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Stygofauna Impact Assessment

BYLONG COAL PROJECT
Environmental Impact Statement

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BYLONG COAL PROJECT ENVIRONMENTAL IMPACT STATEMENT

Stygofauna Impact Assessment

Prepared for
Hansen Bailey
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Executive Summary

In December 2010 KEPCO Bylong Australia Pty Ltd (KEPCO) acquired Authorisations (A) 287 and 342 in the Western Coalfield of NSW. KEPCO is seeking State Significant Development Consent under Division 4.1 of Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) for the development and operation of the Bylong Coal Project (the Project). The State Significant Development Application will be supported by an Environmental Impact Statement (EIS) which is being prepared by Hansen Bailey.

Eco Logical Australia (ELA) was commissioned by Hansen Bailey Environmental Consultants (Hansen Bailey) on behalf of KEPCO to undertake a stygofauna impact assessment for the EIS.

The stygofauna impact assessment included a desktop review of previous stygofauna sampling in the area, a review of available groundwater data to determine the suitability of aquifers on-site for stygofauna species, and two field surveys of 20 bores each, as an assessment of groundwater biodiversity on-site. Following the field surveys, results from the groundwater modelling was considered to determine whether the Project will have any significant impact on the stygofauna community.

The desktop review indicated that alluvial aquifers of the Hunter Valley exhibit areas of high stygofauna diversity. The review of water quality and aquifer characteristics in the Bylong Valley indicated that the alluvial aquifers in this area are suitable habitat for groundwater fauna. Hard rock aquifers were considered as unlikely habitat for stygofauna because of the depth to water table and low hydraulic conductivity.

A total of 20 bores were sampled in October 2012, with most of the survey effort placed in the alluvial aquifers as the desktop review indicated these aquifers are most likely to contain groundwater fauna. This survey indicated that the area has a potentially diverse groundwater invertebrate community, with nine taxa collected. Animals occurred throughout the alluvial aquifer. Where paired bores were sampled, stygofauna were collected more often from the shallow bore than the deeper bore, although at A08, fauna were collected from both deep and shallow bores, both in the alluvial aquifer.

A second survey occurred in February 2014. An additional 19 samples were collected during this survey, bringing the total number to 39 over the two survey rounds. Of the bores sampled during the second survey, 12 had been sampled previously, and seven were new. Ten stygofauna taxa were collected from 12 bores, with all bores but one screened at the shallow alluvial aquifer.

Across both surveys, ten stygofauna taxa were collected, all of which are known from outside the predicted area of impact for the Project. The most widespread taxon was cyclopoida, which occurred in ten bores. This was also the most abundant taxon. The alluvial aquifer appears to be richest from A10 along the Lee Creek alluvium to its confluence with the Bylong River alluvium and northwards to AGE04-S. This section contained all ten taxa present at the site.

Despite the potential for some localised impacts to the stygofauna community caused by predicted drawdowns, the regional significance of these is likely to be minor. This is because:

- Most of the depressurisation would be to the Permian aquifer, which is only marginal stygofauna habitat
- Dewatering is not expected to completely dry the alluvium across extensive areas, leaving refuge habitat for stygofauna

- All taxa occurring in the predicted zone of drawdown are known to occur elsewhere, either from sampling conducted during the two surveys at Bylong, or from other stygofauna surveys in NSW.

1 Introduction

In December 2010 KEPCO Bylong Australia Pty Ltd (KEPCO) acquired Authorisations (A) 287 and 342. Since this time, extensive exploration and mine planning work has been undertaken to determine the most socially responsible and economically viable mine plan to recover the known coal resources within the two Authorisations.

In August 2014 KEPCO commissioned WorleyParsons Services Pty Ltd (WorleyParsons) to manage the Project exploration activities, mine feasibility study planning, environmental approvals and ongoing environmental monitoring for the Bylong Coal Project (the Project).

The Project is located wholly within A287 and A342 which are located within the Mid-Western Regional Council (MWRC) Local Government Area (LGA). The closest regional centre is Mudgee, located approximately 55 km south-west of the Project Boundary. The Project is approximately 230 km by rail from the Port of Newcastle. **Figure 1** illustrates the location of the Project within New South Wales (NSW). **Figure 2** shows the regional locality of the Project in relation to the neighbouring town centres, mining authorities, major transport routes and reserves.

KEPCO is seeking State Significant Development Consent under Division 4.1 of Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) for the development and operation of the Project. The State Significant Development Application will be supported by an Environmental Impact Statement (EIS) which is being prepared by Hansen Bailey.

Eco Logical Australia (ELA) has been commissioned by Hansen Bailey to prepare a Stygofauna Impact Assessment for the Project which is located within the Bylong Valley, within the Western Coalfield of NSW (**Figure 1**).

1.1 Project description

The Project life is anticipated to be approximately 25 years, comprising a two year construction period and a 23 year operational period, with underground mining operations commencing in Year 7. Various rehabilitation and decommissioning activities will be undertaken during both the course of, and following the 25 years of the Project. It is noted that further mineable coal resources exist within both A287 and A342.

The Project is to be developed on land within the Project Boundary as illustrated on **Figure 3**. Key features of the Project are conceptually shown on **Figure 3** and include:

- The initial development of two open cut mining areas with associated haul roads and Overburden Emplacement Areas (OEAs), utilising a mining fleet of excavators and trucks and supporting ancillary equipment;
- The two open cut mining areas will be developed and operated 24 hours a day, 7 days a week over an approximate 10 year period and will ultimately provide for the storage of coal processing reject materials from the longer term underground mining activities;
- Construction and operation of administration, workshop, bathhouse, explosives magazine and other open cut mining related facilities;
- Construction and operation of an underground coal mine operating 24 hours a day, 7 days a week for a 20 year period, commencing mining in around year 7 of the Project;

- A combined maximum extraction rate of up to 6.5 Million tonnes per annum (Mtpa) Run of Mine (ROM) coal;
- A workforce of up to approximately 800 during the initial construction phase and a peak of 470 full-time equivalent operations employees at full production;
- Underground mining operations utilising longwall mining techniques with primary access provided via drifts constructed adjacent to the rail loop and Coal Handling and Preparation Plant (CHPP);
- The construction and operation of facilities to support underground mining operations including personnel and materials access to the underground mining area, ventilation shafts, workshop, offices and employee amenities, fuel and gas management facilities;
- Construction and operation of a CHPP with a designed throughput of approximately 6 Mtpa of ROM coal, with capacity for peak fluctuations beyond this;
- The dewatering of fine reject materials through belt press filters within the CHPP and the co-disposal of dewatered fine and coarse reject materials within OEAs and final open cut voids (avoiding the need for a tailings dam);
- Construction and operation of a rail loop and associated rail load out facility and connection to the Sandy Hollow to Gulgong Railway Line to facilitate the transport of product coal;
- The construction and operation of surface and groundwater management and water reticulation infrastructure including diversion drains, dams (clean, dirty and raw water), pipelines and pumping stations;
- The installation of communications and electricity reticulation infrastructure;
- Construction and operation of a Workforce Accommodation Facility (WAF) and associated access road from the Bylong Valley Way;
- The upgrade of Upper Bylong Road and the construction and operation of a Mine Access Road to provide access to the site facilities;
- Relocation of sections of some existing public roads to enable alternate access routes for private landholders surrounding the Project; and
- Infilling of mining voids, progressive rehabilitation of disturbed areas, decommissioning of Project infrastructure and rehabilitation of the land progressively following mining operations.

Figure 3 illustrates the Conceptual Project Layout.

Figure 1: Location of Bylong Coal Project in NSW

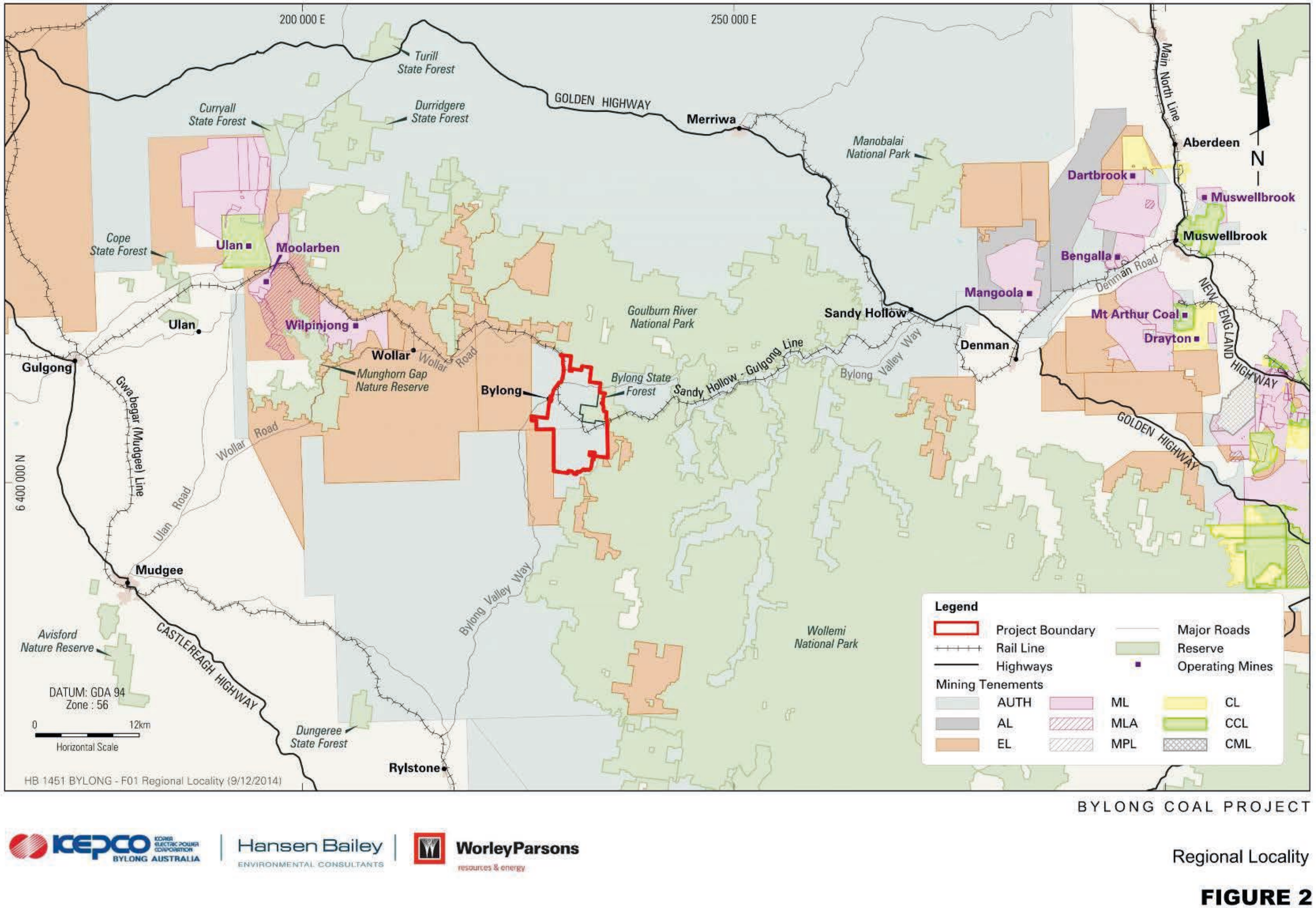

Figure 2: Regional location of the Bylong Coal Project.

