# APPENDIX 12

Stygofauna Assessment

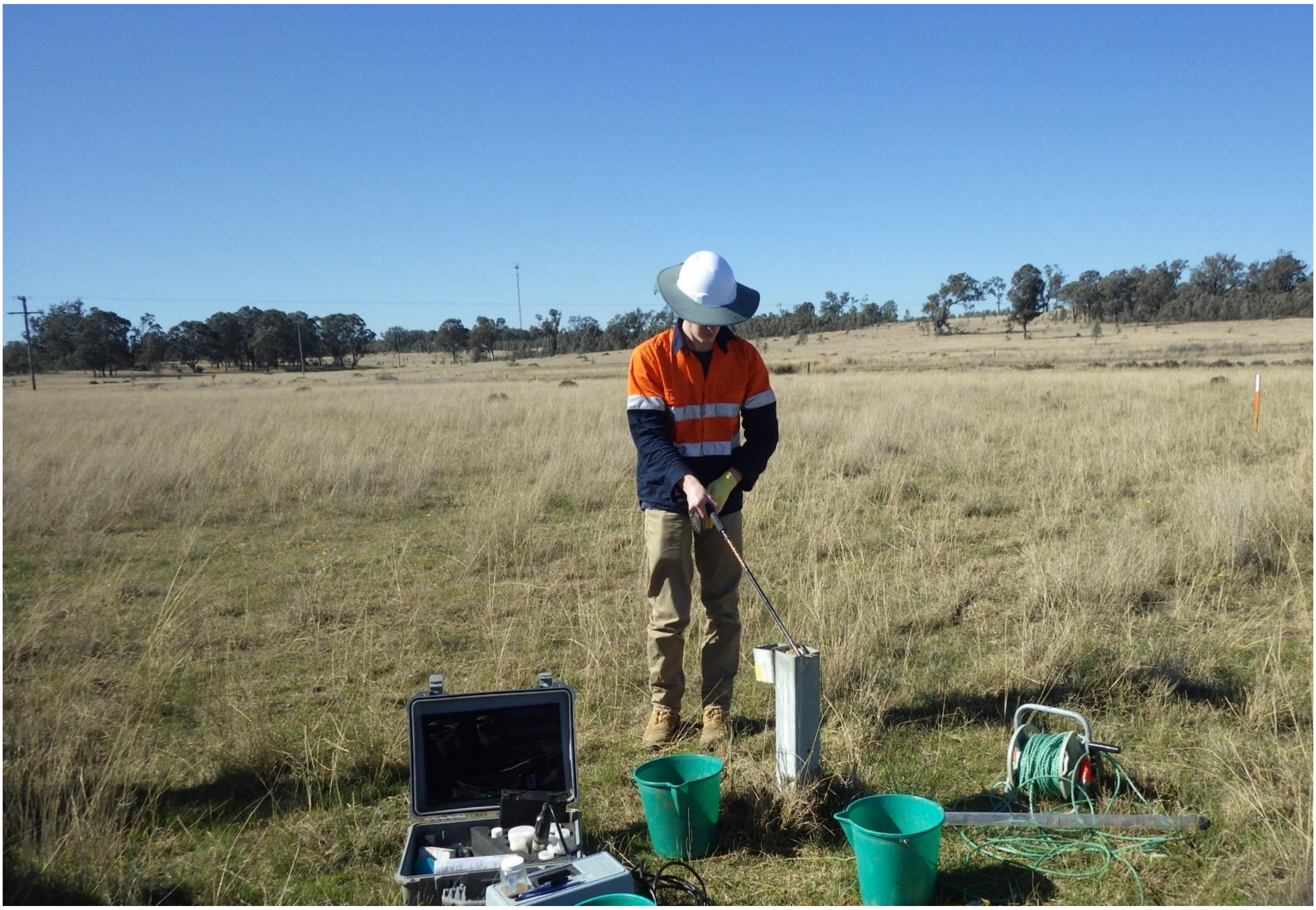



# Mount Owen Continued Operations

# Modification 2

## Stygofauna Assessment

Prepared for
**Umwelt (Australia) Pty Ltd**



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| Prepared by | Dr Peter Hancock |
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# Executive summary

The Mount Owen Complex is located 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 complex consists of three open cut operations: Mount Owen (North Pit), Ravensworth East (Bayswater North Pit), and Glendell (Barrett Pit).

Mt Owen Pty Ltd (Mount Owen), a subsidiary of Glencore Coal Pty Ltd (Glencore), received development consent (SSD-5850) from the Planning Assessment Commission for the Mount Owen Continued Operations Project (Continued Operations Project) in November 2016. The Continued Operations Project development consent incorporates all previously approved operations at the Mount Owen Mine and Coal Handling and Preparation Plant (CHPP) and Ravensworth East Mine and allows for continued and expanded mining until 2031, now referred to as the ‘Approved Operations’. Glendell Mine operates under a separate consent (DA 80/952) and does not form part of the Approved Operations.

Eco Logical Australia (ELA) was commissioned to conduct a stygofauna assessment for the Mount Owen Continued Operations Modification 2 (Proposed Modification). The stygofauna assessment aims to satisfy the relevant Commonwealth and NSW Government guidelines.

The Proposed Modification was referred to the Commonwealth Department of Environment and Energy (DoEE) and was determined not to be a controlled action under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).

Samples were collected from 16 monitoring bores from alluvial aquifers associated with Yorks, Bettys, Swamp, Main and Glennies Creeks, as well as in the shallow rock and coal seam aquifers. The survey focused on areas likely to have stygofauna, so more samples were collected from bores in the alluvium than in rock and coal seams.

Five taxa of stygofauna were collected. These were *Notobathynella* sp, Cyclopoida, Ostracoda, Hydrobiidae sp. (a snail), *Carabhydrus stephanieae* (a subterranean diving beetle). These taxa were collected from the alluvial aquifers of Yorks Creek, Swamp Creek and Glennies Creek. All of the taxa collected are known from elsewhere in the Hunter Valley and generally have a widespread distribution along alluvial aquifers of the Hunter and Pages Rivers. No stygofauna were collected from Bettys and Main Creek alluvial aquifers, nor from the coal and rock aquifers.

Groundwater modelling undertaken for the Proposed Modification indicates that there will be no drawdown of the alluvial aquifers associated with Yorks Creek, Swamp Creek, and Glennies Creek, so operations at Mount Owen will have no impact on the stygofauna community here. As there is unlikely to be an impact to these aquifers, no further monitoring of stygofauna communities is recommended.

# 1 Background

## 1.1 Project Background

The Mount Owen Complex is located within the Hunter Coalfields in the Upper Hunter Valley of New South Wales (NSW), approximately 20 kilometres (km) north-west of Singleton, 24 km south-east of Muswellbrook and to the north of Camberwell. 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; Mount Owen (North Pit) and associated infrastructure, Ravensworth East (Bayswater North Pit (BNP)) and Glendell (Barrett Pit).

