed over one survey phase for seven weeks from October 16 to December 8, 2018. Scrape samples were also collected in conjunction with the stygofauna sampling undertaken in October 2018.

The survey effort undertaken exceeded the recommended number of ten to fifteen samples for a Level 1 low sample intensity (pilot/verification) by the EPA (2016a). The survey intensity undertaken, in conjunction with the habitat present, is considered to be of a sufficient quantity to provide a reliable verification of the troglofauna values present in the Study Area in accordance with the EPA (2016b).

4.7 Sorting and Identification of Specimens

Preserved samples were processed using Leica MZ6, MZ7.5, M80 and M205C stereomicroscopes by Dr Nicholas Stevens, Jack Stanbury and Emma Dobinson. Once sorted, any potential subterranean fauna specimens found would be preserved in 100% ethanol and stored at minus 20°C to ensure viability for future DNA analysis (if required).

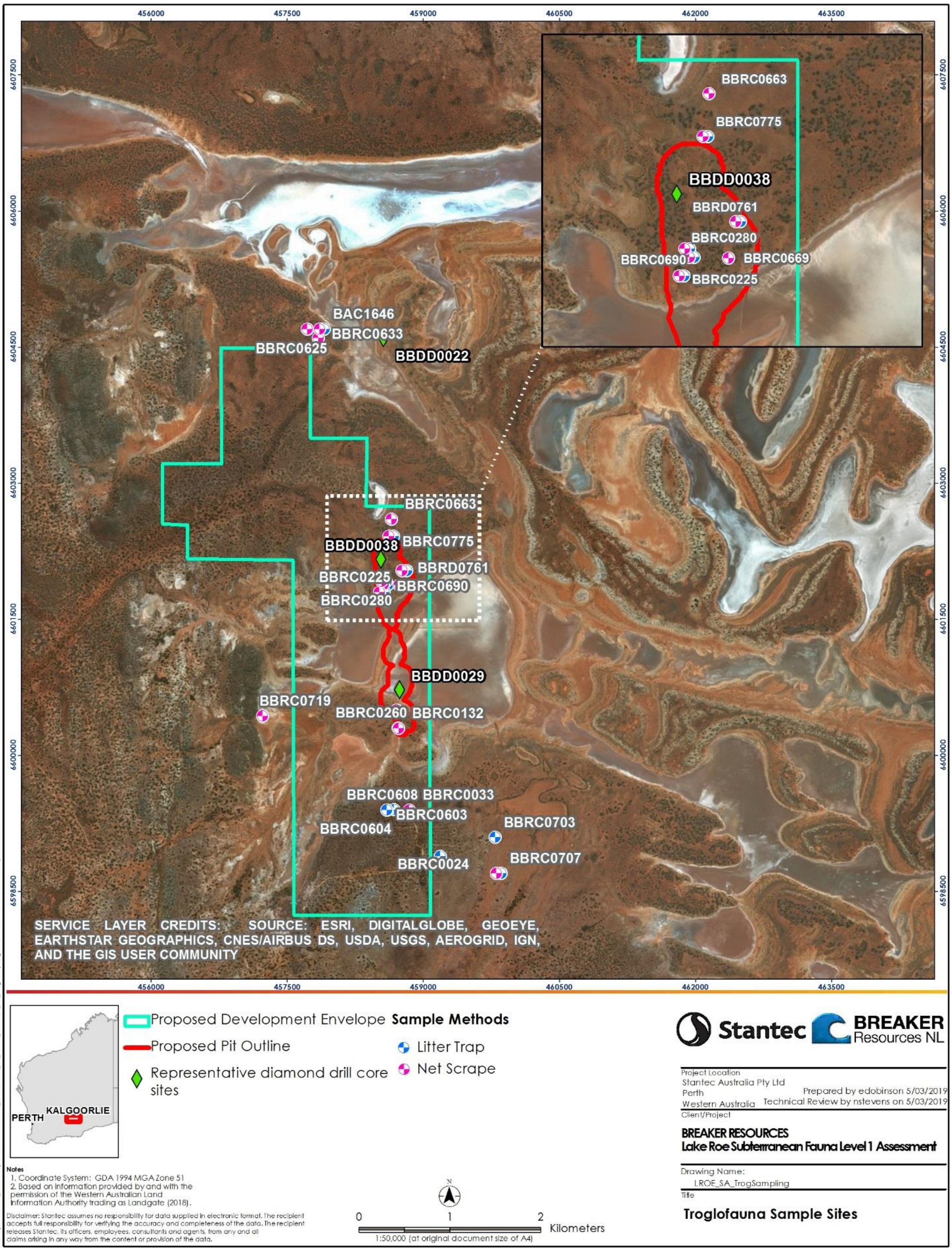

Figure 4-5: Troglofauna sample sites.