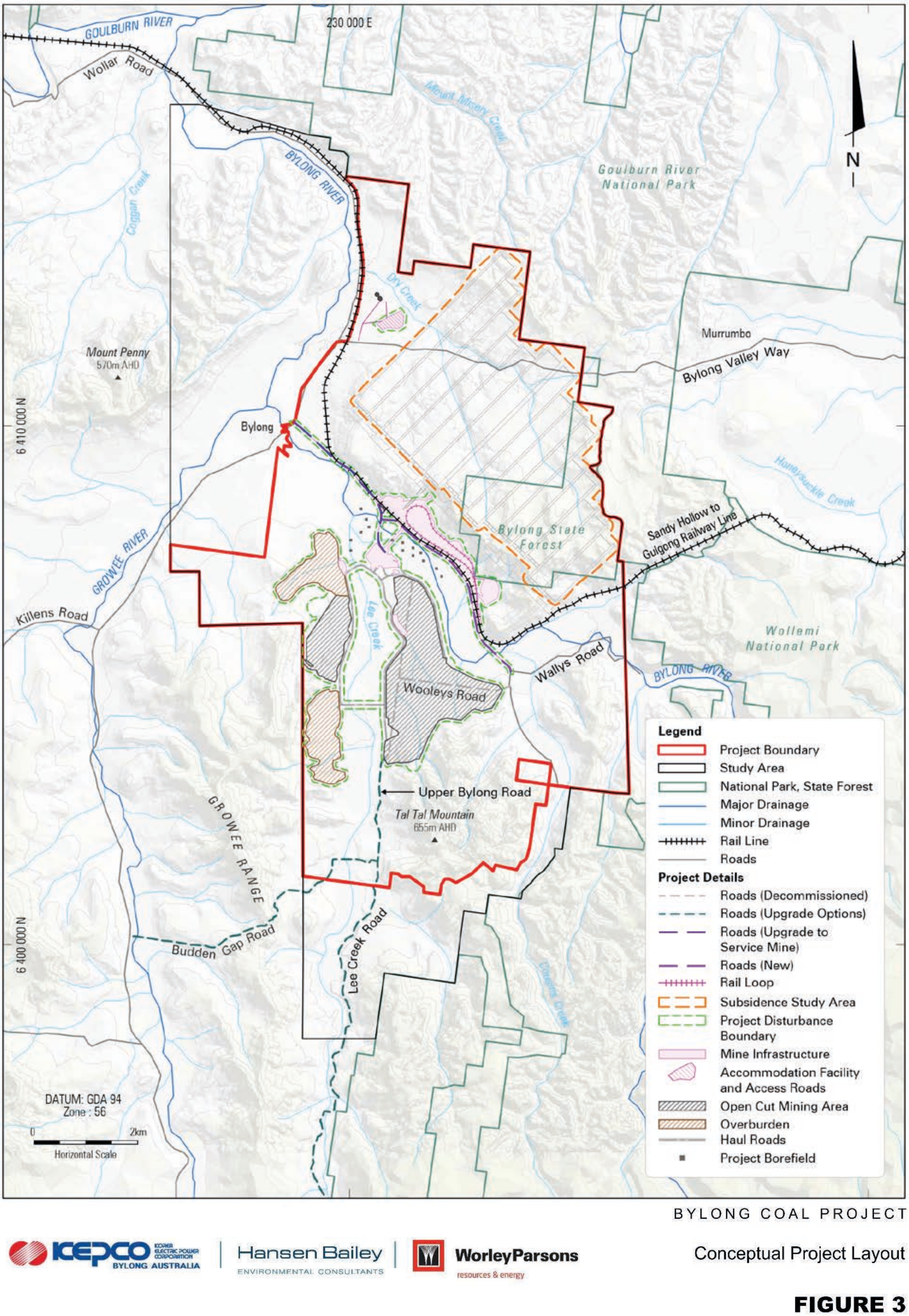

Figure 3: Conceptual layout of Project.

1.2 Scope of Work

ELA has been commissioned to complete a Stygofauna Impact Assessment for the Project that is suitable for inclusion in the EIS. The scope of work for the assessment includes:

- Review literature and previous assessments undertaken in the area surrounding the Project
- Review relevant data and information in the relevant technical reports such as the groundwater impact assessment and the flora and fauna impact assessment that have been developed for the Project by separate consultants
- Following the review of the above, a conference call with Hansen Bailey, the groundwater and ecology specialist (if required) and review of aerial photography and geology to understand the groundwater regime in the area and identify distinctive domains with stygofauna potential
- Design and implement a sampling program based on the results of the literature review;
- Review predicted groundwater impacts and assess the potential impacts to each groundwater domain that may contain stygofauna
- Assess the potential regional, state and national significance of impacts on these stygofauna
- Discuss the impact of groundwater depressurisation predicted for the Project (and cumulative with other mines in the region) and other land-uses in the region including pumping from the aquifer(s) for agricultural purposes
- Provide recommendations for any future groundwater monitoring regimes that could be implemented to monitor the impacts of the Project on stygofauna.

The stygofauna report aims to satisfy the SEAR's for the Project. These are discussed below in **Section 2.1.1**.

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, and sets out guidelines for the assessment of developments. The Act also aims to encourage ecologically sustainable development in NSW and to protect natural habitat, flora and fauna.

2.1.1 Secretary's Environmental Assessment Requirements (SEARs)

The EIS for the Project must be prepared in accordance with the SEARs which were issued on 23 June 2014 and subsequently modified on 11 November 2014. This assessment, which forms part of the EIS, addresses the SEARs for water and biodiversity, and concerns raised by stakeholders. The report specifically addresses the following requirements for:

- **Biodiversity**: An assessment of the likely biodiversity impacts of the development, having regard to OEH's, the Department of Primary Industries' and the (Commonwealth) Department of Environment's requirements,

- **Water**: Including an assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water related infrastructure, and other water users,

This report assesses the impact of the Project on the 'aquifer ecosystem' type of groundwater dependent ecosystem (GDE) and considers only the potential impacts to stygofauna.

Requirement	How it is addressed
NSW Office of Water recommend that the EIS be required to include: - Assessment of impacts on surface and ground water sources (both quality and quantity), watercourses, riparian land, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts. This is to include an assessment to meet the requirements of the NSW Aquifer Interference Policy (2012).	The impacts on aquifer ecosystems, a type of GDE, are considered in Section 8.
<u>Groundwater Assessment</u> To ensure the sustainable and integrated management of groundwater sources, the EIS needs to include adequate details to assess the impact of the project on all groundwater sources including: - Protective measures for any groundwater dependent ecosystems (GDEs).	Baseline monitoring of two survey periods was conducted for this assessment. As there is unlikely to be a significant impact on aquifers containing stygofauna, no protective measures are needed. These impacts are considered in Sections 8 and 10.

Requirement	How it is addressed
<u>Groundwater Dependent Ecosystems</u> It is suggested the EIS considers the potential impacts on any Groundwater Dependent Ecosystems (GDEs) at the site and in the vicinity of the site and: - Identify any potential impacts on GDEs as a result of the proposal including: - the effect of the proposal on the recharge to groundwater systems; - the potential to adversely affect the water quality of the underlying groundwater system and adjoining groundwater systems in hydraulic connections; and - the effect on the function of GDEs (habitat, groundwater levels, connectivity). - Provide safeguard measures for any GDEs.	Potential impacts to aquifer ecosystems are considered in Section 8

2.2 NSW State Groundwater Quality Protection Policy 1998

The *NSW State Groundwater Quality Protection Policy 1998* is designed to encourage the ecologically sustainable management of NSW's groundwater resources. The principles of the policy that are applicable to the protection and management of stygofauna include:

- All groundwater systems should be managed such that their most sensitive identified beneficial use (or environmental value) is maintained
- Groundwater pollution should be prevented so that future remediation is not required
- Groundwater Dependent Ecosystems will be afforded protection
- The cumulative impacts of developments on groundwater quality should be recognised by all those who manage, use, or impact on the resource
- Where possible and practical, environmentally degraded areas should be rehabilitated and their ecosystem support functions restored.

2.3 NSW State Groundwater Dependent Ecosystems Policy 2002

The *NSW State Groundwater Dependent Ecosystems Policy 2002* is designed to protect ecosystems which 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:

- The scientific, ecological, aesthetic and economic values of groundwater dependent ecosystems, 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 Groundwater Dependent Ecosystems
- 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
    - For Groundwater Dependent Ecosystems 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 Groundwater Dependent Ecosystems. 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 Groundwater Dependent Ecosystems 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
    - Rehabilitating groundwater systems where practical.

3 Ecological requirements of stygofauna

This section summarises the groundwater quality and quantity requirements of stygofauna.

3.1 Background - Factors influencing biological distribution in aquifers

Stygofauna are generally small aquatic invertebrates that live in groundwater systems. Recent estimates suggest there could be as many as 2680 species in the western half of the Australian continent, although approximately 12 % of these have been described (Guzik et al 2011). It is difficult to estimate the diversity of eastern Australian aquifers, but they may be just as diverse as western aquifers.

As with all fauna, groundwater invertebrates require favourable conditions to inhabit an aquifer. However, given the large number of species there is a broad range of variability in ecological requirements. Not all aquifers are naturally suitable for stygofauna and those that are suitable may become unsuitable as a result of human activities or natural changes. The biological distribution of stygofauna 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 surveys when compared to Western Australia. Nevertheless, it is possible to briefly summarise what is already known about the aquifer conditions that are likely to influence the distribution of stygofauna.