Mount Owen received development consent (SSD-5850) from the Planning Assessment Commission for the Mount Owen Continued Operations Project (Continued Operations Project) in November 2016. The Continued Operations Project development consent incorporates all previously approved operations at the Mount Owen Mine and Coal Handling and Preparation Plant (CHPP) and Ravensworth East Mine and allows for continued and expanded mining until 2031, now referred to as the 'Approved Operations'. Glendell Mine operates under a separate consent (DA 80/952) and does not form part of the Approved Operations.

In September 2017 Mount Owen modified SSD-5850 (Modification 1) to allow for the construction of a water pipeline from the Integra Underground Mine to the Mount Owen Complex and allow the integration of the Integra Underground Mine into the Greater Ravensworth Area Water and Tailings Scheme (GRAWTS). Mount Owen now proposes to further modify development consent SSD-5850 to allow for the optimisation of the North Pit mine plan to access coal reserves from the mining tenements obtained by Glencore through its acquisition of the Integra Underground Mine (the Proposed Modification).

The Proposed Modification was also referred to the Commonwealth Department of Environment and Energy (DoEE) and was determined not to be a controlled action under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) therefore does not require approval under the EPBC Act.

## 1.2 Proposed Modification

The Proposed Modification will enable access to approximately 35 million tonnes (Mt) of additional run-of-mine (ROM) coal from the North Pit. Recovery of the additional coal reserves will result in approximately 46 hectares (ha) of additional disturbance (Proposed Disturbance Area), representing an increase of approximately 1.8 per cent to the total disturbance area currently approved, and require an increased depth in the North Pit to provide for mining down to the Hebden Seam. The change to the North Pit mine plan will require the extension of the mine life through to 2037 (an additional 6 years) (Figure 1).

Prior to the acquisition of the Integra Underground mining tenements, the mine plan design for the North Pit did not allow access to the deeper coal seams and was restricted to the east of the approved North Pit footprint. This resulted in the pit floor 'stepping up' as it progressed further southwards and the 'stepping in' of the mine plan along its eastern boundary. The acquisition of the Integra Underground Mine and associated mining tenements has removed this previous constraint and allows for deeper and extended coal extraction across the proposed modified North Pit.

The Proposed Disturbance Area extends further east from the Proposed Modification pit boundary to provide for additional infrastructure such as water management structures and access. In addition, the northern extent of the Proposed Disturbance Area is identified to provide for earthworks to shape and improve the final landform of the North Pit to tie into the surrounding topography, these works are located in proximity to the existing approved Bettys Creek diversion. It is not proposed to modify the existing Bettys Creek diversion in this area which continues through the South East Offset and South East Corridor Offset areas into Main Creek.

No changes are proposed to current mining methods, extraction limits, transportation methods, operational hours or workforce numbers. The Proposed Modification will utilise existing and approved infrastructure with the exception of proposed water management structures to manage water from the mining operation.

Table 1 provides a comparison between the Approved Operations and the Proposed Modification.

**Table 1.** Comparison between the Approved Operations and the Proposed Modification

| Component | Approved Operations | Proposed Modification |
|---|---|---|
| Mining Method | Truck and excavator | No change to mining methods |
| Target Seams | Down to Hebden Seam<br>Down to approximately 300 m depth | No change to target seams<br>Down to approximately 380 m depth (average 340 m) |
| Total Reserve Recovered | Total of 257 Mt ROM coal<br>(Ravensworth East – 48 Mt<br>Mount Owen – 209 Mt) | Additional approximately 35 Mt ROM coal over the life of the mine<br>(approximately 13% of total approved reserve) |
| Disturbance Area | Approved Disturbance Area of 2534 ha | Additional 46 ha disturbance (increase of 1.8% of total Approved Disturbance Area)<br>Modification to SSD-5850 consent boundary to include Proposed Disturbance Area |
| Annual Production | Ravensworth East – 4 Mtpa<br>Mount Owen – 10 Mtpa | No change to annual production limit |
| Mine Life | 2031 | 2037 |
| CHPP Capacity | Up to 17 Mtpa | No change to CHPP capacity |
| Management of Mining Waste | Emplacement of waste in-pit and out-of-pit, up to maximum existing approved height of 230 m.<br>Tailings emplacement in Ravensworth East voids (including West Pit), within in-pit tailings cells in North Pit and/or BNP, and transfer under the GRAWTS to Liddell (subject to relevant approvals) | Emplacement of waste in Approved Disturbance Areas (up to maximum existing approved height)<br>Tailings emplacement within West Pit, in-pit tailings cells in North Pit and/or BNP, and transfer under the GRAWTS |
| Water Management | Upper and Middle Bettys Creek Diversions<br>Management of water within the water management system and GRAWTS<br>Works to provide flood attenuation for Yorks Creek | No changes to existing approved creek diversions<br>Extension of water management system to Proposed Disturbance Area and continued management of water within the GRAWTS<br>Proposed amendments to design of existing water management system to provide flood attenuation for Yorks Creek |
| Operational Workforce | Up to approximately 660 at Mount Owen and up to 260 at Ravensworth East | Continued employment of existing Mount Owen workforce (up to approximately 660) for an additional 6 years |

| Component | Approved Operations | Proposed Modification |
|---|---|---|
| Hours of Operation | 24 hours, 7 days per week | No change to hours of operation |
| Interactions with Integra Underground | Minimum 250 m separation subject to strict safety and operational controls | No change to minimum separation – implementation of safety and operational controls through integration of Glencore owned mining operations |
| Final Landform | Final voids at BNP and North Pit<br>Final landform approved with commitments relating to landform design (including micro relief), conservation and water management considerations as part of further detailed mine design | No additional void in final landform<br>Proposed changes to the final void arrangement in North Pit<br>Final landform to be designed to incorporate detailed design commitments relating to landform design (including micro relief), conservation and water management considerations and be consistent with the existing progressive rehabilitation objectives in the development consent |

## 1.3 Scope of Work

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

The assessment includes a field survey to determine what stygofauna occur in the Mount Owen area, and an assessment of potential impacts to the stygofauna community from the Proposed Modification. As part of the assessment, we compared the stygofauna community in Mount Owen aquifers with that of the broader Hunter Valley stygofauna community.

The assessment included:

- A gap analysis, review, and assessment of existing data to identify appropriate bores. Where available, bores were selected from hard rock and alluvial aquifers, in and outside of the direct area of impact. A sampling programme was designed that considered State and Commonwealth guidelines, and the Hunter Bioregional Assessment guidelines.
- Sampling to collect and identify stygofauna in the vicinity of the Proposed Disturbance Area.
- A comparison of the Mount Owen stygofauna with that of the broader Hunter Valley and with other similar aquifers in New South Wales (where relevant).
- An assessment of impacts resulting from the Proposed Modification.
- A report that includes the items above, for inclusion in a Statement of Environmental Effects (SEE) to meet Commonwealth and NSW environmental planning and assessment requirements.