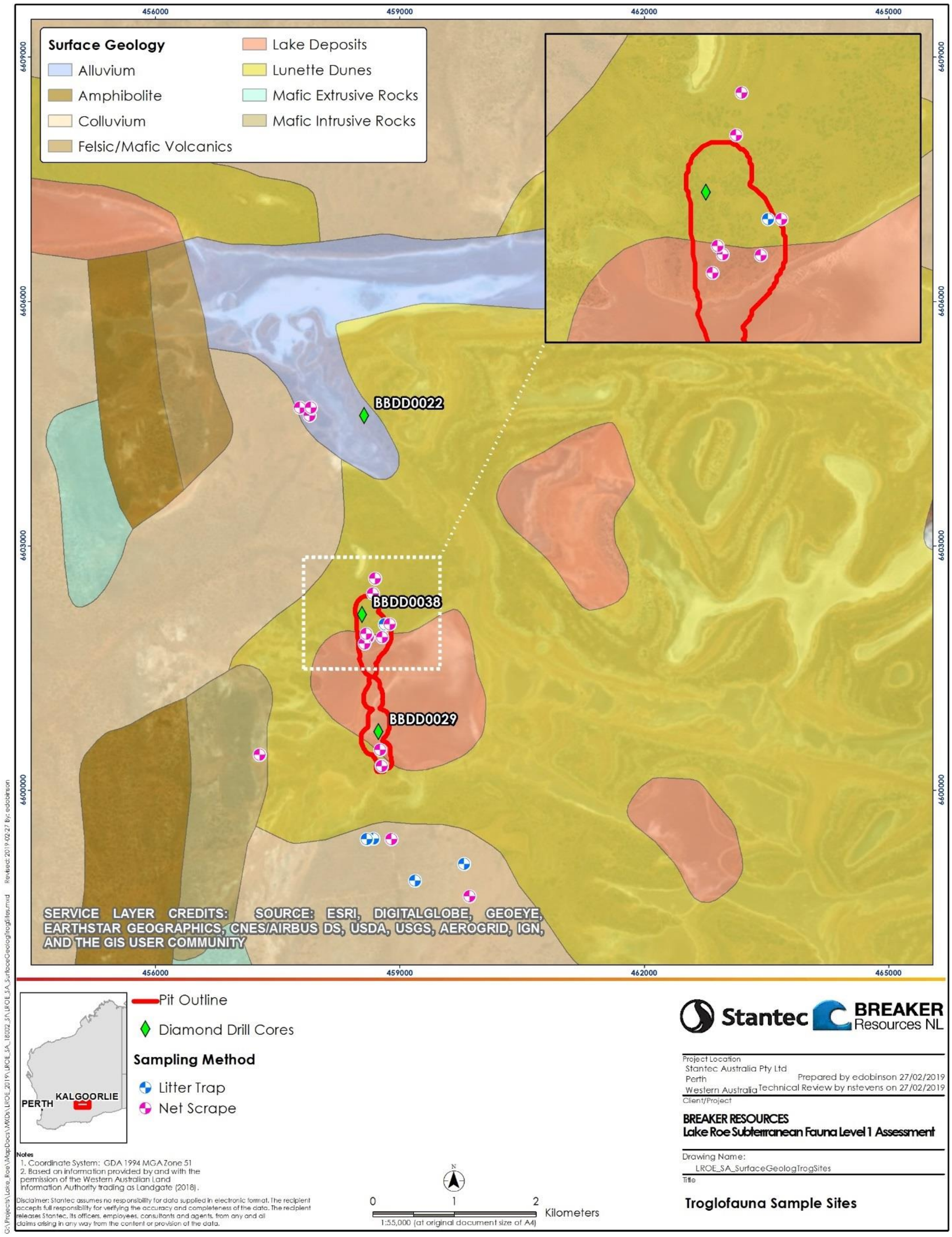

Figure 4-6: Troglofauna sample sites in relation to surface geology.

5. Results and Discussion

5.1 Database Searches and Literature Review

5.1.1 Database Searches

Database searches indicated that there were no TEC or PEC subterranean communities identified within the vicinity of the Project. There were also no listed conservation significant stygofauna or troglofauna records or threatened subterranean fauna taxa found during the database searches.

There were no records identified in the vicinity of the Project during a search of the WAM's crustacean database. In addition, while WAM's arachnid database contained numerous records for the search area, none were classified as subterranean fauna. Instead, terrestrial spiders, scorpions and pseudoscorpions accounted for most entries.

5.1.2 Stygofauna

There is limited publicly available information available on stygofauna in the vicinity of the Project. In addition, those that are available have typically been limited to desktop studies. Several of these have been undertaken in the vicinity of Lake Randall and Lake Lefroy, approximately 50 to 100 km south of Lake Roe (**Table 5-1**).

The findings of these studies suggest that the likelihood of stygofauna occurring in salt lake environments is generally nil to low. This is primarily attributed to a lack of vugs and voids in the saturated strata and hypersaline, often acidic, groundwater conditions in the vicinity of the playas. Low permeability and low hydraulic conductivity were other factors noted when assessing likelihood of stygofauna (Subterranean Ecology 2010a). One of the only hydrogeological units identified as possible stygofauna habitat was the Quaternary transported sediment aquifer on elevated ground near Lake Lefroy. This unit had moderate permeability and comparatively lower salinities (50,000 mg/L) (Subterranean Ecology 2010a).

Literature based on stygofauna sampling appears to be restricted to a single pilot stygofauna survey at Lake Randall, approximately 50 km south of the Project (Outback Ecology 2008a). This survey of 12 bore holes, primarily tageting alluvial groundwater adjacent to the playa, did not find any stygobitic species.

In the northern Yilgarn/Goldfields region, at latitudes north of 29° S, diverse stygofauna communities have primarily been collected from valley calcretes (formed in association with the groundwater) and associated alluvial habitats (Bennelongia 2015, MWH 2015, Outback Ecology 2011c, 2012b, Stantec 2018). Weathered and fractured rock aquifers have also been shown to host stygofauna, although, the diversity has tended to be lower (Bennelongia 2009, ecologia Environment 2008, MWH 2016, Stantec 2017b).

In comparison, no stygofauna have been recorded from the south-eastern Goldfields region, below 29° S, which is considered to approximate the southern limit of the valley calcretes (Humphreys 2001). The absence of stygofauna values is a likely reflection of the sub-optimal habitats present in the region, but may also be influenced to a degree by the limited sampling, highlighted by the paucity of surveys in the region of the Project. The prevailing scientific opinion on the main factor causing the contrast in the diversity of stygofauna between the northern and south-eastern Goldfield regions is the different prehistoric conditons of each (Humphreys 2001).

The northern Yilgarn region, along with the Pilbara region, has remained above sea level since the Proterozoic whereas the southern Yilgarn has not (Humphreys 2001). This has meant the stygofauna of the northern Yilgarn have evolved from freshwater systems, with the development of relatively extensive valley calcrete formations providing favourable refugia with the onset of increasing aridity since the Miocene (Humphreys 2001, 2008, Humphreys *et al.* 2009). In constrast, south of 29° S, little non-pedogenic cacrete is deposited, with groundwaters typically hypersaline and more acidic (Humphreys 2001).

Table 5-1: Literature search results of subterranean fauna studies undertaken in the vicinity of the Project.

Reference	Company	Project	Survey Components	Survey Timing	Key Findings	Conservation Significant Taxa
Phoenix (2016) cited in Talis (2016)	St Ives Gold Mining Company Pty Ltd	Lake Lefroy	Subterranean fauna desktop assessment	2016	Stygofauna considered unlikely, on account of hypersaline groundwater. Limited capacity for troglofauna to occur due to lack of vugs. Shallow water table also a factor in the vicinity of the playa.	Nil
Outback Ecology (2012e)	Integra Mining Ltd	Randalls Gold Project	Regional subterranean fauna desktop assessment	Oct-12	Low prospectivity for stygofauna and troglofauna in the broader area attributed to a general absence of open fractures and interconnected vugs and voids, low hydraulic conductivities and sub-optimal water quality.	Nil
Outback Ecology (2012d)	Integra Mining Ltd	Majestic	Subterranean fauna desktop assessment	Aug-12	Stygofauna and troglofauna communities unlikely based on lack of vugs and voids, in addition to potentially acidic and hypersaline groundwaters.	Nil
Outback Ecology (2011b)	St Ives Gold Mining Company Pty Ltd	West Idough	Subterranean fauna desktop assessment	Jun-11	Low likelihood of stygofauna and troglofauna, attributed to a general lack of vugs/voids and hypersaline groundwater.	Nil
Subterranean Ecology (2010b)	St Ives Gold Mining Company Pty Ltd	Lake Lefroy	Troglofauna desktop assessment	Mar-10	Rare to nil likelihood of troglofauna occurring for the majority of geological units, (lake deposits, palaeochannel and weathered and/or fractured bedrock). Quaternary transported sediments on the Lake Lefroy Islands and higher ground surrounding the playa were identified as only possible habitats for troglofauna.	Nil
Subterranean Ecology (2010a)	St Ives Gold Mining Company Pty Ltd	Lake Lefroy	Stygofauna desktop assessment	Mar-10	Nil likelihood of stygofauna in the superficial, palaeochannel or weathered and fractured bedrock aquifers associated with Lake Lefroy, on the basis that salinities exceeded 170,000 mg/L. For the higher grounds surrounding the lake, the aquifer within the Quaternary transported sediments was identified as a possible stygofauna habitat.	Nil
Outback Ecology (2008a)	Integra Mining Ltd	Lake Randall	Pilot stygofauna survey	Jul-08	Low numbers of copepods, oligochaetes and rotifers collected along the margin of Lake Randall. Copepods identified as surface water inhabitants. Oligochaetes and rotifers considered unlikely to be stygobitic.	Nil
Outback Ecology (2008)	Integra Mining Ltd	Salt Creek	Subterranean fauna desktop assessment	May-08	Area considered unlikely to support stygofauna or troglofauna.	Nil

5.1.3 Troglofauna

Available information on troglofauna in the Study Area and surrounding region is sparse. Subterranean fauna desktop assessments for the Lake Lefroy and Lake Randall areas, approximately 50 to 100 km south represent the most proximal investigations. The general consensus among these desktop assessments was that the likelihood of troglofauna, particularly in playa environments, is low.

