# APPENDIX 21

Stygofauna
Assessment

# Glendell Continued Operations Project- Stygofauna Assessment

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# Executive Summary

The Glendell Continued Operations Project (the Project) forms part of the Mount Owen Complex in the Upper Hunter Valley of New South Wales (NSW), approximately 20 km north-west of Singleton and 24 km south-east of Muswellbrook. The Mount Owen Complex includes three approved open cut pit areas: Bayswater North Pit, North Pit (both already approved under Mount Owen Continued Operations Project consent, SSD-5850), and the Glendell Pit (approved under Glendell Mine consent DA 80/952).

The Project seeks to extend the life of Glendell Mine to 2044. Key aspects of the Project include the continuation of the Glendell Pit to the north (Glendell Pit Extension), the realignment of a section of Hebden Road, the realignment of the lower reach of Yorks Creek and relocation of Ravensworth Homestead.

Eco Logical Australia (ELA) was commissioned to conduct a stygofauna assessment for the Project. The stygofauna assessment aims to satisfy the relevant Commonwealth and NSW Government guidelines.

Thirteen bores were sampled for stygofauna in September 2018. This brings the total number of stygofauna samples from the region to 29, and the number of stygofauna taxa to seven:

- *Notobathynella* sp. (Syncarida crustacean) in Yorks Creek alluvium
- Bathynellidae (Syncarida crustacean) in Bowmans Creek alluvium
- *Carabhydrus stephanieae* (blind diving beetle) in Glennies Creek and Bowmans Creek alluvium
- A subterranean Elmidae (blind riffle beetle) in Bowmans Creek alluvium
- Hydrobiidae snail in Glennies Creek alluvium
- Cyclopoida crustacean in Glennies Creek and Swamp Creek alluvium
- Ostracoda crustacean in Bowmans, Yorks Creek, Swamp Creek and Glennies Creek alluvium

All taxa collected were from alluvial aquifers, and all are known to be widespread throughout the Hunter River alluvial aquifer, and aquifers of tributary streams such as Pages River, Kingdon Ponds, and Dart Brook.

Groundwater modelling indicates that the Bowmans Creek alluvium remains saturated adjacent to the Project, apart from two small areas. This desaturation results from the cumulative impacts from nearby mines and occurs irrespective of any contribution from Glendell operations (either approved or proposed). The Project will have a negligible impact on the extent of this desaturation. The predicted desaturation will result in the fragmentation of the Bowmans Creek alluvium. This fragmentation constitutes a significant threat to the local stygofauna community, although does not threaten regional stygofauna diversity. It is likely that the stygofauna community in upper Bowmans Creek could be reduced in biodiversity due to it becoming isolated, but this would not be caused by the Project.

The Project will delay reconnection of the fragmented aquifer but any impact from the isolation will already have occurred. As this fragmentation occurs without any contribution from the Project, the impact of the Project on the stygofauna community is negligible and no additional monitoring is needed.

# 1. Background

## 1.1 Project Background

The Mount Owen Complex, which includes the Glendell Continued Operations Project (the Project) Area, is in the Hunter Coalfields of the Upper Hunter Valley of New South Wales (NSW). It is approximately 20 kilometres (km) north-west of Singleton, and 24 km south-east of Muswellbrook. Mt Owen Pty Limited (Mount Owen), a subsidiary of Glencore Coal Pty Limited (Glencore), currently owns three existing open cut operations in the Mount Owen Complex (Figure 1); North Pit, Bayswater North Pit and Glendell Pit. The Mount Owen Complex also includes a coal handling and preparation plant (CHPP) and coal handling and transport infrastructure.

The Mount Owen Complex is adjacent to the Integra Underground, Liddell Coal Operations and Ravensworth Operations, which are also operations owned and operated by subsidiaries of Glencore and its joint venture partner (JV).

The Glendell Mine currently operates under development consent DA 80/952 (Glendell Consent). The Glendell Consent regulates the mining of coal from the Glendell Pit and the rehabilitation of the mining area. Glencore is seeking approval to extend open cut mining operations north from the existing Glendell Mine. The proposed extension of the current open cut mining operations at Glendell Mine would extract an additional approximately 135 million tonnes (Mt) of run-of-mine (ROM) coal.

This Glendell Pit Extension includes a proposal to extract reserves down to and including the Hebden seam, with mining continuing to 2044. The Project is a State Significant Development (SSD) and will require development consent under the *Environmental Planning and Assessment Act 1979* (EP&A Act). As an SSD, an Environmental Impact Statement (EIS) is required to accompany the development application for the Project. To facilitate this Glencore commissioned Umwelt Australia Pty Ltd to prepare an EIS to support the Project under Section 4.12(8) of the *Environmental Planning and Assessment Act 1979* (EP&A Act) and Schedule 2 of the Environmental Planning and Assessment Regulation 2000.

The Project was referred to the Commonwealth Department of Environment and Energy (DoEE) and was determined to be a controlled action under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

## 1.2 Secretary's Environmental Assessment Requirements (SEARs)

Secretary's Environmental Assessment Requirements (SEARs) were issued for the Project. Among the key issues to be addressed by the EIS, the following are relevant to this current study:

- Water - an assessment of the likely impacts of the development in the quantity and quality of existing surface and groundwater resources including a detailed assessment of proposed water discharge qualities and quantity against receiving water quality and flow objectives;
- Water- an assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users, including downstream impacts from Yorks Creek diversion;
- Biodiversity- an assessment of the likely biodiversity impacts of the development, paying particular attention to threatened species, populations and ecological communities and

groundwater dependent ecosystems, undertaken in accordance with the Biodiversity Assessment Method and documented in a Biodiversity Development Assessment Report or, subject to agreement with OEH and the Department, undertaken in accordance with the Upper Hunter Strategic Assessment (UHSA)

The additional requirements identified in the DoEE – Assessment Requirements (Attachment 4 to the SEARs (as revised 12 August 2019), insofar as they relate to stygofauna, are covered by the above issues.

## 1.3 Scope of Work

Eco Logical Australia (ELA) was commissioned to conduct a stygofauna assessment for the Project. Stygofauna are relevant to the SEARs outlined above, as they are considered part of, and are impacted by changes to, the groundwater resource. They are critical components of 'aquifer ecosystems', a type of groundwater dependent ecosystem (GDE) requiring special consideration in NSW. The stygofauna assessment aims to satisfy relevant Commonwealth and NSW Government guidelines and assessment standards.

The assessment includes a review of available monitoring data and existing reports, to determine the likelihood of suitable stygofauna habitat. The desktop review was followed by a field survey to determine what stygofauna occur in the Project Area. As part of the assessment, we compared the stygofauna community in aquifers at and near the Mount Owen Complex with that of the broader Hunter Valley stygofauna community and conducted a risk assessment for the potential for the Project to impact on local and regional stygofauna communities.

The assessment includes:

- A gap analysis, review, and assessment of existing data to identify suitable stygofauna habitat, and to select bores for survey. Where available, bores were selected from hard rock and alluvial aquifers, in and outside of the direct area of impact.
- Sampling to collect and identify stygofauna in the Project Area.
- A comparison of stygofauna from the Project with that of the broader Hunter Valley and with other similar aquifers in New South Wales.
- An assessment of impacts resulting from the Project, including the incorporation of groundwater and surface water reports as necessary.

# 2. Summary of the groundwater environment surrounding the Mount Owen Complex

Topography of the Mount Owen Complex is gently undulating along Bowmans Creek, a tributary of the Hunter River. Elevation ranges from 80 to 150 mAHD in the lower parts of the valley and up to 550 m AHD in the higher areas.

There are two main hydrogeological units in the Mount Owen Complex: the alluvial aquifer associated with Bowmans, Yorks, Swamp, Bettys and Main Creeks; and a regional Permian (hardrock/coal) aquifer associated with underlying coal measures (AGE 2019).

A more detailed account of the local and regional geology and groundwater environment is given in the *Glendell Continued Operations Project- Groundwater Impact Assessment* (AGE 2019). Relevant components are summarised briefly below.

## 2.1 Geology

The Mount Owen Complex is dominated by Permian age bedrock formations associated with the Wittingham Coal Measures, which comprises the Jerrys Plains and Vane Subgroups, which overlie the Saltwater Creek Formation (AGE 2019). This is part of the Singleton Supergroup that comprises sandstones, siltstones and coal measures. The coal measures are the main aquifers of the Wittingham Coal Measures and provide groundwater storage and transmission through intra-bed cleats and limited natural porosity.

The coal seam measures and surrounding interburden are fractured around the Camberwell Anticline, which runs approximately north-west to south-east through the centre of Glendell Mine and proposed Glendell Pit Extension. The Hunter Thrust Fault separates the Whittingham Coal Measures from the New England Block and is located to the north and east of the Project Area.