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

Topography of the Mount Owen Complex is gently undulating along the floodplain of the Hunter River, with elevated rangeland in the northeastern portion of the site. Elevation ranges from 100 to 150 mAHD in the lower parts of the valley and up to 550 mAHD 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 hardrock/coal aquifer associated with underlying coal measures (SKM 2012).

## 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 2018). 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 then to the west of Ravensworth East Operations. The Hunter Thrust Fault separates the Whittingham Coal Measures from the New England Block in the northern part of the Proposed Modification consent boundary. North Pit intersects coal seams of the Vane and Jerrys Plains Subgroups at the Hebden Thrust, which cuts from southeast to northwest through the North Pit. The North Pit also intersects the eastern limb of the Rix's Creek Syncline.

## 2.2 Sedimentary aquifers

The Proposed Modification is in the Bowmans and Glennies Creek catchments, which are tributaries of the Hunter River. Yorks, Swamp, and Bettys Creeks are all ephemeral streams that flow into Bowmans Creek. Main Creek is an ephemeral tributary of Glennies Creek. 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 and Glennies Creek. Main Creek and Bettys Creek are the main tributaries in the vicinity of the Proposed Modification.

Bettys Creek previously flowed south-west through the North Pit. The catchment of Bettys Creek upslope of the North Pit has been diverted via the Upper Bettys Creek Diversion into the Main Creek catchment through a channel and dam system (Engeny 2018). The Middle Bettys Creek Diversion channels water along the eastern edge of the Western out-of-pit (WOOP) emplacement area before bending westward through the Lower Bettys Creek Diversion to the south of the Barrett Pit, where it joins Bowmans Creek downstream of the Mount Owen Complex. Most diverted reaches of Bettys Creek have not yet had enough time to weather sufficiently, or accumulate sedimentary deposits to form an aquifer. Downstream of the Middle Bettys Creek Diversion, there is a thin layer of alluvial sediments up to 5 m thick along Bettys Creek. This contains saline water and is likely to go dry in shallower areas (AGE 2018, GeoTerra 2017). The alluvium thickens as it nears Bowmans Creek and may contain permanent water.

The alluvial aquifer associated with Bowmans Creek consists of loams overlying silt and clay lenses. 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, with typical sediment depths between 8 m and 12 m, and a maximum depth of 18 m.

Glennies Creek is a perennial stream that passes to the south of the Proposed Modification. The Glennies Creek alluvium has groundwater that is fresh to brackish, which increases in salinity with distance from the creek (AGE 2018). Glennies Creek flows south-westward into the Hunter River. Main Creek is an ephemeral tributary of Glennies Creek that flows southwards adjacent to the eastern edge of the Proposed Disturbance Area. A thin layer of clay, sand and gravel sediments are deposited along the margins of Main Creek. These have a maximum depth of approximately 10 m, and a saturated thickness up to 9 m in the centre of the floodplain (AGE 2018). Sediments become unsaturated towards the edge of the floodplain and where there are high bedrock features (AGE 2018).

## 2.3 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 (SKM 2012).

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).

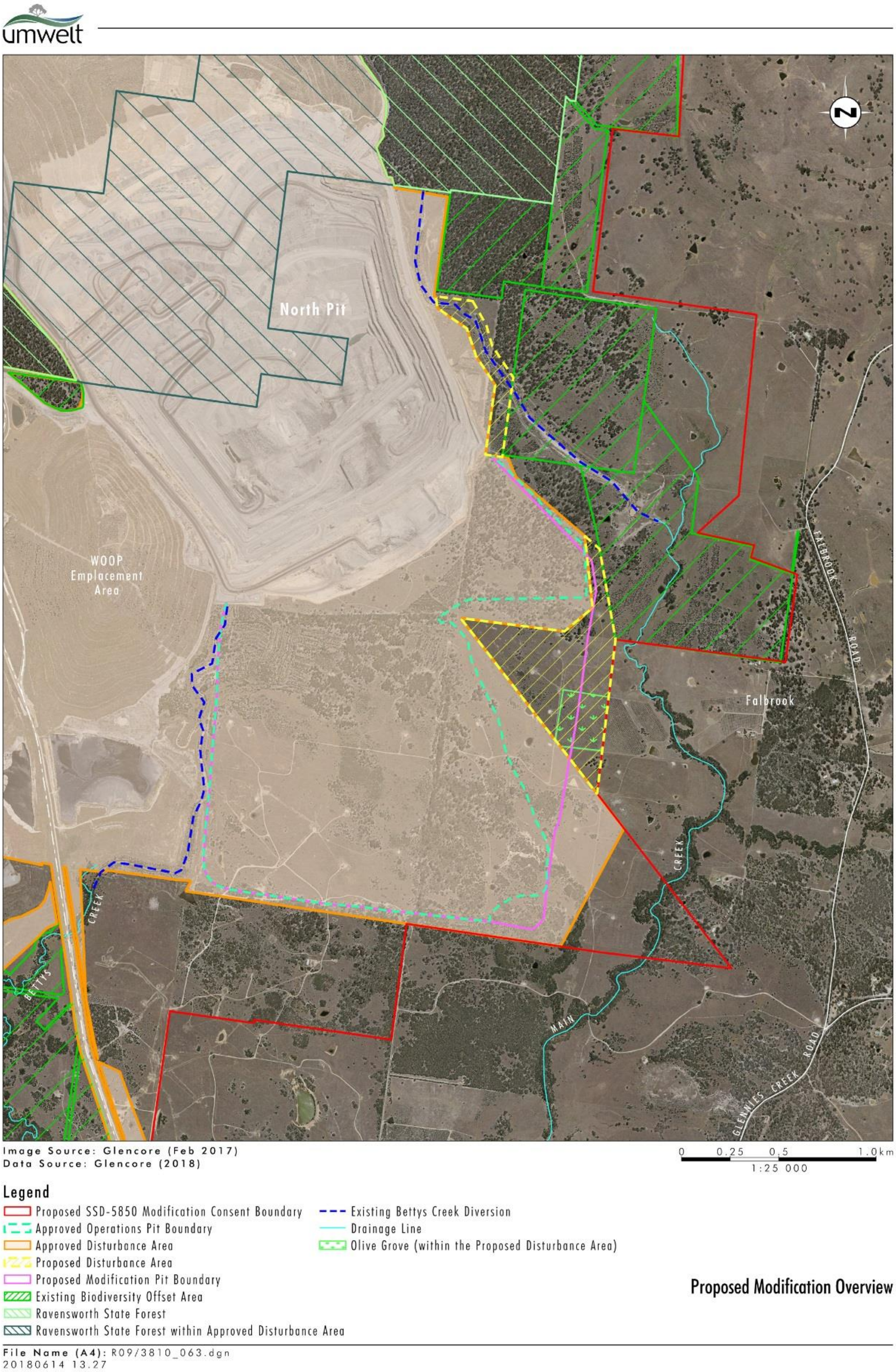


**Figure 1. Overview of Proposed Modification at Mount Owen.**

# 3 Relevant Guidelines, Policies and Legislation

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

- 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 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.

