WATERMARK
COAL PROJECT
ENVIRONMENTAL IMPACT STATEMENT

February 2013

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Stygofauna
Impact Assessment

eco logical AUSTRALIA

WATERMARK COAL PROJECT
STYGOFAUNA IMPACT ASSESSMENT

Prepared for
Hansen Bailey Pty Ltd

30 July 2012

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Contents

List of figures

List of tables

Executive Summary

Eco Logical Australia, on behalf of Hansen Bailey, conducted a stygofauna impact assessment for the Watermark Coal Project for Shenhua Watermark Coal Pty Limited. The purpose of this assessment is to form part of the Environmental Impact Statement (EIS) being prepared to support an Application for a new Development Consent for the Project under Division 4.1 of Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act).

The assessment consisted initially of a desktop review of regional stygofauna surveys, hydrogeological, and geological information. This was followed by a round of sampling involving 20 bores that were selected during the desktop assessment.

As NSW has no standard sampling protocol for stygofauna, Eco Logical Australia used a sampling protocol designed to comply with Western Australian Environmental Protection Authority *Guidance Statements for Sampling Subterranean Fauna* (WA EPA 2003, 2007). These have become the standard guidelines for stygofauna sampling in WA and Queensland. In addition, Eco Logical Australia complemented the WA protocol by undertaking additional sampling with a pump to increase the efficiency of collection.

Samples were collected from bores screened within a range of strata present within the Project Boundary and the immediate vicinity, focusing on aquifers in the Narrabri and Gunnedah Formations and the weathered part of the Permian aquifers, as these were identified as the aquifers most suitable for stygofauna No animals were collected from the Permian aquifers. This absence is likely due to the high electrical conductivity, the depth of the screened section of the bore, and the low aquifer porosity.

A single Oligochaete worm from the family Enchitraeidae was collected from bore WM429A in the Narrabri Formation. Although this family includes species that live in aquifers, Enchitraeids are more common in soil and surface-aquatic environments. As only one animal was identified in the Narrabri Formation, it is likely to have fallen into the bore from the soil horizons. Further sampling may clarify the status of this worm as stygofaunal if it is collected again from the aquifer. If the identified worm is truly stygofaunal, then resampling of this bore may also collect additional taxa such as Copepoda and Bathynellacea, which often co-occur in aquifers with Oligochaetes. These taxa are not known to occur in the Project Boundary or surrounding region.

After one round of sampling, there appear to be no stygofauna in aquifers within the Project Boundary. The alluvial aquifers would be the most suitable habitat for stygofauna, with densities and species diversity increasing with proximity to the Mooki River and to recharge areas.

Hydrogeological modelling indicates that the Project will have maximum drawdown of approximately 3.5 m in the Gunnedah Formation. The majority of this drawdown is less than 2 m and extends to a maximum radial extent of less than 4 km from the Project (AGE 2012). This level of drawdown is within the natural fluctuating range of the water table and is unlikely to significantly impact on any stygofauna.

The Watermark Coal Project poses little threat to aquifer ecosystems because:

- no stygofauna were collected during sampling within the Project Boundary and water quality data indicates that conditions are unsuitable to stygofauna;

- hydrogeological modelling indicates that the Project will have negligible impact on the alluvial aquifers of the Gunnedah Formation, which was identified as the most suitable stygofauna habitat within or surrounding the Project Boundary.

As it is unlikely that there are significant stygofauna communities within the Project Boundary, and as operations are unlikely to cause major changes to the Gunnedah Formation, no further sampling is necessary.

1 Introduction

Ecological Australia was commissioned by Hansen Bailey on behalf of Shenhua Watermark to prepare a stygofauna impact assessment for the Watermark Coal Project (the Project). The purpose of this assessment is to form part of the Environmental Impact Statement (EIS) being prepared to support an Application for a new Development Consent for the Project under Division 4.1 of Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act).

In October 2008, Shenhua Watermark Coal Pty Limited (Shenhua Watermark) was granted Exploration Licence (EL) 7223. Shenhua Watermark is a subsidiary of the Shenhua Group.

The Project is located within EL 7223, approximately 25 km south south-east of Gunnedah and to the immediate west of the village of Breeza, within the Gunnedah Local Government Area (LGA). The Project is approximately 282 km by rail from the export Port of Newcastle. **Figure 1** illustrates the regional location of the Project in relation to the nearest town centres of Breeza and Gunnedah.

1.1 THE PROJECT

The Project generally comprises:

- The construction open cut mining operation extracting up to 10 Million tonnes per annum (Mtpa) of Run of Mine (ROM) coal for a 30 year period;
- An open cut mining fleet of excavators and shovels, supported by haul trucks, dozers, graders, drill rigs and water carts;
- Progressive rehabilitation of all disturbed areas;
- The construction and operation of a Coal Handling and Preparation Plant (CHPP) with a throughput of 10 Mtpa ROM coal;
- The co-disposal of tailings and coarse reject within the Overburden Emplacement Areas (OEA);
- The construction and operation of a rail spur, rail loop, Kamilaroi Highway rail overpass, associated load out facility and connection to the Werris Creek - Moree Railway Line;
- The construction and operation of a Mine Access Road;
- The construction and operation of administration, workshop and related facilities;
- The construction and operation of ground and surface water management and reticulation infrastructure including pipelines, pumping stations and associated infrastructure for access to water from groundwater aquifers, the Mooki River and private dams to the north-east of the Project Boundary;
- The installation of communications and electricity reticulation infrastructure; and
- A workforce of up to approximately 600 full-time equivalent employees during construction and up to 600 full-time equivalent employees during the operation of the Project.

The conceptual layout of the Project is shown in **Figure 2**.