### 2.1.1 Sedimentary aquifers

The Project is in the Bowmans Creek catchment, which is a tributary of the Hunter River. Yorks, Swamp, and Bettys Creeks are ephemeral streams that pass through the Project Area and flow into Bowmans Creek. Bowmans Creek flows in a southerly direction along the western edge of the Project. Each of the ephemeral creeks have minor layers of sediment associated with them, but these are not well developed and may go dry in shallower reaches, although they thicken near Bowmans Creek. Bowmans Creek alluvium contains typically fresh to brackish groundwater, whilst samples of groundwater from Bettys Creek, Swamp Creek and Yorks Creek (which are tributaries of Bowmans Creek) have widely varying salinity from fresh to highly saline waters (AGE 2019).

The alluvial aquifer associated with Bowmans Creek consists of loams overlying silt and clay lenses. This is the main alluvial aquifer in the Project Area and has a maximum saturated thickness of between 5 and 10 m (AGE 2019). The basal sediments are coarse-grained with sand and clean gravel sized particles. A layer of finer grained levee deposits sits above this, and on top of this a layer of upper floodplain deposits. Alluvial deposits are deepest in the lands surrounding Bowmans Creek and become thinner towards the deposit margins.

Glennies Creek is a regulated, perennial stream that passes to the south of the Project Area. The Glennies Creek alluvium has groundwater that is fresh to brackish, which increases in salinity with distance from the creek (AGE 2019). Glennies Creek flows south-westward into the Hunter River.

### 2.1.2 Rock aquifers

Beneath the alluvium, and away from the creek valleys, the main hydrogeological units are coal seams interlain with impermeable interburden strata. The interburden strata consist of Permian siltstones, sandstones, shales, and claystones. These generally have a lower permeability than the coal aquifers, but can be more transmissive at fractures, joints, or faults (AGE 2019).

The interburden aquifers are only likely to have stygofauna in areas of secondary porosity, where fracturing is thick enough to allow animal movement. Coal seams tend to be more fractured than the interburden strata, so are more likely to have stygofauna provided water quality is suitable and they are relatively close to the surface or an inhabited alluvial aquifer. This dependence on proximity to the land surface or alluvial aquifers is largely driven by the dependence of stygofauna on surface-derived organic matter (see Section 4.2).

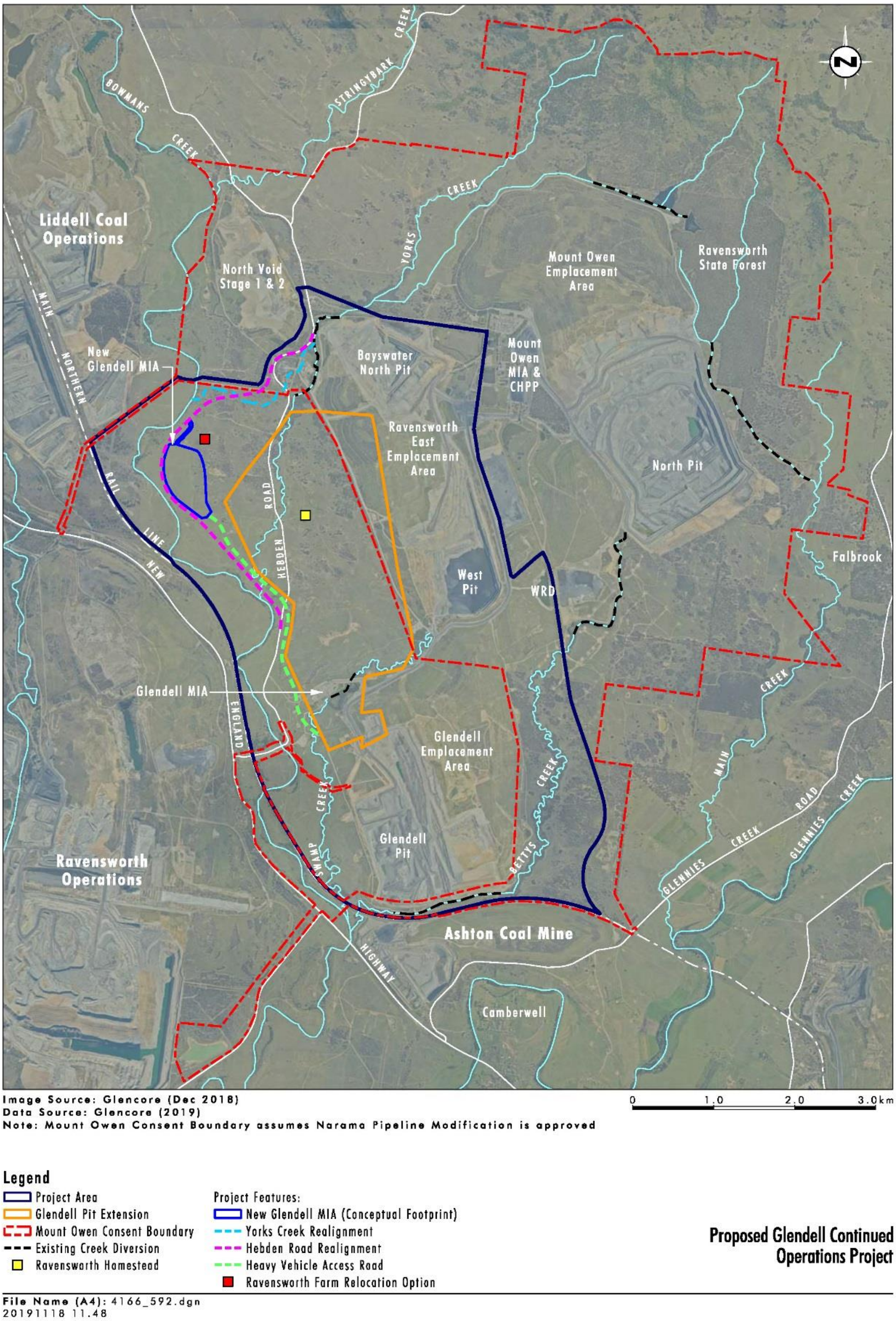


**Figure 1: Overview of the Mount Owen Complex and the Glendell Continued Operations Project.**

# 3. Relevant Guidelines, Policies and Legislation

The importance of aquifer ecosystems is being increasingly recognised in NSW and nationally. The following policies are relevant to the protection and management of aquifer ecosystems for this current assessment:

- Information Guidelines for Assessing Groundwater-Dependent Ecosystems, 2019. http://www.iesc.environment.gov.au/system/files/resources/422b5f66-dfba-4e89-adda-b169fe408fe1/files/information-guidelines-explanatory-note-assessing-groundwater-dependent-ecosystems.pdf
- NSW State Groundwater Policy Framework Document, Department of Land and Water Conservation, 1997. http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Keypolicies/default.aspx
- NSW State Groundwater Dependent Ecosystems Policy, Department of Land and Water Conservation, 2002. http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Keypolicies/default.aspx
- NSW Groundwater Quality Protection Policy, Department of Land and Water Conservation, 1998. http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Keypolicies/default.aspx
- NSW Aquifer Interference Policy, NSW Department of Primary Industries, 2012. http://www.water.nsw.gov.au/__data/assets/pdf_file/0004/549175/nsw_aquifer_interference_policy.pdf

## 3.1 *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)

The Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) considers water resources affected by large coal mining developments to be a matter of national environmental significance. Under the EPBC Act, this means that Commonwealth assessment is required if there is a significant impact to the water resource. Groundwater dependent ecosystems are considered part of the water resource, so must be considered in the assessment.

## 3.2 Information guidelines for assessing groundwater dependent ecosystems

These guidelines (Doody et al. 2019) were released by The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (the IESC), which is a statutory body under the EPBC Act. They are intended to assist proponents in preparing environmental impact assessments for coal seam gas (CSG) and large coal mining (LCM) development proposals. They provide a logical sequence of steps to identify GDEs in the impact area, then determine the level of dependence, their baseline condition, and potential to be impacted. The guidelines prioritise avoidance and mitigation measures to minimise impacts.

## *3.3 Water Management Act 2000*

The Water Management Act 2000 (WM Act) is the key piece of legislation for the management of water in NSW. The WM Act aims to provide for the sustainable and integrated management of the water sources of NSW for the benefit of both present and future generations. The following objects of the WM Act are relevant to the management of groundwater dependent ecosystems (GDEs) to:

- Apply principles of ecologically sustainable development.
- Protect, enhance and restore water sources, their associated ecosystem, ecological processes and biological diversity and their water quality.
- Recognise and foster the significant social and economic benefits to the State that result from the sustainable and efficient use of water, including benefits to the environment.
- Integrate the management of water sources with the management of other aspects of the environment, including the land, its soils, its native vegetation and its native fauna.