### 3.2 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.

# 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 2680 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. 2004). 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. 2004).

### 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 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 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 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.

### 4.3 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 (Table 2,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 2). 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 2.

**Table 2: 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 (Figure 2). 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 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 3.

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.

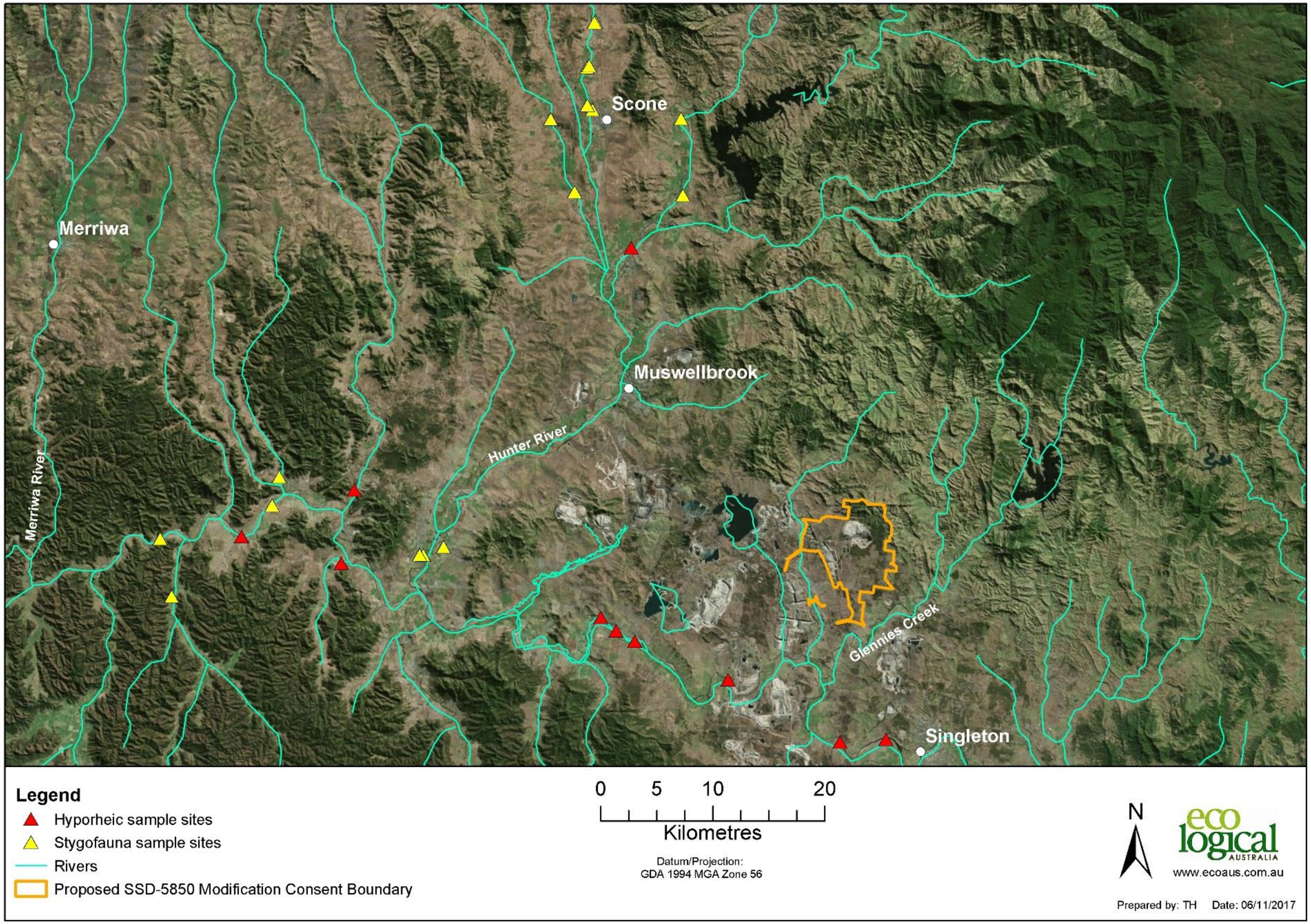


**Figure 2. Location of past stygofauna survey points in the Hunter Valley**

**Table 3: 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) (Table 4). 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.

**Table 4: Stygofauna from three mines in the Hunter Valley**

| Order | Family | Genus/ species | Bengalla | Liddell | Bylong |
|---|---|---|---|---|---|
| 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 study area

Of most relevance to the Mount Owen Complex were the stygofauna taxa collected at Liddell. Most taxa there were collected from the Bowmans Creek alluvial aquifer, upstream of where it is met by the Yorks, Swamp, and Bettys Creeks. The Bowmans Creek alluvial aquifer had nine stygofauna taxa. All of these occur in the Hunter River alluvium or the aquifers of its tributaries. The community had seven taxa and was dominated by crustacea. The only two non-crustaceans were both beetles: the dytiscid *Carabydrus stephanieae*, and the elmid *Austrolimnius* sp. If there are stygofauna in the alluvial aquifers of creeks surrounding the Mount Owen Complex, the likelihood of which depends on aquifer characteristics, communities are likely to resemble those found in the Bowmans Creek alluvium.

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 5000 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 Proposed Modification, 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 vicinity of 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.

From the initial list of 26, 17 were selected for sampling. One bore (GNPS-5) was dry, so it was not sampled. The remainder consisted of two bores in coal aquifers, two in shallow rock aquifers, and 12 in alluvium (Figure 3). Alluvial aquifers of Swamp Creek, Main Creek and Bettys Creek were all sampled from three bores, while Yorks Creek was sampled from two. A single bore was also sampled from the Glennies Creek alluvium.

Bore selection and sampling were completed before the Groundwater Impact Assessment was finalised, so bores were assigned as either control or impact based on their proximity to the Proposed Modification Disturbance Area and the likelihood that drawdown would occur at the bore. Seven control bores and nine impact bores were sampled (Table 5).