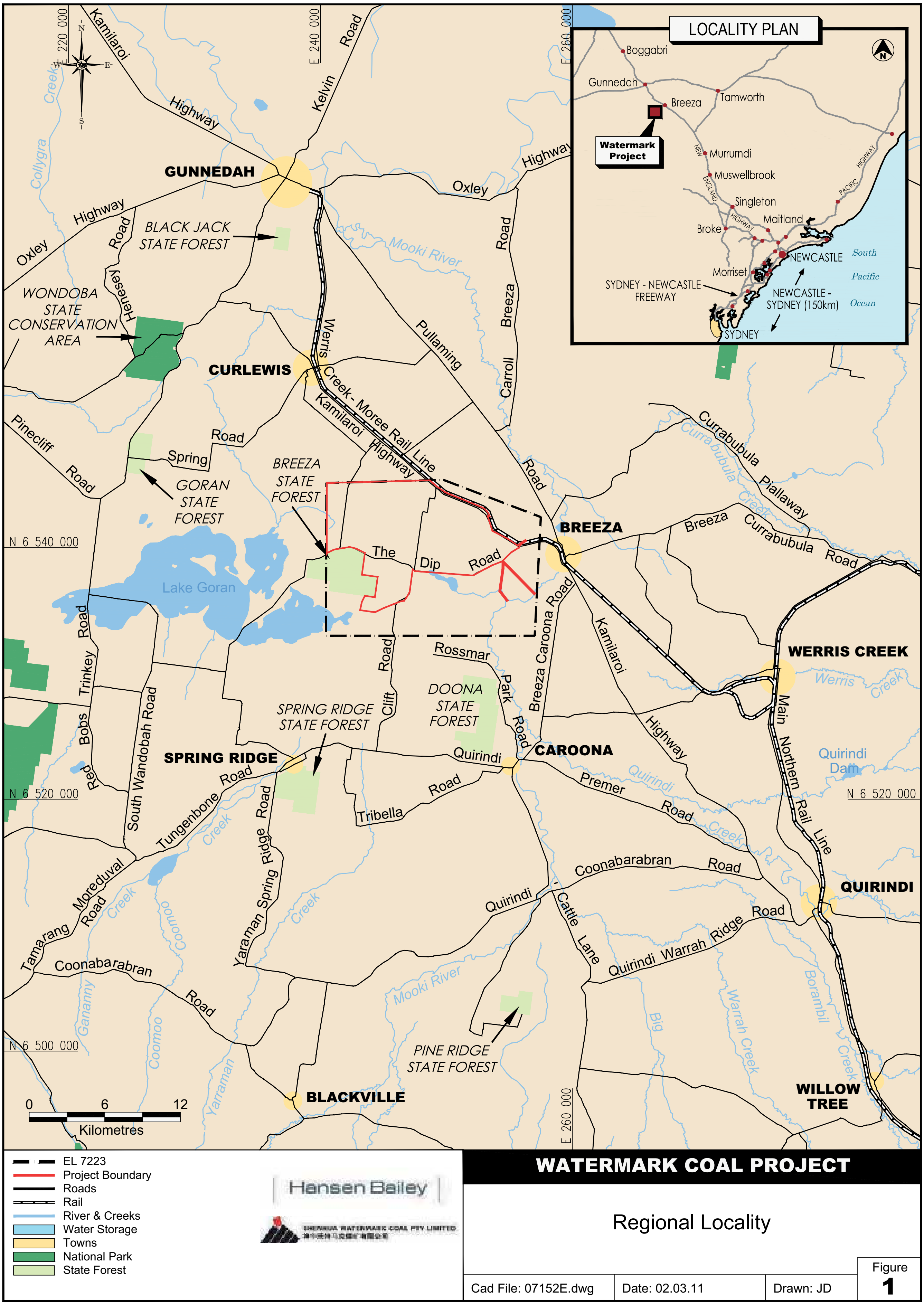
LOCALITY PLAN
Boggabri
Gunnedah
Breeza
Tamworth
Watermark Project
Murrurndi
Muswellbrook
Singleton
Maitland
Broke
NEWCASTLE
Morriset
SYDNEY - NEWCASTLE FREEWAY
NEWCASTLE - SYDNEY (150km)
SYDNEY
South Pacific Ocean
GUNNEDAH
CURLEWIS
BREEZA
WERRIS CREEK
CAROONA
SPRING RIDGE
QUIRINDI
BLACKVILLE
WILLOW TREE
BLACK JACK STATE FOREST
WONDOBA STATE CONSERVATION AREA
GORAN STATE FOREST
BREEZA STATE FOREST
SPRING RIDGE STATE FOREST
DOONA STATE FOREST
PINE RIDGE STATE FOREST
Lake Goran
Quirindi Dam
Mooki River
Oxley Highway
Kamilaroi Highway
Werris Creek - Moree Rail Line
Main Northern Rail Line
The Dip Road
Rossmar Park Road
Breeza Caroona Road
Coonabarabran Road
Quirindi Warrah Ridge Road
Premer Road
Tungenbone Road
South Wandobah Road
Yaraman Spring Ridge Road
E 220 000
E 240 000
E 260 000
N 6 540 000
N 6 520 000
N 6 500 000
0 6 12
Kilometres
EL 7223
Project Boundary
Roads
Rail
River & Creeks
Water Storage
Towns
National Park
State Forest
Hansen Bailey
WATERMARK COAL PROJECT
Regional Locality
Cad File: 07152E.dwg
Date: 02.03.11
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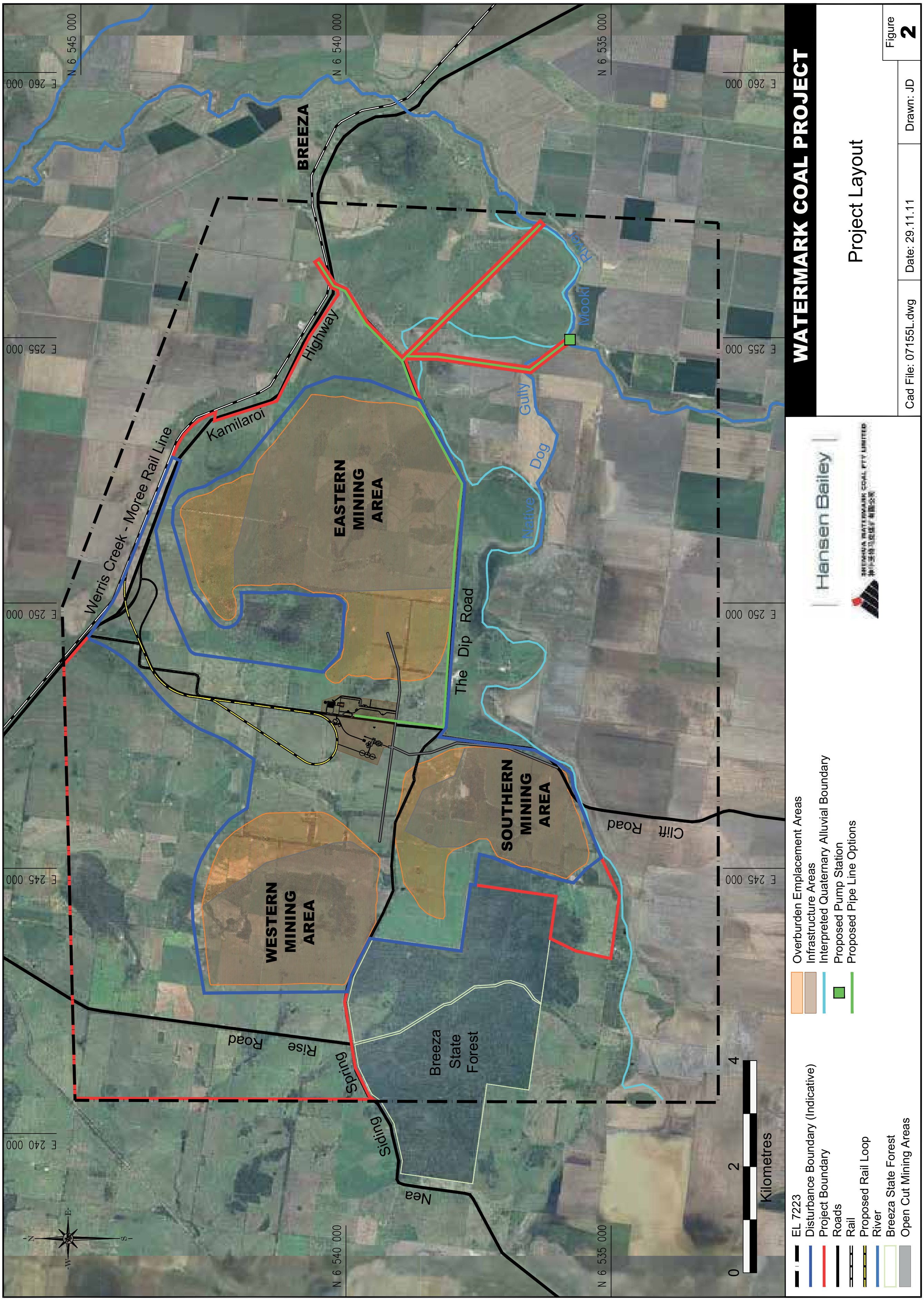
Figure 1


WATERMARK COAL PROJECT
Project Layout
Figure 2
Cad File: 07155L.dwg
Date: 29.11.11
Drawn: JD
Hansen Bailey
EL 7223
Disturbance Boundary (Indicative)
Project Boundary
Roads
Rail
Proposed Rail Loop
River
Breeza State Forest
Open Cut Mining Areas
Overburden Emplacement Areas
Infrastructure Areas
Interpreted Quaternary Alluvial Boundary
Proposed Pump Station
Proposed Pipe Line Options
Kilometres
0
2
4
EASTERN MINING AREA
WESTERN MINING AREA
SOUTHERN MINING AREA
Breeza State Forest
BREEZA
Kamilaroi Highway
Werris Creek - Moree Rail Line
The Dip Road
Cliff Road
Spring Ridge Road
Nea Siding Road
Mooki River
Native Dog Gully
E 240 000
E 245 000
E 250 000
E 255 000
E 260 000
N 6 535 000
N 6 540 000
N 6 545 000

1.2 FACTORS INFLUENCING BIOLOGICAL DISTRIBUTION IN AQUIFERS

Stygofauna are generally crustacean invertebrates that live in groundwater and have special adaptations to survive in relatively resource-poor aquifer environments where there is no light, limited space, and scarce food (Humphreys 2008). Adaptations include blindness, slow metabolism, small size, elongation, and low reproduction rates (Coineau 2000). As there is no photosynthesis below ground, subterranean environments rely on inputs of organic matter from the surface to provide the basis of the food web (Schneider *et al.* 2011).