The WM Act also provides water management principles and the following general principles are relevant to the management of GDEs:

- Water sources, floodplains and dependent ecosystems (including groundwater and wetlands) should be protected and restored and, where possible, land should not be degraded.
- Habitats, animals and plants that benefit from water or are potentially affected by managed activities should be protected and (in the case of habitats) restored.
- The quality of all water sources should be protected and, wherever possible, enhanced.
- The cumulative impacts of water management licences and approvals and other activities on water sources and their dependent ecosystems, should be considered and minimised.
- The principles of adaptive management should be applied, which should be responsive to monitoring and improvements in understanding of ecological water requirement.

## 3.4 Risk Assessment guidelines for groundwater dependent ecosystems

The *Risk assessment guidelines for groundwater dependent ecosystems* (Serov et al. 2012) was developed jointly by the NSW DPI Office of Water to:

- Assist agency staff to support the requirements of the WM Act.
- Provide methods to identify and value GDEs and assist reporting against the state-wide targets that aim to improve the ability of groundwater systems to support GDEs and designated beneficial uses (as part of the NSW Natural Resources Monitoring, Evaluation and Reporting Strategy 2010–2015).
- Provide a risk assessment framework for GDEs for the National Water Commission Project Coastal Groundwater Quality and Groundwater Dependent Ecosystems (GDE).
- Provide detailed methods for defining, identifying and assessing ecological value and risk through a risk analysis conceptual framework for GDEs, with supporting background information. The conceptual framework allows potential and actual impacts of proposed activities on GDEs to be assessed in accordance with the WM Act and other relevant legislation.

## 3.5 NSW Groundwater Quality Protection Policy, 1998

The Groundwater Quality Protection Policy aims to protect water below the ground surface by providing a framework for management of groundwater quality, so resources can sustain environmental, social and economic uses in NSW. The policy has nine management principles to protect groundwater quality, quantity and groundwater dependant ecosystems. These are as follows:

- All groundwater systems should be managed such that their most sensitive identified beneficial use (or environmental value) is maintained
- Town water supplies should be afforded special protection against contamination
- Groundwater pollution should be prevented so that future remediation is not required
- For new developments, the scale and scope of work required to demonstrate adequate groundwater protection shall be commensurate with the risk the development poses to a groundwater system and the value of the groundwater resource
- A groundwater pumper shall bear the responsibility for environmental damage or degradation caused by using groundwaters that are incompatible with soil, vegetation or receiving waters
- Groundwater dependent ecosystems will be afforded protection
- Groundwater quality protection should be integrated with the management of groundwater quantity
- 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.

## 3.6 NSW Aquifer Interference Policy, 2012

The Aquifer Interference Policy aims to clarify requirements for obtaining water licences for aquifer interference activities under NSW legislation. It establishes and defines considerations in assessing and providing advice on whether more than minimal impacts might occur to key water dependent assets. Under the Policy, proponents will be assessed on their:

1. (a) ability to demonstrate that they have the ability to obtain the necessary licences in order to account for the take of water from any relevant water source. The requirements for this are detailed in Section 2 of this Policy. Where there is concern that the necessary licence entitlements cannot easily be obtained, the proposal should include mitigation or avoidance strategies in order to reduce the take of water to a point where it can be accounted for; or

   (b) ability to demonstrate that the proposal has been designed in such a way as to prevent the take of water where applicants are unable to meet the requirements specified in point 1 above; and
2. ability to demonstrate that adequate arrangements will be in place to ensure that the minimal impact considerations specified in The Policy can be met; and
3. proposed remedial actions for impacts greater than those that were predicted as part of the relevant approval. The requirement for remedial actions may occur where modelled predictions were inaccurate or where planned mitigation, prevention or avoidance strategies have failed. The assessment will include:
   a. consideration of the potential types and risks of unforeseen impacts that may occur during the operational phase or post-closure of the aquifer interference activity; and
   b. whether the proposed mitigation, prevention or avoidance strategies will minimise these risks; and
   c. whether the proposed remedial actions are adequate, should the proposed risk minimisation strategies in (b) fail; and
   d. advice on what further mitigation, prevention, avoidance or remedial actions may be required; and

e. appropriate conditions that maintain any mitigation, prevention, avoidance or remediation actions until they are no longer required to keep the impacts at or below the predicted levels.

# 4. Stygofauna of the Hunter Valley

## 4.1 Overview of stygofauna ecology

Stygofauna are generally small aquatic invertebrates that live in groundwater systems. They are typically crustaceans, although there are a few insect taxa and other non-crustacean invertebrates in the communities of the Hunter Valley. Estimates suggest there could be as many as 2,680 species in the western half of the Australian continent, although only 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.

Stygofauna have special adaptations to survive in the relatively resource-poor aquifers, where there is no light, space is limited, and food is scarce (Humphreys 2008). Adaptations include blindness, slow metabolism, reduced body 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). Alluvial aquifers often have gradients in species diversity associated with distance from recharge areas, where dissolved or fine particulate organic matter enters the aquifer (Datry et al. 2005). Tree roots are also important sources of organic matter for groundwater food webs, and where they intersect the water table can have support diverse communities (Hancock and Boulton 2008, Jasinska et al. 1996).

Many ecosystem functions provide essential services to humans, saving both money and resources (Boulton et al. 2008). Despite their small size, the cumulative effect of some key stygofauna processes are likely to cause significant changes to groundwater quality. These processes are evident in alluvial aquifers where water moving though sediment particles is cleaned during transit, in much the same way as water moving through slow sand filters or trickle filters during water and sewage treatment (Hancock et al. 2005). It is likely that through their movement and grazing of sediment-bound microbes, stygofauna also help prevent alluvial aquifer sediments from clogging (Hancock et al. 2005).

Unlike many surface aquatic species, stygofauna have no aerial life stages, and are limited in their ability to disperse. Consequently, movement through aquifers is relatively slow and often restricted to convoluted passages between sediment grains or along fractures in rock. Usually, greater porosity corresponds to higher connectivity between interstitial spaces, meaning that stygofauna can move around in the aquifer with greater ease. Conversely, areas of low porosity can restrict the transfer of genetic material. Aquifers that are hydrologically disconnected from each other often have different stygofaunal compositions, although they may share some species if the aquifers were connected in the past or become connected occasionally during periods of high water level. The more frequent the aquifers are connected, the more similar the stygofauna communities are likely to be. However, with prolonged genetic isolation between adjacent aquifers or isolated sections of the same aquifer, species may begin to evolve, resulting eventually in the development of new species (Watts et al. 2007). Aquifers that have been isolated for long periods often contain several unique species of stygofauna with very limited distributions.

Aquifers are relatively stable compared to surface aquatic environments with little or no daily fluctuations in parameters such as temperature, water level, and electrical conductivity (EC). As such, many stygofauna taxa are sensitive to rapidly changing conditions (Hancock et al. 2005). Activities such as water table draw-down, the removal of aquifer material for mining or quarrying, or rapid changes to water quality can all have detrimental effects to stygofauna communities and possibly cause extinctions (Humphreys 2008).

It is a combination of the features outlined above that have driven concerns for the potential loss of stygofauna biodiversity, particularly in areas subjected to rapid and extensive anthropogenic changes. The key attributes of stygofauna that may place them at risk are:

- The adaptation to relatively stable conditions and vulnerability to rapid or excessive changes in water level, temperature, and salinity;
- Their slow rate of reproduction and slow growth rate;
- The limited ability to disperse through aquifers, and intuitively recolonise following disturbance; and
- The high degree of endemism, with entire species restricted to only small geographic areas.

Concerns over the impact of mining and other large development projects, and concerns for State responsibility to maintain biodiversity, prompted the Western Australian and Queensland Governments to require stygofauna sampling as part of Environmental Impact Assessments (WA EPA 2003, 2007). In NSW, the Department of Primary Industries Office of Water developed the *Risk assessment guidelines for groundwater dependent ecosystems* (Serov et al. 2012). This document lays out the methods to identify and determine the value of GDEs and also provides a risk assessment framework. Under the NSW GDE Guidelines, the aquifer ecosystems that accommodate stygofauna, are classified as either Karst and Cave Ecosystems or Subsurface Phreatic Aquifer Ecosystems (Serov et al. 2012).

## 4.2 Background - Factors influencing biological distribution in aquifers

As with all fauna, stygofauna require favourable conditions to inhabit an aquifer, but with the large number of species occurring in aquifers, 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 to learn 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.

### 4.2.1 Aquifer type

Stygofauna have been collected from many aquifer types, including fractured basalt, fractured sandstone, 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 and karst aquifers than in other geological formations (Hancock et al. 2005, Humphreys 2008). Alluvial aquifers occur beneath floodplains, which often provide the following favourable conditions 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.

### 4.2.2 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 can be replenished.

### 4.2.3 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 the Hunter Valley and other parts of 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 increased availability of organic matter provides food to diverse stygofauna communities (Hancock and Boulton 2008).

### 4.2.4 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. 2005).

### 4.2.5 A space for living

Stygofauna can only live in aquifers that have 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.