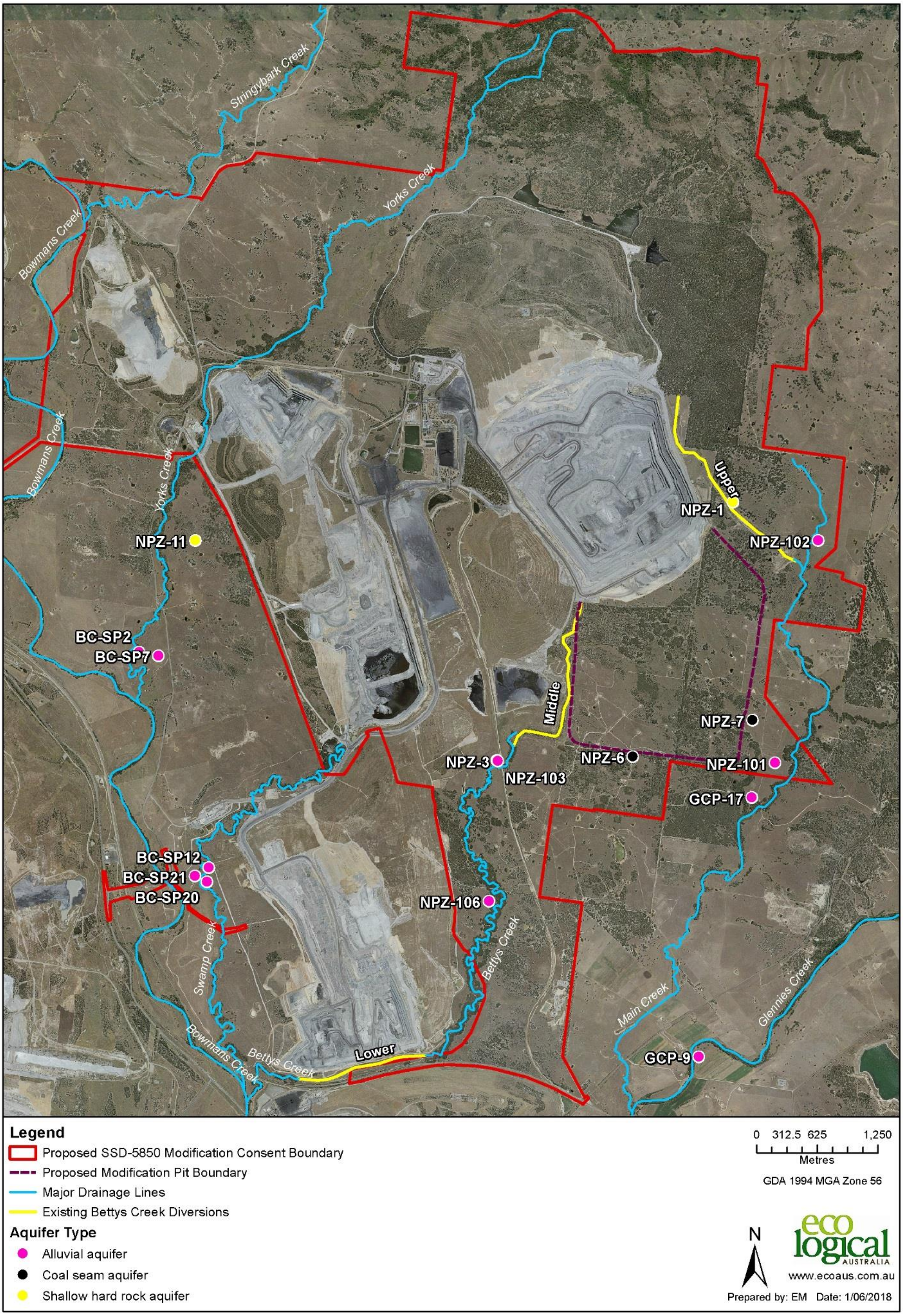


**Figure 3. Location of bores sampled for stygofauna.**

### 5.2 Field sampling and laboratory identification

Field sampling was conducted between 25 and 27 July 2017 by ELA Aquatic Ecologists Dr Peter Hancock and Tim Henderson.

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.

**Table 5. Bore location and depth details**

| Site | Aquifer | Impact/ Control | Zone | Easting | Northing | Depth (mbgl) |
|---|---|---|---|---|---|---|
| BC-SP2 | Alluvium (Yorks Ck/ Bowmans Ck) | Control | 56 H | 317483 | 6411487 | 8.7 |
| BC-SP7 | Alluvium (York Ck) | Control | 56 H | 317681 | 6411448 | 10.2 |
| BC-SP12 | Alluvium (Swamp Ck) | Control | 56 H | 318201 | 6409265 | 6.3 |
| BC-SP20 | Alluvium (Swamp Ck) | Control | 56 H | 318184 | 6409118 | 4.5 |
| BC-SP21 | Alluvium (Swamp Ck) | Control | 56 H | 318057 | 6409176 | 6.7 |
| GCP-9 | Alluvium (Station Ck/Glennies Ck) | Control | 56 H | 323259 | 6407315 | 9 |
| GCP-17 | Alluvium (Main Ck) | Impact | 56 H | 323803 | 6409986 | 7.5 |
| NPZ-101 | Alluvium (Main Ck) | Impact | 56 H | 324046 | 6410343 | 13 |
| NPZ-102 | Alluvium (Main Ck) | Impact | 56 H | 324489 | 6412637 | 9 |
| NPZ-103 | Alluvium (Bettys Ck) | Impact | 56 H | 321177 | 6410370 | 6 |
| NPZ-106 | Alluvium (Bettys Ck) | Impact | 56 H | 321091 | 6408918 | 7 |
| NPZ-3 | Alluvium (Bettys Ck) | Impact | 56 H | 321182 | 6410365 | 6 |
| NPZ-6 | RQ Coal | Impact | 56 H | 322577 | 6410410 | 65 |
| NPZ-7 | LBGF Coal | Impact | 56 H | 323811 | 6410786 | 62 |
| NPZ-1 | Shallow hard rock | Impact | 56 H | 323213 | 6413286 | 60 |
| NPZ-11 | Shallow hard rock | Control | 56 H | 318061 | 6412639 | 61 |

### 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 6) 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 7) 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 6. 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 7: 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. | Continue protection measures for aquifers and GDEs. | Adaptive management. Continue monitoring. |
| | | Baseline Risk monitoring. | Periodic monitoring and assessment. | |
| **B** | High value/Moderate Risk | Protection measures for aquifer and GDEs. | Protection measures for aquifer and GDEs. | Adaptive management. Continue monitoring. |
| | | Baseline Risk monitoring. Mitigation action. | Monitoring and periodic assessment of mitigation. | |
| **C** | High Value/High Risk | Protection measures for aquifer and GDEs. | Protection measures for aquifer and GDEs. | Adaptive management. Continue monitoring. |
| | | Baseline Risk monitoring. Mitigation. | Monitoring and annual assessment of mitigation | |
| **D** | Moderate Value/Low Risk | Protection of hotspots. | Protection of hotspots. | Adaptive management. Continue monitoring. |
| | | Baseline Risk monitoring. | Baseline Risk monitoring. | |
| **E** | Moderate Value/Moderate Risk | Protection of hotspots. | Protection of hotspots. | Adaptive management. Continue monitoring. |
| | | Baseline risk monitoring. | Monitoring and periodic assessment of mitigation. | |
| | | Mitigation action. | | |
| **F** | Moderate Value/High Risk | Protection of hotspots. | Protection of hotspots. | Adaptive management. Continue monitoring. |
| | | Baseline risk monitoring. Mitigation action. | Monitoring and annual assessment of mitigation. | |
| **G** | Low value/Low risk | Protect hotspots (if any). | Protect hotspots (if any). | Adaptive management. Continue monitoring. |
| | | Baseline risk monitoring. | Baseline risk monitoring. | |

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

# 6 Results

## 6.1 Water Chemistry

Bore water was sampled at 16 sites. Site GNPS-05 was dry, so not sampled. The water level at NPZ-6 was greater than the length of the bailer rope (50 meters), so water was collected with the jar attached to the stygofauna bore net, and measured for temperature, electrical conductivity, and pH. A reliable dissolved oxygen concentration could not be measured from this sample.