Recent estimates suggest there could be as many as 2,680 species of stygofauna in the western half of Australia, although only approximately 12 % of these have been described (Guzik *et al*. 2011). It is difficult to estimate the diversity of stygofauna species in eastern Australian aquifers, but they may be as diverse as western aquifers.

In the Mooki Catchment, in which the Project is situated, the surface and groundwater regimes have already been extensively modified by development and agriculture. This is represented by altered stream flows and significant reductions in long term groundwater levels as well as changes to groundwater chemistry. As there is no available information regarding the condition of the stygofauna community in the Mooki Catchment prior to agricultural development, it is not possible to state how much the community had already changed from its original state.

As with all fauna, groundwater invertebrates require favourable conditions to inhabit an aquifer. There is a broad range of variability in ecological requirements for stygofauna habitation. Not all aquifers are suitable for stygofauna, and those that are suitable may become unsuitable as a result of human activities or natural changes. Stygofauna distribution in groundwater is influenced by historical, geological, hydrological, physico-chemical, and biological properties (Strayer 1994, Hancock *et al.* 2005). There is still a lot being learned about stygofauna ecology, particularly in the eastern states where there have been relatively few field surveys compared to Western Australia. Nevertheless, with the limited information available on stygofauna, it is still possible to determine whether a change in aquifer conditions is likely to influence stygofauna diversity and distribution.

1.2.1 Aquifer type

Stygofauna are generally found in karstic and alluvial aquifers, however they have been collected from many other aquifer types, including fractured basalt, fractured sandstone aquifers, and pesolithic aquifers. Critical aquifer conditions which influence stygofauna survivability and diversity are hydraulic conductivity, aquifer connectivity, depth to water table, and porosity.

Generally, stygofauna occur more frequently in alluvial aquifers and karst formations than in other geological formations (Hancock *et al.* 2005, Humphreys 2008). Alluvial aquifers occur beneath floodplains, which often provide the following conditions favourable to stygofauna:

- Water table is shallow, so there is recharge of infiltrating rainwater and organic matter, and the water table is accessible to floodplain tree roots;
- There is often some degree of hydrological connectivity with surface rivers. This is particularly influential in regulated rivers where artificial flow releases may provide aquifer recharge of organic matter and oxygen in periods where natural surface flow would otherwise be absent; and

- Compared to deeper aquifers, water in alluvial aquifers is young and water flows through the aquifer rapidly.

1.2.2 Hydraulic conductivity

Hydraulic conductivity indicates how rapidly water flows through an aquifer. This is important to stygofauna communities because the flux of water through an aquifer often influences how rapidly organic matter and oxygen concentrations are replenished. Hydraulic conductivity can also indicate the degree of inter-connectivity between different parts of an aquifer, which could allow breeding between individuals in the community.

1.2.3 Depth of water table

Depth to water table influences organic matter and oxygen availability in aquifers. With increasing depth below the ground surface, the concentration of organic matter dissolved in infiltrating rainwater diminishes as it is absorbed in transit by soil bacteria and plant roots. Shallow alluvial aquifers of less than 15 m have been found to be populated by diverse stygofauna species in eastern Australia (Hancock and Boulton 2008).

Another source of organic matter to aquifer invertebrates is the presence of phreatophytic roots (Jasinska *et al.* 1996). Root density is likely to be higher in shallower aquifers, and the resultant availability of organic matter provides food to diverse stygofauna communities (Hancock and Boulton 2008).

1.2.4 Connectivity to recharge areas

A large proportion of the organic matter that fuels aquifer food webs originates at the surface and enters groundwater in particulate or dissolved forms. Therefore, sections of aquifers that are nearer to recharge areas are likely to have higher diversity and abundance than those that are further away since the availability of organic matter and oxygen is generally greater at these sites (Datry *et al.* 2004).

1.2.5 A space for living

Stygofauna can only live in aquifers with enough space for them to move around in. Space is present in the solute cavities in karst formations, between pesolithic sediments in calcrete, and fractures in sandstone and basalt. In sedimentary aquifers, the size of pore space between particles often correlates to the size of the animals present, with larger species occurring in aquifers of coarser material (Strayer 1994).

Also important when considering the space available for living is the connectivity between pores, cavities, and fractures. These act as migration pathways to allow fauna to move around in the aquifer and are likely to be important in recolonising following disturbance.

1.2.6 Evolutionary history

Most stygofauna evolved from ancestors that once lived in surface freshwater or marine environments. As a result, it is possible that they have retained some of the traits and environmental tolerances of their ancestors. For example, in coastal areas where ancestral stygofauna species may have originated from a marine environment, contemporary taxa are more likely to be tolerant of high salinity environments (Humphreys 2008, Hancock and Steward 2004). Conversely, stygofauna taxa with a freshwater ancestry are more likely to prefer environments with a lower salinity (Hancock and Boulton 2008).

1.2.7 Food availability

Stygofauna have adapted to the resource-starved conditions in aquifers and can tolerate low concentrations of organic matter (Hahn 2006, Strayer 1994). Food is available to stygofauna as particulate organic matter, groundwater bacteria, or as roots of phreatic trees. In its dissolved or fine particulate form, organic matter enters aquifers with recharging water. Dissolved organic matter is taken up by groundwater bacteria, which are then consumed by smaller stygofauna. Most stygofauna are opportunistic omnivores.

1.2.8 Water regime

Local or regional climate and river-flow regimes can influence aquifer recharge, and so affect the organic matter flow in the aquifer. Periods of high, steady rainfall can increase hydrological connectivity between the ground surface and the aquifer and can reduce depth to the water table. Exchange of water between rivers, the hyporheic zone, and aquifers can provide an important source of nutrients to stygofauna communities (Dole-Olivier *et al.* 1994), therefore flow fluctuations that enhance hyporheic exchange can subsequently enrich stygofauna communities in deeper parts of the aquifer.

1.2.9 Salinity

Stygofauna in inland aquifers are generally restricted to fresh or brackish water. Hancock and Boulton (2008) suggest that most stygofauna taxa collected from alluvial aquifers in NSW and Queensland prefer Electrical Conductivity (EC) less than 5,000 μS/cm. In surveys of coastal areas and near salt lakes in Western Australia, stygofauna were collected from aquifers with salinities equal to or exceeding sea water concentrations (Watts and Humphreys 2004). The Western Australian Environmental Protection Authority (WA EPA) Guidance Statement 54a, suggests that stygofauna is unlikely to occur in waters with a salinity concentration of 60,000 mg/L or above (WA EPA 2007).

1.2.10 Dissolved oxygen

Stygofauna are able to tolerate very low concentrations of dissolved oxygen. Hahn (2006) observed a significant decrease in stygofauna abundance in water with dissolved oxygen concentrations below 1.0 mg/L, with some taxa able to tolerate concentrations as low as 0.5 mg/L. Some taxa are able to survive on virtually no oxygen for periods of up to six months (Malard and Hervant 1999, Henry and Danielopol 1999). Aquifers can be heterogeneous environments, and may contain isolated regions with sufficient oxygen concentration for stygofauna occupation.