### 4.2.6 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 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).

### 4.2.7 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.

### 4.2.8 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.

### 4.2.9 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 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.* Glanville et al. 2016).

### 4.2.10 Dissolved oxygen

Stygofauna can 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 can survive with virtually no oxygen for temporary periods for up to 6 months (Henry and Danielopol 1999, Malard and Hervant 1999). Aquifers can be heterogeneous environments, so may contain patches of water with enough 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.

## 4.3 Previous stygofauna surveys

### 4.3.1 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 from beneath the bed sediments and lateral bars of nine sites along the Hunter River, Goulburn River, and Wollombi Brook (Figure 2).

Hyporheic zones are the areas of river bed where groundwater and surface water mix, and often contain surface water, hyporheic, and groundwater taxa (Marmonier et al. 1993, 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; Coineau 2000, Danielopol et al. 1994). 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, and Aberdeen, and from the Goulburn River at Sandy Hollow. *Notobathynella* sp. occurred at Denman, Dights Crossing, and Aberdeen. The largest stygofaunal 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.

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

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

**Table 1: Stygofauna identified 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 | ✓ | ✓ | | | ✓ | ✓ | | ✓ | ✓ | ✓ |

### 4.3.2 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 (Hancock and Boulton 2008, 2009; Watts *et al.* 2007). Samples were collected from 40 groundwater monitoring bores operated by mining companies and the NSW Office of Water (Table 2). 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 River, Dart Brook (north), and Kingdon Ponds samples have been identified to a species level.

Dart Brook, Pages River, 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 River 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.

Of the stygofauna identified to species level in the survey, only four (*Notobathynella* sp. nov. 3, Anaspid Family A sp. 1, *Dyacyclops cryonastes*, and possibly *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. Similarly, most species in Dart Brook, Pages River 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 many species typically occurring in more than one alluvial aquifer. Only four species are endemic to single aquifers: *Metacyclops* sp. 1, *Haplocyclops* sp. 1, *Hancockcamptus* sp. 1, and *Hydrobiidae* sp. nov.

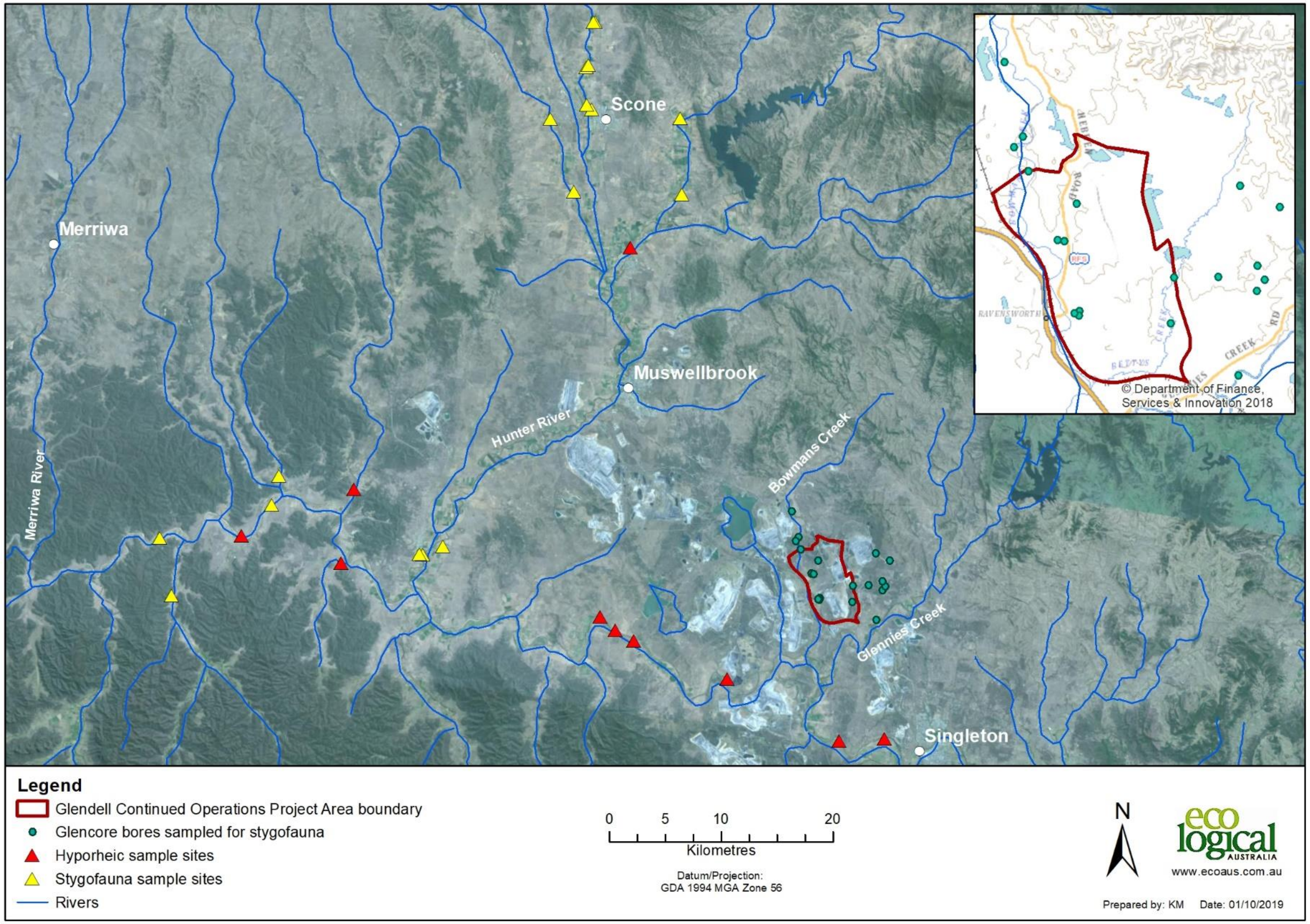


**Figure 2: Location of past stygofauna survey points in the Hunter Valley**

**Table 2: Stygofauna identified in the Hunter Valley Alluvial Aquifer Survey**

| Location | Alluvial aquifer | 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 | Haplocyclops 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 River | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | | ✓ | ✓ | ✓ | | ✓ | ✓ | | ✓ |
| Muswellbrook | Hunter River | ✓ | ✓ | | | | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ | | | | | | | | | | | | | |
| Dart Brook south | Dart Brook | ✓ | ✓ | | | | ✓ | | ✓ | ✓ | ✓ | | | | | | | | | | | | | | | | |
| Goulburn | Goulburn River | ✓ | | ✓ | ✓ | | | | | ✓ | ✓ | | | | | | | | | | | | | | | | |
| Pages | Pages River | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Dart Brook north | Dart Brook | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Kingdon Ponds | Kingdon Ponds | ✓ | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | | |

### 4.3.3 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, including Bengalla (ELA 2013a), Liddell (ELA 2013b), Bylong (ELA 2014) and Mount Owen (ELA 2018) (Table 3). All taxa collected during these surveys were previously known from the alluvial aquifers of the Hunter River or its tributaries, except for two. The exceptions were *Chilibathynella peelensis*, previously known only from near Tamworth, and an unknown species of Anaspidacea that occurred in two bores at Bylong.

During the Mount Owen survey, stygofauna were collected from alluvial aquifers in Yorks, Glennies, and Swamp Creeks, but none were endemic to the Project Area. Most taxa collected during the Liddell surveys were from the Bowmans Creek alluvium.

**Table 3: Stygofauna from four surveys undertaken for mining operations in the Hunter Valley**

| Order | Family | Genus/ species | Bengalla | Liddell | Bylong | Mt Owen |
|---|---|---|---|---|---|---|
| Mollusca | Hydrobiidae | | | | | ✓ |
| Anaspidacea | Psammaspididae | | | ✓ | ✓ | |
| | Family A | Anaspidacea sp. | | | ✓ | |
| Bathynellacea | Parabathynellidae | Notobathynella sp. | ✓ | ✓ | ✓ | ✓ |
| | Parabathynellidae | Chilibathynella peelensis | | | ✓ | |
| | Bathynellidae | Bathynella sp. | ✓ | ✓ | ✓ | |
| Isopoda | Janiridae | Heterias sp. | | ✓ | | |
| Amphipoda | Paramelitidae | Chillagoe sp. | ✓ | ✓ | ✓ | |
| Cyclopoida | Cyclopidae | | ✓ | ✓ | ✓ | ✓ |
| | Harpacticoida | | | | ✓ | |
| Ostrocoda | | | ✓ | ✓ | | ✓ |
| Coleoptera | Dytiscidae | Carabhydrus stephanieae | | ✓ | | ✓ |
| Coleoptera | Elmidae | Austrolimnius sp. | | ✓ | | |
| Oligochaeta | | | ✓ | | | ✓ |

## 4.4 Likelihood of stygofauna occurring in the Project Area

Stygofauna are already known from the Bowmans, Yorks and Swamp Creek aquifers, so occur in the Project Area. Although the taxa collected to date are known from other parts of the Hunter Valley, there are potentially other stygofauna taxa in the aquifers that are not yet known.