The shallow water table is identified as a likely barrier to troglofauna habitation (Phoenix 2016) cited in (Talis 2016) while the lack of vugs and voids has also been noted as a limiting factor. As with the stygofauna desktop assessments in the vicinity of the Project, the Quaternary transported sediments on higher ground (and playa islands) near Lake Lefroy were the only geological units identified as possible troglofauna habitat (Subterranean Ecology 2010b).

5.2 Stygofauna Habitat Characterisation

The habitat assessment indicates that it is highly unlikely that the hydrogeological units present within the Study Area support stygofauna (**Table 5-2**). Within the Lake Roe playa area, the shallow water table (<2m bgl) mostly coincides with Cainozoic transported sediments in the form of lake deposits. Unconsolidated lake clays represent the dominant unit, typically ranging between 1.5-10 m in thickness and exceeding 40 m in some areas. The absence of interconnected pore spaces in this sequence is shown by representative diamond drill core images from BBDD0029 (0 to 1.8 m) and indicate an unsuitable structural environment for stygofauna (**Figure 5-1, Figure 4-6**). This lack of structure and resultant low permeability is also reflected in the underlying residual clays, which extend to 4.2 m at BBDD0029 (**Figure 5-1**).

Bedrock geology below the playa and surrounding area is typified by mafic units, principally dolerite of variable quartz content with limited sections of quartz vein (**Figure 2-6**). Secondary porosity from fractures and weathering within these units, intersected from 4.7 m in drill core BBDD0029 (**Figure 5-1**), represent a more prospective habitat than the overlying transported sediments. However, the clay dominated sequences that overlay much of the area, would restrict the influx of nutrients and organic matter required to support stygofauna.

The deeper palaeochannel deposits that underlay the playa are relatively limited within the Study Area and are not known to represent stygofauna habitat. An increased prevalence of these units is likely to the north of the Project, corresponding with the main trunk of the Roe Palaeochannel (**Figure 2-8**).

The groundwater salinity recorded in the Study Area was mostly hypersaline, *sensu* Hammer (1986), ranging from 128,371 to 60,679 mg/L, mean 76,641 mg/L (**Table 5-3**, **Appendix B**). Two sites, BBRC0132 and BBRC0033, recorded fresh to hyposaline groundwater conditions. Considering the hypersaline conditions recorded in close proximity to each site, it is considered highly likely that the water column conditions were heavily influenced by surface run-off from recent rainfall, and therefore, not representative of the groundwater conditions present.

The extensive hypersaline groundwater conditions (>150,000 mg/L) throughout the Roe palaeochannel, including the playa, would be a significant limiting factor to stygofauna habitation within each of the associated hydrogeological units (**Figure 2-9**). Typically, many stygofauna show a preference for salinity levels less than that of seawater (<35,000 mg/L or <55 mS/cm) (Strayer 1994). However, some species can tolerate salinity levels up to 40,000 mg/L, with fewer species, more commonly copepods, able to exist in salinities in excess of 45,000 mg/L (Humphreys 2008, MWH 2015, 2016b, Outback Ecology 2011b, 2012d). In general, stygofauna diversity is known to decline with increasing salinity above 4,000 mg/L (MWH 2015, 2016b, Outback Ecology 2011b, 2012b). In the absence of adjoining freshwater systems, the hypersaline groundwaters of the Lake Roe aquifers are expected to preclude stygofauna.

The groundwater across the Study Area ranged from acidic (pH 4.1) to circumneutral (pH 7.4), mean acidic (pH 6.2) (**Table 5-3**, **Appendix B**). Only one site, BBRC0033, recorded alkaline conditions (pH 8.2), however, as mentioned above, the water sample from this site is not considered to be representative of the groundwater conditions present. Acidic groundwater conditions, ranging between pH 3 to 5, commonly occur in aquifers of the Kalgoorlie area (Gray 2001). Acidic groundwaters, which are generally associated with igneous and metamorphic sedimentary rocks, provide less suitable conditions for stygofauna (Humphreys 2008). Abundant stygofauna communities are often associated with alkaline groundwaters (Humphreys 2008) and the few collections from acidic environments have typically occurred in conjunction with relatively low groundwater salinities (Reeves *et al.* 2007). Stygobitic copepods were recorded from two bores characterised by slightly acidic (5.98 to 6.7) and mesosaline (26,000 to 34,000 mg/L) groundwater conditions, over 330 km south-west of Lake Roe within the southern wheatbelt region (Karanovic *et al.* 2013). The combination of acidic and hypersaline groundwater conditions within and around the Study Area is considered highly likely to preclude stygofauna.

The hydrogeological units present in the low-lying riparian and terrestrial areas are governed by similar factors to the hydrogeological units within the playa. The components of the Cainozoic transported sediments vary from the playa area, comprising lunette dunes, sand, indurated ferricrete and some lake clay (Breaker Resources NL 2018) (**Figure 4-6**), yet still lack adequate interconnected pore spaces for optimal stygofauna habitat. The underlying residual clay strata also contain very few interconnected pores, as evident in the clay dominated layer (2.53 m to 7.19 m) for diamond drill core BBDD0038 (**Figure 5-2**).

The low permeability of the transported sediments and residual clay units would collectively restrict influx of resources to the underlying bedrock units. Outcropping in the immediate vicinity is limited and would be unlikely to facilitate the movement of nutrients and organic matter for stygofauna. While outcropping of mafic bedrock units to the west (**Figure 4-6**) could provide a more prospective pathway for resource infiltration, groundwater salinities would still exceed the levels expected to support stygofauna.

Shear zones near the claypan shear (eastern branch) have similar sand and clay-dominated upper sequences to other low-lying sections (**Figure 5-3, Figure 2-5, Figure 2-6**). The proximity to the playa also indicates hypersaline groundwater conditions. The geological structure and hypersaline groundwater conditions of palaeochannel deposits in the low-lying terrestrial/riparian area also suggest habitat that is highly unlikely to host stygofauna.

Alluvial gravel within the transported sediments of the more elevated areas could represent a prospective habitat, with coarse alluvium known to host stygofauna (Humphreys 2006). Factors moderating the likelihood include the limited extent of saturated alluvial units and poor surface/groundwater interaction as compared to more favourable alluvial habitat (Hancock and Boulton 2008, Humphreys 2008). In addition, stygofauna from alluvial strata are often recorded in the vicinity of hydrogeological units such as groundwater calcrete (Bennelongia 2015, Outback Ecology 2011c), which do not occur in the Study Area.

Table 5-2: Assessment of prospectivity for stygofauna within the dominant hydrogeological units of the Study Area.