2 Legislative Framework

2.1 ENVIRONMENTAL PLANNING AND ASSESSMENT ACT 1979

The EP&A Act is the overarching planning legislation in NSW. This act provides for the creation of planning instruments that guide land use. The Act also aims to encourage ecologically sustainable development in NSW and to protect natural habitat, flora and fauna.

This stygofauna impact assessment has been prepared in accordance with the Director-General's Requirements (DGRs) issued for the Project under Division 4.1 of Part 4 of the EP&A Act.

2.1.1 Director-General Requirements for the Project

The DGRs for the Project state that in addition to meeting the form and content requirements in Clause 6 and 7 of Schedule 2 of the Environmental Planning and Assessment Regulation 2000 (EP&A Regulation), the EIS must include "*a detailed assessment of potential impacts of the development on any terrestrial or aquatic threatened species or populations and their habitats, endangered ecological communities and groundwater dependent ecosystems"*". This requirement has been addressed in Sections 4 to 8 of this assessment.

The assessment of potential impacts on Groundwater Dependent Ecosystems (GDEs) is described in the ecology and groundwater impact assessments (see Appendix K and T of the EIS prepared by Hansen Bailey for the Project).

2.2 NSW GROUNDWATER DEPENDENT ECOSYSTEMS POLICY 2002

Alluvial aquifers also need to be considered under the NSW Groundwater Dependent Ecosystem Policy (2002), which protects ecosystems that rely on groundwater for survival, and the ecological processes and biodiversity associated with them. Under the policy, stygofauna are considered as the faunal component of aquifer ecosystems.

The Policy applies the following principles for managing GDEs:

- The scientific, ecological, aesthetic and economic values of GDEs, and how threats to them may be avoided, should be identified and action taken to ensure that the most vulnerable and the most valuable ecosystems are protected.
- Groundwater extractions should be managed within the sustainable yield of aquifer systems, so that the ecological processes and biodiversity of their dependent ecosystems are maintained and/or restored. Management may involve establishment of threshold levels that are critical for ecosystem health, and controls on extraction in the proximity of GDEs.
- Priority should be given to ensure that sufficient groundwater of suitable quality is available at the times when it is needed:
  - For protecting ecosystems which are known to be, or are most likely to be, groundwater dependent; and,
  - For GDEs which are under an immediate or high degree of threat from groundwater-related activities.

- Where scientific knowledge is lacking, the Precautionary Principle should be applied to protect GDEs. The development of adaptive management systems and research to improve understanding of these ecosystems is essential to their management.
- Planning, approval and management of developments and land-use activities should aim to minimise adverse impacts on GDEs by:
    - Maintaining, where possible, natural patterns of groundwater flow and not disrupting groundwater levels that are critical for ecosystems;
    - Not polluting or causing adverse changes in groundwater quality; and
    - Rehabilitating groundwater systems where practical.

3 Existing Aquifer Environment

The following sections are summarised from AGE (2012).

3.1 SITE STRATIGRAPHY

Geology within the Project Boundary consists of Quaternary-Late Tertiary sediments overlying a Permian to Triassic aged Gunnedah Basin Sequence that outcrops in the central and western areas.

The Upper Namoi alluvial plains surrounding the Project Boundary consist of two main formations; the Narrabri Formation and the Gunnedah Formation. The alluvium consists of the Narrabri Formation and is dominated by brown clays, while the underlying Gunnedah Formation consists of interbedded clays with sand and gravel layers. Sand and gravel deposits within the Gunnedah Formation are between 5 and 30 m thick. The Gunnedah Formation does not occur inside the Project Boundary.

Minor Tertiary Basalts and Dolerite are present in the eastern section of the site. These are possibly outliers of the Liverpool Range Beds.

The alluvial sediments overlie the Gunnedah Basin Sequence. The uppermost strata in this sequence are the alluvial fan deposits of Early Triassic aged Digby Formation Lithic and Quartz conglomerates in the west of the Project Boundary. Beneath this are the Late Permian aged Black Jack Group sediments containing the Breeza Coal Member, Hoskissons Coal Seam and underlying Pamboola Formations containing the Melvilles seam. These strata are underlain by the Watermark, Porcupine and the Maules Creek Formation (**Figure 3**).

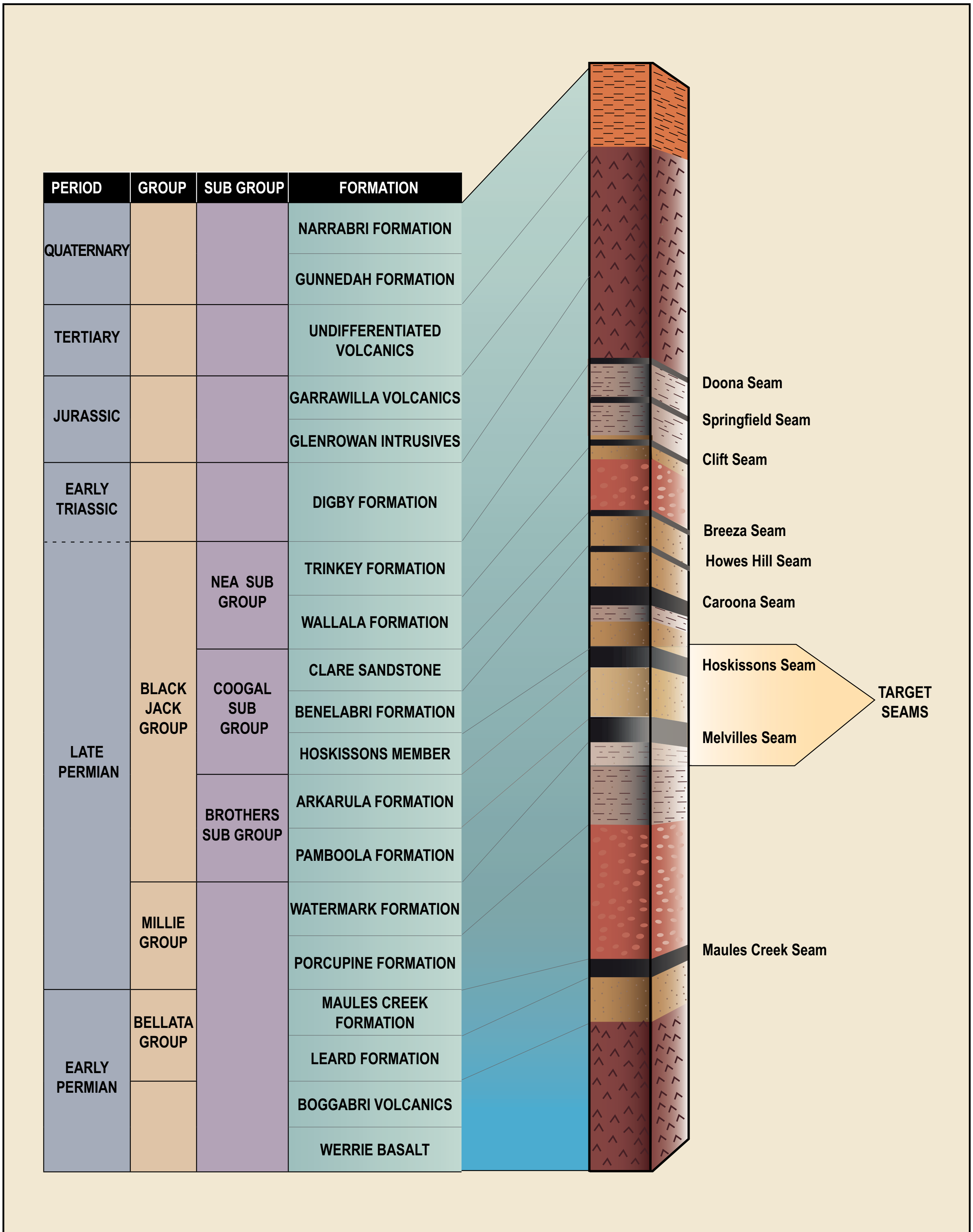
A colluvial deposit of mixed sand, clay silts and gravels occurs to the east of Breeza State Forest. This deposit is up to 50 m thick.