Stygofauna will be most likely in the alluvial aquifers that are well developed, with thick deposits of coarse sediment, and are connected frequently or continuously to the Bowmans Creek alluvium. Where alluvial deposits are thin and the aquifer dries frequently, stygofauna will be unlikely.

The sedimentary rock and coal seam aquifers may also contain stygofauna. However, they are unlikely to occur in unfractured parts of the rock. Communities will be most diverse adjacent to alluvial aquifers such as Bowmans Creek, from which they can colonise areas of secondary porosity. Stygofauna will extend into the rock and coal aquifers for as far as the network of fracturing allows. For this reason, the bores most likely to give access to stygofauna communities in the rock and coal aquifers will be relatively shallow (50 to 60 m).

Although stygofauna are unlikely to occur in the underlying Permian aquifer due to increasing depth, low hydraulic conductivity and generally high salinity, there may be areas where EC is less than 5,000 µS/cm and weathering is likely to have increased the space available for stygofauna. As the Permian aquifers are the most likely to be impacted by the Project, samples were collected to confirm if stygofauna occur there.

# 5. Methods

## 5.1 Study sites

The Western Australian EPA (2003, 2007) specifies that bores selected for stygofauna sampling should be at least three months old before the first sampling. This resting period allows stygofauna to colonise the immediate the bore following the disturbance created during construction and subsequent development.

Following a review of previous groundwater assessments, drilling programmes and recent groundwater monitoring data, a list of bores was generated for sampling. Generally, bores were chosen which:

- Gave a range of spatial and depth coverage across each aquifer type present;
- Were most likely to contain stygofauna;
- Had casings that were vertical, at least 50 mm in diameter, and were screened at appropriate depths;
- Had water quality (if data were available) that was favourable to stygofauna; and
- Had shallow water tables (where this information was available).

These criteria aimed to maximise the chances of collecting as many stygofauna taxa as possible. The objective of this survey was to gain an initial estimate of groundwater biodiversity, and determine which species are present.

Twenty-two bores were visited during the field survey, although nine were dry and could not be sampled. This left 13 bores that could be successfully sampled (refer to **Figure 3**), making a total of 29 stygofauna samples, when combined with the sixteen bores previously sampled as part of the Mount Owen assessment (ELA 2018).

As all previous stygofauna from the area was collected from alluvial aquifers, these were targeted during the current round of sampling, with eight of the thirteen bores sampled being alluvial bores. Five bores were sampled at the junction of Bowmans Creek and Yorks Creek alluvium, two were from the Bowmans Creek alluvium, and one was from the Bettys Creek alluvium. Of the five non-alluvial bores sampled, three were from interburden, one was from the shallow hard rock aquifer, and one was from a coal seam (Table 4).

**Table 4: Bore location and depth details**

| Site | Aquifer | Site | Zone | Easting | Northing |
|---|---|---|---|---|---|
| BC-SP02 | Alluvium (Yorks Ck/ Bowmans Ck) | Mt Owen | 56H | 317483 | 6411487 |
| BC-SP08 | Alluvium (Yorks Ck/ Bowmans Ck) | Mt Owen | 56H | 317592 | 6411869 |
| BC-SP22 | Alluvium (Yorks Ck/ Bowmans Ck) | Mt Owen | 56H | 317992 | 6409051 |
| GA2 | Alluvium (Yorks Ck/ Bowmans Ck) | Mt Owen | 56H | 318578 | 6407367 |
| GCP3D | Coal - Bayswater | Integra | 56H | 320838 | 6409800 |

| Site | Aquifer | Site | Zone | Easting | Northing |
|---|---|---|---|---|---|
| GCP3S | Alluvium (Bettys Ck) | Integra | 56H | 323149 | 6404757 |
| GNP09D | Interburden | Glendell | 56H | 316223 | 6412806 |
| GNP10D | Interburden | Glendell | 56H | 316817 | 6411318 |
| GNP10S | Alluvium (Bowmans Ck) | Glendell | 56H | 316818 | 6411319 |
| GNP11D | Interburden | Glendell | 56H | 317818 | 6408381 |
| GNPS-02 | Alluvium (Bowmans Ck) | Mt Owen | 56H | 317564 | 6410201 |
| GNPS-06 | Alluvium (Yorks Ck/ Bowmans Ck) | Mt Owen | 56H | 317605 | 6411062 |
| NPZ11 | Shallow hard rock | Mt Owen | 56H | 318059 | 6412639 |


**Figure 3: Location of bores sampled for stygofauna.**

## 5.2 Field sampling and laboratory identification

Bores were sampled using a weighted net with 50 µm mesh. The net was lowered to the bottom of each bore, then raised and dropped over approximately 50 cm three to five times to dislodge resting fauna. It was then slowly retrieved to the surface. Slow retrieval is necessary to avoid a bow-wave pushing fauna from 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, where possible, were retrieved. Sieve contents were washed into a sample jar containing ethanol and labelled.

Samples were transported to the laboratory and sorted under a Leica MZ8 dissecting microscope. They were then identified as far as possible using available taxonomic keys.

## 5.3 Risk assessment process

*Risk Assessment Guidelines for Groundwater Dependent Ecosystems* (Serov et al 2012) outlines the processes for risk assessment of GDEs. The steps involved in the assessment process (specific to aquifer ecosystems) are:

- Identify and classify the ecosystems,
- Assess the level of dependence on groundwater
- Identify high ecological value components of the aquifer
- Determine the ecological value of the aquifer
- Determine the impact of the activity on the aquifer community
- Determine risk magnitude to the aquifer community
- Apply the GDE Risk Matrix
- Apply management actions, including mitigation measures.

The GDE Risk Matrix (Table 5) is a method of outlining appropriate management responses for an environmental value under a particular activity.

The matrix consists of a vertical axis that plots ecological value, and a horizontal axis that plots the level of risk of an activity. The ranking of both ecological values and risk is divided into a three-category system of "High, Medium, and Low" values.

The Risk Matrix management action table (Table 6) identifies both the level of management action required and the time frame in which this action needs to be implemented (Action Priority). The management action is aligned with ecological value and does not vary with changes in risk (i.e. the rules for the management of high ecological value ecosystems or aquifers are the same whether the risk is high or low). However, the timing of the management action is aligned and determined by the level of risk.

**Table 5: GDE Risk Matrix (Serov et al. 2012)**

| | Category 1: Low Risk | Category 2: Moderate Risk | Category 3: High Risk |
|---|---|---|---|
| **Category 1:** High Ecological Value (HEV) Sensitive Environmental Area (SEA) | A | B | C |
| **Category 2:** Moderate Ecological Value (MEV) Sensitive Environmental Area (SEA) | D | E | F |
| **Category 3:** Low Ecological Value (LEV) | G | H | I |

**Table 6: Risk Matrix Management Actions (Serov et al. 2012)**

| Risk Matrix Box | Descriptor | Management action | | |
|---|---|---|---|---|
| | | Short term | Mid-term | Long term |
| A | High value/Low risk | Protection measures for aquifer and GDEs.<br><br>Baseline Risk monitoring. | Continue protection measures for aquifers and GDEs.<br><br>Periodic monitoring and assessment. | Adaptive management. Continue monitoring. |
| B | High value/Moderate Risk | Protection measures for aquifer and GDEs.<br><br>Baseline Risk monitoring. Mitigation action. | Protection measures for aquifer and GDEs.<br><br>Monitoring and periodic assessment of mitigation. | Adaptive management. Continue monitoring. |
| C | High Value/High Risk | Protection measures for aquifer and GDEs.<br><br>Baseline Risk monitoring. Mitigation. | Protection measures for aquifer and GDEs.<br><br>Monitoring and annual assessment of mitigation | Adaptive management. Continue monitoring. |
| D | Moderate Value/Low Risk | Protection of hotspots.<br><br>Baseline Risk monitoring. | Protection of hotspots.<br><br>Baseline Risk monitoring. | Adaptive management. Continue monitoring. |
| E | Moderate Value/Moderate Risk | Protection of hotspots.<br><br>Baseline risk monitoring.<br><br>Mitigation action. | Protection of hotspots.<br><br>Monitoring and periodic assessment of mitigation. | Adaptive management. Continue monitoring. |
| F | Moderate Value/High Risk | Protection of hotspots.<br><br>Baseline risk monitoring. Mitigation action. | Protection of hotspots.<br><br>Monitoring and annual assessment of mitigation. | Adaptive management. Continue monitoring. |
| G | | Protect hotspots (if any). | Protect hotspots (if any). | |

| Risk Matrix Box | Descriptor | Management action | | |
|---|---|---|---|---|
| | | Short term | Mid-term | Long term |
| | Low value/Low risk | Baseline risk monitoring. | Baseline risk monitoring. | Adaptive management. Continue monitoring. |
| H | Low Value/Moderate Risk | Protect hotspots (if any).<br>Baseline risk monitoring. Mitigation action. | Protect hotspots (if any).<br>Monitoring and periodic assessment of mitigation. | Adaptive management. Continue monitoring. |
| I | Low Value/High Risk | Protect hotspots (if any).<br>Baseline risk monitoring. Mitigation Action. | Protect hotspots (if any).<br>Monitoring and annual assessment of mitigation | Adaptive management. Continue monitoring. |

# 6. Results

## 6.1 Water Chemistry

Field sampling was conducted between 4 and 6 September 2018 by ELA Aquatic Ecologist Dr Peter Hancock.