Water temperature in the alluvial aquifers ranged from 17.9°C to 20.9°C (mean = 19.8 ± 1°C), and had a similar range for the non-alluvial aquifers (Table 8). Electrical conductivity (EC) ranged from 800 µS/cm at BC-SP20 to 9047 µS/cm at NPZ-3, with an average of 3360 (± 2987 µS/cm) across all bores. EC varied within most aquifers (Table 8). For example, EC was between 800 and 3601 µS/cm in Swamp Creek alluvium, 1339 and 6683 µS/cm in Main Creek alluvium, and 1358 and 9047 µS/cm in Bettys Creek alluvium.

Across all bores, pH was between 6.73 and 8.27 (Table 8). Only at GCP-9 (Glennies Creek alluvium), and NPZ-6 (RQ Coal aquifer) was the pH greater than 8 (Table 8).

Dissolved oxygen (DO) concentration was lowest in the non-alluvial bores, where it ranged from 0.87 mg/L at NPZ-11 to 1.53 at NPZ-1. In the alluvial bores, DO concentration was between 1.32 and 3.19 mg/L (Table 8).

**Table 8: Groundwater physico-chemistry at Mount Owen bores sampled for stygofauna**

| Site | Aquifer | Sample Date | 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) | 27/07/2017 | 5.79 | 19.4 | 7.42 | 5165 | 19.2 | 1.6 |
| BC-SP07 | Alluvium (Yorks Ck) | 25/07/2017 | 8.97 | 20.9 | 6.85 | 1197 | 23.7 | 2.03 |
| BC-SP12 | Alluvium (Swamp Ck) | 25/07/2017 | 3.35 | 19.8 | 6.94 | 1762 | 25.7 | 2.32 |
| BC-SP20 | Alluvium (Swamp Ck) | 25/07/2017 | 3.99 | 20.4 | 7.51 | 800 | 36.2 | 3.19 |
| BC-SP21 | Alluvium (Swamp Ck) | 25/07/2017 | 5.42 | 20.8 | 7.67 | 3601 | 28 | 2.48 |
| GCP-9 | Alluvium (Glennies Ck) | 27/07/2017 | 4.93 | 17.9 | 8.27 | 1103 | 13.9 | 1.32 |
| GCP-17 | Alluvium (Main Ck) | 25/07/2017 | 6.98 | 20.9 | 6.73 | 1726 | 27.3 | 2.25 |

| Site | Aquifer | Sample Date | Water level (mbgl) | Water Temperature (°C) | pH | Electrical Conductivity (µS/cm) | Dissolved Oxygen (% saturation) | Dissolved Oxygen (mg/L) |
|---|---|---|---|---|---|---|---|---|
| NPZ-101 | Alluvium (Main Ck) | 26/07/2017 | 4.35 | 20.3 | 7.39 | 1339 | 18.2 | 1.52 |
| NPZ-102 | Alluvium (Main Ck) | 26/07/2017 | 1.43 | 20.0 | 7.59 | 6683 | 22.3 | 1.97 |
| NPZ-103 | Alluvium (Bettys Ck) | 26/07/2017 | 2.57 | 19.2 | 7.27 | 7453 | 27.4 | 2.51 |
| NPZ-106 | Alluvium (Bettys Ck) | 26/07/2017 | n.d.* | 18.7 | 7.54 | 1358 | 33.7 | 2.99 |
| NPZ-3 | Alluvium (Bettys Ck) | 26/07/2017 | 13.44 | 19.1 | 7.82 | 9047 | 29.3 | 2.59 |
| NPZ-6 | RQ Coal | 25/07/2017 | > 50 | 17.9 | 8.48 | 1166 | n/a** | n/a** |
| NPZ-7 | LBGF Coal | 26/07/2017 | 13.55 | 20.5 | 7.65 | 8634 | 16.8 | 1.4 |
| NPZ-1 | Shallow hard rock | 26/07/2017 | 15.58 | 20.6 | 7.22 | 1571 | 18.1 | 1.53 |
| NPZ-11 | Shallow hard rock | 27/07/2017 | 14.65 | 19.8 | 7.48 | 1147 | 10 | 0.87 |
| | Mean | | | 19.7 | 7.5 | 3360 | 23.3 | 2.0 |
| | Standard deviation | | | 1 | 0.5 | 2987 | 7.3 | 0.7 |

* Water level was not detected at NPZ-106

** Not enough water was collected from NPZ-6 for accurate measurement of dissolved oxygen concentration

### 6.2 Stygofauna

Five of the taxa collected are classified as stygofauna. These were *Notobathynella* sp, Cyclopoida, Ostracoda (all crustaceans), Hydrobiidae sp. (a snail), *Carabhydrus stephanieae* (a subterranean diving beetle). These taxa were collected from the alluvial aquifers of Yorks Creek and Swamp Creek near the Bowmans Creek confluence, and the alluvial aquifer Glennies Creek near the confluence of Station Creek.

Another four taxa were collected from bores at Mount Owen. These taxa were considered as possible stygofauna because the taxonomy and biology of these groups is largely unknown in Australia. While some of these groups may contain stygofauna, they are more commonly members of the soil communities. These included oligochaete and nematode worms, as well as astigmatid mites. These taxa occurred in low numbers at seven bores, but were all abundant at BC-SP12 (Table 9).

Stygofauna were most abundant at GCP-9 in Glennies Creek alluvium, where 693 animals from four stygofauna taxa (and one possible stygofauna) were collected. There were also relatively high numbers of stygofauna at BC-SP12 (Swamp Creek alluvium).

BC-SP7 and BC-SP12 both had similar pH, EC and DO (Table 8). GCP-9 had an EC similar to these two bores, but had pH over 8 and much lower DO (Table 8).

No stygofauna were collected from the shallow hard rock aquifers, coal seam aquifers, nor the Bettys Creek and Main Creek alluvial aquifers.