3.2 SITE GROUNDWATER

Unconsolidated alluvial sediments are confined to the black soil plains along the Mooki River. The Narrabri Formation is generally the lowest yielding of the two alluvial aquifers, and has a higher salinity (2,220 mg/L to 23,000 mg/L – AGE 2012). The Gunnedah Formation has high yields of fresh groundwater (<500 mg/L to 3,000 mg/L Total Dissolved Solids (TDS)), and is the main source of water for agriculture in the region. The Gunnedah Formation does not occur inside the Project Boundary.

Deeper sections of the Permian strata are low-yielding and water is generally saline. In shallower sections, the strata are more weathered and the water is generally fresher. Groundwater in the Permian aquifer within or close to elevated ridges generally has a salinity of less than 3,000 mg/L TDS, suggesting that these may be localised recharge areas for the Permian sediments. Further down-slope in the same strata, salinity increases to 5,000 to 10,000 mg/L TDS (AGE 2012), suggesting slow resonance times and an increase in TDS concentrations with distance from recharge locations.

Groundwater in both Permian and alluvial aquifers at the base of slopes to the south of the Project Boundary have TDS concentrations exceeding 10,000 mg/L. The groundwater level is often high at such breaks in topographic slope as a result of shallow groundwater evaporation and a generally high concentration of residual salts.



Coal | Sandstone | Claystone | Volcanics | Conglomerate | Siltstone

Hansen Bailey

SHENHUA WATERMARK COAL PTY LIMITED
神华沃特马克煤矿有限公司

Source: Tadros (1993)

WATERMARK COAL PROJECT

Indicative Stratigraphic Column

Filename: 0917.watermark.indd | Date: 5.8.12 | Drawn: MB | Figure 3

4 Desktop Assessment

4.1 PAST SURVEYS FOR STYGOFAUNA

No stygofauna surveys had previously been conducted within the Project Boundary. There are four regions within 100 km that have been surveyed and contain diverse stygofauna communities. The nearest region to be sampled is the Peel Alluvial Aquifer situated downstream of Tamworth, approximately 56 km to the east of the Project Boundary (Tomlinson and Boulton 2008). The Peel Alluvial Aquifer contains at least 20 taxa of stygofauna. Stygofauna have also been identified in water samples collected from alluvial aquifers of Maules Creek (Anderson 2008), Timor Caves (Rutledge *et al.* 2008, Hancock 2010), and near Scone (Hancock and Boulton 2008).

4.2 SUITABILITY OF AQUIFERS WITHIN THE PROJECT BOUNDARY

The two alluvial aquifers surrounding the Project Boundary may be suitable habitats for stygofauna. The Narrabri Formation has a highly variable salinity and overlies the Gunnedah Formation. There are lenses of sand and gravel in the Gunnedah Formation which are porous and may provide pockets of space for stygofauna occupation if suitable water quality conditions are present. The location of this aquifer beneath the Narrabri Formation reduces the likelihood of stygofauna occurrence in the Gunnedah Formation slightly, since this would reduce the direct recharge from rainfall over the whole aquifer.

Agricultural activities in the region may have already had significant impacts on the stygofauna community in the alluvial floodplain aquifers. Cropping and grazing have occurred in the area since the 1830's, and although stygofauna are known to occur within alluvial aquifers impacted by agriculture in other locations, these have been in areas where water table depth and connectivity to surface have been artificially enhanced by regulation, such as in the Pioneer Valley, Hunter Valley and Macquarie Valley (Hancock and Boulton 2008). Although diverse stygofauna communities were identified in these areas, it is impossible to determine how representative these communities are to pre-agricultural stygofauna communities, and also what level along a trajectory of succession the stygofauna communities are. At Breeza, agriculture may have had the following impacts on stygofauna communities:

- Removal of phreatophytic trees would reduce the availability of organic matter (used in stygofauna food webs) in the alluvial aquifer;
- Lowering of the water table through pumping from aquifers;
- Bank slump and erosion may result in reduced connectivity to parts of the Mooki River;
- Extraction and pressure reduction in the Gunnedah Formation may increase connectivity to the Mooki River.

It is unlikely that stygofauna will occur in the deeper Permian strata given their isolation from surface recharge, low permeability, and high salinity. The weathered sections of the Permian strata particularly where adjacent to the alluvial aquifer, experiences influxes of relatively fresh water. This environment may be suitable for stygofauna occupation.

5 Sampling Program

5.1 FIELD SAMPLING PROGRAM

There are no specific guidelines for sampling stygofauna in New South Wales. Queensland currently adopts the criteria outlined in the Western Australian Environmental Protection Authorities' *Guidance Statement 54* and *54a* (WA EPA 2003, 2007), which require at least 40 samples to be collected over two seasons for an impact area. The most efficient way of doing this is collect 20 samples twice in different seasons. However, for all aquifers known to contain stygofauna in eastern Australia, only one round of sampling was needed to confirm that they were present (Hancock 2004, Hancock and Boulton 2008, Hancock *unpublished,* Queensland Department of Resource Management *unpublished*). A t Watermark, the initial round of sampling included 20 bores. The purpose of this was to determine whether stygofauna were present.

The most common method of sample collection in WA and Queensland is to use a stygofauna haul net. The WA EPA guidelines are conservative and recognise that sampling with a net is very inefficient because only a relatively small part of the aquifer (i.e. the water column inside a bore cavity) is dragged with the net and stygofauna occur in low numbers in the aquifer. One way to increase efficiency is to complement netting with pumping to draw animals into the bore cavity from further parts of the aquifer (Hancock and Boulton 2008). Pumping is often limited by bore construction characters, water table depth, and time constraints, so it is not always practical to use the combined method. However, where pumping can be used, the resultant increased efficiency may give reason to reduce the number of samples collected.

For the Project, an initial round of sampling was conducted from 12 to 15 September 2011. Following a review of geological conditions, water quality, and bore construction details, 20 bores were selected for sampling (Table 1). Samples were collected from all aquifer types represented within EL 7223, but greater sampling effort was given to aquifers where stygofauna were likely to occur, based on current ecological understanding.

A sampling program was developed to provide a selection of bores representative of likely stygofauna habitats within the Project Boundary and in the immediate vicinity. Bores were selected to target the geological strata identified as potential stygofauna habitats, and to provide geographical coverage across the Project Boundary. Four bores were selected from inside or immediately adjacent to each of the mining areas, and eight bores were selected from outside of the disturbance boundary targeting alluvial and weathered Permian aquifers, which were determined to be the most likely aquifers to be stygofauna habitats (Figure 4).

Electrical conductivity (EC) was also considered during bore selection, with preference given to bores with favourable EC values for stygofauna occupation (i.e. EC < 5,000 µS/cm). However, to provide spatial coverage and an assessment of the identified geological strata, it was necessary to include bores containing water with EC > 5,000 µS/cm. Generally, bores were selected with water tables less than 20 m below ground surface. Exceptions were made to this criterion in order to assess the deeper strata identified within the Project Boundary.