3.1.1 Aquifer type

Stygofauna have been collected from many aquifer types, including fractured basalt, fractured sandstone aquifers, and pesolithic aquifers, but are most common in karstic and alluvial aquifers. Critical aquifer characteristics are the hydraulic conductivity, depth to water table, and porosity.

Generally, stygofauna occur more frequently in alluvial aquifers and karst 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 from upstream dams may provide aquifer recharge of organic matter and oxygen in periods where natural surface flow would be absent
- Compared to deeper aquifers, water in alluvial aquifers is young, has a rapid flux, and can have a lower salinity.

3.1.2 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 can be replenished.

3.1.3 Depth of water table

Depth to water table influences the amount of organic matter and oxygen that are available to aquifer food webs. With increasing depth below the land surface, the concentration of organic matter dissolved in infiltrating rainwater diminishes as it is absorbed in transit by soil bacteria and plant roots. Shallow water tables of less than 15 m have been found to favour high diversity in alluvial aquifers 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).

3.1.4 Connectivity to recharge areas

A large proportion of the organic matter that fuels aquifer food webs has its origin 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 transfer of organic matter and oxygen is greater at these sites (Datry et al 2004).

3.1.5 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, between pesolithic sediments in calcrete, and fractures in sandstone and basalt. In unconsolidated 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.

3.1.6 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 ancestry. As an example, in coastal areas where ancestral stygofauna species may have come from a marine origin, contemporary taxa may be tolerant of high salinity (Hancock and Steward 2004, Humphreys 2008). Conversely, taxa with a freshwater ancestry may prefer lower salinities (Hancock and Boulton 2008).

3.1.7 Food availability

Stygofauna have adapted to the resource-starved conditions in aquifers and can tolerate low concentrations of organic matter (Strayer 1994, Hahn 2006). 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 imbibed by smaller stygofauna. Most stygofauna are opportunistic omnivores.

3.1.8 Water regime

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

3.1.9 Salinity

Stygofauna in inland aquifers are generally restricted to fresh or partly brackish water. Hancock and Boulton (2008) suggest that most taxa collected from alluvial aquifers in NSW and Queensland prefer Electrical Conductivity (EC) less than 5000 μS/cm. In surveys of coastal areas and near salt lakes in Western Australia, stygofauna were collected from aquifers with salinities at or exceeding sea water (50 000 μS/cm, Watts and Humphreys 2004). No stygofauna in NSW are known from aquifers where EC is this high, but there have been recent collections from an aquifer in the Condomine basin, Qld, where EC was between 36 000 and 56 000 μS/cm (Andrea Prior *pers comm.*).

3.1.10 Dissolved oxygen

Stygofauna are able to tolerate very low concentrations of dissolved oxygen. Hahn (2006) observed a strong decrease in concentrations below 1.0 mg/L, but found some fauna in concentrations down to 0.5 mg/L. Some taxa are able to survive virtually no oxygen for temporary periods for up to six months (Henry and Danielopol 1999, Malard and Hervant 1999). Aquifers can be heterogeneous environments, so may contain patches of water with sufficient oxygen concentration to be suitable for stygofauna. As dissolved oxygen is measured from water pumped from bores, it can be difficult to identify where these patches occur.

4 Desktop Assessment of Stygofauna in the Hunter Valley

4.1 Hunter River Hyporheic Survey

Stygofauna research in the Hunter Valley began in 2000, with a four year survey investigating the impacts of river flow variation on groundwater adjacent to the Hunter River (Hancock 2004, 2006). During this survey, samples were collected beneath the bed sediments and lateral bars of nine sites along the Hunter River, Goulburn River and Wollombi Brook (**Figure 4**).

Hyporheic zones are the area of river bed where groundwater and surface water mix, and often contain surface water, hyporheic, and groundwater taxa (Marmonier and Creuzé des Châtelliers 1991). The results from the survey validated such diversity in the invertebrate community, with groundwater representatives from Microturbellaria (flatworms), Oligochaeta (aquatic worms), and Ostracoda, Cyclopoida, and Harpacticoida (microcrustacea) recorded at all sites (**Table 1**). At the time of the survey, stygofauna taxonomy for microcrustaceans was poorly developed for eastern Australia, therefore it was not possible to identify specimens to species level; however, groundwater affinity was inferred by the presence of troglomorphic characteristics (e.g. blindness, elongation and depigmentation; Danielopol et al. 1994, Coineau 2000). This was later confirmed in consultation with international experts (Pierre Marmonier, Tom Karanovic, Ivana Karanovic *pers comm.*).

Two genera of Bathynellacea (an order of crustacean) were collected from the hyporheic zone. *Bathynella* sp. was collected from Hunter River sites at Bowmans Bridge, Dights Crossing, Aberdeen and from the Goulburn River at Sandy Hollow. *Notobathynella* sp. occurred at Denman, Dights Crossing, and Aberdeen. The largest stygofauna taxon collected was a single species (Peter Serov *pers comm.*) of the undescribed Anaspidacean family; Family A. Specimens were collected at all Hunter River sites except Dights Crossing.

The amphipod family, Paramaletidae, occurred at six hyporheic sites. It is often difficult to distinguish between amphipod species based solely on morphological characters (Finston et al. 2004) and until recently, molecular techniques were not sufficiently available to allow identification to species level. As a result, there is uncertainty about the number of species present in the Hunter hyporheic specimens, although they are thought to be members of the genus *Chillagoe*.

One species of the isopod, *Heterias* sp. 1, was also collected at five sites along the Hunter River.

A complete inventory of the species identified in the survey of the hyporheic zones is shown in **Table 1**.

Table 1: Stygofauna collected in the Hunter River Hyporheic Survey

Location	Alluvial aquifer sampled	Oligochaeta	Microturbellaria	*Bathynella* sp.	*Notobathynella* sp.	Anaspid Family A sp. 1	Paramelitidae sp.	*Heterias* sp. 1	Ostracoda	Cyclopoida	Harpacticoida
Bowman Bridge	Hunter River	✓	✓	✓		✓	✓	✓	✓	✓	✓
Jerrys Plains	Hunter River	✓	✓			✓			✓	✓	✓
Moses Crossing	Hunter River	✓	✓			✓	✓	✓	✓	✓	✓
Denman	Hunter River	✓	✓		✓	✓	✓	✓	✓	✓	✓
Dights Crossing	Hunter River	✓	✓	✓	✓		✓	✓	✓	✓	✓
Warkworth	Wollombi Brook	✓	✓						✓	✓	✓
Sandy Hollow	Goulburn River	✓	✓	✓					✓	✓	✓
Aberdeen	Hunter River	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Maison Dieu	Hunter River	✓	✓			✓	✓		✓	✓	✓

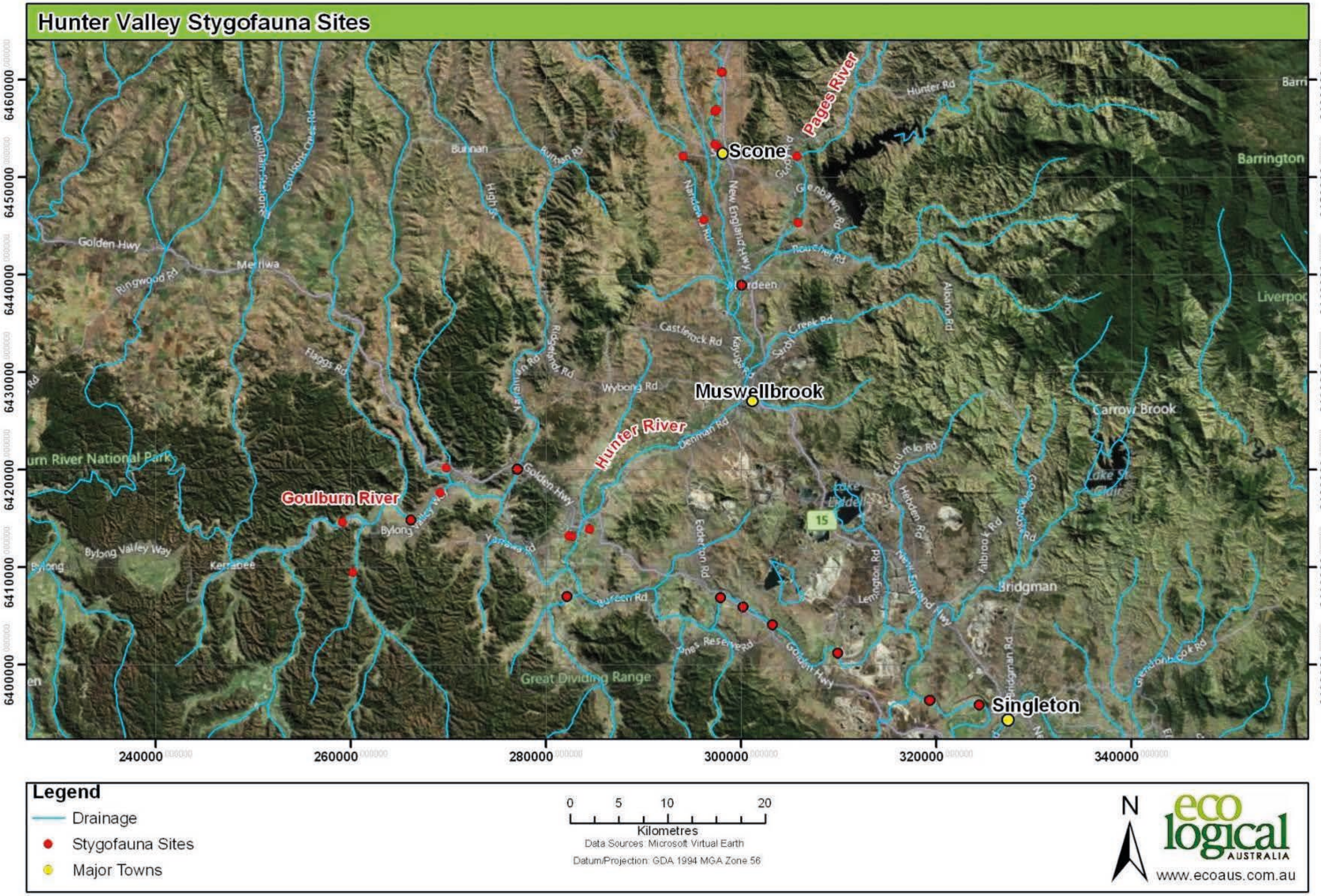

Figure 4: Location of past stygofauna survey points in the Hunter Valley

4.2 Hunter Valley Alluvial Aquifer Survey

The confirmation that stygofauna was present throughout much of the Hunter Valley led to further sampling between 2004 and 2008 of bores in the Hunter River, Pages River, Dart Brook, and Kingdon Ponds alluvial aquifers (Watts *et al.* 2007; Hancock and Boulton 2008, 2009). Samples were collected from 40 groundwater monitoring bores operated by mining companies and the NSW Office of Water (**Figure 4**). The results of the sampling program increased the number of known stygofauna taxa in the Hunter Valley to at least 26 groups with this number likely to rise as more of the collected taxa are formally described (Ana Camacho, Tom Karanovic, Ivana Karanovic *pers comm.*). To date, copepods and ostracods from Denman, Muswellbrook, Pages Creek, Dart Brook (north), and Kingdon Ponds samples have been identified to a species level.