Water temperature in the alluvial aquifers ranged from 18.83°C to 20.56°C and for the non-alluvial aquifers ranged from 18.68°C to 20.58°C (Table 7). Electrical conductivity (EC) in alluvial aquifers was between 1,242 µS/cm at GNP10D and 34,190 µS/cm at GCP3S, and was between 1,040 µS/cm and 11,080 µS/cm for non-alluvial bores (Table 7). EC was highest in Bettys Creek alluvium, at BC-SP22 followed by Yorks Creek/Bowmans Creek alluvium.

Across all bores, pH was between 6.48 and 7.38 (Table 7). Dissolved oxygen (DO) concentration in the non-alluvial bores ranged from 1.21 mg/L to 1.73 mg/L. In the alluvial bores, DO concentration was between 0.76 mg/L and 4.3 mg/L (Table 7).

**Table 7: Groundwater physico-chemistry at bores sampled for stygofauna**

| Site | Aquifer | Water level (mbgl) | Water Temperature (°C) | pH | Electrical Conductivity (µS/cm) | Dissolved Oxygen (% saturation) | Dissolved Oxygen (mg/L) |
|---|---|---|---|---|---|---|---|
| BC-SP02 | Alluvium (Yorks Ck/ Bowmans Ck) | 7.6 | 19.61 | 6.92 | 6,318 | 26.2 | 2.34 |
| BC-SP08 | Alluvium (Yorks Ck/ Bowmans Ck) | 6.24 | 20.56 | 7.21 | 1,405 | 19.8 | 1.7 |
| BC-SP22 | Alluvium (Yorks Ck/ Bowmans Ck) | 5.79 | 19.98 | 7.38 | 18,680 | 50.8 | 4.3 |
| GA2 | Alluvium (Yorks Ck/ Bowmans Ck) | 7 | 19.68 | 6.93 | 3,614 | 20.4 | 1.78 |
| GCP3D | Coal - Bayswater | 39.7 | 20.58 | 7.35 | 11,080 | 20 | 1.73 |
| GCP3S | Alluvium (Bettys Ck) | 5.65 | 19.91 | 6.96 | 34,190 | 25.16 | 2.04 |
| GNP09D | Interburden | 8.51 | 18.68 | 6.86 | 1,681 | 13 | 1.21 |
| GNP10D | Interburden | 5.24 | 18.81 | 7.29 | 1,040 | 16.1 | 1.51 |
| GNP10S | Alluvium (Bowmans Ck) | 5.06 | 18.83 | 7.17 | 1,741 | 29.8 | 2.76 |
| GNP11D | Interburden | 5.69 | 18.9 | 7.11 | 2,200 | 30.4 | 2.86 |
| GNPS-02 | Alluvium (Bowmans Ck) | 5.94 | 19.11 | 6.48 | 1,242 | 8.3 | 0.76 |
| GNPS-06 | Alluvium (Yorks Ck/ Bowmans Ck) | 7.10 | 20.07 | 6.49 | 3,843 | 19.9 | 1.75 |
| NPZ11 | Shallow hard rock | 24.39 | 19.46 | 7.33 | 11,620 | 14.13 | 1.29 |

## 6.2 Stygofauna

Four stygofauna taxa were collected from GNPS-06 and GNP10S, and one troglofaunal taxon (Diplura) was collected from BC-SP02 and GNPS-06 (Table 8). Of the stygofauna, Ostracoda (Crustacea) were in GNPS-06, while *Carabhydrus stephanieae* (a subterranean diving beetle), *Elmidae* sp. (riffle beetle), and Bathynellidae were present in GNP10S. These bores were linked to the alluvial aquifers of Bowmans Creek and Yorks Creek.

Diplura (a two-pronged bristletail hexapod related to insects), are part of subterranean fauna which dwell in caves or the sediments above the water table.

No stygofauna were collected from the shallow hard rock aquifers, interburden, nor the coal seam aquifer.

**Table 8: Stygofauna collected.**

| Taxon | Classification | GNPS-06 | BC-SP02 | GNP10S |
|---|---|---|---|---|
| Ostracoda | Stygofauna | 5 | - | - |
| Diplura | Troglofauna | 1 | 1 | - |
| *Carabhydrus stephanieae* | Stygofauna | - | - | 2 |
| *Elmidae* sp. | Stygofauna | - | - | 2 |
| Bathynellidae | Stygofauna | - | - | 1 |

# 7. Risk assessment

The following sections assess the potential for these impacts to occur as a result of the Project, based on the processes outlined in *Risk Assessment Guidelines for Groundwater Dependent Ecosystems* (Serov et al 2012).

During this risk assessment, data collected during the 2017 survey for the Mount Owen assessment (ELA 2018) and Liddell assessment (ELA 2013b) are also considered.

## 7.1 Identify and classify the ecosystems

Stygofauna were collected from the alluvial aquifers of Yorks Creek, Swamp Creek, and Glennies Creek during 2017 (ELA 2018) and from the alluvium of Bowmans and Yorks Creek during the September 2018 surveys. Stygofauna have also previously been collected from other sections of the Bowmans Creek aquifer that runs to the west of the Mount Owen Complex (ELA 2013b).

The alluvial aquifers listed above are classified as:

- Type: Subsurface phreatic aquifer ecosystem
- Subtype 1: Unconsolidated alluvial aquifers.

## 7.2 Assess the level of dependence on groundwater

Unconsolidated alluvial aquifers occur beneath river floodplains and are completely dependent on groundwater. Bowmans Creek has the most extensive aquifer ecosystem in the Project Area, but this is small compared to the Hunter River alluvial aquifer. Minor alluvial aquifers occur along Swamp Creek, Bettys Creek, and Yorks Creek. Moderate alluvial aquifers occur along Glennies Creek.

## 7.3 Identify high ecological value components of the aquifer

The definition of high ecological value suggested by Serov et al. (2012) includes, by default, all aquifer ecosystems. The definition of high ecological value is based largely on the premise that any stygofauna taxa present are rare or unique. The ecological components of most value in these aquifers are the following stygofauna taxa:

- *Notobathynella* sp. (Syncarida crustacean) in Yorks Creek alluvium
- Bathynellidae (Syncarida crustacean) in Bowmans Creek alluvium
- *Carabhydrus stephanieae* (blind diving beetle) in Glennies Creek and Bowmans Creek alluvium
- A subterranean Elmidae (blind riffle beetle) in Bowmans Creek alluvium
- Hydrobiidae snail in Glennies Creek alluvium
- Cyclopoida crustacean in Glennies Creek and Swamp Creek alluvium
- Ostracoda crustacean in Bowmans, Yorks Creek, Swamp Creek and Glennies Creek alluvium

These seven invertebrate taxa all live in groundwater. However, none of them are endemic to aquifers in the Project Area. All have been collected previously from other alluvial aquifers in the Hunter Valley, including those associated with Kingdon Ponds, Pages River, Dart Brook, Goulburn River, and Hunter River.

*Notobathynella* sp. is a widespread genus, and Bathynellidae a widespread family, from the Bathynellacea (Syncarida). Both taxa have previously been collected from alluvial aquifers throughout the Hunter Valley (Table 1, Table 2) and are known widespread in many large alluvial aquifers in eastern Australia (Hancock and Boulton 2008).

Groundwater cyclopoids and ostracods are widespread in the Hunter Valley (Table 2) and in many other alluvial aquifers in eastern Australia. These include aquifers associated with Namoi River, Bellinger River, Macquarie River, and Peel River.

*Carabhydrus stephanieae* was found in the Glennies Creek alluvium in 2017 and in the Bowmans Creek alluvium in September 2018. It has previously been collected from alluvial aquifers associated with Bowmans Creek (Table 3), Hunter and Pages Rivers, Dart Brook, and Kingdon Ponds (Table 2). A second groundwater beetle, from the Elmidae family, was also collected from the Bowmans Creek alluvium. Groundwater elmids have been collected from the Pages, Dart Brook, Kingdon Ponds, and Hunter River alluvial aquifers (Table 2).