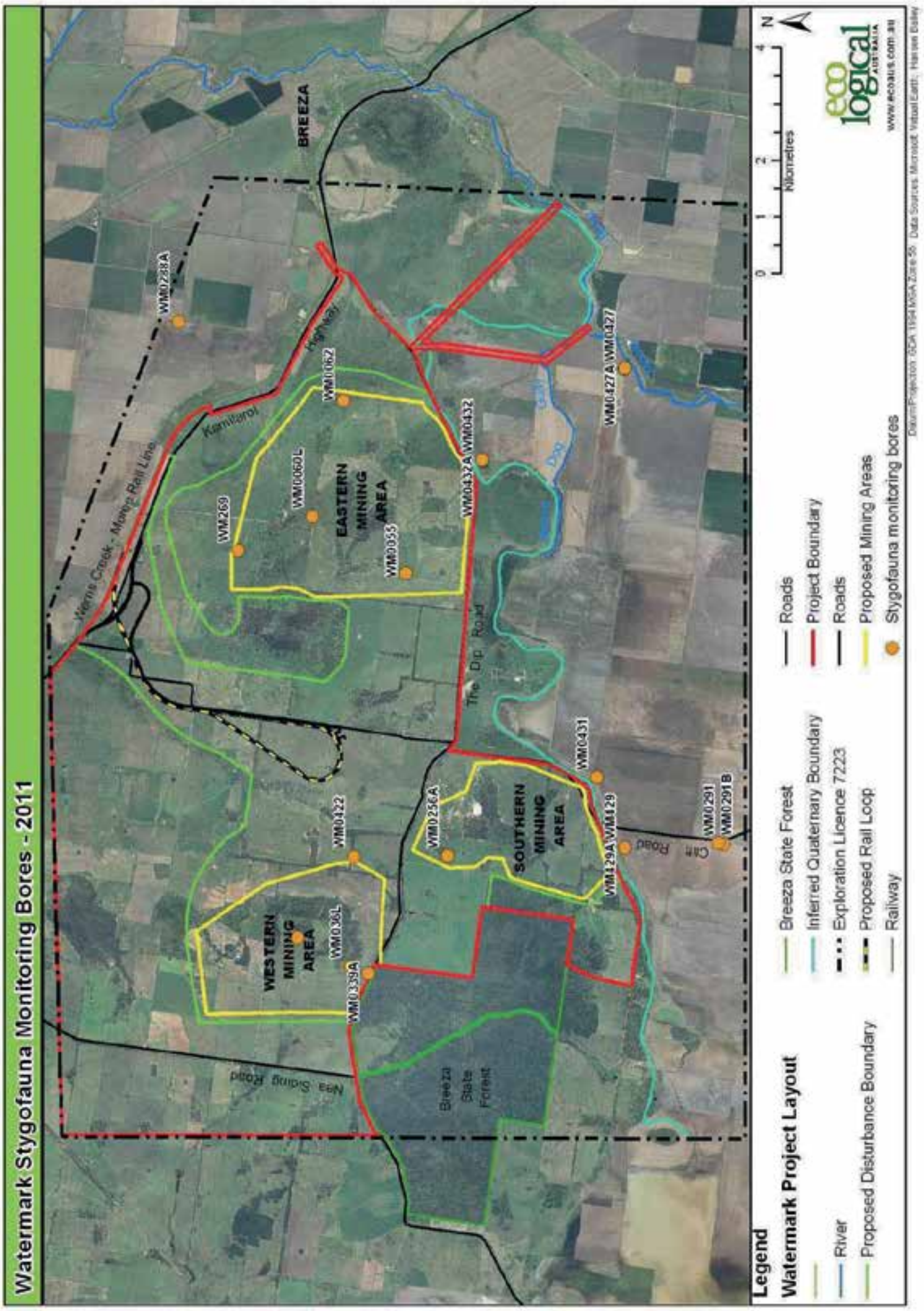


Figure 4: Stygofauna Monitoring Bore Locations

Table 1: Bores selected for stygofauna sampling and average water quality measurements

BORE	STRATA	EASTING (MGA)	NORTHING (MGA)	DO (mg/L)	EC (µS/cm)	pH	TEMP (^{o}C)	BOUWER RICE HYD. COND.	AVERAGE WATER LEVEL (mbgl)
WM0036L	Fractured Interburden	243510	6539991	1.64	3940	7.26	21.50	2.1*	37.53
WM0055	Melvilles Seam	250481	6538990	0.46	3849	7.05	22.09	0.12	13.08
WM0060L	Interburden	251491	6540670	0.71	1358	7.21	25.30	-	11.86
WM0062	Melvilles Seam	253551	6540115	4.02	1351	9.26	21.12	0.005	28.70
WM0247	Hoskisson Seam	244019	6540923	1.99	4660	6.79	22.92	0.028	31.64
WM0256A	Melvilles Seam	245469	6538253	1.74	4136	7.26	20.80	0.006	26.14
WM0260A	Interburden fault zone	246132	6537340	1.89	4094	6.72	22.06	0.001	37.04
WM0269	Pamboola Formation	251022	6541997	1.67	8915	6.79	21.28	0.007	15.04
WM0288A	Narrabri Formation (alluvial)	254946	6543039	2.64	11259	8.17	20.60	0.003	12.19
WM0291	Gunnedah Formation (alluvial)	245685	6533375	0.19	4856	7.01	20.73	7.2	2.54
WM0291B	Weathered Permian Lower Nea Sub-group	245685	6533375	0.63	6019	6.84	19.71	7.6	2.90
WM0339A	Fractured interburden	243383	6539685	0.03	7581	6.82	23.10	0.48	26.19
WM0422	Colluvium	245448	6539935	3.51	16316	7.05	23.10	0.002	12.86
WM0427	Weathered Perm	254164	6535120	0.90	4551	7.45	19.17	0.2	9.66
WM0427A	Gunnedah Formation (alluvial)	254170	6535125	0.18	1599	7.69	20.06	29	10.40
WM0429	Weathered Permian	245619	6535120	0.57	24640	6.72	101.55	0.11	1.70
WM0429A	Narrabri Formation (alluvial)	245615	6535117	0.27	25520	7.48	19.50	0.022	1.26
WM0431	Weathered Permian	246859	6535623	48.30	34260	6.95	19.15	0.018	0.88
WM0432	Weathered Permian	252490	6537653	1.44	33318	6.78	19.02	0.11	1.58
WM0432A	Narrabri Formation (alluvial)	252495	6537655	5.88	20528	7.34	18.67	0.022	1.45

Source: AGE (2012)

*estimated from pump test results

5.2 SAMPLE COLLECTION

Samples were collected using combined net and pump methods (Hancock and Boulton 2009) where conditions were suitable (i.e. if well construction allowed, and water table was < 50 m below the ground surface for 50 mm diameter bores, and < 25 m below the ground surface for 150 mm diameter bores). The combined sampling protocol is suitable for cased, vertical groundwater monitoring bores with an internal diameter of 50 to 150 mm internal diameter. For wells and unlined bores, stygofauna samples were collected using a stygofauna sampling net only.

A total of 18 bores were sampled using the combined net and pump method, and an additional two bores were sampled using the net method (no pumping).

5.2.1 Collecting stygofauna samples using a net

A weighted sampling net with 50 μm mesh was lowered to the bottom of each bore (Plate 1). The net was raised and dropped over approximately 50 cm for three to five times to dislodge resting fauna, then the net was retrieved slowly. Slow retrieval is necessary to avoid a bow-wave pushing fauna out of the net entrance. Once the net was at the surface, it was rinsed into a 50 μm mesh sieve and then lowered once more to the bottom of the bore. This process was repeated until the contents of six net hauls were in the sieve. Sieve contents were washed into a sample jar and preserved in 100% ethanol to preserve any organic matter for laboratory examination.

Plate 1: Collecting stygofauna sample using haul net

5.2.2 Collecting stygofauna samples with a pump

After net sampling, a hose was lowered into the bore so that the inlet was either above or below the screened section of the bore. If this was not possible because the screened section was too deep (i.e. >50 m), then the hose was lowered as far below the water table as possible. Once in place, 300 L of water was pumped into buckets and subsequently poured through a 50 μm mesh sieve (Plate 2). Water was pumped into buckets rather than straight through the sieve to allow mineral content entrained in the water to settle. Each bucket was elutriated through the sieve by gently swirling so that heavier sediments remained at the bottom, while lighter sediments, water and organic matter (including stygofauna) were poured into the sieve. Sieve contents were then transferred to a sample jar and stored in 100 % ethanol to preserve any organic matter for laboratory examination.