Area	Hydrogeological Unit	Factors	Prospectivity for Stygofauna
Playa			
	Transported sediments-lake deposits	Low permeability, hypersaline groundwater (>150,000mg/L), low pH	Highly unlikely
	Palaeochannel deposits	Hypersaline groundwater	Highly unlikely
	Residual clay/saprolite	Low permeability, hypersaline groundwater (>150,000mg/L), low pH	Highly unlikely
	Weathered and fractured bedrock	Low permeability, hypersaline groundwater (>150,000mg/L), overlain by low permeability clay in most areas	Highly unlikely
Riparian/Terrestrial			
Low-lying areas	Transported sediments-sand, ferricrete, lake clay	Low permeability, hypersaline groundwater (inferred >150,000), low pH	Highly unlikely
	Residual clay/saprolite	Low permeability, hypersaline groundwater (>150,000mg/L), low pH	Highly unlikely
	Palaeochannel deposits	Hypersaline groundwater	Highly unlikely
	Weathered and fractured bedrock	Hypersaline groundwater (>150,000mg/L), overlain by low permeability clay in most areas	Highly unlikely
Elevated areas	Transported sediments–ferricrete, alluvial gravels	Saline to hypersaline groundwater, limited saturated extent, not adjoining highly prospective habitat (calcrete)	Highly unlikely
	Residual clay/saprolite	Low permeability, hypersaline groundwater	Highly unlikely
	Weathered and fractured bedrock	Hypersaline groundwater, overlain by low permeability clay in most areas	Highly unlikely

Table 5-3: Minimum, maximum and mean of groundwater parameters recorded from Study Area in 2018.

	Elevation upper (AHD)	SWL (AHD)	SWL (mbgl)	DO (mg/L)	EC (mS/cm)	TDS (mg/L)	pH
Min	319	316.07	1.56	0.02	2.284	1,485	4.08
Max	323	320.02	6.93	9.45	197.494	128,371	8.22
Mean	321	317.96	3.04	2.26	117.91	76,641	6.24
Number	16	16	16	16	16	16	16

Figure 5-1: Diamond drill core images from BBDD0029, located along the margin of Lake Roe.

Figure 5-2: Diamond drill core images from BBDD0038, located within the low-lying area beyond the playa of Lake Roe.

Figure 5-3: Diamond drill core images from BBDD0022, located within the low-lying area, near the Claypan Shear (eastern branch).

5.3 Troglofauna Habitat Characterisation

The shallow water table within the playa, riparian and low-lying terrestrial areas equates to an unsaturated zone of less than 1 m in some sections. The probability of troglofauna occurring under these conditions is considered highly unlikely (**Table 5-4)**. A limited extent of unsaturated strata, exacerbated by seasonal fluctuations, would likely create an environment unsuitable for troglofauna. In addition, the primary geological units within the unsaturated zone, generally lake clays in the playa and sand, ferricrete and residual clays in the surrounding areas do not support the interconnected vugs and voids traditionally associated with troglofauna (**Figure 5-1,Figure 5-2,Figure 5-3**). While work in the northern Goldfields has identified troglofauna in fine-grained materials adjacent to playas, distributions have typically incorporated units such as groundwater calcrete which are lacking in the Study Area (Outback Ecology 2011b;2012b).

Based on geology and depth to groundwater, elevated areas away from the playa represent a more prospective habitat for troglofauna (**Table 5-4**). Transported sediments, primarily comprising sand, ferricrete and alluvial gravel, represent the most likely habitat. In particular, alluvial units are known to support troglofauna, although generally in conjunction with geological facies such as banded ironstone or groundwater calcrete (Biota 2015; Outback Ecology 2011b;2012b). The level of prospectivity for alluvial strata is likely to be reduced in the absence of these more prospective units.

As with the low-lying playa and terrestrial areas, the clay sequence in elevated areas is expected to lack the matrix of vugs and voids associated with favourable troglofauna habitat. Limited sections of outcropping or sub-cropping bedrock within the Study Area are unlikely to be of sufficient extent to provide habitat or adequate pathways for resource infiltration.

Table 5-4: Assessment of prospectivity for troglofauna within the dominant unsaturated geological units of the Lake Roe Study Area

Area	Geological Unit	Factors	Prospectivity for Troglofauna
Playa			
Playa	Transported cover – sand, lake clay	Very thin unsaturated zone, lacks interconnected vugs and voids	Highly unlikely
	Residual clay/saprolite	Predominantly saturated, lacks interconnected vugs and voids	Highly unlikely
	Weathered and fractured bedrock	Predominantly saturated, typically overlain by low permeability clay	Highly unlikely
Riparian/Terrestrial			
Low-lying areas	Transported cover- sand, ferricrete, lake clay	Very thin unsaturated zone, lacks interconnected vugs and voids	Highly unlikely
	Residual clay/saprolite	Predominantly saturated, lacks interconnected vugs and voids	Highly unlikely
Elevated areas	Transported cover – sand and alluvial gravels	Lacks interconnected vugs and voids, not adjoining highly prospective habitat (calcrete, BIF)	Unlikely/possible
	Residual clay/saprolite	Lacks interconnected vugs and voids	Highly unlikely
	Weathered and fractured bedrock	Predominantly saturated but some outcropping/sub-cropping identified, often overlain by low permeability clay	Highly unlikely/unlikely

5.4 Subterranean Fauna Survey Findings

There were no species of stygofauna or troglofauna collected from the 23 sites sampled within the Study Area during the subterranean fauna survey (**Figure 4-1**, **Figure 4-5**, **Appendix A**). The survey effort conducted was considered more than sufficient to provide a reliable verification of the likely prospectiveness of the habitats sampled for hosting stygofauna and/or troglofauna within the Study Area. The survey findings were consistent with the habitat characterisation and desktop assessment, and indicated that the Study Area does not provide prospective habitat for subterranean fauna.

6. Conclusion

The Level 1 subterranean fauna assessment undertaken, incorporating a desktop review and pilot survey, has demonstrated that the Lake Roe gold deposit in the Study Area does not provide prospective habitat for subterranean fauna and does not support stygofauna or troglofauna values. The survey findings confirmed that the clay dominated regolith does not provide the extensive interconnected vugs, voids and open fractures required for subterranean fauna colonisation.

The acidic and hypersaline groundwater conditions within and surrounding the Study Area, in conjunction with the clay-dominated strata that restricts the influx of resources (e.g., nutrients and oxygen), present unfavourable habitat for stygofauna. For troglofauna, the limited unsaturated strata, due to the shallow water table, lacks the interconnected vugs and voids required for troglofauna habitation.

The findings indicate that stygofauna and troglofauna do not represent an environmental factor for future regulatory approvals of the Project in accordance with EPA (2016), and there is no risk of impacts to subterranean fauna values. Therefore, no further stygofauna or troglofauna assessment is considered necessary to provide further information on the subterranean fauna values of the Study Area. The proposed development of the Project will meet the relevant EPA objectives and the proposal does not pose a threat to maintaining subterranean fauna representation, diversity, viability and ecological function at the species, population or assemblage level.

7. References

Allford, A., Cooper, S. J. B., Humphreys, W. F. and Austin, A. D. (2008) Diversity and distribution of groundwater fauna in a calcrete aquifer: does sampling method influence the story? *Invertebrate Systematics* 22: 127-138.

Barranco, P. and Harvey, M. S. (2008) The first indigenous palpigrade from Australia: a new species of Eukoenenia (Palpigradi : Eukoeneniidae). *Invertebrate Systematics* 22: 227-233.

Beard, J. S. (1976) *The vegetation of the Boorabbin and Lake Johnston Areas* Vegmap Publications, Perth, Western Australia.

Beard, J. S. (1979) Phytogeographic Regions. In: J. Gentilli (ed) *Western Landscapes*. University of Western Australia Press, Perth, pp 107-121

Beard, J. S. (1990) *Plant Life of Western Australia.* Kangaroo Press, Kenthurst.

Bennelongia. (2009) *Yilgarn Iron Ore Project: Carina Deposit, Subterranean Fauna Assessment.* Report prepared for Polaris Metals NL, Western Australia.