The groundwater snail, Hydrobiidae sp., is known from the Hunter River alluvial aquifer near Denman (Table 2), though is likely to occur in other parts of the Hunter alluvium between Denman and the Bowmans Creek confluence.

All taxa are known from other aquifers in the Hunter Valley and appear widespread. The stygofauna communities in the Bowmans, Yorks, Swamp and Glennies Creek alluvial aquifers are not unique, and are typical of other alluvial aquifers in the region (Table 2, Table 3). Yorks Creek and Swamp Creek aquifers are considered to have a Moderate Ecological Value, but only in their lower reaches where they are thicker and close to Bowmans Creek alluvial aquifer. Upstream these two aquifers are thin and are unlikely to support permanent stygofauna communities, so the aquifers can be considered as having a Low Ecological Value upstream of where they meet the Bowmans Creek alluvium.

Bowmans Creek and Glennies Creek aquifers are more extensive than Yorks, Bettys, and Swamp Creeks, and contain at least 4 stygofauna taxa each. These aquifers have a Moderate Ecological Value, as they contain groundwater beetles which, although not endemic, are not as widespread throughout the Hunter Valley as the crustacean taxa also present.

## 7.4 Determine the impact of the activity on the aquifer community

Mining potentially poses the following threats to stygofauna communities:

- Reductions in groundwater levels in regional aquifers. This can be caused by mine dewatering, seepage into mine voids, or fracturing of confining layers and subsequent seepage. There is also a large-scale shaping of the land surface, which can channel water away from or towards groundwater recharge areas. If drawdown occurs too quickly, fauna can become stranded; if the water table is lowered too far, critical hydrological connections to the surface can be lost. In extreme cases, aquifers may dry out completely, as may be the case for small alluvial aquifers with thin sediment deposits.

- The direct removal of aquifer material. This is a threat when stygofauna occur in shallow coal seams, overlying material, or any other aquifers that need to be excavated as part of the mining process.
- A reduction in water quality, either through increased linkages with aquifers of poor water quality, or through other means such as seepage of acids or heavy metals from overburden piles.

Models suggest that drawdown in the Bowmans Creek alluvial aquifer that is attributable to approved and proposed mining at Glendell, will be less than 1 m at most and occur over only a small area adjacent to the Glendell Pit Extension (Figure 4). This means that aquifer desaturation due to the Project, will be almost negligible when compared to that of already-approved activities. Already-approved projects will cause desaturation of Bowmans Creek alluvium at two locations, effectively isolating the Bowmans Creek stygofauna community from the regional Hunter River stygofauna community (Figure 5).

Groundwater modelling along the Bowmans Creek alluvium indicates that already-approved mining operations will result in drying of the aquifer west of the northern boundary of the Glendell Pit Extension by 2026 (Year 6), approximately north of bore GNP10D (AGE 2019). A second area of desaturation occurs south of the Glendell Pit Extension (south of bore GA2), downstream from the Swamp Creek confluence with Bowmans Creek. This creates an 'island' of saturated aquifer that is bound to the north and south by desaturated sediments (Figure 5**)** and reconnects only during periods of high rainfall. During this current round of sampling, all stygofauna that were collected came from this 'island'.

Following the cessation of mining, cumulative drawdown in the Bowmans Creek alluvium will reach a maximum of approximately 2 m below current levels, which is within the range of natural variation (AGE 2019). The overall recovery of the groundwater system is modelled to occur within approximately 500 years of mine closure (AGE 2019). The aquifer will remain isolated from the Hunter River alluvium for some time, but resaturation will eventually occur once a new equilibrium is reached in the groundwater regime. Again, these changes are attributable mostly to operations that are already approved, and the additional contribution from the Project will be negligible.

The drying out and fragmenting of alluvial aquifers constitutes one of the main threats to stygofauna. Desaturation of two sections of the Bowmans Creek alluvial aquifer has been modelled to occur, regardless of whether the Project proceeds. This effectively isolates the Bowmans Creek alluvium from the Hunter River alluvium and prevents the migration of stygofauna between the two aquifers, except for during periods of temporary connectivity driven by rainfall events. A section of saturated aquifer approximately 5.5 km long, will persist between the areas of desaturation, but will be cut off from the main aquifer of the Hunter River. Small areas of alluvium in the upper reaches, and associated aquifers in Yorks and Swamp Creeks will be mined through and removed by the Project. However, the lower reaches should still be connected to the saturated section of Bowmans Creek alluvium that becomes cut off during alluvium desaturation. The alluvium in the middle section of Bettys Creek is isolated from the Bowmans Creek alluvium through the existing approved diversion of Bettys Creek to the south of the Glendell Pit. The Project is not predicted to have any short or long term impacts on the Bettys Creek alluvium.

For the duration of modelled isolation, there may be occasional periods of reconnection, when high rainfall and recharge allow migration opportunities for stygofauna to move in and add diversity to this part of the aquifer before it becomes isolated again. However, for the most part, the stygofaunal community of this reach of aquifer will be isolated, so will have a limited ability to recover from any disturbances that may occur.

Desaturation of the alluvium would be caused by already approved operations, not the Glendell Pit Extension. The Project will delay reconnection of the fragmented aquifer, but any impact from the isolation will already have occurred. It is likely that the stygofauna communities in the upper Bowmans Creek could be reduced in biodiversity when they become isolated, however, this would not be caused by the Project.

The Project will not impact the groundwater quality of aquifers containing stygofauna (AGE 2019).

## 7.5 Determine risk magnitude to the aquifer community

The Project will pose a low magnitude of risk to the stygofauna community. This is because the impact of desaturating the Bowmans Creek alluvium from the Project is negligible compared to the extent of desaturation already modelled to occur from other approved operations nearby.

## 7.6 Apply the GDE Risk Matrix

The alluvial aquifers of Yorks Creek and Swamp Creek have a Moderate Ecological Value in their downstream reaches where the groundwater regime is likely influenced by Bowmans Creek aquifers. Upstream of this, in the areas of alluvium removed by the Project, the chance of stygofauna occurring diminishes as the aquifer thins, and ecological value can be classified as Low. Glennies Creek and Bowmans Creek have a Moderate Ecological Value because they have a diverse stygofauna community, despite a lack of known endemic taxa.

Fragmentation has been modelled for Bowmans Creek alluvium, with two sections likely to be desaturated. However, this is not due to the Glendell Pit Extension. Desaturation from the Project will initially have negligible impact on the Bowmans Creek alluvium, when it contributes to a delay in reconnection with the northern end of Bowmans Creek alluvium, so there is a Low Risk to the alluvial aquifers. The Risk Matrix categories for the lower reaches of York, Swamp, Glennies and Bowmans Creek aquifers is D.

Aquifers associated with Bettys Creek alluvium, the Permian shallow hard rock and coal seams all have Low Ecological Value. While some drawdown will occur in these aquifers, it will only be minor and unlikely to affect any stygofauna communities, so has a Low Risk Category. These aquifers are categorised in the Risk Matrix as a G.

## 7.7 Apply management actions, including mitigation measures

Under the GDE Assessment Guidelines, management actions for Type G and D impacts require the protection of hotspots and baseline monitoring. The main hotspots of stygofauna diversity are along the Bowmans Creek alluvium, and in the lower reaches of Yorks and Swamp Creek where they meet the alluvial aquifer of Bowmans Creek. These areas are in a section of alluvium that will remain saturated for the duration of the Project but will be isolated from the remaining Bowmans alluvium until many years after the Project.

The isolated section of alluvium will effectively become an island, with stygofauna unable to move between it and the aquifer upstream or downstream. This means that the stygofauna community would be less robust to change (because if an impact occurs that reduces the population size or biological diversity, there are no means of recolonising the aquifer through migration, except for brief periods of reconnection following recharge events). As the stygofauna collected during this current round of sampling all came from this 'island', it is possible that, over time these will be lost from this reach. However, the loss of these species will be localised, as all are widespread in the Hunter Valley.

Equally, there may be potential for repopulation of this 'island', if surrounding populations are able to migrate during reconnecting flow events.  However, as the island would likely be isolated again, it is likely that such recolonizations would be considered temporary.

Some threat exists to the stygofauna community of Bowmans Creek alluvium, although from already approved operations, and not the Project. As drawdown from the Glendell Pit Extension poses negligible additional threat to stygofauna communities in the Bowman Creek alluvium, no additional monitoring is necessary.