Only seven out of 18 pumped bores yielded 300 L (WM0060L, WM0432, WM0291, WM0291B, WM0429, WM0431, WM0427A). The remaining 11 pumped bores were pumped dry.

Plate 2: Pumping bore water into buckets prior to sieving

5.2.3 *In-situ* parameter measurement

The water level was measured at each bore using a water interface dip meter prior to sampling. Groundwater pH, EC, temperature, and dissolved oxygen (DO) were all measured during sampling using the pumping methods at 10 L, 50 L, and then every subsequent 50 L. In order to determine *in-situ* parameters in bores where pumping was not possible, water was collected using a groundwater bailer and the parameters were measured after 5 L was bailed from the bore. Although the bailed water parameters were representative of the bore cavity rather than the aquifer water, these parameters were measured because it is the water from which net sampling collected stygofauna. Parameters were measured using a calibrated YSI-556 multi-parameter meter.

5.3 LABORATORY ANALYSIS

Following sampling, the collected samples were transported to a laboratory and analysed. Samples were initially sorted using a dissecting microscope. Where stygofauna were encountered, specimens from each taxon were counted and removed for later identification as far as possible using dissecting and compound microscopes, and available taxonomic keys.

Many stygofauna in NSW are undescribed because of the relatively recent interest in stygofauna taxonomy in this state. Where undescribed taxa were encountered, they were assigned a morphospecies name.

6 Results

6.1 WATER CHEMISTRY AND WATER LEVEL

Bore yield was generally low during sampling. Less than 70 L of water was extracted from 11 of the 18 bores sampled using the net and pump methods. 300 L was collected from bore WM60L in the Permian aquifer, bores WM432, WM291B, WM429, and WM431 in the weathered Permian aquifer, and bores WM291 and WM427A in the Gunnedah Formation.

In-situ parameters measured during sampling were generally similar in bores screened in the same aquifer (Table 2). The measured parameter most likely to influence stygofauna survival is EC. The EC measured in groundwater from the Permian aquifers ranged from:

- the Permian aquifers ranged from 1,396 to 32,350 µS/cm;
- the weathered Permian aquifer ranged between 4,509 and 33,010 µS/cm;
- the Narrabri Formation alluvial aquifer ranged between 4,012 and 26,430 µS/cm; and
- the Gunnedah Formation ranged between 1,618 and 4,897 µS/cm.

DO concentrations measured *in-situ* ranged from:

- 0.3 to 4.1 mg/L in the Permian aquifers;
- 0.7 to 2.6 mg/L in the weathered Permian aquifers; and
- 0.5 to 1.0 mg/L in the Gunnedah Formation.

There is often a lot of agitation involved in collecting water samples with the bailer and in pumping when the well becomes dry. Agitation can cause artificial aeration in water samples, so the measured DO concentration in bores where less than 300 L was collected may not be representative of actual DO concentrations in the aquifer. DO concentrations in these samples ranged from 1.0 to 4.1 mg/L. These values should be taken as indicative only.

In bores where 300 L of water was successfully pumped, dissolved oxygen concentrations ranged from 0.3 to 1.0 mg/L.

The water level was shallower than 16 m below the ground surface in all bores except for WM247, WM36L, WM339A, WM256A, WM260A and WM62.

Table 2: Physico-chemical properties and water level for bores sampled for stygofauna.

BORE NAME	AQUIFER	DATE	WATER LEVEL (m bgl)	AVERAGE PAST EC (µS/cm)	EC (µS/cm)	pH	DO (%sat)	DO (mg/L)	TEMP (°C)	VOLUME PUMPED (L)
WM269	Pamboola Fm	12/9/11	14.50	10,340	10,450	6.6	38.5	3.24	22.56	16
WM60L	Interburden	12/9/11	12.17	1,358	1,460	7.3	5.3	0.47	21.66	300
WM55	Melvilles Seam	12/9/11	13.02	3,798	3,814	7.0	45.8	4.05	20.80	50
WM432	Weathered Permian	12/9/11	2.07	30,850	32,350	6.7	3.5	0.28	18.93	300
WM0432A	Narrabri Alluvium	12/9/11	1.92	12,020	21,970	7.1	28.4	2.37	19.23	35
WM0247	Hoskisson	13/9/11	31.22	4,450	4,495	6.8	45.1	4.14	18.72	10
WM0036L	Fractured Interburden	13/9/11	36.36	3,940	3,395	10.8	47.2	4.06	22.09	12
WM0339A	Fractured Interburden	13/9/11	27.11		8,314	7.2	11.7	0.96	24.08	54
WM0256A	Melvilles Seam	13/9/11	25.85	4,372	4,668	7.2	38.6	3.19	24.39	38
WM0260A	Interburden	13/9/11	36.36	4,390	4,455	6.6	18.8	1.69	21.06	Bailer
WM0422	Colluvium	13/9/11	12.84	15,720	1,701	6.8	41.1	3.42	21.34	20
WM0291	Gunnedah Formation	14/9/11	2.40	5,087	4,897	6.9	11.7	1.02	21.02	300
WM0291B	Weathered Permian	14/9/11	2.29	6,052	6,413	6.8	8.6	0.73	22.15	300
WM429	Weathered Permian	14/9/11	1.72	24,380	23,410	6.5	8.9	0.72	19.74	300
WM429A	Narrabri Alluvium	14/9/11	1.59	24,640	26,430	6.6	83.3	6.59	22.13	50
WM0431	Weathered Permian	14/9/11	1.18	34,320	33,010	6.8	10.3	0.81	19.38	300
WM0062	Melvilles Seam	14/9/11	24.24	1,518	1,396	9.3	17.3	1.54	20.35	Bailer
WM288A	Narrabri Alluvium	15/9/11	10.55	3,686	4,012	8.1	34.2	3.07	19.98	70
WM0427	Weathered Permian	15/9/11	9.73	3,940	4,509	7.4	29.0	2.59	20.64	60
WM0427A	Gunnedah Formation	15/9/11	10.30	1,451	1,618	7.5	5.3	0.48	20.41	300

6.2 IDENTIFIED FAUNA

No definite stygofauna taxa were identified. A single Enchytraeidae worm (Oligochaeta) was collected from bore WM429A, which is screened in the Narrabri Formation. While stygofauna enchytraeids are known, this family is generally found in upper soils and in surface waters.

7 Discussion

7.1 CONTEXT OF SURVEY

No previous sampling for stygofauna has been conducted within the Project Boundary, although stygofauna species are known from several alluvial aquifers within a 100 km radius. The nearest known site is the Peel River Alluvial Aquifer downstream of Tamworth, approximately 56 km to the east of the Project Boundary (Tomlinson and Boulton 2008). The Peel Alluvial Aquifer is known to contain at least 20 taxa of stygofauna. Stygofauna have also been collected from alluvial aquifers of Maules Creek (Anderson 2008), with is located approximately 86 km north of the Project Boundary; Timor Caves (Rutledge 2008, Hancock 2010), 85 km south-east of the Project Boundary; and near Scone, 95 km south-east of the Project Boundary (Hancock and Boulton 2008).

It is not possible to know the original composition of the stygofauna community, as the alluvial floodplain overlying the Gunnedah and Narrabri Formations has been subject to more than 170 years of agricultural disturbances which could have impacted on the stygofauna. Agriculture and stygofauna can co-exist in alluvial aquifers of regulated rivers with permanent flow (e.g. Hunter River, Macquarie River, Pioneer River– Hancock and Boulton 2008, Hancock and Boulton 2009), but there is no way of knowing how these communities have been altered by agricultural activities.

The Gunnedah Formation alluvial aquifer was considered to be the most likely aquifer to contain stygofauna because of the low EC measurements and coarse sediments that provide space for stygofauna occupation, however neither of the samples collected from these bores contained stygofauna.