**Table 9. Stygofauna collected from Mount Owen bores.**

| Order | Family | Genus/species | Classification | BC-SP02 | BC-SP07 | BC-SP12 | BC-SP20 | BC-SP21 | GCP-9 | GCP-17 | NPZ-101 | NPZ-102 | NPZ-103 | NPZ-106 | NPZ-3 | NPZ-6 | NPZ-7 | NPZ-1 | NPZ-11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bathynellacea | Parabathynellidae | *Notobathynella* sp. | Stygofauna | | 5 | | | | | | | | | | | | | | |
| Mollusca | Hydrobiidae | | Stygofauna | | | | | | 169 | | | | | | | | | | |
| Coleoptera | Dyticidae | *Carabhydrus stephanieae* | Stygofauna | | | | | | 4 | | | | | | | | | | |
| Cyclopoida | Cyclopidae | | Stygofauna | | | 24 | 22 | | 2 | | | | | | | | | | |
| Ostracoda | | | Stygofauna | | 1 | 58 | | | 517 | | | | | | | | | | |
| Oligochaeta | | | Possible stygofauna | | 1 | 89 | | | | 1 | | | | 1 | | | | | |
| Nematoda | | | Possible stygofauna | | | 8 | 3 | 1 | | 1 | | | | 5 | | | | | |
| Acarina | Astigmatid | | Possible stygofauna | | | 28 | | 1 | 1 | | | | | 1 | | | | | 1 |
| | Oribatid | | Unlikely stygofauna | | | 2 | 4 | | | | | | | | | | 23 | 1 | |

# 7 Risk assessment

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

## 7.1 Identify and classify the ecosystems

Stygofauna were collected from the alluvial aquifers of Yorks Creek, Swamp Creek, and Glennies Creek. They have also previously been collected from the Bowmans Creek aquifer that runs to the west of the Mount Owen Complex.

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. Minor alluvial aquifers occur along Main Creek, Swamp Creek, Bettys Creek, and Yorks Creek. Moderate alluvial aquifers occur along Glennies Creek and Bowmans 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 the any stygofauna taxa present are rare or unique. However, this is not the case for any taxa collected. The ecological components of most value in these aquifers are the following stygofauna taxa:

- *Notobathynella* sp. crustacean in Yorks Creek alluvium
- *Carabhydrus stephanieae* blind diving beetle in Glennies Creek alluvium
- Hydrobiidae snail in Glennies Creek alluvium
- Cyclopoida crustacean in Glennies Creek and Swamp Creek alluvium
- Ostracoda crustacean in Yorks Creek, Swamp Creek and Glennies Creek alluvium

These invertebrates are all dependent on groundwater, but at the level of identification possible, none of them are endemic to aquifers at Mount Owen. All were also collected close to or in the alluvial aquifers of Bowmans or Glennies Creeks, so are probably associated more strongly with these aquifers, rather than the minor tributary aquifers.

*Notobathynella* sp. is a widespread genus from the Bathynellacea. It has previously been collected from alluvial aquifers throughout the Hunter Valley (Table 2, Table 3), and is known from several large alluvial aquifers in eastern Australia (Hancock and Boulton 2008). Likewise, groundwater cyclopoids and ostractods are widespread in the Hunter Valley (Table 3) and in many other alluvial aquifers in eastern Australia. *Carabhydrus stephanieae* was found in the Glennies Creek alluvium. It has previously been collected from alluvial aquifers associated with Bowmans Creek (Table 4), Hunter and Pages Rivers, Dart

Brook, and Kingdon Ponds (Table 3). The groundwater snail, Hydrobiidae sp., is known from the Hunter River alluvial aquifer near Denman (Table 3), though is likely to occur in other parts of the Hunter alluvium between Denman and the Bowmans Creek confluence.

As all taxa are known from other aquifers in the Hunter Valley, and the biological diversity of the stygofauna community in the Yorks, Swamp and Glennies Creek alluvial aquifers is not unique, and is typical of other alluvial aquifers in the region (Table 3, Table 4). 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.

Glennies Creek aquifer is more extensive than Yorks and Swamp Creek, and the sample collected from the GCP-9 had high numbers of stygofauna and taxa not found at other sites during this study, so it has a Moderate Ecological Value.

Possible stygofauna were collected from the Main Creek and Bettys Creek alluvial aquifers, and from the hard rock aquifers at NPZ-11, near Yorks Creek. These taxa consisted of oligochaete and nematode worms, and astigmatid mites, all of which are commonly represented in the soil invertebrate community (Coleman et al 2004). In the absence of true stygofauna in these aquifers, and considering the relatively thinness of the sediment layers, it is likely that the specimens in these samples were part of the soil fauna. The coal and shallow rock aquifers are likely to be too deep, and not porous enough to be suitable stygofauna habitat.

It is possible that Main Creek and Bettys Creek alluvial aquifers contain stygofauna close to their junctions with Glennies Creek. This is because the alluvium is relatively well developed and likely to have a good hydrological connection to Glennies Creek alluvium. However, the upper reaches of these aquifers, as well as the rock and coal aquifers, have **low** ecological values.

## 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.

*Drawdown in alluvium*

For alluvial aquifers near Mount Owen Mine, groundwater modelling indicates that there will be up to 0.5 m of cumulative drawdown in the Main Creek alluvium. This is attributed to the already approved cumulative impact of all the mines included in the groundwater model, with drawdown in the order of 0.1 m attributable to the Approved Operations. There is not likely to be any increase in the extent of drawdown as a result of the Proposed Modification (Figure 4, AGE 2018).This is because mining for the Proposed Modification occurs in deeper seams that are separated from the alluvium by interburden strata of limited permeability (AGE 2018).

No drawdown is predicted as a result of the Approved Operations or Proposed Modification in the aquifers of Bettys Creek (Figure 4, AGE 2018).

Neither the Bettys Creek, nor Main Creek alluvial aquifers contained stygofauna, so there would be no direct impact to groundwater diversity.

No drawdown is predicted as a result of the Proposed Modification in the aquifers of Yorks Creek, Swamp Creek or Glennies Creek (AGE 2018), which were the only aquifers associated with the Mount Owen Complex where stygofauna were found.

Dewatering of coal seam aquifers will not impact on stygofauna biodiversity, as the seams do not contain stygofauna habitat and there will be no significant drawdown in the aquifers known to have stygofauna.

The Proposed Modification will not impact the groundwater quality of aquifers containing stygofauna.

## 7.5 Determine risk magnitude to the aquifer community

Operations at Mount Owen will pose a Low magnitude of risk to the stygofauna community. This is because there will be no drawdown in the aquifer reaches containing stygofauna, nor will there be a significant change to groundwater quality.

## 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, the chance of stygofauna occurring diminishes as the aquifer thins, and ecological value can be classified as Low. Glennies Creek has a Moderate Ecological Value because it appears to have a diverse stygofauna community, but does not contain endemic taxa.

There is not predicted to be any drawdown or changes to water chemistry in these aquifers as a result of the Proposed Modification, so there is a Low Risk to the alluvial aquifers. The Risk Matrix category for the Yorks Creek and Swamp Creek upstream of the Bowmans Creek floodplain is G. The Risk Matrix categories for the lower reaches of York, Swamp, and Glennies Creek aquifers is D.

Aquifers associated with Main Creek, Bettys Creek, the shallow hard rock and shallow 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 in the lower reaches of Yorks and Swamp Creek where they meet the alluvial aquifer of Bowmans Creek and at the junction of Station Creek and Glennies Creek alluvial aquifers. No drawdown is predicted for these areas, nor is the Proposed Modification predicted to change water chemistry, so no further management actions are needed to protect these areas.