Bennelongia. (2015) *Yeelirrie Subterranean Fauna Assessment* Prepared for Cameco Australia.

Bennelongia Environmental Consultants. (2009) *Yilgarn Iron Ore Project: Carina Deposit, Subterranean Fauna Assessment.* Report prepared for Polaris Metals NL, Western Australia.

Biota. (2006) *BHP Billiiton Iron Ore Regional Subterranean Fauna Study: Research Programme Design* Biota Environmental Science Pty Ltd, Perth, WA.

Boulton, A. J. (2000) The Subsurface Macrofauna. In: B. J. Jones and P. J. Mulholland (eds) *Streams and Ground Waters*. Academic Press, San Diego, pp 337-361

Boulton, A. J., Findlay, S., Marmonier, P., Stanley, E. H. and Valett, H. M. (1998) The functional significance of the hyporheic zone in streams and rivers. *Annual Review of Ecology and Systematics* 29: 59-81.

Breaker Resources NL. (2018) *Lake Roe - Bombora geology for resource.* Unpublished report.

Campagna, V. S. (2007) *Limnology and biota of Lake Yindarlgooda - an inland salt lake in Western Australia under stress*. Doctoral Thesis. Curtin University of Technology.

Cooper, S. J. B., Hinze, S., Leys, R., Watts, C. H. S. and Humphreys, W. F. (2002) Islands under the desert: molecular systematics and evolutionary origins of stygobitic water beetles (Coleoptera: Dytiscidae) from central Western Australia. *Invertebrate Systematics* 16: 589-598.

Cowan, M. (2001a) Coolgardie 3 *(COO3 - Eastern Goldfields subregion)*. In: N. L. McKenzie, J. E. May and S. McKenna (eds) *A Biodiversity Audit of Western Australia's 53 Biogeographical Subregions in 2002*. Department of Conservation and Land Management, Kensington, WA, pp 156-169

Cowan, M. (2001b) *Coolgardie 3 (COO3 - Eastern Goldfields Subregion)* Department of Conservation and Land Management.

Culver, D. C. and Sket, B. (2000) Hotspots of subterranean biodiversity in caves and wells. *Journal of Cave and Karst Studies* 62(1): 11-17.

Danielopol, D. L. and Pospisil, P. (2000) Biodiversity in groundwater: a large-scale view. *TREE* 15: 223-224.

Eberhard, S. M., Halse, S. A., Williams, M., Scanlon, M. D., Cocking, J. S. and Barron, H. J. (2007) Exploring the relationship between sampling efficiency and short range endemism for groundwater fauna in the Pilbara region, Western Australia. *Freshwater Biology* 54: 885-901.

ecologia Environment. (2008) *Koolanooka/Blue Hills DSO Mining Project. Troglofauna Biological Assessment.* Report prepared for Midwest Corporation Limited Western Australia.

Environmental Protection Authority. (2007) *Guidance for the assessment of environmental factors (in accordance with the Environmental Protection Act 1986). Sampling methods and considerations for subterranean fauna in Western Australia - No. 54a. Technical appendix to guidance statement 54* Environmental Protection Authority, Western Australia.

Environmental Protection Authority. (2013) *Environmental Assessment Guideline (EAG) 12 for consideration of subterranean fauna in environmental impact assessment in Western Australia*.

Environmental Protection Authority. (2016a) *Technical Guidance Sampling Methods for Subterranean Fauna Survey* Environmental Protection Authority, Western Australia.

Environmental Protection Authority. (2016b) *Technical Guidance Subterranean Fauna Survey* Environmental Protection Authority, Western Australia.

EPA. (2003) *Guidance for the Assessment of Environmental Factors Consderation of Subterranean Fauna in Groundwater and Caves during Environmental Impact Assessment in Western Australia*.

Gray, D. J. (2001) Hydrogeochemistry in the Yilgarn Craton. *Geochemistry: Exploration, Environment, Analysis* 1: 253-264.

Gregory, S. J. (2007) *The classification of inland salt lakes in Western Australia*. Masters. Curtin University of Technology.

Halse, S. and Pearson, G. B. (2014) Troglofauna in the vadose zone: comparison of scraping and trapping results and sampling adequacy. *Subterranean Biology* 13: 17-34.

Halse, S. A., Scanlon, M. D. and Cocking, J. S. (2002) *Do springs provide a window to the groundwater fauna of the Australian arid zone?* Department of Conservation and Land Managment, Perth.

Halse, S. A., Scanlon, M. D., Cocking, j. S., Barron, H. J., Richardson, J. B. and Eberhard, S. (2014) Pilbara stygofauna: deep groundwater of an arid landscape contains globally significant radiation of biodiversity. *Records of the Western Australian Museum. Supplement* 78: 443-483.

Hamilton-Smith, E. and Eberhard, S. (2000) The diversity of the karstic and pseudokarstic hypogean habitats in the world. In: H. Wilkens, D. C. Culver and W. F. Humphreys (eds) *Subterranean Ecosystems*. Elsevier, Amsterdam, The Netherlands, pp 647-664

Hammer, U. T. (1986) *Saline Lake Ecosystems of the World.* Dr. W. Junk Publishers, Dordrecht.

Hancock, P. J. and Boulton, A. J. (2008) Stygofauna biodiversity and endemism in four alluvial aquifers in eastern Australia. *Invertebrate Systematics* 22: 117-126.

Harrison, S. E., Guzik, M. T., Harvey, M. S. and Austin, A. D. (2014) Molecular phylogenetic analysis of Western Australian troglobitic chthoniid pseudoscorpions (Pseudoscorpiones : Chthoniidae) points to multiple independent subterranean clades. *Invertebrate Systematics* 28: 386-400.

Harvey, M. E., Rix, M. G., Volker, W. F., Hamilton, Z. R., Johnson, M. S., Teale, R. J., Humphreys, G. and Humphreys, W. F. (2011) Protecting the innocent: studying short-range endemic taxa enhances conservation outcomes. *Invertebrate Systematics* 25: 1-10.

Harvey, M. S. (2002) Short-range endemism among the Australian fauna: some examples from non-marine environments. *Invertebrate Systematics* 16: 555-570.

Humphreys, W. F. (1991) Experimental re-establishment of pulse-driven populations in a terrestrial troglobite community. *Journal of Animal Ecology* 60: 609-623.

Humphreys, W. F. (2000a) The hypogean fauna of the Cape Range Peninsula and Barrow Island, northwestern Australia. In: H. Wilkens, D. C. Culver and W. F. Humphreys (eds) *Subterranean Ecosystems*. Elsevier, Amsterdam, The Netherlands, pp 581-602

Humphreys, W. F. (2000b) Relict faunas and their derivation. In: H. Wilkens, D. C. Culver and W. F. Humphreys (eds) *Subterranean Ecosystems*. Elsevier, Amsterdam, The Netherlands, pp 417-432

Humphreys, W. F. (2001) Groundwater calcrete aquifers in the Australian arid zone: the context to an unfolding plethora of stygal biodiversity. *Records of the Western Australian Museum Supplement No.* 64: 63-83.

Humphreys, W. F. (2006) Aquifers: the ultimate groundwater-dependent ecosystems. *Australian Journal of Botany* 54: 115-132.

Humphreys, W. F. (2008) Rising from Down Under: developments in subterranean biodiversity in Australia from a groundwater fauna perspective. *Invertebrate Systematics* 22: 85–101.