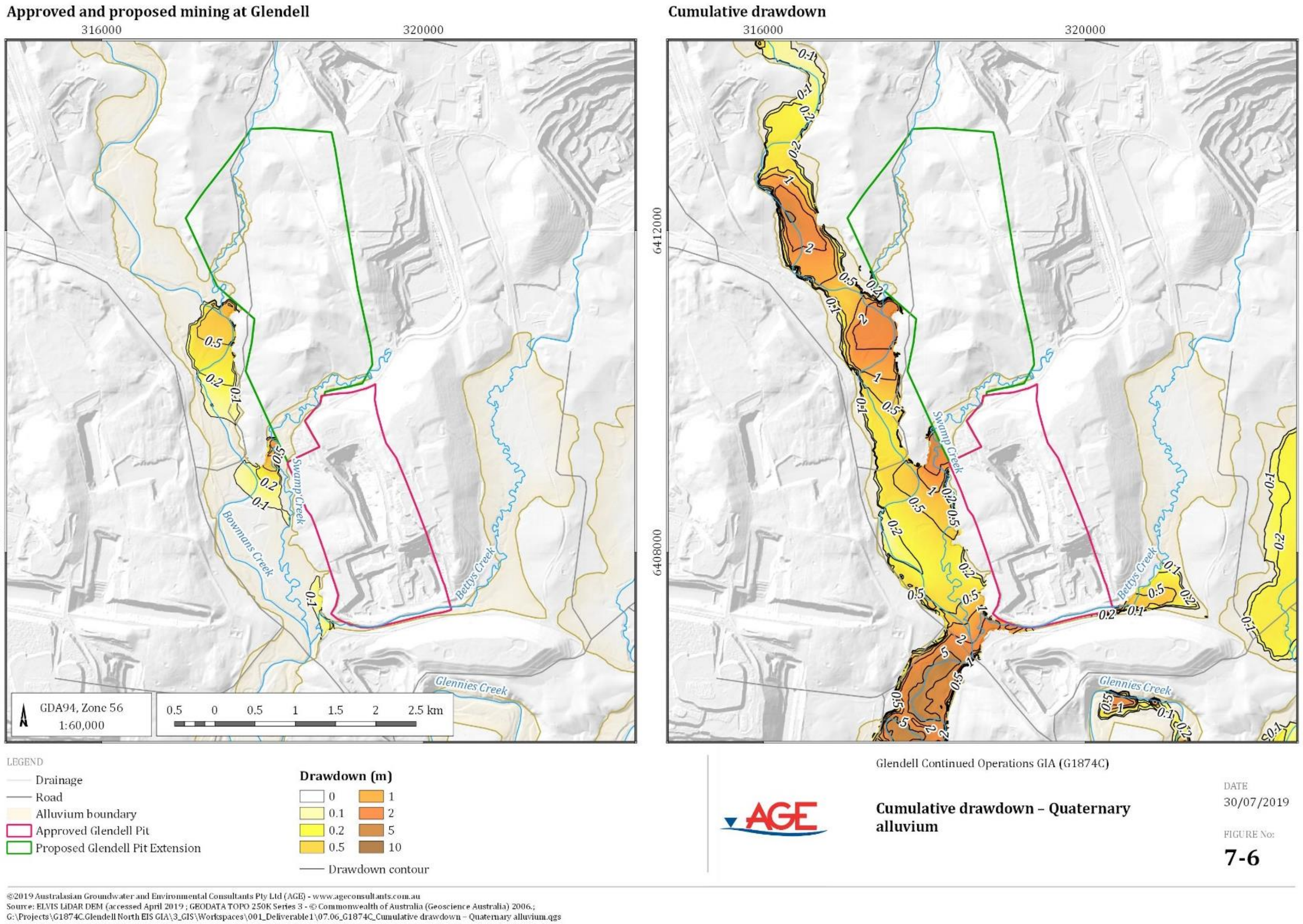


**Figure 4: Saturation modelling for alluvium showing drawdown attributable to Glendell (approved operations and Glendell Pit Extension), compared to cumulative drawdown from other already approved mining operations and including the Glendell Pit Extension (AGE 2019).**

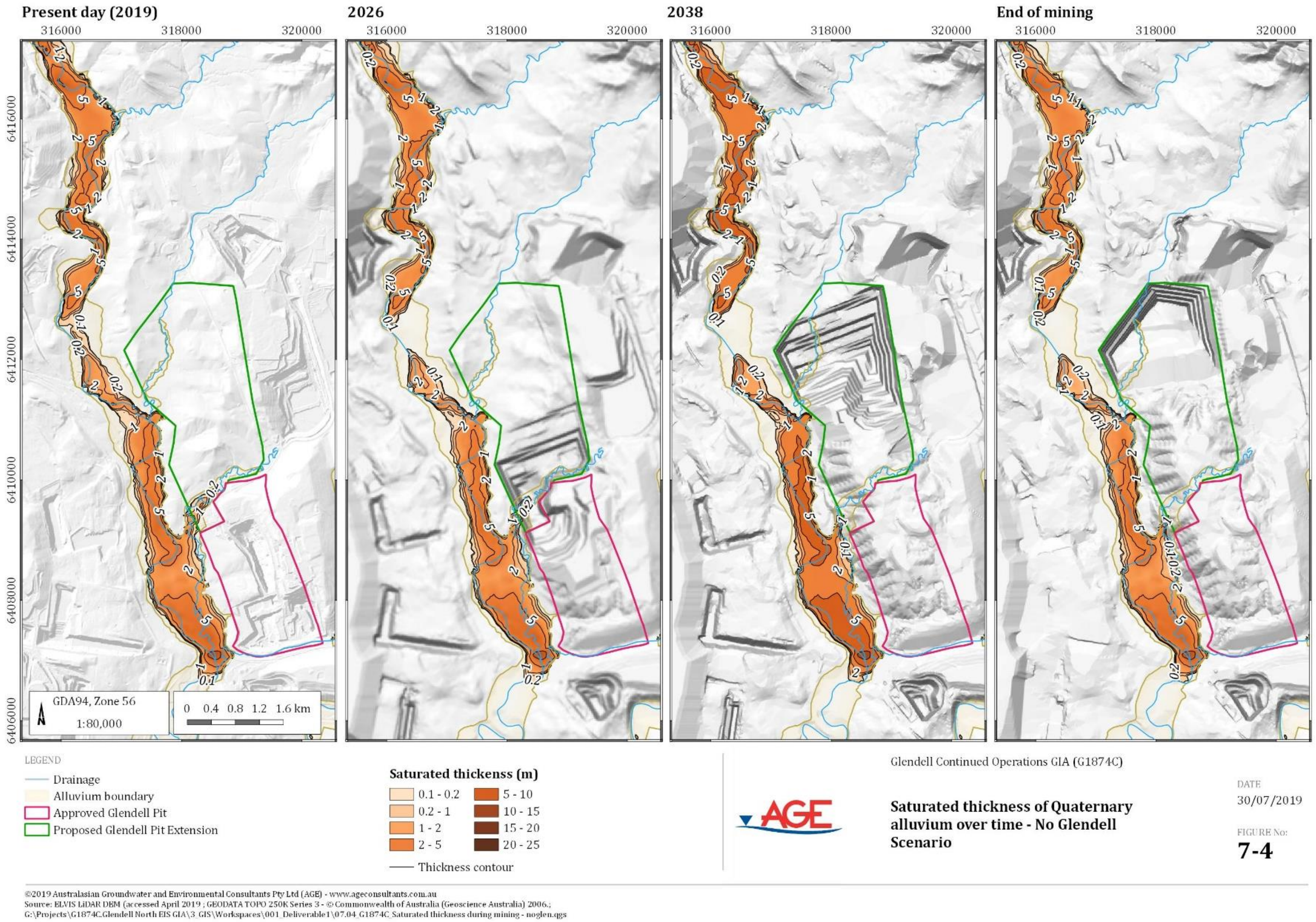


**Figure 5: Saturation modelling for alluvium without Glendell (approved operations or Glendell Pit Extension), but with impacts from other already approved operations.**

# 8. Conclusion and recommendations

Four stygofauna taxa, and one troglofauna taxon were collected in the shallow alluvial aquifers associated with the Project. This brings the number of known stygofauna taxa local to the Mount Owen Complex to seven. In considering all previous sampling in the area, stygofauna were collected from Bowmans, Glennies, Swamp, and Yorks Creeks alluvium, but not from the underlying or adjacent rock or coal seam aquifers or the alluvium of Bettys Creek. All taxa have a broad distribution in the Hunter Valley and are widespread along the Hunter River, Dart Brook, Kingdon Ponds and Pages River alluvial aquifers.

Groundwater modelling indicates that there will be complete desaturation in two sections of the Bowmans Creek alluvium, which will potentially isolate a 5.5 km length of aquifer from both upstream and downstream reaches and separate the upstream reaches of Bowmans Creek alluvium from the Hunter River alluvium. The 5.5 km length of Bowmans Creek alluvium to be isolated includes the junctions with Yorks and Swamp Creeks and was where all stygofauna collected during this round of sampling came from. Isolation will last at least until beyond the end of mining, although there may be intermittent periods of reconnection. The desaturation will be caused by already-approved projects, and not the Glendell Pit Extension.

As desaturation will occur regardless of any impact from the proposed Project, monitoring of the stygofauna would not provide any benefit to aquifer ecosystems and is not recommended.

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