Dart Brook, Pages Creek, and Kingdon Ponds alluvial aquifers each had similar diversity to the Hunter River alluvial aquifer at Denman. The Hunter River alluvial aquifer near Denman and the Pages Creek alluvial aquifer had 20 stygofauna taxa. The northern Dart Brook bores had 21 taxa, while Kingdon Ponds had 18 taxa and the Hunter River alluvial aquifer near Muswellbrook had only eight taxa.

A list of the species identified in the survey is shown in **Table 2**. None of the species known from the Hunter Valley are listed under the *Threatened Species Conservation Act* 1995, nor the *Environment Protection and Biodiversity Conservation Act (EPBC Act)* 1999. However, this reflects the relatively few surveys and sparse research that has been done on NSW stygofauna, rather than an indication that the species are widespread and at no risk. In Western Australia, where stygofauna research has been occurring since the early 1990's, there are two fish (Blind Gudgeon, *Milyeringa veritas* and Cave Eel, *Lasinectus exleyi*) and one invertebrate (the Remipede, *Lasinectus exleyi*) listed as vulnerable under the EPBC Act.

Of the stygofauna identified to a species level in the survey, only four (*Notobathynella* sp. nov. 3, Anaspid Family A sp. 1, *Dyacyclops cryonastes*, and *Eucyclops* cf *ruttneri*) out of 19 are known to occur at sites beyond the Hunter Valley. With the exception of a previously undescribed species of Hydrobiidae snail, all taxa collected from the Hunter River aquifer occurred in at least one of the tributary aquifers.

Table 2: Stygofauna Identified in the Hunter Valley Alluvial Aquifer Survey.

Location	Alluvial aquifer	Distance from study area (km)	Oligochaeta	Microturbellaria	*Bathynella* sp.	*Notobathynella* sp.	Anaspid Family A sp. 1	Paramelitidae sp.	*Heterias* sp. 1	Ostracoda	Cyclopoida	Harpacticoida	*Eucyclops* cf. *ruttneri*	*Diacyclops cryonastes*	*Diacyclops* sp. 1	*Metacyclops* sp. 1	*Haplocyclop s* sp. 1	*Elaphoidella* sp. 1	*Australocamptus* sp. 1	*Hancockcamptus* sp. 1	*Huntercamptus* sp. 1	*Huntercamptus* sp. 2	*Huntervallia* sp. 1	Aturidae sp 1	Elmidae sp 1	*Carabhydrus stephanieae*	*Limnobodesis* sp nov	*Hydrobiidae* sp nov
Denman	Hunter	15	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓		✓	✓	✓		✓	✓		✓
Muswellbrook	Hunter	17	✓	✓				✓		✓	✓		✓	✓	✓													
Dart Brook south	Dart Brook	27	✓	✓				✓		✓	✓	✓																
Goulburn	Goulburn River	30	✓		✓	✓					✓	✓																
Pages	Pages	36	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓			✓	✓		✓		✓	✓	✓	✓	✓	
Dart Brook north	Dart Brook	42	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓		✓	✓	✓	✓	✓	✓	✓	
Kingdon Ponds	Kingdon Ponds	49	✓		✓	✓	✓	✓			✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓			✓	✓		

Similarly, the majority of species in Dart Brook, Pages Creek and Kingdon Ponds bores were shared with at least one other aquifer. This suggests that approximately 80% of the species recorded are endemic to the region with the many species typically occurring in more than one alluvial aquifer. Only four species identified in the survey are endemic to single aquifers: *Metacyclops* sp. 1, *Haplocyclops* sp. 1, *Hancockcamptus* sp. 1, and *Hydrobiidae* sp. nov. (**Table 2**).

4.3 Other surveys

Other opportunistic sampling for stygofauna has been conducted by Dr Grant Hose (University of Technology, Sydney) from some of the bores sampled in the 2004 to 2008 Hunter Valley Alluvial Aquifer Survey. No further taxa were found during these surveys.

Eco Logical Australia has conducted stygofauna surveys for several Hunter Valley Mines (**Table 3**), including Bengalla (ELA 2013a), Liddell (ELA 2013b), and Drayton South (ELA 2014). All taxa collected during these surveys were previously known from the alluvial aquifers of the Hunter River or its tributaries.

Stygofauna sampling for the Mt Penny Coal Project collected four taxa from the Coggan Creek and Bylong River alluvial aquifers (Marine Pollution Research Pty Ltd 2012). The taxa collected from Mt Penny were Cyclopoida, Harpacticoida, Ostracoda and Syncarida (**Table 3**). All of these orders are known from the Hunter alluvium, although their distribution at the species level might be more restricted if more detailed taxonomy was possible.

Table 3: Stygofauna collected during other surveys of the Hunter Valley

Order	Family	Genus/ species	Bengalla	Liddell	Drayton South	Mt Penny
Syncarida						■
Anaspidacea	Psammaspididae			■		
Bathynellacea	Parabathynellidae	*Notobathynella* sp.	■	■		
	Bathynellidae	*Bathynella* sp.	■	■		
Isopoda	Janiridae	*Heterias* sp.		■		
Amphipoda	Paramelitidae	*Chillagoe* sp.	■	■		
Cyclopoida	Cyclopidae		■	■	■	■
	Harpacticoida					■
Ostrocoda			■	■		■
Coleoptera	Dytiscidae	*Carabhydrus stephanieae*		■		
Coleoptera	Elmidae	*Austrolimnius* sp.		■		
Oligochaeta			■			

5 Groundwater regime at Bylong

5.1 Regional geology

The Bylong Valley consists of outcropping Narrabeen Sandstone in the south and north-western parts of the site. These overlie the Illawarra Coal Measures, which outcrop on the valley sides in the northern part of the site. Beneath these, the Shoalhaven Group outcrops on the valley sides in southern and western parts of the site.

The valley floor consists of Quaternary Alluvium with permeable sand and gravel strata throughout. This is generally associated with the Bylong River and its tributaries. Various constrictions occur along the alluvium where spurs or ridges of rock extend from both sides of the valley.

5.2 Current groundwater regime

5.2.1 Alluvial aquifers

The alluvial aquifer running along the base of the valley consists of permeable sand and gravel sediments and is the source for most of the registered groundwater bores and wells in the area. Alluvium is recharged by direct rainfall, runoff from the valley sides, and infiltration from Crows Nest, Cousins, Lee, and Dry Creeks as well as the Growee and Bylong Rivers. Creeks have regular periods of no flow, but sustained flows occur following periods of ongoing rainfall. When flows are high, water recharges the aquifer.

EC for the alluvial aquifer is generally between 580 and 3340 μS/cm, with most bores having EC of less than 1500 μS/cm (Douglas Partners 2012). This is well below the upper limit of 5000 μS/cm preferred by most stygofauna in the eastern states. In shallower bores, EC increases following rainfall and then declines with time. In deeper bores, EC appears to be lower and fluctuate less (Douglas Partners 2012).

The pH of alluvial groundwater ranges from 6.3 to 8.5 but for most bores it is within the ANZECC drinking water guidelines of 6.5 to 8.5 (Douglas Partners 2012), and should be suitable for stygofauna.

Constrictions in the alluvium may have a partial damming effect on upstream groundwater, and likely result in a series of terraced sub-aquifers along the line of each valley, with groundwater spilling over from the upstream terrace to downstream terrace (Douglas Partners 2012).

5.2.2 Coal measures

The alluvial aquifers are underlain by the Illawarra Coal Measures, consisting of layered sandstone, siltstone, and coal. On either side of the valleys the coal measures are overlain by Narrabeen Sandstone. This has been eroded along the valleys, which may have caused stress-induced horizontal fracturing in the rocks of the valley floor and vertical cracking in the rocks above the valley sides. Fracturing is likely to result in high horizontal hydraulic conductivity in the rocks below the valley floor, and higher vertical hydraulic conductivity on the higher ground.

Coal aquifers in the region are generally more permeable than the sandstone and siltstone. The main coal seams on site are the Ulan and Coggan Seams, which dip towards the north and are generally below the alluvium but intersect below Lee Creek and Bylong River in the south of the site.

Recharge of the coal seam aquifers occurs via infiltration of the vertical fractures from rainfall on the higher valley sides. Coal seams are also recharged by direct seepage from the alluvium where the two are in contact.

Hydraulic heads in the northern parts of the site are significantly higher in the coal seam aquifers than in the alluvium, suggesting that there are limited connections between the two aquifers. Faulting and fractures in the northern areas provide a potential vertical pathway from the coal seam upwards to the alluvium.

5.3 Suitability of on-site aquifers as habitat for stygofauna

The shallow water table, low EC, and relatively high hydraulic conductivity make the alluvial aquifers suitable habitat for stygofauna. Unconsolidated alluvial deposits along Growee River, Lee Creek, and Bylong River appear to be sufficiently developed and have hydraulic conductivity that should be suitable for stygofauna. As recharge of these aquifers is through direct infiltration of rain water, which has only a short distance to travel before reaching the water table, there is likely to be sufficient dissolved organic carbon available to support groundwater food webs.

Coal aquifers are likely to be unsuitable habitat for stygofauna because they are generally too deep and effectively isolated from surface sources of suitable organic matter. Deeper coal aquifers are also likely to be compressed and not have sufficient space or interconnectedness between fractures/pores to allow stygofauna movement.