Humphreys, W. F., Watts, C. H. S., Cooper, S. J. B. and Leijs, R. (2009) Groundwater estuaries of salt lakes: buried pools of endemic biodiversity on the western plateau, Australia. *Hydrobiologia* 626: 79-95.

Johnson, S. L., Commander, D. P. and O'Boy, C. A. (1999) *Groundwater resources of the Northern Goldfields, Western Australia.* Water and Rivers Commission, Report HG 2, Perth.

Juberthie, C. (2000) The diversity of the karstic and pseudokarstic hypogean habitats in the world. In: H. Wilkens, D. C. Culver and W. F. Humphreys (eds) *Subterranean Ecosystems*. Elsevier, Amsterdam, The Netherlands, pp 17-40

Karanovic, T., Eberhard, S. M., Perina, G. and Callan, S. (2013) Two new subterranean ameirids (Crustacea: Copepoda: Harpacticoida) expose weaknesses in the conservation of short-range endemics threatened by mining developments in Western Australia. *Invertebrate Systematics* 27: 540-566.

Kern, A. M. (1995) *Hydrogeological Series: (Western Australia, scale 1:250,000). Hydrogeological Series. Sheet SH 51 -10. Kurnalpi.* Geological Survey of Western Australia. Available online at.

Kern, A. M. (1996a) *Hydrogeology of the Kurnalpi 1:250,000 Sheet. Explanatory notes.* Geological Survey of Western Australia.

Kern, A. M. (1996b) *Hydrogeology of the Widgiemooltha 1:250000 Sheet (Explanitory notes)*. Geological Survey of Western Australia. Available online at.

MWH. (2014a) *Mesa K Troglofauna Annual Compliance Monitoring: 2014* Prepared for Rio Tinto Iron Ore, Perth, Western Australia.

MWH. (2014b) *Troglofauna Annual Compliance Monitoring: Mesa K 2013* Prepared for Rio Tinto Iron Ore, Perth, Western Australia.

MWH. (2015) *Wiluna Uranium Project: Millipede Targeted Subterranean Fauna Assessment* Report prepared for Toro Energy Ltd.

MWH. (2016) *Mount Keith Satellite Operations Subterranean Fauna Assessment* Report prepared for BHP Billiton Nickel West.

Outback Ecology. (2008a) *Randalls Project. Pilot Assessment of Stygofauna* Internal report prepared for Integra Mining Limited, Perth, Western Australia.

Outback Ecology. (2008b) *Stygofauna assessment for the Magellan Lead Project - Wiluna 2008* Report prepared for Magellan Metals Pty Ltd, Perth, Western Australia.

Outback Ecology. (2008) *Salt Creek Gold Mine Feasibility Studies, Subterranean Fauna - Desktop Study.* , Perth, Western Australia

Outback Ecology. (2011a) *BHP Billiton Nickel West NDS1 Mine and Corridor Project Subterranean Fauna Assessment* Prepared for BHP Billiton NIckel West, Perth, Western Australia.

Outback Ecology. (2011b) *West Idough Deposit subterranean fauna desktop review* Internal report prepared for St Ives Gold Mining Company Pty Ltd, Perth, Western Australia.

Outback Ecology. (2011c) *Wiluna Uranium Project Subterranean Fauna Assessment, March 2011*. Prepared for Toro Energy Ltd, Perth, Western Australia.

Outback Ecology. (2011d) *Wingellina Nickel Project Subterranean Fauna Assessment*. Prepared for Metals X Ltd, Perth, Western Australia.

Outback Ecology. (2012a) *BHP Billiton Nickel West NDS1 Project: Lake Way Borefield Subterranean Fauna Assessment* Prepared for BHP Billiton NIckel Wes, Perth, Western Australia.

Outback Ecology. (2012b) *Lake Maitland Uranium Project Level 2 Stygofauna Assessment* Prepared for Mega Lake Maitland Pty Ltd, Perth, Western Australia.

Outback Ecology. (2012c) *Lake Maitland Uranium Project Level 2 Troglofauna Assessment* Prepared for Mega Lake Maitland Pty Ltd, Perth, Western Australia.

Outback Ecology. (2012d) *Majestic Gold Project. Subterranean Fauna Desktop Assessment.* Unpublished report prepared for Integra Mining Limited., Perth, Western Australia.

Outback Ecology. (2012e) *Randalls Gold Project Regional Subterranean Fauna Desktop Assessment* Prepared for Integra Mining Limited.

Outback Ecology. (2012f) *Wiluna Uranium Project Stygofauna Assessment* Prepared for Toro Energy Ltd, Perth, Western Australia.

Outback Ecology. (2014) *Browns Range Project Subterranean Fauna Assessment* Report prepared for Northern Minerals Ltd, Perth, Western Australia.

Phoenix. (2016) *Memo - B2018 Project - Desktop review of biological data* Prepared for Gold Fields (Australia) Ltd.

Platnick, N. I. (2008) A new subterranean ground spider genus from Western Australia (Araneae:Trochanteriidae) *Invertebrate Systematics* 22: 295-299.

Pringle, H. J. R., Van Vreeswyk, A. M. E. and Gilligan, S. A. (1994) *An inventory and condition survey of rangelands in the north-eastern goldfields, Western Australia.* Department of Agriculture, Perth.

Reeves, J. M., De Deckker, P. and Halse, S. A. (2007) Groundwater Ostracods from the arid Pilbara region of northwestern Australia: distribution and water chemistry. *Hydrobiologia* 585: 99–118.

Schmidt, S. I., Hahn, H. J., Hatton, T. J. and Humphreys, W. F. (2007) Do faunal assemblages reflect the exchange intensity in groundwater zones. *Hydrobiologia* 583: 1-19.

Stantec. (2017a) *Mesa K Troglofuana Annual Compliance Monitoring: 2017* Report prepared for Rio Tinto Iron Ore, Perth, Western Australia.

Stantec. (2017b) *Mount Keith Satellite Operations Stygofauna Assessment* Report prepared for BHP Billiton Nickel West.

Stantec. (2018) *Camelot Subterranean Fauna Level 2 Assessment* Report prepared for BHP Nickel West, Perth, Western Australia.

Strayer, D. L. (1994) Limits to biological distributions in groundwater. In: J. Gibert, D. L. Danielopol and J. A. Stanford (eds) *Groundwater Ecology*. Academic Press, San Diego, pp 287-310

Subterranean Ecology. (2008a) *Goldsworthy Iron Ore Mining Operations: Cundaline and Callawa Mining Operations Stygofauna Assessment*, North Beach, Western Australia.

Subterranean Ecology. (2008b) *Goldsworthy Iron Ore Mining Operations: Cundaline and Callawa Mining Operations Troglofauna Assessment* North Beach, Western Australia.

Subterranean Ecology. (2009) *Stygofauna Survey. Tropicana Gold Project. Minigwal Water Supply Area* Report prepared for Tropicana Joint Venture AngloGold Ashanti Australia Ltd. Independence Group NL.

Subterranean Ecology. (2010a) *Gold Fields, St Ives Gold Mines: Stygofauna Desktop Assessment* Unpublished report for Gold Fields Pty Ltd.

Subterranean Ecology. (2010b) *Gold Fields, St Ives Gold Mines: Troglofauna Desktop Assessment* Unpublished report for Gold Fields Pty Ltd.

Subterranean Ecology. (2011) BHP Billiton Yeelirrie Development Company Pty Ltd. Yeerlirrie Uranium Project. Subterraean Fauna Survey.