The main factors with potential to impact on stygofauna communities in these aquifers would result from changes to water chemistry and groundwater level. However, as none of these changes are expected, direct monitoring of the stygofauna community is not recommended.

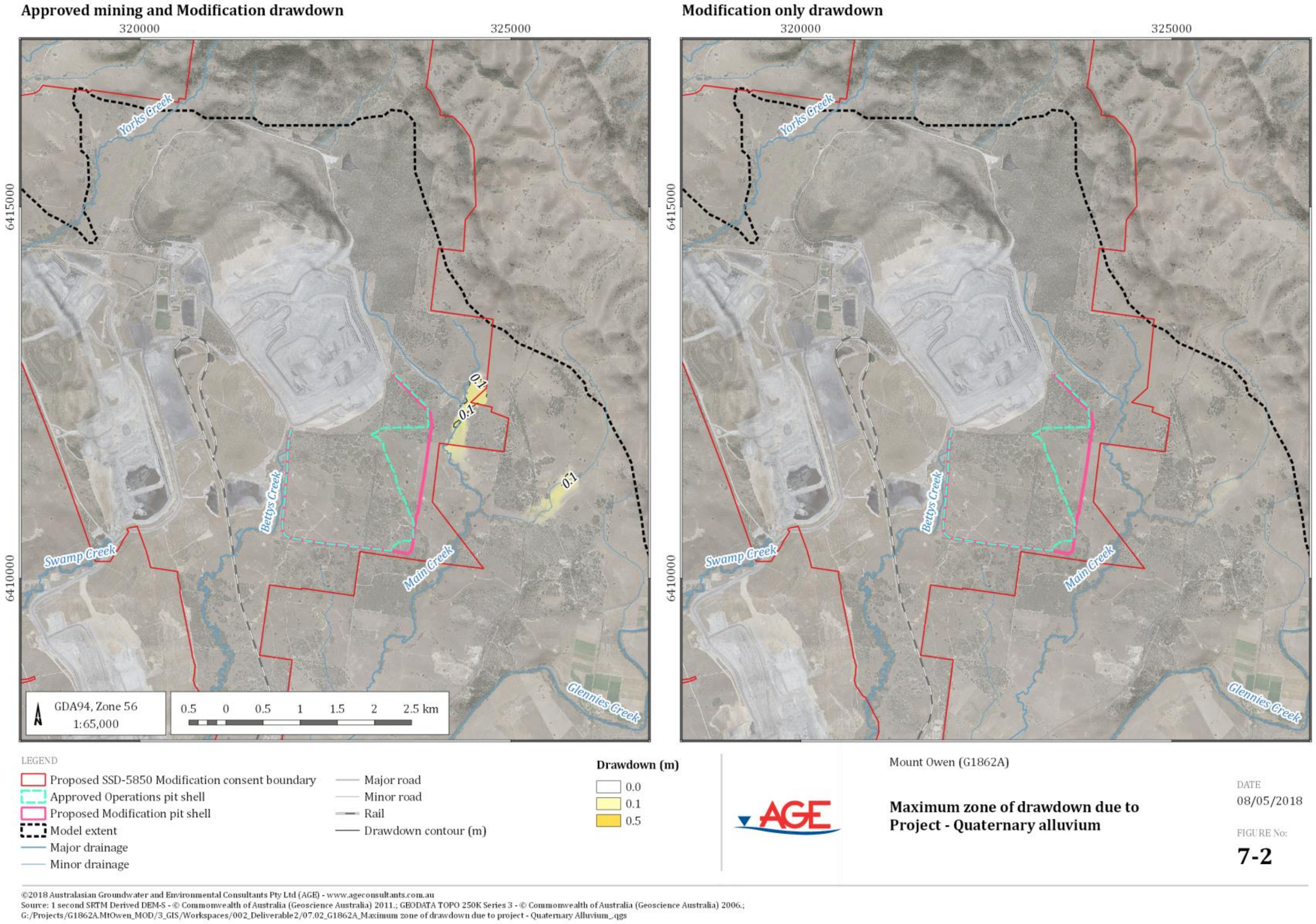


**Figure 4. Predicted drawdown in alluvial aquifer from Approved Operations plus Proposed Modification (left) and Proposed Modification only (right). Source: AGE 2018.**

# 8 Conclusion

Five stygofauna taxa were collected in the shallow alluvial aquifers associated with the Mount Owen Complex. Stygofauna were only collected in parts of the aquifers downstream of the Proposed Modification, where the smaller tributary aquifers meet the better-developed aquifers of Bowmans Creek and Glennies Creek. All taxa have a broader distribution in the Hunter Valley and are widespread along the Hunter River and Pages River alluvial aquifers.

Groundwater modelling indicates that there will be no drawdown in the aquifers containing stygofauna, nor will there be any significant changes to water chemistry. It is unlikey that the Proposed Modification will have an impact on the stygofauna community, both when considered alone and together with impacts from Approved Operations. As a result,  no regular stygofauna monitoring is recommended.

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**HEAD OFFICE**
Suite 2, Level 3
668-672 Old Princes Highway
Sutherland NSW 2232
T 02 8536 8600
F 02 9542 5622

**CANBERRA**
Level 2
11 London Circuit
Canberra ACT 2601
T 02 6103 0145
F 02 9542 5622

**COFFS HARBOUR**
35 Orlando Street
Coffs Harbour Jetty NSW 2450
T 02 6651 5484
F 02 6651 6890

**PERTH**
Suite 1 & 2
49 Ord Street
West Perth WA 6005
T 08 9227 1070
F 02 9542 5622

**DARWIN**
16/56 Marina Boulevard
Cullen Bay NT 0820
T 08 8989 5601
F 08 8941 1220

**SYDNEY**
Suite 1, Level 1
101 Sussex Street
Sydney NSW 2000
T 02 8536 8650
F 02 9542 5622

**NEWCASTLE**
Suites 28 & 29, Level 7
19 Bolton Street
Newcastle NSW 2300
T 02 4910 0125
F 02 9542 5622

**ARMIDALE**
92 Taylor Street
Armidale NSW 2350
T 02 8081 2685
F 02 9542 5622

**WOLLONGONG**
Suite 204, Level 2
62 Moore Street
Austinmer NSW 2515
T 02 4201 2200
F 02 9542 5622

**BRISBANE**
Suite 1, Level 3
471 Adelaide Street
Brisbane QLD 4000
T 07 3503 7192
F 07 3854 0310

**HUSKISSON**
Unit 1, 51 Owen Street
Huskisson NSW 2540
T 02 4201 2264
F 02 9542 5622

**NAROOMA**
5/20 Canty Street
Narooma NSW 2546
T 02 4302 1266
F 02 9542 5622

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Unit 1, Level 1
79 Market Street
Mudgee NSW 2850
T 02 4302 1234
F 02 6372 9230

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Suite 5, Baker One
1-5 Baker Street
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T 02 4302 1221
F 02 9542 5622

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2, 70 Pirie Street
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