In some cases, stygofauna may occur in shallow sections of the coal seam or sedimentary rock layers, where the rock is weathered and joins the alluvial aquifer. However, any species occurring in the shallow coal seam is probably incidental and likely to prefer conditions in the alluvium, where they will be widespread.

6 Sampling Program

6.1 Field sampling program

There are no specific guidelines for sampling stygofauna in NSW, as there is in Western Australia, so the protocol used at Bylong conforms to this. 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.

The most common method of sample collection in Western Australia 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.

For the Project, an initial round of sampling was conducted from 22 to 25 October 2012, and a second round occurred from 19 to 21 February 2014. Bores were selected after a review of geological conditions, water quality, and bore construction details (**Table 4**). Samples were collected from the sandstone and Coggan Seam Aquifers, but most were collected from the alluvial aquifers, where stygofauna were likely to occur. **Figure 5** shows the location of bores sampled during both rounds.

A sampling program was developed to provide a selection of bores representative of likely stygofauna habitats and targeting the different areas of impact proposed for the Project. Bores were selected to target the alluvial aquifer, which is the most likely stygofauna habitat, and to provide geographical coverage across the Project Boundary.

EC was also considered during bore selection, with preference given to bores with favourable EC values for stygofauna occupation (i.e. EC < 5000 µS/cm). Stygofauna still occur in water with EC > 5000 µS/cm, but are less common. 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 bores in the Coggan Seam.

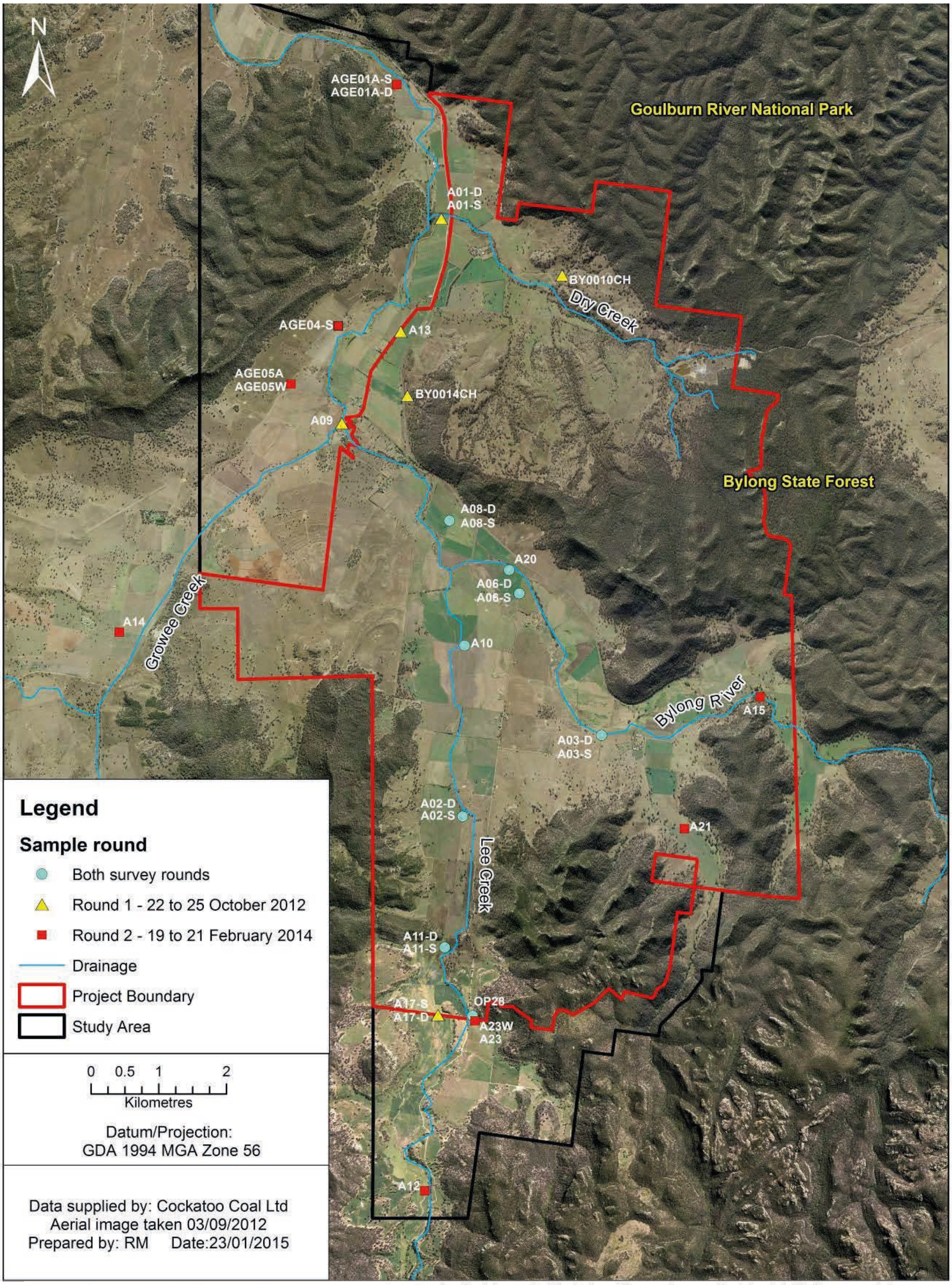

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Figure 5: Bores sampled for stygofauna at Bylong in 2012 and 2014.

Table 4: Bores sampled, and methods used during the stygofauna surveys at Bylong over both rounds.

Bore	Screen Depth (mbgl)	Aquifer	Round sampled	Sampling Method	
				Round 1	Round 2
A01-D	15.6-18.6	Alluvium- Lower	1	net, pump	none
A01-S	1.9-7.9	Alluvium-Lower	1	Dry-not sampled	
A02-D	7-10	Alluvium- Lower	1, 2	net	net, pump
A02-S	5.53-8.53	Alluvium- Upper	1, 2	net	net
A03-D	6.4-9.4	Alluvium- Lower	1, 2	net, pump	net, pump
A03-S	0.5-3.5	Alluvium- Upper	1, 2	net, pump	net
A06-D	7-10	Alluvium- Lower	1, 2	net, pump	net, pump
A06-S	1.5-4.5	Alluvium- Upper	1, 2	net, pump	none
A08-D	5.6-8.6	Alluvium- Lower	1, 2	net, pump	net
A08-S	2-5	Alluvium- Upper	1	net	none
A09	0.6-6.6	Alluvium- Upper	1, 2	net, pump	net
A10	3-9	Alluvium- Upper	1, 2	net, pump	net
A11-D	6.1-12.2	Alluvium- Lower	1, 2	net, pump	net, pump
A11-S	0.9-3.9	Alluvium- Upper	1, 2	net	net
A12	0.9-3.9	Alluvium- Upper	2	none	net
A13	1.2-7.2	Alluvium- Upper	1	net	none
A14	2.1-8.3	Alluvium- Upper	2	none	none
A15	0.3-6.3	Alluvium- Upper	2	none	net
A17-D	7.3-11.3	Alluvium- Lower	1	net, pump	none
A17-S	1.15-4.15	Alluvium- Upper	1	net, pump	none
A20	1.2-7.2	Alluvium- Upper	1, 2	net, pump	net
A21		Alluvium- Upper	2	none	none
A23	3.4-9.4	Alluvium- Upper	2	none	none
A23W	10.4-16.4	Weathered Permian	2	none	net, pump
AGE01A-D	6.4-9.4	Alluvium- Lower	2	none	net, pump
AGE01A-S	1.8-4.8	Alluvium- Upper	2	none	net
AGE04A-S	5.3-11.3	Alluvium- Upper	2	none	net, pump
AGE05-A	5.4-8.4	Alluvium- Upper	2	none	none
AGE05-W	9.7-15.7	Weathered Permian	2	none	net, pump
BY0010CH	133-139	Coggan Seam	1	net	none
BY0014CH	50.2-56.2	Coggan Seam	1	net	none
OP28		Sandstone	1, 2	net	net

6.2 Sample collection

Samples were collected using combined net and pump methods (Hancock and Boulton 2009) where conditions were suitable (i.e. if bore guards were spacious enough to allow pump attachment, and the water table was less than 30 m below ground level). The combined sampling protocol is suitable for cased, vertical groundwater monitoring bores with an internal diameter of 50 mm internal diameter.

Twelve bores were sampled in the first round using the combined net and pump method, and an additional eight bores were sampled using the net method (**Table 4**). In the second round, eight bores were sampled with the combined method and eleven were sampled using the net only (**Table 4**).

8.2.1 Collecting stygofauna samples using a net

A weighted sampling net with 50 μm mesh was lowered to the bottom of each bore (**Figure 6**). The net was raised and dropped over approximately 50 cm for three to five times to dislodge resting fauna, then 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. During sampling, the net became stuck during retrieval in some bores. When this occurred, only three hauls were retrieved. This was a precaution to prevent bores becoming blocked if the net became stuck and broke off. Sieve contents were washed into a sample jar and preserved in 100% ethanol.

8.2.2 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. Once in place, water was pumped into buckets and subsequently poured through a 50 μm mesh sieve. Water was pumped into buckets rather than straight through the sieve to allow mineral content entrained in the water to settle. The volume of water pumped varied from 24 to 300 L (most often 100 - 200 L), depending on how quickly the bore recharged. 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.

Figure 6: Collecting stygofauna samples with a net.

8.2.3 Water chemistry 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 pump sampling using the pumping methods at 10 L, 50 L, and then every subsequent 50 L. Where pumping was not possible, water was collected using a groundwater bailer and the parameters 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.

6.3 Laboratory analysis

Preserved 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 their taxonomy here. Where undescribed taxa were encountered, they were assigned a morphospecies name.

7 Results

7.1 First survey round - 22 to 25 October 2012

7.1.1 Water chemistry and water level

Water level in the alluvial bores was deepest at A10, where it was 5.24 m below ground level (bgl). At most alluvial bores, the water level was less than 3 m bgl (**Table 5**). Of the non-alluvial bores sampled, the water level in BY0010CH was more than 50 m bgl, while in the other bore from this seam, BY0014CH, the water level was only 5.11 m bgl.

EC ranged from 336 µS/cm to 1627 µS/cm in the alluvial aquifer. Where paired alluvial bores were sampled, EC was higher in the shallow bore than in the deep bore (**Table 5**). EC of the non-alluvial bores were 1109 and 2353 µS/cm.

DO concentration was between 1.4 and 29.4 % saturation (0.14 - 2.69 mg/L) across all bores. DO was generally higher in shallow bores than in deep bores (**Table 5**).