Talis. (2016) *St Ives Gold Mine. The Beyond 2018 Project.*, Perth, Western Australia

Thackway, R. and Cresswell, I. D. (1995) *An interim biogeographical regionalisation of Australia.* Australian Nature Conservation Agency (now DEWHA), Canberra.

Thurgate, M. E., Gough, J. S., Spate, A. and Eberhard, S. (2001) Subterranean biodiversity in New South Wales: from rags to riches. *Records of the Western Australian Museum Supplement No.* 64: 37-47.

Timms, B. V., Datson, B. and Coleman, M. (2006) The wetlands of the Lake Carey catchment, northeast Goldfields of Western Australia, with special reference to large branchiopods. *Journal of the Royal Society of Western Australia* 89: 175-183.

Williams, W. D. (1998) *Guidelines of lake management, Volume 6. Management of inland saline waters.* International Lake Environment Committee, United Nations Environment Programme, Shiga, Japan.

8. Glossary

alluvium – sediment deposited by a stream or river

aquatic – relating to water

aquifer – a body of permeable rock or sediment capable of storing groundwater

arid – a region characterised by a severe lack of available water, to the extent that the growth and development of biota is hindered or prevented

bedrock – consolidated rock attached to the earth's crust

biodiversity – the diversity of biota in a particular environment or region

calcrete – carbonate deposits that form in arid environments, as a result of groundwater evaporation

cave – a subsurface cavity of sufficient size that a human could enter

dissolved oxygen – a measure of the amount of gaseous oxygen dissolved in a solution; oxic = > 3 mg/L; dysoxic = 0.3 to 3.0 mg/L; suboxic = < 0.3 mg/L levels

distribution range – the overall geographic area that a species is known to occur in

divergence – degree of separation from a common ancestor

diversity – a combination of species richness and abundance

drawdown – the lowering of the adjacent water table or piezometric surface as a result of groundwater extraction

ecotone – zone of transition among different ecosystems

electrical conductivity – an estimate of the total dissolved salts in a solution, or salinity

endemic – having a distribution restricted to a particular geographic region

epigean – pertaining to the surface zone

fractured rock – a rock formation characterized by separation or discontinuity, usually as a result of geological stress (e.g. faulting)

geological ages (e.g. Cainozoic) – distinct time periods within the geological history of the earth

groundwater – water occurring below the ground surface

habitat – an ecological or environmental area that is inhabited by a particular animal or plant species

hypogean – pertaining to the subterranean zone

hyporheic zone – spatially fluctuating ecotone within the bed of a river or stream between surface and groundwater. Considered important component of groundwater ecosystems and involved in the 'interstitial highway', forming hyporheic corridor linking associated aquifers.

invertebrates – animals lacking vertebrae

karst – a region of limestone or other soluble rock, characterized by distinctive features such as caves, caverns, sinkholes, underground streams and springs

lineage – a group of organisms related by descent from a common ancestor

molecular – pertaining to the genetic characteristics of an organism or group

morphology – the specific form and structure of an organism or taxon

morphospecies – a general grouping of organisms that share similar morphological traits, but is not necessarily defined by a formal taxonomic rank

palaeoriver, palaeochannel, palaeodrainage – a remnant of a stream or river channel cut in older rock and filled by the sediments of younger overlying rock

pH – a measure of the hydrogen ion concentration of a soil or solution (values below pH of 6.5 are 'acidic', and those above pH 7.5 are 'alkaline')

relictual – having survived as a remnant

salinity – the concentration of all dissolved salts in a solution. The salinity level classification *sensu* Hammer (1986): freshwater = salinity less than 5 mS/cm (3 ppt); hyposaline = salinity ranging from 5–30 mS/cm (3–20 ppt); mesosaline = salinity ranging from 30–70 mS/cm (20–50 ppt); hypersaline = salinity equal to or greater than 70 mS/cm (50 ppt)

semi-arid – a climatic region that receives low annual rainfall (250 – 500 mm)

species – a formal taxonomic unit defining a group or population of organisms that share distinctive characters or traits, are reproductively viable and/or are otherwise identifiable as a related group

species richness – the number of species present in a particular habitat, ecosystem or region

species accumulation curve – a model used to estimate species diversity or richness

standing water level (SWL) – the depth to groundwater from a particular reference point (e.g. in a monitoring bore)

stygal – pertaining to groundwater habitat or biota

stygobite – an obligate aquatic species of groundwater habitats

stygobiont – another term used to describe obligate inhabitants of groundwater systems

stygofauna – a general term for aquatic groundwater fauna

stygophile – an aquatic species that temporarily or permanently inhabits groundwater habitats

stygoxene – an aquatic species that has no fixed affinity with groundwater habitats, but may nonetheless occur in groundwater habitats

sympatry / sympatric – two or more species that are considered to exist in the same or overlapping geographic area and may regularly interact with, or encounter, each another (without interbreeding)

taxon (singular), taxa (plural) – an identifiable group of organisms, usually based on a known or inferred relationship or a shared set of distinctive characteristics

troglobite – an obligate terrestrial species of subterranean habitats

troglofauna – a general term for terrestrial subterranean fauna

troglomorphic features – morphological characteristics resulting from an adaptation to subterranean habitats (e.g. a reduction in pigment)

troglophile – a terrestrial species that temporarily or permanently inhabits subterranean habitats

trogloxene – a terrestrial species that has no fixed affinity with subterranean habitats, but may nonetheless occur in subterranean habitats

void – a pore space in the rock or stratum

Yilgarn – pertaining to the Yilgarn Craton, a 65,000 km2 body of the earth's crust in south-western Australia that dates back to the Archaean period, 2.6 to 3.7 million years ago

Appendices

Appendix A Subterranean Fauna Site Details and Sample Effort

Table A-1: Subterranean Fauna Site Details.

Site Name	Latitude	Longitude	Collection method	Elevation upper	SWL (AHD)	SWL (mbgl)	Angle of Bore	Bore Diameter (mm)	Casing Type
BBRC0024	-30.74222	122.57363	Litter Trap	324			60	150	Uncased
BBRC0033	-30.73762	122.57063	Net Haul	323	319.17	3.83	60	150	Uncased
BBRC0132	-30.72949	122.56941	Net Haul	321	318.92	2.08	60	150	Uncased
BBRC0225	-30.71594	122.56728	Litter Trap & Net Haul	320	317.41	2.59	60	150	Uncased
BBRC0260	-30.72945	122.56937	Net Haul	321	318.92	2.08	60	150	Uncased
BBRC0280	-30.71486	122.56752	Litter Trap & Net Haul	321	318.01	2.99	60	150	Uncased
BBRC0412	-30.72768	122.56921	Net Haul	321	317.83	3.17	60	150	Uncased
BBRC0603	-30.73762	122.56753	Litter Trap	325			60	150	Uncased
BBRC0604	-30.73756	122.56833	Litter Trap	325			60	150	Uncased
BBRC0608	-30.73759	122.56747	Litter Trap	324			60	100	Uncased
BBRC0625	-30.68974	122.55908	Net Haul	323	320.02	2.98	60	150	Uncased
BBRC0628	-30.68974	122.56048	Litter Trap & Net Haul	320	317.16	2.84	60	150	Uncased
BBRC0629	-30.68975	122.56037	Litter Trap	321			60	150	Uncased
BBRC0633	-30.69063	122.56037	Litter Trap & Net Haul	322	316.81	5.19	60	150	Uncased
BBRC0663	-30.7087	122.56867	Net Haul	320	318.44	1.56	60	100	Uncased
BBRC0690	-30.71521	122.56774	Litter Trap & Net Haul	321	317.95	3.05	60	150	Uncased
BBRC0703	-30.74037	122.57994	Litter Trap	320			60	150	Uncased
BBRC0705	-30.7421	122.58036	Litter Trap	321			60	150	Uncased
BBRC0707	-30.74396	122.58062	Litter Trap & Net Haul	323	316.07	6.93	60	150	Uncased
BBRC0719	-30.72819	122.55377	Net Haul	319	317.37	1.63	60	150	Uncased
BBRC0775	-30.71039	122.56840	Litter Trap & Net Haul	320	317.41	2.59	60	150	Uncased
BBRD0669	-30.71524	122.56953	Net Haul	320	317.7	2.3	60	150	Uncased
BBRD0761	-30.71379	122.56988	Litter Trap & Net Haul	321	318.19	2.81	60	150	Uncased

Figure A-8-1: Representative site photos: A) BBRC024; B) BBRC033; C) BBRC604; D) BBRC625; E) BBRC663; F) BBRC690; G) BBRC707; H) BBRC719; I) BBRD761.