Where the Gunnedah Formation is close to the Mooki River, stygofauna occupation is more likely, particularly if there is water flow from the river to the aquifer. Bore WM427A is less than 200 m from the main channel of the Mooki River, therefore was the most likely of the bores sampled to contain stygofauna, however none were identified. The main impediment to considering the Gunnedah Formation as prime stygofauna habitat is that it is located beneath the Narrabri Formation, which may prevent surface water and rainfall flow into the Gunnedah Formation.

The Narrabri Formation may contain stygofauna because it is shallow and some places may be connected to the Mooki River. Although the Narrabri Formation in EL 7223 is made of finer sediments (predominately clays) than the Gunnedah Formation, it contains isolated lenses of sandy material that could provide enough pore space for stygofauna, however in general the Narrabri formation within the Project Boundary consists of dense clay.

A limiting factor in the Narrabri Formation is the high electrical conductivity, which exceeded 21,000 μS/cm in two out of three of the sampled bores. WM288A had an EC of only 4,012 μS/cm and was located in alluvium north of the Permian outcrop, but once again, no stygofauna were identified.

7.2 FAUNA COLLECTED DURING SAMPLING

A single worm from the oligochaete family Enchytraeidae was collected from bore WM429A. This bore was screened within the Narrabri Formation. While stygofauna enchytraeids are known, this family is generally found in upper soils and surface waters and is not unique to aquifers. It is possible that the specimen collected from this bore was living in the groundwater at the time of collection, and salt-tolerant oligochaetes are known (Pinder 2010), but this is unlikely because most salt tolerant taxa occur in areas where groundwater is influence by sea water. The taxonomy and ecology of aquatic oligochaetes is almost completely unknown in NSW beyond family level, so it is impossible to conclusively distinguish between soil, groundwater, and aquatic species. The presence of this specimen in the sample collected from bore WM429A, which is screened within the Narrabri Formation, may indicate that representatives of other taxa may be present in the aquifer that are less ambiguously stygofauna.

7.3 LIKELIHOOD THAT STYGOFAUNA OCCUR IN THE PROJECT BOUNDARY

Stygofauna generally occur at low densities in aquifers (Humphreys 2008) unless there are areas of resource abundance, such as at tree roots (Jasinska *et al.* 1996, Hancock and Boulton 2008). The relatively low abundance of stygofauna in aquifers reduces the chance of collection at bores and often requires more than one sampling (EPA 2007). Despite this, one round of sampling has been enough to indicate the presence of stygofauna in aquifers in eastern Australia (e.g., Pioneer, Condomine, Burdekin, Burnett Regions in Queensland; Hunter Valley, Tamworth, and Dubbo Regions in NSW). Therefore it is reasonable to expect that if a stygofauna community was present within the Project Boundary, specimens would have been collected from at least one of the 20 bores sampled. Sampling within the Project Boundary partially compensated for low stygofauna densities by complementing net hauls with pump sampling where possible to increase the capture area of the survey.

Stygofauna in New South Wales are known mostly from alluvial aquifers, particularly in aquifers with coarse sediments, shallow water tables, and low EC (Hancock and Boulton 2008). With the exception of the two proposed pipeline alignments, which meet the Mooki River, the nearest part of the Project Boundary to the Mooki River is approximately 3 km. The likelihood of the two alluvial aquifers within the Project Boundary being suitable for stygofauna declines with distance from the main channel of the Mooki River. The most suitable aquifer, based on water parameters measured during sampling and sediment porosity, is the Gunnedah Formation. The Gunnedah Formation is generally located at a distance of greater than 0.9 km from the Eastern and Southern Mining Areas. Two bores within the Gunnedah Formation were sampled and yielded no stygofauna.

7.4 POTENTIAL IMPACTS OF PROPOSED OPERATIONS

The Preliminary Environmental Risk Assessment for the Project (Hansen Bailey 2011) identified the following potential impacts to aquifers within the Project Boundary:

- Accelerated groundwater drawdown, changes to groundwater flow direction, and changes to groundwater quality;
- Further depressurisation of aquifers in the area through mine void dewatering;
- Increased groundwater flow to mining areas;
- Accelerated loss of groundwater yield at existing bores; and
- Long term changes (post mine closure) to groundwater levels and groundwater quality.

Groundwater modelling for the Project (AGE 2012) indicates that the Project is anticipated to only intercept the Permian strata, which are typically unsuitable for stygofauna. Therefore there is no immediate threat to aquifer ecosystems in the Permian strata within the Project Boundary.

As there will be no mining directly on the floodplain, the main impacts to the alluvial aquifers are likely to be through potential lowering of the water table from seepage from the Permian aquifers into the mine voids. Groundwater modelling indicates that small parts of the Gunnedah Formation could experience a decline in water table of up to 3.5 m during the life of the Project. The majority of this drawdown is less than 2 m and extends to a maximum radial extent of less than 4 km from the Project. Drawdown in the Gunnedah Formation commences towards the latter stage of mining activities (year 21). Groundwater impacts within the Gunnedah Formation recover close to detectable limits (less than 1 m) at the end of mining in year 30 (AGE 2012). This is within the current range of fluctuations in the Gunnedah Formation, and would be unlikely to impact significantly on stygofauna communities if they occurred in the Project Boundary or in the immediate vicinity.

The vulnerability of stygofauna to impacts from development stems mainly from their lack of ability to adapt to rapid environmental change, their limited dispersal ability and the often restricted range of many species (Hancock et al. 2005, Finston et al. 2004). Minor changes are anticipated in the water level and quality of the alluvial aquifers due to the Project, therefore the Project is unlikely to have any significant impact on aquifer ecosystems in the area.

7.5 SURVEY LIMITATIONS

Stygofauna sampling was restricted to existing bores. These bores were installed as part of a water quality sampling program, or as agricultural watering points, and are not necessarily placed to maximise the chance of collecting stygofauna. The conditions of the Gunnedah Formation are suitable for stygofauna occupation, suggesting that stygofauna may be present in the aquifer. Stygofauna are most likely in areas of the aquifer near the Mooki River, which are outside of the Project Boundary.

Stygofauna generally occur in low densities, making one-off surveys often inadequate for biodiversity assessments (WA EPA 2003). As only one round of sampling has been conducted within the Project Boundary, it is possible that a second round targeting the alluvial aquifer may yet yield stygofauna samples. However, for all stygofauna surveys in eastern Australia, a single round of sampling that strategically targets bores with suitable habitat conditions, has been sufficient to establish the presence, if not diversity of a stygofauna community.

8 Recommendations

A review of geological and hydrogeological data concluded that stygofauna may be present in aquifers within the Project Boundary, and that they are likely to be present in the Gunnedah Formation and Narrabri Formation alluvial aquifers. Sampling undertaken for this assessment in September 2011 within these formations failed to collect any taxa which could definitively be classified as stygofauna.

No stygofauna were identified in samples collected from the Permian aquifers where the main impacts of the Project are anticipated. These aquifers are generally too deep to be considered suitable stygofauna habitat, and probably do not have sufficient living space. They were sampled initially because it may have been possible that there were pockets of suitable habitat intersected by the bores, particularly in the weathered sections of Permian Rock. However, high EC and low hydraulic conductivity make the Permian aquifers unlikely stygofauna habitats.

Hydrogeological modelling indicates that the Project will have maximum drawdown of 3.5 m in the Gunnedah Formation (AGE,2012). The majority of this drawdown is less than 2 m and extends to a maximum radial extent of less than 4 km from the Project. This level of drawdown is within the natural fluctuating range of the water table and is unlikely to significantly impact on any stygofauna.

The Project poses little threat to aquifer ecosystems because:

- no stygofauna were collected during sampling at Watermark and water quality data indicate that conditions are unsuitable to stygofauna; and
- modelling indicates that there will be negligible impact on the alluvial aquifers of the Gunnedah Formation, which is the most suitable stygofauna habitat.

As it is unlikely that there are significant stygofauna communities within or immediately surrounding the Project Boundary, and as operations are unlikely to cause major changes to the groundwater conditions in the Gunnedah Formation, no further sampling is necessary.

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