Temperature of the groundwater was between 14.16 and 21.04°C, with the shallow bore being cooler than the deeper bore in all except A11 (**Table 5**).

Table 5: Physico-chemical values of groundwater sampled at Bylong in Round 1. Where 5 net hauls were not possible, only 3 hauls were collected to prevent the bore becoming blocked.

Bore	Date	Water Level (mbgl)	Net Hauls	Pump Vol	EC µS/cm)	pH	DO (% sat)	DO (mg/L)	Temp (° C)
A06-D	25/10/2012	2.29	5	40	822	7.18	13.4	1.14	21.04
A06-S	25/10/2012	2.23	6	50	1563	6.83	4.7	0.44	17.83
A20	25/10/2012	1.72	6	300	1217	7.03	3.5	0.34	16.45
BY0010CH	26/10/2012	>50	3	0					
BY0014CH	26/10/2012	5.11	3	0	1109	7.63	17.9	1.81	19.29
A13	26/10/2012	2.82	5	0	1333	7.14	10.4	0.98	17.63
A01-D	26/10/2012	4.85	5	77	1177	7.67	16.5	1.54	18.55
A01-S	26/10/2012	Not sampled. No water.							
A17-D	26/10/2012	0.77	5	100	336	6.46	3.6	0.34	17.79
A17-S	26/10/2012	0.78	5	100	422	6.34	4.5	0.45	15.02
A03-D	26/10/2012	0.67	5	100	1208	7.06	1.4	0.14	16.74
A03-S	26/10/2012	0.69	5	24	1627	7.33	1.9	0.19	14.16
OP28	27/10/2012	9.15	3	0	2353	7.31	13	1.16	20.6
A11-D	27/10/2012	1.29	5	100	612	6.64	4.4	0.42	17.17
A11-S	27/10/2012	1.29	5	0	780	7.02	14.3	0.32	17.77
A02-D	27/10/2012	1.84	5	0	1058	6.75	4.1	0.37	19.69
A02-S	27/10/2012	1.82	5	0	1455	7.04	15.6	1.48	16.98
A10	27/10/2012	5.24	5	100	644	6.78	29.4	2.69	19.55
A09	27/10/2012	2.02	5	100	1142	7.2	4.3	0.43	14.84
A08-D	27/10/2012	3.29	5	100	888	7.03	3.5	0.36	17.51
A08-S	27/10/2012	3.4	5	0	1265	7.59	28	2.79	15.57

7.1.2 Stygofauna

An initial survey of the alluvial aquifers of the Bylong Valley indicates that the area has a potentially diverse groundwater invertebrate community. Half of the bores sampled contained stygofauna, with animals occurring throughout the valley (**Figure 7**). Where paired alluvial bores were sampled, stygofauna were collected more often from the shallow bore than the deeper bore, although at A08, fauna were collected from both deep and shallow bores.

Nine stygofauna taxa were collected from ten bores spread along the Lee Creek and Bylong River alluvium (**Table 6**). Cyclopoid copepods were the most abundant invertebrate and occurred in 6 bores, while Oligochaete worms were the most widespread. Oligochaetes were collected from nine bores, and appear to occur along the aquifer. Harpacticoid copepods were the third-most common taxa in the samples (**Table 6**).

Five different species of Syncarid occur in the alluvial aquifers at Bylong. The most abundant and widespread is *Bathynella* sp., which was collected from four bores along the Lee Creek/Bylong River alluvium south of the confluence with Growee River. A single *Chilibathynella joshuai* was collected from A08D, while the three other Syncarid taxa occurred in A10. Of these, *Notobathynella* sp. 1 was represented by two individuals, and Psammaspididae sp. 1 and Anaspidacea sp. 1 were represented by single specimens (**Table 6**).

Bore A09 had the most individuals, with 317 animals collected from five taxa. However, A10 had the highest diversity, with seven taxa. The fauna at both sites was dominated by Cyclopoida.

Table 6: Stygofauna collected during the first survey round at Bylong.

Bore	Location	Oligochaeta	Ostracoda	Harpacticoida	Cyclopoida	*Bathynella* sp 1	*Chillibathynella joshuai*	*Notobathynella* sp 1	Psammaspididae sp 1	Anaspidacea sp 1	Total
A09	Bylong	12	1	27	267	22					329
A20	Bylong			5	1						6
A10	Lee Ck	19		46	183	25		2	1	1	277
A11-S	Lee Ck	1			74						75
A02-D	Lee Ck					31					31
A06-S	Bylong	6		3	42						51
A08-S	Bylong	47				9					56
A08-D	Bylong						1				1
A13	Bylong	27	5								32
A17-S	Lee Ck	1			51						52

7.2 Second survey round- 19 to 21 February 2014

7.2.1 Water chemistry and water level

Electrical Conductivity (EC) in the upper alluvium was between 331 and 3891 µS/cm, in the lower alluvium it was between 570 and 1784 µS/cm. EC in the weathered Permian and sandstone aquifers it was between 1257 and 2866 µS/cm (**Table 7**).

Across all bores, pH was circum-neutral and between 6.44 and 7.80. Dissolved Oxygen (DO) concentration was between 1.27 and 5.9 mg/L for the shallow alluvium, although most bores had concentrations between 1 and 2 mg/L. DO concentration in the lower alluvium was between 0.31 and 1.89 mg/L. For the Permian and Sandstone aquifers DO was between 2.14 and 5.95 mg/L (**Table 7**).

Table 7: Physico-chemistry of bores sampled for stygofauna at Bylong during Round 2

Bore	Date	Water Level (mbgl)	Net Hauls	Pump Vol	EC (µS/cm)	pH	DO (% sat)	DO (mg/L)	Temp (°C)
A02-D	20/02/2014	3.5	6	200	998	6.81	4.1	0.37	20.4
A02-S	20/02/2014	3.8	6	0	1251	7.29	43.1	3.74	21.97
A03-D	21/02/2014	2	6	200	1412	6.95	3.4	0.31	19.38
A03-S	21/02/2014	1.96	6	0	1926	7.19	22.6	1.94	23.2
A06-D	19/02/2014	3.95	6	20	795	7.39	21.2	1.89	20.93
A06-S	19/02/2014	Not sampled. No water.							
A08-D	19/02/2014	4.4	6	0	802	7.63	79.1	1.75	19.4
A08-S	19/02/2014	Not sampled. No water.							
A09	19/02/2014	4.2	6	0	2117	7.46	19.2	1.65	21.49
A10	21/03/2014	6.97	7	0	646	7.25	24.1	2.19	19.96
A11-D	21/02/2014	3	6	200	570	6.82	4.7	0.45	17.71
A11-S	21/02/2014	2	6	0	648	7.8	18	1.56	21.05
A12	19/02/2014	3.9	6	0	395	6.99	13.9	1.27	19.19
A14	19/02/2014	8	6	0	1735	7.44	64.3	5.9	18.91
A15	19/02/2014	3.32	6	0	331	6.44	19.5	1.75	19.85
A20	20/02/2014	3.26	6	0	1150	7.38	14.8	1.37	18.91
A21	20/02/2014	Not sampled. No water.							
A23	21/02/2014	Not sampled. No water.							
A23W	21/02/2014	9.24	6	200	1257	6.94	62.7	5.95	19.32
AGE01A-D	20/02/2014	2.92	6	200	1784	7.28	4.4	0.4	19.53
AGE01A-S	20/02/2014	2.91	6	0	1795	7.48	15.1	1.34	20.17
AGE04A-S	20/02/2014	6.58	6	200	3891	7.2	42.9	3.87	20.08
AGE05-A	20/02/2014	Not sampled. No water.							
AGE05-W	20/02/2014	7.02	6	0	2866	7.33	24.1	2.14	19.97
OP28	21/02/2014	9.57	6	0	2264	7.71	24.4	2.2	19.49

7.2.2 Stygofauna

Nine invertebrate taxa were collected from 12 bores (**Table 8**). All stygofauna collected came from bores in the upper alluvium, except for the oligochaetes and cyclopoids from bore A23W, screened at the weathered Permian. Both of these taxa occurred in only one Permian bore, but were widespread throughout the alluvium.

AGE04A-S had the highest diversity, with eight taxa including Anaspidacea sp. 1, collected previously from A10. This bore also had four amphipods from the Paramelitidae family, which have not yet been collected from the Bylong aquifers.

Syncarids were represented by four taxa, the most widespread being *Notobathynella* sp. 1, which was in the Bylong River and Lee Creek alluvium (**Table 8**). Both representatives of the Anaspidacea were present only in ACE04A-S, with 13 Psammaspididae sp. 1 and one Anaspidacea sp. 1.

Cyclopoida were the most widespread taxa, occurring in eight bores spread throughout Lee Creek and northern Bylong River alluvium. Harpacticoids appeared to have a similar distribution to the cyclopoids, although were not collected in the constricted part of the Lee Creek Aquifer south of A20.

Ostracoda were present only in AGE04A-S, but are known from many locations in alluvial aquifers of the Hunter and Peel Rivers. Oligochaetes are another widespread taxon that was present at Bylong, although occurred only in low numbers.

Table 8: Stygofauna collected during the second survey at Bylong.

Bore	Location	Oligochaeta	Ostracoda	Harpacticoida	Cyclopoida	Paramelitidae sp. 1	*Bathynella* sp 1	*Notobathynella* sp 1	Psammaspididae sp 1	Anaspidacea sp 1	TOTAL
A09	Bylong			1	10			3			14
AGE01A-S	Bylong				9						9
A03-S	Bylong	3		1	1						5
AGE04A-S	Bylong	5	2	1	25	4		1	13	1	52
A20	Bylong			35	7			9			51
A15-S	Bylong	1						1			2
A10	Lee Ck				6		2				8
A11-S	Lee Ck				1						1
A23W	Permian	1			3						4
A02-S	Lee Ck						1				1
A14	Growee	1									1
A12	Lee Ck	3									3

7.2.3 Summary of fauna from both rounds

Over both rounds of sampling, ten stygofauna taxa were collected from 18 bores (**Table 9, Figure 7**). This represents a success rate of 46.2%. Of the bores containing stygofauna, 83.3% (15 bores) sampled the shallow alluvial aquifers, 11.1% (two bores) sampled the deep alluvium, and 5.6% (one bore) was screened at the weathered Permian strata. Stygofauna appear to be distributed throughout the shallow alluvial aquifers of Lee Creek and Bylong River. Only a single oligochaete was collected from the Growee Creek aquifer, although only one bore was sampled from this system.