Table A-2: Stygofauna Sample Effort.

Site Name	Latitude	Longitude	Sample Date	Collection method
BBRC0033	-30.73762	122.57063	18/10/2018	Net Haul
BBRC0132	-30.72949	122.56941	17/10/2018	Net Haul
BBRC0225	-30.71594	122.56728	17/10/2018	Net Haul
BBRC0260	-30.72945	122.56937	17/10/2018	Net Haul
BBRC0280	-30.71486	122.56752	17/10/2018	Net Haul
BBRC0412	-30.72768	122.56921	17/10/2018	Net Haul
BBRC0625	-30.68974	122.55908	17/10/2018	Net Haul
BBRC0628	-30.68974	122.56048	17/10/2018	Net Haul
BBRC0633	-30.69063	122.56037	17/10/2018	Net Haul
BBRC0663	-30.70870	122.56867	17/10/2018	Net Haul
BBRC0690	-30.71521	122.56774	17/10/2018	Net Haul
BBRC0707	-30.74396	122.58062	16/10/2018	Net Haul
BBRC0719	-30.72819	122.55377	17/10/2018	Net Haul
BBRC0775	-30.71039	122.56840	17/10/2018	Net Haul
BBRD0669	-30.71524	122.56953	17/10/2018	Net Haul
BBRD0761	-30.71379	122.56988	17/10/2018	Net Haul

Table A-3: Troglofauna Sample Effort.

Site Name	Latitude	Longitude	Sample Start Date	Sample End Date	Collection method
BBRC0024	-30.74222	122.57363	16/10/2018	8/12/2018	Litter Trap
BBRC0033	-30.73762	122.57063	18/10/2018		Net Scrape
BBRC0132	-30.72949	122.56941	17/10/2018		Net Scrape
BBRC0225	-30.71594	122.56728	17/10/2018	8/12/2018	Litter Trap
BBRC0225	-30.71594	122.56728	17/10/2018		Net Scrape
BBRC0260	-30.72945	122.56937	17/10/2018		Net Scrape
BBRC0280	-30.71486	122.56752	17/10/2018	8/12/2018	Litter Trap
BBRC0280	-30.71486	122.56752	17/10/2018		Net Scrape
BBRC0412	-30.72768	122.56921	17/10/2018		Net Scrape
BBRC0603	-30.73762	122.56753	18/10/2018	8/12/2018	Litter Trap
BBRC0604	-30.73756	122.56833	18/10/2018	8/12/2018	Litter Trap
BBRC0608	-30.73759	122.56747	18/10/2018	8/12/2018	Litter Trap
BBRC0625	-30.68974	122.55908	17/10/2018		Net Scrape
BBRC0628	-30.68974	122.56048	17/10/2018	8/12/2018	Litter Trap
BBRC0628	-30.68974	122.56048	17/10/2018		Net Scrape
BBRC0629	-30.68975	122.56037	17/10/2018	8/12/2018	Litter Trap
BBRC0633	-30.69063	122.56037	17/10/2018	8/12/2018	Litter Trap
BBRC0633	-30.69063	122.56037	17/10/2018		Net Scrape
BBRC0663	-30.70870	122.56867	17/10/2018		Net Scrape
BBRC0690	-30.71521	122.56774	17/10/2018	8/12/2018	Litter Trap
BBRC0690	-30.71521	122.56774	17/10/2018		Net Scrape
BBRC0703	-30.74037	122.57994	16/10/2018	8/12/2018	Litter Trap
BBRC0705	-30.74210	122.58036	16/10/2018	8/12/2018	Litter Trap
BBRC0707	-30.74396	122.58062	16/10/2018	8/12/2018	Litter Trap
BBRC0707	-30.74396	122.58062	16/10/2018		Net Scrape
BBRC0719	-30.72819	122.55377	17/10/2018		Net Scrape
BBRC0775	-30.71039	122.56840	17/10/2018	8/12/2018	Litter Trap
BBRC0775	-30.71039	122.56840	17/10/2018		Net Scrape
BBRD0669	-30.71524	122.56953	17/10/2018		Net Scrape
BBRD0761	-30.71379	122.56988	17/10/2018	8/12/2018	Litter Trap
BBRD0761	-30.71379	122.56988	17/10/2018		Net Scrape

Appendix B Groundwater Properties Recorded

Table B-1: Groundwater Properties Data.

Site Name	Elevation upper (AHD)	SWL (AHD)	SWL (mbgl)	DO (mg/L)	EC (SPC) (mS/cm)	TDS (mg/L)	pH	Redox (mV)	Water Temp. (C)
BBRC0033	323	319.17	3.83	4.66	4.175	2,714	8.22	183.9	21.9
BBRC0132	321	318.92	2.08	4.56	2.284	1,485	7.03	124.7	21.9
BBRC0225	320	317.41	2.59	1.55	121.203	78,782	7.39	104.2	23.4
BBRC0260	321	318.92	2.08	0.56	197.494	128,371	5.04	143.2	22.6
BBRC0280	321	318.01	2.99	0.37	154.065	100,142	6.45	126	23.6
BBRC0412	321	317.83	3.17	0.64	190.031	123,520	6.62	79.6	23.3
BBRC0625	323	320.02	2.98	0.47	176.289	114,588	6.76	270.1	21
BBRC0628	320	317.16	2.84	1.5	125.592	81,635	4.16	280.7	20.9
BBRC0633	322	316.81	5.19	9.45	68.495	44,522	4.08	268.9	20.4
BBRC0663	320	318.44	1.56	3.92	112.726	73,272	6.85	256.1	21.7
BBRC0690	321	317.95	3.05	2.82	115.503	75,077	6.75	53.5	22.2
BBRC0707	323	316.07	6.93	2.47	116.006	75,404	4.26	223.3	23.6
BBRC0719	319	317.37	1.63	0.02	165.666	107,683	6.53	-78.1	22.6
BBRC0775	320	317.41	2.59	2.82	93.353	60,679	6.56	164.5	21.8
BBRD0669	320	317.7	2.3	0.04	129.911	84,442	6.7	-199.9	22.3
BBRD0761	321	318.19	2.81	0.33	113.75	73,938	6.5	5.2	22.1

Perth

41 Bishop Street,
JOLIMONT, WA 6014
Tel +61 (08) 9388 8799

Please visit **www.stantec.com** to learn more about how Stantec design with community in mind.

Stantec