Five of the twelve bores that were sampled twice had fauna in both rounds, while four bores had fauna in only the first round, and two bores had fauna in only the second round. One taxon, the amphipod Paramelitidae sp. 1, was collected in the second round and not the first.

Table 9: Stygofauna collected over both survey rounds at Bylong.

Bore	Location	Round	Oligochaeta	Ostracoda	Harpacticoida	Cyclopoida	Paramelitidae sp. 1	*Bathynella* sp 1	*Chillibathynella joshuai*	*Notobathynella* sp 1	Psammaspididae sp 1	Anaspidacea sp 1	Total
A09	Bylong Alluvium	1	12	1	27	267		22					329
		2			1	10				3			14
AGE01A-S	Bylong Alluvium	1	not sampled										
		2				9							9
A03-S	Bylong Alluvium	1	sampled but no fauna										0
		2	3		1	1							5
AGE04-S	Bylong Alluvium	1	not sampled										
		2	5	2	1	25	4			1	13	1	52
A20	Bylong Alluvium	1			5	1							6
		2			35	7				9			51
A15-S	Bylong Alluvium	1	not sampled										
		2	1							1			2
A10	Lee Ck Alluvium	1	19		46	183		25		2	1	1	277
		2				6		2					8
A11-S	Lee Ck Alluvium	1	1			74							75
		2				1							1
A23W	Weathered Permian	1	not sampled										
		2	1			3							4
A02-S	Lee Ck Alluvium	1	sampled but no fauna										0
		2						1					1

Bore	Location	Round	Oligochaeta	Ostracoda	Harpacticoida	Cyclopoida	Paramelitidae sp. 1	*Bathynella* sp 1	*Chillibathynella joshuai*	*Notobathynella* sp 1	Psammaspididae sp 1	Anaspidacea sp 1	Total
A02-D	Lee Ck Alluvium	1						31					31
		2	sampled but no fauna										0
A14	Growee Alluvium	1	not sampled										
		2	1										1
A12	Lee Ck Alluvium	1	not sampled										
		2	3										3
A06-S	Bylong Alluvium	1	6		3	42							51
		2	Dry										
A08-S	Bylong Alluvium	1	47					9					56
		2	Dry										
A08-D	Bylong Alluvium	1							1				1
		2	sampled but no fauna										0
A13	Bylong Alluvium	1	27	5									32
		2	not sampled										
A17-S	Lee Ck Alluvium	1	1			51							52
		2	not sampled										

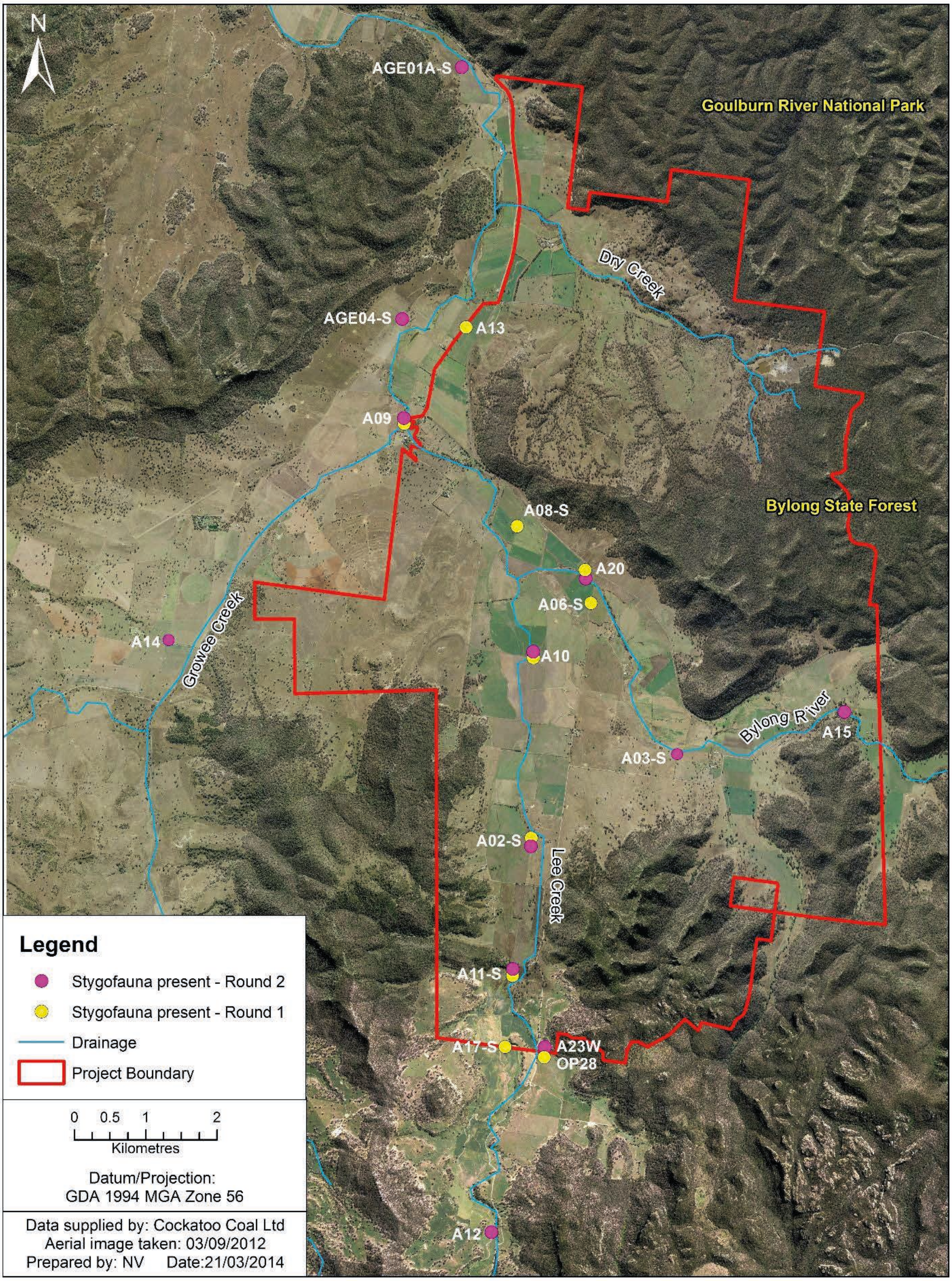

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Figure 7: Distribution of bores containing stygofauna for the two surveys conducted for the Bylong Project.

8 Impact assessment

8.1 Conservation significance of the Bylong stygofauna

Across both survey rounds, 10 taxa were collected from bores at Bylong. At the level of identification possible, the stygofauna at Bylong have all previously been collected from other locations in the region. None of the taxa were endemic to the predicted groundwater drawdown area as identified in the preliminary groundwater model undertaken for the Project by AGE (2013). At a regional scale, fauna at Bylong appear to be spread throughout the Bylong River and Lee Creek alluvial aquifers and have distributions beyond the predicted groundwater drawdown area. In this regard, there is no significant risk to the existing stygofauna community as a consequence of the Project.

The ecology and taxonomy of oligochaetes, particularly in NSW, is not well known. This group is very common in the soil fauna, so the specimens collected at Bylong may not be stygofauna. Halse and Pearson (2014) consider oligochaetes most likely to be part of the soil community and exclude them from their analyses of subterranean fauna. For this report, the Bylong oligochaetes are included in **Table 9** but no significance is given to them.

The most widespread taxon was Cyclopoida, which was collected from ten bores in the Bylong Valley. Harpacticoids were also widespread, collected from six bores. Cyclopoids and harpacticoids are known from many alluvial aquifers throughout NSW and WA. The nearest known stygofauna community with cyclopoids and harpacticoids is in the Goulburn River alluvium near Baerami (**Section 4**), and they are widespread in aquifers of the Upper Hunter Valley (Hancock and Boulton 2008).

The syncarid genus *Bathynella* occurs in most alluvial aquifers in NSW and Queensland that are known to have stygofauna. This taxon was abundant at Bylong and resembled those collected from other parts of the Upper Hunter Valley, indicating that it is widespread and not threatened by the proposed development at Bylong.

Notobathynella is another common genus of syncarid that is common in aquifers of NSW and Queensland (Hancock and Boulton 2008). During the Bylong surveys, this genus was found in bores A09, AGE04A-S, A20, A15-S, and A10, so it is widely distributed throughout the Bylong River and Lee Creek alluvium.

Chilibathynella joshuai was collected from A08-S during the first round of sampling. This species is also known from the alluvial aquifer of the Macquarie River near Dubbo (Camacho and Hancock 2012), so it is not endemic to the region nor threatened by mining at Bylong.

Anaspidacea sp. 1 was collected from bore A10 in the first survey round and bore AGE04-S in the second survey round. AGE04-S is approximately 1 km from the nearest predicted 1-m contour at drawdown maximum, and is unlikely to receive any drawdown from the proposed development. Further, following the assumption of WA EPA (2013) that suitable habitat occurs between bores inhabited by the same species, there is a reach of Bylong River alluvium extending for at least 5 km (and probably longer) that is suitable for Anaspidacea sp. 1 and is not expected to experience any drawdown as a result of the Project.

The amphipod Paramelitidae was collected only from bore AGE04A-S during the second Bylong survey. Although only known from one site at Bylong, this family has been regularly collected from alluvial aquifers in the Peel, Pages, and upper Hunter Rivers (Hancock and Boulton 2008), indicating that it is generally widespread in alluvial aquifers.

8.2 Potential impacts to stygofauna from mining

Open cut and underground operations are proposed for the Project, so the impacts from both of these mining methods on stygofauna are considered here. Generally, mining can impact on stygofauna habitat in the following ways, all of which may be relevant to some degree at Bylong:

- Direct removal of rock and aquifer sediments during open cut operations
- Lowering of groundwater tables while dewatering for both underground and open cut operations
- Depressurisation of lower aquifers that results in trans-aquifer flow, altering water level and water chemistry
- Increased fracturing of basement rocks, resulting in the draining of surface aquifers
- Subsidence at the land surface that changes recharge location
- Changes to water chemistry by mobilising rock-bound chemicals through changes in aquifer physico-chemistry.

8.2.1 Excavation of aquifer material

The two open cut mining areas have been designed to remain outside of the alluvial material associated with Bylong River and Lee Creek, so this habitat will be unaffected by direct excavation.

The Permian aquifers associated with the Illawarra Coal Measures, are only secondary habitat for fauna, known only to be inhabited by two taxa. Both oligochaetes and cyclopoids are widespread and common in the alluvial aquifer, and their presence in bore A23 is likely to have been accidental or temporary. Therefore, the excavation of material for both open cut mining areas is unlikely to have a significant impact on the stygofauna community at Bylong.

8.2.2 Modelled alluvial drawdown

Preliminary groundwater modelling by AGE (2015) indicates that the proposed mining will result in a lowering of water level in the alluvial aquifer during the first ten years of the Project when the open cut pit is active. By Year 10, open cut mining is expected to be complete, so the pits will be backfilled and groundwater levels in the alluvium will start to recover. At the end of the program, drawdown in the alluvium will only affect the margins (AGE 2015).

Open cut and underground mining depressurises water in the coal seam in a zone extending 1 to 2 km from the proposed mining areas. Beyond this, drawdown will be less than 1 m. Without mining, the net upward flow of water from the Permian to alluvium is 1.1 to 8.5 ML/day. Depressurisation of the Permian strata will begin once mining commences. This will reduce the upward water movement into the alluvium in some places, and reverse it in others so that water moves from alluvium to Permian. The ultimate result of this will be to lower the water level in the alluvium, and subsequently reduced baseflow in parts of Lee Creek and the Bylong River.

Of the bores containing stygofauna, A10, A02S, A02D, A20 and A06S are likely to occur in or near the area of drawdown. During open cut mining, drawdown will be between 1 and 5 m for these bores. Once underground operations commence, drawdown for the bores in the impacted area have more than 2 m drawdown until Year 25.

Seven stygofauna taxa were collected from the sections of Lee Creek and Bylong River alluvium where drawdown will occur. These were Oligochaeta, Harpacticoida, Cyclopoida, *Bathynella* sp. 1, *Notobathynella* sp. 1, Psammaspididae sp. 1 and Anaspidacea sp. 1. All of these taxa were present only in shallow bores, except for Cyclopoida at A02 in the Lee Creek Alluvium, which came from a deep alluvium bore.

In alluvial aquifers, the availability of surface-derived organic matter declines with depth below the land surface, meaning that deeper stygofauna communities are often less diverse than shallow stygofauna communities (Datry 2005). The loss of organic matter occurs as a result of consumption by soil microbiota, and the longer the dissolved organic matter has to travel between the land and water table, the more organic matter is removed (Datry 2005). For this reason, stygofauna diversity is lower when the water table is deeper below ground level than when it is shallow. This truncation of available organic carbon is also why there are often fewer stygofauna in deeper parts of the aquifer than there are nearer the water table.

Lowering the water level at the Bylong River and Lee Creek alluvial aquifers by 2 to 5 m may lead to a local reduction in stygofauna diversity because of the increased distance to the land surface, and reduction in the amount of organic matter reaching the food web. If the most suitable stygofauna habitat in the aquifer is at the groundwater interface, the downward movement of that interface by 2-5 m will not necessarily be a significant factor in changing the community assemblage. Provided that there are no obstacles to vertical migration (aquatards, aquifer basement, etc), fauna should be able to move downwards to follow the water table. Most stygofauna taxa have some tolerance of water level fluctuations, as these are a natural part of the hydrological cycle. However, most seasonal fluctuations are temporary and the ability of species to adapt to long-term lowering of water levels is unknown.

There will also be drying of marginal and shallow sections where the aquifers are thinner than the 2-5 m drawdown predicted. This will reduce the volume of suitable aquifer available for stygofauna along parts of the Lee Creek and Bylong River alluvium. As there are still large areas of suitable shallow aquifer outside of the predicted drawdown zone, the overall impact of this will be minimal.

8.2.3 Changes to water chemistry

During mining, the options were considered to dispose of fine and coarse reject material in the Western and Eastern Open Cut Mining areas. Flow models indicate that water will move from these areas, once disposed of in the open cut voids, to the alluvium.

Geochemical assessment of samples from coal and waste material for the project by RGS (2015) found that the material is likely to cause few problems to groundwater. Material analysed had the following properties:

- Most materials had low sulphur content and can be classified as Non-Acid Forming (NAF);
- Some coal reject material from processing the Ulan and Coggan seams is Potentially Acid Forming (PAF) and will need to be managed carefully;
- Concentrations of total metals/metalloids in coal and mining waste and seepage is typically low and unlikely to present any environmental problems;
- Most NAF coal and mining waste should generate pH that is neutral to slightly alkaline run-off/seepage with low salinity;

- The overall risk of potentially significant water quality impacts from NAF coal and mining waste material is low.

RGS (2015) suggest the following mitigation measures to prevent or reduce the potential for acid water:

- Placement of coal reject materials deep in open pits, below the predicted post-mining groundwater level and encapsulated in at least 5 m of NAF overburden material;
- Provision for treatment of acid water in underground workings or in open cut pits; and
- Development of Water Management Plan to include monitoring and geochemical water chemistry trigger values.

RGS (2015) estimate that overburden and managed coal reject material used to backfill the pits, may result in pore water salinity of between 3000 and 4000 µS/cm. This is within the upper range of electrical conductivity measured in the alluvium, so may result in a slight increase in EC for some areas (AGE 2015). During periods of no rainfall, there could be an increase in salinity in alluvium groundwater of 13% (from 705 µS/cm to approximately 795 µS/cm, AGE 2015).

Most of the rock appears to be relatively inert and is unlikely to cause any changes to water chemistry that will significantly impact on the stygofauna community. Where acidity is expected, the suggested mitigation measures appear sufficient to protect the leaching of acidic water into the surrounding aquifers and impacting on stygofauna.

9 Discussion

9.1 Significance of the Bylong stygofauna

Apart from the cyclopoids and oligochaetes collected from bore A23 in the second survey period, all stygofauna were collected from the alluvial aquifer. Bore A23W is screened at the weathered Permian at 10.4 to 16.4 m below ground level. This is still relatively shallow, and the presence of stygofauna in this bore suggests that there are parts of the Permian rock that are sufficiently connected to the alluvium to allow it to act as a secondary stygofauna habitat.

No stygofauna was collected from the Coggan Seam, nor are they likely to occur there. This is because the water table is too deep to allow a sufficient hydrological connection to the surface. Poor water chemistry, relatively low porosity (compared to the alluvium), and the occurrence of confining layers between the coal aquifers and alluvium provide further impediments to stygofauna.

The two rounds of sampling confirm that stygofauna are widespread along the Lee Creek and Bylong River alluvial aquifers. All of the sampling points, excluding deep bores, had stygofauna. This suggests that the shallowest sections of the alluvial aquifer immediately below the water table are better stygofauna habitat than the deeper sections of the same aquifer. This is probably because the shallower section of the aquifer is where groundwater is youngest and has the highest concentrations of DO and dissolved organic matter (Datry *et al*. 2005, Hancock and Boulton 2008).

The alluvial aquifer appears to have the greatest species richness from bore A10 along the Lee Creek alluvium to its confluence with the Bylong River alluvium and northwards to AGE04-S. This section contained all ten taxa present at the site. One factor that may contribute to this high diversity is location of the screened section of the bore in relation to the water table. In bore A10, the screen extends from 3 to 9 m below ground level, while the water table is 5.24 m. Stygofauna diversity and abundance generally declines with depth below the water table (Hancock and Boulton 2008), so there is a better chance of collecting more species if the water table occurs within the region of sampling (i.e. the screened section of bore).

All of the stygofauna collected during the surveys are known from locations outside the proposed area of impact. In this regard, there is not likely to be a significant risk to most species from the Project. Oligochaeta, Ostracoda, Harpacticoida, and Cyclopoida are all commonly encountered in alluvial aquifer invertebrate communities in the Upper Hunter Valley region.

The genus *Bathynella* also occurs in most alluvial aquifers in NSW and Queensland known to have stygofauna. This taxon was abundant at Bylong and resembled those collected from other parts of the Upper Hunter Valley. It is therefore unlikely to be threatened by the Project. *Chilibathynella joshuai* was collected from the Bylong Valley, but this species is also known from the alluvial aquifer of the Macquarie River near Dubbo, so is not endemic to the region (Camacho and Hancock 2012).

Anaspidacea sp. 1 was collected from two bores separated by 5 km of suitable aquifer habitat, and is likely to be distributed both upstream and downstream of these bores along the alluvium. AGE04-S is outside of the Project Boundary and approximately 1 km from the drawdown area. This bore is unlikely to be impacted by mining, so the species has sufficient habitat outside the predicted drawdown area.

10 Conclusions and recommendations

Stygofauna surveys confirmed that stygofauna are widely distributed through the alluvial aquifers within and surrounding the Project Boundary. Ten taxa were collected over two rounds of survey for the Project. All of these were either collected elsewhere outside of the impact area, or are known from previous surveys to occur elsewhere.

The preliminary groundwater impact assessment indicates a drawdown of up to 1 to 5 m will occur at five of the bores where stygofauna were collected during the two surveys at Bylong. Seven stygofauna taxa occur in the sections of the Lee Creek and Bylong River alluvium where drawdown will occur. These were Oligochaeta, Harpacticoida, Cyclopoida, *Bathynella* sp. 1, *Notobathynella* sp. 1, Psammaspididae sp. 1 and Anaspidacea sp. 1. All of these taxa, except for Cyclopoida at A02 in the Lee Creek Alluvium, live in the shallow alluvium so there is likely to be some localised impact as the water levels fall. Some taxa may be able to migrate to deeper parts of the alluvium allowing populations to survive there while water level is down. All of the taxa collected from Bylong are known from other locations outside of the area of impact at Bylong, so although there may be a reduction in abundance at the local scale, the regional consequences are likely to be minor.

Mining operations for the Project are expected to have a minimal impact on stygofauna communities because:

- The main impacts from mining, which include pit excavation and most of the dewatering, will be to the Permian aquifers, which are only minor stygofauna habitat;
- Dewatering is expected to occur along approximately 3 km of Lee Creek Alluvium and 2 km of the Bylong River Alluvium, and will not completely dry the alluvium. There will still be large areas of suitable habitat available for stygofauna; and
- All taxa occurring in the predicted zone of drawdown are also known to occur outside of the expected drawdown areas, either from sampling conducted during the two surveys at Bylong, or from other stygofauna surveys in NSW.

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